EMERGING SAFETY COUNTERMEASURES FOR WRONG-WAY DRIVING

AMERICAN TRAFFIC SAFETY SERVICES ASSOCIATION

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SAFER ROADS SAVE LIVES

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Overview

Wrong-Way Driving (WWD), by definition, happens when a driver, inadvertently or deliberately, drives in the opposite direction of traffic flow along a physically divided highway (freeway, expressway, or interstate highway) or its access ramps. These WWD crashes are mainly head-on or opposite direction sideswipes which tend to be more severe in terms of type of injuries and number of fatalities. A recently conducted inquiry of the Fatality Analysis Reporting System (FARS) database revealed that an average of 358 people were killed in WWD crashes each year over an eight year period (2004 to 2011).

According to previously conducted studies (Zhou et al 2012, Morena and Leix 2012), exit ramp terminals are the most likely locations for wrong-way drivers to enter a physically separated highway. Therefore, exit ramps should be given special consideration for appropriate traffic control devices (signage, pavement markings, signals, lighting, etc.) and geometric layouts (medians, driveways) in order to minimize driver confusion and discourage wrong-way maneuvers.

There are a number of factors that may increase the probability of WWD maneuvers on a roadway facility prone to WWD maneuvers. While impaired driving accounts for over 60% of wrong-way crashes, studies also found that inconsistency in location, angles, and size of wrong-way related traffic signs, lack of pavement markings, and improper geometric design are contributing factors. Over the past few decades, different engineering countermeasures have been proposed, implemented and tested by various state and local agencies to mitigate WWD incidents, including (1) changing the size, location, and angle of wrong-way related signs, (2) proper use of conventional and innovative pavement markings, (3) implementing proper geometric elements (raised medians, channelizing islands, and control radii at intersections), and (4) application of Intelligent Transportation Systems (ITS). However, there has been lack of comprehensive documentation that brings together in one place the various emerging WWD countermeasures to serve as an enriched reference for transportation agencies to help them select suitable solutions to achieve targeted outcomes for their existing problems.

This publication is developed in the framework of an executive summary of various case studies that aim at providing transportation practitioners with a good understanding of WWD incidents and emerging safety countermeasures. In addition to bringing available information together in one document, a contact person(s) is suggested for each case study. This will assist readers to obtain further information regarding the countermeasure they are considering.

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U.S.Department of Transportation
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Introduction

Wrong-Way Driving (WWD), by definition, happens when a driver, inadvertently or deliberately, drives against the main direction of flow along a high-speed physically divided highway or access ramp (NTSB 2012). Each year, hundreds of fatal WWD crashes occur across the United States and thousands of injuries are reported in crashes caused by wrong-way drivers. Although WWD crashes of this type have been a matter of concern since the advent of access-controlled, divided roadways, the problem persists despite efforts to address it over time. It is hoped that this document will help to achieve a significant reduction in the number of WWD crashes and fatalities in the future.

According to a query of eight years of crash data (2004-2011) from the Fatality Analysis Reporting System[1] (FARS) database, an average of 269 fatal crashes resulting in 359 people killed occurred each year due to WWD in the United States. The distribution of this number differs from one state to another. Figure 1 depicts the average number of WWD fatalities and the percentage of total traffic fatalities represented by WWD in each state over that eight year period.

Further analysis of this FARS data reveals that although overall fatalities and fatal crashes decreased by more than 20 percent since 2004, WWD fatalities and fatal crashes remained quite steady. Figure 2 (fatal crashes) and Figure 3 (fatalities) contrast these trends.

Average Annual U.S. Wrong Way Driving Fatalities (2004-2011)								
Group 1 (2% and Higher)			Group 2 (Between 1-2%)			Group 3 (Below 1%)		
State	Frequency	% U.S. Total	State	Frequency	% U.S. Total	State	Frequency	% U.S. Total
Texas	51	14.2%	Louisiana	7	1.9%	Idaho	3	0.8%
California	35	9.7%	New Jersey	7	1.9%	Indiana	3	0.8%
Florida	28	7.8%	New York	7	1.9%	New Mexico	3	0.8%
Pennsylvania	14	3.9%	North Carolina	7	1.9%	Wisconsin	3	0.8%
Missouri	13	3.6%	Virginia	7	1.9%	Delaware	2	0.6%
Illinois	12	3.3%	Washington	7	1.9%	Montana	2	0.6%
Georgia	11	3.1%	Colorado	6	1.7%	Hawaii	1	0.3%
Mississippi	11	3.1%	Kansas	6	1.7%	Maine	1	0.3%
Tennessee	11	3.1%	Ohio	6	1.7%	New Hampshire	1	0.3%
Arizona	10	2.8%	Arkansas	5	1.4%	Rhode Island	1	0.3%
Alabama	9	2.5%	Maryland	5	1.4%	South Dakota	1	0.3%
Michigan	8	2.2%	Minnesota	5	1.4%	Vermont	1	0.3%
Oklahoma	8	2.2%	Nevada	5	1.4%	Wyoming	1	0.3%
			South Carolina	5	1.4%	Alaska	0	0.0%
			Utah	5	1.4%	District of Columbia	0	0.0%
			West Virginia	5	1.4%	Nebraska	0	0.0%
			Connecticut	4	1.1%	North Dakota	0	0.0%
			Iowa	4	1.1%			
			Kentucky	4	1.1%			
			Massachusetts	4	1.1%			
			Oregon	4	1.1%			

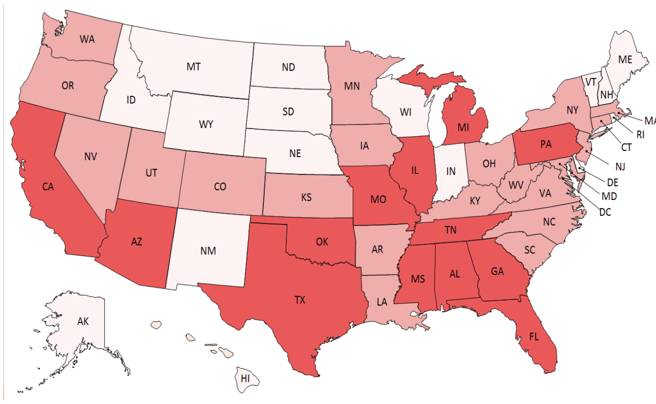
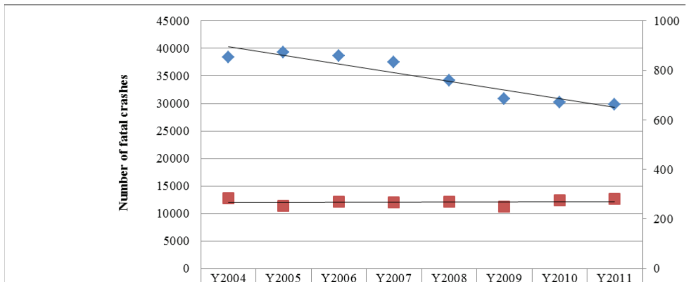
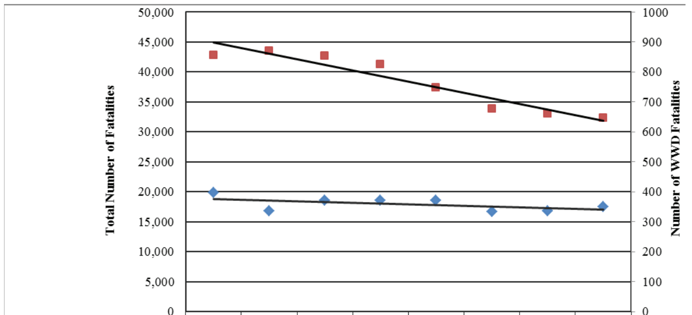


Figure 1. Average and Percentage of WWD Fatalities in Each State (2004-2011)



	Y2004	Y2005	Y2006	Y2007	Y2008	Y2009	Y2010	Y2011
Total number of fatal crashes	38444	39252	38648	37435	34172	30862	30196	29757
WWD fatal crashes	283	253	270	266	271	249	276	281

Figure 2. Total Number of Fatal Crashes vs. Number of WWD Fatal Crashes



	Y2004	Y2005	Y2006	Y2007	Y2008	Y2009	Y2010	Y2011
Total Number of Fatalities	42,836	43510	42708	41259	37423	33883	32999	32367
Number of WWD Fatalities	397	336	372	370	370	334	336	349

Figure 3. All Roadway Fatalities vs. WWD Fatalities

Background

To identify, share and discuss the best practices and emerging countermeasures for mitigating WWD incidents, the first National WWD Summit was held on July 18-19, 2013, in Edwardsville, Illinois. The purpose of this summit, sponsored by the Illinois Center for Transportation (ICT) and Illinois Department of Transportation (IDOT), was to provide a platform for traffic and safety professionals of all backgrounds to exchange ideas, evaluate current countermeasures, and develop the best practices to reduce WWD crashes and incidents through a "4E" approach (Engineering, Education, Enforcement, and Emergency Response). Approximately 130 attendees participated in this summit, including representatives from the National Transportation Safety Board (NTSB), Federal Highway Administration (FHWA), American Traffic Safety Services Association (ATSSA), several state agencies (transportation, police/highway patrol, tollway authorities), multiple universities, and many private sector companies. A total of 23 state DOTs were represented, many from states that had already begun addressing WWD, as well as those who planned to do so upon returning from the event with new knowledge and ideas. The Summit was structured as a combination of podium presentations on current practices, latest research results, and group breakout sessions for smaller, interactive forums. Table 1 contains a list of engineering countermeasures implemented by different agencies for mitigating WWD incidents and crashes.

Engineering Countermeasures			
Signing	**Pavement Marking**	**Geometric Improvement**	**ITS Technologies**
▪ Implementing Standard Wrong-way Sign Package ▪ Improved Static Signs ▪ Lowering Sign Height ▪ Using Oversized Signs ▪ Mounting Multiple Signs on the Same Post ▪ Applying Red Retroreflective Strip to the Vertical Posts ▪ "Freeway Entrance" Sign for All Entrance Ramps (Ensure the Right Way)	▪ Stop Line ▪ Wrong-Way arrow ▪ Turn/Through Lane Only Arrow ▪ Red Raised Pavement Markers ▪ Short Dashed Lane Delineation Through Turns	▪ Entrance/Exit Ramp Separation ▪ Raised Curb Median ▪ Longitudinal Channelizers ▪ Change in Ramp Geometrics: ❖ Obtuse Angle ❖ Sharp Corner Radii	▪ LED Illuminated Signs ▪ Dynamic Signs – Warn Other Drivers ▪ Use Existing GPS Navigation Technologies to Provide Wrong-way Movement Alerts ▪ Provide Consistent Messages or Alerts That Are Intuitive to the Driver

Table 1 Various WWD Countermeasures Implemented by Different Agencies

This publication consists of two parts: (1) Traffic Signs, Pavement Markings, Multiple Devices and (2) Geometric Design Examples. Ten implementation examples were developed based on the presentations and inputs by the participants at the Summit. The geometric design examples were developed based on review of current practices and design policies across the United States. Implementation examples in this report include:

1. Lower-Mounted DO NOT ENTER and WRONG WAY signs, various locations in California
2. Flashing LED Border WRONG WAY Signs, San Antonio, Texas
3. Red Retroreflective Strips on Sign Posts and Red Retroreflective Raised Pavement Markers, various locations in Texas
4. Access Management near Interchange Ramp, Dallas, Texas
5. Raised and Vertical Longitudinal Channelization, Detroit, Michigan
6. ITS Detection System, Harris County Toll Road Authority, Houston, Texas
7. Wrong-Way Entry ITS Warning System, Buffalo, New York
8. Oversized DO NOT ENTER and WRONG WAY Signs, various locations in Illinois and Texas
9. Enhanced Pavement Markings, various locations in Illinois and Texas
10. Multiple Countermeasure Package for Partial Cloverleaf Interchanges, Michigan

Special Notes

At the time of publication, some of the WWD countermeasures presented in this report, while anticipated to be effective in addressing WWD, have not yet been formally evaluated using statistically valid methods. Readers are encouraged to obtain more up-to-date information on results by contacting their responsible agency directly.

The vast majority of treatments illustrated in this document are either allowed or not precluded by the Manual on Uniform Traffic Control Devices (MUTCD). In addition, non-compliant traffic control devices may be piloted through the MUTCD experimentation process. That process is described in Section 1A.10 of the MUTCD and on the FHWA website at http://mutcd.fhwa.dot.gov/condexper.htm. A searchable database of official rulings, interim approvals, interpretations and experimentations can also be found at http://mutcd.fhwa.dot.gov/orsearch.asp.

Part I: Signs, Pavement Markings and Multiple Devices

CASE 1: Lower-Mounted DO NOT ENTER and WRONG WAY Signs - Various Locations in California

The DO NOT ENTER and WRONG WAY signs, described in Section 2 of the Manual on Uniform Traffic Control Devices (2009 MUTCD), are widely used and recognizable countermeasures for WWD. The MUTCD states that the DO NOT ENTER sign "shall be used where traffic is prohibited from entering a restricted roadway" and that a WRONG WAY sign may be used as a supplement to a DO NOT ENTER sign where an exit ramp intersects a crossroad or a crossroad intersects a one-way roadway in a manner that "does not physically discourage or prevent wrong-way entry." In general, the MUTCD establishes the minimum mounting height for road signs as 7 feet in urban areas and 5 feet in rural areas. However, the California Department of Transportation (Caltrans)-with a long-standing WWD safety program-has been mounting DO NOT ENTER and WRONG WAY signs at lower heights since the early 1970s. Figures 4 and 5 depict examples of lower mounting heights from sites in California. Note the angles at which the signs are installed to best face potential wrong-way drivers.

Lowering the height of DO NOT ENTER and WRONG WAY signs proved an effective treatment, reducing the frequency of WWD incidents from 50–60 per month to 2–6 per month at some problem ramps (Copelan, 1989). The lower mounting height was reported to make the signs more visible at night because lower signs are more directly in the path of vehicle headlights. A lower mounting height may also make the sign more visible to impaired and older drivers, who tend to look for visual cues from the pavement area (Cooner, 2004).

The MUTCD permits lower mounting height of DO NOT ENTER and WRONG WAY signs, to a minimum height of 3 feet, at certain locations indicated by engineering study. It should be noted that low mounted signs may not be appropriate in urban areas where on-street parking exists, where pedestrian activity would preclude it, or if other obstructions may interfere. As shown in Figure 6, standard height DO NOT ENTER and WRONG WAY signs are placed at the entrance of a one-way street with on-street parking.

Figure 4. Low Mounted Sign During the Day in California (Image: Huaguo Zhou)

Figure 6. Standard Height DO NOT ENTER and WRONG WAY Signs at the Entrance of One-way Street with On-Street Parking (Image: Huaguo Zhou)

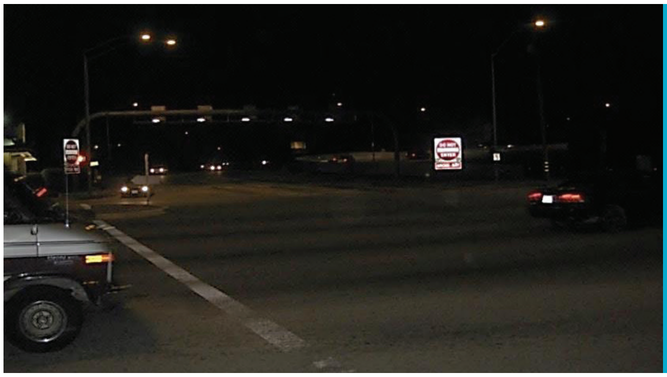


Figure 5. Low Mounted Sign at Night in California (Image: Huaguo Zhou)

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CASE 2: LED Illuminated Sign Borders San Antonio, Texas

Because nearly 80 percent of wrong-way driving incidents occur at night, with 45 percent occurring between 2AM and 4AM, a particular need exists to address night time conditions (Clay, 2013). One effective countermeasure is to enhance static signs to make them more conspicuous, especially at night. Flashing light emitting diode (LED) lights, placed along the border of a sign, tend to be initially visible from a greater distance, and as the driver gets closer to the sign, the vehicle headlights will illuminate the retroreflective sign sheeting (Clay, 2013). Figure 7 depicts examples of flashing LED borders on DO NOT ENTER and WRONG WAY signs.

Figure 7. A Sample of LED Wrong Way Sign at Night (Image: TAPCO)

In early 2012, the Texas Department of Transportation (TxDOT) undertook a review of WWD crashes along the freeway system in the San Antonio district (Chacon and Fariello, 2013). The results revealed that, in 2011, a 15-mile corridor of U.S. 281 between Interstate 35 and Sonterra Boulevard had the highest number of reported wrong-way driving crashes compared to other freeway corridors in the district. Figure 8 shows the WWD incident "heat map" that TxDOT created, and with the U.S. 281 corridor circled.

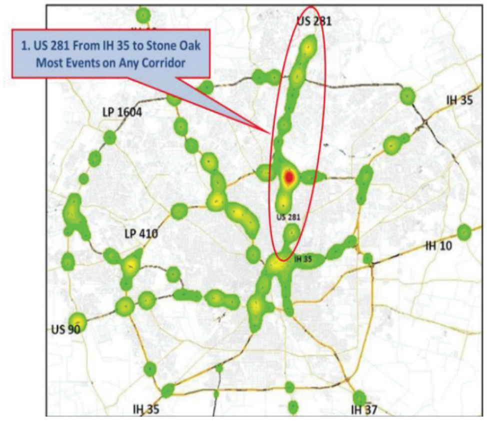

Figure 8. US 281 Pilot Project Corridor (Image: TxDOT)

Based on this analysis, TxDOT implemented flashing LED border WRONG WAY signs at 29 exit ramps along this corridor. These signs were equipped with photocell activation for night and low visibility conditions. Figure 9 illustrates a picture after implementation of the countermeasure at the location.

The flashing LED border signs were installed in the March to June 2012 time frame. A review of crash data in the one-year period after installation showed that WWD incidents dropped by roughly 30 percent. Moreover, the initial evaluation by TxDOT shows a benefit-cost ratio of 13.1:1, and a projected cost recovery time period of 1.5 years (Chacon and Fariello, 2013).

Figure 9. A Sample of Flashing LED WRONG WAY Signs at South End of Dallas North Tollway (Image: TxDOT)

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CASE 3: Red Retroreflective Strips and Red Retroreflective Raised Pavement Markers - Various Locations in Texas

Two low-cost countermeasures, red retroreflective strips on sign supports and red retroreflective raised pavement markers (RRPMs), are often used by transportation agencies to increase the nighttime conspicuity of DO NOT ENTER and WRONG WAY signs and associated pavement markings, respectively.

The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009) states that a strip of retroreflective material attached to a sign support shall be at least two inches in width and shall be placed for the full length of the support from the sign to within two feet above the edge of the roadway. Its color shall match the background color of the sign except for the YIELD and DO NOT ENTER signs, which shall have red-colored strips. For enhancing pavement markings targeted at preventing wrong-way maneuvers, the MUTCD provides options that allow the use of red retroreflective raised pavement markers to supplement wrong-way arrows placed on the roadway. Figure 10 shows a nighttime view of DO NOT ENTER and WRONG WAY signs with red retroreflective tape.

Figure 10. Red Retroreflective Tape on the Sign Post to Enhance Nighttime Visibility (Image: Huaguo Zhou)

The North Texas Tollway Authority (NTTA) is actively addressing wrong-way driving on their system. The NTTA Wrong-Way Driving Task Force was established in 2009 to investigate a sudden increase of wrong-way related crashes on one NTTA facility during the first half of the year. NTTA staff conducted a thorough analysis of all wrong-way crashes within their jurisdiction, followed by researching possible countermeasures, and documented their findings and recommendations in a special report (NTTA 2009). The Task Force recommended a comprehensive "3E" approach, which combines and focuses Engineering countermeasures, law Enforcement, and public Educational efforts on a specific problem in an effort to reduce future incidents. Based on the Task Force recommendations, NTTA immediately implemented several low-cost engineering enhancements across their system, including the combination of Red Retroreflective Strips on all DO NOT ENTER and WRONG WAY sign supports and red RRPM-supplemented wrong way arrows at every exit ramp. Figures 11 and 12 depict a treated NTTA location in daytime and nighttime conditions, respectively.

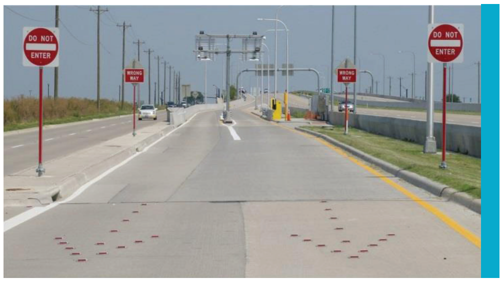

Figure 11. NTTA Exit Ramp with Red Retroreflective Strips on Sign Supports and Red RRPM-supplemented Wrong Way Arrow Pavement Markings (Daytime)

Figure 12. NTTA Exit Ramp with Red Retroreflective Strips on Sign Supports and Red RRPM-supplemented Wrong Way Arrow Pavement Markings (Nighttime)

Moreover, NTTA updated its signing and marking standards to require the use of red RRPM-supplemented wrong way arrow pavement markings at all exit ramps in the future. Combined, these low-cost enhancements to signing and markings at NTTA exit ramps are expected to help make these locations less susceptible to wrong-way driving incidents by increasing visibility and conspicuity, especially during nighttime conditions.

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CASE 4: Access Management in the Vicinity of an Exit Ramp Dallas, Texas

Access management in the vicinity of an interchange area can have a profound effect on overall safety performance, including potential wrong-way driving incidents involving exit ramps. Managing access can involve several different types of established WWD countermeasures, including signing and marking, but also geometric elements, such raised medians and channelizing islands, to restrict turning movements at and near exit ramps where WWD tends to originate (AASHTO 2011). Raised medians that separate opposing directions of traffic along the crossroad are often used to prevent wrong-way left turns onto exit ramps by providing a physical means of impeding this wrong way maneuver.

A North Texas Tollway Authority (NTTA) special report identified a location -Wycliff Avenue in Dallas- involving a two-way side street in close proximity to the exit ramp, along with an undivided crossroad. As shown in Figure 13, this situation allowed motorists to make all movements to and from the side street, but the adjacent exit ramp left open the possibility of wrong-way turns, especially at night when traffic volumes are low and driver confusion may be more likely. Several WWD incidents were reported to originate from this location, so NTTA staff proposed to close the median opening to prevent future recurrence of wrong-way left-turns onto the exit ramp (Ouyang 2013).

Figure 13. NTTA Southbound Exit Ramp at Wycliff Avenue, Before Median Enhancement (Image: Yang Ouyang)

NTTA worked closely with the City of Dallas to obtain their support, because the median modification was within the City's maintenance limit and would have implications on local access. As shown in Figure 14, the reconstructed median now nearly eliminates the possibility of the eastbound left-turning traffic entering the exit ramp. An alternative opening was provided for those impacted motorists to access the side street.

Figure 14. DNT's Southbound Exit Ramp at Wycliff Avenue, After Median Enhancement (Image: Huaguo Zhou)

Figure 15 provides an aerial comparison of the geometric configurations "before" (2009) and "after" (2011) the median enhancement. Since the completion of this project, the number of WWD incidents before/after associated with only median, change 2 in the before and 0 in the after.

Figure 15. Before (left figure, 2009) and After (right figure, 2011) Pictures of the Modified Median at Wycliff Avenue (Image: Google Earth)

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CASE 5: Raised/Vertical Longitudinal Channelizing Devices Detroit, Michigan

Surface-mounted, raised or vertical longitudinal channelizing devices are often used as a low-cost countermeasure by transportation agencies to fulfill various permanent and temporary safety or operational needs. The devices used today can offer easy installation, low maintenance, resistance to damage, excellent durability, and day and nighttime conspicuity - all resulting in cost effectiveness. Even in locales where winter road maintenance is intense, these devices can still be effective and are worth considering.

The Michigan Department of Transportation (MDOT) installed raised and vertical longitudinal channelizing devices at two locations as a wrong-way driving countermeasure at certain intersections with freeway exit ramps. A study conducted by MDOT in 2010 determined that a particular feature of freeway interchange design that is more susceptible to wrong-way maneuvers is the arrangement of parallel, side-by-side exit and entrance ramps in the same quadrant-known as a “parclo” design. Based on this analysis, MDOT targeted 161 parclo interchanges with this design across the state to be treated with a WWD countermeasure package of low-cost signing and marking enhancements. However, according to MDOT, one interchange stood out in need of additional treatment. Through their analysis, MDOT determined that the interchange of Gratiot Avenue along Interstate 94 in Detroit was where 10 of the 35 total WWD crashes in the analysis period originated. Furthermore, these 10 crashes did not primarily occur at night or involve mainly impaired drivers. In reviewing the intersection geometry, MDOT determined that installing a combination of raised and vertical longitudinal channelization, between the left-turn lane and the opposing direction of traffic, would serve as a physical restriction of potential wrong-way left turns onto the exit ramp. This treatment could also be installed immediately, without significant modification to the intersection or interchange. Figure 16 shows the combination of preformed curbing and vertical panels. Since the treatment was completed there have been no WWD incidents that have been traced to the Gratiot Avenue interchange.

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Figure 16. Application of Longitudinal Channelizers in Restriction of Wrong-way Left-Turn (Image: MDOT)

CASE 6: Wrong-Way Incident ITS Detection System Houston, Texas

Intelligent Transportation System (ITS) technologies have been used by many transportation agencies to develop wrong-way driving countermeasures. The application of ITS in detecting and deterring WWD incidents consists of three steps:

1. **Detection:** This step can be accomplished using a variety of different detectors such as Inductive Loop Detectors (ILD), Video Image Processing (VIP) Systems, Microwave Radar-based Traffic Detection Systems, Infrared Detection Systems, and others.

2. **Warning:** Different methods can be employed to warn both wrong-way and right-way drivers. In-pavement warning lights, flashing wrong-way signs, warning lights, and Dynamic Message Signs (DMS) are some examples of these warning systems.

3. **Action:** Action can be taken by patrol units or other responsible parties after receiving an alert from the traffic management center (TMC) or some centralized dispatch to intercept wrong-way drivers.

Based on WWD incident reports from the public and law enforcement involving their Westpark Tollway, the Harris County Toll Road Authority (HCTRA) in Houston decided to implement a radar-based WWD detection system. This system was designed for twelve sites at exit ramps and along the mainline, all connected to the HCTRA TMC, at an overall cost of $337,000 (Thurman, 2013). Figure 17 depicts the various elements of the ITS system installed by HCTRA.

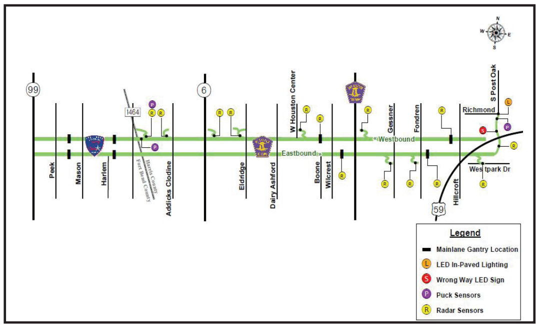

Figure 17. Westpark Tollway WWD Detection Sensors (HCTRA 2012)

In October 2008, the HCTRA WWD detection and warning system became fully operational, able to determine exactly where vehicles were entering the system in the wrong direction. When a wrong-way incident is detected by the system, an audible alert is broadcast over the speakers at the TMC, and simultaneously an automated call slip with the location of the wrong-way driver is sent to dispatchers by the Incident Management System (IMS). Next, the system interfaces with the HCTRA GIS-based maps to zoom in on the location and direction of travel. A photo of this GIS-map is shown in Figure 18. The TMC dispatchers use this information to broadcast the location of the incident to the nearest law enforcement units in the field. Additionally, to visually verify a wrong-way driver has entered the system, the IMS queries the HCTRA closed-circuit television (CCTV) software to automatically pan, tilt, and zoom nearby cameras to the vicinity of the incident. Upon visual confirmation, the dispatcher posts the most appropriate archived message such as “Wrong Way Driver Ahead” and “All Traffic Move to Shoulder and Stop” on the full-color Dynamic Message Signs (DMS) warning other motorists of the incident while responding law enforcement units attempt to intercept the vehicle (HCTRA 2012).

Figure 18. Automatic WWD Warning System at TMCs of the HCTRA (Image: Huaguo Zhou)

According to HCTRA, in 2012, thirty WWD incidents were detected by the system, and *“twenty-two were verified on closed-circuit television (CCTV) u-turning around to correct themselves; seven drivers were verified on CCTV facing the correct way but reversing on the main lanes to take an exit that was missed; and one driver was located by law enforcement after driving the wrong-way and getting stuck trying to correct their direction of travel”* (HCTRA, 2012).

Moreover, since the implementation of the wrong-way detection system in 2008, law enforcement units succeeded in stopping nineteen WWD motorists. Eleven of those nineteen motorists were determined to be impaired and were arrested, and three others were arrested for other traffic violations. The remaining five motorists were issued WWD-related citations (HCTRA, 2012). Taken as a whole, these results confirm that ITS can be an effective strategy to addressing WWD on a system level.

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CASE 7: Wrong-Way Entry ITS Warning System Buffalo, New York

The New York State Thruway Authority (Thruway) operates 570 miles of tolled expressways across the state, most of which has been incorporated into the Interstate System, placing it among the largest and busiest toll road networks in the United States. According to their website, the Thruway "is interested in pursuing new technologies to improve operations, increase safety, enhance energy efficiency and reduce environmental impacts." As evidence of this, the Thruway recently implemented a new ITS-based, wrong-way entry warning system at Porter Avenue (Exit 9) along I-190 in Buffalo, and plans to install the system at additional sites elsewhere in the state.

Thruway engineers began closely examining wrong-way incidents and crashes following a series of fatal crashes that had occurred in different locations across their system in recent years. Upon reviewing incident data, examining existing interchange characteristics, and consulting local Thruway staff and State Police, the Thruway decided to install an ITS-based warning system at a handful of locations with histories of wrong-way problems.

The system implemented by the Thruway consists of two major components: Doppler radar detection and programmable, changeable message signs. A solar power station is an option for locations where electricity is not readily available. This system is illustrated in Figure 19.

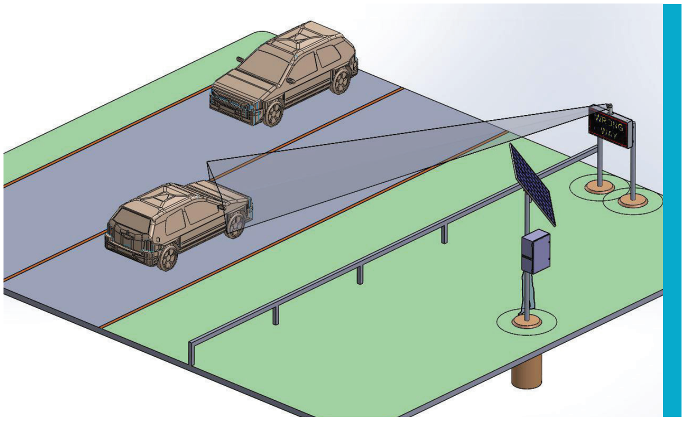

Figure 19. Conceptual Rendering of N.Y. Thruway WW Entry ITS Warning System (Image: Courtesy of Fiberdyne Labs, Inc., and Herkimer Industries)

The use of Doppler radar detection allows for the wrong-way detection to be customized to a particular location's geometric design and traffic characteristics, as the sensitivity and coverage can be adjusted, while also avoiding the need to cut into the pavement. The programmable, changeable message signs use light emitting diode (LED) boards, which allow for different colors, message text and shapes, and are able to adjust brightness according to local lighting. The LED boards are activated after a wrong-way vehicle is detected by the Doppler radar.

The initial installation at Exit 9 (Porter Avenue) in Buffalo directs a series of messages to a wrong-way driver in the following sequence: "WRONG WAY", "STOP" and "PULL OVER", as shown in Figure 20. The system is also designed to send alerts to other parts of the Thruway communication infrastructure, such as the Traffic Management Center, State Police and even other variable message signs along the mainline in the vicinity of the detected wrong-way entry.

Figure 20. N.Y. Thruway Wrong-way Entry ITS Warning System (Images: taken from video from New York State Media Services Center)

This system was conceived by Thruway engineering staff, and was further developed and tested in partnership with the hardware manufacturers. The cost of this system was $10,000 per sign, inclusive of the development and testing. Since this countermeasure was implemented only very recently, there is no data on the effect on wrong-way incidents or crashes. A photo taken during construction of the system in November 2013 is shown in Figure 21.

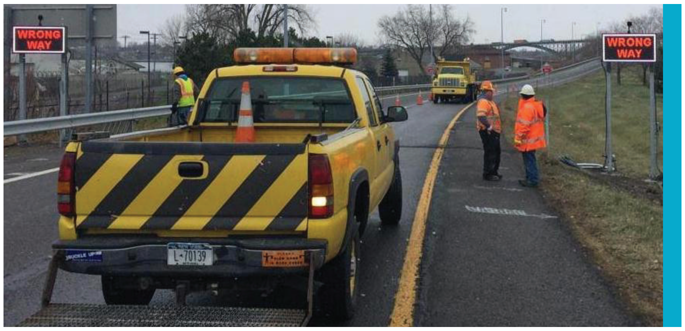

Figure 21. N.Y. Thruway Wrong-Way Entry ITS Warning System at I-190 Exit 9 (Porter Avenue), Buffalo N.Y. (Image: Justin Welyczko, Fiberdyne Labs, Inc.)

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CASE 8: Enhanced DO NOT ENTER and WRONG WAY Signs Various Locations in Illinois and Texas

Several studies concluded that impaired drivers, older drivers, and fatigued drivers were overrepresented in wrong-way driving crashes (Copelan 1989; Moler 2002; NTTA 2009; and Zhou et al. 2012). Other studies (FHWA 2001; and Potts et al. 2004) suggest that signs that are larger than the minimum required dimensions can increase their visibility, especially for older drivers at night.

The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009) requires a minimum of one DO NOT ENTER sign where traffic is prohibited from entering a restricted roadway, as well as one WRONG WAY sign placed along the right side of the exit ramp or one-way roadway, some further distance beyond the crossroad. The MUTCD prescribes the nominal (minimum) dimensions of the signs based on the type of roadway and number of lanes (i.e. single or multiple lanes, expressway or freeway, etc.). However, the MUTCD allows as an option the use of larger-than-minimum-dimension signs, stating that there may be situations for "special applications where speed, volume, or other factors result in conditions where increased emphasis, improved recognition, or increased legibility is needed, as determined by engineering judgment or study.

In response to an increase in wrong-way driving crashes in the Chicago area, the Illinois Department of Transportation (IDOT) replaced nominal sized DO NOT ENTER signs with larger ones, going from 30"×30" to 36"×36" to increase the visibility of these signs at a number of exit ramps. Figure 22 depicts a comparison between the conditions before and after improving at IL 394 northbound to US 30 westbound Will County.

Figure 22. Before (top) and After (bottom) Pictures of DNE Signs at I.L. 394/US 30 (Image: Regina Cooper)

Another example of oversizing signs to address WWD comes from the North Texas Tollway Authority (NTTA) in the Dallas area. This location is at the southern terminus of the Dallas North Tollway where it joins side-by-side with a one-way local street and becomes part of the local street network. NTTA observed a high frequency of wrong-way incidents originating from this area due to the adjacent developments and the unique roadway configuration. Similar to the WWD countermeasures that NTTA deployed at other locations on their system, this site was treated with multiple oversize signs, flashing LED border signs, red retroreflective strips on sign posts, lower mounted DO NOT ENTER and WRONG WAY signs, and red retroreflective raised pavement marker (RRPM) enhanced wrong-way arrows all at the same location. Since the implementation of these treatments, the number of WWD incidents has decreased. While it is not possible to explicitly associate the WWD reduction to one specific countermeasure, the larger signs contribute to the overall enhanced visibility and conspicuity of the location, and provide a degree of valuable redundancy to further ensure that WWD is less likely. Figure 23 depicts the first set of enhanced WRONG WAY signs used by NTTA at this location.

Figure 23. Three Pairs of Large WW Signs by NTTA (Image: Huaguo Zhou)

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CASE 9: Enhanced Pavement Markings Various Locations in Illinois and Texas

Pavement markings provide road users with visual cues on the roadway regarding the proper direction of traffic and lane use (including through and turning movements). Several studies (Copelan 1989; Vicedo 2006; Braam 2006; and NTTA 2009) indicate that certain enhanced pavement markings can be effective in reducing WWD incidents, including lane-use arrows, wrong-way arrows, lane line extensions, and stop lines at the end of exit ramps.

As part of its efforts to address WWD incidents, the Illinois Department of Transportation (IDOT) improved the pavement markings at several exit ramp intersections to provide additional guidance for motorists. Figure 24 provides a comparison between "before" and "after" conditions along Ohio Street at Interstate 90/94 in Chicago.

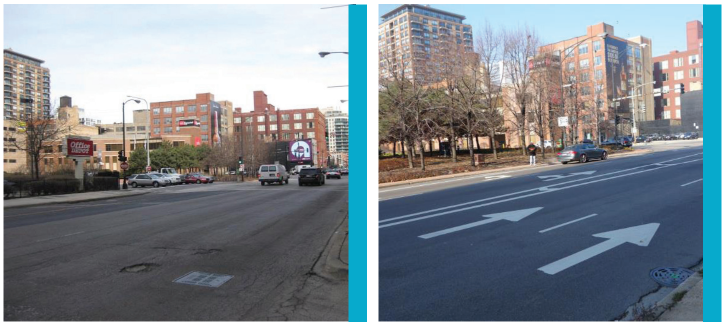

Figure 24. Before (left) and after (right) Conditions of the Pavement Marking Improvements at an Ohio Street (Image: Huaguo Zhou)

The North Texas Tollway Authority (NTTA) also utilized a variety of pavement markings to address WWD, such as through movement arrows on arterials, and stop line and wrong-way arrows at exit ramps. Within the Dallas area, a total of 22 lane-use arrows were applied at several cross streets in 2011. Since then, the number of incidents at those locations has declined from 5 during the six month "before" period to 3 during the six month "after" period.

NTTA also addressed issues related to how pavement markings were typically applied at exit ramps of diamond interchanges. One issue involved locations where a left-turn lane extended beyond the limits of the ramps due to heavy turning movement queue storage. Typically, left-turn arrows were used along the entirety of the left-turn lane, including the portion beyond the far-side ramps. However, realizing that the left-turn arrows could be mistakenly associated with the exit ramp, NTTA replaced the left-turn arrows with through lane-use arrows. Figure 25 depicts the "before" and "after" conditions at the intersection of U.S. 380 and Dallas Parkway. Following NTTA's finding and recommendations, a group of traffic engineers in the Dallas-Fort Worth region convened to review and recommend consistent pavement marking practices at all diamond interchanges throughout the region. These recommendations are now being implemented.

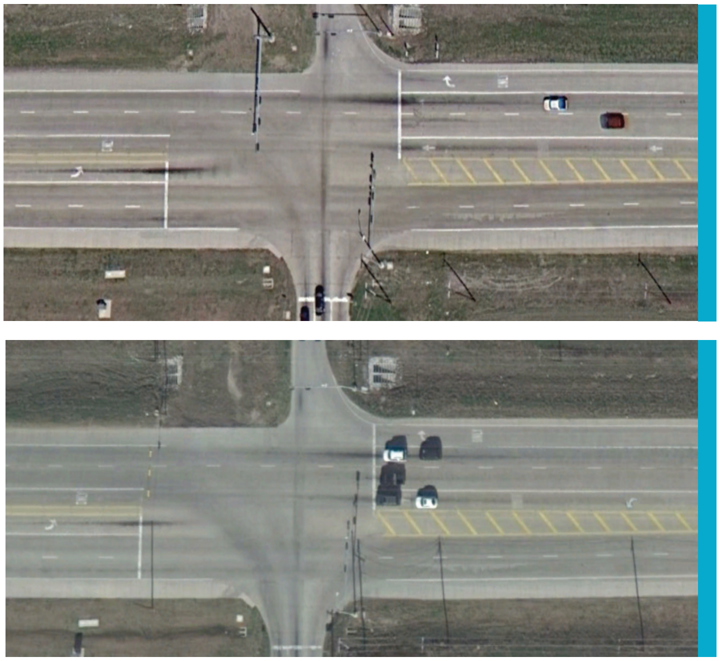

Figure 25. Before (top, 2009) and After (bottom, 2010) Pavement Marking Modifications at U.S. 380 and Dallas Parkway (Image: Google)

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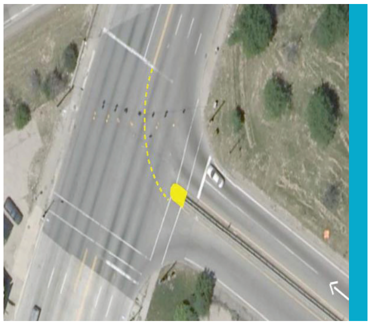
CASE 10: Countermeasure Package for Partial Cloverleaf Interchanges - Various Locations in Michigan

Several studies (Howard 1980; Copelan 1989; Moler 2002; Cooner et al. 2004; Braam 2006; and Neuman et al. 2008, Zhou et al. 2012) have demonstrated that certain interchange types and ramp designs, particularly partial cloverleaf and diamond layouts, may be particularly susceptible to wrong-way movements. A recent study (Morena and Leix, 2012) by the Michigan Department of Transportation (MDOT) and Federal Highway Administration (FHWA), identified 35 wrong-way crashes throughout the state of Michigan in 2010, and concluded that 60 percent of those crashes could be traced to wrong-way entries at partial cloverleaf, or "parclo", interchanges.

With this information, researchers then assessed the characteristics of the parclo interchanges, and concluded that side-by-side, parallel exit and entrance ramps in the same quadrant, intersecting at or near a perpendicular angle with a crossroad, created a situation where drivers could be confused about which roadway to turn on to. MDOT then assembled a package of multiple low-cost countermeasures that would address this situation by providing more extensive and comprehensive visual cues, and targeted 161 of these interchanges across the state for implementation. The WWD countermeasure package consisted of:

1. Lower DO NOT ENTER and WRONG WAY Sign Mounting Height (4 feet from the edge of the pavement)
2. Red Retroreflective Strips on Sign Supports
3. Stop Lines
4. Exit Ramp Wrong-way Arrow
5. Pavement Marking Extension
6. Painted Island
7. Wrong-way Delineation

MDOT selected four feet as the sign mounting height because this height puts the signs more directly in a wrong-way driver's cone of vision, and it also better coincides with where vehicle headlights are aimed, as many WWD incidents occur at night. Figure 26 illustrates the pavement marking extension and stop line countermeasures implemented by MDOT at two locations. MDOT estimated the average cost of implementing this countermeasure package at approximately $6500 per treated exit ramp.



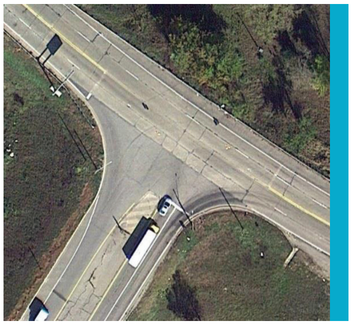


Figure 26. Pavement Marking Extensions for Left-turn Movement from Crossroad (left) and Stop Line (right) for Exit Ramps Next to Parallel Entrance Ramps (Image: MDOT)

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Part II: Geometric Design Examples

This chapter presents various geometric design treatments for discouraging WWD based on a review of technical literature and current design policies in the United States. Past studies (Copelan 1989; Moler 2002; Braam 2006; Leduc 2008; Zhou et al. 2012) have indicated that certain interchange configurations and ramp geometric designs may be more susceptible to WWD incidents, but that minor geometric changes can effectively reduce the number of wrong-way entrances onto freeways. Although major geometric modifications are seldom proposed to prevent WWD incidents, some geometric elements, which are less expensive and easily applicable to the site, should be considered more frequently.

Geometric Elements

1. Raised Medians: This solution can be applied wherever left-turn wrong-way maneuvers from a crossroad onto exit ramps are a major of concern. Figure 27 illustrates an example of a raised median at a divided crossroad.

Figure 27. Raised Median to Discourage Wrong-Way Left-Turn Movements (Image: Google)

However, when raised medians are used to separate movements along the same direction of traffic flow on some exit ramps, it can actually cause a driver to mistake the far side of the raised median as an entrance ramp, especially at night and when traffic volumes are low. Figure 28 illustrates an example of using a raised median to separate the dual left-turn and through movements along the same direction of an exit ramp.

Figure 28. Raised Median for Separating Same Direction Traffic on an Exit Ramp (Image: Google)

2. Median Barrier: This element can be applied when the proximity of exit and entrance ramps can cause confusion to drivers. Figure 29 exhibits the application of concrete barriers (highlighted in red) to separate exit and entrance ramps of a trumpet interchange in order to eliminate wrong-way maneuvers.

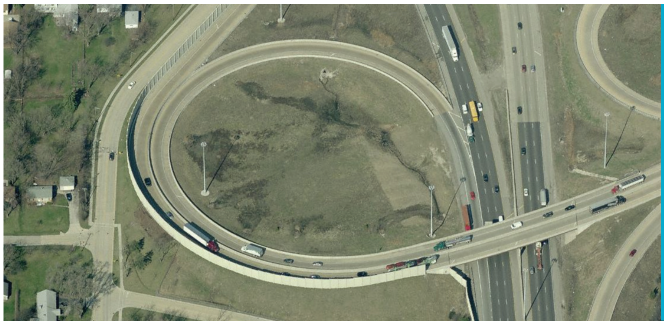

Figure 29. Application of Median Barrier at Trumpet Interchange (Image: Bing)

While utilizing concrete barriers or guardrails as median barriers, it should be noted that these devices can cause a sight distance problem for drivers on the crossroad if used to separate adjacent entrance and exit ramps at partial cloverleaf interchanges. Figure 30 depicts a guardrail blocking a left-turning driver's view of an entrance ramp throat.

Figure 30. Median Barrier (Guardrail) Blocking View of Entrance Ramp Throat (Morena and Leix 2012)

3. Control Radius: Use of a short-radius curve or angular break at the intersection of the left edge of an exit ramp and the right edge of a crossroad (Figure 31) can make the right-turn wrong-way movements harder or more awkward, and therefore less likely. If a curve is used as the control radius, the crossroad centerline, and not the edge of the crossroad, should be considered as the tangent line (Figure 32).

Figure 31. Right Angle Between the Left Edge of Exit Ramp and Right Edge of Crossroad (Image: Bing)

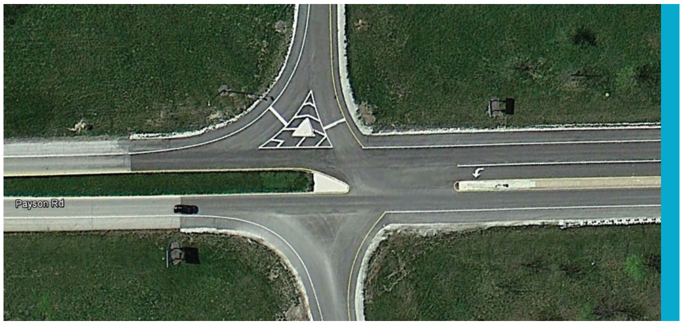

Figure 32. Control Radius Tangent to the Centerline (Image: Google)

4. Channelizing Island: Application of a channelizing island is an effective way to reduce wrong-way movements, especially among older drivers. This element can reduce the width of the exit ramp throat and reduce the possibility of wrong-way entries (Figure 33).

Figure 33. Utilizing Channelizing Island to Reduce the Exit Ramp Throat Width (Image: Google)

Geometric Design Examples at Conventional Diamond Interchanges

Figures 34 and 35 are excerpts from A Policy on Geometric Design of Highways and Streets (AASHTO, 2011), referred to as the “Green Book,” that address how to use geometric design features to discourage wrong-way maneuvers along undivided and divided crossroads at conventional diamond interchanges. For undivided crossroads, the control radius and channelizing island are often used to prevent wrong-way entries. For divided crossroads, raised median, control radius, and channelizing islands can be used to discourage wrong-way movements.

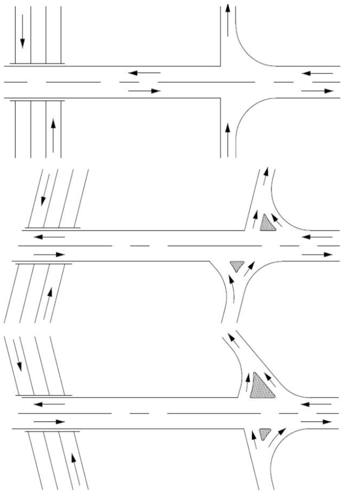

Figure 34. Two-Lane Crossroad Design to Discourage Wrong-Way Entry (AASHTO 2011)

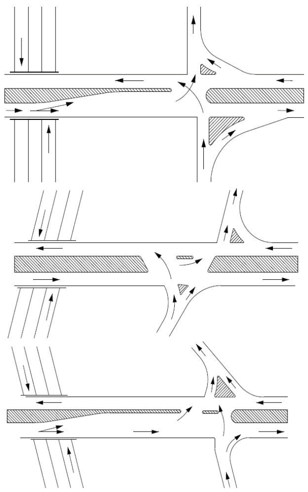

Figure 35. Divided Crossroad Design to Discourage Wrong-Way Entry (AASHTO 2011)

Figure 36 depicts a real-world example of the proper use of a raised median, control radius and channelizing island at the intersection of ramps of a conventional diamond interchange with crossroads. The control radius for left-turn wrong-way movements onto exit ramps is approximately angular. Channelizing islands reduce the width of the exit ramp entrance and a raised median is also extended far enough to prevent possible left-turn wrong-way movements onto the exit ramp.

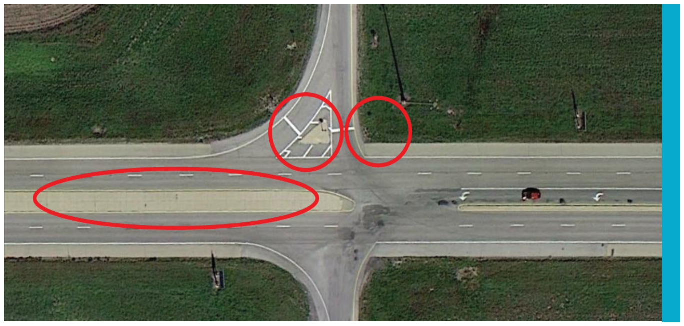

Figure 36. Diamond Interchange Design for WWD Mitigation (Image: Google)

Geometric Design Examples of Partial Cloverleaf Interchange

Figure 37 illustrates a ramp-crossroad design approach to discourage wrong-way entries from the Illinois Department of Transportation (IDOT 2010). The raised median and channelizing island are used to decrease the likelihood of potential left-turn wrong-way movements. An 80-foot radius is suggested for left-turn movements from the crossroad onto the entrance ramp, and a 100-foot radius is suggested for left-turn movements from the exit ramp onto the crossroad.

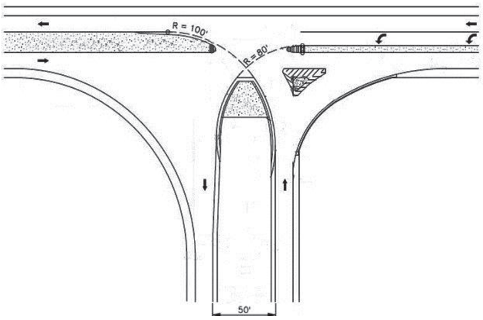

Figure 37. Typical Ramp-Crossroad Design for a Two-Quadrant Partial Cloverleaf Interchange (IDOT 2010)

Figure 38 represents a ramp/crossroad intersection for a partial cloverleaf interchange, which, as mentioned earlier, may be more susceptible to wrong-way movements due to the arrangement and proximity of exit and entrance ramps. Highlighted in the figure are the control radius, raised median, and channelizing island -all geometric features intended to mitigate WWD potential.

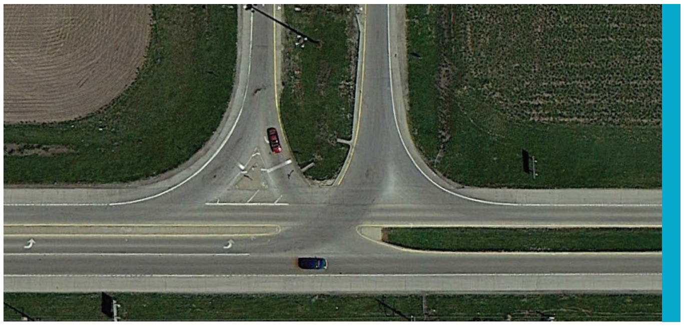

Figure 38. Partial Cloverleaf Interchange Design for WWD Mitigation (Image: Google)

Other Strategies

There are other geometric design strategies related to WWD that should inform the evaluation of an interchange and ramp-crossroad intersection, including:

1. Maintaining sufficient sight distance along the entire length of the ramp and at the ramp intersections
2. Avoiding unusual or odd arrangements of exit ramps, such as:
    A. Isolated exit ramps;
    B. Left-side exit ramps;
    C. Button-hook or J-shaped ramps (illustrated in Figure 39);
    D. Joining exit ramps to two-way frontage roads;

Figure 39. Button-Hook (J-shaped) Ramp Connecting Two-way Frontage Road and Freeway (Image: Bing)

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Wrong Way Driving

Road Safety Audit Prompt List

Purpose

This document contains a Road Safety Audit (RSA) prompt list intended to focus specific attention on Wrong Way Driving (WWD) issues and contributing factors. The prompt list has been developed in a similar framework to the broader RSA prompt lists contained in Chapter 8 of the FHWA RSA Guidelines document. Like the original lists, the Wrong Way Driving prompt list is intended to help the RSA team identify potential safety issues, avoid overlooking important factors, and proactively identify potential issues. The prompts are only an aid to the RSA team and they are not intended to cover all conditions or circumstances an RSA team may encounter.

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Numerous studies of the contributing causes and issues surrounding WWD crashes, conducted primarily by State departments of transportation since the 1960s, indicate that WWD crashes are much more likely to result in fatalities or severe injuries than other highway crash types and highlight several factors that must be acknowledged by any WWD-related RSA. Categorically, there are significant human factors and environmental conditions generally associated with WWD crashes. Various research efforts have found the following correlations:

- A substantial percentage of wrong way drivers are impaired by alcohol.
- Over-representation of certain driver age groups, such as older drivers (particularly those over the age of 70) and younger drivers (under the age of 25).
- The majority of WWD crashes that result in a fatality occur at night, when visibility of roadway attributes and signs are diminished, and a disproportionate number occur on the weekend, which potentially coincides with elevated levels of alcohol consumption amongst the driving population.

Based on this information, RSA teams should carefully consider the conditions under which to conduct an RSA that includes review of WWD crashes. The RSA should consider the potential for various human factors, such as impaired driving, older drivers with diminished eyesight, and inexperienced drivers prone to driving mistakes, to affect WWD crash potential.

Additionally, environmental factors, such as nighttime conditions or elevated traffic activity related to events on weekends, may affect safety within the RSA site. For instance, it may be critical for WWD-related RSA teams to involve user groups comprised of drivers in the most vulnerable demographics and schedule field reviews to coincide with the prevailing crash periods, including nighttime, weekends, and closing time for drinking establishments. Given the elevated severity potential of WWD crashes, the RSA team is encouraged to consider the perspective of critical RSA partners, including law enforcement and emergency response agencies, whose knowledge of localized conditions and vulnerable user groups may be critical to developing mitigation strategies, outreach approaches, and enforcement policies.

Wrong Way Driving RSA Prompt List

Master Prompt List

Scope of Project, Function, Traffic Mix, and Road Users	Design	Signs and Markings	Time of Day Conditions	Seasonal and Temporary Conditions
Proximity of freeway access and intersections	Alignment	Positioning (conspicuity)	Lighting	Weather
Older, unfamiliar, intoxicated drivers	Spacing	Visibility (day and night)	Visibility	Construction
Changes in traffic volume and mix	Visibility	Clutter	Peak vs. off-peak traffic conditions	
	Sight lines	Confusion		
	Lane configuration	Supplementary signs and pavement markings		

Detailed Prompt Lists

Scope of Project, Function, Traffic Mix, Road Users

Does the study area include all critical freeway access points and other intersections in close proximity?

Is there reasonable expectation of older (over the age of 70) or younger (under the age of 25) drivers in the study area?

Is the study area located in proximity to or along a corridor with drinking establishments?

Is there a significant population of drivers who may be unfamiliar with the facility, particularly during nighttime conditions?

Are there notable differences in traffic activity during nighttime conditions, as compared to daytime conditions?

Design

Are any exit ramps located adjacent to entrance ramps (i.e., a partial cloverleaf design)?

Does ramp alignment reinforce appropriate access to ramps and deter WWD?

Do local roadways or driveways intersect near interchange ramps?

Is the spacing between ramps and/or intersections adequate to allow drivers to clearly identify the correct direction to travel?

Are entrance and exit ramps separated by pavement markings, median, or other physical separation? Is the median or other physical separation conspicuous?

Do medians, channelization, or other physical barriers prohibit or deter wrong way access to the freeway ramps?

Does guardrail, or any other traffic barrier along or between ramps, obstruct visibility of the respective ramps?

Could the layout and/or number of lanes on exit ramps contribute to potential driver confusion when approaching from the mainline roadway?

Does vehicle queuing or spillover between ramps or intersections affect sign visibility or driver behavior?

Is the corner radius at an exit ramp designed to deter wrong way entry by turning vehicles?

Is the paved width (total of lanes and shoulders) of the ramps adequate for turning movements of design vehicles, but to the point of creating potential wrong way confusion?

Do any paved shoulders along the ramps detract from lane channelization?

Does horizontal or vertical curvature affect visibility of interchange ramps or signs?

Are sight lines on ramps and at ramp termini appropriate for the location, traffic, and vehicle speeds?

Are traffic signals or other traffic control devices configured to reinforce the proper travel directions for ramps?

Signs and Markings

Are signs at both entrance and exit ramps positioned to be conspicuous to drivers approaching from all directions?

Do parked vehicles, pedestrian activity, vegetation, other signs, or roadside objects affect the visibility of regulatory signs, warning signs, or geometric conditions at entrance and exit ramps?

Are DO NOT ENTER, WRONG WAY, and ONE WAY signs provided on freeway exit ramps? What sizes are the signs? What height are they posted? Are signs double-posted? Are the signs in adequate condition?

Are supplemental signs provided on the approaching roadways (i.e., warning or regulatory signs to deter left and right turns from a roadway onto an exit ramp)?

Are appropriate wayfinding or guide signs provided at freeway entrance ramps?

Could any steps be taken to draw driver attention to entrance ramps when approaching an interchange?

Are dynamic warning systems (such as actuated Wrong Way signs) provided on any exit ramps?

Are signs or other visual cues to deter WWD provided along the length of the exit ramp and at the junction of the exit ramp and freeway?

Does the presence of non-warning or non-regulatory signs contribute to sign clutter or driver confusion?

Wrong Way Driving RSA Prompt List (continued)

Are any directional arrows or other pavement markings provided on exit ramps?

Are dashed markings (i.e. skip markings) or reflective pavement markers provided to guide left-turn movements at the proper locations?

Time of Day Conditions

Is lighting provided at exit ramps locations? Is lighting functional?

Are signs and markings that are clearly visible at night (i.e. illuminated or sufficiently retro-reflective) provided at ramps?

Are signs mounted at heights and positions consistent with where drivers will be looking?

Does sun glare at certain hours of the day affect driver visibility of exit ramp signs or markings from any approach?

Do area traffic generators experience unique volume peaks at unusual hours or days?

Seasonal and Temporary Conditions

Does crash data suggest any trends that may indicate seasonal contributing factors?

Does inclement weather affect the visibility of signs or geometric conditions at or approaching interchange ramps?

Have freeway construction or other temporary conditions impacted the visibility or retention of adequate signs at exit ramps?

For more information on Road Safety Audits

Federal Highway Administration
FHWA Road Safety Audit Guidelines
Publication No. 33 FHWA-SA-06-06
Washington, D.C. 20006

http://safety.fhwa.dot.gov/rsa/guidelines

RSA
Making Your Roads Safer

Notes

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