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Assessment of countermeasure effectiveness and informativeness in mitigating wrong-way entries onto limited-access facilities

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ABSTRACT

Wrong-way crashes are a major cause for safety concerns along freeways and limited-access facilities. Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions often results in severe injuries or fatalities compared to any other type of crash. To seek solutions for mitigating wrong-way driving (WWD), multiple field tests involving a number of countermeasures using Intelligent Transportation Systems (ITS) technologies have been conducted in Florida. This study was aimed to evaluate these WWD countermeasures in Florida and develop recommendations regarding the most effective and informing WWD countermeasures through (1) analysis of existing data and studies, (2) field WWD testing using focus groups, (3) a public opinion survey, and (4) capturing human factors elements using simulation via a driving simulator. The results proved that red Rectangular Rapid Flashing Beacons (RRFBs) are the top countermeasure for mitigating WWD at freeway off-ramps, with wigwag flashing beacons as the second best, and detection-triggered blank-out signs and detection-triggered LED lights around "WRONG WAY" signs (tie) as third best. Red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs) were found to be statistically significantly effective for possible consideration as a supplemental countermeasure for mitigating WWD at freeway off-ramps. The countermeasure of delineators along off-ramps was found to be the least effective and was not considered for recommendation for deterring WWD at freeway off-ramps. This study further confirms that the newly-developed signing and pavement marking standards in Florida are a positive countermeasure on arterials to mitigate wrong-way entries onto freeway off-ramps.

1. Introduction

A wrong-way driving (WWD) crash is one in which a vehicle traveling in a direction opposing the legal flow of traffic on a high-speed divided highway or access ramp collides with a vehicle traveling on the same roadway in the proper direction (FHWA, 2016). Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions often results in severe injuries or fatalities. Despite providing the necessary "DO NOT ENTER" and "WRONG WAY" signs and pavement markings (wrong-way arrows, etc.) as per the *Manual on Uniform Traffic Control Devices* (MUTCD), wrong-way entry onto limited-access facilities is still occurring.

With an annual average of 28 WWD fatalities from 2004 to 2011, Florida ranked 3rd in the nation, behind only Texas and California (Baratian-Ghorghi et al., 2014). According to the results of a statewide wrong-way crash study for the Florida Department of Transportation (FDOT) by Kittelson and Associates (2015), there were 280 wrong-way crashes on Florida highways between 2009 and 2013, resulting in 75 fatalities. The majority (71%) of these wrong-way crashes occurred in night-time (dark) conditions, and at least 45% of drivers in wrong-way crashes were found to be impaired. Wrong-way countermeasures using ITS technologies have emerged in the past several years, and new technologies continue to expand opportunities to reduce crashes and WWD incidents.

To seek solutions for mitigating WWD, tests involving a number of countermeasures using ITS technologies have been performed through FDOT pilot projects and approved requests for experiments (RFEs) from the Federal Highway Administration (FHWA). As illustrated in Fig. 1, seven innovative WWD countermeasures in the pilot studies were identified, including (1) newly-developed signing and pavement marking (S&PM) standards (*FDOT Plans Preparation Manual*), (2) red rectangular rapid flashing beacons (red RRFBs), (3) red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs), (4) detection-triggered LED lights around "WRONG WAY" signs, (5) detection-triggered blank-out signs that flash "WRONG WAY," (6) delineators

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Fig. 1. Seven wrong-way driving countermeasures evaluated.

along off-ramps, and (7) wigwag flashing beacons. However, it was not initially clear which countermeasures (or combination of countermeasures) were more promising for widespread implementation.

Before the completion of RFEs and final approval of the proposed countermeasures by FHWA, guidance needed to be provided for the implementation of the most effective and informative traffic control devices to reduce WWD in the near future. In addition, given the choice to prioritize among WWD countermeasures, the selection of a countermeasure is very important for a department of transportation. Therefore, a comprehensive evaluation of identified WWD countermeasures used in FDOT pilot projects and RFEs was essential for the development of such guidance.

The major objective of this study was to compare the seven identified WWD countermeasures (Fig. 1) and recommend the appropriate measures for future deployment consideration. Specifically, this study aimed to (1) compare the available results from each pilot study based on existing data, (2) conduct field evaluation on WWD countermeasures at each selected site, (3) assess public perception of WWD countermeasures via public opinion surveys and (4) capture human factors elements using simulation via a driving simulator. Recommendations were developed for statewide uniform implementation of the most effective and accepted wrong-way countermeasures to reduce WWD.

2. Literature review of WWD and selected countermeasures

Wrong-way crashes are a major cause for safety concerns along freeways and limited-access facilities. Because wrong-way crashes typically involve head-on or side-swipe opposite direction crashes, they tend to result in more severe injuries. Over the past five decades, national, state, and local agencies have been working toward mitigating WWD incidents and have been implementing countermeasures focusing on all the 4 E's of roadway safety—Engineering, Education, Enforcement, and Emergency Medical Services. More details about the summarized countermeasures can be found in the *Proceedings* of the 2013 National Wrong-Way Driving Summit (Zhou and Pour Rouholamin, 2014).

From the transportation policy perspective, Ponnaluri (2016) presented a "policy-oriented framework toward addressing WWD incidents in a systematic manner and suggested a systemic discipline for transforming policy objectives to actionable outcomes." The framework with the backdrop of leadership-supported institutionalization to strategize road safety improvements was proposed. The holistic approach taken includes (1) implementing pilot projects, (2) conducting a statewide study with crash evaluation and field reviews, identifying interchange types, and developing countermeasures, (3) evaluating and deploying experimental devices specifically approved by FHWA, (4) conducting a human factors study, (5) transforming recommendations to design guidance, (6) discussing with planners on interchange types susceptible to WWD incidents, (7) retrofitting off-ramps with the recommended countermeasures, and (8) leveraging the media to promote awareness and educate the public about the dangers of driving under the influence (Ponnaluri, 2016).

From the statistical analysis perspective, Kittelson and Associates (2015) conducted a detailed statewide study of WWD crashes in Florida focusing on analyzing trends and contributing factors surrounding WWD crashes on limited access facilities. They found that from 2009 to 2013, approximately 280 WWD crashes occurred on Florida's freeways and expressways, resulting in 75 fatalities and more than 400 injuries. Weekends and early morning hours (12:00–6:00 A.M.) were found to be more susceptible to WWD crashes. Approximately 75% of WWD crashes occurred in urban areas and 25% in rural areas. The majority of WWD movements were entering the freeway/expressway from an off-ramp. Diamond/partial diamond, partial cloverleaf, and trumpet interchange types experienced the highest number of WWD crashes; the full cloverleaf interchange type experienced the lowest. However, this information is not normalized by the level of exposure. The wrong way crash frequency versus severity for Florida from 2009 through 2013 is depicted in Fig. 2, with PDO standing for property damage only.

The FDOT districts with the highest frequency of wrong way crashes were found to be Districts 2, 5, 6 and the Turnpike, whereas Districts 2, 3, and 7 were found to be proportionally higher in wrong way crashes resulting in fatalities (Kittelson and Associates, 2015).

From the human cognitive perspective, Boot et al. (2015) conducted a human factors study to understand the role of human cognition in the driver decision-making process, primarily focusing on nighttime crashes involving impaired drivers and daytime crashes involving older drivers. The authors concluded that a combination of cues help drivers pursue safe driving options; no particular sign or lane marking but a combination of cues provides sensory inputs for driver decision-making. Based on an extensive literature review, the authors developed a