Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-15/0-6769-1		

4. Title and Subtitle	5. Report Date
ASSESSMENT OF THE EFFECTIVENESS OF WRONG WAY DRIVING COUNTERMEASURES AND MITIGATION METHODS	Published: December 2014
	6. Performing Organization Code
7. Author(s) Melisa D. Finley, Steven P. Venglar, Vichika Iragavarapu, Jeffrey D. Miles, Eun Sug Park, Scott A. Cooner, and Stephen E. Ranft	8. Performing Organization Report No. Report 0-6769-1
9. Performing Organization Name and Address Texas A&M Transportation Institute College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6769
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: September 2012–August 2014 14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Wrong Way Driving Countermeasures
URL: http://tti.tamu.edu/documents/0-6769-1.pdf

16. Abstract

This report describes the methodology and results of tasks performed to evaluate the effectiveness of wrong way driving countermeasures and mitigation methods. Researchers reviewed the state of the practice regarding wrong way driving in the United States and Texas. Based on Texas crash data from 2007 through 2011, the majority of wrong way driving crashes on controlled-access highways occur in major metropolitan areas at night between midnight and 5:00 a.m. Driving under the influence was the primary contributing factor.

Therefore, researchers designed and conducted two closed-course studies to determine the effectiveness of select wrong way driving countermeasures on alcohol-impaired drivers. In addition, researchers obtained data from several Texas agencies that had installed wrong way driving countermeasures and/or mitigation methods on their road network. Using these datasets, researchers assessed the effectiveness of these strategies in actual operational environments. Researchers used the findings from these studies to develop recommendations regarding the implementation of wrong way driving countermeasures and mitigation methods.

Researchers used the focus group discussion method to obtain motorists' opinions regarding the design of wrong way driver warning messages. Researchers also reviewed previous literature and message design manuals to gain insight into the design of wrong way driver warning messages that could be posted on dynamic message signs. Based on the findings, researchers developed two single-phase wrong way driver warning messages for dynamic message signs.

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

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	172	

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

ASSESSMENT OF THE EFFECTIVENESS OF WRONG WAY DRIVING COUNTERMEASURES AND MITIGATION METHODS

by

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

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

Vichika Iragavarapu, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

Jeffrey D. Miles, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

Eun Sug Park, Ph.D.
Research Scientist
Texas A&M Transportation Institute

Scott A. Cooner, P.E.
Research Engineer
Texas A&M Transportation Institute

and

Stephen E. Ranft
Assistant Research Specialist
Texas A&M Transportation Institute

Report 0-6769-1
Project 0-6769
Project Title: Wrong Way Driving Countermeasures

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: December 2014

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

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. Wade Odell, Cary Choate, and Darrin Jenson of TxDOT served as the project managers. The following TxDOT employees served on the project working group: Michael Chacon, Ted Clay, Rick Cortez, Brian Fariello, John Gaynor, John Gianotti, Martin Gonzalez, Omar Madrid, and Roy Parikh. The authors gratefully acknowledge the assistance and direction that these individuals provided over the course of the project.

The authors recognize Mack Cowan, Margaret Cunningham, and the many other Department of Public Safety staff that assisted with the alcohol dosing and blood alcohol content measurements. The authors also acknowledge the contributions of Maury Dennis, Laura Higgins, Bari Kotwal, Albert Reeder, Sandra Stone, Nada Trout, Troy Walden, Christin Yager, and the many other Texas A&M Transportation Institute staff that assisted in the design and conduct of the various studies completed during this project.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

Since the beginning of the interstate highway system in the 1950s, crashes related to driving the wrong way on freeways have posed a problem for transportation officials. To this day, even though wrong way collisions are infrequent (only about 3 percent of all crashes on high-speed, divided highways) wrong way driving (WWD) remains a serious problem because the resulting crashes almost always result in death or serious injury to the persons involved. According to the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, nationally 1566 fatal WWD crashes on divided highways occurred over a six-year period from 2004 to 2009, resulting in 2139 fatalities. On average, about 360 people are killed each year as a result of WWD (*1*).

The first research in the United States regarding WWD occurred in the mid-1960s, but a resurgence of WWD research and countermeasure implementation has taken place over the last decade. To date, most research activities have focused on quantifying the WWD problem and summarizing traditional and innovative countermeasures and mitigation methods, instead of evaluating the effectiveness of these strategies. Therefore, questions remain as to which countermeasures actually get the attention of wrong way drivers and are effective at getting them to stop and turn around, especially those that are impaired. In addition, recent implementations of WWD countermeasures and detection systems in several locations in Texas provided the opportunity to assess the effectiveness of several strategies and technologies in actual operational environments.

CONTENTS OF THIS REPORT

This report describes the methodology and results of tasks conducted to (1) evaluate the effectiveness of WWD countermeasures and mitigation methods, and (2) develop recommendations regarding the implementation of WWD countermeasures and mitigation methods. Chapter 2 documents the state of the practice regarding WWD in the United States and Texas. Chapter 3 details the experimental design and findings from two closed-course studies aimed at determining the effectiveness of select WWD countermeasures on alcohol-impaired drivers. Chapter 4 explores the findings from the operational field analysis of several WWD countermeasures and mitigation methods implemented in Texas. Chapter 5 describes the findings from focus groups conducted to obtain motorists' opinions regarding WWD warning messages. Chapter 6 summarizes all findings and recommendations regarding the implementation of WWD countermeasures and mitigation methods.

CHAPTER 2: STATE OF THE PRACTICE

INTRODUCTION

To determine the state of the practice regarding WWD, Texas A&M Transportation Institute (TTI) researchers:

- Reviewed previous literature to gather information regarding WWD in the United States and Texas in fall 2013.
- Cataloged installations of WWD countermeasures and mitigation methods in Texas in fall 2013.
- Conducted an analysis of WWD crashes in Texas using the Texas Department of Transportation (TxDOT) Crash Records Information System (CRIS) in the beginning of 2014.

The following subsections describe the findings of these activities.

HISTORICAL AND ONGOING WRONG WAY DRIVING RESEARCH

Outside of Texas

Some of the earliest WWD research was conducted by the California Department of Transportation (Caltrans) in the mid-1960s (*2*, *3*, *4*). This research revealed a strong correlation between alcohol consumption and WWD crashes, and a corresponding increase in crash severity. Furthermore, an increase in weekend WWD crashes occurring in the early morning hours was related to increased alcohol consumption. Other studies of WWD causes and contributing factors over the past three decades have produced comparable findings (*1*, *5*, *6*, *7*, *8*, *9*, *10*, *11*, *12*).

The mid-1960s Caltrans research also involved identifying more favorable ramp designs and alternative signing and pavement markings at freeway interchanges. Additionally, Caltrans examined the use of preventive measures including the spike strip on exit ramps, and a detection and warning system that featured a WRONG WAY sign that was automatically illuminated when a wrong way vehicle was detected on an exit ramp in conjunction with an electric horn warning to alert the WWD driver. Caltrans staff concluded that spike strips:

- Were not a safe and viable countermeasure because they disabled but did not stop a wrong way vehicle.
- Could create a hazard when spikes were broken.

- Were an ongoing maintenance concern to ensure proper operation.
- Could be misinterpreted by right way drivers as a hazard.

In the 1970s, Caltrans examined a modified form of the wrong way vehicle detection system it originally developed in the late 1960s (*13*). Caltrans placed this system in over 4,000 freeway exit ramp locations throughout California to assess which ramp designs and other factors were associated with WWD activity. This research showed that changes to standard exit ramp signing, which included lowering DO NOT ENTER and WRONG WAY signs so that they could be better illuminated by headlights at night, were effective in reducing wrong way entries to freeways. Similarly, the Georgia Department of Transportation sponsored research in the late 1970s that used the wrong way camera system from Caltrans in a study to monitor exit ramps in order to correlate various ramp designs with WWD activity (*14*).

In the mid-1970s, the Virginia Transportation Research Council conducted research to identify the causes of wrong way movements and developed countermeasures to address the causes identified (*15*, *16*). The countermeasures were mainly directed at exit ramp configurations and included improved pavement markings that used reflectorized wrong way pavement arrows on all exit ramps, implementation of sensors on exit ramps for detecting WWD in future construction projects, and consideration of lowered DO NOT ENTER and WRONG WAY signing to address alcohol and nighttime problem locations.

In the 1980s, the Illinois Department of Transportation experimented with sensors embedded in the roadway to detect wrong way traffic movement, which, if activated, would lower a signal arm across the road and initiate a dynamic message sign (DMS) to alert exiting traffic about the WWD hazard ahead (*17*). In New Mexico in the 1990s, a directional traffic sensor system (DTSS) was implemented that used loop sensors that detected wrong way vehicles on exit ramps and activated red flashers on a WRONG WAY sign to warn the wrong way driver. Additionally, yellow flashers on a STOP AHEAD sign for right way ramp vehicles were used to warn traffic of an exit ramp obstacle (*18*).

In the 2000s, the Washington Department of Transportation used video monitoring systems on select exit ramps to detect wrong way drivers (*19*). When a wrong way vehicle was detected, a blank-out sign with the message WRONG WAY and flashers were activated. Concurrently, the system videotaped the vehicle’s movements and the driver’s behavior to further assess the problem.

In 2006, a wrong way detection system was implemented on the Pensacola Bay Bridge in Florida (*20*). This system used a low-power microwave radar detector that was not affected by adverse weather conditions. The detector was mounted approximately 20 ft above the roadway and could detect a wrong way movement at approximately 1000 ft prior to the bridge. When a wrong way movement was detected, flashing beacons visibly enhanced the DO NOT ENTER and WRONG WAY signs above the travel way.

More recently, the Michigan Department of Transportation implemented an initiative to address serious crashes that included low-cost countermeasures to deter wrong way movements onto freeways (*11, 21*). A recent study of crash data within the state revealed that 32 percent of freeway wrong way movement crashes resulted in a fatality or serious injury. Most of these crashes occurred on the freeway after the driver had maneuvered down a ramp going the wrong way. To counter this behavior, in 2012 the Michigan Department of Transportation began implementing several low-cost safety improvements over a five-year period at locations where this behavior was more frequently observed (i.e., a partial cloverleaf configuration). These improvements include:

- Lowered height of DO NOT ENTER and WRONG WAY signs.
- Reflective sheeting on the supports of lowered signs.
- Stop bars at exit ramps.
- Wrong way pavement marking arrows.
- Left turn pavement marking guides.
- Painted islands between exit and entrance ramps.
- Increased two-sided delineation along the exit ramp.

In October 2012, the Illinois Center for Transportation finished a study for the Illinois Department of Transportation related to WWD on freeways (*10*). The research included analysis of wrong way crashes in Illinois over a six-year period to determine the contributing factors to wrong way crashes on freeways and the development of promising, cost-conscious countermeasures to reduce the WWD errors and their associated crashes. The findings of the wrong way crash analysis suggested that a large proportion of the wrong way crashes occurred during the weekend from midnight to 5:00 a.m., with approximately 60 percent of the wrong way drivers under the influence of alcohol. Researchers developed a method to rank the high-frequency crash locations based on the number of recorded or estimated wrong way freeway entries. Interchanges were identified for field reviews, with site-specific and general countermeasures identified for future implementation. Some of the wrong way countermeasures identified for implementation included:

- Larger DO NOT ENTER and WRONG WAY signs.
- Red reflective sheeting on sign supports.
- WRONG WAY signs with flashing light-emitting diodes (LEDs) around the border at high-frequency crash locations.
- Pavement marking and geometric design enhancements at on-off ramp configurations.

In 2012, the Ohio Legislature began considering tougher fines for wrong way drivers (*22*). Ohio senators have urged their colleagues to increase penalties, particularly when drunken driving, driving under suspension, and injuries or fatalities are involved. Currently, driving on the wrong side of a divided interstate is a minor misdemeanor that carries a maximum fine of $150 and no jail time. If a driver has been guilty of other traffic or motor vehicle infractions within the previous year, the crime can be elevated to as high as a third-degree misdemeanor, punishable by up to 60 days in jail and a $500 fine. Possible new legislation would mandate the following:

- Someone who drives farther than 500 ft on the wrong side of a divided highway would see his or her license suspended for up to a year (the 500-ft threshold was added so that a driver who mistakenly drives the wrong way but promptly turns around prior to 500 ft would not be caught up in the increased penalties).
- If the person violates his or her suspension, the judge would have to send him or her to jail for a year and fine him or her up to $1,000.
- If the wrong way driver were to kill or injure another person, the driver would lose his or her license for two to 10 years.
- If that driver then violates his or her suspension, he or she would face a third-degree felony punishable by a three-year prison term and a fine of up to $10,000.
- A person guilty of WWD while drunk would face a fourth-degree felony carrying a six- to 18-month prison sentence and a fine of $5,000.

During that year, the Ohio Department of Transportation (ODOT) was also in the process of finalizing systematic upgrades of DO NOT ENTER, WRONG WAY, and ONE WAY signs to the 2012 *Ohio Manual on Uniform Traffic Control Devices* standards. The work is part of an ongoing sign replacement program, which provides for traffic control signs to be replaced regularly to assure adequate nighttime visibility. By the end of 2012, ODOT intended to have performed the following (*23*):

- Upgraded signage along freeway and expressway interchanges to enhance the visibility of signage for wrong way drivers.
- Installed supplemental WRONG WAY signs at 3-ft mounting heights on the non-cloverleaf exit ramps.
- Installed dual directional route marker assemblies at the ramp ends and pavement marking arrows for positive guidance on the entrance ramps for interchanges where the entrance and exit ramps are side by side.

The Wisconsin Department of Transportation (WisDOT) planned to implement a detection system at nine locations that the Milwaukee County Sheriff's Office had identified. Additionally, two ramps will use solar-powered WRONG WAY signs with flashing LEDs around the border during the twilight hours. The motion detectors and blinking signs were planned to be installed by Thanksgiving of 2012. Once the detectors sense a wrong way movement, text messages will immediately be sent to the State Traffic Operations Center and the Milwaukee County Sheriff's Department. Law enforcement in the vicinity will be quickly notified of the wrong way driver. The WisDOT traffic camera system will provide support in tracking the wrong way driver. Federal highway funds will pay for equipment, installation, engineering, and wrong way driver monitoring for one year. WisDOT will collect data, and depending on the results, motion detection sensors could be added at other ramps (*24*).

More recently, the 2012 special investigation report of the National Transportation Safety Board (NTSB) aimed to identify relevant safety recommendations to prevent wrong way collisions on highways and access ramps (*1*). The report characterized WWD in the United States, summarized nine NTSB wrong way collision investigations, and provided recommendations to address wrong way collisions. The key findings regarding WWD crashes were:

- Wrong way crashes occur more frequently at night and on the weekend.
- The primary origin of wrong way movements is entering an exit ramp.
- Most wrong way crashes occur in the lane closest to the median.

- More than half of wrong way drivers are impaired by alcohol. In addition, more than half of the alcohol-impaired wrong way drivers had a blood alcohol concentration (BAC) at or above 0.15 g/dL.
- Drivers over the age of 70 are over-represented in wrong way collisions.
- Recommendations to address wrong way collisions included:
- The installation of alcohol ignition interlocks on the vehicles of all driving while intoxicated (DWI) offenders.
- Widespread implementation of new in-vehicle alcohol detection technologies in U.S. vehicles.
- Traffic control devices should be used to make exit ramps more distinguishable from entrance ramps.
- Wrong way monitoring programs should be used to identify wrong way drivers.
- The use of navigation system alerts in the vehicle to inform drivers that they have performed a wrong way movement.
- The development of an assessment tool that states can use to select appropriate countermeasures.
- The development of a best practices guide for law enforcement on how to respond to a wrong way driver.

Within Texas

The first research regarding WWD in Texas occurred from the late 1960s to the early 1970s. TTI researchers conducted a survey of state and local highway engineers and law enforcement personnel in an attempt to qualitatively determine the nature of WWD in Texas (*25*). Researchers also summarized the state of the knowledge on WWD on freeways and expressways, including a review of countermeasures and the development of a detection and communication system to warn drivers of WWD (*26*).

In 2003, TxDOT sponsored WWD research following several severe WWD-related crashes around the state (*18,* 27). The major findings from the research called for the use of reflectorized wrong way arrows on exit ramps, lowered DO NOT ENTER and WRONG WAY signs mounted together on the same sign support, and the development of a field checklist for wrong way entry problem locations.

In October 2008, the Harris County Toll Road Authority (HCTRA) began to operate a wrong way driver detection system on a 13.2-mile portion of the West Park Tollway, a controlled-access roadway in Houston. The system uses Doppler radar detection sensors supplemented with in-pavement loop sensors at 14 points along the tollway. Incident management center (IMC) personnel receive all wrong way movement detections and monitor the system 24 hours a day and seven days a week. Once a vehicle is detected, operators at the IMC can immediately dispatch law enforcement officers, monitor the vehicle's whereabouts via closed-circuit television (CCTV) and a geographic information system (GIS) wrong way detection map integrated into the software platform, and warn other motorists of the detected wrong way vehicle using DMSs. This deployment was the first of its type in the United States and incorporated a number of innovative aspects including site-specific design, configuration, and communications dispatch and response protocols (*28*). The original cost in 2007 was $337,000 (about $25,530 per mile).

In 2011, HCTRA spent an additional $175,000 to enhance the system, which increased the cost per mile to approximately $38,788. Figure 1 shows the current detection system components and locations, as well as the other countermeasures that HCTRA implemented. The following additional features have been included since implementing the system:

- Once the alarm is activated, the nearest CCTV camera automatically pans toward the detection site so that IMC dispatchers can track a wrong way vehicle and relay information to first responders.
- Warning messages conveyed to other drivers on DMSs can be displayed in automated incident response plans based on the direction of travel and location of the detection.
- LED in-ground lighting were installed to warn motorists at Post Oak and Richmond Avenue.
- WRONG WAY signs with flashing LEDs around the border were installed at locations that have a higher rate of incidents.
- Through attrition, in-ground puck loop systems are replacing radar sensors. To date, three sites are using the puck system.

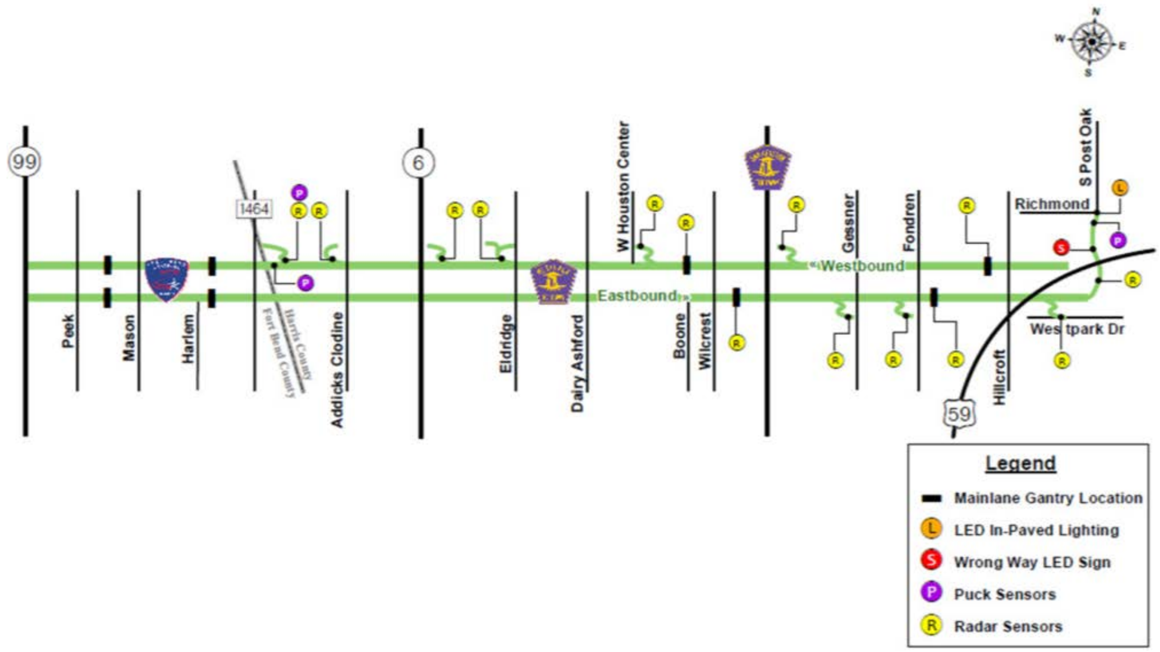


Figure 1. West Park Tollway Wrong Way Detection Sensors (HCTRA).

In 2009, in response to WWD crashes on the Dallas North Tollway, the North Texas Tollway Authority (NTTA) formed a WWD task force and deployed a number of signing and marking countermeasures, including wrong way pavement markings created with retroreflective raised pavement markers (RRPMs) at every exit ramp and red retroreflective sheeting on exit ramp sign supports (November 2009). Further countermeasure implementation included:

- WRONG WAY signing with flashing red LEDs around the border at three exit ramp locations in December 2010. These signs flash continuously (i.e., day and night).
- Pavement marking and signing modifications at cross street approaches at problem locations (January 2011 at Wycliff Avenue and June 2012 at the south end of the Dallas North Tollway).

Based on previous research recommendations (*18*) and success in other states (notably California), NTTA also considered the use of lowered DO NOT ENTER and WRONG WAY signing. Although NTTA was aware that a 3-ft mounting height was an option, it was unable to locate any crash tests to verify that signs at this height would not be hazardous to an errant vehicle that was traveling the right way on the system. In addition, TTI researchers had concerns regarding how a sign mounted at 3 ft would perform using the latest crash test criteria in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for*

Assessing Safety Hardware (MASH) (*29*). Thus, the 2-ft mounting height (measured vertically from the bottom of the sign to the elevation of the near edge of the pavement) was proposed as a height capable of catching an impaired driver's attention while still being able to alert unimpaired drivers of restricted movements and meeting current crashworthiness criteria. Using standard 36 inch by 36 inch DO NOT ENTER signs and 24 inch by 36 inch WRONG WAY signs, the sign assemblies had a total height of 5 ft and 4 ft, respectively (measured vertically from the top of the sign to the elevation of the near edge of the pavement).

NTTA contracted with TTI to determine if the 2-ft sign assemblies described above would meet the provisions of the AASHTO MASH. The testing was conducted, and the findings were submitted to the Federal Highway Administration (FHWA) Office of Safety for review. On December 7, 2010, NTTA received a letter from FHWA stating that the 24 inch by 36 inch WRONG WAY sign mounted 2 ft above the ground was acceptable to use on the National Highway System under the provisions of the AASHTO MASH (see Figure 2). In January 2011, TTI completed a crash test on a 36 inch by 36 inch DO NOT ENTER sign mounted at a 2-ft height (Figure 2). The results showed that the test assembly and sign passed.

Figure 2. Crash Testing of Lowered Sign Mounts.

In spring 2011, NTTA, in cooperation with TxDOT, requested experimentation to mount 36 inch by 36 inch DO NOT ENTER (R5-1) and 24 inch by 36 inch WRONG WAY (R5-1a) signs at 2 ft instead of the standard mounting height (7 ft) described in the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) (*30*). FHWA approved this request on July 14, 2011.

At that time, NTTA had 142 exit ramps on its system; of these, 51 were tolled (meaning they had in-ground loops sending wrong way driver alerts to the Command Center). NTTA decided to install lowered signs at 28 exit ramps (11 tolled and 17 non-tolled locations) based on the frequency of WWD events, geometry of the ramp, presence of pedestrians, and desire to have system-wide coverage. NTTA implemented the following three configurations of the DO NOT ENTER and WRONG WAY signage to accommodate pedestrian and cross-traffic visibility concerns (*31*):

- DO NOT ENTER signs at the 2-ft mounting height and WRONG WAY signs at the standard mounting height (7 ft). This configuration was installed at 12 locations where pedestrians and sight visibility issues were not a significant issue (see Figure 3).
- DO NOT ENTER signs at the standard mounting height (7 ft) and WRONG WAY signs at the 2-ft mounting height. This configuration was installed at two locations where DO NOT ENTER signs could cause an issue with sight visibility or pedestrians at cross streets and also where the slope of the ramp could make lowered WRONG WAY signs more visible from the intersection than the standard mounting height.
- DO NOT ENTER and WRONG WAY signs both at the 2-ft mounting height. This configuration was installed at 14 locations where both sets of lowered signs were visible (see Figure 4).

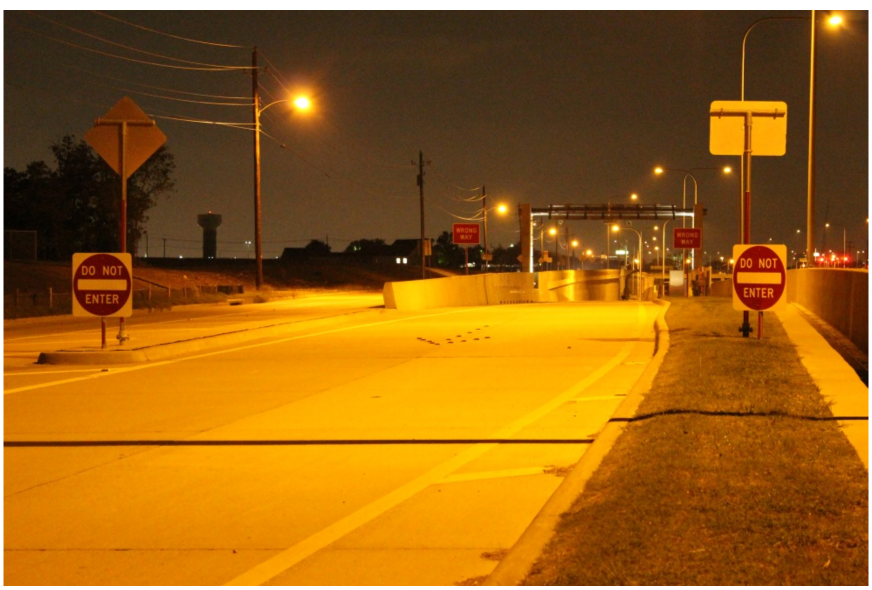


Figure 3. Example of NTTA DO NOT ENTER Lowered Signs.

Figure 4. Example of NTTA DO NOT ENTER and WRONG WAY Lowered Signs.

Figure 5 shows the locations of the lowered sign assembly configurations that FHWA approved (*32*). As of August 2014, NTTA had not experienced any maintenance issues, such as vandalism or theft, with the lowered signing.

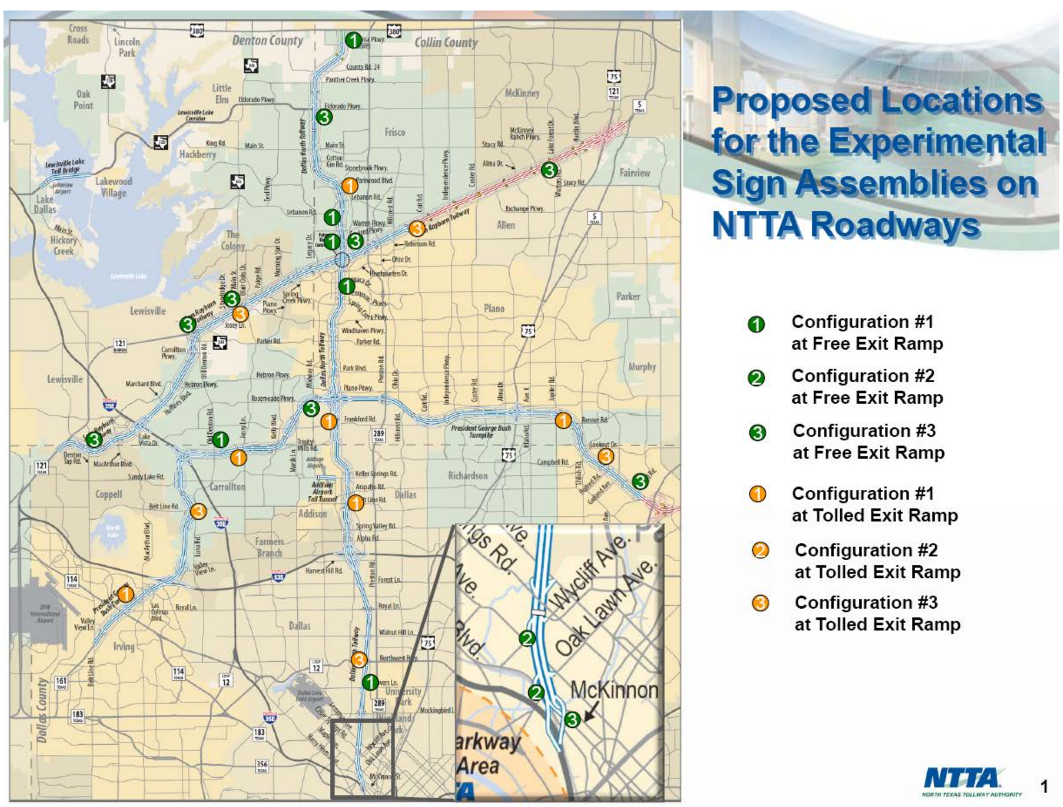


Figure 5. Lowered Sign Locations Approved by Federal Highway Administration (NTTA).

At the remaining 114 exit ramps in the NTTA system (40 tolled and 74 non-tolled), the DO NOT ENTER and WRONG WAY signs remained at the standard height (7 ft). The standard configuration served as a control group during the evaluation period.

In May 2011, public transportation and law enforcement agencies in the San Antonio area created a WWD task force to share information and identify the means to address and reduce WWD activity. Participating agencies included:

- TxDOT San Antonio District.
- TxDOT Traffic Operations Division.
- City of San Antonio (CoSA) Police Department (SAPD).
- CoSA Public Works Department.
- Bexar County Sheriff's Office.
- FHWA Texas Division.
- City of Balcones Heights Police Department.
- Southwest Research Institute (SwRI).
- TTI.

Goals established at the inaugural meeting of the task force included (*33*):

- Identifying high-risk locations.
- Investigating prior wrong way driver research, including wrong way driver countermeasures implemented elsewhere.
- Identifying potential wrong way driver countermeasures for San Antonio.
- Identifying funding resources for the implementation of wrong way driver countermeasures.

The task force also identified some challenges to the implementation of an effective response to the WWD issue that included the following:

- There are more than 400 exit ramps in the San Antonio area.
- Determining the highway points of entry for wrong way movements.
- Determining how to get the attention of drivers that are severely impaired.
- Finding a cost-effective solution that is compliant with the TMUTCD.

Even before the task force was created, SAPD and TxDOT implemented several procedures with regard to responding to WWD events. In August 2010, SAPD began to use an emergency call signal (i.e., E-Tone) for its radio network when a wrong way driver was reported to 911. In January 2011, SAPD implemented a code in their computer-aided dispatch (CAD) system that specifically identified all wrong way driver events. Similarly, in March 2011, TxDOT TransGuide traffic management center operators began logging all WWD events, not just those that resulted in a crash. In May 2011, TxDOT TransGuide operators began displaying wrong way driver warning messages on DMSs when an E-tone was issued (previously they waited to display warning message until the wrong way driver was visually verified). Two of these procedures (code in the SAPD CAD system and TxDOT logging all WWD events) created databases that could be used to determine the WWD trends in San Antonio. Institutional actions also included site reviews of select freeway exit ramps around San Antonio, an ongoing effort that involves staff from TxDOT, the CoSA Public Works Department, and TTI, and employs a site review checklist developed during previous research (*18*).

The task force used various methods to document WWD activity in San Antonio, with the purpose of identifying where WWD countermeasure deployment would be most meaningful and effective. After analyzing the various WWD event data sources and the information details available from each source, analysts determined that insufficient information existed to link WWD events with specific freeway ramps where wrong way drivers entered the freeway network. Accordingly, there was no logical means that could be devised for prioritizing the treatment of one freeway ramp over another.

The task force concluded that treatment of an entire freeway corridor was necessary in order to determine the effectiveness of WWD countermeasures. To assist with the selection of a test corridor in San Antonio, TTI researchers imported WWD data points from SAPD 911 call logs, TxDOT's TransGuide operator logs, and TxDOT's CRIS into a GIS database to form a single set of WWD event locations. TTI researchers then used spatial analysis functions native to the ArcView GIS platform to create a density map of WWD activity in San Antonio that used a color ramp from green (low WWD density) to red (high WWD density) to emphasize locations of the most intense WWD activity. Figure 6 shows the resulting map for 2011.

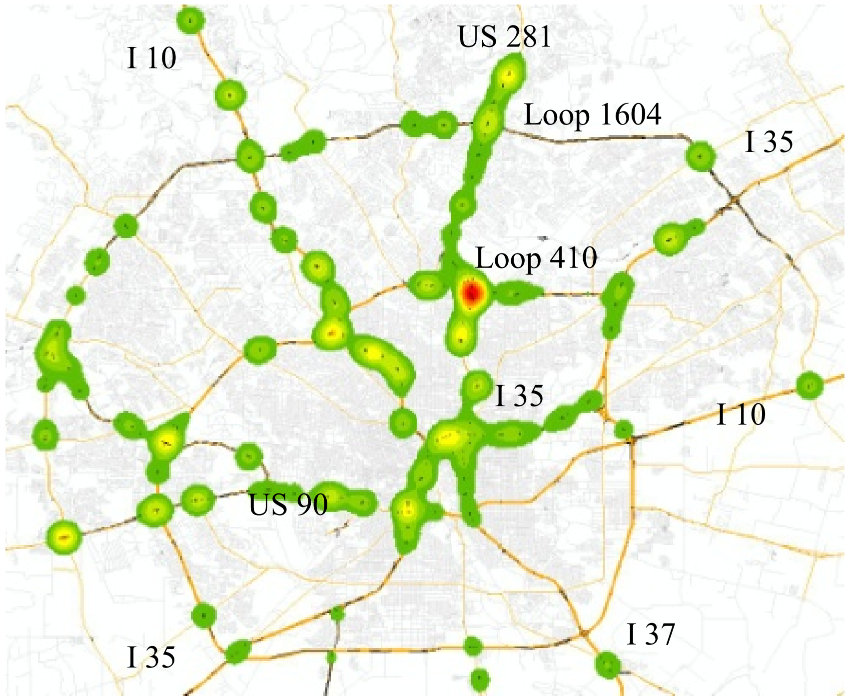


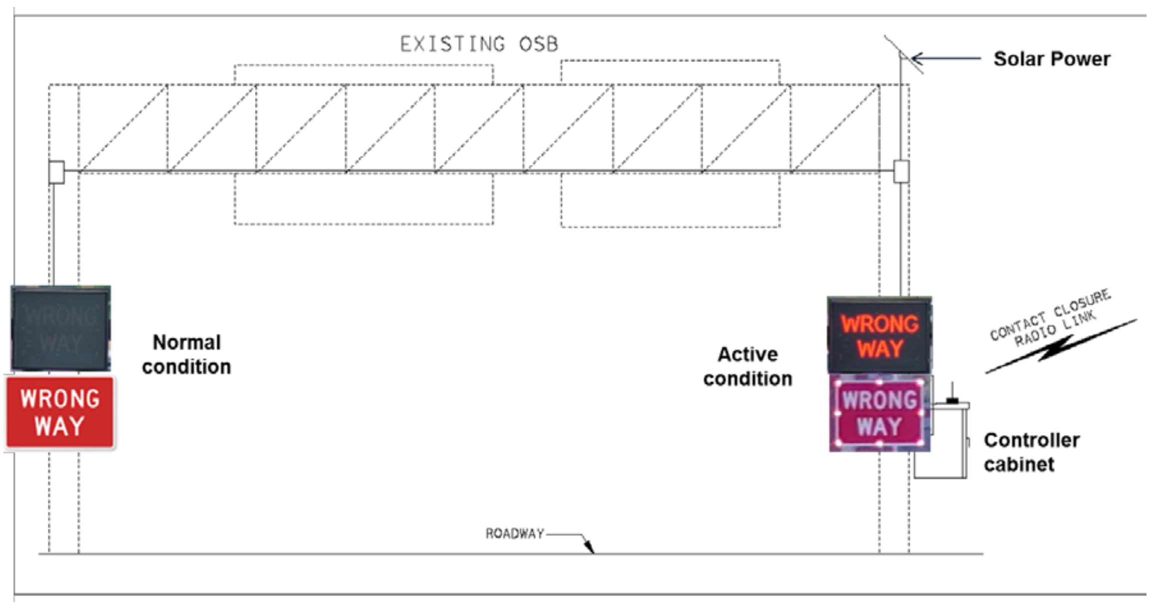
Figure 6. 2011 WWD Density Map of San Antonio.

This map shows that the highest number of WWD events occurred at US 281 and Airport Boulevard. In addition, US 281 from I-35 to Stone Oak Parkway contained the most WWD events of all the corridors analyzed. Based on this information, the task force selected the 15-mile US 281 corridor from I-35 (near downtown) to just north of Loop 1604 (the far north central side of San Antonio) as the Wrong Way Driver Countermeasure Operational Test Corridor. The countermeasure implementation plan for this test corridor included the following:

- On each exit ramp in the corridor (*29*), there would be one radar speed sensor and two WRONG WAY signs with flashing red LEDs around the border (see Figure 7). All radar speed sensors would be connected to the TxDOT TransGuide Operations Center and would provide an alarm notifying TransGuide operators and SAPD dispatchers of the location of the wrong way entry.
- At four locations, there would be wrong way identification and warning systems on the freeway mainlanes that consist of radar sensors (using a different technology than at the exit ramps) and detector-activated illuminated signing (only illuminated when a wrong way vehicle is present). The radar sensors would provide an alarm notifying TransGuide operators and SAPD dispatchers of the location of the wrong way vehicle. The illuminated message signs would include two WRONG WAY signs with flashing red

LEDs around the border (one on each side of the road) and two LED WRONG WAY blank-out signs (one on each side of the road) (see Figure 8). At three of the sites, a mainlane warning system would be implemented in both directions of travel. At the fourth site, however, a mainlane warning system would be installed in only one direction of travel.

Figure 7. Example of WRONG WAY Sign with Flashing Red LEDs around Border.



OSB = Overhead Sign Bridge

Figure 8. Original Mainlane System Design (TxDOT).

In 2013, another WWD project began in the Dallas area. The purpose of this pilot project was to implement intersection improvements that would assist in reducing WWD incidents within Dallas County. Approximately 354 intersections within Dallas County were included in this pilot project. A project budget of approximately $1,000,000 was used in Dallas County; this equates to about $2,200 to $2,900 per intersection. The pilot project incorporated the following procedures to conduct the project:

- Inventory potential locations.
- Develop criteria to evaluate and prioritize locations.
- Develop and finalize tailored designs, including pavement markings, new signage, and relocation of sign positioning.
- Initiate traffic signal enhancements, including replacement of incandescent bulbs with LED bulbs and installation of vertical green arrows.
- Implement proposed improvements.
- Conduct an after study of the project.

CATALOG OF WRONG WAY DRIVING COUNTERMEASURES AND MITIGATION METHODS

Based on information from the literature review and various entities, in fall 2012 researchers developed a catalog of known WWD countermeasures and mitigation methods being used or under research in the United States. Each catalog entry is composed of a one-page synopsis that:

- Describes the device or technique.
- Lists advantages or disadvantages associated with the measure.
- Reports the effectiveness of the measure (if available).
- Describes challenges that have been associated with the measure.
- Lists deployment locations and dates.

The catalog is found in Appendix A and is divided into the following four categories:

- Traffic control devices countermeasures—includes such devices as signs and pavement marking enhancements.
- Intelligent transportation systems—includes such devices as detection and notification systems, and advanced in-vehicle technologies.

- Geometric modifications—includes roadway changes, ramp modifications, and diamond interchange enhancements.
- Institutional coordination—includes enforcement, public education, and legislative modifications.

In May 2014, the Illinois Center for Transportation and the Illinois Department of Transportation published guidelines for reducing wrong way crashes on freeways (*34*). Researchers compiled the guidebook from previous literature, national and state standards, and current practices. Similar to the catalog in Appendix A, the Illinois guidebook contains information on common countermeasures (e.g., signs and pavement markings), advance technologies, geometric elements and related design considerations, enforcement, and education. The Illinois guidebook also contains a wrong way entry field inspection checklist and WWD road safety audit prompt list. However, the guidebook does not provide specific recommendations regarding the appropriate WWD countermeasures and mitigation methods based on conditions.

ANALYSIS OF WRONG WAY DRIVING CRASHES IN TEXAS

Previous TTI research (*18*) reviewed wrong way crash reports extracted from the statewide crash database from January 1, 1997, to December 31, 2000. Key findings were:

- Wrong way crashes were more prevalent during nighttime hours, particularly in the early morning hours.
- Wrong way crashes tended to be more severe and had a greater proportion resulting in a fatality or serious injury than other types of crashes.
- Driving under the influence was the primary contributing factor in wrong way crashes.
- About two-thirds of wrong way crashes involved a male driver.
- Almost half of the wrong way drivers were 16 to 34 years old.

In an effort to update this information, researchers analyzed the TxDOT CRIS data from 2007 to 2011. In addition, researchers compared wrong way crashes by major roadway, county, city, and TxDOT district to identify trends. Researchers also analyzed driver BAC levels for wrong way crashes.

Dataset

CRIS has four datasets: unit, charge, crash, and person. Each of these datasets has different codes that could distinguish crashes involving WWD from other reported crashes. The following explains how crashes involving WWD were identified for this analysis:

- Unit—This dataset describes characteristics of the vehicles/entities involved in the recorded crashes. In this dataset, researchers used the CONTRIB_FACTR_ID variable to identify WWD-related crashes. This variable is defined as "the factor for the vehicle, which the officer felt contributed to the crash." The dataset lists up to three contributing factors and up to two possible contributing factors for each crash. A contributing factor code of 69 represents "wrong side—approach or intersection," 70 represents "wrong side—not passing," and 71 represents "wrong way—one way road." While code 71 best represents wrong way crashes on controlled-access facilities, researchers included the other two codes in order to capture all possible WWD crashes.
- Charge—This dataset describes the police charges for each person involved in the recorded crashes. In this dataset, researchers used the charge description variable CHARGE_CAT_ID to identify WWD-related crashes. This variable is defined as "the charge category applied by the officer." A charge code of 28 represents "wrong side or WWD." Again, researchers choose to include crashes with this code to capture all possible WWD crashes.
- Crash—The information in this dataset pertains to crash characteristics (e.g., date, time, weather, and crash severity) and crash location characteristics (e.g., intersection relation, surface condition, and traffic control devices). There are no variables in this dataset that identify WWD crashes. However, researchers used this dataset to determine roadway classification. For this project, researchers were primarily concerned with WWD crashes on controlled-access highways. Unfortunately, there is no variable in CRIS that could be used to isolate controlled-access highway crashes. Instead, researchers used the variable ROAD_CLS_ID, which is defined as "the functional classification group of the priority road the motor vehicle(s) was traveling on before the First Harmful Event occurred." Researchers used a road class code of 1 (interstates) and 2 (state and U.S. highways). Researchers acknowledge that some state and U.S. highways are not controlled-access facilities. However, in major metropolitan areas (the focus of this project) state and U.S.

highways tend to be controlled-access freeways. To capture crashes on these facilities, researchers had to include all state and U.S. highways in the database. Researchers also used the TxDOT reportable flag variable in this dataset (TxDOT_Rptable_Fl = Y) to identify crashes that occur on a roadway and result in injury, death, or at least $1,000 in damage.

- Person—The information in this dataset describes the characteristics of people involved and injuries sustained. There are no variables in this dataset that identify WWD crashes. However, researchers used this dataset to determine age, gender, and BAC level, when available.

In summary, to obtain the freeway and highway WWD crash database, the following CRIS codes were used:

- CONTRIB_FACTR_1_ID = 69, 70, or 71 in the unit dataset.
- CONTRIB_FACTR_2_ID = 69, 70, or 71 in the unit dataset.
- CONTRIB_FACTR_3_ID = 69, 70, or 71 in the unit dataset.
- CONTRIB_FACTR_P1_ID = 69, 70, or 71 in the unit dataset.
- CONTRIB_FACTR_P2_ID = 69, 70, or 71 in the unit dataset.
- CHARGE_CAT_ID = 28 in the charges dataset.
- ROAD_CLS_ID = 1 or 2 in the crash dataset.
- TxDOT_Rptable_Fl = Y in the crash dataset.

Using the contributing factor and charge category variables, researchers identified 20,788 wrong way crashes in the CRIS database. Of the 20,788 wrong way crashes, 18,917 crashes (91 percent) were coded as TxDOT reportable. Of the 18,917 TxDOT-reportable WWD crashes, 6503 crashes (34 percent) had the ROAD_CLS_ID variable coded as 1 or 2. Of these, 1003 crashes (15 percent) were on an interstate (coded as 1), and 5500 crashes (85 percent) were on a state or U.S. highway (coded as 2). Ninety percent of these 6503 WWD crashes had latitude and longitude information, which researchers plotted in Google® Earth to identify whether or not each crash occurred on a controlled-access highway. As shown in Table 1, 1409 crashes (21 percent) of the 6503 WWD crashes occurred on controlled-access freeways. These 1409 WWD TxDOT-reportable crashes on Texas freeways involved 3601 vehicles and 4180 persons (each crash involved more than one vehicle and person).

Table 1. Distribution of Wrong Way Crashes by Functional Class/Access Type.

Functional Class	Number of Crashes	Percent of Crashes
Arterial	1670	26
Frontage Road	38	1
Freeway	1409	21
Other	2722	42
Location Information Missing	664	10
Total	6503	100

Results

General Trends

Using latitude and longitude data, researchers created a heat map (see Figure 9) with the Google Fusion Table tool to visualize WWD crashes on freeways in Texas. This map shows that most WWD crashes in Texas occur in urban areas. In addition, it is evident that most WWD crashes occur along and to the east of I-35. Table 2 shows that less than 1 percent of all traffic crashes and 1 percent of all fatal crashes were WWD crashes on freeways. Figure 10 shows the trend of total, injury, and fatal WWD crashes by year on freeways. Overall, the graph shows a downward trend in WWD crashes over the five-year period analyzed.

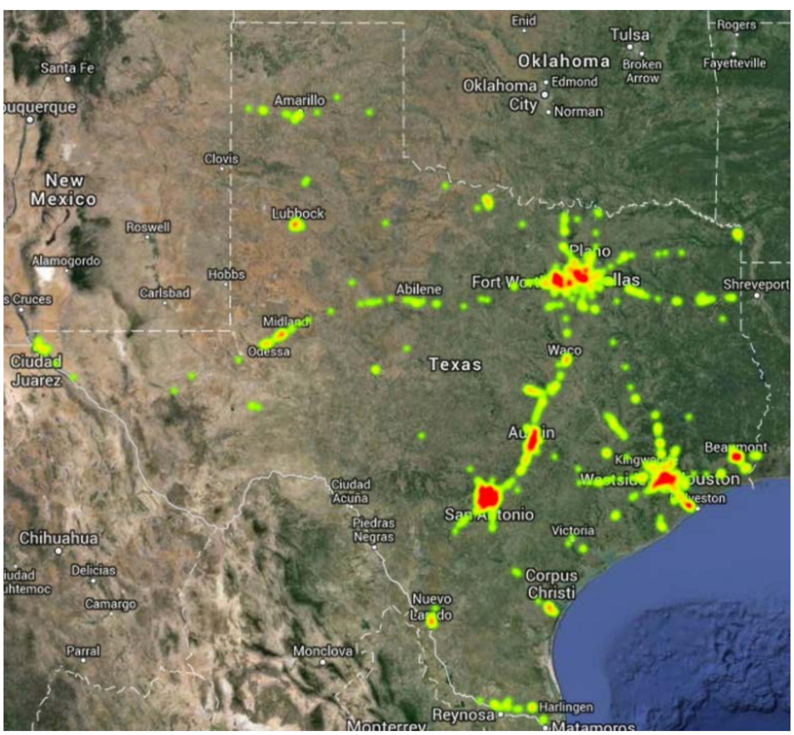


Figure 9. Heat Map of Texas Freeway WWD Crashes (2007–2011).

Table 2. Freeway WWD Crashes as a Percentage of All Traffic Crashes, by Severity (Includes Only TxDOT Reportable Crashes).

Year	2007	2008	2009	2010	2011	Overall
All Traffic Crashes	458,027	438,982	428,303	391,005	380,788	2,097,105
Freeway Wrong Way Crashes	346	329	264	277	193	1409
Percent Freeway Wrong Way Crashes	< 1	< 1	< 1	< 1	< 1	< 1
All KABC* Crashes	175,488	162,871	157,493	144,280	141,098	781,230
Freeway Wrong Way KABC Crashes	195	178	139	165	117	794
Percent Freeway Wrong Way KABC Crashes	< 1	< 1	< 1	< 1	< 1	< 1
All K Crashes	3,101	3,126	2,817	2,752	2,744	14,540
Freeway Wrong Way K Crashes	27	32	30	30	31	150
Percent Freeway Wrong Way K Crashes	1	1	1	1	1	1

*K = killed; A = incapacitating injury; B = non-incapacitating; C = possible injury; O = not injured/property damage only; U= unknown severity.
Note: All crashes included KABCOU on all roadways. Wrong way crashes represent those on freeways only.

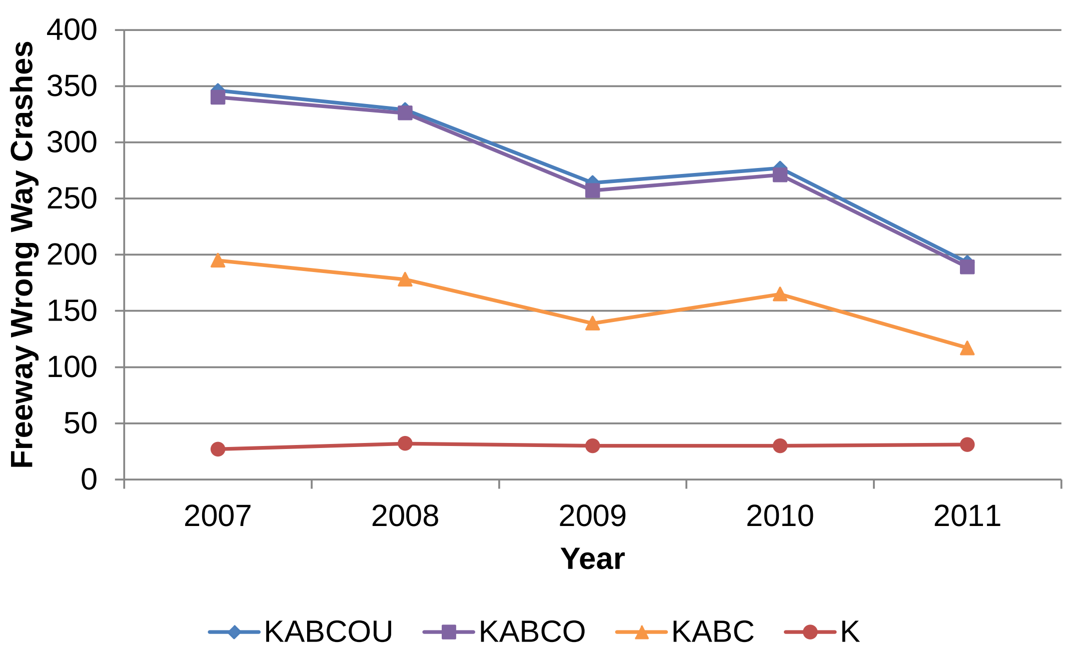


Figure 10. Freeway WWD Crashes (2007–2011).

Researchers examined the contributing factors associated with the freeway wrong way crashes and found that 36 percent could be attributed to someone that had been drinking or was under the influence of alcohol. The next most prevalent contributing factor was driver inattention (16 percent).

Table 3 and Figure 11 show the distribution of fatal and non-fatal freeway WWD crashes by the time of day (hour). While there are evident peaks at 2:00 a.m. for both fatal and non-fatal crashes (the typical time for establishments that serve alcohol to close in Texas), prevalence of WWD crashes seems to increase beginning at 7:00 p.m. These trends are similar to those in previous research efforts that found WWD crashes to be more frequent at night.

Table 3. Freeway WWD Crashes by Time of Day (2007–2011).

Hour	Non-fatal Crashes	Fatal Crashes	Total	Percentage of Total Wrong Way Crashes
0	88	10	98	7
1	80	12	92	7
2	129	31	160	11
3	71	18	89	6
4	38	15	53	4
5	44	9	53	4
6	35	4	39	3
7	39	3	42	3
8	30	1	31	2
9	32	2	34	3
10	30	1	31	2
11	36	3	39	3
12	54	2	56	4
13	40	4	44	3
14	46	2	48	3
15	44	2	46	3
16	50	4	54	4
17	46	1	47	3
18	60	4	64	5
19	43	0	43	3
20	50	1	51	4
21	57	5	62	4
22	55	6	61	4
23	62	10	72	5
Total	1,259	150	1,409	100

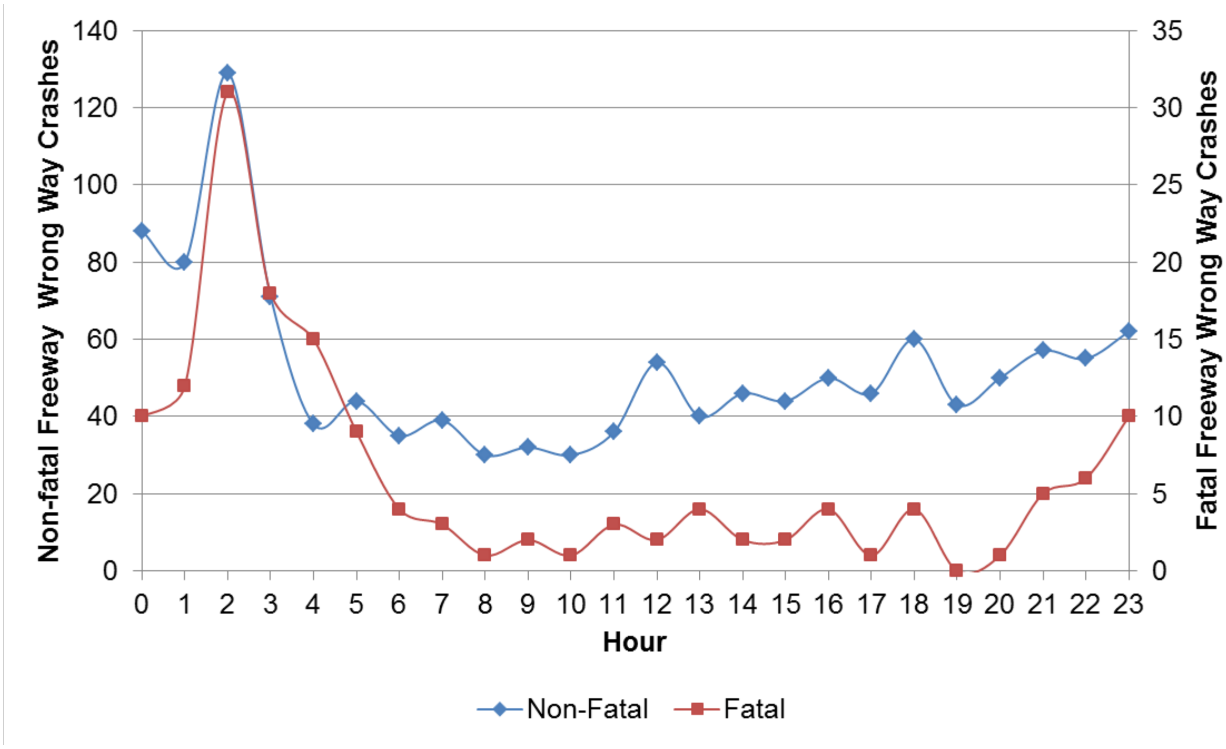


Figure 11. Freeway WWD Crashes by Time of Day (2007–2011).

To further analyze these trends, researchers categorized the freeway WWD crashes by weekday (6:00 a.m. on Monday to 6:00 p.m. on Friday) and weekend (7:00 p.m. on Friday to 5:00 a.m. on Sunday). Figure 12 and Figure 13 show the distribution by time of week and time of day for non-fatal and fatal freeway WWD crashes, respectively. These figures show that during the week WWD crashes tend to be more common during the day. In contrast, on the weekend WWD crashes are more prevalent at night. As expected, most fatal WWD crashes occurred between midnight and 5:00 a.m. (57 percent), with an evident peak at 2:00 a.m. and with an additional 15 percent occurring between 8:00 p.m. and midnight.

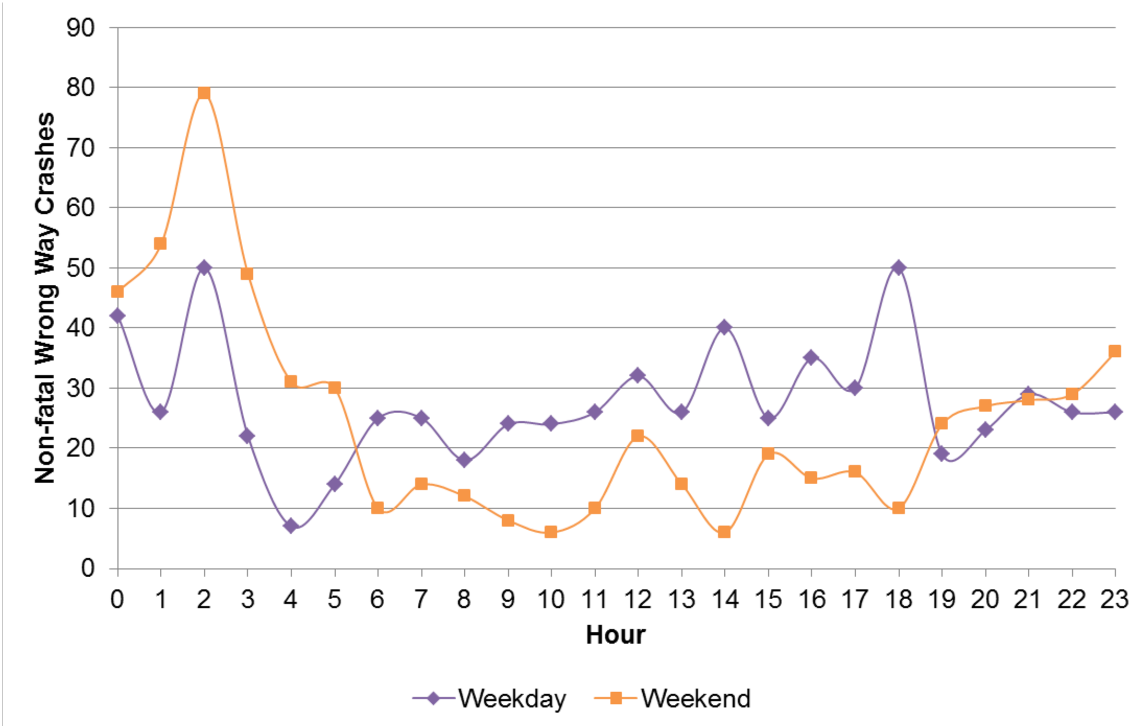


Figure 12. Freeway Non-fatal WWD Crashes by Time of Week and Time of Day (2007–2011).

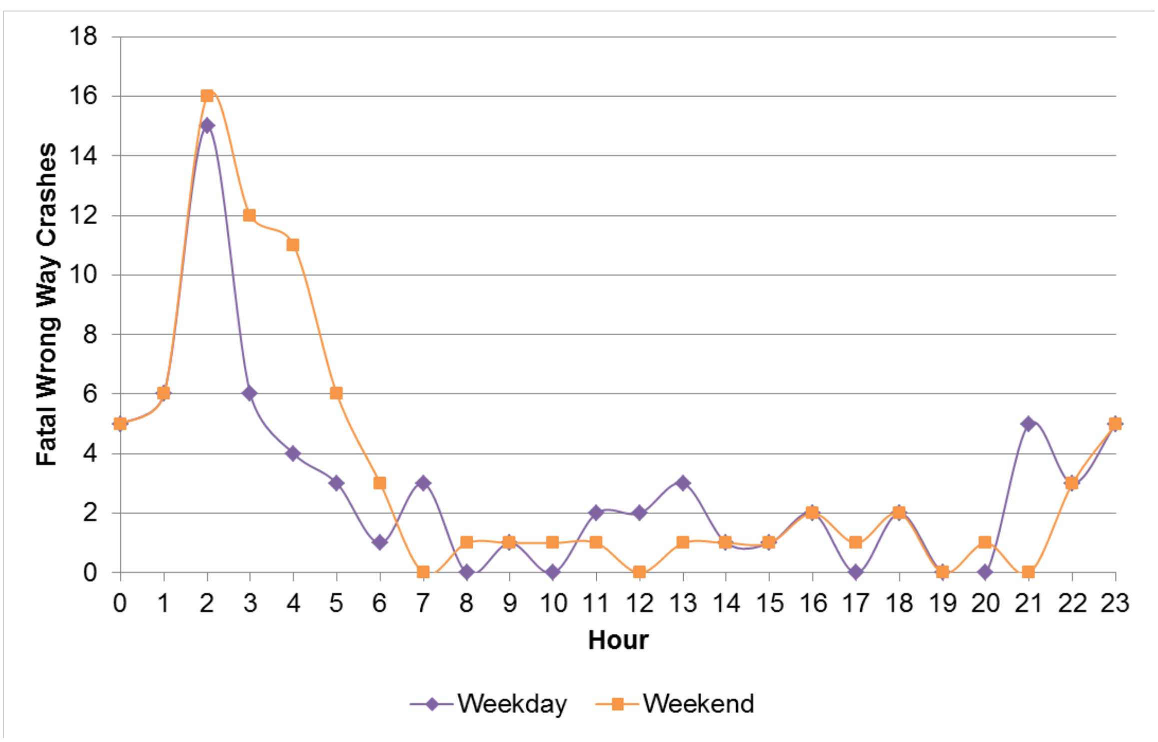


Figure 13. Freeway Fatal WWD Crashes by Time of Week and Time of Day (2007–2011).

Roadway, County, and District Trends

In an effort to identify specific roadways and areas where WWD crashes are more prevalent, researchers compared wrong way crashes by roadway, county, city, and TxDOT district to identify trends. Table 4 lists the top 10 freeways with the highest number of WWD crashes. Overall, these 10 freeways represent approximately 61 percent of all WWD crashes and all fatal WWD crashes in Texas. This table also shows that US 281 was ranked number eight in the state. As mentioned previously, various WWD countermeasures and detection systems were recently implemented on a portion of US 281 in San Antonio.

Table 4. Top 10 Freeways with Highest Number of WWD Crashes (2007–2011).

Highway System	Highway Number	Non-fatal	Fatal	Total	Percent Total Crashes[a]	Percent Total Fatal Crashes[b]
IH	35	216	26	242	17	17
IH	10	130	13	143	10	9
IH	45	89	12	101	7	8
IH	20	89	10	99	7	7
US	59	66	8	74	5	5
IH	30	49	10	59	4	7
IH	410	55	3	58	4	2
US	**281**	**27**	**2**	**29**	**2**	**1**
IH	610	25	3	28	2	2
SH	121	22	4	26	2	3
Total		768	91	859	60	61

[a] Percent computed out of all wrong way crashes (n = 1409).
[b] Percent computed out of all fatal wrong way crashes (n = 150).

Table 5 and Table 6 list the top 10 counties and cities, respectively, with the highest number of freeway WWD crashes. The top six counties and cities are directly related (Bexar–San Antonio, Harris–Houston, Dallas–Dallas, Tarrant–Fort Worth, Travis–Austin, and Jefferson–Beaumont). Not surprisingly, all the major metropolitan areas are represented, though it is interesting that three of the counties are in the Houston District (i.e., Harris, Galveston, and Montgomery).

Table 7 provides a summary of freeway WWD crashes by crash severity and TxDOT district. As expected, districts with major metropolitan areas top the list (i.e., Houston, San Antonio, Dallas, Fort Worth, and Austin). Overall, 20 percent of the WWD crashes result in a fatality or incapacitating injury (KA crashes). In addition, another 36 percent of the WWD crashes cause non-incapacitating injuries or possible injury (BC crashes).

Table 5. Top 10 Counties with Highest Number of Freeway WWD Crashes (2007–2011).

County	District	Non-fatal	Fatal	Total	Percent Total Crashes[a]	Percent Total Fatal Crashes[b]
Bexar	San Antonio	206	20	226	16	13
Harris	Houston	173	26	199	14	17
Dallas	Dallas	134	9	143	10	6
Tarrant	Fort Worth	113	8	121	9	5
Travis	Austin	56	4	60	4	3
Jefferson	Beaumont	37	2	39	3	1
Bell	Waco	23	5	28	2	3
Galveston	Houston	22	1	23	2	1
Montgomery	Houston	20	2	22	2	1
Midland	Odessa	18	3	21	1	2
Total		802	80	882	63	52

[a] Percent computed out of all wrong way crashes (n = 1409).
[b] Percent computed out of all fatal wrong way crashes (n = 150).

Table 6. Top 10 Cities with Highest Number of Freeway WWD Crashes (2007–2011).

City	District	Non-fatal	Fatal	Total	Percent Total Crashes[a]	Percent Total Fatal Crashes[b]
San Antonio	San Antonio	189	15	204	14	10
Houston	Houston	139	16	155	11	11
Dallas	Dallas	84	3	87	6	2
Fort Worth	Fort Worth	55	4	59	4	3
Austin	Austin	51	4	55	4	3
Beaumont	Beaumont	29	1	30	2	1
Arlington	Fort Worth	27	0	27	2	< 1
Irving	Dallas	22	2	24	2	1
Rural Harris County	Houston	17	6	23	2	4
Corpus Christi	Corpus Christi	15	4	19	1	3
Total		628	55	683	49	39

[a] Percent computed out of all wrong way crashes (n = 1409).
[b] Percent computed out of all fatal wrong way crashes (n = 150).

Table 7. Freeway WWD Crashes by Severity and TxDOT District (2007–2011).

TxDOT District	All Crashes	KA Crashes	BC Crashes	K Crashes	O Crashes	Percent Total Crashes	Percent Fatal Crashes
Houston	273	58	94	32	116	19	21
San Antonio	254	42	88	24	116	18	16
Dallas	196	37	81	15	77	14	10
Fort Worth	134	25	42	10	64	10	7
Austin	95	18	47	8	29	7	5
Beaumont	67	10	28	5	28	5	3
Waco	52	8	19	7	24	4	5
Odessa	41	10	13	5	17	3	3
Bryan	31	13	10	4	8	2	3
Pharr	28	4	10	2	14	2	1
Amarillo	27	9	8	7	9	2	5
Wichita Falls	24	6	8	5	10	2	3
Abilene	22	8	12	1	2	2	< 1
Yoakum	22	2	6	1	13	2	< 1
Corpus Christi	22	7	5	4	9	2	3
Lubbock	21	2	8	1	11	1	< 1
Tyler	20	7	6	5	7	1	3
Atlanta	19	4	5	3	10	1	2
El Paso	19	2	7	2	8	1	1
Paris	17	10	2	7	5	1	5
Laredo	12	0	6	0	6	1	0
San Angelo	7	2	2	1	3	0	< 1
Brownwood	3	0	2	0	1	0	0
Childress	2	1	0	1	1	0	< 1
Lufkin	1	0	0	0	1	0	0
Total	1,409	285	509	150	589	100	100

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

Persons Involved

Overall, 4180 people were involved in the 1409 freeway WWD crashes. Table 8 shows the distribution of person type by injury severity of people involved in WWD crashes. As expected, the majority of the persons involved were drivers (69 percent). Passengers accounted for 29 percent of the persons involved. Out of the 2894 drivers involved, 153 (5 percent) were killed, and 850 (29 percent) were injured. Similar trends were found for passengers (3 percent and 34 percent, respectively).

Table 8. Person Type by Injury Severity Distribution of Persons Involved in Freeway WWD Crashes (2007–2011).

Person Type	Unknown	Incapacitating Injury	Non-incapacitating Injury	Possible Injury	Killed	Not Injured	Blank	Total	Percent Total Crashes
Driver	369	191	300	359	153	1515	7	2894	69
Passenger	49	79	137	194	40	693	3	1195	29
Pedal Cyclist	2	4	11	15	0	3	0	35	1
Pedestrian	0	2	0	0	2	1	0	5	< 1
Driver of Motorcycle-Type Vehicle	2	10	8	2	4	2	0	28	1
Other	0	0	0	0	0	2	0	2	< 1
Unknown	3	0	0	0	0	0	0	3	< 1
No Match with Charge	18	0	0	0	0	0	0	18	< 1
Total	443	286	456	570	199	2216	10	4180	100

Table 9 shows the distribution of driver age group. Most drivers involved in freeway WWD crashes were 16 to 34 years old (44 percent). Previous research supports this finding. Interestingly, there was not a peak for older adults (as found in other research); instead, the percentage of drivers decreased with age. Compared with the previous TTI research project (*18*), the percentage of drivers in the 45 to 54 age group was higher (13 percent versus 9 percent). Table 10 shows that freeway WWD crash drivers tend to be males (59 percent), and about 40 percent of these males are 21 to 34 years old. Previous research also supported these findings.

Table 9. Age Group of Drivers Involved in Freeway WWD Crashes (2007–2011).

Age Group	Number of Drivers	Percentage of Total
< 16	5	< 1
16–24	654	23
25–34	616	21
35–44	472	16
45–54	367	13
55–64	232	8
≥65	165	6
Unknown	383	13
Total	2,894	100

Table 10. Age Group by Gender Distribution of Drivers Involved in Freeway WWD Crashes (2007–2011).

Age Group	Unknown	Male	Female	Blank	Total
< 16	1	1	3	0	5
16–24	2	394	257	1	654
25–34	1	429	186	0	616
35–44	2	319	151	0	472
45–54	0	260	107	0	367
55–64	0	147	85	0	232
≥ 65	1	104	60	0	165
Unknown	287	50	16	30	383
Total	294	1,704	865	31	2,894
Percent Total	10	59	30	1	100

Table 11 shows the drug and alcohol results for drivers involved in freeway WWD crashes. Unfortunately, the drug test was not provided for 98 percent of drivers, and the alcohol result was unknown for 92 percent of the drivers, even though alcohol was noted as one of the contributing factors in 36 percent of the crashes. Therefore, impairment information was not available in CRIS for most drivers involved in the freeway WWD crashes. Actual BAC levels were available for only 71 (31 percent) of the 228 drivers who tested positive (BAC ≥ 0.08 g/dL) or negative (BAC < 0.08 g/dL) for alcohol. Figure 14 shows the cumulative distribution of the BAC levels for these drivers. Key findings include:

- Almost 90 percent had a BAC level equal to or greater than the legal limit (0.08 g/dL).
- Approximately 50 percent had a BAC level equal to or greater than twice the legal limit (0.16 g/dL).
- Approximately 10 percent had a BAC level equal to or greater than three times the legal limit (0.24 g/dL).
- The BAC ranges with the highest percentage of drivers (30 percent) were 0.16 to 0.199 g/dL and 0.20 to 0.239 g/dL.
- Most drivers (60 percent) had a BAC level of 0.16 to 0.239 g/dL.
- The average BAC level was 0.18 g/dL (over twice the legal limit).

Table 11. Alcohol and Drug Result of Drivers Involved in Freeway WWD Crashes (2007–2011).

Drug Result	Alcohol Result			Total	Percent Total
	Positive	Negative	Blank		
Positive	15	6	5	26	1
Negative	27	10	1	38	1
Unknown	8	1	21	30	1
Not Applicable	109	10	2,188	2,307	80
Blank	34	8	451	493	17
Total	193	35	2,666	2,894	100
Percent Total	7	1	92	100	

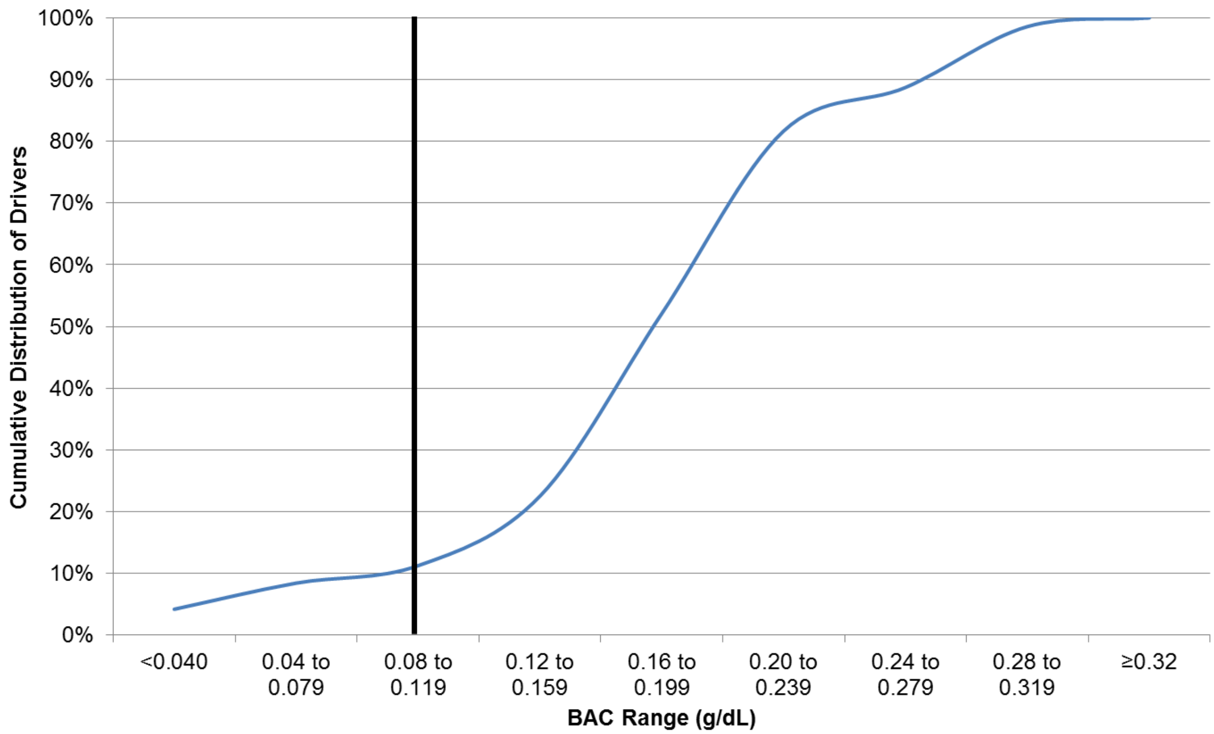


Figure 14. Cumulative Distribution of BAC Levels for Drivers Involved in Freeway WWD Crashes.

SUMMARY

Even though WWD crashes are infrequent, they result in severe injuries and fatalities, and continue to occur despite more than 50 years of research and countermeasure implementation. To date, previous research has focused on quantifying the WWD problem, and documenting traditional and innovative countermeasures and mitigation methods. Even though various WWD countermeasures and detection systems have been implemented over the years, only a limited number of studies have actually evaluated their effectiveness. Therefore, questions remain as to which countermeasures actually get the attention of wrong way drivers and are effective at getting them to stop and turn around, especially those that are impaired.

Based on Texas crash data, researchers verified that the majority of WWD crashes on controlled-access highways occur in major metropolitan areas. These WWD crashes typically happen at night between midnight and 5:00 a.m., with a peak around 2:00 a.m. (the typical time for establishments that serve alcohol to close in Texas). Most wrong way drivers were young males, and driving under the influence was the primary contributing factor. While actual BAC levels were available for only a third of the drivers that tested positive for alcohol, researchers found that almost 90 percent had a BAC level greater than or equal to the legal limit (0.08 g/dL). In fact, 60 percent had a BAC level of 0.16 to 0.239 g/dL (two to three times the legal limit).

While traditional and enhanced signs and pavement markings are among some of the most commonly implemented WWD countermeasures, it is not clear how effective they are at conveying to alcohol-impaired drivers that they are going the wrong way. Therefore, researchers designed and conducted two nighttime closed-course studies to evaluate the effectiveness of select WWD countermeasures on alcohol-impaired drivers. These studies are discussed in Chapter 3.

Since 2008, HCTRA, NTTA, and TxDOT have deployed various WWD countermeasures and mitigation methods in Texas. These recent on-road implementations provided the opportunity to assess the effectiveness of these WWD strategies in an actual operational environment. Chapter 4 documents the research team's efforts to collect and analyze preexisting data from these agencies.

Both HCTRA and TxDOT use DMSs to display warning messages to right way drivers when a WWD event occurs. However, TxDOT's message is more general in nature than HCTRA's message, which directs drivers to take a specific action. While there are extensive human factors and traffic operations research on DMS message design (conducted mostly by TTI researchers), these efforts have not looked at the design of wrong way driver warning messages. Thus, researchers used the focus group discussion method to obtain motorists' opinions regarding the design of wrong way driver warning messages for DMSs. Researchers also reviewed previous literature and DMS message design manuals to gain insight into the design of wrong way driver warning messages. These efforts are documented in Chapter 5.

CHAPTER 3: CLOSED-COURSE STUDIES

INTRODUCTION

As seen in Chapter 2 and Appendix A, the most common WWD countermeasures include traditional and enhanced signs and pavement markings. However, it is not clear how effective the countermeasures are at conveying to alcohol-impaired drivers that they are going the wrong way. Since alcohol was a contributing factor in over one-third of the WWD crashes in Texas, researchers designed and conducted two nighttime closed-course studies to:

- Determine where alcohol-impaired drivers look in the forward driving scene.
- Provide insight into how alcohol-impaired drivers recognize and read signs.
- Assess the conspicuity of select WWD countermeasures from the perspective of alcohol-impaired drivers.

While data in response to a simulated environment cannot be directly compared to data collected on an actual road, closed-course study data can be used to compare the relative differences in performance between the various treatments evaluated. The following subsection describes the design, conduct, and findings from the first closed-course study. This subsection is followed by information regarding the experimental design and results of the second closed-course study.

FIRST STUDY

The first study was conducted in February through March 2013. The objectives were to determine:

- Where alcohol-impaired drivers look in the forward driving scene.
- The impact of alcohol on sign color recognition.
- The impact of alcohol on sign legibility distance.
- The impact of alcohol on how drivers look at signs.

Treatments

The primary focus of the first study was rectangular white-on-red signs. To reduce the likelihood of learning effects, researchers did not use standard sign messages like WRONG WAY. Instead, researchers used simpler words not typically found on signs that were vetted in previous studies. Figure 15 shows the five white-on-red signs used. Only the KID sign had eight LED red lights around the border of the sign (the same design used with the WRONG WAY signs). Researchers also included distractor signs (diamond black on yellow, diamond black on orange, and rectangular black on white) in order to vary the sign color and legend. Figure 16 displays the five distractor signs. Table 12 contains the sign characteristics for all of the signs used.

TxDOT uses dual WRONG WAY and DO NOT ENTER signing at exit ramps, so in this study researchers placed signs on the right and left side of the road (although not at the same locations). Researchers located all signs 12 ft from the edgeline of the simulated two-lane, two-way road (the standard TxDOT lateral offset) and varied the sign height. Researchers mounted signs at the TxDOT standard sign height (7 ft) and the NTTA lowered sign height (2 ft), both of which were measured from the bottom of the sign to the roadway surface.

The participants saw all of the white-on-red signs, except the KID sign, at all of the lateral position/height combinations (i.e., right 7 ft, right 2 ft, left 7 ft, and left 2 ft). The KID sign was only seen on the right side of the road at 7 ft. The distractor signs were also not seen at all of the lateral position/height combinations. Other research activities in the area limited the researchers' ability to mount certain signs at some sign locations.

Overall, there were 26 treatments, separated into four treatment orders. Each treatment order consisted of:

- The ACE, SKY, TEA, and ZOO signs, each at a different lateral position/height combination.
- The KID sign mounted at 7 ft on the right side of the road.
- The PEOPLE/LITTLE and SIMPLE/DESIGN signs mounted at different heights on the right side of the road.
- The DURING/MOTION sign mounted at 2 ft on the left side of the road.
- The SPEED LIMIT 96 and SPEED LIMIT 76 signs mounted at different heights on the left side of the road.

To reduce learning effects, each participant saw a different treatment order at each BAC level (i.e., 0.00, 0.04, 0.08, and 0.12 g/dL). In addition, researchers tried to balance the treatment orders across the four BAC levels.

a) ACE sign.

b) SKY sign.

c) TEA sign.

d) ZOO sign.

e) KID sign.

Figure 15. First Study White-on-Red Signs.

a) PEOPLE/LITTLE sign.

b) SIMPLE/DESIGN sign.

c) DURING/MOTION sign.

d) SPEED LIMIT 92 sign.

e) SPEED LIMIT 76 sign.

Figure 16. First Study Distractor Signs.

Table 12. First Study Sign Characteristics.

Sign	Background			Legend		
	Color	Retroreflectivity ($cd/lx/m^2$)[a]	Size (inches)	Color	Retroreflectivity ($cd/lx/m^2$)[a]	Height (inches)
ACE	Red	137	42 × 30	White	646	8
SKY	Red	128	42 × 30	White	667	8
TEA	Red	125	42 × 30	White	604	8
ZOO	Red	130	42 × 30	White	641	8
KID[b]	Red	142	42 × 30	White	664	8
PEOPLE LITTLE	Yellow	488	36 × 36	Black	NA	5
SIMPLE DESIGN	Yellow	479	36 × 36	Black	NA	5
DURING MOTION	Orange	256	36 × 36	Black	NA	5
92	White	469	24 × 30	Black	NA	10[c]
76	White	483	24 × 30	Black	NA	10[c]

NA = not applicable.
[a] The retroreflectivity levels shown are an average of four readings measured at an observation angle of 0.2 degrees and an entrance angle of −4.0 degrees.
[b] The pulse integration measurement was 1.2 lx*s.
[c] Height of the numerals.

Vehicles and Instrumentation

The study used two instrumented state-owned vehicles, both 2005 Dodge Grand Caravans. As headlight performance can differ greatly between vehicles based on age, varied use, and maintenance, the headlight assemblies and HB4 bulbs were completely replaced and aimed in accordance with the manufacturer's instructions. Figure 17 shows the in-vehicle equipment used. Researchers mounted a global position system (GPS) on the windshield and connected it to a laptop with data collection software. The GPS collected latitude, longitude, and speed data. Using an American Standard Code for Information Interchange (ASCII) tag system in the software, the researchers indicated when the participant began each segment of the course and when the participant identified the sign colors and legends. Researchers also mounted an eye-tracking system on the dashboard. This system includes two cameras and an infrared pod used to track the driver's eyes and measure the diameter of his pupils. In addition, researchers used a forward driving scene camera. This camera uses the data from the eye-tracking system to visually document a point of gaze for the driver in the forward driving scene video. Researchers synchronized all data with the laptop clock time.

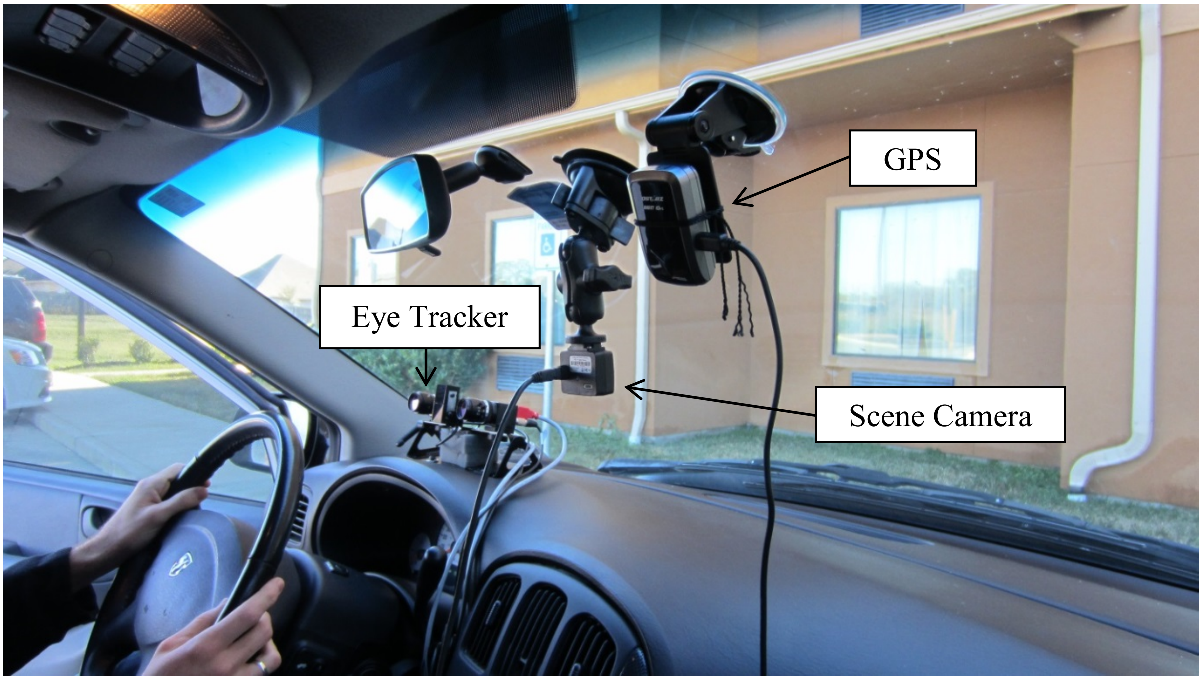


Figure 17. First Study In-Vehicle Equipment.

Study Procedure

Researchers recruited potential participants from the Bryan/College Station, Texas, area. Participants had to meet the following criteria:

- Have a current driver's license with no nighttime driving restrictions.
- Be male.
- Be at least 21 years old.
- Weigh less than or equal to 250 pounds.
- Not be color blind.

All participants were required to have a valid driver's license with no nighttime restrictions because the participant would be driving the study vehicle at night. Only male participants were used since the study involved consuming alcohol; the budget did not provide funding for staff and the equipment needed to test female participants for possible pregnancy. Participants had to be at least 21 years old since that is the legal drinking age in Texas. Researchers set a maximum weight limit in an effort to minimize the time needed for alcohol consumption and to maintain a similar alcohol consumption period for all participants. Since the study involved identifying sign colors, the participants could not be color blind.

Researchers conducted the first study in three parts: pre-screening, part 1, and part 2. Each part was conducted on a different date. The pre-screening portion took about an hour and was conducted during the day at the TTI State Headquarters and Research Building. Upon arrival, participants read and signed an informed consent form. A researcher verified that each participant had a valid driver's license with no nighttime restrictions and that he was at least 21 years old. Each participant's weight was also measured using a standard scale. Researchers then asked participants their race and how many alcoholic beverages they typically drank in a day. Texas Department of Public Safety (DPS) staff used the answers to these questions, as well as the weight measurements, to determine the approximate number of drinks each participant needed to consume to reach the target BAC levels. Each participant underwent two eye tests (standard visual acuity test and color blindness) to ensure that he had at least the minimal levels of acceptable vision (20/40 and not color blind). Each participant also completed two assessments that provided information about his typical alcohol consumption and behavior. Researchers used the answers to these assessments to identify naïve drinkers, individuals that may be at risk for alcohol dependence, and individuals that were alcohol dependent. At-risk individuals were not allowed to participate. Participants that met all the pre-screening criteria and agreed to complete the remaining parts of the study were scheduled for part 1.

Part 1 was conducted at night at the Texas A&M University Riverside Campus and took about two hours. Participants did not consume any alcohol. Upon arrival, participants read and signed the informed consent form again. Before driving, each participant had his BAC level determined by standard DPS breath sample equipment to ensure that his BAC level was zero. Prior to the driving task, researchers calibrated the eye-tracker equipment to each participant. Participants then drove an instrumented state-owned vehicle at 30 mph along a simulated two-lane, two-way roadway on a closed-course. While in the vehicle, two persons accompanied the participants: a study administrator who sat in the front passenger seat and provided verbal directions, and an equipment operator who sat in the back seat).

While driving the predetermined route, participants encountered multiple sign treatments. For each sign, participants verbally indicated the color and legend (i.e., text). Researchers marked the participants' responses on standard forms and within the in-vehicle equipment software program. In addition, researchers recorded all of the participants' comments as they traveled through the course for later review.

At the end of the driving task, a researcher showed each participant six pieces of sign sheeting (one at a time in random order): orange, white, yellow, green, red, and blue. The participant verbally indicated the color of each piece of sheeting, and a researcher documented the participant's response on a standard form.

At the end of the driving task, all participants also completed three standard police field sobriety tests:

- Following a stimulus with their eyes.
- Walking in a line using heel-to-toe steps.
- Balancing on one leg.

Upon completion of part 1 of the study, researchers scheduled participants for part 2.

Part 2 was conducted at night at the Texas A&M University Riverside Campus and took approximately 10 hours. Participants were required to consume alcoholic beverages (either regular beer or 80-proof spirit mixed drinks). Upon arrival at the Riverside Campus, participants reviewed and signed the informed consent form. Before consuming any alcohol, each participant had his BAC level determined by standard DPS breath sample equipment. Participants then consumed alcoholic beverages over approximately a two-hour period until they reached a BAC level of 0.12 g/dL. Researchers used the same standard DPS breath sample equipment to monitor each participant's BAC level. At a minimum, each participant's BAC level was measured immediately prior to and after each driving task. Prior to each driving task, researchers calibrated the eye-tracker equipment to each participant.

When each participant reached a BAC level of 0.12 g/dL, he drove an instrumented state-owned vehicle at 30 mph along a simulated two-lane, two-way roadway on a closed-course. The state-owned vehicle and driving task were the same as in part 1. At the end of the BAC 0.12 g/dL driving task, the participant completed the sign sheeting color survey and three standard police field sobriety tests (the same as in part 1). Participants then returned to the study check-in building conference room where they had a comfortable place to sit, food, and non-alcoholic drinks. When each participant reached a BAC level of 0.08 g/dL and 0.04 g/dL, he repeated the driving task and the three standard police field sobriety tests. In addition, upon reaching a BAC level of 0.10 g/dL and 0.06 g/dL, each participant repeated the three standard police field sobriety tests. All participants had to remain on-site until their BAC level was less than 0.04 g/dL, at which time researchers drove them home.

While data from Texas showed that approximately 77 percent of the alcohol-impaired drivers involved in WWD crashes had a BAC level equal to or greater than 0.12 g/dL, researchers did not study higher BAC levels mainly because they wanted to minimize the risk to participants. In addition, part 2 of the study typically took eight hours per participant (ending between 2:00 a.m. and 3:00 a.m.). Higher BAC levels would have extended the study time outside of the desired range (i.e., a maximum of 10 hours).

Participants

Researchers prescreened 42 male participants. Nine participants did not meet the prescreening criteria and thus were not allowed to participate. Of the remaining 33 participants, 30 completed part 1 and part 2 of the study. The average age of the 30 participants was 25 and ranged from 21 to 42. The average visual acuity was 20/18, and the average weight was 190 pounds. Researchers dropped three participants due to the following reasons:

- One individual was not available on the scheduled study dates.
- One individual did not show up for part 1 as scheduled.
- The eye-tracker equipment could not accurately track one individual's eyes.

Data Reduction

Following data collection, the research team screened and reduced each participant's raw data into a fully formatted dataset to obtain the necessary information for analysis. During the data-screening process, any anomalous data (e.g., misidentifications and malfunctioning treatment/equipment) were eliminated.

Next, researchers reviewed the BAC level data measured immediately before and after each driving task. Researchers computed the average BAC level of each participant for each driving task by averaging the two before and two after BAC-level measurements. A review of these data identified two outliers (one at 0.08 g/dL and one at 0.04 g/dL), which were removed from the final dataset. Figure 18 shows the average BAC level for each remaining participant for the three target BAC levels (i.e., 0.12, 0.08, and 0.04 g/dL), and Table 13 contains the overall BAC level descriptive statistics.

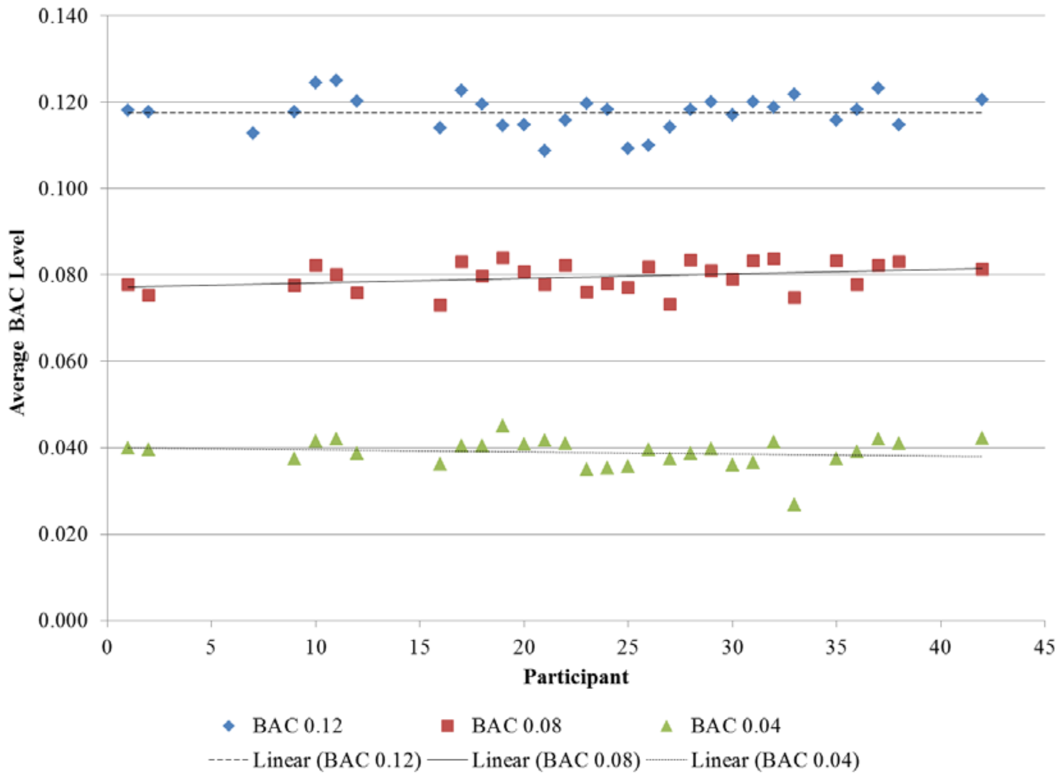


Figure 18. First Study Participants' Average BAC Levels (g/dL).

Table 13. First Study Overall BAC Level Descriptive Statistics.

Target Level (g/dL)	Average (g/dL)	Standard Deviation (g/dL)	Minimum (g/dL)	Maximum (g/dL)
0.000	0.000	0.000	0.000	0.000
0.120	0.118	0.004	0.109	0.125
0.080	0.080	0.003	0.073	0.084
0.040	0.039	0.003	0.027	0.045

Researchers then used the GPS data to isolate the one course segment where there were no treatments (i.e., base condition) for each participant at BAC levels 0.00 g/dL and 0.12 g/dL (i.e., either taxiway northeast or taxiway southwest). Unfortunately, due to the randomization of the treatment orders, the no-treatment segment varied among participants and BAC level (Table 14). In addition, during the initial review of the scene camera video, it became evident that participants traveling in the northeast direction looked at miscellaneous lights not located on the segment (i.e., on buildings in the distance, on adjacent property, and along another portion of the closed-course facility). Preliminary statistical analysis on the eye tracker data showed that segment and the interaction between segment and BAC level were statistically significant (α = 0.05), so researchers decided to focus on the southwest segment. Overall, researchers reduced and analyzed no-treatment eye-tracker data from seven participants to determine the impact of alcohol on where a driver looks in the forward driving scene.

Table 14. Sample Size for No-Treatment Segments by BAC Level.

BAC Level (g/dL) and No-Treatment Segment	Sample Size[a]
BAC 0.00, Northeast BAC 0.12, Northeast	8
BAC 0.00, Northeast BAC 0.12, Southwest	3
BAC 0.00, Southwest BAC 0.12, Northeast	7
BAC 0.00, Southwest BAC 0.12, Southwest	7

[a] Only 25 participants had complete datasets for BAC = 0.00 g/dL and BAC = 0.12 g/dL.

For the course segments with treatments, researchers reduced the GPS data to the points of interest (i.e., any point marked with an ASCII tag). Using the GPS software, researchers drove through the course once without any participants, denoting the start location of each segment and each sign location. These data were reduced as well and were used to determine the actual travel distance between the beginning of a segment and each sign location. Recognition and legibility distances were calculated by subtracting the participants' identification distance (from the lap start to the identification of the color or legend) from the sign location distance (from the lap start to the actual sign).

Researchers also manually reviewed the eye-tracker scene camera data for each participant at each BAC level to determine the beginning and end of each sign glance. From these data, researchers computed the participants' total number of glances, total glance duration, average glance duration, maximum glance duration, and minimum glance duration for each sign treatment.

Results

The following subsections contain the results of the analyses on the forward driving scene, background color recognition distance, legend legibility distance, glance data, and sign sheeting color survey. When appropriate, researchers used the predicted values (least squares means) for each response variable to compare different treatments. When there are multiple factors in the model, it is not fair to make comparisons between raw cell means in data because raw cell means do not compensate for other factors in the model. The least squares means are the predicted values of the response variable for each level of a factor that have been adjusted for the other factors in the model. A 5 percent significance level ($\alpha = 0.05$) was used for all statistical analyses.

Forward Driving Scene

Researchers used three analyses to determine the impact of alcohol on where a driver looks in the forward driving scene. For the first two analyses, researchers used the eye-tracker output file that documented the X and Y coordinates of each glance. First, researchers compared the mean X and mean Y look positions of seven participants at BAC levels of 0.00 g/dL and 0.12g/dL. A review of the findings revealed a shift down and to the left at BAC level 0.12 g/dL, implying that alcohol-impaired drivers may tend to look more at the pavement area in front of the vehicle instead of at the far roadway horizon. Unfortunately, this shift resulted in only small changes in the mean X,Y look coordinates at the distances in front of the vehicle where the participants were typically looking, so researchers did not find any statistically significant differences among the position means at the two BAC levels. Researchers believe that the limited sample size ($n = 7$) may have impacted the ability of this analysis to detect small differences in the change in the mean X and mean Y.

Second, researchers analyzed the spread (total variance) of the X,Y look coordinates of seven participants at BAC levels of 0.00 g/dL and 0.12 g/dL. This analysis showed that there was statistically less variability in looks at BAC level 0.12 g/dL, and suggests that alcohol-impaired drivers do not actively search the forward driving scene as much as non-impaired drivers. Instead, alcohol-impaired drivers concentrate their glances in a smaller area within the forward driving scene.

For the third analysis, researchers analyzed the seven participants’ glance location data manually reduced from the scene camera video. To do this, researchers established nine glance regions, shown as the yellow dashed lines overlaid on the video screenshot in Figure 19. Region 4 included glances at the roadway horizon and at signs mounted to the right of the roadway. Region 3 included glances at signs mounted to the left of the roadway. Regions 2 and 5 included far left and far right glances, respectively, at signs close to the vehicle (near field) or far-field objects off the roadway. Region 7 included glances on the pavement in front of the vehicle in the travel lane. Similarly, region 9 included glances on the pavement, but these glances were located in the area right over the vehicle's hood. Region 6 included glances on the pavement in the opposing lane. Region 8 included glances on the pavement to the right of the travel lane (e.g., shoulder). Region 1 was above all the other regions and was included for completeness. The green circle in the screenshot represents the glance location. Once researchers categorized each glance into one of the nine regions, they computed the percent of glances in each region for each BAC level (0.00 and 0.12 g/dL).

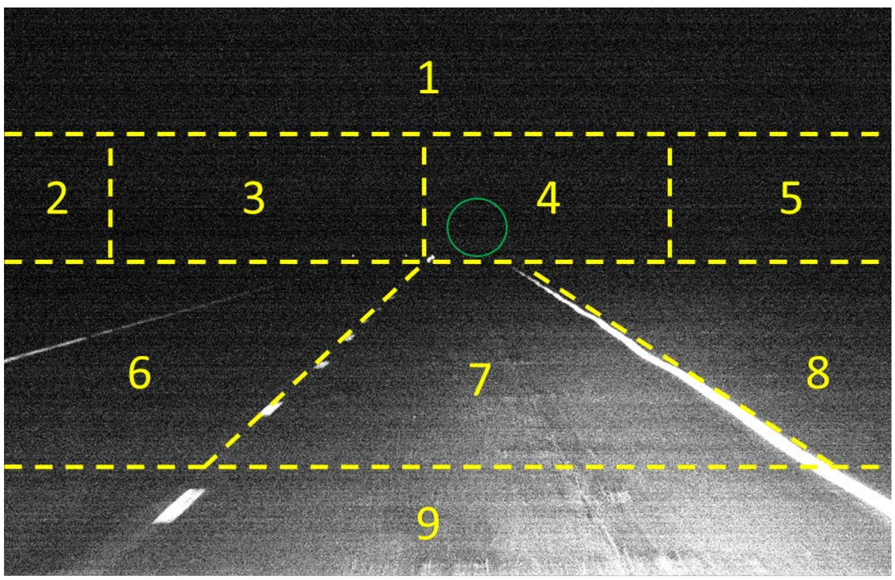
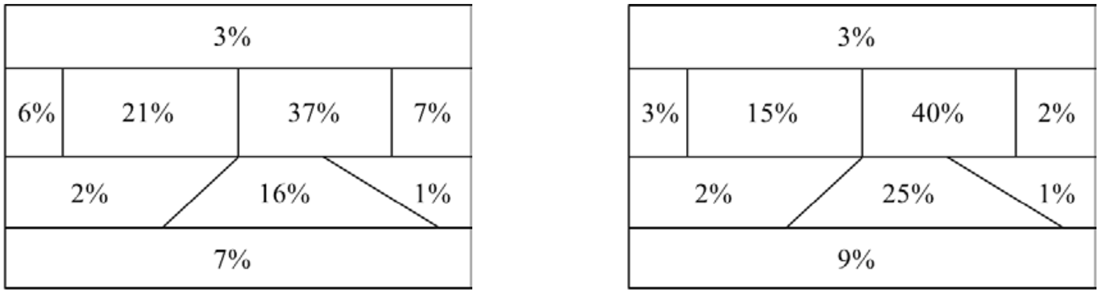


Figure 19. Video Screenshot with Glance Regions Overlaid.

Figure 20 shows that alcohol-impaired drivers (BAC = 0.12 g/dL) tend to look less to the left and right and more toward the pavement area in front of the vehicle, while continuing to also look at the roadway horizon. The percentage of glances in regions 3 and 4 at 0.12 (15 percent and 40 percent, respectively) was higher than expected, but researchers believe this may be a result of the study design. Participants were instructed to identify the background color and read the legend of signs placed to the left and right of the roadway along the route. Although these data were taken from a portion of the course without signs (i.e., no treatments), participants may have still been actively searching in regions 3 and 4 for signs.



a) BAC = 0.00 g/dL. **b) BAC = 0.12 g/dL.**

Figure 20. Glance Location Results.

Researchers determined that the percentages in the nine regions were dependent on BAC level using a bivariate chi-square test of independence (computed χ^2 value [42.90] greater than table χ^2 $\text{value}_{(0.05,8)}$ [15.51]). Thus, the proportion of glances in each region varies depending on BAC level. These findings support the shift in the mean X and mean Y findings (i.e., down and to the left), and the decrease in glance spread (total variance) at a BAC level of 0.12 g/dL previously described.

Background Color Recognition

Researchers initially fit a model for the sign background color recognition response variable with the main effects and two-way interactions shown below:

- BAC level (0.00, 0.12, 0.08, and 0.04 g/dL).
- Sign lateral position (the right and left side of the road).
- Sign height (7 ft and 2 ft).
- Sign color (yellow, white, red, and orange).
- BAC level * sign lateral position.
- BAC level * sign height.
- BAC level * sign color.
- Lateral position * sign height.

Not all two-way interactions could be included because some of the factor-level combinations did not exist (i.e., not all of the sign colors were evaluated at all lateral position/height combinations). This dataset included 1050 observations.

This statistical analysis showed that BAC level, sign color, and the two-way interaction between sign lateral position and sign height were statistically significant ($\alpha = 0.05$). However, Tukey's Honestly Significant Difference (HSD) multiple comparison procedure showed that the predicted background color recognition distance for the BAC level 0.00 g/dL was statistically shorter than all the other BAC levels. Upon further investigation, researchers believe this finding primarily occurred for two reasons:

- All participants completed part 1 of the study first (BAC level 0.00 g/dL) so that they would be able to receive instructions, drive the vehicle, and familiarize themselves with the study protocol before consuming alcohol. Therefore, part 1 was the initial learning experience for all participants.
- Participants generally want to perform to the best of their abilities during a study. In addition, participants were instructed to tell the study administrator when they could clearly identify the color of the sign. When the participants were not under the influence of alcohol, they may have waited longer to respond in order to be certain of the sign color.

Considering these issues and the indication of similar trends in the legend legibility distance, researchers decided to remove the BAC level 0.00 g/dL data from further sign data analyses. The initial analysis also revealed the need to consider the KID sign separate from the other white-on-red signs (i.e., lit versus unlit signs, respectively).

Further analyses revealed several other concerns. First, the background color recognition distance for the KID sign ranged from 354 to 4623 ft. At night with only headlight illumination, it would be difficult to identify the sign background color at such long distances. Researchers believe that the participants were identifying the color of the red LED lights, not the sign background color. These data are not surprising since lights are added to a sign face to increase a sign's conspicuity (ability to attract attention). Researchers used exploratory data analysis based on a box plot of color recognition distances to identify and remove 27 outliers (i.e., an observation more than 1.5 times the interquartile range from the closest end of the box). Nevertheless, the remaining distances still ranged from 354 to 3252 ft. Since there was no way to determine which distances were associated with the red LED lights and which distances were associated with the sign sheeting, researchers decided to remove the KID sign from further analysis.

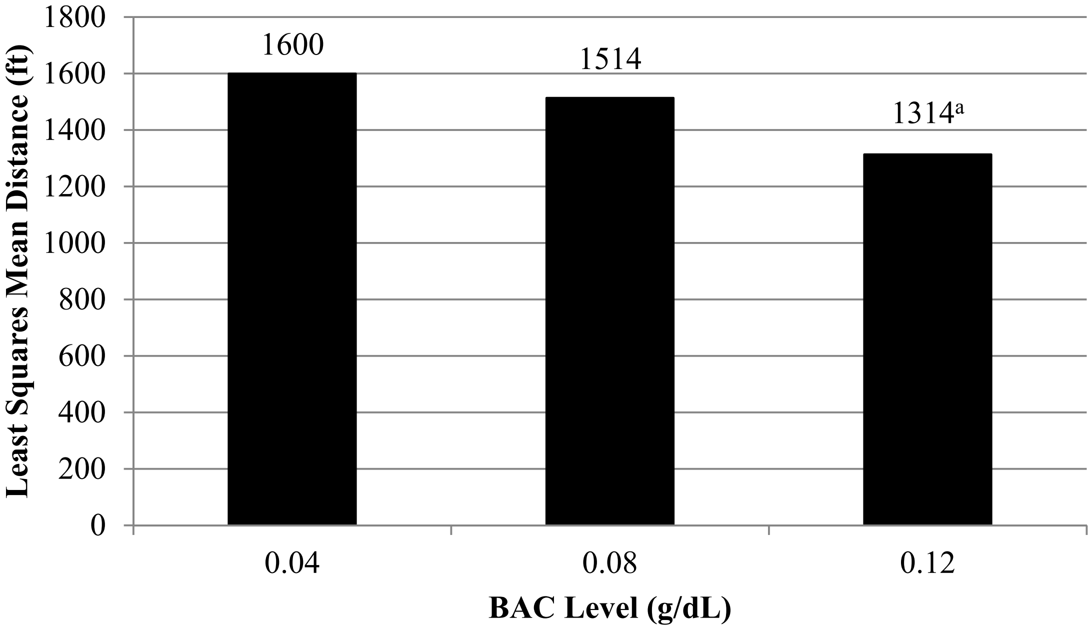
Second, for one of the treatment orders a white-on-red sign was seen mounted at 2 ft on the left of a taxiway instead of the main runway. Using exploratory data analysis, researchers verified that this sign location yielded background color recognition distances outside of the expected range. Thus, researchers did not use the data for this sign location in the final dataset. Researchers also decided to remove the distractor signs from further analysis since it became evident that their use at only certain sign locations impacted their background color recognition distance. In addition, the primary focus of the first study was white-on-red signs.

The final dataset included 283 observations. Researchers decided to use sign position (one variable) instead of sign lateral position and height (two variables) because it allowed researchers to combine data from multiple sign locations along the course where the same sign position had been used (i.e., collapse across treatment orders since no statistically significant differences were found). The final model included the following main effects and their two-way interaction effect:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Sign position (2 ft left, 7 ft left, 2 ft right, and 7 ft right).

This model found BAC level ($p = 0.0048$) and sign position ($p = 0.0073$) to be statistically significant. Researchers used Tukey's HSD procedure to determine which treatment factor levels were statistically different. The interaction between BAC level and sign position was not found to be significant.

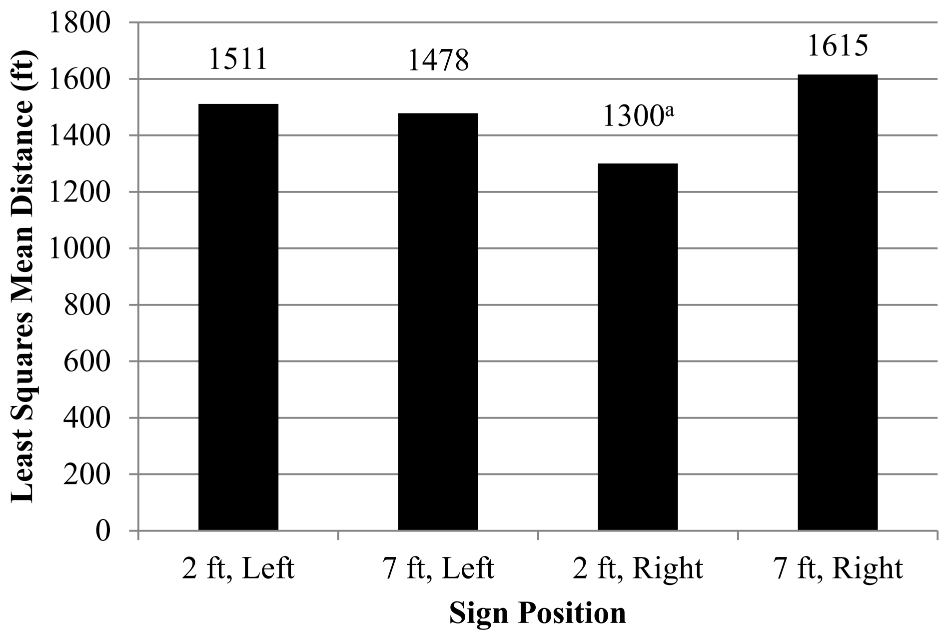
Figure 21 presents the predicted means for the background color recognition distance for the non-lit white-on-red signs (ACE, SKY, TEA, and ZOO) by BAC level. As expected, background color recognition distance decreases as the BAC level increases. BAC level 0.04 g/dL was found to have the farthest predicted mean background color recognition distance (1600 ft). However, this distance was not statistically different from the predicted mean background color recognition distance for BAC level 0.08 g/dL (1514 ft). The shortest predicted mean background color recognition distance (1314 ft) occurred at BAC level 0.12 g/dL. This distance was found to be statistically less than those for BAC levels 0.08 g/dL and 0.04 g/dL. Based on the predicted means, participants at a BAC level equal to 0.12 g/dL traveled 200 to 286 ft closer to the white-on-red signs before being able to recognize the red background color (approximately 5 to 7 seconds at 30 mph). Thus, a BAC level of 0.12 g/dL did appear to negatively impact a motorist's ability to recognize the red background color of signs.



[a] BAC level 0.12 was statistically different from BAC levels 0.04 and 0.08 g/dL.

Figure 21. Background Color Recognition Distance for Non-lit White-on-Red Signs by BAC Level.

Figure 22 shows the predicted means for the background color recognition distance for the non-lit white-on-red signs by sign position (height and lateral position). The farthest predicted mean background color recognition distance (1615 ft) occurred when the white-on-red signs were mounted on the right side of the road at 7 ft (i.e., standard sign position). Placing the white-on-red signs on the left side of the road did not significantly change the background color recognition distance. However, placing the white-on-red signs at 2 ft on the right side of the road did result in a predicted mean background color recognition distance (1300 ft) statistically less than that for signs mounted at 7 ft on the right side of the road. Researchers did not expect this since the vehicle headlights would provide the highest illumination for this position (i.e., toward a 2-ft, right mounted sign). Further review of the data revealed that all of the 2-ft, right mounted signs were located at one sign location and that this sign location was at the beginning of one of the course segments. In contrast, all the other sign positions were located in the middle or near the end of a course segment, which meant that the maximum available viewing distance for each of the positions was the least for the 2-ft, right mounted sign. Again, other research activities in the area limited the researchers' ability to test certain sign positions at some sign locations. Researchers believe that the sign location used for the 2-ft, right mounted signs may have negatively impacted the background color recognition distance.



[a] Signs mounted at 2 ft on the right side of the road were statistically different from those mounted at 7 ft on the right side of the road.

Figure 22. Background Color Recognition Distance for Non-lit White-on-Red Signs by Sign Position.

Legend Legibility Distance

As with the background color recognition distance analysis, for the legend legibility distance analysis, researchers:

- Did not include BAC level 0.00 g/dL data.
- Considered the KID (lit) sign data separate from the unlit white-on-red sign data.
- Did not include distractor sign data.

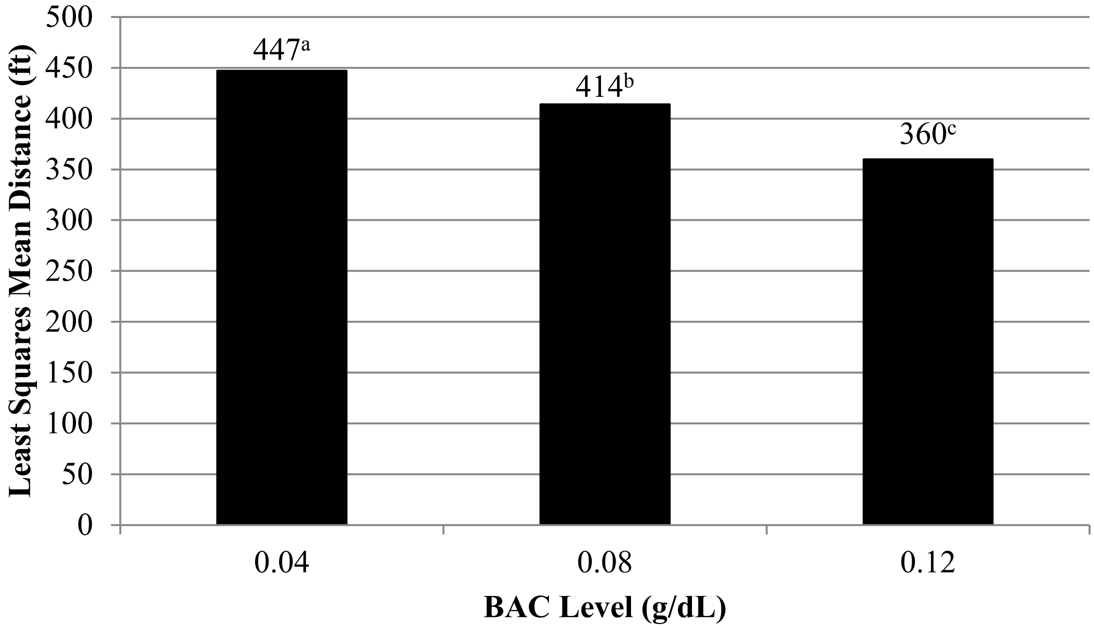
The exploratory data analysis of the legend legibility distances identified 12 outliers that were removed from further analyses, yielding a white-on-red sign dataset that included 392 observations. The initial model included the following main effects and two-way interactions:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Sign category (lit [KID] and unlit [ACE, SKY, TEA, and ZOO]).
- Sign lateral position (right and left side of the road).
- Sign height (7 ft and 2 ft).
- BAC level * sign category.
- BAC level * sign lateral position.
- BAC level * sign height.

This model found BAC level ($p < 0.0001$), sign category ($p < 0.0001$), lateral position ($p = 0.0380$), and the interaction between sign lateral position and height ($p = 0.0225$) to be statistically significant. Researchers then fit a more parsimonious model with main effects and the significant interaction between sign lateral position and sign height. Researchers again used Tukey's HSD procedure to determine which treatment factor levels were statistically different.

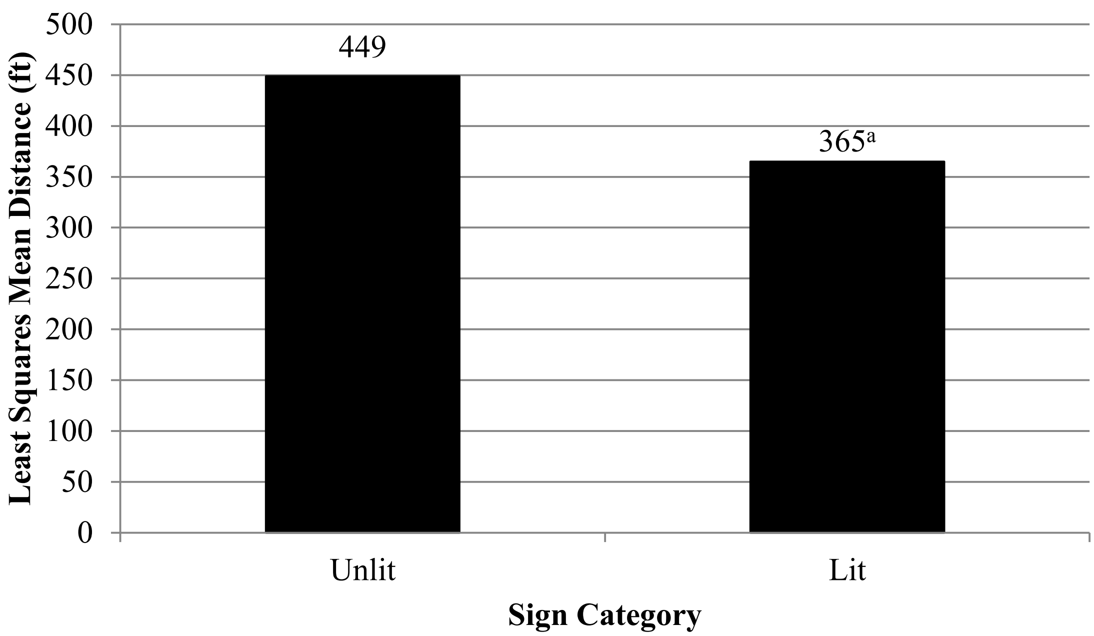
Figure 23 shows the predicted means for the legend legibility distance for the white-on-red signs by BAC level. As expected, legend legibility distance decreases as the BAC level increases. BAC level 0.04 g/dL was found to have the farthest predicted mean legibility distance (447 ft), and this distance was statistically different from the predicted mean legibility distance for the other two BAC levels. The shortest predicted mean legibility distance (360 ft) occurred at BAC level 0.12 g/dL and was statistically less than those for BAC levels 0.08 g/dL and 0.04 g/dL. Based on the predicted means, participants at a BAC level equal to 0.12 traveled 87 ft closer to the white-on-red signs before being able to read the sign legend (approximately 2 seconds at 30 mph). Therefore, it does appear that BAC levels equal to 0.08 g/dL and 0.12 g/dL negatively impact a motorist's ability to read the legend of white-on-red signs.

One way to improve the conspicuity of signs is to incorporate flashing LEDs around the border of a sign. However, it was unknown how the flashing lights impact the legibility of the sign legend. Figure 24 shows the predicted means for the legend legibility distance for the white-on-red signs by sign category (i.e., unlit and lit). As seen in this figure, the predicted mean legend legibility distance for the lit signs was statistically less than the predicted mean legend legibility distance for the unlit signs. Thus, it does appear that alcohol-impaired drivers have to be closer to a sign with flashing red lights embedded around the border of the sign before they can read the legend. However, this finding does not seem to vary across the BAC levels studied since there was no interaction between the BAC level and the sign category variable.



[a] BAC level 0.04 g/dL was statistically different from BAC levels 0.08 and 0.12 g/dL.
[b] BAC level 0.08 g/dL was statistically different from BAC levels 0.04 and 0.12 g/dL.
[c] BAC level 0.12 g/dL was statistically different from BAC levels 0.04 and 0.08 g/dL.

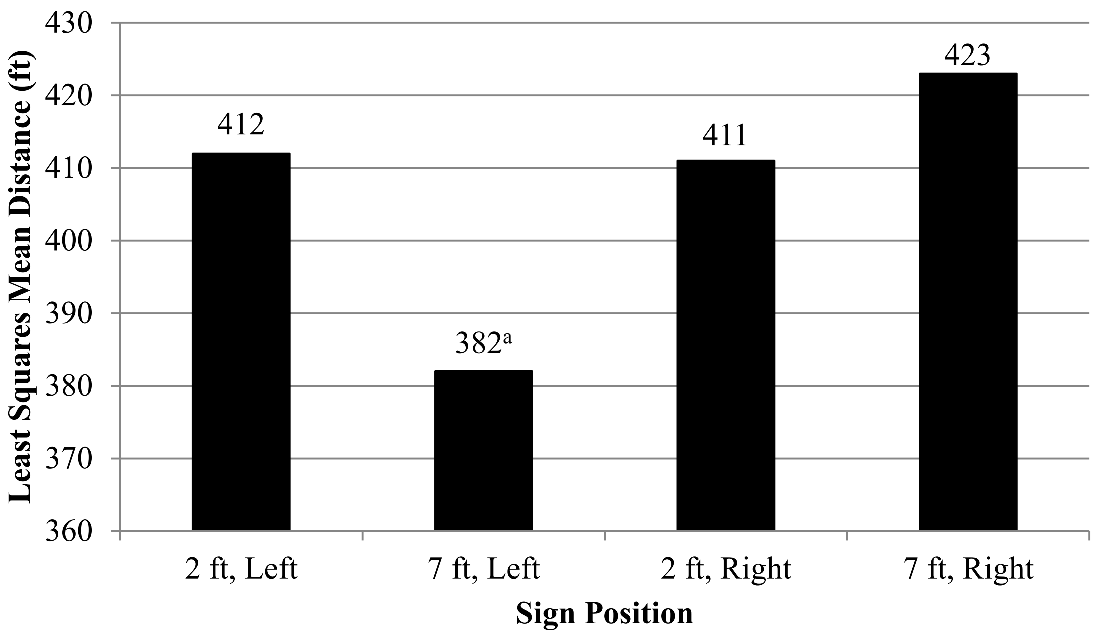
Figure 23. Legend Legibility Distance for Non-lit White-on-Red Signs by BAC Level.



[a] Lit signs were statistically different from unlit signs.

Figure 24. Legend Legibility Distance for White-on-Red Signs by Sign Category.

Since sign lateral position and height were found to interact, researchers could not look at these factors separately. Figure 25 presents the predicted means for the legend legibility distance for the white-on-red signs by sign height and sign lateral position. As seen in this figure, signs mounted at 7 ft on the right side of the road (standard installation) yielded the longest predicted mean legibility distance (423 ft). However, this distance was not statistically different from that of signs mounted at 2 ft on the right or left side of the road (411 ft and 412 ft, respectively). Thus, all three of these sign positions yielded similar predicted mean legibility distances. In contrast, the shortest predicted mean legibility distance (382 ft) was found for signs mounted at 7 ft on the left side of the road, and this predicted mean legibility distance was statistically different from the signs mounted at 7 ft on the right side of the road. These findings are not surprising since the headlights were designed to minimize the light projected above and to the left to reduce headlight glare for on-coming vehicles.



[a] Signs mounted at 7 ft on the left side of the road were statistically different from those mounted at 7 ft on the right side of the road.

Figure 25. Legend Legibility Distance for Non-lit White-on-Red Signs by Sign Position.

Sign Glances

As with the other analyses previously described, researchers:

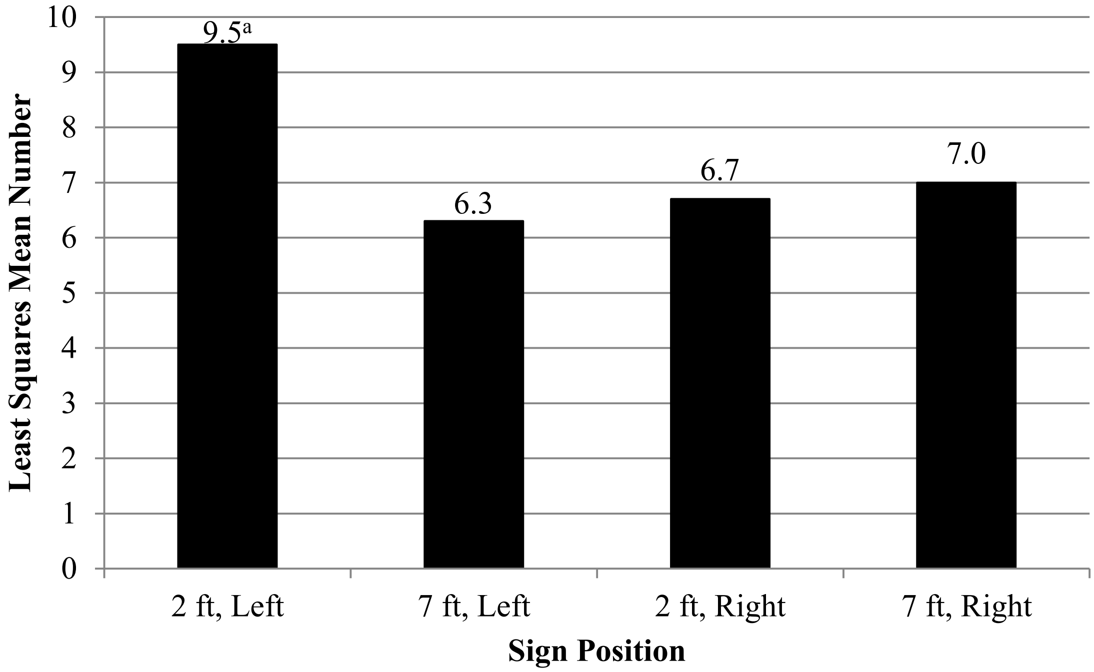
- Did not include BAC level 0.00 g/dL data.
- Did not include distractor sign data.
- Considered the KID (lit) sign data separate from the unlit white-on-red sign data.

Researchers compiled two datasets. The first dataset consisted of only unlit white-on-red sign glance data since the lit sign was not seen at all lateral position/height combinations. As with other analyses, researchers decided to use sign position (one variable) instead of sign lateral position and height (two variables) because they were able to combine data from multiple sign locations along the course where the same sign position had been used (i.e., collapse across treatment orders since no statistically significant differences were found). Researchers performed the exploratory data analysis to identify outliers in the data. Any observations having an outlying value for at least one of the dependent variables (i.e., total number of glances, total glance duration, and average glance duration) were removed from the data. The final unlit white-on-red sign dataset included 261 observations, and the final model included the following main effects and their two-way interaction effect:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Sign position (2 ft left, 7 ft left, 2 ft right, and 7 ft right).

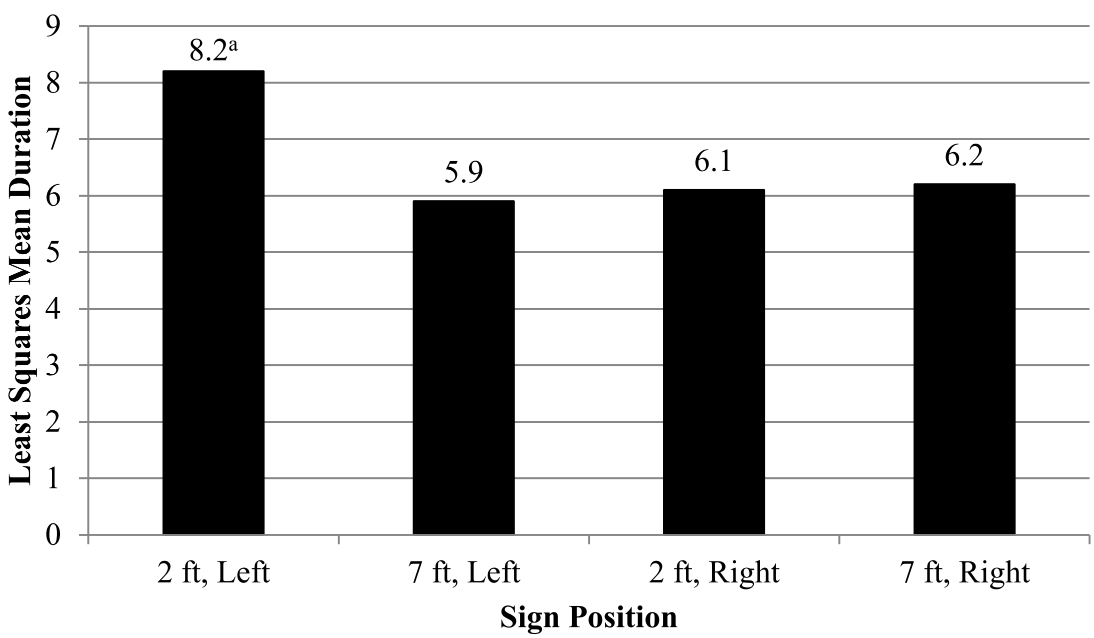
Researchers used this dataset and model to assess the impact of alcohol and sign position on the total number of sign glances, total sign glance duration, and average sign glance duration.

For the total number of glances and total sign glance duration, researchers found only sign position to be statistically significant ($p < 0.0001$ and $p = 0.0031$, respectively). Researchers used Tukey's HSD procedure to determine which treatment factor levels were statistically different. Figure 26 and Figure 27 show the total number of glances and total sign glance duration by sign position, respectively. These figures show that the 2-ft left position resulted in statistically more glances (9.5 versus 6.3 to 7.0) and statistically longer total glance duration (8.2 seconds versus 5.9 to 6.2 seconds). This finding is surprising since the background color recognition distance and legibility distance at the 2-ft left position were not statistically less than the other sign positions. Therefore, researchers could not determine an apparent reason as to why participants would have glanced more times and longer at signs mounted at 2 ft on the left side of the road.



[a] Signs mounted at 2 ft on the left side of the road were statistically different from all the other sign positions.

Figure 26. Total Number of Glances for Non-lit White-on-Red Signs by Sign Position.



[a] Signs mounted at 2 ft on the left side of the road were statistically different from all the other sign positions.

Figure 27. Total Glance Duration for Non-lit White-on-Red Signs by Sign Position.

For the average glance duration, researchers did not find either of the two variables (BAC level or sign position) to be statistically significant at a 5 percent significance level ($\alpha = 0.05$). However, BAC level was found to be borderline significant ($p = 0.0579$). The trend showed that the average glance duration increased as BAC level increased. This supports the idea that participants had to look at the signs longer to identify the background color and read the legend as their BAC level increased.

The second dataset consisted of lit and unlit white-on-red sign glance data. Researchers wanted to determine if the flashing red LEDs around the border of the KID sign impacted the total number of sign glances, total sign glance duration, and average sign glance duration. Researchers hypothesized that at higher BAC levels, participants may look less at the lit sign since their eyes may not be able to adjust to the lights as well. Researchers again determined outliers from the box plots of each of the dependent variables (i.e., total number of glances, total glance duration, and average glance duration). There were a total of 12 observations having an outlying value for at least one of the dependent variables. The final dataset after removing these outliers included 146 observations, and the final model included the following main effects and their two-way interaction effect:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Sign category (lit [KID] and unlit [ACE, SKY, TEA, and ZOO]).

For all three dependent variables, neither the main effects nor their interaction was found to be significant at a 5 percent significance level ($\alpha = 0.05$). Researchers believe that they did not find any significant differences in the glance behavior between the lit and unlit signs because of the study design. As previously indicated, the participants were instructed to identify the background color and read the legend of signs placed to the left and right of the roadway along the route. Thus, the participants were required to keep looking at the lit sign at all BAC levels even if it was uncomfortable. This behavior differs from that of an alcohol-impaired driver that can decide not to look at a sign if it appears too bright. While red LEDs around the border of white-on-red signs may increase the conspicuity of the sign, it must be done in such a manner that it does not degrade the ability of drivers to read the sign legend.

Sign Sheeting Color Survey

At both BAC levels (0.00 g/dL and 0.12 g/dL), all of the participants correctly identified the color of pieces of sign sheeting. However, a review of the participants that incorrectly identified the sign background color while driving (4 percent of the dataset), revealed that participants did experience some difficulty distinguishing between yellow and orange signs, as well as orange and red signs. While incorrect color identifications occurred at all BAC levels, incorrect color identifications increased as the BAC level increased from 0.04 g/dL to 0.08 g/dL to 0.12 g/dL (13 percent, 39 percent, and 47 percent, respectively). At a BAC level of 0.12 g/dL, the participants that thought a red sign was an orange sign made up 67 percent of the incorrect color identifications.

SECOND STUDY

The second study was conducted January through March 2014. The primary objective was to evaluate the conspicuity (ability to attract a driver's attention) of select WWD signing countermeasures compared to standard signing applications. A secondary objective was to assess the effectiveness of a modified wrong way arrow pavement marking design.

Treatments

In the second study, researchers focused on WRONG WAY signs. The WRONG WAY sign treatments included:

- Normal size signs.
- Oversized signs.
- Normal size signs with red retroreflective sheeting on the sign support.
- Normal size signs with flashing red LEDs around the border of the sign.

All of these treatments were evaluated at two sign heights (7 ft and 2 ft). To reduce learning effects, researchers used three lateral sign positions (left, middle, and right) and included distractor signs (i.e., YIELD, STOP, or DO NOT ENTER) in the sign treatment arrays. Figure 28 contains an example of a sign treatment array that includes a normal size WRONG WAY sign with red retroreflective sheeting on the sign support.

Figure 28. Example of a Sign Treatment Array.

Table 15 contains the sign characteristics and treatments studied. The normal size and oversized WRONG WAY signs (42 inches by 30 inches and 48 inches by 36 inches, respectively) are used in Texas on controlled-access freeways. Researchers selected the size of the normal distractor signs so that they were similar in size to the normal WRONG WAY sign; therefore, the sizes of the distractor signs used in the second study were smaller than the recommended normal size and oversized signing used on controlled-access freeways in the TMUTCD (*30*).

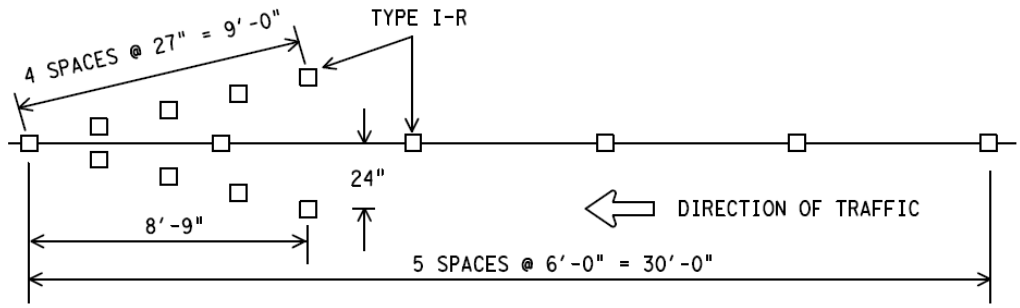
The second study also included two wrong way arrows constructed of RRPMs. Figure 29 shows the current wrong way arrow detail that TxDOT uses (*35*). On several occasions, TxDOT personnel noted that the RRPMs that comprise these wrong way arrows have to be replaced frequently, especially those in the arrow head. Previous TTI research (*18*) also confirmed that wrong way arrows in Texas sometimes had RRPMs missing (see Figure 30). Researchers suspect that when RRPMs are missing from the arrow head, drivers (especially those that are impaired) find it more difficult to discern the arrow shape. Thus, researchers narrowed the wrong way arrow head design so that the RRPMs at the end of the head are located 18 inches from the stem in hopes of reducing maintenance while preserving the shape of an arrow (Figure 31).

To reduce learning effects, researchers used three lateral positions (left, middle, and right) and included two distractor markings (i.e., a Y and a T) in the pavement marking treatment arrays. Figure 32 and Figure 33 contain examples of the TxDOT design and modified design, respectively, in a pavement marking treatment array.

Table 15. Sign Characteristics and Treatments.

Sign	Background				Legend				Pulse Integration Measurement (lx*s)
	Color	Retroreflectivity (cd/lx/m^2)[a]	Normal Size (inches)	Oversized (inches)	Color	Retroreflectivity (cd/lx/m^2)[a]	Normal Height (inches)	Oversized Height (inches)	
WRONG WAY	Red	101.3	42 × 30	48 × 36	White	586.3	8	9	0.8
DO NOT ENTER	Red	210.3	30 × 30[b]	36 × 36[c]	White	906.3	4	5	1.1
STOP	Red	187.3	30 × 30[b]	36 × 36[c]	White	847.3	10	12	1.1
YIELD	Red	128.5	36 × 36[b]	48 × 48[c]	White	591.0	3	4	1.2

[a] The retroreflectivity levels shown are an average of four readings measured at an observation angle of 0.2 degrees and an entrance angle of −4.0 degrees.
[b] Size chosen so that it was similar to the normal WRONG WAY sign size.
[c] Oversized compared to the normal size used.



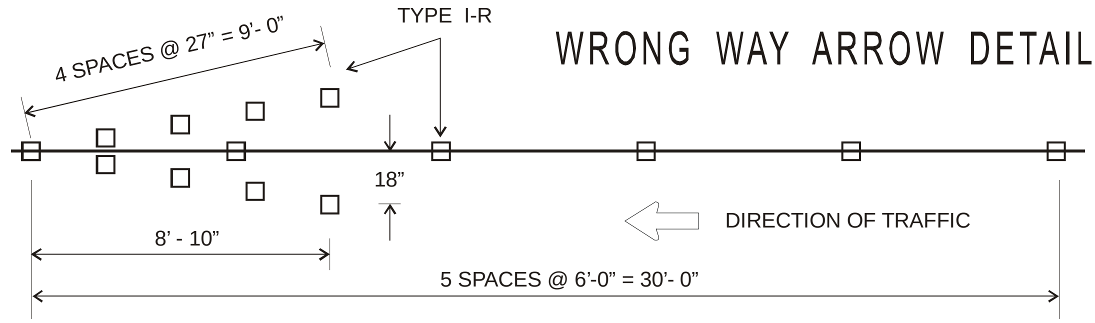
ALL RAISED MARKERS IN THE WRONG WAY ARROW SHALL BE TYPE I-R REFLECTORIZED PAVEMENT MARKERS WITH THE REFLECTORIZED SURFACE FACING THE WRONG WAY TRAFFIC. TYPE II-C-R SHALL NOT BE USED.

REFLECTORIZED WRONG WAY ARROWS, NOT TO EXCEED TWO, MAY BE PLACED ON EXIT RAMPS. LOCATION OF THE ARROWS SHALL BE AS SHOWN IN THE PLANS OR AS DIRECTED BY THE ENGINEER.

WRONG WAY ARROW DETAIL

Figure 29. TxDOT Wrong Way Arrow Typical Standard (*35*).

Figure 30. Example of Missing RRPMs in a Wrong Way Arrow.



ALL RAISED MARKERS IN THE WRONG WAY ARROW SHALL BE TYPE I-R REFLECTORIZED PAVEMENT MARKERS WITH THE REFLECTORIZED SURFACE FACING THE WRONG WAY TRAFFIC. TYPE II-C-R SHALL NOT BE USED.

REFLECTORIZED WRONG WAY ARROWS, NOT TO EXCEED TWO, MAY BE PLACED ON EXIT RAMPS. LOCATION OF THE ARROWS SHALL BE AS SHOWN IN THE PLANS OR AS DIRECTED BY THE ENGINEER.

Figure 31. Modified Wrong Way Arrow Design.

Figure 32. Example of TxDOT Design in a Pavement Marking Treatment Array.

Figure 33. Example of the Modified Design in a Pavement Marking Treatment Array.

Overall, there were 24 treatments, separated into four treatment orders. Each treatment order consisted of:

- The normal WRONG WAY sign at 2 ft on the left, 7 ft on the left, 2 ft on the right, and 7 ft on the right.
- The oversized WRONG WAY sign at 2 ft on the left, 7 ft on the left, 2 ft on the right, and 7 ft on the right.
- The normal WRONG WAY sign with red retroreflective sheeting on the sign support at 2 ft on the left, 7 ft on the left, 2 ft on the right, and 7 ft on the right.
- The WRONG WAY sign with flashing red LEDs around the border of the sign at 2 ft on the left, 7 ft on the left, 2 ft on the right, and 7 ft on the right.
- Four sign distractor treatments.
- The standard arrow design in the middle position.
- The modified arrow design in the middle position.
- Two arrow distractor treatments.

All of the sign treatments were always seen before the arrow treatments. To reduce learning effects, each participant saw a different treatment order at each BAC level (i.e., 0.00, 0.04, 0.08, and 0.12 g/dL). In addition, researchers tried to balance the treatment orders across the four BAC levels.

Vehicles and Instrumentation

The study used one instrumented state-owned vehicle (2005 Dodge Grand Caravan) with the headlights aimed according to the manufacturer's instructions. Figure 34 shows the in-vehicle equipment used. Participants wore occlusion glasses that blocked their vision until the start of the study and in between treatment arrays (Figure 35). The study administrator controlled the occlusion glasses via a laptop computer, while the participant controlled the glasses with a handheld unit.

Study Procedure

Like the first study, researchers conducted the second study in three parts: pre-screening, part 1, and part 2. Each part was again administered on a different date. The pre-screening portion was the same as the first study and thus is not described again.

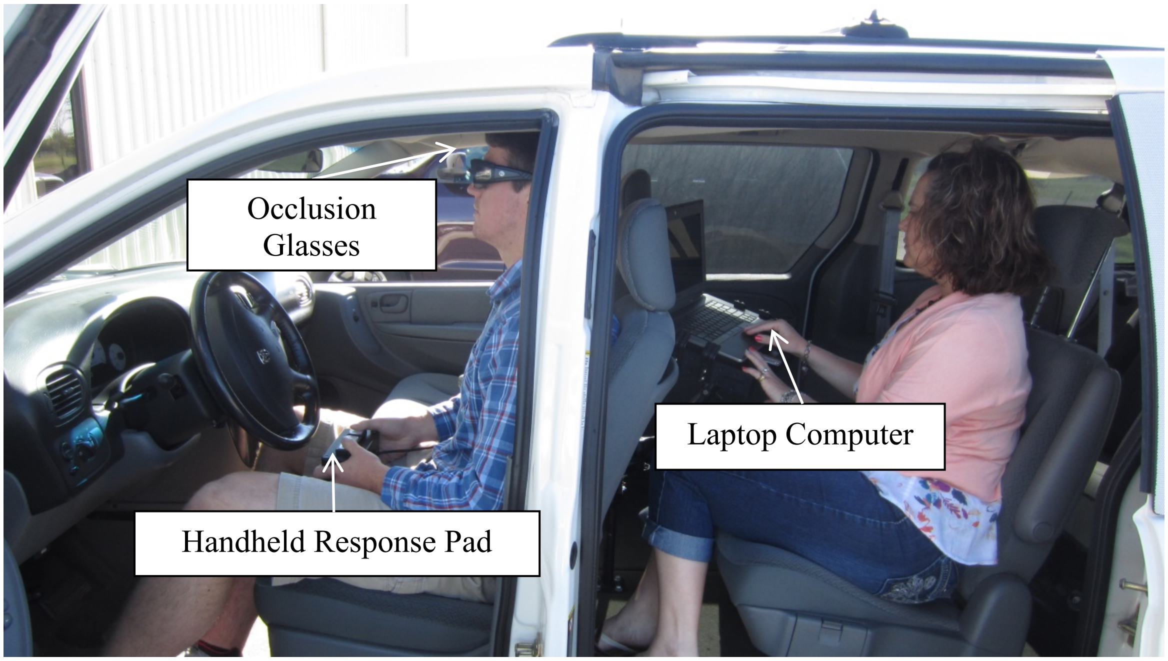


Figure 34. Second Study In-Vehicle Equipment.

a) Glasses Activated—Blocking Vision. b) Glasses Deactivated—Not Blocking Vision.

Figure 35. Occlusion Glasses.

Part 1 was conducted at night at the Texas A&M University Riverside Campus and took about two hours. Participants did not consume any alcohol. Upon arrival, participants read and signed the informed consent form. Before beginning the study, each participant had his BAC level determined by standard DPS breath sample equipment to ensure that his BAC level was zero.

A study administrator then drove the participant to the study location on the closed course. Once parked at the study location, the participant moved into the driver's seat and put on the occlusion glasses. The vehicle remained stationary during the study and was positioned 240 ft away from the treatment arrays. Once the study administrator gave the participant the in-vehicle instructions and handheld response pad, the study administrator activated the occlusion glasses (i.e., blocked the participant's vision) via software on a laptop computer. When the first sign treatment array was ready, the study administrator deactivated (or cleared) the occlusion glasses, restoring the participant's vision. The participant then found the WRONG WAY sign in the treatment array and pushed the correct button (left, right, or middle) on the response pad. When a button was pushed, the occlusion glasses were immediately activated, blocking the participant's vision. The time it took the participant to locate the WRONG WAY sign and respond was measured and recorded in the software program. The study administrator then asked the participant whether the task of locating the WRONG WAY sign among the other treatments was easy or difficult and why. The study administrator then marked the participant's response on a standard form. This procedure was repeated multiple times until the participant had viewed all of the sign treatment arrays.

Next, the participant located arrow pavement markings in treatment arrays using the same procedure. Once this was completed, the study administrator drove the participant back to the check-in building where the participant completed the same three standard police field sobriety tests described in the first study. Upon completion of part 1 of the study, researchers scheduled participants for part 2.

Part 2 was conducted at night at the Texas A&M University Riverside Campus and took approximately 10 hours. Participants were required to consume alcoholic beverages (80-proof spirit mixed drinks). Upon arrival, participants reviewed and signed the informed consent form. Before consuming any alcohol, each participant had his BAC level determined by standard DPS breath sample equipment. Participants then consumed alcoholic beverages over approximately a two-hour period until they reached a BAC level of 0.12 g/dL. Standard DPS breath sample equipment was used to monitor each participant's BAC level. At a minimum, each participant's BAC level was measured immediately prior to and after each task.

When each participant reached a BAC level of 0.12 g/dL, a study administrator drove the participant to the study location on the closed-course. The state-owned vehicle, equipment, and participant tasks were the same as in part 1. Once this was completed, the study administrator drove the participant back to the check-in building where the participant took a survey that assessed his opinion regarding the WRONG WAY sign treatments. Each participant also completed three standard police field sobriety tests (the same as in part 1). The participants were then brought to a comfortable place to sit and given food and non-alcoholic drinks. At a BAC level of 0.08 g/dL and 0.04 g/dL, each participant repeated the closed-course task and the three standard police field sobriety tests. In addition, upon reaching a BAC level of 0.10 g/dL and 0.06 g/dL, each participant repeated the three standard police field sobriety tests. The participants had to remain on-site until their BAC level was less than 0.04 g/dL, at which time researchers drove them home.

Participants

Researchers recruited potential participants from Bryan/College Station, Texas, area based on the same criteria used in the first study. Researchers prescreened 59 male participants. Fifteen participants did not meet the pre-screening criteria and thus were not allowed to participate. In addition, after completing the pre-screening, two participants decided not to participate, and eight were never scheduled. Of the remaining 34 participants, 34 completed part 1 and 30 completed part 2 of the study. After part 1, researchers dropped one participant due to medical concerns, and three other participants were not available on the scheduled part 2 study dates. The average age of the 30 participants was 25 and ranged from 21 to 48. The average visual acuity was 20/18, and the average weight was 194 pounds.

Data Reduction

Following data collection, each participant's raw data were screened and reduced into a fully formatted dataset to obtain the necessary information for analysis. During the data-screening process, researchers eliminated anomalous data (e.g., misidentifications and malfunctioning treatment/equipment).

Next, researchers reviewed the BAC-level data measured immediately before and after each closed-course task. Researchers computed the average BAC level of each participant for each closed-course task by averaging the two before and two after BAC-level measurements. A review of these data identified one outlier at 0.08 g/dL, which was removed from the final dataset. Figure 36 shows the average BAC level for each remaining participant for the three target BAC levels (i.e., 0.12, 0.08, and 0.04 g/dL), and Table 16 contains the overall BAC level descriptive statistics.

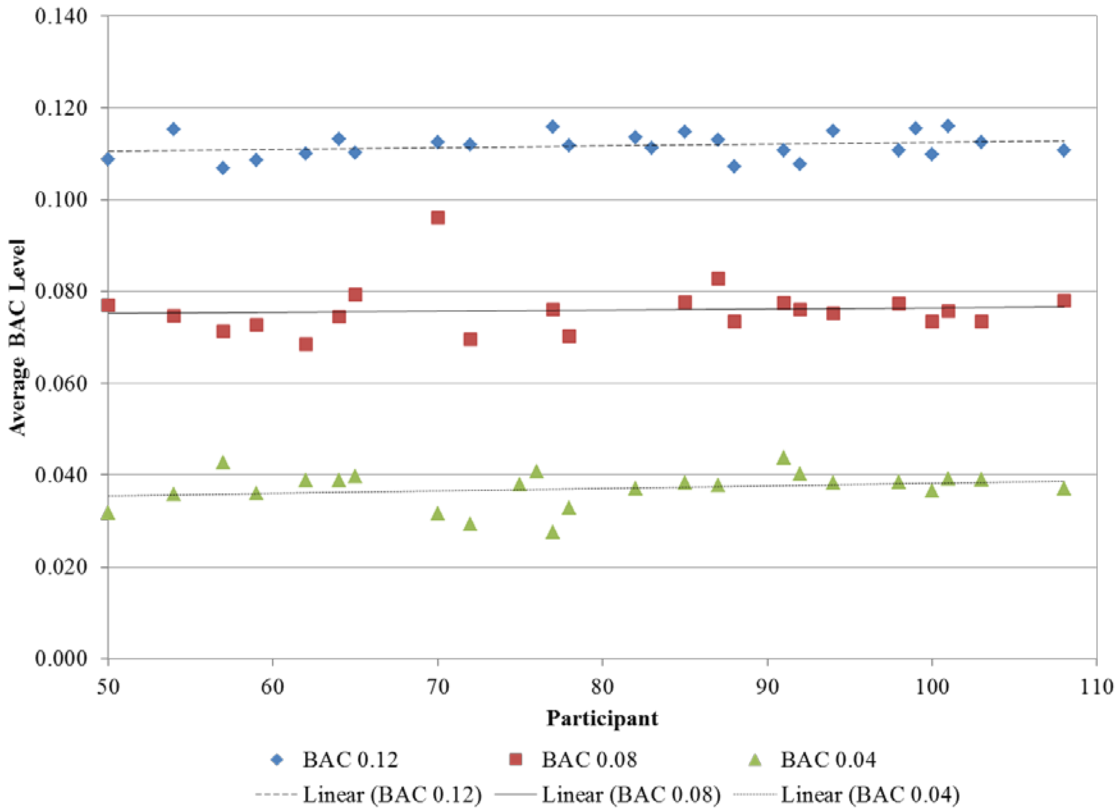


Figure 36. Second Study Participants' Average BAC Levels (g/dL).

Table 16. Second Study Overall BAC Level Descriptive Statistics.

Target Level (g/dL)	Average (g/dL)	Standard Deviation (g/dL)	Minimum (g/dL)	Maximum (g/dL)
0.000	0.000	0.000	0.000	0.000
0.120	0.112	0.003	0.107	0.116
0.080	0.076	0.006	0.069	0.096
0.040	0.037	0.004	0.028	0.044

Researchers calculated recognition times by subtracting the participants' identification time (i.e., the moment they pressed a button on the response pad) from the time the occlusion glasses restored the participants' vision (i.e., cleared by the study administrator). Researchers also reduced and analyzed the opinion data collected during each closed-course portion of the study and the BAC 0.12 g/dL survey.

Results

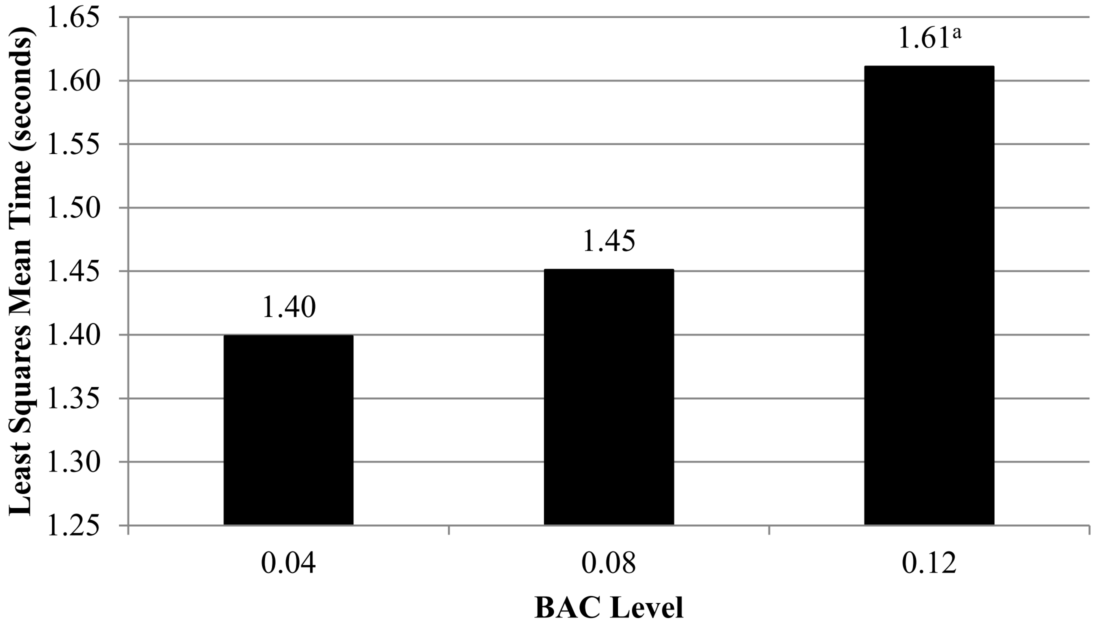
The following subsections contain the results of the recognition time analyses for the WRONG WAY sign and wrong way arrow pavement marking treatments. For the reasons discussed previously (see part 1 study results), researchers did not include BAC level 0.00 g/dL and distractor sign/arrow data in the recognition time analyses, and researchers used the predicted values (least squares means) for each response variable to compare different treatments. A 5 percent significance level ($\alpha = 0.05$) was used for all statistical analyses.

WRONG WAY Signs

The final dataset included 1108 observations, and the final model included the following main effects and two-way interactions:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Sign height (7 ft and 2 ft).
- Treatment (normal size, oversized, retroreflective sheeting, and LEDs).
- BAC level * sign height.
- BAC level * treatment.
- Sign height * treatment.

This statistical analysis showed that only the BAC level was statistically significant ($p = 0.001$). Researchers used Tukey's HSD procedure to determine which BAC levels were statistically different. Figure 37 presents the predicted means for the WRONG WAY sign recognition time by BAC level. As expected, the recognition time increases as the BAC level increases. BAC level 0.04 g/dL was found to have the shortest predicted mean recognition time (1.4 sec). However, this time was not significantly different from the predicted mean recognition time for BAC level 0.08 g/dL (1.45 sec). The longest predicted mean recognition time (1.61 sec) occurred at BAC level 0.12 g/dL. This time was found to be significantly more than those for BAC levels 0.08 g/dL and 0.04 g/dL. Thus, a BAC level of 0.12 g/dL did appear to negatively impact a motorist's ability to recognize the WRONG WAY signs among the other distractor signs independent of treatment.



[a] BAC level 0.12 g/dL was statistically different from BAC levels 0.04 and 0.08 g/dL.

Figure 37. WRONG WAY Sign Recognition Time by BAC Level.

Neither height nor treatment was found to be a significant variable in the model. Thus, the quantitative data yielded no significant differences between the conspicuity of a normal WRONG WAY sign mounted at 7 ft and the other treatments (i.e., lowered sign height, oversized sign, retroreflective sheeting on support, and flashing red LED border). However, the qualitative difficulty assessment and participant opinion data did reveal some differences among the treatments.

Table 17 shows the percentage of participants that thought the task of locating the WRONG WAY sign among the other signs was difficult by treatment. These data show that the participants thought the normal size WRONG WAY signs without any conspicuity element were more difficult to find than the WRONG WAY signs with a conspicuity element (31 percent versus 13 to 17 percent). Based on a test of proportions using a 5 percent significance level, the researchers determined that the difficulty percentage for the normal size WRONG WAY sign without any conspicuity element was statistically different from the other three percentages. No statistical differences were found between the other three treatments.

Table 17. WRONG WAY Sign Participant Difficulty Assessment.

Treatment	The Task of Locating the WRONG WAY Sign among the Other Signs Was Difficult
Normal Size Sign	31%[a]
Oversized Sign	17%
Normal Size Sign with Red Retroreflective Sheeting on Sign Support	13%
Normal Size Sign with Flashing Red LEDs around Border	13%

[a] Statistically different from the other percentages based on a test of proportions using an overall significance level of 5 percent ($\alpha = 0.05$).

Table 18 shows data from the post survey that researchers administered to each participant at a BAC level of 0.12 g/dL. A multivariate chi-square test of independence showed that the answers to the four questions were dependent on the treatment (computed χ^2 value [16.63] greater than table χ^2 $value_{(0.05,6)}$ [12.59]). A review of the findings shows that only 56 percent of participants thought that the normal sign mounted at 2 ft (i.e., lowered sign) caught their attention more than the normal sign mounted at 7 ft. Comparatively, between 84 and 92 percent of participants thought the oversized WRONG WAY sign, the addition of a retroreflective sheeting on the WRONG WAY sign support, and the addition of flashing red LEDs around the border of the WRONG WAY sign caught their attention more than the normal sign (all treatments mounted at 7 ft).

Table 18. WRONG WAY Sign Participant Preference Data.

Treatment	Given How You Feel Right Now, Which Wrong Way Treatment Caught Your Attention More?		
	Treatment	Normal Sign[a]	Both the Same
Lowered Sign[b]	56%	36%	8%
Oversized Sign[c]	92%	0%	8%
Retroreflective Sheeting[d]	88%	8%	4%
LEDs around Border[e]	84%	16%	0%

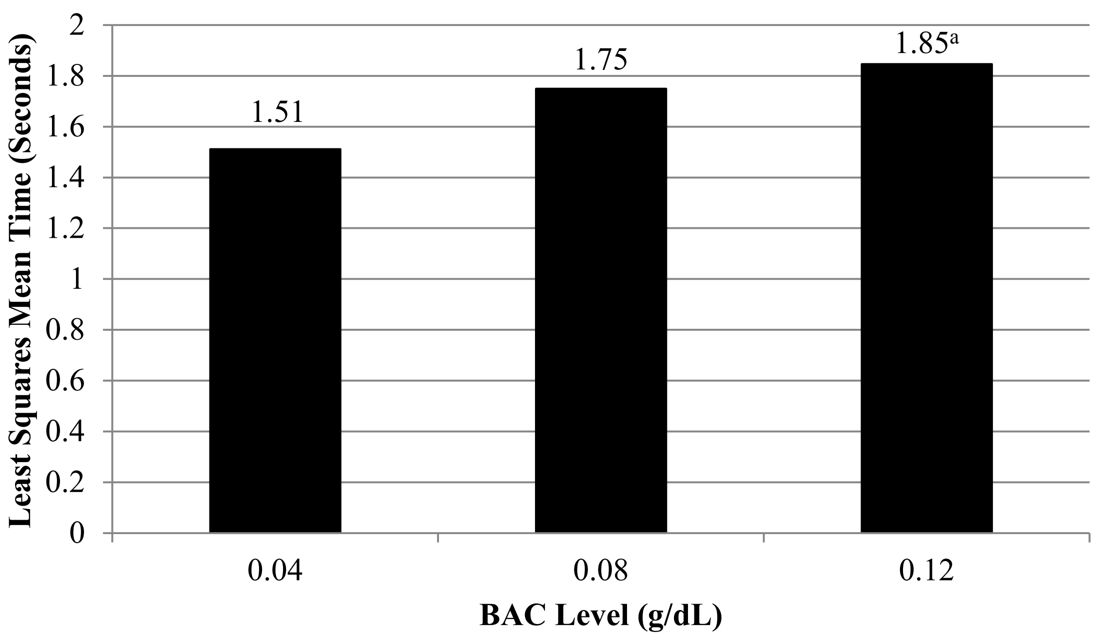
[a] Normal WRONG WAY sign mounted at 7 ft.
[b] Normal WRONG WAY sign mounted at 2 ft.
[c] Oversized WRONG WAY sign mounted at 7 ft.
[d] Normal WRONG WAY sign mounted at 7 ft with red retroreflective sheeting on the sign support.
[e] Normal WRONG WAY sign mounted at 7 ft with flashing red LEDs around the border.

Wrong Way Arrow Pavement Markings

The final dataset included 135 observations, and the final model included the following main effects and their two-way interaction effect:

- BAC level (0.12, 0.08, and 0.04 g/dL).
- Treatment (standard arrow and modified arrow).

This statistical analysis showed that only the BAC level was statistically significant ($p = 0.016$). Researchers used Tukey's HSD procedure to determine which BAC levels were statistically different. Figure 38 presents the predicted means for the wrong way arrow pavement markings recognition time by BAC level. Again, as expected, the recognition time increases as the BAC level increases. The longest predicted mean recognition time (1.85 sec) occurred at BAC level 0.12 g/dL. This time was found to be significantly more than the BAC level 0.04 g/dL time, but not the BAC level 0.08 g/dL time. Thus, a BAC level of 0.12 g/dL did appear to negatively impact a motorist's ability to recognize both types of wrong way arrow pavement markings among the other distractor markings independent of treatment.



[a] BAC level 0.12 g/dL was statistically different from BAC level 0.04 g/dL.

Figure 38. Wrong Way Arrow Pavement Marking Recognition Time by BAC Level.

Treatment was not found to be a significant variable in the model. Thus, there was no statistical difference in the recognition time between the two wrong way arrow marking designs. This means that the modified design performed as well as the current design. In addition, Table 19 shows that participants assessed the ease at which they could find the two arrow designs among the other markings similarly.

Table 19. Wrong Way Arrow Pavement Marking Participant Difficulty Assessment.

Treatment	The Task of Locating the WRONG WAY Sign among the Other Signs Was Difficult
Standard Design	21%
Modified Design	19%

SUMMARY AND CONCLUSIONS

Researchers designed and conducted two nighttime closed-course studies to assess:

- Where alcohol-impaired drivers look in the forward driving scene.
- The impact of alcohol on sign color recognition.
- The impact of alcohol on sign legibility distance.
- The impact of alcohol on how drivers look at signs.
- The conspicuity of select WWD signing countermeasures from the perspective of alcohol-impaired drivers.
- The effectiveness of a modified wrong way arrow pavement marking design using alcohol-impaired drivers.

Researchers found that alcohol-impaired drivers may tend to look less to the left and right and more toward the pavement area in front of the vehicle. In addition, researchers confirmed that alcohol-impaired drivers do not actively search the forward driving scene as much as non-impaired drivers. Instead, alcohol-impaired drivers concentrate their glances in a smaller area within the forward driving scene.

Researchers also confirmed that drivers at higher BAC levels took longer to locate signs and must be closer to a sign before they can identify the background color and read the legend. In addition, alcohol-impaired drivers have to be closer to signs with flashing red LEDs around the border before they can read the legend compared to signs without flashing LEDs.

Researchers also found that as the BAC level increased, more drivers misidentified the red sign background color, with most thinking that a red sign was an orange sign.

Compared to the standard sign height (7 ft), lowering the height of the white-on-red signs studied did not improve the ability of alcohol-impaired drivers to locate signs, identify the background color, or read the legend. Making the sign larger (i.e., oversized), adding red retroreflective sheeting to the sign support, or adding flashing red LEDs around the border of the sign also did not improve the ability of the alcohol-impaired drivers to locate WRONG WAY signs. However, the participants felt that these three countermeasures made it easier to find the WRONG WAY sign. The participants also thought that these three countermeasures caught their attention more than the normal size WRONG WAY sign mounted at 7 ft and 2 ft.

Researchers did not find a significant difference in the recognition time between the two wrong way arrow marking designs. In addition, the participants assessed the ease at which they could find the arrow among the other markings similarly. Thus, it appears that the modified design performed as well as the current design. Researchers also found that at higher BAC levels, the participants took longer to locate the wrong way arrow pavement markings, independent of the design, among the other markings.

Since alcohol-impaired drivers tend to look more at the pavement in front of the vehicle, researchers recommend that wrong way arrows should be installed and maintained on all exit ramps on controlled-access highways. As existing wrong way arrows are replaced, the modified wrong way arrow design should be used. Future research should evaluate the effectiveness of other in-road WWD countermeasures.

TxDOT should continue to mount WRONG WAY and DO NOT ENTER signs on the left and right sides of the roadway. These signs should be mounted at 7 ft (measured vertically from the bottom of the sign to the elevation of the near edge of the pavement or top of the curb). However, researchers recommend that enhanced conspicuity elements be added to these signs to attract the attention of alcohol-impaired wrong way drivers. Based on the participants' preferences, researchers recommend the use of red retroreflective sheeting on WRONG WAY and DO NOT ENTER sign supports, oversized WRONG WAY and DO NOT ENTER signs, and flashing red LEDs around the border of WRONG WAY signs. Future research is needed to determine the minimum and maximum light levels for the flashing red LEDs around the border of WRONG WAY signs to ensure that they provide enhanced conspicuity but do not degrade the ability of drivers to read the sign legend. This research should include alcohol-impaired drivers, as well as older drivers.

CHAPTER 4: OPERATIONAL FIELD STUDIES

INTRODUCTION

As discussed in Chapter 2, since 2008, several Texas agencies have installed WWD countermeasures and/or mitigation methods on their road network. Specifically, this project investigated:

- TxDOT's use of WRONG WAY signs with flashing red LEDs around the border.
- HCTRA's WWD detection system.
- NTTA's use of lowered DO NOT ENTER and WRONG WAY signs.

In spring 2014, researchers assessed the effectiveness of these measures in an actual operational environment using preexisting data that the agencies provided. Researchers also examined the characteristics of WWD events in the San Antonio region. The following subsections describe the findings from these investigations.

SAN ANTONIO

Background

Table 20 documents the activities in the San Antonio region from August 2010 to March 2014. In Chapter 2, researchers discussed the formation and goals of the San Antonio Wrong Way Driving Task Force. Researchers also documented the process used to select the 15-mile US 281 corridor from I-35 (near downtown) to just north of Loop 1604 (the far north central side of San Antonio) as the Wrong Way Driver Countermeasure Operational Test Corridor.

Between March 2012 and June 2012, TxDOT staff and their contractors installed the WRONG WAY signs with flashing red LEDs around the border along the US 281 test corridor. The purpose of the flashing red LEDs was to increase the conspicuity of WRONG WAY signing at night. Therefore, the signs were set to flash under low ambient light conditions (i.e., at night and during some inclement weather events), whether or not a wrong way vehicle was detected. Where the length and design of the exit ramp allowed, WRONG WAY signs with flashing red LEDs around the border supplemented the existing, static WRONG WAY signs. On shorter ramps, the WRONG WAY signs with flashing red LEDs around the border replaced the existing static WRONG WAY signing. The battery for the signs was encased in the sign pole and charged by a small solar array attached to the top of the sign support.

Table 20. San Antonio Agency Actions Regarding WWD Events 2010–2014.

Date of Change	WWD Response Action Change
August 2010	SAPD implemented an emergency call signal (i.e., E-tone) for its radio network for WWD events.
November 2010	SAPD authorized the use of portable spike strips in certain situations to stop wrong way drivers.
January 2011	SAPD implemented a code in their CAD system to identify WWD events.
March 2011	TxDOT TransGuide traffic management center operators began logging all WWD events (previously logged only if a crash resulted).
May 2011	TxDOT TransGuide operators began displaying WWD warning messages on changeable message signs (DMSs) to right way drivers when E-tone issued (previously waited to display warning message until wrong way driver was visually verified). San Antonio WWD task force formed. Started monthly meetings.
June 2011	TxDOT and staff from other task force agencies performed a few exit ramp site visits to identify issues in the field and identify whether or not signing or marking deficiencies of any kind exist.
July 2011	SAPD traffic crash investigators asked to determine entry point used by wrong way drivers if possible. Test installation of a radar unit to identify WWD events in the field installed at I-35 and Nogalitos southbound exit. Signal from radar unit received at TxDOT TransGuide, but discovered that modifications were needed to TransGuide's Lonestar software to properly receive WWD event signal. WWD research problem statement developed by task force and sent to TxDOT's research office.
September 2011	TTI created first GIS-based map of San Antonio WWD events using TransGuide and SAPD 911 logs. Using this map, the task force determined that the initial WWD countermeasure deployment would be along US 281 near the San Antonio International Airport and along the corridor from downtown to Loop 1604.
October 2011	The task force selected flashing LED border-illuminated WRONG WAY signs in conjunction with radar units (WWD event detection devices) as the preferred WWD countermeasures for test corridor implementation. The task force also recommended mainlane systems that include blank-out WRONG WAY signs.
November 2011	TxDOT installed the first flashing LED border-illuminated WRONG WAY sign at I-35/Nogalitos test location.
December 2011	SwRI completed changes to TxDOT's Lonestar software to allow receipt of a WWD event signal from radar units.
January 2012	TxDOT approved use of internal funding to install WWD countermeasures on US 281 test corridor ramps.
February 2012	Media event hosted at TxDOT TransGuide to announce the US 281 WWD test corridor and other WWD countermeasure efforts.

Table 20. San Antonio Agency Actions Regarding WWD Events 2010–2014 (Continued).

Date of Change	WWD Response Action Change
March 2012	TxDOT began flashing LED border-illuminated WRONG WAY sign installation on US 281 (southern end of corridor near downtown). Funding approval was sought for ramp WWD countermeasures on I-35 on the north and west sides of downtown.
April 2012	Over half of the US 281 ramp flashing LED border-illuminated signs installed (installation began from the south and reached Bitters Road).
May 2012	TxDOT and TTI delivered a presentation at the Intelligent Transportation Society America Annual Meeting on the San Antonio WWD task force and US 281 WWD countermeasure test corridor efforts.
July 2012	Flashing LED border-illuminated WRONG WAY sign installation effectively completed on US 281. TxDOT installed the first ramp radar detection units at Nakoma; however, communications to TxDOT TransGuide were not yet enabled.
September 2012	Nine radar units installed on US 281, to date. SwRI completed testing of ramp radar units (detection of wrong way vehicles and transmission of detection signal). TTI began two-year research project to evaluate the effectiveness of wrong way driving countermeasures.
October 2012	14 radar units installed on US 281, to date. TxDOT began construction project on I-35 from Judson Road to FM 3009. Flashing LED border-illuminated WRONG WAY signs to be installed as ramps are reconstructed.
December 2012	Radar installation on US 281 completed from downtown to Bitters Road. Calibration and orientation of the radars with the manufacturer were ongoing because false signals to TxDOT TransGuide proved to be problematic.
March 2013	Ramp radar manufacturer visited US 281 test corridor to help resolve false call detection issues. Flashing LED border-illuminated WRONG WAY sign installation began on I-35 from Laredo Street to US 281/I-37.
April 2013	SwRI demonstrated the mainlane WWD detection and response system installed at its test track to TxDOT.
July 2013	TxDOT completed installation of flashing LED border-illuminated WRONG WAY signing along I-35 in the downtown area. Task force group merged its meetings into monthly meetings of the San Antonio Traffic Incident Management Group.
December 2013	TxDOT installed first wrong way mainlane system on I-10 at Callaghan/Wurzbach.
January 2014	TxDOT began flashing LED border-illuminated WRONG WAY sign installation on I-10 from Huebner to Loop 410.
March 2014	TxDOT completed flashing LED border-illuminated WRONG WAY sign installation on I-10 from Huebner to Loop 410. TxDOT installed second wrong way mainlane system on I-35 at Judson Road.

Automatic detection of wrong way drivers and the communication of their presence on a specific exit ramp along the US 281 test corridor were envisioned as an intrinsic element of countermeasure deployment. Since a sign-support-mounted radar sensor was readily available from an equipment manufacturer, that device was chosen for implementation on the US 281 exit ramps. Power for the radar sensor derives from the same solar power array used for the WRONG WAY signs with flashing red LEDs around the border. Radios were used to transmit radar readings (essentially speed, where negative values represent wrong way drivers) from the radar sensors to the nearest TransGuide communications hub.

By December 2012, radar speed sensors were installed on all US 281 exit ramps from I-35 (the downtown area) to Bitters Road (the northern extent of TransGuide communications along the US 281 corridor). However, the following issues were encountered during implementation that impeded continuous activation of the exit ramp radar speed sensors, yielding no data for TTI researchers to analyze the effectiveness of the exit ramp detection system:

- In July 2011, it was determined that TxDOT had to work with SwRI to get the wrong way driver detection from the radar sensor recognized by the TxDOT Lonestar Active Traffic Management System (ATMS) software. Necessary changes to Lonestar were completed by December 2011.
- Installation of radar speed sensors at the US 281 exit ramps began in summer 2012. Communication from US 281 radar sensors back to TransGuide was enabled late in summer 2012, but false detections resulted in TransGuide staff deactivating the radar-produced WWD alerts for the US 281 ramps.
- From fall 2012 to March 2013, TxDOT and SwRI consulted with the radar sensor manufacturer to reposition and recalibrate the sensors. While some improvements were made, the number of false detections remained too high. Therefore, the radar-related wrong way warnings continued in deactivated status.
- Throughout the remainder of 2013, SwRI studied the exit ramp radar sensor installations for TxDOT. In April 2014, SwRI suggested that two radar sensors per ramp may be needed so that the second radar could authenticate the primary radar’s wrong way detection. Other alternatives identified included the use of a different (though substantially higher-cost) radar unit with reduced false detection issues or the pursuit of an altogether different wrong way vehicle detection technology.

Due to funding limitations, the mainlane systems on the US 281 corridor have not been implemented. However, TxDOT obtained separate funding to install two mainlane systems at other locations: one on I-10 at Callaghan in December 2013 and one on I-35 at Judson Road in March 2014. As of May 2014, these two systems were not fully activated, so TTI researchers could not evaluate the effectiveness of the mainlane systems.

Initially TxDOT installed the mainlane system as shown in Figure 8. However, during the initial system test, it quickly became evident (based on the high number of phone calls received) that drivers traveling in the correct direction could easily read the set of signs on the overhead sign bridge support between the two travel directions. After some additional testing, TxDOT decided to move that set of signs over the mainlanes (see Figure 39 and Figure 40).

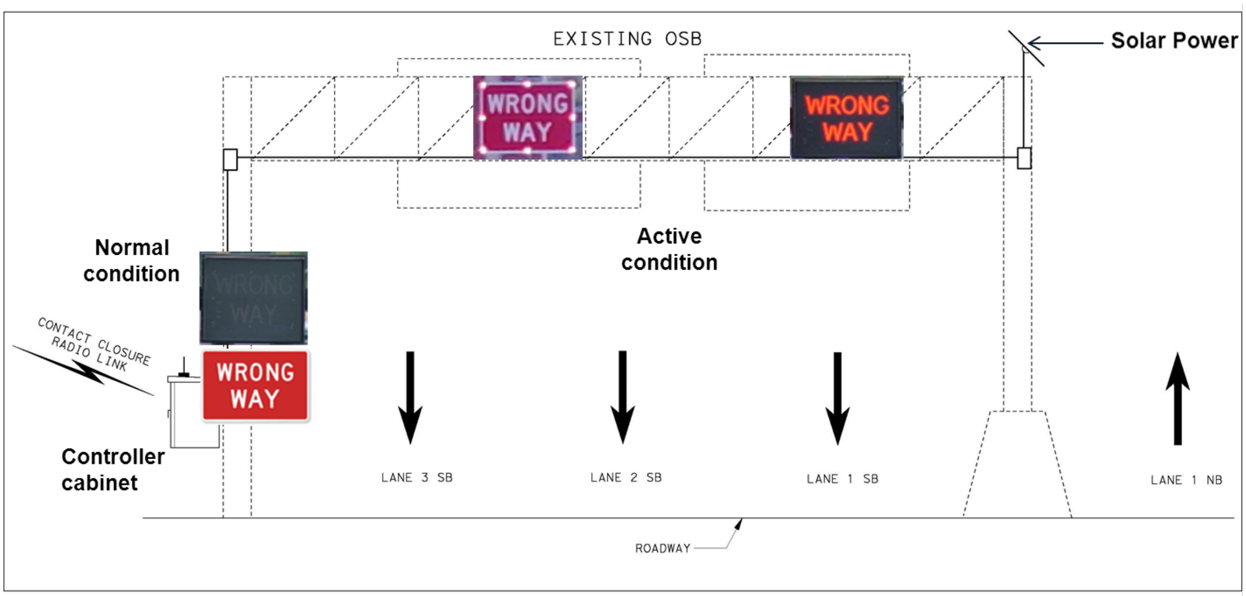


Figure 39. Revised Mainlane System Design (TxDOT).

As part of a construction project on I-35 from Judson Road to FM 3009, TxDOT was also able to install WRONG WAY signs with flashing red LEDs around the border on exit ramps that were being reconstructed. This was completed in July 2013; however, TTI researchers did not include these sites in the analysis described here since the signs were not implemented at every ramp along the corridor. Similarly, TxDOT received funding to install WRONG WAY signs with flashing red LEDs around the border on I-10 from Huebner to Loop 410. This was completed in March 2014, so this corridor could not be used in the analysis either.

Figure 40. Example of Installed Mainlane System.

Data Sources

Through their involvement in the San Antonio WWD Task Force, both SAPD and TxDOT have shared WWD data logs for the flashing red LED border WRONG WAY signing evaluation. SAPD shared a subcomponent of its 911 call logs having to do with WWD events, and TxDOT shared the subcomponent of its TransGuide operator's logs for events including wrong way drivers. However, the TxDOT TransGuide operator logs generally include only the events that occur in their coverage area—about half of the freeways in the San Antonio region. So, researchers primarily used the SAPD 911 call logs for the statistical analysis since these logs began in January 2011 and contain more data points. Researchers did use the TxDOT TransGuide operator logs to provide a snapshot per year of the WWD activity in the San Antonio area since theses logs contain additional information not found in the SAPD 911 logs. Researchers also extracted WWD-involved crash information from the TxDOT CRIS. As indicated previously, due to false detections, limited funding, and changes to the initial implementation plan for the US 281 Wrong Way Driver Countermeasure Operational Test Corridor, adequate data were not available to evaluate the exit ramp wrong way driver detection sensors and the mainlane wrong way driver systems.

SAPD 911 Wrong Way Driver Logs

The SAPD staff selected the subset of 911 calls related to WWD and saved this as a spreadsheet by month. If multiple calls were related to a single WWD event, SAPD staff color-coded those calls using filled cells in the spreadsheet to indicate that those were all related to the same event. Each 911 call entry features the following data:

- Monthly identification number.
- Date (MM/DD/YYYY).
- Time (HH:MM).
- Day (text).
- SAPD incident number.
- Highway (primary roadway).
- At/near (crossing roadway).
- Travel (direction of travel).
- Known (if freeway ramp known).
- Details (brief event description).
- Result (code or case file number).

Each month, staff from the captain's office within the Traffic Section (contained within the Tactical Support Division of SAPD) made available an updated version of the spreadsheet. Upon receipt of the monthly spreadsheet, a TTI researcher extracted the first entry for each WWD event based on date and time, and added it to a master spreadsheet of all SAPD WWD events, creating a list where one record represents each event. Based on the primary and crossing roadway data and the brief text description for each WWD event, the event is geocoded into an ArcView GIS shape file as a point data event with a unique numerical identification (ID) number that is also cross-referenced in the spreadsheet. When GIS maps are needed, analysts join the spreadsheet with the GIS coordinate information using the unique ID, allowing the event data (e.g., date, time, and description) from the spreadsheet to be imported into the ArcView shape file.

SAPD 911 WWD log data were available beginning in January 2011 and continued without interruption through January 2014. Over 95 percent of the records have adequate primary roadway and cross street information to be geocoded with reasonable accuracy into the ArcView GIS database.

TxDOT TransGuide Operator Logs

TransGuide traffic management system operators have been logging WWD events in San Antonio since March 2011. Since SAPD staff are co-located on the TransGuide operations floor with TxDOT staff, TransGuide operators are usually alerted to the presence of a WWD event on the San Antonio freeway network about the same time SAPD receives notification of these events from 911 calls. For each WWD event, TransGuide operators log information that includes:

- Identification number.
- Date (MM/DD/YY).
- Time (HH:MM).
- Day of the week (12:00 a.m.–12:00 a.m.).
- Day of the week (6:00 a.m.–6:00 a.m.).
- Highway (primary roadway).
- Reported cross street.
- Direction.
- Reported by (source).
- Whether or not a WWD warning was executed on a DMS.
- Whether or not WWD was observed with a camera.
- Result (a brief description).

At the end of each month, TxDOT staff makes available an updated version of this spreadsheet. A TTI researcher geocodes this information by using a web-based map and logging the latitude and longitude of the location identified in the operator log. When it is necessary to produce maps or perform spatial analysis of WWD event data, the TransGuide operator log is imported into the GIS database using the latitude and longitude data contained within the appended operator log spreadsheet.

If insufficient information is available to log the WWD event location, analysts provide a note in the spreadsheet reflecting this fact. Information contained within the result entry occasionally (but not always) indicates if the driver of the WWD event was driving under the influence, what the driver's BAC level was, and other details about a crash (if one occurred).

TxDOT CRIS Data

As with all other crash types, WWD-related crashes are logged within the TxDOT CRIS database according to the information contained on official crash reporting forms and encoded into CRIS. Because there are myriad details pertaining to the vehicles, person(s) involved, and the crash itself, mining the data can prove challenging. WWD events were filtered from the overall database by extracting only records encoded with "Wrong way—one way road" from the crash contributing factors list.

Among the details that have been useful in analyzing WWD crashes in San Antonio are:

- Details about crash contributing factors, which can indicate if at least one of the drivers involved in the crash had been drinking and/or driving under the influence.
- Crash severity, which indicates if any drivers or vehicle occupants were injured or killed.

Details about the "road part," "manner of collision," and "intersection related" can be used to separate crashes that occur on the arterial roadway network and those that occur in freeway corridors. However, determining whether a crash occurred on the mainlanes of the freeway or on its frontage road often required detailed examination of the crash report for the event. There is no specific CRIS database entry that can be properly and consistently used to differentiate whether a freeway corridor crash occurred on the primary travel lanes or frontage road.

A broad range of details can be extracted from the database and exported for post-processing using a spreadsheet or database, including the latitude and longitude of the crash. For use in the research analysis of WWD events, the latitude and longitude obtained for each WWD crash record were used to directly import the CRIS records into the ArcView GIS WWD database. Other details regarding each WWD crash that were extracted from CRIS for WWD analysis in San Antonio include the following:

- Highway.
- Crash year (YYYY).
- Crash date (MM/DD/YYYY).
- Crash milepoint.
- City.
- Crash identification number.
- Road part.

- Roadway related.
- Road condition.
- Manner of collision.
- Intersection related.
- Intersecting road.
- Object struck.
- Crash contributing factor list.
- Crash severity.
- Crash latitude.
- Crash longitude.
- Total crashes.

Because CRIS documents WWD-related crashes rather than any event where WWD activity is observed, crash involved or not, the number of records was small compared to the SAPD 911 WWD call logs and the TxDOT TransGuide operator WWD logs.

Results

Wrong Way Driving Overview

Using the TxDOT TransGuide operator log data, researchers were able to discern the result for each WWD event documented. Table 21 shows that for 87 percent of the WWD events that had occurred since March 2011, there was no crash and the driver of the vehicle was not apprehended. These data also show that only a small portion (about 1 percent) of the WWD events was attributed to disoriented elderly drivers or drivers with a medical condition. Of those WWD events where the driver was apprehended or a crash occurred (n = 92), 67 percent were attributed to alcohol impairment (DWI), of which almost half (45 percent) resulted in serious injury or a fatality.

Figure 41Figure 41 shows the number of WWD events by hour that TxDOT TransGuide operators had documented from 2011 to 2013. WWD events begin to increase around 8:00 p.m. and peak at 2:00 a.m. This figure also shows that WWD events do occur throughout the day but are not as common as at night. Figure 42 shows that the number of WWD events increases throughout the week, peaking on Saturday.

Table 21. TxDOT TransGuide Operator Log WWD Event Result Summary (2011–2013).

Result	2011[a]	2012	2013	Total
No Crash				
- Driver Not Apprehended	81%	88%	90%	87%
- Disoriented Elderly Driver Apprehended	2%	< 1%	< 1%	1%
- Driver with Medical Condition Apprehended	0%	< 1%	< 1%	< 1%
- Driver Apprehended and Arrested for DWI	8%	5%	3%	5%
Subtotal	91%	93%	94%	93%
Crash				
- No Injuries	5%	3%	2%	3%
- Minor Injuries	0%	0%	< 1%	< 1%
- Serious Injury or Fatality	0%	0%	< 1%	< 1%
- Serious Injury or Fatality and DWI Suspected or Confirmed	4%	4%	4%	4%
Subtotal	9%	7%	6%	7%
Total	100%	100%	100%	100%

[a] Partial year from March 15, 2011, to December 31, 2011.

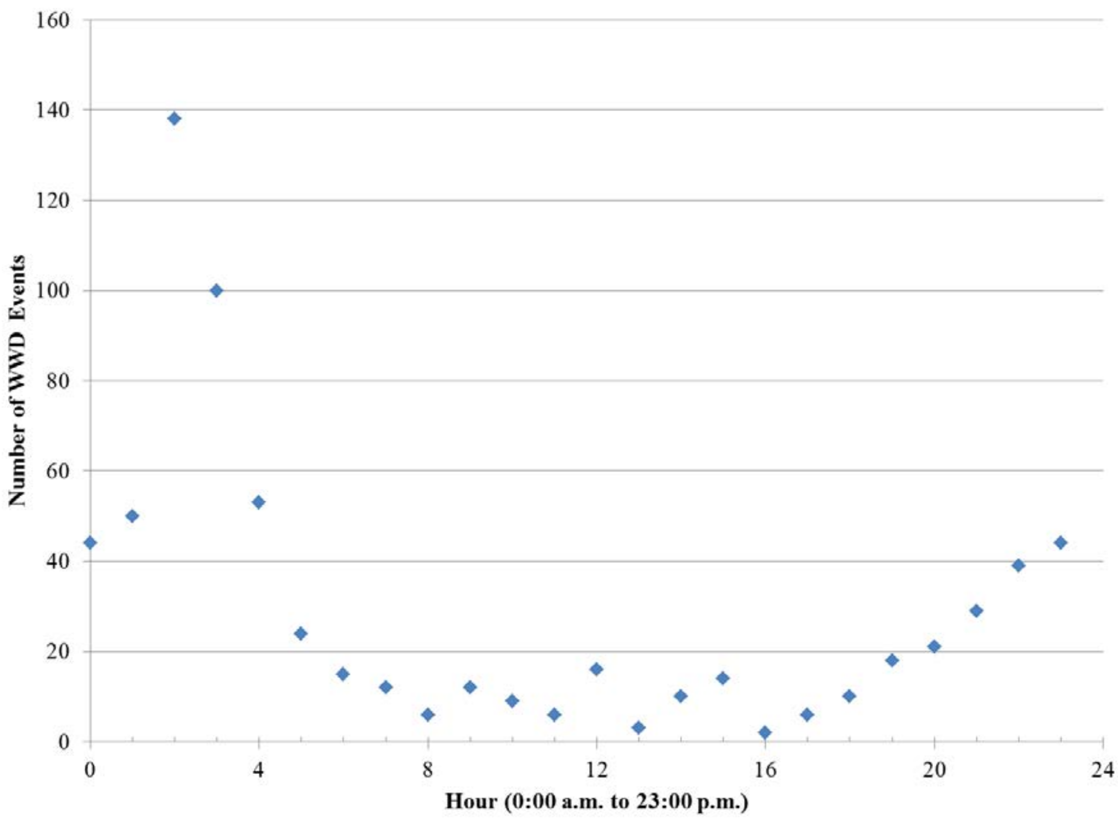


Figure 41. TxDOT WWD Events by Hour (2011–2013).

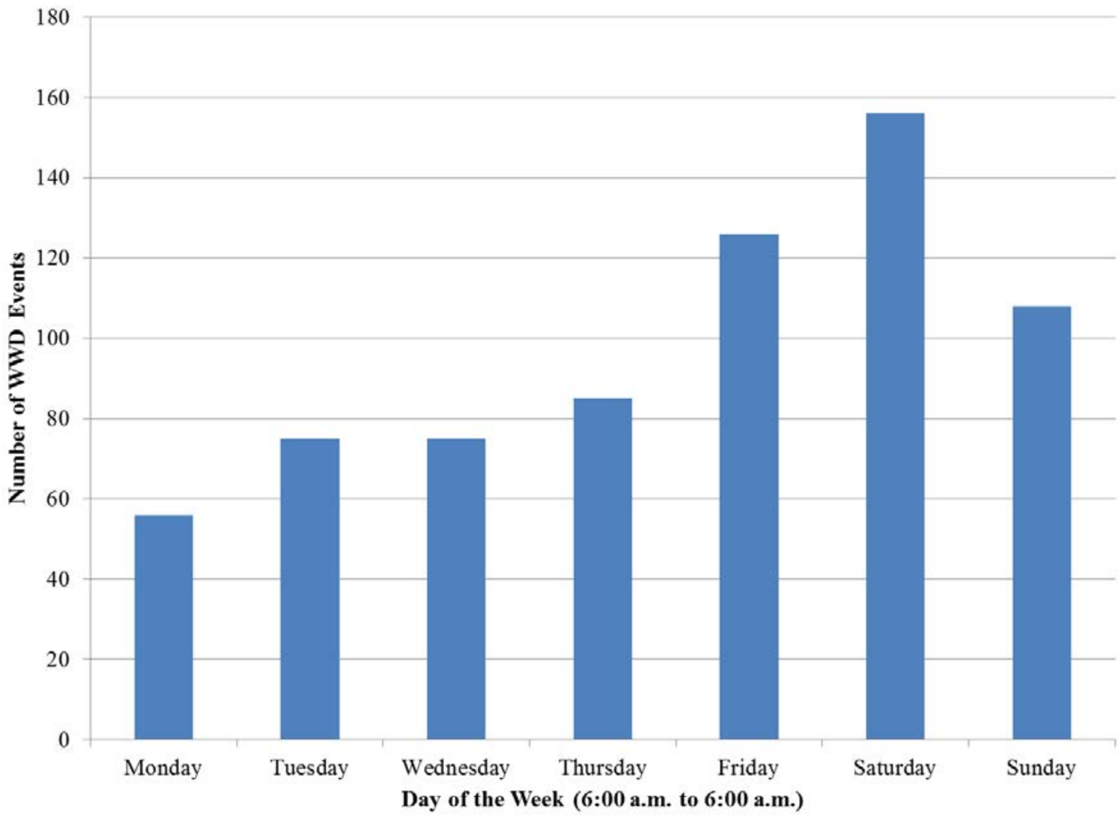


Figure 42. TxDOT WWD Events by Day of the Week (2011–2013).

Table 22 shows that for over three-quarters of the WWD events, TxDOT was able to post a WWD warning message on at least one DMS in the area. This message warns drivers of the potential for a wrong way driver. Unfortunately, DMSs are not always located in the area where a WWD event occurs. Even so, these data show that TxDOT has increased the use of the wrong way driver warning message over the past three years.

Table 22. Summary of TxDOT Use of WWD Warning Message on DMS (2011–2013).

Message Posted	2011[a]	2012	2013	Total
Yes	68	75	87	77
No	32	25	13	23
Total	100	100	100	100

[a] Partial year from March 15, 2011, to December 31, 2011.

WRONG WAY Signs with Flashing LED Border

Figure 43 and Table 23 contain a month-by-month record from January 2011 to April 2014 of the number of WWD events occurring within the limits of the US 281 test corridor, as well as across the city of San Antonio as a whole. These data were obtained from the SAPD 911 call logs. The before period was 14 months long (January 2011–February 2012). The WRONG WAY signs with flashing red LEDs around the border were installed between March 2012 and June 2012. Researchers did not include data from this time period in the analysis since the traffic control devices in the corridor were in flux. The after period was 22 months long (July 2012–April 2014).

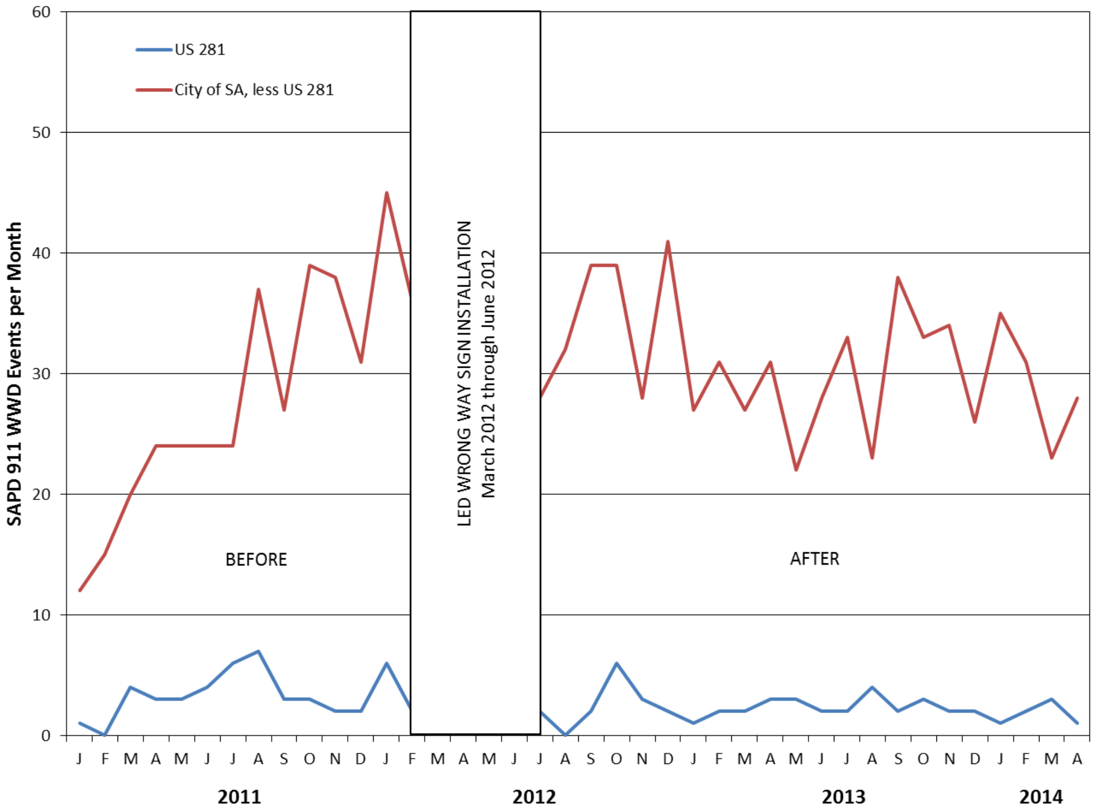


Figure 43. WWD Frequency—US 281 Test Corridor and City of San Antonio.

Table 23. SAPD WWD Events—US 281 Test Corridor and the City of San Antonio.

Year	Month	Flashing LED Border-Illuminated WRONG WAY Sign Implementation Status	On US 281: I-35 to Loop 1604	Total for the City of San Antonio (Less US 281)
2011	January	Before	1	12
	February		0	15
	March		4	20
	April		3	24
	May		3	24
	June		4	24
	July		6	24
	August		7	37
	September		3	27
	October		3	39
	November		2	38
	December		2	31
2012	January		6	45
	February		2	36
	March	During	8	54
	April		1	43
	May		6	38
	June		3	31
	July	After	2	28
	August		0	32
	September		2	39
	October		6	39
	November		3	28
	December		2	41
2013	January		1	27
	February		2	31
	March		2	27
	April		3	31
	May		3	22
	June		2	28
	July		2	33
	August		4	23
	September		2	38
	October		3	33
	November		2	34
	December		2	26
2014	January		1	35
	February		2	31
	March		3	23
	April		1	28

Researchers performed a before-after evaluation with yoked comparisons to determine whether or not a meaningful reduction in monthly WWD events was observed along the US 281 test corridor, with comparison data as all WWD events in the remainder of the city of San Antonio (but not including the US 281 test corridor). Researchers calculated a 38 percent reduction in the WWD events on the US 281 test corridor after the installation of WRONG WAY signs with flashing red LEDs around the border at all exit ramps in the corridor. This percent change was statistically significant at a 5 percent significance level ($\alpha = 0.05$) (the 95 percent confidence interval was −63 percent to −13 percent). In addition, the US 281 test corridor experienced a 31 percent decrease in the average monthly rate of WWD events, while the average monthly rate for the remainder of the region increased by 9 percent. These two trends can be seen by comparing Figure 6 and Figure 44.

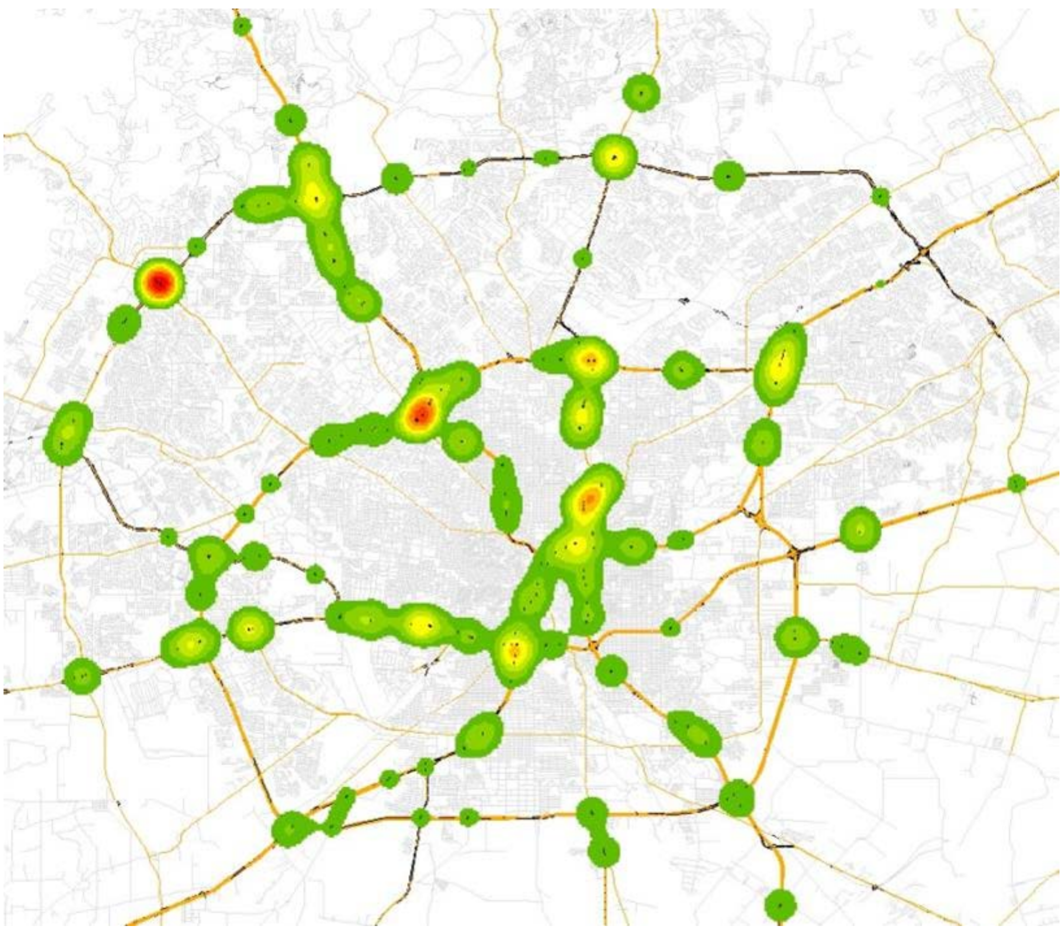


Figure 44. 2013 WWD Density Map of San Antonio.

HARRIS COUNTY TOLL ROAD AUTHORITY

In October 2008, HCTRA began to operate a wrong way driver detection system on the West Park Tollway, a 13.2-mile controlled-access highway in Houston. Researchers described the initial system, as well as the current system components and locations, in Chapter 2. Table 24 shows the verified WWD alerts received by the HCTRA wrong way driver detection system from 2009 to 2013. As this table shows, the majority of WWD alerts verified that the driver self-corrects (74 percent). Law enforcement catches only about 13 percent of the wrong way drivers that result in an alert. Of these, two-thirds of the drivers were arrested for DWI. The HCTRA detection system also sends alerts when a driver's vehicle is facing the correct direction but reversing down the roadway. In most instances, this appeared to occur because the driver missed the exit.

Table 24. HCTRA-Verified WWD Alerts (2009–2013).

Result	2009	2010	2011	2012	2013	Total
Driver Self-Corrected[a]	6	10	41	23	37	117
Driving in Reverse on Mainlanes[b]	0	0	0	6	5	11
Caught by Law Enforcement	4	5	6	1	5	21
Unable to Determine[c]	0	0	2	0	8	10
Total	10	15	49	30	55	159

[a] Majority U-turned on ramp before entering mainlanes.
[b] Most instances appear to be drivers who missed their exit.
[c] Verified by phone call or camera but unable to determine result.

Table 24 also shows an increase in the total verified WWD alerts beginning in 2011. Researchers attribute this increase to the installation of puck sensors. Based on the notes included in the data file that HCTRA provided, it appears that the puck sensors improved HCTRA's ability to detect and document drivers that self-corrected on the ramp, thus increasing the number of verified WWD alerts.

HCTRA activated the flashing LED in-pavement lighting and WRONG WAY signs with flashing red LEDs around the border at South Post Oak in late 2011. However, a before-after evaluation of these two devices could not be completed since the addition of the puck sensors (also in 2011) increased the number of overall alerts received. Even so, the HCTRA data do show that out of the 62 WWD alerts received for this location between January 2012 and December 2013, 86 percent of the drivers self-corrected before reaching the mainlanes.

Figure 45 shows the number of WWD alerts by hour that HCTRA received from 2009 to 2013. Similar to the TxDOT findings, WWD events begin to increase around 10:00 p.m. and peak at 2:00 a.m. This figure also shows that WWD events do occur throughout the day but are not as common as at night.

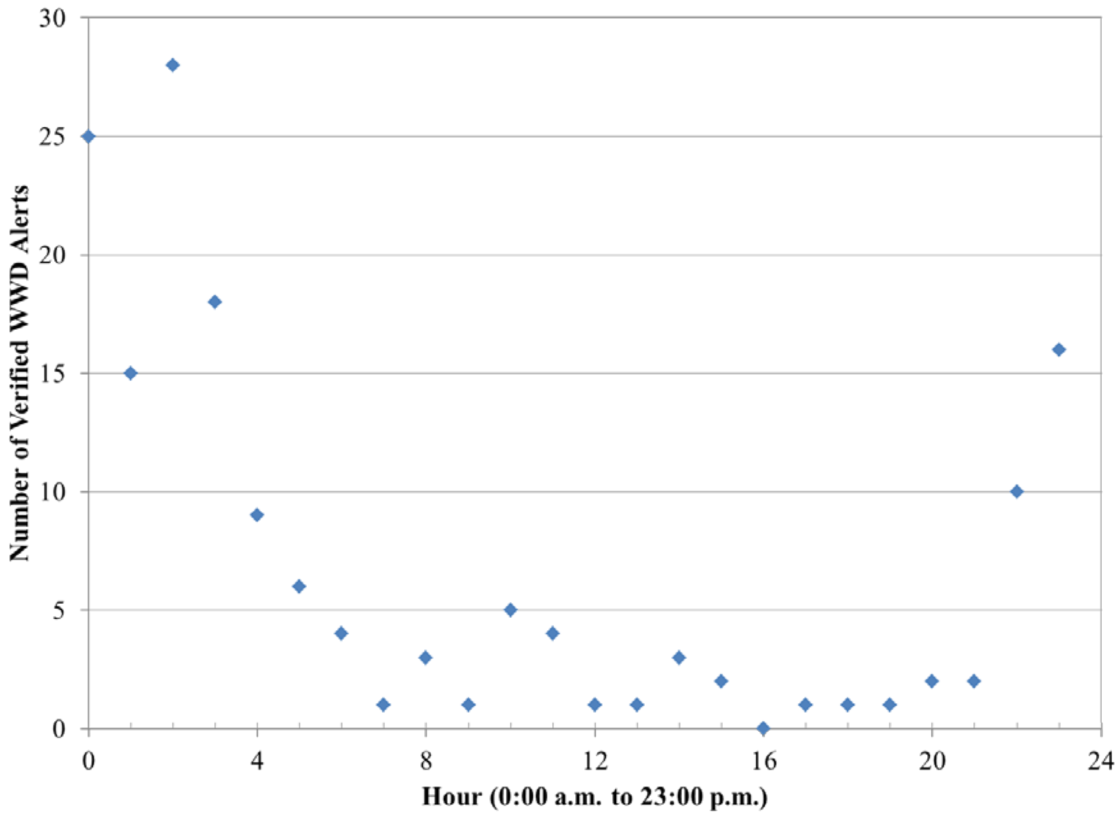


Figure 45. HCRTA WWD Alerts by Hour (2009–2013).

NORTH TEXAS TOLLWAY AUTHORITY

Since 2009, NTTA has implemented various countermeasures to combat WWD on its road network in the Dallas area. However, researchers were primarily interested in NTTA's experiment with lowered DO NOT ENTER and WRONG WAY signs. Since 2010, NTTA has been monitoring wrong way movements at the 51 tolled ramps equipped with detection (i.e., pavement loops). Since detection was not available at all ramps, NTTA also tracked WWD events confirmed by other means. NTTA's investigation included:

- A review of 911 phone calls.
- Use of intelligent transportation system (ITS) cameras on the system where available.

- A review of official police reports.
- Interviews with witnesses, if available.

While NTTA also documented WWD crashes, the number of crashes was small compared to the number of overall WWD events. Therefore, researchers used the WWD event data that NTTA provided to conduct a before-after evaluation with a comparison group to assess whether or not a meaningful reduction in WWD events occurred as a result of the installation of lowered signing.

For this analysis, the before period was 11 months (August 2010–June 2011), and the after period was 24 months (August 2011–July 2013). NTTA installed the lowered DO NOT ENTER and WRONG WAY signs in July 2011, so researchers did not include data from this month in the analysis. Comparing the control (standard signs) and treatment (lowered signs) data, researchers determined that lowered signing (all three configurations) reduced WWD events by 41 percent. However, this percent reduction was not found to be statically significant at a 5 percent significance level (the 95 percent confidence interval was 2 percent to −85 percent).

Additional years of data might increase the sample size so that the decrease in crashes could be determined with at least 95 percent certainty. However, the limited before data (i.e., only 11 months) severely impact the precision (standard error) with which the confidence interval is estimated. In addition, while the method used accounted for changes in events due to factors other than the lowered signing (e.g., traffic volumes), it did not account for regression to the mean, which may have occurred since NTTA installed lowered signing at ramps in areas with high frequencies of WWD events. Also, other types of WWD countermeasures were installed at three exit ramps and two cross streets during the evaluation period. Considering these concerns and the insignificant findings, researchers cannot confidently conclude whether lowered signs will result in a reduction in WWD events, no change in WWD events, or an increase in WWD events.

SUMMARY

Overall, researchers were able to obtain and analyze data from the San Antonio region, HCTRA, and NTTA to evaluate the effectiveness of WWD countermeasures and mitigation methods in actual operational environments. Data from the US 281 test corridor in San Antonio showed that WRONG WAY signs with flashing red LEDs around the border are effective at reducing WWD events. Unfortunately, due to the small number of crashes that occurred during the evaluation period, the impact on WWD crashes is still unknown. One might assume that a reduction in WWD events would correlate to a reduction in WWD crashes. However, as discussed in Chapter 2, driving under the influence was the primary contributing factor to WWD crashes in Texas. While traffic control devices such as signs and pavement markings may be effective at conveying to wrong way drivers that are confused, disoriented, or slightly intoxicated that they need to turn around, researchers do not believe that highly intoxicated wrong way drivers will be able to receive and process the same information from traffic control devices. Texas crash data and anecdotal information from TxDOT show that WWD crashes involve drivers with BAC levels two to three times the legal limit (0.08 g/dL). Thus, there remains some uncertainty as to the impact enhanced traffic control devices, like the WRONG WAY signs with flashing red LEDs around the border, will have on WWD crashes. Nevertheless, a reduction in WWD events is a positive finding.

Data from HCTRA showed that detection systems, in conjunction with other systems (e.g., cameras and law enforcement), can be successfully used to detect, verify, and document WWD events. The HCTRA detection system provides data regarding wrong way driver entry points, a critical piece of information needed to help practitioners further combat WWD. Based on the limited NTTA dataset, researchers could not confidently conclude whether or not lowered signs are effective at reducing WWD events.

CHAPTER 5: WRONG WAY DRIVER WARNING MESSAGES

INTRODUCTION

Currently, the TxDOT San Antonio District displays a single-phase wrong way driver warning message (see Figure 46) in both directions of travel when a SAPD E-tone is issued for a wrong way driver (i.e., reported but not confirmed). The current message includes the problem (WRONG WAY DRIVER REPORTED) and a nonspecific driving action (USE EXTREME CAUTION). TxDOT prefers to limit its wrong way driver warning message to a single phase to ensure that motorists can read and process all the information.

Figure 46. TxDOT's San Antonio District Wrong Way Driver Warning Message.

As shown in Figure 47, the HCTRA message contains two phases. In both phases, the first line is comprised of the word WARNING in red text. The remaining lines in the first phase include the problem (WRONG WAY DRIVER) and problem location (AHEAD), while the remaining lines in the second phase include the audience (ALL TRAFFIC) and a specific driver action (MOVE TO SHOULDER AND STOP). The TxDOT message is shorter and more general in nature than HCTRA's wrong way driver warning message. These differences may be attributed to HCTRA's ability to verify entry and monitor progress of the wrong way driver with its wrong way driver detection system discussed in Chapter 2 and Chapter 3.

Figure 47. HCTRA's Wrong Way Driver Warning Message (*34*).

While extensive human factors and traffic operations research on DMS message design has been previously conducted, mostly by TTI researchers, these efforts have not looked at the design of wrong way driver warning messages. Therefore, researchers used the focus group discussion method to obtain motorists' opinions regarding the design of wrong way driver warning messages for DMSs. Researchers also reviewed previous literature and DMS message design manuals to gain insight into the design of wrong way driver warning messages. The following subsections describe the findings from these efforts.

FOCUS GROUP

Researchers conducted focus groups in Dallas and Houston to obtain motorists' opinions regarding the design of wrong way driver warning messages on DMSs. The following subsections describe the focus group protocol, participant demographics, and focus group results.

Protocol

Upon arrival, a researcher provided the participants with an explanation of the study. The participants then read and signed an informed consent document. Before the focus group began, the participants filled out a short questionnaire (using paper and pen) to gauge their experience with WWD. The questionnaire asked each participant the following questions:

- Have you ever driven the wrong way on a roadway? If yes, explain how you ended up going the wrong way and what action you took.
- Have you ever encountered a wrong way driver on a roadway? If yes, what did you do?

- Have you ever seen a message warning you of a wrong way driver on a roadway? If so, what did it say? Did you think it was effective? Do you think the message could be improved?

Researchers used a focus group guide to set the agenda for the discussion and ensure each relevant topic was covered. In addition to the short questionnaire, the guide was divided into five sections:

- Introduction.
- Motorist input.
- Development of potential messages.
- Review of TxDOT potential messages.
- Summary.

Demographics

Nineteen participants were recruited (10 in Dallas and nine in Houston). Demographics were recorded for the participants, although the primary demographic of concern was the number of years of driving experience for each participant. Table 25 shows that a split of experience levels was garnered during these focus groups.

Table 25. Years of Driving Experience (n = 19).

≤ 20	21–34	35–39	40+
16%	26%	26%	32%

The participants were female (53 percent) and male (47 percent), with their ages ranging between 32 and 70 years old. Additionally, all but 11 percent of the participants had an educational level of at least some college.

Results

To begin the discussion, the participants introduced themselves by stating their subject number, how long they had been driving, and whether they had ever encountered a vehicle traveling the wrong way on a Texas roadway. During the introduction portion of the discussion, the moderator also went over the questionnaire with the participants.

Questionnaire

Surprisingly, 53 percent of the participants had driven the wrong way on a roadway. The majority of these participants (90 percent) had driven the wrong way on a city street. However, 10 percent stated they had driven the wrong way on a multi-lane, controlled-access freeway. Half of the participants admitted that they were not really paying attention or concentrating on driving when they went the wrong way. Other reasons for driving the wrong way were:

- The driver did not see the one way sign (30 percent).
- The driver was in an unfamiliar city (10 percent).
- Construction made it hard to determine where to go (10 percent).

When participants were asked what action they took when they realized they were going the wrong way, 60 percent stated that they turned around and went the correct way. In addition, 30 percent responded that they turned onto the nearest side street or pulled over to the side of the road and waited for other cars to pass by before proceeding in the correct direction. The remaining 10 percent stated that they started flashing their lights and honking their horn to get the oncoming motorists' attention and to let them know that they knew they were going the wrong way. All of these participants corrected their direction of travel before any major incident occurred.

Not only had more than half of the participants driven the wrong way on a roadway, but 79 percent had encountered a wrong way driver before. Locations where these participants had met a wrong way driver included:

- City street (74 percent).
- Entrance ramp (13 percent).
- Four lane, divided roadway (6.5 percent).
- Multi-lane, controlled-access freeway (6.5 percent).

All of the participants stated they either pulled over to the right side of the road or into a parking lot to avoid the wrong way driver. Additionally, 40 percent of the participants stated that they honked their vehicle's horn and flashed their vehicle's headlights to try to get the wrong way driver's attention.

Researchers asked the last question to determine if any of the participants had ever seen a wrong way driver warning message. Almost three-quarters of the participants (74 percent) commented that they had never seen a wrong way driver warning message. While the remaining participants (26 percent) indicated that they had seen a wrong way driver warning message, based on the discussion researchers believe the participants misunderstood the question. All of these participants referenced standard wrong way warning messages (i.e., DO NOT ENTER and WRONG WAY signs), not wrong way driver warning messages. Thus, researchers assumed that none of the participants had ever seen a wrong way driver warning message on a DMS prior to the focus group.

Motorist Input

Researchers designed this portion of the discussion to obtain the motorists' opinions and suggestions regarding:

- What information should be included in wrong way driver warning messages displayed on DMSs.
- When wrong way driver warning messages should be used.
- Where wrong way driver warning messages should be displayed.
- How long wrong way driver warning messages should be displayed.

Before the moderator asked any questions, she read the following to the group with an actual freeway and city from the local area inserted appropriately (e.g., I-10 in Houston): "Today, our discussion is going to be on messages that could be used on electronic signs to warn motorists of the possibility of a wrong way driver. I want you to imagine that you are driving on *(freeway)* in *(selected city)*. The Texas Department of Transportation (or TxDOT) receives a notification of a possible wrong way driver on *(freeway)*. TxDOT wants to display a message on an electronic sign along the roadway to notify you of the situation."

The moderator then asked the participants what type of information they felt should be displayed on the DMS (i.e., electronic sign). At this point in the discussion, the message was not constrained (i.e., no limit on characters or lines of information). Researchers found that the information the two focus groups had suggested could be divided into six information categories: alert, action, problem, location, validation, and vehicle information.

The participants felt that it was important to provide some type of warning to alert motorists to the urgency of the situation and the possible danger of a wrong way driver. Participants also felt that a word or phrase was needed to distinguish wrong way driver warning messages from other messages displayed on DMSs (e.g., work zone, incident, and traffic safety).

Suggestions included caution, warning, and danger. Some participants also stated that these words should be red (not yellow) and flashing. Participants mentioned that a secondary intention of providing this type of information would be to warn motorists to slow down immediately and proceed with caution. The majority of the participants did not think that motorists should be told to take a specific action (e.g., pull over to the shoulder or exit the freeway) because they understood that the situation was dynamic, making it difficult for an agency to provide accurate information.

All of the participants agreed that the problem needed to be included in the message. Suggestions included wrong way driver, wrong way traffic, and oncoming vehicle. However, several participants indicated that they did not like the word "traffic" because it implied more than one wrong way driver. Overall, the majority of the participants agreed on the phrase "wrong way driver" to identify the problem.

During both focus groups, there was lengthy discussion regarding the difficulty with providing the location, direction, and lane position of the wrong way driver (e.g., exact street, nearest street, last seen at, headed toward, or right/middle/left lane). The participants understood that this information would be constantly changing, making it challenging to monitor and update in a timely manner. Ultimately, both groups agreed that providing location information would be a lower priority than the driver action and problem information.

The participants also discussed the need to indicate the time the wrong way driver was reported or confirmed (i.e., validation). While the time reported or confirmed could be beneficial, participants also acknowledged the following limitation. If a time is displayed (e.g., 2:00 a.m.) and the actual time is later (e.g., 2:30 a.m.), it may cause some drivers to be less cautious, thinking that the wrong way driver was gone and there was no longer any danger. With this in mind, participants concluded that the validation information should be a lower priority.

The majority of the participants did not think that vehicle description information (e.g., make, model, and color) was important because it really did not matter what type of vehicle it was, and there would not be enough time to process detailed vehicle information. The participants noted that motorists should be more concerned with avoiding the wrong way driver.

There was a lengthy discussion regarding when a wrong way driver warning message should be posted. This discussion revolved around the following topics:

- Post when reported but not confirmed.
- Post only when confirmed.
- Display different messages based on whether the wrong way driver was confirmed.

At the end of the discussion, all the participants agreed that it would be best to post wrong way driver warning messages whenever a wrong way driver is reported, even if not confirmed, in order to alert motorists to the possibility of a wrong way driver as soon as possible.

The majority of the participants thought it was appropriate to display a wrong way driver warning message until the problem was resolved. Several participants also felt that TxDOT (or other public agency) should let motorists know if and how the situation was resolved (e.g., incident, police apprehension, report canceled, or all clear). The participants thought wrong way driver warning messages should be located along the entire length of the roadway in the direction of travel of the reported wrong way driver.

Development of Potential Messages

Next, the moderator asked participants to create messages that could be used on a DMS to warn motorists of a wrong way driver on the roadway. The moderator explained to participants that this type of message could contain only three lines of text, and each line could contain only 15 to 18 characters including spaces.

Table 26 shows the consensus of the participants as to what information should be included and where (i.e., what line) the information should be located on the DMS. All participants agreed that some type of alert should be placed on the first line of the message to distinguish wrong way driver warning messages from other messages displayed on DMSs, especially traffic safety messages (e.g., BACK TO SCHOOL/DRIVE SMART/WATCH FOR KIDS). About half of the participants chose WARNING (47 percent), and half choose DANGER (53 percent), so no preferred term was identified. All of the participants also chose to include the problem on the second line of the message. The majority (74 percent) preferred the phrase WRONG WAY DRIVER.

For the third line of the message, the majority of the participants (85 percent) preferred to provide location information even though they realized it would be difficult. Those participants that selected the phrase NEXT 10 MILES (43 percent) stated that providing a distance would inform motorists about how long to be alert and watching for a wrong way driver. Those that preferred a specific cross street be provided (42 percent) thought this information would let motorists know where the wrong way driver was last located or reported.

Table 26. Type of Information Selected by Line Location.

Response	Percentage
First Line	
Category—Driver Action - WARNING - DANGER	 42 48
Category—Driver Action and Validation - WARNING *time*[a, c] - DANGER *time*[c]	 5 5
Second Line	
Category—Problem - WRONG WAY DRIVER[b] - ONCOMING VEHICLE[b]	 74 26
Third Line	
Category—Location - NEXT 10 MILES - *Cross street*[a,c]	 43 37
Category—Validation - REPORTED AT *time*[a, c]	 15
Category—Location and Validation - *Time* AT *cross street*[a, c]	 5

[a] May exceed character length requirement of 15 and/or 18.
[b] Exceeds 15 characters but is less than 18 characters.
[c] Actual time and/or cross street name would be used.

About one-third of the participants (30 percent) wanted the time a wrong way driver was reported or confirmed (validation) included in message. These participants felt this would help motorists determine the timeliness of the information. The majority of these participants (25 percent) were from Dallas where they do not typically report a time with other types of DMS messages (e.g., travel times). In contrast, all but one participant in Houston did not prefer to include a time, even though in Houston TxDOT currently posts a last updated time with its travel time messages (e.g., 4 MIN TO SH 6 AT 11:48). Based on the discussion, researchers believe that the participants in Houston better understood the dynamic nature of the situation and how difficult it would be to monitor and update the time.

In addition to message design, the participants discussed how to improve the visibility of the message. Several participants noted that the color of the text on DMSs is sometimes hard to read, especially during the day when there is sun glare. The following suggestions were made:

- Use bold, red text on the first line of the message.
- Make the first line of the message flash.
- Activate flashing beacons on top of the DMS.

Review of TxDOT Potential Messages

In the final section, the participants reviewed and discussed three potential messages that TxDOT developed. The moderator displayed each message individually and allowed the participants to compare the TxDOT messages to those that the group created in the last section.

The moderator showed the message in Figure 48 first. Both groups felt strongly that this message would not get motorists' attention and did not convey the seriousness of the situation. The participants suggested that the first line of the message needed to convey the urgency and seriousness of the situation. Both groups feared that some motorists would think this message was just a traffic safety message instead of a current situation. The participants also felt that the message did not need to include USE EXTREME CAUTION. Everyone agreed that if the seriousness of the situation was properly conveyed on the first two lines, it would be commonplace for motorists to exercise caution.

WRONG WAY DRIVER REPORTED—USE EXTREME CAUTION

Figure 48. TxDOT Message 1.

Figure 49 shows the second TxDOT message shown to the participants. Both groups concurred that that first line of this message (i.e., WRONG WAY) implied that they were going the wrong way. The participants also felt that the term TRAFFIC inferred more than one vehicle. Both groups decided that AHEAD was not needed because motorists should know the problem is in front of them (or downstream). In addition, the participants felt that the message lacked any type of information that would catch motorists' attention and inform them to be alert and cautious as they proceed. Overall, neither group liked this message.

WRONG WAY TRAFFIC AHEAD

Figure 49. TxDOT Message 2.

Figure 50 shows the third TxDOT message shown to the participants. The majority of the participants also did not like this message. Most participants felt the message regarded road work and construction vehicles (not a wrong way driver) because of the phrase PREPARE TO STOP. In addition, the participants felt that ONCOMING VEHICLE was not as specific as WRONG WAY DRIVER (i.e., it could be any type of vehicle).

ONCOMING VEHICLE PREPARE TO STOP

Figure 50. TxDOT Message 3.

Final Message Suggestions

Figure 51 shows the final messages that both focus groups had suggested. Both groups agreed on the type of information (i.e., alert and problem) and wording (i.e., DANGER/WRONG WAY DRIVER) of the first two lines of the message. For the third line, the participants in Dallas preferred the time the wrong way driver was last reported, while the participants in Houston preferred the location where the wrong way driver was last reported.

DANGER WRONG WAY DRIVER REPORTED AT *time*

a) Dallas.

DANGER WRONG WAY DRIVER *location*

b) Houston.

Figure 51. Focus Group Suggested Messages.

Summary

Overall, the majority of the focus group participants thought that the first line of the wrong way driver warning message should include a word that conveys the urgency and seriousness of the situation, and distinguishes the message from other types of messages displayed on DMSs. For the alert, DANGER was preferred over WARNING. In addition, all participants agreed that the problem should be displayed on the second line of the message. For the problem, WRONG WAY DRIVER was preferred over ONCOMING VEHICLE. For the third line of the message, the majority of participants preferred location information: either a distance over which to expect a wrong way driver (e.g., NEXT 10 MILES) or a cross street where the wrong way driver was last reported. However, participants did understand that the desired location information would be difficult to monitor and update due to the dynamic nature of the situation.

All of the participants agreed that it would be best to post wrong way driver warning messages whenever a wrong way driver is reported, even if not confirmed, to alert motorists to the possibility of a wrong way driver as soon as possible. In addition, the majority of the participants thought it was appropriate to display a wrong way driver warning message until the problem was resolved. Most participants also thought wrong way driver warning messages should be located along the entire length of the roadway in the direction of travel of the reported wrong way driver.

MESSAGE DESIGN DISCUSSION

Since the early 1980s, research has been conducted on DMS message design to ensure that the motoring public understood the posted messages. Today, DMS message design is addressed in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*36*), the TMUTCD (*30*), and the TxDOT *Dynamic Message Sign Message Design and Display Manual* (*37*). Typically, the message elements include:

- Type of problem.
- Location of problem.
- Lanes affected.
- Effect on travel.
- Audience for the message.
- Proper driver action.
- Reason to follow the recommended driving action.

While these elements of information are easily acquired for incidents or roadwork, wrong way driver situations typically have more unknowns. In addition, an agency does not want to post information on DMSs that is not accurate because this reduces the credibility of all DMS messages. Therefore, one would not expect a wrong way driver warning message to include as many message elements as traditional DMS messages (e.g., road work and incidents).

Based on the focus groups results and current practice, the problem can be described by either of the following phrases: WRONG WAY DRIVER (preferred) or ONCOMING VEHICLE. As discussed previously, the location of a wrong way driver and the lanes affected can be difficult to verify and can change rather quickly. In addition, the focus group results showed that motorists understand the dynamic nature of the situation and difficulty with providing this type of information in a timely manner. TxDOT personnel also noted that even if the operators have the capability to monitor a wrong way driver via camera, these operators do not always have time to continuously update a DMS message. Instead, the priority is to convey information to law enforcement so they can apprehend the wrong way driver. The focus group results also showed that the problem (i.e., WRONG WAY DRIVER or ONCOMING VEHICLE) adequately conveyed the effect on travel (i.e., motorists might encounter a wrong way driver) and the proper driving action (i.e., motorists should slow down and proceed with caution). In addition, the majority of the focus group participants did not think drivers should be told to do a specific driving action (e.g., pull over to the shoulder or exit the freeway). Again, due to the dynamic nature of the situation, providing a specific action would be difficult. The audience message component is used only when the action message component applies to a specific group of motorists rather than all motorists traveling past the DMS. Thus, for wrong way driver warning messages, the audience message component is not needed.

The current HCTRA wrong way driver warning message (see Figure 47) is a two-phase message that contains seven units of information (three units in the first phase and four units in the second phase). This is in contradiction to the standard practice of using no more than four units of information in a message when the traffic operating speeds are 35 mph or more (*37*). In addition, no more than three units of information should be displayed in a single message phase (*37*). Based on accepted message design principles and the focus group results, researchers believe that the following two information components are unnecessary: the problem location (AHEAD) and audience (ALL TRAFFIC). In addition, it is not recommended that redundant information be displayed on a two-phase message (i.e., WARNING) (*37*). Based on the focus group results and dynamic nature of a wrong way driving situation, researchers also do not believe that specific driving actions (e.g., MOVE TO SHOULDER AND STOP) should be included.

Researchers also had some concerns regarding the TxDOT San Antonio District wrong way driver warning message (see Figure 46 or Figure 48). Based on previous research and current guidance, a single message line should not contain portions of two different units of information (i.e., REPORTED—USE) (*30, 36, 37*). In addition, researchers do not believe that USE EXTREME CAUTION is needed since the focus group participants felt that the problem (i.e., WRONG WAY DRIVER) implied that drivers should slow down and use caution.

The primary objective of the wrong way driving warning message should be to alert motorists about the potential for a wrong way driver, which can be considered an emergency situation. This is different from traditional DMS messages that provide real-time traffic or traffic safety-related messages. Consequently, researchers believe that a new message element is needed to convey the urgency and seriousness of the situation, as well as distinguish the wrong way driver warning message from other types of messages displayed on DMSs. Focus group participants recommended that the alert element be WARNING or DANGER. However, researchers prefer WARNING since the message itself is a warning about the potential for a wrong way driver.

As a whole, the focus group participants concluded that validation information was a low priority. However, about one-third of the participants wanted the time the wrong way driver has been reported or confirmed included in the message. While researchers do not believe that a specific time should be included in the message, they do think that REPORTED should be used to convey that the message is regarding an active or current event, not just a general traffic safety message.

Based on the accepted message design principles, the focus group findings, and a review of currently used wrong way driver warning messages, researchers developed the single-phase message shown in Figure 52. This message contains three units of information:

- WARNING—the alert element that conveys urgency and differentiates the message from other messages.
- WRONG WAY DRIVER—the problem element that infers additional driver actions such as slowing down and using caution.
- REPORTED—the validation element implies that the problem is currently ongoing.

WARNING WRONG WAY DRIVER REPORTED

Figure 52. Recommended Message.

Researchers recommend that this message be displayed in both directions of travel since the actual direction of the wrong way driver is not always known or is sometimes incorrectly reported to police by motorists.

To catch the attention of motorists passing by the DMS and to further distinguish the wrong way driver warning message from other DMS messages, researchers believe that beacons on the DMS should be activated when a wrong way driver warning message is displayed. Researchers are aware that not all DMSs operated by TxDOT have beacons. Another option is to flash the entire single-phase message. While previous research (*38*, *39*) has shown that flashing a single-phase three-unit message had no significant effect on motorist comprehension, the data did show that flashing the message increased the amount of time required to read and comprehend the message. Therefore, flashing a single-phase message is not recommended in the TxDOT *Dynamic Message Sign Message Design and Display Manual* (*37*), but it is allowed as long as the single-phase message is limited to three units of information or less. Since the message in Figure 52 contains three units of information, researchers believe that flashing the entire wrong way driver warning message is acceptable but should be used sparingly. Therefore, the entire single-phase message should be flashed only if the DMS does not have beacons. Another option would be to flash one line of the single-phase message (i.e., WRONG WAY DRIVER), but currently this is not recommended in the TxDOT *Dynamic Message Sign Message Design and Display Manual* (*37*) because flashing one line of a message has adverse effects on motorist comprehension (*38, 39*).

Researchers recognize that some TxDOT districts still have DMSs with only 15 characters per line and that the second line of the message in Figure 52 (i.e., WRONG WAY DRIVER) contains 16 characters. One option would be to abbreviate one or more words in the second line. The following three strategies are commonly used to abbreviate words, although typically in DMS message design the first two abbreviation strategies are used:

- Key consonants—Vowels are omitted, as are certain consonants, but the first and last consonant in each syllable is usually retained (e.g., BLVD).
- First syllable—The first syllable or three to four letters of the word are used (e.g., EMER).
- First letter—The first letter of a word or multiple words is used (e.g., MUTCD).

Out of the three words in the second message line, wrong and/or driver could be abbreviated. Based on the MUTCD (*36*), the TMUTCD (*30*), and previous research (*40*), WRNG (key consonants) cannot be used for wrong since motorists can interpret this to mean warning and wrong. In addition, the MUTCD (*36*) and TMUTCD (*30*) do not contain an approved abbreviation for driver. Researchers completed a literature review and found no previous research that has examined motorist understanding of abbreviations for driver. However, VEH can be used as an abbreviation for vehicle with a prompt word (i.e., WRONG WAY) (*30*, *36*, *40*, *41*, *42*). Thus, researchers developed the alternative message in Figure 53 for DMSs with 15 characters per line. On DMSs with 18 characters per line, the message in Figure 52 should be used.

WARNING
WRONG WAY VEH
REPORTED

Figure 53. Alternative 15-Character Messages.

SUMMARY AND RECOMMENDATIONS

Researchers conducted two focus groups to obtain motorists' opinions regarding the design of wrong way driver warning messages on DMSs. Researchers also reviewed previous literature and DMS message design manuals to gain insight into the design of wrong way driver warning messages. Based on the findings, researchers recommended the use of the single-phase message in Figure 52. Researchers also recommended an alternative single-phase message for use on DMSs with only 15 characters per line (Figure 53). Anytime one of these messages is displayed on a DMS, the beacons located on the DMS should be activated. If the DMS does not have beacons, the entire message may be flashed. One line of these messages should never be flashed.

One of the recommended messages should be posted on DMSs whenever a wrong way driver is reported, even if not confirmed, in order to alert motorists to the possibility of a wrong way driver as soon as possible. When a wrong way driver is confirmed, there is no need to change the third line of the messages. The message should be displayed along the entire length of the roadway in both directions of travel, and should be displayed until the wrong way driver is apprehended or the report is canceled.

CHAPTER 6: SUMMARY, RECOMMENDATIONS, AND FUTURE RESEARCH NEEDS

The objectives of this research project were to:

- Evaluate the effectiveness of WWD countermeasures and mitigation methods.
- Develop recommendations regarding the implementation of WWD countermeasures and mitigation methods.

To do this, researchers reviewed the state of the practice regarding WWD in the United States and Texas. Researchers then designed and conducted two closed-course studies to determine the effectiveness of select WWD countermeasures on alcohol-impaired drivers. In addition, researchers obtained data from several Texas agencies that had installed WWD countermeasures and/or mitigation methods on their road network. Using these datasets, researchers assessed the effectiveness of these strategies in actual operational environments. Researchers also used the focus group discussion method to obtain motorists' opinions regarding the design of wrong way driver warning messages. Based on the findings from all of these tasks, researchers developed recommendations regarding the implementation of WWD countermeasures and mitigation methods.

SUMMARY

State of the Practice

Even though WWD crashes are infrequent, they result in severe injuries and fatalities, and continue to occur despite more than 50 years of research and countermeasure implementation. To date, previous research has focused on quantifying the WWD problem, and documenting traditional and innovative countermeasures and mitigation methods. Even though various WWD countermeasures and mitigation methods have been implemented over the years, only a limited number of studies have actually evaluated their effectiveness.

Based on Texas crash data from 2007 to 2011, researchers verified that the majority of WWD crashes on controlled-access highways occur in major metropolitan areas. These WWD crashes typically happen at night between midnight and 5:00 a.m., with a peak around 2:00 a.m. (the typical time for establishments that serve alcohol to close in Texas). Likewise, driving under the influence was the primary contributing factor of these crashes. While actual BAC levels were available for only a third of the drivers that tested positive for alcohol, researchers found that almost 90 percent had a BAC level greater than or equal to the legal limit (0.08 g/dL). In fact, 60 percent of the WWD drivers had a BAC level of 0.16 to 0.239 g/dL (two to three times the legal limit).

Closed-Course Studies

While traditional and enhanced signs and pavement markings are among some of the most commonly implemented WWD countermeasures, it was not clear from past research or experience how effective these countermeasures actually are at conveying to alcohol-impaired drivers that they are going the wrong way. Therefore, researchers designed and conducted two nighttime closed-course studies to:

- Determine where alcohol-impaired drivers look in the forward driving scene.
- Provide insight into how alcohol-impaired drivers recognize and read signs.
- Assess the conspicuity of select WWD countermeasures from the perspective of alcohol-impaired drivers.

Researchers found that alcohol-impaired drivers may tend to look less to the left and right and more toward the pavement area in front of the vehicle. In addition, researchers confirmed that alcohol-impaired drivers do not actively search the forward driving scene as much as non-impaired drivers. Instead, alcohol-impaired drivers concentrate their glances on a smaller area within the forward driving scene.

Researchers also confirmed that drivers with higher BAC levels must be closer to a sign before they can identify the background color and read the legend relative to lower BAC levels. In addition, alcohol-impaired drivers have to be closer to signs with flashing red LEDs around the border before they can read the legend compared to signs without flashing LEDs. Researchers also found that as the BAC level increased, more drivers misidentified the red sign background color, with most thinking a red sign was an orange sign.

Lowering the height of the white-on-red signs studied did not improve the ability of alcohol-impaired drivers to locate signs, identify the background color, or read the legend compared to the standard sign height (7 ft). Making the sign larger (i.e., oversized), adding a red retroreflective sheeting on the sign support, or adding red flashing LEDs around the border of the sign also did not improve the ability of the alcohol-impaired drivers to locate WRONG WAY signs. However, participants felt that these three countermeasures did make it easier to find the

WRONG WAY sign. Participants also thought these three countermeasures caught their attention more than the lowered WRONG WAY signs and the normal size WRONG WAY signs without a conspicuity element.

In an effort to reduce the occurrence of missing RRPMs, researchers modified the design of the current RRPM wrong way arrow that TxDOT uses. Researchers did not find a significant difference in the recognition time between the two wrong way arrow marking designs. In addition, the participants similarly assessed the ease with which they could find the arrow among the other markings. Thus, it appears that the modified design performed as well as the current design. Researchers also found that at higher BAC levels, the participants took longer to locate the wrong way arrow pavement markings, independent of the design, among the other markings.

Operational Field Studies

Researchers obtained and analyzed preexisting data from the San Antonio region, HCTRA, and NTTA to evaluate the effectiveness of several WWD countermeasures and mitigation methods in actual operational environments. Data from the US 281 test corridor in San Antonio showed that WRONG WAY signs with flashing LEDs in the border are effective at reducing WWD events. Unfortunately, the impact on WWD crashes is still unknown due to the small number of crashes that occurred during the evaluation period. One might assume that a reduction in WWD events would correlate to a reduction in WWD crashes. However, it must again be remembered that driving under the influence was the primary contributing factor to WWD crashes in Texas. While traffic control devices, such as signs and pavement markings, may be effective at conveying the need to stop and turn around to wrong way drivers that are confused, disoriented, or only slightly intoxicated, researchers do not believe that highly intoxicated wrong way drivers will be able to receive and process the same information from traffic control devices and so are less likely to correct their driving behavior prior to a WWD crash occurring. Texas crash data and anecdotal information from TxDOT show that WWD crashes involve drivers with BAC levels two to three times the legal limit (0.08 g/dL). Thus, there remains some uncertainty as to the impact that enhanced traffic control devices, such as the WRONG WAY signs with flashing red LEDs around the border, will have on WWD crashes. Nevertheless, a reduction in WWD events is a positive finding.

Data from HCTRA showed that detection systems, in conjunction with other systems (e.g., cameras and law enforcement), can be successfully used to detect, verify, and document WWD events. The HCTRA detection systems provide data regarding the wrong way driver entry points, a critical piece of information that is needed to help practitioners further combat WWD. Based on the limited NTTA dataset, researchers could not confidently conclude whether or not lowered signs are effective at reducing WWD events.

Wrong Way Driver Warning Messages

Researchers conducted two focus groups to obtain motorists' opinions regarding the design of wrong way driver warning messages on DMSs. Also, researchers reviewed previous literature and DMS message design manuals to gain insight into the design of wrong way driver warning messages. Based on the findings, researchers developed two single-phase WWD warning messages that can be posted on DMSs.

RECOMMENDATIONS

The findings from this research effort show that a wide variety of countermeasures and mitigation methods are needed to combat WWD on controlled-access highways. Researchers believe that traditional and innovative traffic control device countermeasures are effective at reducing WWD events. However, based on the findings of this research and anecdotal evidence, researchers suspect that highly intoxicated drivers will not be attracted to or understand these countermeasures. Therefore, WWD detection systems are also needed. Detection systems, once vetted, can be used to detect wrong way drivers as they enter controlled-access highways, thereby reducing the time it takes to identify and respond to WWD events. In addition, detection systems provide data regarding actual wrong way driver entry points, a critical piece of information that is needed to help practitioners further combat WWD. Detection systems, in conjunction with cameras, can also provide data about wrong way drivers that self-correct before reaching the mainlanes. These data would help practitioners further assess the effectiveness of implemented countermeasures.

In Texas districts where WWD has been identified as an issue, researchers recommend that TxDOT follow the guidelines described below and summarized in Figure 54. First, TxDOT should form a task force that includes local agencies (e.g., city, county, and police) to share information about WWD activity and collaborate on means to address the issue. CRIS data should be used to determine where WWD crashes are occurring. While crash data typically do not provide the actual wrong way entry point, they can be used to determine corridors with a high frequency of WWD crashes. Surrogate data, such as WWD event logs, can also be used to help identify problem locations.

Once a location or roadway corridor has been identified as having a WWD issue, TxDOT, in conjunction with other agencies as needed, should perform a field review of all of the exit ramps in the impacted area to ensure that the signing and pavement markings in place meet the current TxDOT standards and are in adequate condition. Any noted traffic control device deficiencies should be corrected as soon as possible. The field review should also note other items that may impact WWD, such as the location of nearby businesses (e.g., establishments that serve alcohol and special event facilities), the location of driveways near the ramp, the downstream intersection geometry and traffic control devices, and the interchange design. The one-page field review sheet located in Appendix B should be used to document all observations. This sheet is a revision to the original one published in TTI Report 0-4128-2 (*27*).

The installation of low-cost pavement marking and signing countermeasures at exit ramps could be accomplished rather quickly. Since alcohol-impaired drivers tend to look more at the pavement in front of the vehicle, researchers recommend the use of wrong way arrows on exit ramps on controlled-access highways. Researchers also recommend that TxDOT revise its standard wrong way arrow design as shown in Figure 31 to reduce maintenance activities to replace RRPMs damaged or removed by tire impacts. Existing wrong way arrows should be repaired as needed.

To increase the conspicuity of WRONG WAY and DO NOT ENTER signs, researchers recommend the use of red retroreflective sheeting on the sign supports. This countermeasure is low-cost and can be implemented rather quickly. At locations with standard size signs, oversized WRONG WAY and DO NOT ENTER signs can also be installed. WRONG WAY signs with flashing red LEDs around the border may also be used; however, they are more costly (about $1200 each versus about $100 each for oversized signs). At this time, researchers do not recommend that TxDOT use a 2-ft sign mounting height for WRONG WAY and DO NOT ENTER signs. TxDOT should continue to monitor NTTA's lowered sign evaluation and revisit the possible use of this countermeasure based on future findings.

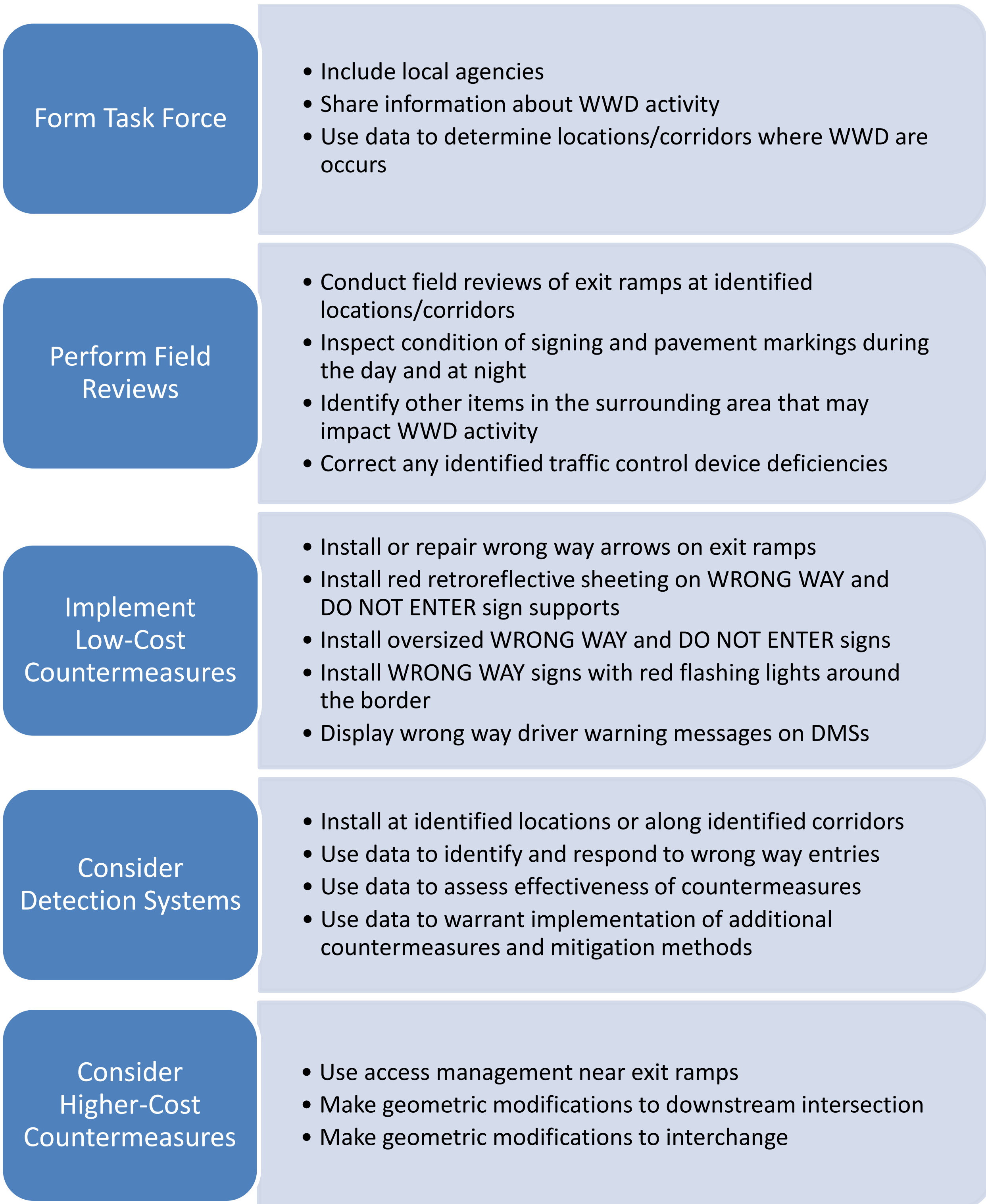


Figure 54. WWD Guidelines.

Even after the installation of low-cost traffic control device countermeasures, WWD activity may still continue in the area, especially if driving while intoxicated is identified as a contributing factor. In these instances, TxDOT should consider installing vetted WWD detection systems on exit ramps. Data from these systems can be used to:

- Identify and respond to wrong way entries.
- Assess the effectiveness of traffic control device countermeasures.
- Warrant the implementation of further traffic control device countermeasures, detection systems, and/or geometric modifications.

TxDOT should also consider higher-cost countermeasures and mitigation methods, such as access management or geometric modifications, on a case-by-case basis.

Whenever a wrong way driver is reported, researchers recommend that TxDOT display the wrong way driver warning message shown in Figure 52 on DMSs in both directions of travel in the impacted area. This message should be displayed until the wrong way driver is apprehended or the report is canceled. Anytime a wrong way driver warning message is displayed on a DMS, the beacons located on the DMS should be activated. If the DMS does not have beacons, the entire message may be flashed. One line of the message should never be flashed. The message in Figure 53 should be used only on DMSs with only 15 characters per line.

FUTURE RESEARCH NEEDS

Since alcohol-impaired drivers tend to look more at the pavement in front of their vehicle and search the forward driving scene less than non-impaired drivers, researchers recommend that future research identify and evaluate the effectiveness of other in-road WWD countermeasures. Future research should also assess the use of connected vehicle technology to mitigate WWD. Connected vehicles and their integration with transportation infrastructure provide new approaches to WWD detection, warning, and intervention that will help practitioners further reduce the occurrence and severity of WWD crashes.

To ensure that the flashing red LEDs around the border of WRONG WAY signs provide enhanced conspicuity but do not degrade the ability of drivers to read the sign legend, future research needs to determine minimum and maximum light levels. This research should include alcohol-impaired drivers and older drivers.

REFERENCES

1. *Highway Special Investigation Report: Wrong Way Driving.* Report NTSB/SIR-12/01. National Transportation Safety Board, Washington, DC, December 11, 2012.
2. Tamburri, T.N., and D.J. Theobald. *Wrong Way Driving (Phase II)*. Traffic Department, Division of Highways, Department of Public Works, State of California, February 1965.
3. Tamburri, T. *Report on Wrong Way Automatic Sign, Light and Horn Device.* Traffic Department, Division of Highways, Department of Public Works, State of California, June 1965.
4. Doty, R.N., and C.R. Ledbetter. *Full Scale Dynamic Tests on One-Way Spike Barriers*. Traffic Department, Division of Highways, Department of Public Works, State of California, January 1965.
5. *Analysis of Wrong Way Incidents on Michigan Freeways*. Michigan Department of Highways, Lansing, MI, 1968.
6. *Wrong Way Driving*. Missouri State Highway Commission, Jefferson City, MO, 1970.
7. Scifres, P., and R. Loutzenheiser. *Wrong Way Movements on Divided Highways*. Purdue University Joint Highway Research Project No. JHRP-13-75, West Lafayette, IN, 1975.
8. Vaswani, N. Virginia's Program to Reduce Wrong Way Driving. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 644, Transportation Research Board of the National Academies, Washington, DC, 1977, pp. 84–90.
9. Copelan, J. *Prevention of Wrong Way Accidents on Freeways*. Report No. FHWA/CA-TE-89-2. California Department of Transportation, Traffic Operations Division, Sacramento, CA, 1989.
10. Lathrop, S., T.B., Dick, and K.B. Nolte. Fatal Wrong Way Collisions on New Mexico's Interstate Highways, 1990–2004. In *Journal of Forensic Sciences*, Volume 55, No. 2, March 2010.
11. Morena, D., and T. Leix. Where These Drivers Went Wrong. In *Public Roads*, Volume 75, No. 6, May/June 2012. Available at http://www.fhwa.dot.gov/publications/publicroads/12mayjune/05.cfm. Accessed March 1, 2013.

12. Zhou, H., J. Zhao, and R. Fries. *Investigation of Contributing Factors Regarding Wrong Way Driving on Freeways.* Report FHWA-ICT-12-010. Illinois Center for Transportation, Urbana, IL, October 2012.

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

14. Parsonson, P., and J. Marks. *Wrong Way Traffic Movements on Freeway Ramps*. Georgia Institute of Technology, School of Civil Engineering, Atlanta, GA, 1979.

15. Vaswani, N. *Measures for Preventing Wrong Way Entries on Highways*. Virginia Highway Research Council, Charlottesville, VA, June 1973.

16. Vaswani, N. *Further Reduction in Incidences of Wrong Way Driving*. Virginia Highway and Transportation Research Council, Charlottesville, VA, May 1977.

17. Knight, D. Danger! Wrong Way Driver Ahead! In *Traffic Safety* (Chicago), Volume 83, No. 5, National Safety Council, Chicago, IL, 1983.

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

19. Moler, S. Stop. You're Going the Wrong Way! In *Public Roads*, September/October 2002, pp. 24–29. Available at http://www.fhwa.dot.gov/publications/publicroads/02sep/06.cfm. Accessed February 28, 2013.

20. Williams, C. District 3 ITS Project Update. Florida Department of Transportation. 2007. Available at http://www.ce.siue.edu/faculty/hzhou/ww/paper/District3%20ITS%20Engineer.pdf. Accessed March 1, 2013.

21. *Highway Safety White Paper. 2035 MI Transportation Plan. State Long-Range Transportation Plan*. Michigan Department of Transportation, Lansing, MI, September 2012.

22. Provance, J. Ohio Senators Urge Tougher Fines for Wrong Way Drivers. In *Toledo Blade*, April 27, 2012. Available at http://www.toledoblade.com/State/2012/04/27/Ohio-senators-urge-tougher-fines-for-wrong way-drivers-1.html. Accessed March 1, 2013.

23. *ODOT to Enhance Wrong Way Signage.* Ohio Department of Transportation, Columbus, OH, June 13, 2012. Available at http://www.dot.state.oh.us/districts/D02/newsreleases/Pages/ODOT.aspx. Accessed March 1, 2013.

24. Jones, M. Milwaukee County Launches Effort to Halt Wrong-Way Drivers on Freeways. In *Journal Sentinel*, October 9, 2012. Available at http://www.jsonline.com/news/milwaukee/milwaukee-county-launches-effort-to-halt-wrongway-drivers-4t75rpk-173358061.html. Accessed April 30, 2013.

25. Messer, C.J., J.D. Friebele, and C.L. Dudek. *A Qualitative Analysis of Wrong Way Driving in Texas*. Report No. 139-6, Texas Transportation Institute, College Station, TX, May 1971.

26. Friebele, J.D., C.J. Messer, and C.L. Dudek. *State-of-the-Art of Wrong Way Driving on Freeways and Expressways*. Report No. 139-7, Texas Transportation Institute, College Station, TX, June 1971.

27. Cooner, S.A., A.S. Cothron, and S.E. Ranft. *Countermeasures for Wrong Way Movement on Freeways: Guidelines and Recommended Practices*. Report No. FHWA/TX-04/4128-2, Texas Transportation Institute, College Station, TX, January 2004.

28. Wrong Way Detection System Prevents Accidents, Improves Safety. In *ITS International*, June 2010. Available at http://www.itsinternational.com/sections/cost-benefit-analysis/features/wrong-way-detection-system-prevents-accidents-improves-safety/. Accessed April 30, 2013.

29. *Manual for Assessing Safety Hardware*. First Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2009.

30. *Texas Manual on Uniform Traffic Control Devices, Revision 1*. Texas Department of Transportation, Austin, Texas, December 6, 2012. Available at http://www.txdot.gov/government/enforcement/signage/tmutcd.html. Accessed August 13, 2014.

31. Request to Experiment—Low Mounted Do Not Enter and Wrong Way Signs. Letter from NTTA to TxDOT dated May 25, 2011.
32. Request to Experiment—Low Mounted Do Not Enter and Wrong Way Signs. Letter from FHWA to TxDOT dated June 14, 2011.
33. The San Antonio Wrong Way Driver Initiative Website. Texas Department of Transportation, San Antonio, TX. Available at http://www.transguide.dot.state.tx.us/sat/wwd/. Accessed April 26, 2013.
34. Zhou, H., and M.P. Rouholamin. *Guidelines for Reducing Wrong-Way Crashes on Freeways*. Report FHWA/ICT-14-010. Illinois Center for Transportation, University of Illinois at Urbana-Champaign, Urbana, IL, May 2014.
35. *Typical Standard Freeway Pavement Markings with Raised Pavement Markers FPM(1)-12.* Texas Department of Transportation, Austin, TX, February 2012.
36. *Manual on Uniform Traffic Control Devices,* 2009 edition, with Revisions 1 and 2. Federal Highway Administration, U.S. Department of Transportation, May 2012. Available at http://mutcd.fhwa.dot.gov/. Accessed August 18, 2014.
37. Dudek, C. *Dynamic Message Sign Message Design and Display Manual*. Report FHWA/TX-04/0-4023-P3, Texas A&M Transportation Institute, College Station, TX, April 2006. Available at http://tti.tamu.edu/documents/0-4023-P3.pdf. Accessed December 18, 2013.
38. Dudek, C., N. Trout, S. Booth, and G. Ullman. *Improved Dynamic Message Sign Messages and Operations.* Report FHWA/TX-01/1882-2, Texas A&M Transportation Institute, College Station, TX, October 2000. Available at http://tti.tamu.edu/documents/1882-2.pdf. Accessed August 18, 2014.
39. Dudek, C.L., S.D. Schrock, G.L. Ullman, and S.T. Chrysler. Flashing Message Features on Changeable Message Signs. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 1959, Transportation Research Board of the National Academies, Washington, DC, 2006, pp. 122–129.
40. Huchingson, R.D., and C.L. Dudek. How to Abbreviate on Highway Signs. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 904,

Transportation Research Board of the National Academies, Washington, DC, 1983, pp. 1–4.

41. Hustad, M.W., and C.L. Dudek. Driver Understanding of Abbreviations on Changeable Message Signs in New Jersey. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 1689, Transportation Research Board of the National Academies, Washington, DC, 1999, pp. 46–52.

42. Durkop, B.R., and C.L. Dudek. *Texas Driver Understanding of Abbreviations for Dynamic Message Signs*. Report FHWA/TX-00/1882-1, Texas A&M Transportation Institute, College Station, TX, February 2000. Available at http://tti.tamu.edu/documents/1882-1.pdf. Accessed December 19, 2013.

APPENDIX A:
CATALOG OF WRONG WAY DRIVING COUNTERMEASURES AND MITIGATION METHODS

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Lowered Signing

DESCRIPTION

Lower the DO NOT ENTER/WRONG WAY sign height from the standard MUTCD height of 7 feet for urban signs and 5 feet for rural signs in problem locations for enhanced visibility.

ADVANTAGES/DISADVANTAGES

- (+) Lowered signs more visible at night due to better reflection of low beam headlights
- (+) Lowered signs potentially more visible to impaired drivers that tend to drive with more focus on the pavement
- (−) Potential safety impacts if lowered sign is struck

EFFECTIVENESS

- In California, wrong-way entries were reduced from 50 to 60 entries per month at some problem locations, down to 2 to 6 entries per month.
- In Virginia, two criteria were met:
  - Successful deterrence of wrong-way movements
  - No endangerment to right-way motorist
- In Texas, preliminary results showed a reduction in wrong way incidents at the lowered sign locations compared to control sites

CHALLENGES

- Easy implementation on reduced height mount after checking line of sight issues
- Similar maintenance to existing sign infrastructure

DEPLOYMENT LOCATIONS AND DATES

National

- California, 1973
- Georgia, 1979
- Virginia, 1980

Texas

- In Dallas on NTTA toll system, July 2011

TECHNIQUE

LED-Enhanced Regulatory Signing

DESCRIPTION

The WRONG WAY sign is enhanced with light emitting diode (LED) pixel lighting around the perimeter of the standard sign to increase sign visibility at night.

ADVANTAGES/DISADVANTAGES

- (+) Signs more noticeable at night due to increased visibility from LED enhancement
- (+) Can be solar powered
- (+) No negative impact on right-way drivers reported
- (−) If solar power not feasible, then needs power source near sign

EFFECTIVENESS

- Preliminary data on US 281 corridor in San Antonio suggests 36 percent reduction in monthly wrong way driving event rate
- At other Texas installations, limited data to offer conclusive finding on effectiveness in preventing wrong-way driving

CHALLENGES

- Installation and maintenance comparable to conventional signs
- Need power source

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

Texas

- In Dallas on NTTA toll system, 2009
- San Antonio, 2012

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Supplemental Sign Placards

DESCRIPTION

The DO NOT ENTER sign is supplemented with a RAMP placard or a ONE WAY placard located underneath the main sign to enhance the message by providing more description of application.

ADVANTAGES/DISADVANTAGES

- (+) Provides more information to the driver
- (+) Is relatively inexpensive to implement
- (−) None

EFFECTIVENESS

- Limited data to offer conclusive finding on its effectiveness in preventing wrong-way driving

CHALLENGES

- Similar maintenance to existing sign infrastructure

DEPLOYMENT LOCATIONS AND DATES

National

- The RAMP supplemental placard is not used in most states
- The ONE WAY supplemental placard is used in other states

Texas

- The RAMP and ONE WAY supplemental signs are used throughout various counties in Texas

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Enhanced Static Signing

DESCRIPTION

Additional DO NOT ENTER and WRONG WAY signs can be added at some locations to reinforce the message.

The DO NOT ENTER and WRONG WAY signs may be enhanced using a larger sized sign in place of the standard sized sign in order to increase the sign visibility.

(Source: New York Department of Transportation)

ADVANTAGES/DISADVANTAGES

+ Signs are more noticeable due to increased visibility from size enhancement
− Increased costs due to use of larger sign and/or use of more signs than standard design

EFFECTIVENESS

- Limited data to offer conclusive finding on its effectiveness in preventing wrong-way driving

CHALLENGES

- Similar maintenance to existing sign infrastructure
- Potential placement conflicts due to limited area

DEPLOYMENT LOCATIONS AND DATES

National

- Select sites in the State of New York

Texas

- On all NTTA roadways in North Texas as of October 2010
- Throughout the state

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Overhead Wrong Way Signing

DESCRIPTION

Overhead placement of WRONG WAY and DO NOT ENTER signs can be used as a wrong way entry countermeasure. The signs can be placed on the back of right-way overhead sign structures where available.

(Source: Florida DOT—ITS Project Update)

ADVANTAGES/DISADVANTAGES

- (+) Signs are located over a roadway where a driver tends to be looking forward instead of on the side of a roadway
- (+) Relatively low cost to implement
- (−) May not be seen by drivers under the influence of alcohol who tend to look down at the roadway pavement

EFFECTIVENESS

- Unknown

CHALLENGES

- May have to provide additional support structure to implement
- May have limited locations for proper placement

DEPLOYMENT LOCATIONS AND DATES

National

- Arizona, prior to 2003
- Florida, 2006

Texas

- Several urban locations

TECHNIQUE

Reflective Tape on Sign Mount Post

DESCRIPTION

The sign mount post for the WRONG WAY and DO NOT ENTER signs can be enhanced with retroreflective tape or a vertical retroreflective strip to increase visibility and maximize nighttime brightness.

(Source: North Texas Tollway Authority)

ADVANTAGES/DISADVANTAGES

- (+) Signs more noticeable during the day and at night due to increased visibility from reflective enhancement
- (−) Additional cost associated with using the tape over standard design

EFFECTIVENESS

- Unknown

CHALLENGES

- Additional maintenance associated with the tape including periodic cleaning and replacement

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

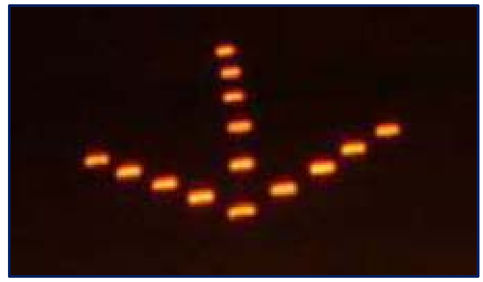
Texas

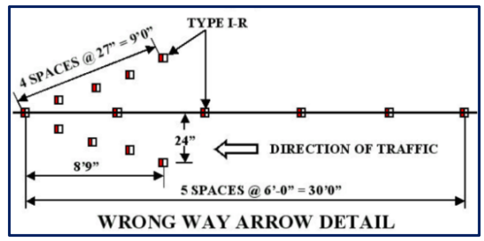
- On some NTTA exit ramp locations in North Texas as of October 2010

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Raised Pavement Markers (RPM)





DESCRIPTION

Red RPM can be used as a countermeasure on freeway lanes. Type II-R is the common RPM placed on freeway main lanes with the red side facing in the wrong-way direction. RPMs can be placed on exit ramps, either along the edge lines and/or as part of a wrong-way pavement arrow. Type I-R is the common RPM placed on edge lines and in wrong-way pavement arrows. Red delineators on the edge line can be placed on each side of the ramp up to the WRONG WAY sign.

ADVANTAGES/DISADVANTAGES

- (+) Reflective raised pavement markers are more noticeable during nighttime due to increased visibility from reflective enhancement
- (+) Shows correct direction of traffic flow on exit ramps to discourage traveling in the wrong direction
- (−) Additional cost associated with using the RPM over standard design

EFFECTIVENESS

- Used extensively on freeways for lane separation with established results

CHALLENGES

- Raised pavement markers used in arrows must be methodically maintained in order to preserve the intent of the arrow to the motorist

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- In Dallas on all NTTA exit ramps, 2009
- Throughout the state

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Painted Arrows on Ramp

DESCRIPTION

Painted arrows on exit ramps can be used as a countermeasure for wrong-way movements. Where crossroad channelization or ramp geometrics do not make wrong-way movements difficult, a directional lane-use arrow can be placed in each lane of an exit ramp near the crossroad terminal where it will be clearly visible to a potential wrong-way movement driver.

(Source: Colorado DOT—E470 Authority)

ADVANTAGES/DISADVANTAGES

- (+) Low cost addition to standard exit ramp design
- (+) Can be used in combination with other exit ramp countermeasure techniques to reinforce message
- (−) Painted markings typically have short life span

EFFECTIVENESS

- Painted markings are used extensively on roadways with established results

CHALLENGES

- In order to be effective, painted markings must be frequently maintained due to excessive wear from vehicle traffic and weather elements

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

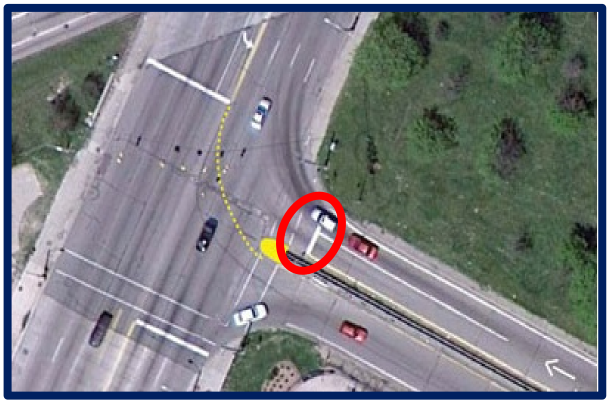
TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Stop Bars at Exit Ramps

DESCRIPTION

Painted stop bars can be used at exit ramps as a wrong-way movement countermeasure. The painted stop bar should be placed as close to the crossroad as possible in order to minimize the impression that the ramp is an entrance ramp.



(Source: FHWA—Where These Drivers Went

ADVANTAGES/DISADVANTAGES

- ➕ Low-cost addition to standard exit ramp design
- ➕ Can be used in combination with other exit ramp countermeasure techniques to reinforce message
- ➖ Painted markings typically have short life span

EFFECTIVENESS

- Painted markings are used extensively on roadways with established results

CHALLENGES

- In order to be effective, painted markings must be frequently maintained due to excessive wear from vehicle traffic and weather elements

DEPLOYMENT LOCATIONS AND DATES

National

- At intersection crossings throughout most states

Texas

- At intersection crossings throughout the state

TECHNIQUE

Painted Islands

DESCRIPTION

Painted islands between side-by-side exit/entrance ramps can be used as a wrong-way movement countermeasure. The painted island helps to reinforce that the entrance ramp is located to the right of the painted median.

(Source: NTSB/SIR—Wrong Way Driving)

ADVANTAGES/DISADVANTAGES

- \+ Low-cost addition to standard exit ramp design
- \+ Can be used in combination with other exit ramp countermeasure techniques to reinforce message
- − The paint may have a short life span due to exposure to weather elements

EFFECTIVENESS

- Painted markings are used extensively on roadways with established results

CHALLENGES

- In order to be effective, the paint on the island must be maintained

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

Texas

- Applied to several driveway locations in San Antonio, including US 281, to reinforce need to make a right turn (onto a one-way roadway) for drivers leaving local businesses

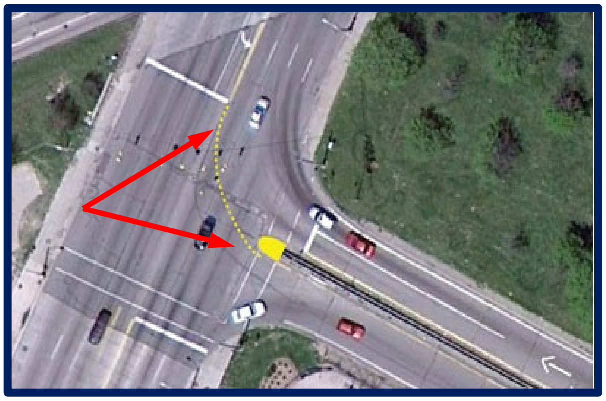
TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Left-Turn Pavement Marking Extensions

DESCRIPTION

Painted left-turn pavement marking extensions can be used as a wrong way movement countermeasure. The left-turn pavement marking extension uses a painted dashed-line marking that provides a guide to direct drivers to the entrance ramp of a side-by-side exit/entrance ramp configuration.



(Source: FHWA—Where These Drivers Went

ADVANTAGES/DISADVANTAGES

- (+) Low-cost addition to side-by-side exit/entrance ramp configuration design
- (+) Can be used in combination with other exit ramp countermeasure techniques to reinforce message
- (−) Painted markings typically have short life-span

EFFECTIVENESS

- Painted left-turn marking extensions are used extensively at roadway intersections with established results

CHALLENGES

- In order to be effective, painted markings must be frequently maintained due to excessive wear from vehicle traffic and weather elements

DEPLOYMENT LOCATIONS AND DATES

National

- At some intersection crossings throughout some states

Texas

- At some intersection crossings throughout the state

TRAFFIC CONTROL DEVICE COUNTERMEASURES

TECHNIQUE

Supplemental Flashers

DESCRIPTION

Overhead placement of supplemental flashers can be used as a wrong way entry countermeasure. The flashers can be placed on the back of right-way overhead sign structures where available or placed on span wire (shown at right).

(Source: Countermeasures for Wrong-Way Movement on Freeways)

ADVANTAGES/DISADVANTAGES

- (+) Flashers are located over a roadway where a driver tends to be looking forward instead of on the side of a roadway
- (+) More noticeable at night due to increased visibility from flasher
- (−) May not be seen by drivers under the influence of alcohol who tend to look down at the roadway pavement

EFFECTIVENESS

- Flashers at intersection crossings are used with established results

CHALLENGES

- Need power source
- May have to provide additional support structure to implement
- May have limited locations for proper placement

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

Texas

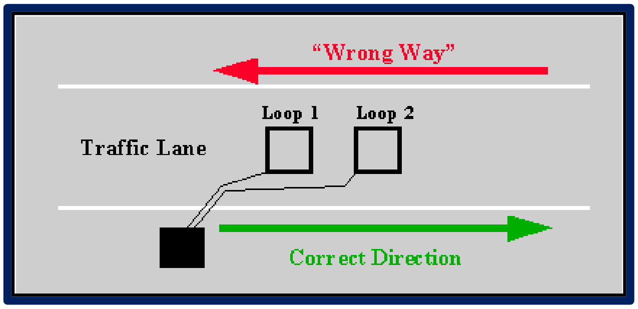
- Limited locations

TECHNIQUE

Detection and Notification Systems

DESCRIPTION

Use detection sensors (varying types) on exit ramp locations that send audible and/or visual alerts to either a wrong way driver or to a Command Center upon detection of wrong way movement. Law enforcement can then be notified of a wrong way driver in near real time.



ADVANTAGES/DISADVANTAGES

- (+) Provides real-time monitoring of active detection sites
- (+) Insensitive to inclement weather, depending on detection sensor type
- (−) High-maintenance issues
- (−) Possible legal issues related to wrong way driver notification

EFFECTIVENESS

- Early experience plagued with technical problems including false alarms

CHALLENGES

- Requires site-specific design
- Can be labor intensive to actively monitor locations

DEPLOYMENT LOCATIONS AND DATES

National

- New Mexico, 1998
- Washington, 2004
- Florida, 2006
- Arizona, 2011

Texas

- In Houston on HCTRA toll system, 2008
- San Antonio, 2012

INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

Closed-Circuit TV Cameras

DESCRIPTION

In urban areas with a traffic management Command Center and widespread video surveillance, closed-circuit television enables operators to both detect the occurrence of wrong way drivers and support law enforcement intervention in stopping such drivers.

ADVANTAGES/DISADVANTAGES

- (+) Monitors multiple locations
- (+) Can aid in law enforcement tracking and capture of wrong way drivers
- (+) Can be used to verify wrong way driver activity identified by 911 calls, etc.
- (−) Performance affected by inclement weather; sun glare; occlusion; day-to-night transition; and camera lens obstructions such as water, icicles, and cobwebs

EFFECTIVENESS

- Has been used extensively for highway monitoring and incident detection
- Some success in verifying presence of wrong way drivers and supporting law enforcement on related stops

CHALLENGES

- Requires periodic lens cleaning
- Operator ability to find wrong way driver after 911 call is limited
- Command Center may not be manned 24/7, and most wrong way events occur during late night hours (especially 2:00 a.m. to 4:00 a.m.)

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

Texas

- In Dallas on NTTA toll system, unknown
- In Houston on HCTRA toll system, unknown
- San Antonio, 2011
- Other major cities, unknown

INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

In-Pavement Warning Lights

DESCRIPTION

Use loop sensors on exit ramp locations that activate a series of warning lights imbedded in the pavement, alerting the driver that he or she has entered an off-ramp traveling the wrong direction or has entered some other restricted roadway.

(Source: Countermeasures for Wrong-Way Movement on Freeways)

ADVANTAGES/DISADVANTAGES

- (+) Warning light system is very noticeable at night
- (−) Performance of lighting may be affected by accumulated snow
- (−) Expensive to implement at multiple locations
- (−) Installation requires pavement cut, which can decrease pavement life

EFFECTIVENESS

- No information available

CHALLENGES

- Maintenance of lighting system requires closing of lane

DEPLOYMENT LOCATIONS AND DATES

National

- California, 1976

Texas

- In Houston on HCTRA toll system, 2011

INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

Blank Out Signs

DESCRIPTION

Active roadway signing may be more successful than passive signing in capturing driver attention in some situations. Blank-out signs use detection sensors to activate a WRONG WAY message display. The signs can be located on exit ramps or the main lanes of a highway or freeway.

(Source: Washington State DOT)

ADVANTAGES/DISADVANTAGES

- (+) Provides active signing message, which may have more success than passive signing or lighted passive signing in attracting wrong way driver attention
- (−) An experimental application at this time (limited deployment and testing)
- (−) Expensive to implement at multiple locations

EFFECTIVENESS

- No information available

CHALLENGES

- Sign operation is activated based on sensing of wrong way vehicle, and sensors can be affected by weather, lighting conditions, etc.
- Maintenance

DEPLOYMENT LOCATIONS AND DATES

National

- Tested in Washington beginning in 2001

Texas

- San Antonio, 2013

INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

Right-Way Driver Warnings

DESCRIPTION

Upon detection of wrong way movement automatically or manually activate dynamic message signing (DMS) to inform all drivers in the affected location.

(Source: Texas Department of Transportation)

ADVANTAGES/DISADVANTAGES

- ➕ Provides real-time information to all vehicles that may be affected by a wrong way driver
- ➖ May not provide immediate and direct countermeasure for the detected wrong way vehicle

EFFECTIVENESS

- No information available

CHALLENGES

- Sign spacing/location limits dissemination of message
- Content and format of message displayed

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown

Texas

- In Houston on HCTRA toll system, unknown
- San Antonio, 2010

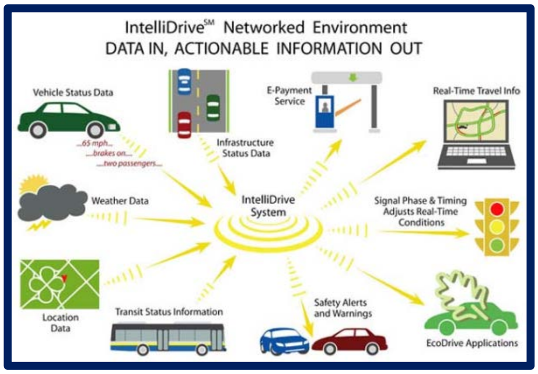
INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

Intellidrive

DESCRIPTION

IntelliDrive[SM] is a USDOT initiative to create interoperable connectivity among vehicles, infrastructure, and passengers' wireless devices to produce safety, mobility, and environmental benefits. Combining this information with data currently being collected by the public sector agencies through various detectors types can provide system managers and users with detailed, real-time, dynamic data about the status of the transportation system and the vehicles using it.



(Source: The Detroit Bureau)

ADVANTAGES/DISADVANTAGES

- \+ Capability of navigation system alerts (I2V) that inform drivers of wrong way movements onto controlled-access highway exit ramps prior to reaching main lanes
- \+ Capability of vehicle-to-infrastructure (V2I) communication to alert of potential safety issues related to a wrong way vehicle
- \+ Capability of vehicle-to-vehicle (V2V) avoidance systems communication
- − Validation of technology is still being researched

EFFECTIVENESS

- No information available

CHALLENGES

- Availability of this technology is limited
- Development of a common system architecture

DEPLOYMENT LOCATIONS AND DATES

National

- Test basis in Michigan, California, and New York, 2011
- Research basis in automobile industry

Texas

- None

INTELLIGENT TRANSPORTATION SYSTEMS

TECHNIQUE

Advanced In-Vehicle Technologies

DESCRIPTION

Use of intelligent non-invasive, seamless technology to measure driver blood alcohol content (BAC) and reduce the incidence of drunk driving. Two technologies being developed:

- Tissue Spectrometry—Estimation of BAC by measuring how much light has been absorbed at a particular wavelength from a beam of Near-Infrared (NIR) reflected from the subject skin.
- Distant Spectrometry—Infrared (IR) or laser light is transmitted to the subject from a source that receives and analyzes the reflected and absorbed spectrum, to assess chemical content of tissue or liquid in vapor.

(Source: NHTSA)

ADVANTAGES/DISADVANTAGES

- (+) Shorter time measurement and less intrusive over current breath alcohol ignition locks
- (+) Intended to support a non-regulatory, market-based approach to preventing drunk driving
- (−) Public and key leader acceptability

EFFECTIVENESS

- No information available

CHALLENGES

- Has to work each time, over the life of the vehicle, and in a variety of challenging environments
- Anticipating and addressing likely circumvention strategies by drivers

DEPLOYMENT LOCATIONS AND DATES

National

- Demonstration vehicles being tested, 2012

Texas

- None

GEOMETRIC MODIFICATIONS

TECHNIQUE

Roadway Layout Changes

DESCRIPTION

According to the AASHTO Green Book, some typical countermeasures for wrong way movements may include:

- Using raised curb medians.
- Using channelized medians, islands, and adequate signing.
- Increasing the distance from the gorge of the exit ramp to the entrance ramp for partial cloverleaf interchanges.
- Reducing the wrong way turning radius.
- Not using off-ramps that join two-way frontage roads.

(Source: FHWA—Where These Drivers Went Wrong)

ADVANTAGES/DISADVANTAGES

- (+) Based on previous design engineering studies
- (+) Can be a low-cost improvement at minimal problem locations
- (−) May not provide enough safety improvement at high problem locations

EFFECTIVENESS

- May require additional countermeasure technique in problem locations

CHALLENGES

- Funding issues if needed at many locations

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

GEOMETRIC MODIFICATIONS

TECHNIQUE

Entrance/Exit Ramp Offsets

DESCRIPTION

Some proper geometric techniques for ramp offsets include:

- Separate the on- and off-ramps.
- Orient the on-ramp for easy access.
- Construct a better-lit and larger opening for the on-ramp than the off-ramp.
- Reconstruct the curb nose between adjacent ramps.
- Grade the on-ramp entrance for better visibility than the off-ramp as viewed from the crossroad.
- Remove concrete barriers for better visibility of the exit ramp.

(Source: FHWA - Where These Drivers Went Wrong)

ADVANTAGES/DISADVANTAGES

+ Based on previous design engineering studies
+ Can be a low cost improvement at minimal problem locations
− May not provide enough safety improvement at high problem locations

EFFECTIVENESS

- May require additional countermeasure technique in problem locations

CHALLENGES

- Funding issues if needed at many locations

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

GEOMETRIC MODIFICATIONS

TECHNIQUE

Off-Ramp Throat Reductions

DESCRIPTION

Some proper geometric techniques for reducing the size of the off-ramp throat width to discourage wrong way entrance include using the following:

- Dikes.
- Curbs.
- Delineator posts.
- Painted gores and islands.

(Source: Countermeasures for Wrong-Way Movement on Freeways)

ADVANTAGES/DISADVANTAGES

- (+) Based on previous design engineering studies
- (+) Can be a low-cost improvement at minimal problem locations
- (−) May not provide enough safety improvement at high problem locations

EFFECTIVENESS

- May require additional countermeasure technique in problem locations

CHALLENGES

- Funding issues if needed at many locations
- Maintenance issues if using delineator posts, or painted gores or islands

---

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

GEOMETRIC MODIFICATIONS

TECHNIQUE

Approach Pavement Marking and/or Signing Modifications at Diamond Interchanges

DESCRIPTION

Modify approach pavement markings and signs on nearby diamond interchange cross streets to include the following:

- Eliminate conflicting lane assignments.
- Add straight arrow markings in extended bays.
- Add or relocate larger ONE WAY signs on signal mast arm as close to left turn lane as possible.
- Trailblazer signs should not have a left arrow in advance of intersection.

(Source: North Texas Tollway Authority)

ADVANTAGES/DISADVANTAGES

- ✚ Promotes consistent traffic control for better driver compliance
- ✚ Low cost for implementation

EFFECTIVENESS

- Addresses the needs of both the general motoring public and impaired drivers

CHALLENGES

- Similar maintenance to existing pavement marking and signing
- Gaining consensus among agency leaders

DEPLOYMENT LOCATIONS AND DATES

National

- Unknown in other states

Texas

- North Texas, on select NTTA diamond interchanges, 2010
- Proposed plan on all diamond interchanges in Dallas County, 2012

INSTITUTIONAL COORDINATION

TECHNIQUE

Enforcement

DESCRIPTION

Use law enforcement in the following manner:

- Coordinate with Traffic Management Centers to expedite responses to detections or reported incidents of wrong way driving.
- Conduct frequent DUI Task Force operations.

(Source: North Texas Tollway Authority)

ADVANTAGES/DISADVANTAGES

- ✚ Provides real-time information to law enforcement on wrong way driver description and locations
- ✚ Increased visibility of law enforcement may deter some DUI offenders
- ▬ May not provide immediate and direct countermeasure for the detected wrong way vehicle

EFFECTIVENESS

- Should perform evaluations of task force efforts in order to enhance and to determine the effectiveness of the program

CHALLENGES

- Can be costly and labor intensive to perform frequent DUI Task Force operations
- Coordination between agencies can be difficult due to logistics and communication technology differences

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

INSTITUTIONAL COORDINATION

TECHNIQUE

Public Education

DESCRIPTION

Use public involvement techniques to educate the motoring community in the following manner:

- Perform public awareness campaigns related to driving under the influence of alcohol and/or drugs.
- Identify efforts to reduce the involvement of older drivers in wrong way collisions and develop effective countermeasures.
- Develop programs, such as Teens-In-The-Driver Seat, that can positively influence the driving habits of particular groups

Teens IN THE Driver Seat t-driver.com

MADD

ADVANTAGES/DISADVANTAGES

+ Addresses the problem in a proactive preventive manner
+ Most state departments of transportation currently have some type of public awareness campaign that can be expanded
− Not always effective in communicating the right message

EFFECTIVENESS

- Education has proven to be an effective tool in most aspects

CHALLENGES

- Acceptance of programs by entire motoring community is required
- Finding appropriate funding sources can be a difficult task

DEPLOYMENT LOCATIONS AND DATES

National

- Throughout most states

Texas

- Throughout the state

INSTITUTIONAL COORDINATION

TECHNIQUE

Legislative Modification

DESCRIPTION

Urge the legislative branch of government to modify current laws and encourage the development of new laws related to wrong way driving on highways. Some potential options to consider include the following:

- Adopt and/or increase the fine for driving the wrong way over a certain distance of travel, with possible license suspension.
- Violation of license suspension involving wrong way driving would incur steep penalty increases, possibly including jail time.
- Drastically increase the penalty for a DWI conviction when it occurs in combination with wrong way driving and/or crashes.

ADVANTAGES/DISADVANTAGES

+ May provide deterrence to wrong way driving due to severe consequences

− Creates more laws that must be enforced in order to obtain benefit

EFFECTIVENESS

- Stronger DWI penalties have resulted in lowering the alcohol related crash rates throughout the country in the past

CHALLENGES

- Difficult to find compromise that all constituents can agree on

DEPLOYMENT LOCATIONS AND DATES

National

- Considered legislation in New York, 2011
- Considered legislation in Ohio, 2012

Texas

- Unknown

INSTITUTIONAL COORDINATION

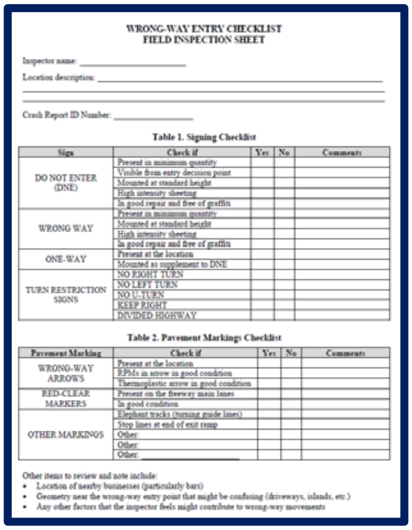
TECHNIQUE

Field Checklist for Problem Locations

DESCRIPTION

Use checklist for inspection of wrong way entry problem locations to assess the following during day and at night:

- Check all pertinent signing including DO NOT ENTER, WRONG WAY, ONE WAY, and turn restriction signing:
  1. Present in minimum quantity.
  2. Mounted at standard height.
  3. High-intensity sheeting.
  4. In good repair and free of graffiti.
- Check all pertinent pavement markings including wrong way arrows, red-clear markers, and other markings:
  1. Present at the location.
  2. RPMs in arrow in good condition.
  3. Thermoplastic arrow in good condition.
  4. Red-clear markers in good condition.
  5. Stop-bars present at the end of exit ramp.



WRONG-WAY ENTRY CHECKLIST
FIELD INSPECTION SHEET

Inspector name: ____________________

Location description: ____________________

Crash Report ID Number: ____________________

Table 1. Signing Checklist

Sign	Check if	Yes	No	Comments
DO NOT ENTER (DNE)	Present in minimum quantity			
	Visible from entry decision point			
	Mounted at standard height			
	High intensity sheeting			
	In good repair and free of graffiti			
WRONG WAY	Present in minimum quantity			
	Mounted at standard height			
	High intensity sheeting			
	In good repair and free of graffiti			
ONE-WAY	Present at the location			
	Mounted as supplement to DNE			
TURN RESTRICTION SIGNS	NO RIGHT TURN			
	NO LEFT TURN			
	NO U-TURN			
	KEEP RIGHT			
	DIVIDED HIGHWAY			

Table 2. Pavement Markings Checklist

Pavement Marking	Check if	Yes	No	Comments
WRONG-WAY ARROWS	Present at the location			
	RPMs in arrow in good condition			
	Thermoplastic arrow in good condition			
RED-CLEAR MARKERS	Present on the freeway main lanes			
	In good condition			
OTHER MARKINGS	Elephant tracks (turning guide lines)			
	Stop lines at end of exit ramp			
	Other:			
	Other:			
	Other: ____________			

Other items to review and note include:
- Location of nearby businesses (particularly bars)
- Geometry near the wrong-way entry point that might be confusing (driveways, islands, etc.)
- Any other factors that the inspector feels might contribute to wrong-way movements

(Source: Countermeasures for Wrong-Way Movement on Freeways)

ADVANTAGES/DISADVANTAGES

- (+) Provides a tool for the assessment of potential wrong way entry problem locations
- (+) Can be used to address the problem in a proactive, preventive manner
- (−) Provides only minimal information related to a potentially severe problem

EFFECTIVENESS

- Checklists can provide an organized manner for understanding a problem

CHALLENGES

- Is only one part of a larger effort including obtaining and analyzing crash data at potential wrong way entry problem locations

DEPLOYMENT LOCATIONS AND DATES

National

- California, 1989

Texas

- Throughout the state

APPENDIX B:
WRONG WAY ENTRY FIELD REVIEW SHEET

WRONG WAY ENTRY FIELD REVIEW SHEET

Date: ____________

Name of reviewer(s): ____

Location description: ____

____

Table 1. Signing Checklist

Sign	Check if	Yes	No	Comments
DO NOT ENTER	Standard size			
	Minimum number installed			
	Mounted at 7 ft height			
	Meets TMUTCD retroreflectivity requirements			
	Visible from entry decision point			
	In good condition			
	Retroreflective sheeting on support			
WRONG WAY	Standard size			
	Minimum number installed			
	Mounted at 7 ft height			
	Meets TMUTCD retroreflectivity requirements			
	Visible from ramp			
	In good condition			
	Retroreflective sheeting on support			
ONE-WAY	Present (if yes, note how many)			
Turn Restriction Signs	NO RIGHT TURN			
	NO LEFT TURN			
	NO U-TURN			
	KEEP RIGHT			
	DIVIDED HIGHWAY			
Other Signs				

Table 2. Pavement Marking Checklist

Sign	Check if	Yes	No	Comments
Wrong Way Arrows	Present (if yes, note how many)			
	Any missing RRPMs			
	RRPMs in good condition			
Red-White RRPMs	Present on freeway mainlanes			
	Any missing RRPMs			
	In good condition			
Other Pavement Markings	Elephant tracks at intersection			
	Stop lines at end of ramp			

Other items to review and note include:

- Location of nearby businesses (particularly bars or special event facilities such as stadiums and arenas)
- Location of driveways and cross streets in close proximity to ramp
- Geometry where the ramp intersects with a cross street or frontage road
- Interchange design

Use the area below to draw sketches, as needed.