Current Practices of Safety Countermeasures for Wrong-Way Driving Crashes

Mahdi Pour-Rouholamin*
Ph.D. Graduate Student, Department of Civil Engineering
Auburn University, Auburn, AL 36849-5337
Phone: +1-618-660-4123
mahdipn@auburn.edu

Huaguo Zhou
Associate Professor, Department of Civil Engineering
Auburn University, Auburn, AL 36849-5337
Phone: +1-334-844-1239
zhouhugo@auburn.edu

Jeffrey Shaw
Highway Engineer, Office of Safety
United States Department of Transportation, Federal Highway Administration
Phone: +1-708-283-3524
Jeffrey.Shaw@dot.gov

Priscilla Tobias
State Safety Engineer, Bureau of Safety Engineering
Illinois Department of Transportation (IDOT) Division of Highways
Phone: +1-217-782-3568
Priscilla.Tobias@illinois.gov

*Corresponding Author

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ABSTRACT

Driving the wrong way on high-speed, physically divided highways, namely wrong-way driving (WWD), has been a consistent issue in the United States since the introduction of the interstate system in the 1950s. This type of crash, which constitutes only about three percent of crashes on these facilities, tend to be more severe, increasing the probability for fatalities or incapacitating injuries. Despite employing numerous countermeasures to combat WWD issues in the nation, no recent research has been conducted to investigate the effectiveness and level of acceptance of these countermeasures and current practices. The purpose of this paper is to fill this gap by assessing the information gathered from a survey at the first National WWD Summit held in July 2013 and by studying emerging countermeasures currently employed in various jurisdictions. On the basis of analyzing the survey results and developed countermeasures, an insight into various characteristic aspects of WWD countermeasures is provided.

Keywords: Wrong-way Driving (WWD); Countermeasure; Survey; Case Study

INTRODUCTION

Wrong-way driving, defined as the movement against the stream of traffic on freeways, expressways, interstate highways, and their access ramps, has been found to be a major concern for more than six decades (*1, 2, and 3*). A query on the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) revealed that from 2004 to 2011, an average of 359 people perished in 269 fatal WWD crashes per year (*4*). To overcome this, various countermeasures, ranged from low-cost (e.g., signs and pavement markings), to more expensive (e.g., geometric modification and ITS technologies), have been applied to minimize frequency and severity of the problem. However, there is still a lack of a comprehensive insight of the current practices and regulations to make a consistent guideline for WWD mitigation at the national level.

The first National Wrong-way Driving Summit, sponsored by the Illinois Center for Transportation (ICT) and the Illinois Department of Transportation (IDOT), was held on July 18-19, 2013, in Edwardsville, Illinois. The purpose of this Summit was to provide a platform for both practitioners and researchers to exchange ideas, to evaluate current countermeasures, and to develop the best practices to reduce WWD crashes and incidents through a 4E's approach (Engineering, Education, Enforcement, and Emergency Response). In order to enhance the quality of this Summit, a significant number of representatives were brought together to discuss various topics during presentations as well as during group discussion sections from all around the nation, including the National Transportation Safety Board (NTSB), the Federal Highway Administration (FHWA), the American Traffic Safety Services Association (ATSSA), and members from state departments of transportation, state police, state highway patrols, Tollway authorities, universities, and consulting firms. Approximately 130 attendees participated in this Summit from 23 states, including states that have already implemented and tested various countermeasures and states that have labeled WWD as a major concern. Based on the survey results, and the Summit's discussions and presentations, the countermeasures outlined in Table 1 were found to be either implemented by various agencies or worthy of implementation for mitigating WWD incidents and crashes.

TABLE 1 Various WWD Countermeasures Implemented by Different Agencies (*5*)

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

The purpose of this paper is to give an overview of current practices of WWD countermeasures through the Summit's survey results and to identify the emerging WWD countermeasures through 10 case studies in which these countermeasures have been successful in addressing the issues. Table 2 summarizes the 10 case studies of various emerging countermeasures and their corresponding locations.

TABLE 2 Case Studies of Emerging Countermeasures

Countermeasure	Location
1. Low-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 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	Houston, Texas
7. Wrong-Way Entry ITS Warning System	Buffalo, New York
8. Enhanced DO NOT ENTER and WRONG WAY Signs	Various Locations in Illinois and Texas
9. Enhanced Pavement Markings	Various Locations in Illinois and Texas
10. Countermeasure Package for Partial Cloverleaf Interchanges	Various Locations in Michigan

LITERATURE REVIEW

Numerous studies have already been conducted to evaluate the effectiveness of the WWD-related countermeasures both in the U.S. and outside the country. While some of these studies have focused merely on one specific countermeasure, some others evaluated the effectiveness of a countermeasure package instead. In other words, they were not able to quantify the effect of each countermeasure separately or to relate a portion of the reduction in the number of wrong-way maneuvers to one specific countermeasure (e.g., Delineation, DO NOT ENTER sign).

In 2005, Chrysler and Schrock (*7*) conducted a before-after study to investigate the effect of directional arrows painted on two-way frontage roads on the number of wrong-way maneuvers. In doing so, one location, which was a short section of a two-way frontage road transitioned into an exit ramp, in College Station, Texas, was chosen for experiment. The pavement marking treatment was actually a pair of nine-foot, thorough lane-use arrows, as defined by the MUTCD, located 120 feet away from the gore of the exit ramp. Analysis of the results demonstrated a 90% reduction in the number of wrong-way maneuvers. In other words, incorrect movements dropped from 7.4% of the correct movements in the before to only 0.7% in the after period.

Campbell and Middlebrooks (*8*) studied the effect of a package of countermeasures for wrong-way driving of an exit ramp in Atlanta, Georgia, using actual counts. These countermeasures include: trailblazers, lowering WRONG WAY signs, placing stop bar at the end of the studied exit ramp, and installation of the yellow ceramic buttons to improve the visibility of longitudinal pavement markings. Their observations revealed that the rate of wrong-way maneuvers reduced from 88.6 per month to 2.0 per month after the countermeasure application, representing more than 97% reduction.

Vaswani (*9*), in a research sponsored by Virginia Department of Transportation (VDOT), conducted a before/after study to evaluate the effectiveness of a “Divided Highway Crossing” sign on mitigating wrong-way movements. Route 29 was chosen for the experiment and the signs were placed at the intersections along the corridor. Their study included three years before the improvement data collection and a period of seven months after the installation of sign. Field observations showed nine wrong-way maneuvers during the before study while these movements were completely eliminated after sign implementation.

METHODOLOGY AND DATA COLLECTION

A survey questionnaire was designed to collect the data concerning current practices of WWD countermeasures from the Summit. Questions and sections of the questionnaire were assembled and organized based on a thorough review of previous studies that were refined according to the feedback received from a panel of experts. These questions were arranged to gather necessary data in a logical, hierarchical order of sections, from general data to more specific with conclusive questions, as follows:

- The first section of the questionnaire was dedicated to the general questions, such as the importance of the problem in the specific jurisdiction, the types of countermeasures implemented, the employment of any monitoring program, etc.
- The second section was concerned with the characteristics of WWD signage, including type, size, and location of signs, and the methods used for augmenting the visibility of wrong-way related signs.
- The third section was aimed to decipher the types and characteristics of wrong-way-related pavement markings as well as their retroreflectivity.
- The fourth and fifth sections of the questionnaire were concerned with traffic signals and geometric modifications.
- Intelligent Transportation Systems (ITS) and their role in mitigating WWD issues in various states were evaluated in the sixth section.
- Lastly, the questionnaire was finalized with closing questions to gather new ideas from the participating states.

The survey questionnaires were distributed to representatives from 23 states. Sixteen states responded to the survey, including states that have already implemented and tested various countermeasures (e.g., Illinois, California, Texas, Michigan) and those that have future plans to address this problem. Of these participants, half have already conducted WWD studies in their jurisdictions; the remaining half are planning to conduct similar studies or to implement some type of countermeasure they learned from the Summit. Nearly half of the WWD fatalities from 2004 to 2011 occurred in these 16 participating states, providing a reliable sample for the purpose of this research. (*4*).

Aside from the questionnaire, presentations and discussions from the Summit recognized current, undergoing efforts made by the represented states. These efforts were all reviewed to investigate their consistency with current practices. In addition, 10 case studies, mostly chosen from this Summit, were conducted to investigate the effectiveness of those emerging safety countermeasures. This study was funded by ATSSA and co-sponsored by FHWA and IDOT.

FINDINGS AND DISCUSSION

After collecting all the required data from a thorough literature review, contact persons, and respondents for each of the questions and cases, an analysis on the data was performed to disclose any possible trends, to draw conclusions, and to provide suggestions. These findings are presented below and organized into two major groups: survey questionnaire and case examples.

Survey Questionnaire

General Information

Initially, respondents were asked if the WWD is a severe problem in their jurisdiction with nearly 70.0% agreed it is a severe issue in their state. Regarding employing pertinent countermeasures, 63.0% of state representatives admitted they have implemented exclusive countermeasures to reduce WWD incidents and crashes, while the remaining claimed they are following regular policies and guidelines without specific emphasis on WWD mitigation. In terms of type of countermeasure, Engineering (91.7%), Program and Funding (50.0%), Enforcement (33.3%), and Education (16.7%) were the most popular ones. Only one state confirmed employing a comprehensive 4E's program. A WWD monitor program has been developed in 31.0% of participating states. This program is designed to obtain information about the location, severity, time of day, etc. for wrong-way collisions.

While current guidelines and manuals (e.g., Green Book, MUTCD) ask practitioners to meet minimum requirements in order to combat WWD issues, around one-fifth of the states have added supplements to the Manual on Uniform Traffic Control Devices (MUTCD) and have intensified the regulations. On the other hand, just one state has supplements to the American Association of State Highway and Transportation Officials (AASHTO) Green Book.

Although some studies have found a relationship between low light conditions and possibility of wrong-way maneuvers, extra lighting at locations susceptible to wrong-way maneuvers is perceived as a good solution to help drivers distinguish the entrance ramp from the exit ramp when they are closely spaced; however, only one state currently provides extra lighting for such locations.

Wrong-way Related Signage

Several questions in the survey were directed toward the wrong-way-related signs. The first question was to identify the type and placement of two popular wrong-way-related signs: "DO NOT ENTER" (DNE) and "WRONG WAY" (WW). Table 3 summarizes the placement of these signs based on the type of facility where a wrong-way incident or crash may originate or occur.

TABLE 3 Percentage of States Considering Particular Type of Sign Based on the Location

Location	Percentage by type of sign	
	DNE	WW
Exit Ramp	87.5	100.0
Frontage Road	68.8	56.3
Divided Highway (along non-ramp sections)	81.3	75.0

One noteworthy conclusion drawn from Table 3 is the lack of attention to frontage roads. In regard to this, 68.8% of states implement the installation of DNE signs at frontage roads while this percentage drops to 56.3% for the installation of WW signs. This situation persists as past studies (*2, and 10*) have ranked frontage roads, which are connected to diamond interchanges, among locations with a high rate of wrong-way entries (entries per 100 interchanges per year); and additionally, two-way frontage roads are more confusing to drivers than one-way frontage roads when it comes to WWD (*11*). This fact implies that frontage roads need more attention in terms of WWD.

Various combinations of DNE and WW signs were identified through a review of existing documents and were asked to figure out the level of their applicability. These signs include: combined DNE signs above WW signs and doubled-up DNE and WW signs. These signs, along with the possible placement and pertinent findings (provided in percent), are compiled and presented in Table 4. Our findings reveal that combined DNE and WW signs are the more popular choice currently used by respondent agencies compared to the remaining two.

TABLE 4 Usage Percentage of Combination of DNE and WW Signs

Location	Sign		
			
Exit Ramp	50.0	Not Used	6.3
Frontage Road	18.8	Not Used	Not Used
Divided Highway (along non-ramp sections)	18.8	Not Used	Not Used

Signs conspicuity and its methods were two other significant questions. Figure 1 depicts the percentage of each method's application to improve the visibility of wrong-way signs. As illustrated, the majority of respondents use additional identical sign(s) on the left-hand side and they increase the size of sign to make it proportionate to the width of the target facility.

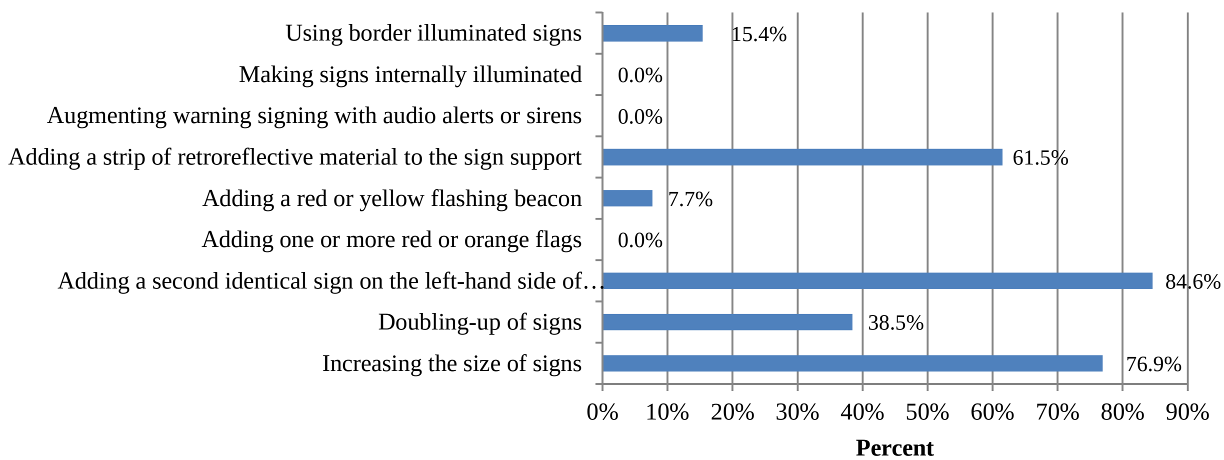

FIGURE 1 Various Methods of Enhancing Sign Visibility with Application Percentage

In terms of sign height, the vast majority of respondents (81.3%) used standard height for the signs as mentioned in the 2009 MUTCD (7 ft. in urban settings vs. 5 ft. in rural settings), and nearly half of the states lowered the signs in special conditions to the minimum height allowed by their manual (3 ft. in the MUTCD). Moreover, there were two states choosing to mount signs overhead.

Another issue with wrong-way related signs is that they do not face the intended user. In other words, the MUTCD requires (but does not mandate) the signs to be oriented toward the target users so that the highest possible visibility is attained. The survey indicates that while 62.5% of states chose to leave the signs perpendicular to roadways, the remaining have angled the signs toward potential wrong-way drivers (Figure 2).

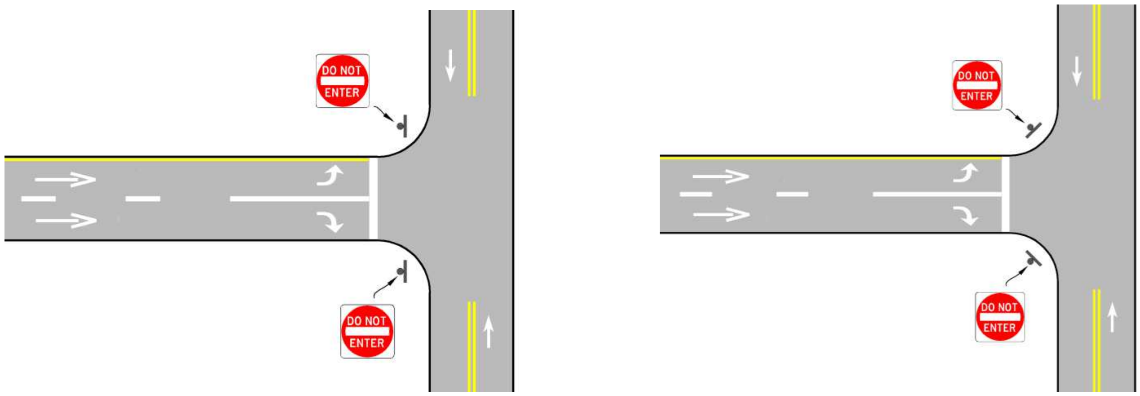

FIGURE 2 Schemes of Perpendicular Signs (left) and Angled Signs toward Intended Users (right) at Exit Ramps

Pavement Markings

Pavement markings (e.g., lane-use and wrong-way arrows, lane line extensions, and stop lines at the end of exit ramps) efficiently guide drivers through lanes by providing visual cues on the roadway. Conversely, the absence of proper pavement markings and/or improper or faded ones could lead to driver confusion.

While roughly 70.0% of respondents use the wrong-way arrow as described in the 2009 MUTCD, the remaining do not place this type of arrow or employ other ones. As for the placement of these markings, the majority of agencies place these arrows on the exit ramp near the intersection with a crossroad (71.4%) and at the middle of the exit ramp (64.3%); however, there are situations in which these kinds of pavement markings are located on the exit ramp near the gore point off the main line (21.4%) and on the main line (7.1%). All the respondents claimed that they are using retroreflective pavement markings and no agency is utilizing other types of illumination. Additionally, more than half (56.3%) of the states have equipped the pavement markings at problematic roads with red retroreflective raised pavement markers (RRPM). These devices are proven to be effective in helping drivers realize when they are traveling the wrong direction (*12*).

Traffic Signal

Zhou et al. (*2*) have found that changing traffic signal indication from a green circle to a green arrow at the intersection of one-way exit ramps and crossroads (e.g., diamond interchanges) can provide a better understanding of the allowed movements at the intersections and can reduce the possibility of WWD incidents. Therefore, 37.5% of the respondents claimed that their jurisdiction made this change to combat wrong-way problems.

Geometric Modification

Past studies (*2*, *3*, *6*, *13*, *14*, *15*, and *16*) have identified that interchange configurations as well as various geometric design elements can greatly affect the wrong-way entrances. These geometric elements can include: exit/entrance ramps, frontage roads, raised medians, and control radii.

In the questionnaire, respondents were asked to rank these various geometric elements with reference to the level of given attention in their jurisdictions. Afterward, these individual rankings were combined together using weighted percentage to get to a final weighted ranking. As would be expected, exit ramps (i.e., their angle with crossroad, their shape such as button-hook or J-shaped, etc.), were ranked the top priority because they constitute the most frequent origin of wrong-way driving incidents. Type of interchange was the second-ranked priority with channelizing islands as the third most important geometric considerations. Control radius at the ramp-crossroad intersection and the application of medians and their openings were the fourth and fifth remarkable geometric elements, respectively. Finally, frontage roads (i.e., their continuity, outer separation, one-way vs. two-way, etc.) were also the next geometric considerations for wrong-way mitigation. Table 5 summarizes these findings altogether with their corresponding weighted ranking.

TABLE 5 Ranking of Various Geometric Elements based on Weighted Percentage

Geometric Element	Weighted Percentage	Weighted Ranking
Exit Ramps	75.0	1
Type of Interchange	61.1	2
Channelizing Islands	58.3	3
Control Radius	50.9	4
Medians	47.2	5
Frontage Roads	37.0	6

Intelligent Transportation Systems (ITS) Technologies

ITS technologies can help in addressing WWD issues following three main steps: (1) Detection, which can be accomplished by application of numerous detectors, such as Inductive Loop Detectors (ILDs) and Video Image Processing (VIP); (2) Warning, which uses various methods, such as in-pavement warning lights, flashing wrong-way signs, warning lights, and Dynamic Message Signs (DMSs); and (3) Action, which is taken by responsible units coordinated with traffic management centers (TMC) to correct or intercept the at-fault driver (*4*).

Surprisingly, just one-third of agencies are found to exploit ITS technologies to identify wrong-way drivers and to take prompt and proactive actions. Radar detectors, closed-circuit television (CCTV) cameras, and ILDs were used as popular detectors. After detection, flashing wrong-way signs, warning signs, and DMS are available means of warning other drivers of an imminent danger ahead. Various messages may appear on DMS such as “Wrong Way Driver Ahead” and “All Traffic Move to Shoulder and Stop” (*17*). After detection and verification of the at-fault driver, patrol units may step in and position ahead of the wrong-way driver to either help the driver pull over or to correct his or her direction. If it is not possible to position, responding units may attempt to intercept the vehicle by deploying tire deflation devices (e.g., portable spike) to slow or stop the wrong-way driver or by using extra force to stop the vehicle.

Closing Remarks

At the end, respondents were asked to recommend elements of the WWD program based upon their experience. These recommendations include:

- Having a consistent approach or standard design for various geometrics of exit ramps;
- Prioritizing interchange types that are problematic and limiting their implementation to necessary situations;
- Conducting an analysis on using language versus symbols;
- Recommending data queries to use to research high-impact locations;
- Strengthening driving under the influence (DUI) legislations; and
- Using the ignition interlock devices (IIDs) for repeat DUI offenders.

Case Studies

Wrong-way-related Signage

Many researchers have connected the WWD issue not to the lack of appropriate signage, but to the signs' invisibility (or low visibility), especially during nighttime conditions where the chance of entering an exit ramp mistakenly is higher in relation to daytime conditions. Following, four real-world case examples and their outcomes are presented.

1. The California Department of Transportation (Caltrans) has been using lower mounting signs since the early 1970s. Evaluations of the treated sites show this method to be an effective treatment, reducing the frequency of WWD incidents from 50-60 per month to 2-6 per month at some problematic locations (*16*). The decrease in incidents is attributed to putting the signs directly in the path of vehicle headlight beams. Impaired and older drivers are two major groups more positively affected by this kind of countermeasure.
2. A study conducted by the Texas Department of Transportation (TxDOT) estimated that nearly 80.0% of WWD incidents occur at night, with 45.0% between 2 a.m. and 4 a.m. (*18*). Therefore, various methods were identified and assessed to enhance the conspicuity of wrong-way-related signs. For instance, flashing light-emitting-diode-(LED) bordered WRONG WAY signs were installed at 29 exit ramps along a corridor in San Antonio, Texas, where a high number of WWD crashes had previously occurred. Initial investigations on WWD incidents after treatment in this corridor revealed a 30.0% reduction in frequency. Further analysis indicated a 13.1:1 benefit ratio with 1.5 years as the projected cost recovery time period (*4, and 19*).
3. Red retroreflective strips on sign supports (DNE and WW signs) in combination with other countermeasures have also been employed by a number of agencies, such as the North Texas Tollway Authority (NTTA), as their proposed program to reduce the frequency of future WWD incidents (*20*). The NTTA, after noticing a sudden increase in wrong-way-related crashes on one facility in 2009, implemented red retroreflective strips on all DNE and WW signs and red RRPM-supplemented wrong-way arrows at every exit ramp. Although no statistical analysis has been conducted, these two countermeasures combined are expected to lessen the probability that treated exit ramps will cause WWD problems.
4. In response to an increase in WWD crashes in the Chicago area, the IDOT replaced nominal-sized DNE signs with larger ones, going from 30”×30” to 36”×36” to increase the visibility of these signs at multiple exit ramps. Another example of oversizing signs to address WWD comes from the NTTA in the Dallas area. Adding a second set of identical signs on the left-hand side of the roadway was one of several considered treatments by the NTTA. Since the implementation of these countermeasures in Dallas, the number of WWD

incidents has decreased. While this reduction cannot be solely related to these treatments, as they are utilized and combined with other countermeasures, they do help in enhancing visibility of the signs and reducing the likelihood of wrong-way incidents (*4*).

Pavement Markings

5. The IDOT, as part of its efforts to address WWD incidents, improved the pavement markings at several exit ramp intersections to provide additional guidance for motorists. Furthermore, the NTTA has also improved 22 lane-use arrows at a number of exit ramps within the Dallas area in 2011. Statistics demonstrated a reduction from five incidents in a six-month period before the change to three in the same time-period after the treatment, representing 40.0% reduction (*4*).

Geometric Modification

6. A location was identified in Wycliff Avenue in Dallas as the originating point of several WWD incidents due to the presence of an adjacent two-way street and exit ramp. This situation could confuse drivers who are turning left from the crossroad toward the side street, leading them to enter the exit ramp mistakenly. As a countermeasure, the responsible agency proposed to close the median opening at the crossroad to completely eliminate the possibility of wrong-way, left-turn movements. Consequently, no other WWD incidents were observed in this location after the project completion. Table 6 summarizes WWD statistics at this location before and after the median closure (*21*).

TABLE 6 WWD Statistics before (2010) and after (2011, 2012) Median Closure

WWD Incidents	2010	2011	2012
Associated with This Location	2	0	0
In the Proximity Area without Hard Evidence Linking to This Location	7	3	2

7. Raised/vertical longitudinal channelizing devices as low-cost countermeasures have been used by a number of transportation agencies to alleviate various traffic issues, such as WWD problems. For example, in 2010, the Michigan Department of Transportation (MDOT) identified a feature of parclo interchanges that make them prone to WWD maneuvers, which include: parallel, closely-spaced exit and entrance ramps. Accordingly, 161 parclo interchanges were recognized for treatment, including one needing additional attention because the location was the originating point for 10 out of the 35 studied WWD crashes. Further analyses could not relate these crashes to nighttime conditions nor to impaired drivers; therefore, geometric modification, using raised/vertical longitudinal channelization, was thought to be helpful (*22*). Investigation of crashes after completion of this project revealed that since June 2012, zero wrong-way crashes have occurred at this intersection, revealing complete elimination of these events.

Intelligent Transportation Systems (ITS) Technologies

8. 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 12 sites at exit ramps and along the mainline, all connected to the HCTRA TMC, with an overall

cost of $337,000 (*23*). According to the HCTRA, in 2012, 30 WWD incidents were detected by the system. Moreover, since the implementation of the wrong-way detection system in 2008, law enforcement units succeeded in stopping 19 WWD motorists; eleven of those nineteen motorists were determined to be impaired and were arrested, while three others were arrested for other traffic violations. The remaining five motorists were issued WWD-related citations (*17*). Taken as a whole, these results confirm that ITS is an effective strategy for addressing WWD at a system level.

9. The New York State Thruway Authority (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. Since this countermeasure was recently implemented, there is no data showing the effect it has on wrong-way incidents or crashes.

Countermeasure Package

10. A recent study (*24*) by the MDOT and FHWA concluded that 60.0% of total WWD crashes in 2010 in Michigan could be traced to wrong-way entries at parclo interchanges. The MDOT then assembled a package of multiple low-cost countermeasures that would address the situation by providing more extensive and comprehensive visual cues, targeting these interchanges across the state for treatment. The WWD countermeasure package consisted of lower DNE and WW sign mounting height (four feet from the edge of the pavement), red retroreflective strips on sign supports, stop lines, exit ramp wrong-way arrows, pavement marking extensions, painted islands, and wrong-way delineations. The MDOT estimated the average cost of implementing this countermeasure package at approximately $6,500 per treated exit ramp.

SUMMARY AND CONCLUSIONS

Various countermeasures have already been developed by agencies to combat WWD issues, among which engineering countermeasures (with 91.7%) are given the top priority. According to the survey questionnaire, adding a second identical sign on the left-hand side of the roadway and increasing the size of wrong-way related signs, as implemented by the IDOT and the NTTA, are the most acceptable and beneficial countermeasures. Caltrans' case study justified the application of lower mounting signs with about 90.0% reduction in WWD incident frequency and the TxDOT experienced a 30.0% reduction in WWD incident frequency after adding LEDs to DNE and WW sign borders; however, it was found that there is a lack of attention to placement of wrong-way signs at frontage roads. Pavement marking applications and improvement at problematic locations show promising outcomes with a decreasing frequency of wrong-way incidents by 40.0% in the NTTA. Access management in the vicinity of an interchange area, using geometric elements, was found to be an efficient method. As perceived to be the most considerable elements by respondents, controlling access to exit ramps was able to eliminate wrong-way entries in one problem exit ramp in Michigan entirely. Lastly, while only one-third of participating agencies claim to deploy ITS technologies, the HCTRA had successful experience, authenticating the use of these devices.

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