# WRONG WAY DRIVING ANALYSIS AND RECOMMENDATIONS

## FINAL REPORT

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# 1 INTRODUCTION

Wrong-way driving is defined as driving in the opposite direction of legal movement on divided highways or access ramps connecting to highways (Tamburri et al. 1965; Zhou et al. 2014a; Zhou et al. 2014b; Pour Rouholamin et al. 2015a). Wrong-way movements are relatively infrequent but have high potential to produce head-on or opposite-direction sideswipe crashes, resulting in serious injuries and fatalities compared to other types of freeway crashes (Zhou, et al. 2014a; Zhou et al. 2014b; Rogers et al. 2014).

Although wrong-way crashes represent only 3% of the crashes on high-speed highways, they are much more likely to result in fatal and serious injuries than other types of highway crashes. Braam analyzed available freeway-related crash data in North Carolina from 2000 to 2006. Results indicated that nearly 60% of wrong-way crashes on freeways involved a fatality or serious injury (A-level injury) but this percentage was only 2.5% for all crashes on freeways Figure 1-1) (Braam 2006). According to the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, from 2004 to 2011, the annual average number of fatalities in the US due to wrong-way driving on high-speed divided highways is approximately 360 (Finley et al. 2014; Zhou et al. 2014b; Zhou et al. 2012; Cooner et al. 2008). Figure 1-2 depicts the annual average frequency of wrong-way driving fatalities across all 50 U.S. states between 2004 and 2011. The figure presents frequency of crashes and is not adjusted for mile of freeway or lane miles.

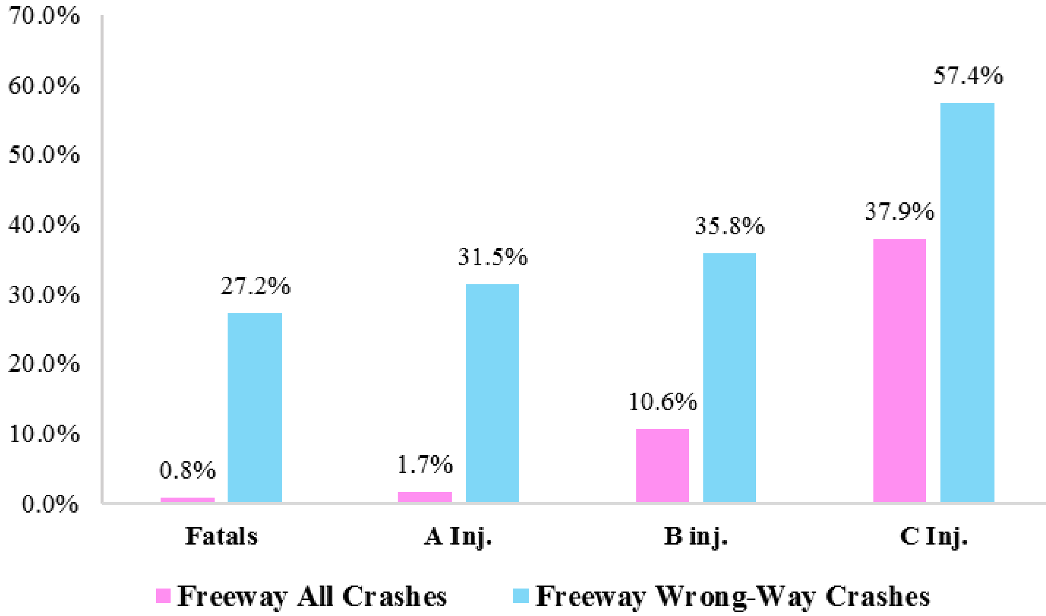
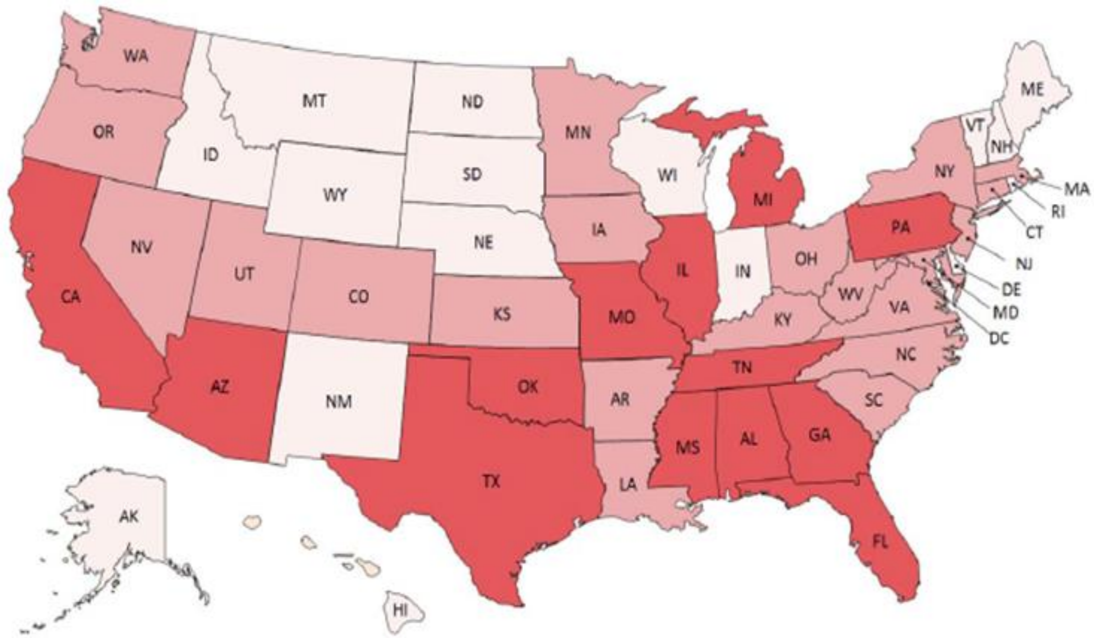



Figure 1-1: Distribution of Severity Levels of All Crashes Compared to Wrong-Way Crashes on North Carolina Freeways, (Braam 2006).




| 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 1-2: Annual Average Frequency of wrong-way driving Fatalities across the United States (2004–2011), (Zhou et al. 2014a).

## 1.1 RESEARCH OBJECTIVES

The goal of this research project was to examine past literature on the wrong-way driving, review current crash data and develop a list of recommendations to address wrong-way driving on limited access freeway facilities in Oregon.

## 1.2 ORGANIZATION OF REPORT

This report contains 1) review of the literature, which examines contributing factors for these crashes, and 2) existing countermeasures for wrong-way crashes divided highways and access ramps 3) a basic analysis of wrong-way crashes on Oregon interstates, and 4) a recommended systemic approach to addressing wrong-way entrances at exit ramps.

## 1.3 DISCLAIMER

This document was produced under contract to the Oregon Department of Transportation in the interest of information exchange. The State of Oregon assumes no liability of its contents or use thereof. The contents of this report reflect the view of the authors who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Oregon Department of Transportation. The State of Oregon does not endorse products of manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document. Finally, this report does not constitute a standard, specification, or regulation.

# 2 REVIEW OF CONTRIBUTING FACTORS

Contributing factors for wrong-way crashes have been discussed in many studies. In general, driving under the influence (DUI) of alcohol or drugs, age, gender, interchange and ramp configurations, and the origin of wrong-way movements were found to be significant factors in wrong-way crashes. To gain insight into the causality of wrong-way crashes, each of these causative factors is discussed in more detail below.

## 2.1 DRIVER-RELATED FACTORS

### 2.1.1 Intoxication

Many studies indicate that intoxication is a main contributing factor in the occurrence of wrong-way driving events. Braam analyzed wrong-way driving-related crashes from 2000 to 2005, occurring on freeways in North Carolina and found that 43% of wrong-way crashes, including 53% of fatal wrong-way crashes, involved alcohol-impaired drivers (Braam 2006). The National Transportation Safety Board analyzed Fatality Analysis Reporting System (FARS) data between 2004 and 2009. Results indicated that 936 of 1,566 (60%) fatal wrong-way driving crashes involved alcohol-impaired drivers. Of wrong-way driving crashes in which blood-alcohol concentrations (BACs) were reported, 10% had BACs between 0.08 and 0.15 and 59% had BACs at or above 0.15 (NTSB 2012). Zhou et al. analyzed wrong-way driving crashes from 2004 to 2009 occurring on freeways in Illinois. Results indicated that DUI was the leading contributing factor to both fatal and A-injury wrong-way driving crashes. Half of the wrong-way driving crashes involved alcohol-impaired drivers (Zhou et al. 2014b; Zhou et al. 2013). Lathrop et al. analyzed medical files from 1990 to 2004 to identify risk factors resulting in fatal wrong-way crashes and prevention strategies on New Mexico's interstate highways. Results indicated alcohol was a factor for 60% (29/49) of wrong-way driving crashes (Lathrop et al. 2010). Pour Rouholamin et al. analyzed fatal crashes in Alabama between 2009-2013 using the FARS database and found that DUI drivers comprised about half of wrong-way drivers (Pour Rouholamin et al. 2016b).

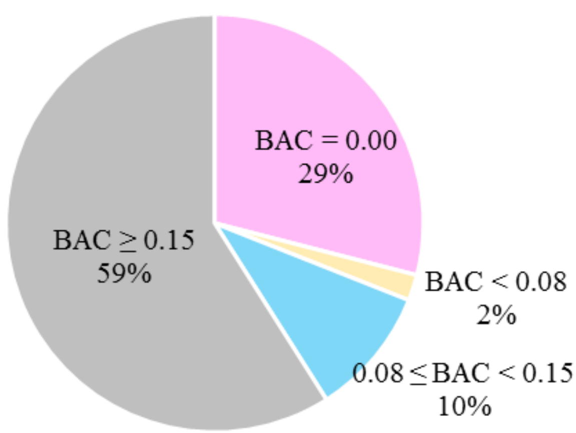



Figure 2-1: BAC Levels of Wrong-Way Drivers through Analysis of FARS Data (2004-2009) (NTSB 2012).

### 2.1.2 Gender

Several studies indicated that male drivers were involved in majority of wrong-way driving crashes. Cooner et al. analyzed 323 wrong-way driving-related crashes from 1997 to 2000 on freeways in Texas. Statistics indicated that 67% of wrong-way drivers were male as opposed to 27% female (Cooner et al. 2003). Zhou et al. analyzed 203 wrong-way driving crashes from 2004 to 2009 in Illinois. Results indicated that males were involved in 67% of wrong-way driving crashes, while female wrong-way driving crashes accounted for only 25%. In addition, female wrong-way drivers were mostly middle aged (between 35 - 44 years), while male wrong-way drivers were either younger or older adults (between 21-34 and over 65). In addition, wrong-way drivers associated with crashes at a partial cloverleaf interchange were mostly male. However, female wrong-way drivers were over-represented in a diamond interchange (Zhou et al. 2012). Fisher and Garcia analyzed crash metadata from 2008 to 2014. Results indicated that on average, 63% of wrong-way drivers on Texas and Florida divided highways were male and 33% female (Figure 2-2) (Fisher and Garcia 2016).

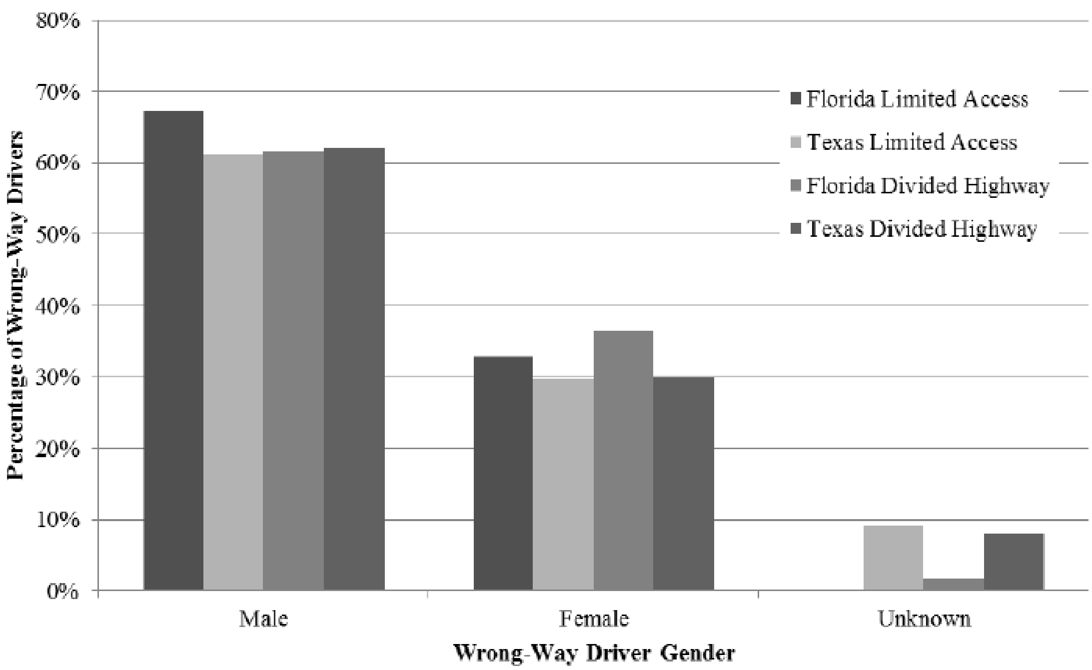



Figure 2-2: Gender Distribution of Wrong-Way Crashes on Florida and Texas Divided Highways and Limited Access Freeways (2008-2014), (Fisher and Garcia 2016).

### 2.1.3 Past Infractions

Previous studies show that previous driver record of infractions plays a role in wrong-way crashes. According to Tamburri and Theobald, wrong-way drivers in California had double the accident rate and double the citation rate for violations (Tamburri and Theobald, 1965). In another study by Howard, 10% percent of wrong-way drivers did not have a valid driver license, and 41% of wrong-way drivers had been previously convicted of a crime. Of wrong-way drivers previously convicted of a crime, 53% were involved in an accident (Howard 1980). In another study by the Michigan Department of State Highway, half of wrong-way accident drivers had ten or more violation points, and many of them did not have a valid driver license (MDOT 1968). According to NTSB, 19% of wrong-way drivers in fatal crashes, from 2004 to 2009, did not have a valid driver license (NTSB 2012). NHTSA reports that in 2012 13% of drivers involved in fatal crashes were unlicensed (NHTSA, 2012).

### 2.1.4 Age

In a study by Braam, statistics indicated that older drivers (age ≥ 65) were involved in only 5% of all North Carolina freeway crashes, but they were involved in 17% of wrong-way driving crashes on North Carolina freeways (Figure 2-3). This result suggests that older drivers are over-represented in wrong-way driving crash by three times (Braam 2006). In another study by Cooner et al., statistics indicated that older drivers (age ≥ 65) were involved in wrong-way driving crashes at a higher rate (12.7%) than other types of crashes (Cooner et al. 2003). A study by Zhou et al., showed that younger drivers (age 16-24) and older drivers (age>65) significantly contributed to wrong-way driving crashes (Zhou et al. 2013). A recent study showed that during daytime hours, drivers over 65 and below 21 years old were more likely to be involved in wrong-way driving crashes on Florida and Texas divided highways. During nighttime hours, drivers' ages between 21 and 34 had the highest percentage of wrong-way driving crashes on divided highways in both states. This age group also had the highest fatality rate (Fisher and Garcia 2016). Jalayer et al. analyzed 305 wrong-way crashes from 2004 to 2013 in Illinois and Pour Rouholamin et al., analyzed 93 wrong-way crashes from 2009 to 2013 in Alabama. Results indicated that drivers older than age 65 driving at night and under the influence of alcohol are at greatest risk of wrong-way driving crashes (Jalayer et al. 2017; Pour Rouholamin et al. 2016). Similarly, analyzing wrong-way driving crashes on divided roadways in France showed that older drivers (age ≥ 65) and DUI drivers are most likely to be involved in wrong-way driving crashes (Kemel 2015). Although applying countermeasures declined the overall numbers of wrong-way driving crashes, these were found to be not as effective at reducing the rate of wrong-way driving crashes among older drivers. Wrong-way driving crashes among older driver were a result of other contributing factors not addressed by countermeasures, such as reduced way-finding ability. In research conducted by Read et al., they found that wayfinding ability declined as the age of participants increased (Read et al. 2011). Alam et al., found that driver errors increased as age increased due to a decrease in cognitive abilities (Alam et al. 2008). Older drivers are faced with higher rates of impaired conditions such as disease, dementia, confusion and weak memory, and therefore a higher risk of collision (NTSB 2012; Zhou et al. 2012).

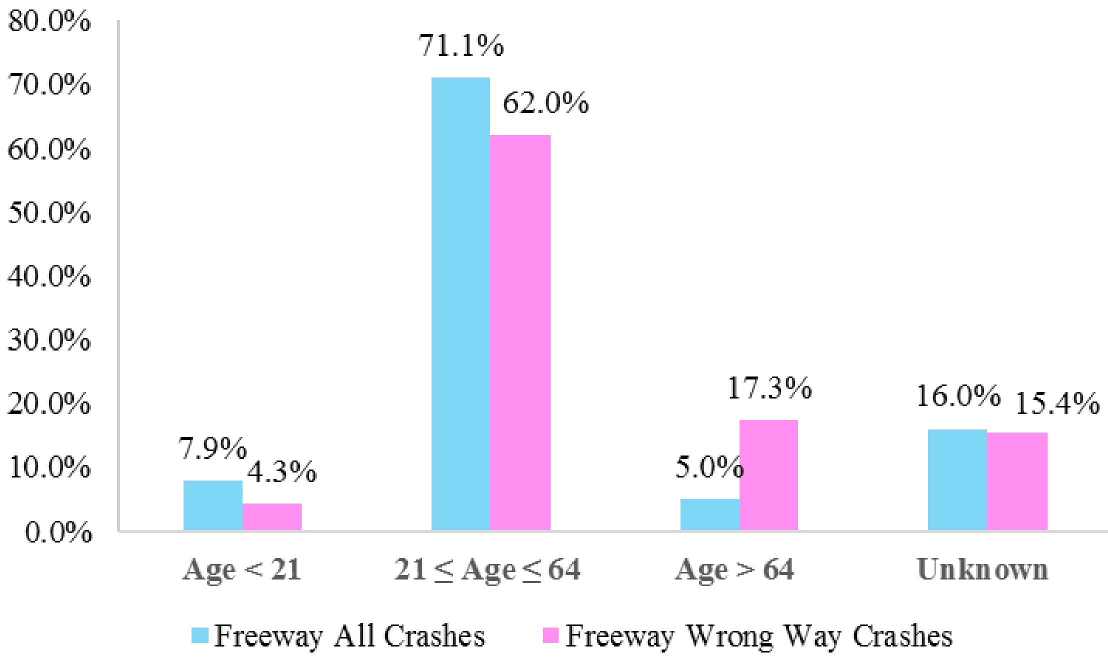



Figure 2-3: Age Distribution of All Crashes Compared to Wrong-Way Crashes on North Carolina Freeways, (Braam 2006).

## 2.2 Environmental Factors

### 2.2.1 Time of Day

In research by Howard, it was found that wrong-way driving crashes occurred more often on weekends due to a higher incidence of impaired drivers (Howard 1980). This finding was consistent with Fisher and Garcia, which analyzed crash data from 2008 to 2014, and found increased occurrences during weekends and nighttime in Florida and Texas (Fisher and Garcia 2016). However, According to Fisher and Garcia, California showed a weekday-daytime trend for wrong-way driving crashes. It was also found that the risk of wrong-way driving movements is higher at night than during the day (Fisher and Garcia 2016). Reduced visibility and alcohol-impaired drivers were main factors of a higher incidence of wrong-way driving crashes at night, with a peak at 2:00 a.m. In addition, a peak in wrong-way driving crashes at 11:00 a.m. was attributed to older drivers (Howard 1980). It should be noted that obstacles that block a driver's view, including poor geometric designs and overgrown vegetation, as well as poor lighting, could reduce visibility and increase wrong-way movements (Copelan 1989; Vaswani 1975). Many other studies confirm that more wrong-way driving crashes occur at night, particularly between 12:00 and 6:00 a.m. on weekends and that alcohol-impaired driver is a primary contributing factor (Braam 2006; Cooner and Ranft 2008; Copelan 1989; Cooner et al. 2004; Lathrop et al. 2010; Finley et al. 2014; Zhou et al. 2013; Zhou et al. 2014b). A recent study of 93 wrong-way driving crashes in Alabama showed that 80% of wrong-way driving crashes occurred at night (Pour Rouholamin et al. 2016b). However, analyzing a phone survey of 400 survey respondents about unreported wrong-way driving crashes indicated that almost 50% of wrong-way driving crashes occurred during daytime while only 31% of wrong-way driving crashes occurred at night on Central Florida toll roads and freeways (Sandt et al. 2015). Zhang et al. studied 112 verified wrong-way driving crashes on Alabama highways. Results indicated that dark roadway conditions was a significant contributing factor to wrong-way driving crashes (Zhang et al. 2017). Results of another study showed that poor lighting and darkness were the most significant environmental factors contributing to fatal and A-injury wrong-way driving crashes (Figure 2-4) (Zhou et al. 2013).

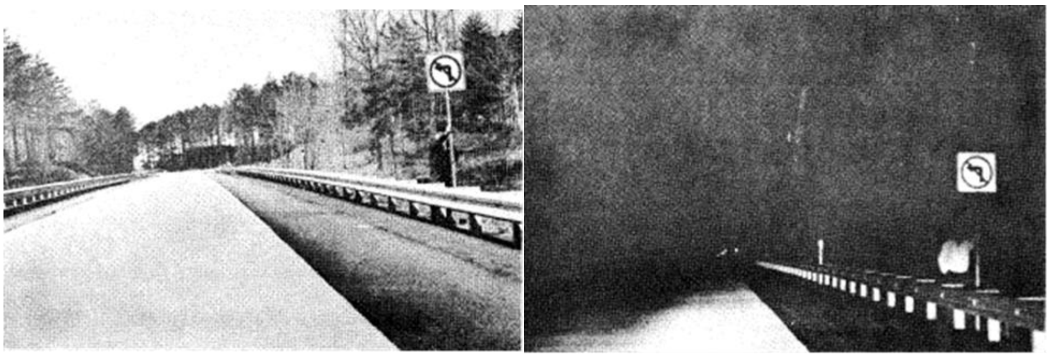


Figure 2-4: Day and Night Photograph of 8 ft. High Sign Taken from the Same Position, (Vaswani 1975)

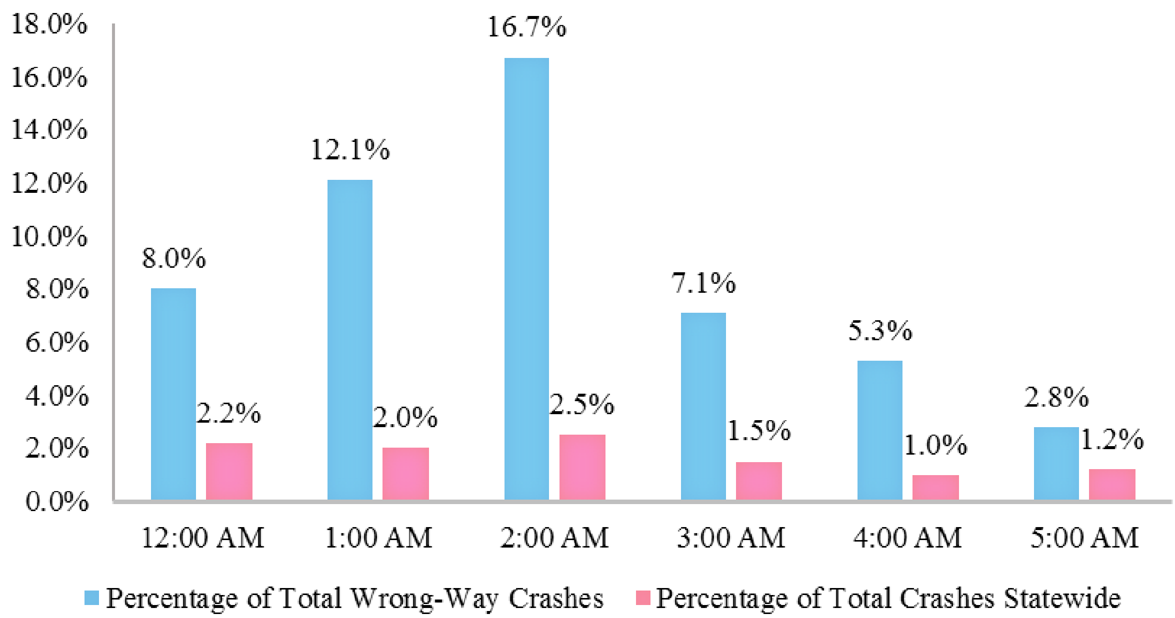



Figure 2-5: Wrong-Way Freeway-Related Crashes Versus Total Crashes in Texas Occurring Over Midnight from 1997 to 2000, (Cooner et al. 20

### 2.2.2 Urban versus Rural Areas

Previous studies do not show consistent results regarding wrong-way driving crash rates in urban versus rural areas. Tamburri and Theobald found that only 8% of 1143 wrong-way crashes occurred in heavy traffic conditions, as opposed to 44.3% and 47.7%, respectively, in light and moderate traffic conditions (Tamburri and Theobald 1965). They also found that, unlike urban areas with high-volume traffic, rural areas with low-volume provide fewer clues for drivers to realize they are moving in a wrong direction but greater opportunity to correct their direction once they realize it (Tamburri and Theobald 1965). Likewise, Scifres and Loutzenheiser, and Baisyet et al. found more wrong-way crashes in rural areas with low-volume than urban areas with high-volume traffic conditions (Scifres and Loutzenheiser 1975; Baisyet et al. 2015). In contrast, analyzing recent crash metadata, provided by the parent project from 2008 to 2014, indicated that wrong-way driving crashes mostly occurred in urban areas on Florida divided highways (83%) and California divided highways (72%) (Fisher and Garcia 2016). More access points and high volume were considered main reasons for this trend in those states. However, Texas rural areas showed a higher percentage of wrong-way driving crashes (57%) on divided highways due to having vast rural lands and many divided highways (Figure 2-6) (Fisher and Garcia 2016). Similarly, Ponnaluri found that most of wrong-way driving crashes (75%) along limited access exit ramps in Florida occurred in urban areas during 2009-2013 (Ponnaluri 2016). Zhang et al. analyzed 112 wrong-way driving crashes on Alabama federal and state partially/uncontrolled-access divided highways from 2009 to 2013. Results indicated that wrong-way driving events are more likely to occur in urban areas, but fatal crashes were more likely in rural areas (Zhang et al. 2017).

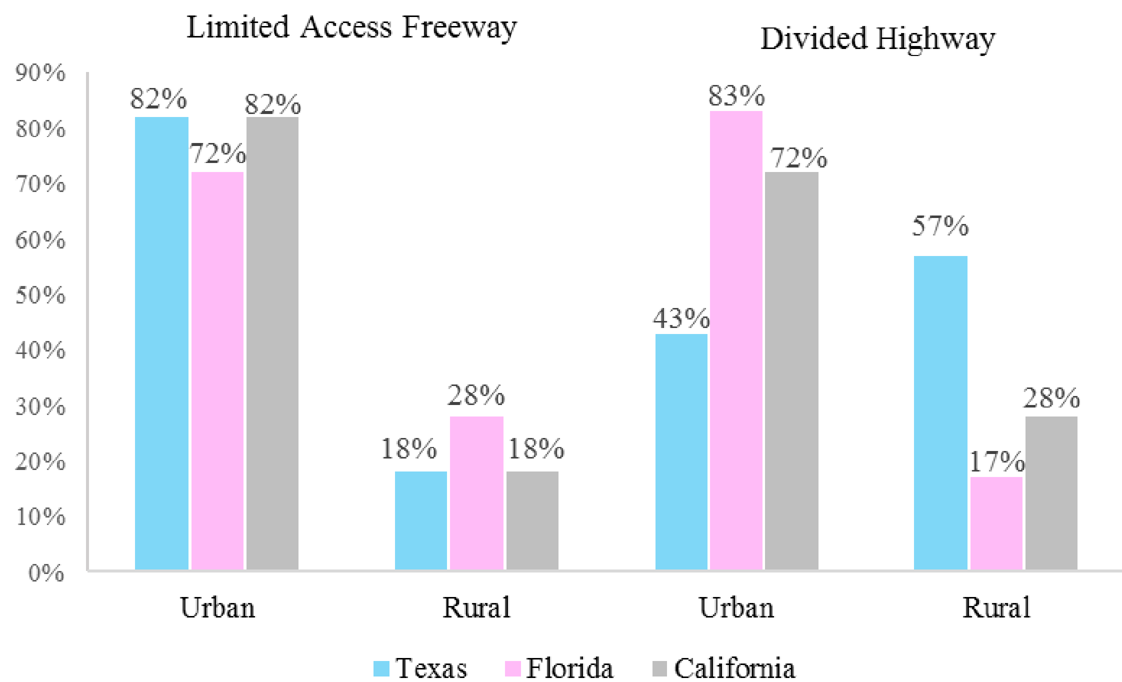



Figure 2-6: Urban Versus Rural Crash Percentile through Analysis of Crash Metadata (2008-2014), (Fisher and Garcia 2016).

## 2.3 GEOMETRIC FACTORS

While identifying the origin location of wrong-way movement is critical for studying wrong-way crashes, the origin location is often not documented in crash reports. Nevertheless, many studies utilized available sources such as police crash reports, surveys, and images from camera surveillance systems to identify the origin location of wrong-way movements. A review of the literature confirms that most wrong-way driving crashes occur at interchanges. However, the rate of wrong-way driving movements and crashes depends on the types of interchanges, which are further discussed below.

Ponnaluri (2016) studied 280 wrong-way driving crashes along limited access exit ramps at 40 locations in Florida were studied for the 2009-2013 period. They found similar crash distributions for interchange as shown in Table 2.1.

**Table 2.1: Interchange Type and Wrong Way Driving Crash Distribution (Ponnaluri 2016).**

| Interchange Type | Statewide (%) | WWD (%) |
|---|---|---|
| Diamond/partial diamond | 56 | 49 |
| Two-quadrant/partial cloverleaf | 26 | 23 |
| Trumpet | 6 | 8 |
| Direct connection design | 5 | 4 |
| Y-intersection | 3 | 3 |
| Other | 4 | 13 |

### 2.3.1 Full Cloverleaf

Previous studies suggest that the safest type of interchange against wrong-way movements are full cloverleaf interchanges because they eliminate left-turning movements to/from the freeway in both directions (Figure 2-7). However, cloverleaf interchanges require greater space as the design speed of the loop ramp increases (Copelan 1989; Garber and Fontaine 1999; NTSB 2012). Zhou et al. found that cloverleaf interchanges had a wrong-way crash rate lower than the average among all interchanges in Illinois (3.39 vs. 3.57) (Zhou et al. 2014b). Howard found that the full cloverleaf interchanges had the lowest rates of wrong-way entries (Howard 1980).

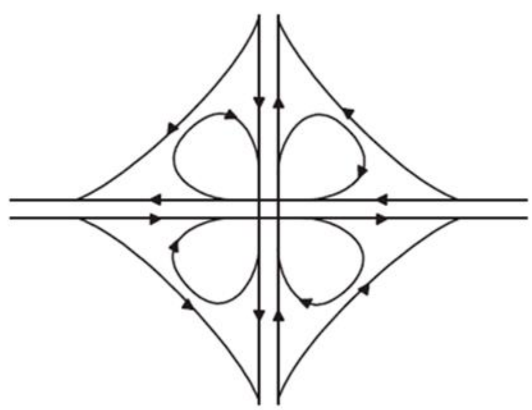


Figure 2-7: Typical Full Cloverleaf, (Garber and Fontaine 1999)

### 2.3.2 Partial Cloverleaf

According to Garber and Fontaine, partial cloverleaf interchanges follow diamond interchanges as the most common interchanges in both rural and urban areas, with the lowest construction costs across the U.S. (Figure 2-8) (Garber and Fontaine 1999). According to Copelan, partial interchanges are prone to wrong-way entries (Copelan 1989). Parsonson and Marks studied forty-four off-ramps in the Greater Atlanta area. They found that half-diamond interchanges, followed by partial cloverleaf loop ramps, are most susceptible to wrong-way movements. Lack of distance between on-ramps and off-ramps results in wrong-way movements in partial cloverleaf interchanges (Figure 2-9) (Parsonson and Marks 1979). In a study of 122 off-ramps in California, Howard found that the rate of wrong-way entries in partial cloverleaf interchanges is almost twice the average (Howard 1980).

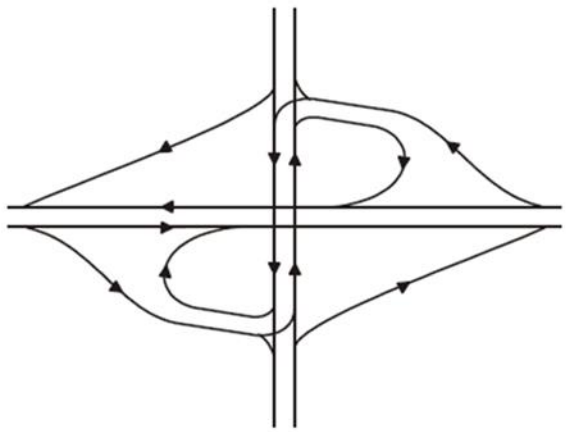


Figure 2-8: Typical Partial Cloverleaf, (Garber and Fontaine 1999)

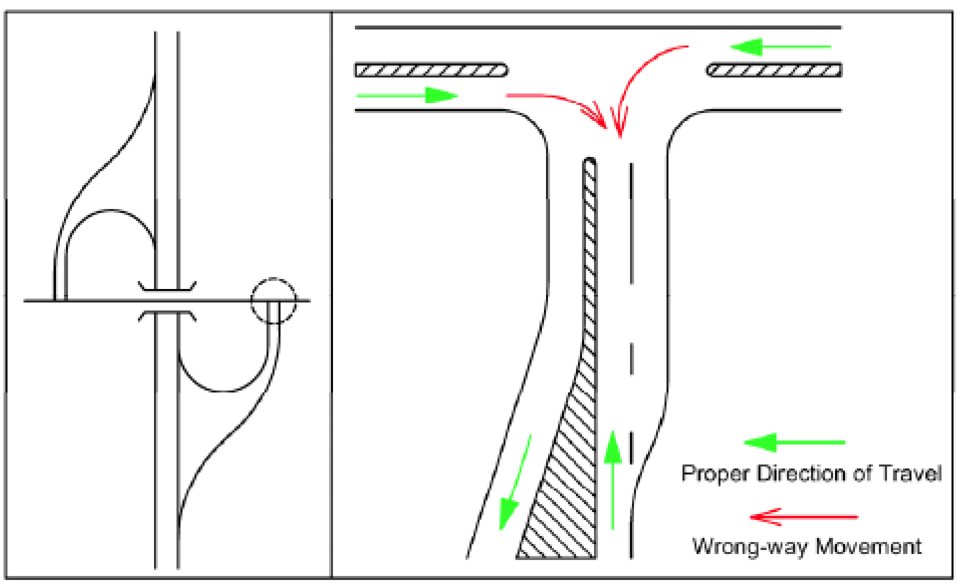



Figure 2-9: Potential Wrong-Way Movement Due To Lack of Distance between Exit Ramp and Entrance Ramp, (Zhou and Pour Rouholamin 2014a).

### 2.3.3 Full Diamond

The most commonly used interchange in U.S. is the full diamond interchange (Figure 2-10), (NTSB 2012; Garber and Fontaine 1999). In a study of 122 of California's off-ramps, Howard found that after the full cloverleaf, full diamond interchanges had the lowest rate of wrong-way entries (Howard 1980). However, the configuration of the full diamond interchange may sometimes become confusing leading to wrong-way movements especially in the presence of a frontage road parallel to an off-ramp (Figure 2-11). Turning left onto an off-ramp from a crossroad is another potential wrong-way movement (Figure 2-11) (Copelan 1989). In a study of diamond and partial cloverleaf interchanges by Scifres and Loutzenheiser, they found that wrong-way movements are more likely to occur where lighting was poor, traffic volumes were low, and land use was light (Scifres and Loutzenheiser 1975). Zhou et al. determined the origin point of wrong-way crashes at interchanges in Illinois. They found that diamond interchanges had a wrong-way crash rate lower than the average (2.44 vs. 3.55 % per year) while compressed diamond interchanges had the highest wrong-way crash rate (13.39 % per year) (Zhou et al. 2014b).

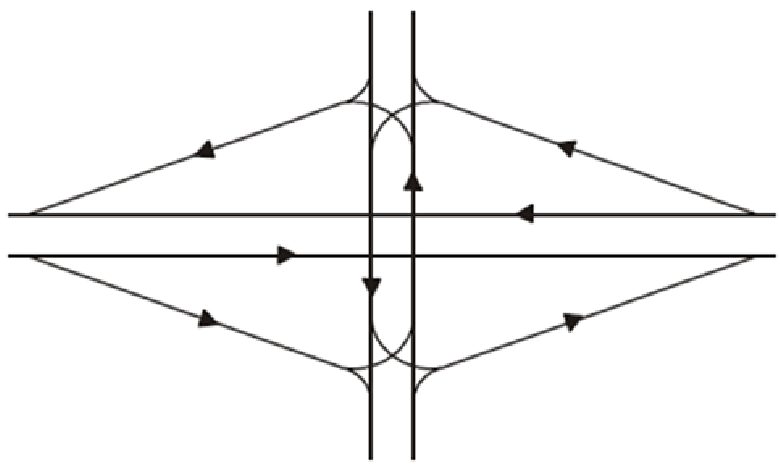


Figure 2-10: Typical Full Diamond, (Garber and Fontaine 1999)

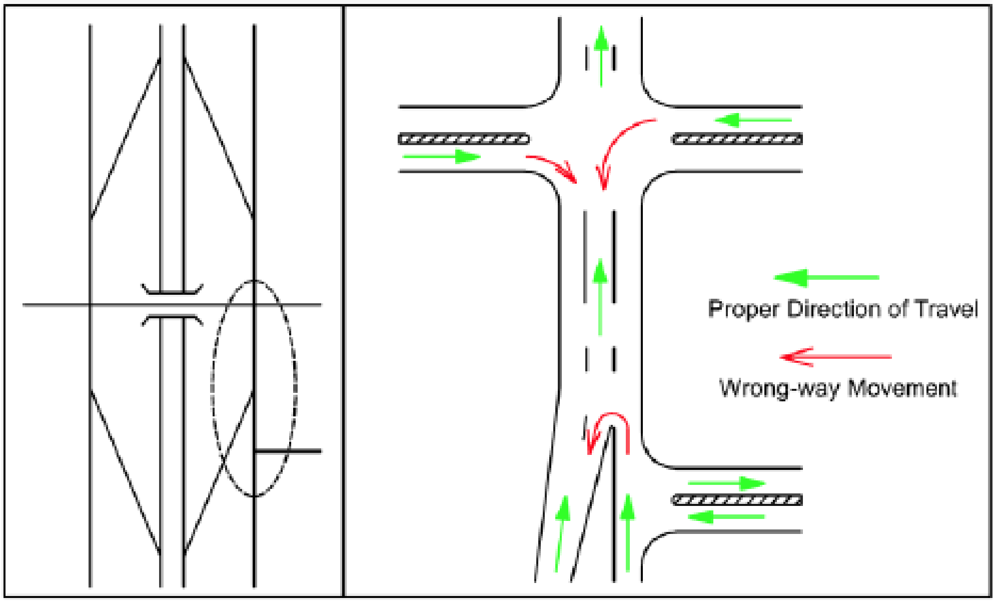



Figure 2-11: Potential Wrong-Way Movement In The Presence Of A Frontage Road Parallel to an Off-Ramp in Diamond Interchanges, (Zhou and Pour Rouholamin 2014a)

### 2.3.4 Half-Diamond

Parsonson and Marks found that half-diamond interchanges are conducive to wrong-way entries because these interchanges do not provide access to the freeway from all directions. Therefore, drivers who miss an entrance ramp may attempt to drive in the wrong direction to avoid driving a long distance to the next interchange (Figure 2-12) (Parsonson and Marks 1979). Zhou et al. found that compressed diamond interchanges had the highest wrong-way crash rate (13.39 % per year) among interchanges in Illinois (Zhou et al. 2014b). Rinde found that half-diamond interchanges had a higher rate of wrong-way entries (Rinde 1978). Howard also found the rate of wrong-way entries in half-diamond interchanges was twice the average among 122 off-ramps in California (Howard 1980).

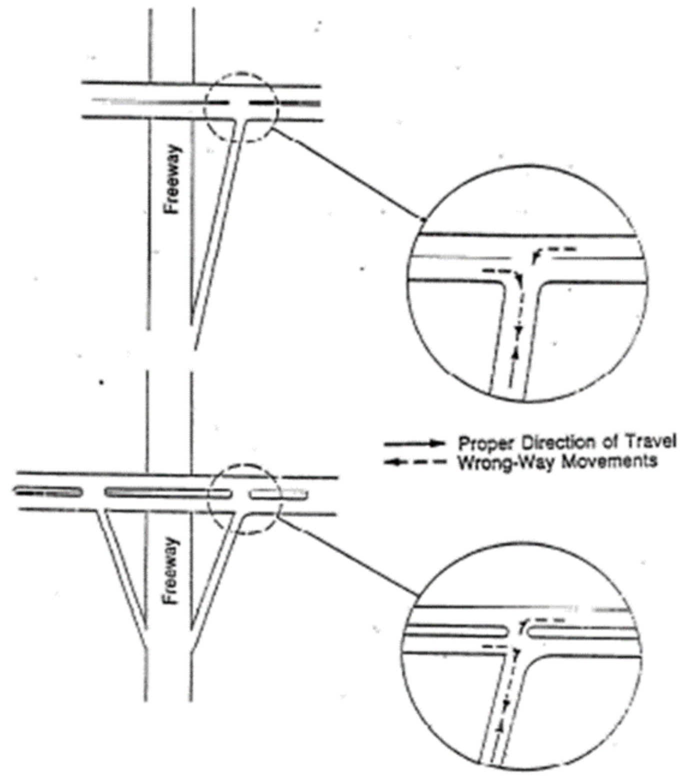



Figure 2-12: Typical Half-Diamond, (Copelan 1989)

### 2.3.5 Diverging Diamond

With an increasing number of diverging diamond interchanges (DDIs) in the US, safety concerns about their potential for wrong-way crashes has been growing. Vaughan et al. investigated the rate and causes of wrong-way maneuvers by analyzing video records in five DDIs over a six-month period in 2012. Although 155 unintentional wrong-way maneuvers were observed, no wrong-way crashes occurred. The main findings of this research showed that low crossover angle and low volume are positively associated with wrong-way maneuvers. In addition, drivers passing through the first crossover, an inbound movement, are more likely to travel in a wrong direction than those in outbound movements. Wrong-way maneuvers mostly occurred during nighttime, off-peak times of day, and dry conditions. *Figure 2-13* displays the movements at a DDI.

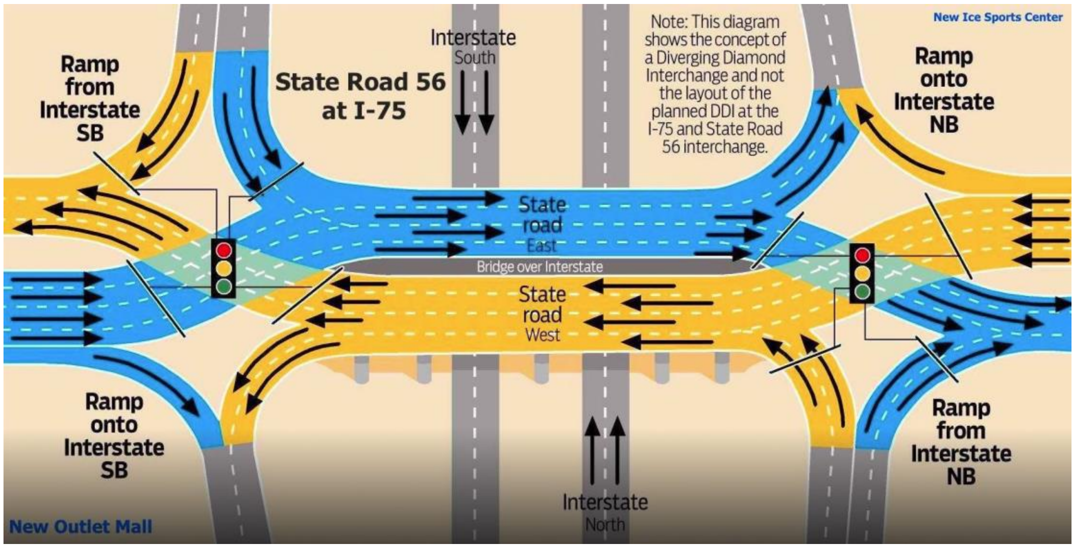



Figure 2-13: Correct and Wrong Movements at a DDI, (Florida DOT).

### 2.3.6 Left-Side Exit Ramps

Cooner et al. found that many locations with left-side exit ramps had a high rate of wrong-way crashes (Cooner et al. 2003; Cooner et al. 2004). Copelan suggests avoiding construction of left-side exit ramps (Figure 2-14), (Copelan 1989). Howard found that the rate of wrong-way movements in left-side exit ramps was five times higher than the average in 122 off-ramps in California (Howard 1980). Chen et al. studied crash records at 74 sites on freeways. Results from that study indicated that the severity and average frequency of crashes were higher at left-side exit ramps, as opposed to other types of off ramps (Chen et al. 2011).

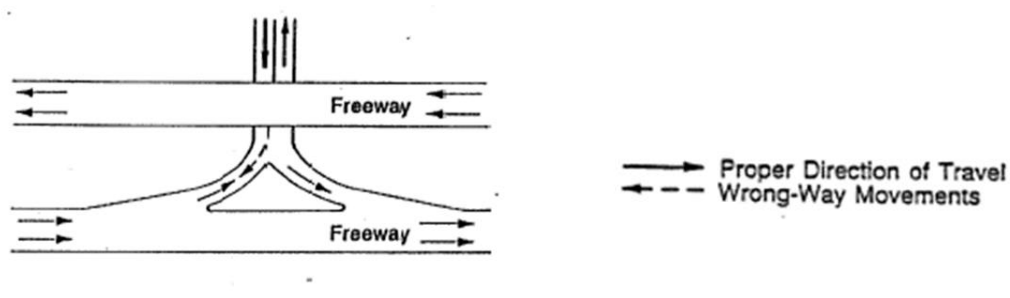



Figure 2-14: Left-Side Exit Ramp, (Copelan 1989)

Boot et al. noted that diamond interchanges are over-represented in most studies because they comprise 68% of all interchanges in the U.S. The frequency of each type of interchange in a study affects the wrong-way movement rate. Furthermore, ramps under investigation are often problematic ramps that are not randomly sampled, and therefore any conclusion from studying a biased sample of ramps cannot be generalized beyond the study area. In addition, other factors that are not related to characteristics of interchange designs may significantly affect the wrong-way movement rate. These include the surrounding area, such as the presence of frontage roads, tourism attractions and recreational areas, a dense business area, or a steep-grade blocking view (Boot et al. 2015).

## 2.4 SUMMARY

Wrong-way driving crashes while occurring infrequently, are much more likely to result in fatal and serious injuries than other types of highway crashes. Contributory factors for wrong-way driving include driving while intoxicated, being male, history of previous infractions, and younger and older drivers. The origin location of wrong-way movements (entering via the exit ramp), time of day (higher at night), and land use (higher severity in rural vs. urban areas) were found to be main environmental factors contributing to wrong-way crashes.

Characteristics of most commonly used interchanges in US were studied. These interchanges included full cloverleaf, partial cloverleaf, full-diamond, half-diamond, and diverging-diamond as well as left-side exit ramps. Interchange designs such as half-diamond and partial cloverleaf were identified as designs that caused higher proportions of wrong-way maneuvers. The literature suggests the following are more susceptible to wrong-way driving crashes and/or incidents:

- Rural divided highways with low volumes
- Urban divided highways with high volume
- Half Diamond interchange
- Partial Cloverleaf interchange
- Full Diamond interchange
- Diverging Diamond interchange

Previous studies do not show consistent results regarding wrong-way driving crash rates in urban versus rural areas. A review of literature shows that rural divided highways with low-volume and urban divided highways with high-volume and more access points are prone to wrong-way entries, and that fatal crashes are more likely to occur in rural areas (Fisher and Garcia 2016; Zhang et al. 2017). Previous studies showed that most wrong-way maneuvers originated where a driver entered a freeway through an exit ramp, particularly from a left lane (Tamburri and Theobald 1965; Copelan 1989; Finley et al. 2014).

Wrong-way maneuvers often occur at interchanges, resulting in wrong-way crashes (Vaswani 1975; Scifres and Loutzenheiser 1975; Howard 1980). However, the rate of wrong-way driving movements and crashes depends on the types of interchanges. According to Copelan, partial interchanges are prone to wrong-way entries (Copelan 1989). Parsonson and Marks found that half-diamond interchanges, followed by partial cloverleaf loop ramps, are most susceptible to wrong-way movements (Parsonson and Marks 1979). Half-diamond interchanges do not provide access to the freeway from all directions. Therefore, drivers who miss an entrance ramp may attempt to drive in the wrong direction to avoid driving a long distance to the next interchange. At partial cloverleaf interchanges, where exit and entrance ramps are adjacent to one another, lack of distance between on-ramps and off-ramps results in wrong-way movements. In a study of 122 off-ramps in California, Howard found that the rate of wrong-way entries in partial cloverleaf and half-diamond interchanges were almost twice the average and the rate of wrong-way movements in left-side exit ramps was five times higher than the average (Howard 1980).

The most commonly used and cost effective interchange in U.S. is the full diamond interchange. Copelan found that if there is a frontage road parallel to an off-ramp, drivers might think the off-ramp is the frontage road's entrance, thus entering an off-ramp in the wrong direction (Copelan 1989). Turning left onto an off-ramp from a crossroad is another potential wrong-way movement. Scifres and Loutzenheiser found that wrong-way movements are more likely to occur where lighting is poor, traffic volumes are low, and land use is light (Scifres and Loutzenheiser 1975)

With an increasing number of diverging diamond interchanges (DDIs) in the US, safety concerns about their potential for wrong-way crashes has been growing. Vaughan et al. investigated the rate and causes of wrong-way maneuvers by analyzing video records in five DDIs over a six-month period in 2012. The main findings of this research showed that low crossover angle and low volume are positively associated with wrong-way maneuvers. In addition, drivers passing through the first crossover, an inbound movement, are more likely to travel in a wrong direction than those in outbound movements. Wrong-way maneuvers mostly occurred during nighttime, off-peak times of day, and dry conditions (Vaughan et al. 2015).

Boot et al. found that diamond interchanges are over-represented in most studies because they comprise 68% of all interchanges in the U.S. The frequency of each type of interchange in a study affects the wrong-way movement rate. Furthermore, ramps under investigation are often problematic ramps that are not randomly sampled, and therefore any conclusion from studying a biased sample of ramps cannot be generalized beyond the study area.  In addition, other factors such as the presence of frontage roads, tourism attractions and recreational areas, a dense business area, or a steep-grade blocking view may significantly affect the wrong-way movement rate (Boot et al. 2015).

# 3 POTENTIAL COUNTERMEASURES

Countermeasures for wrong-way driving crashes can be categorized according to the 4E's of highway safety – engineering, emergency, education, and enforcement measures (Messer et al. 1971). Engineering countermeasures include signage, pavement markings, and geometric designs. Advanced technologies include ITS strategies implemented by Traffic Management Centers (TMCs). Education countermeasures include training, education campaigns, and public awareness. Table 3.1 outlines common countermeasures implemented by different states to reduce wrong-way crashes. The feasibility and potential effectiveness of these countermeasures are discussed in detail next.

**Table 3.1: Wrong-Way Driving Countermeasures**

| Signs | Pavement Markings | Geometric Designs | ITS Technologies |
|---|---|---|---|
| Oversized Signs | Wrong-Way Arrows | Channelizing Islands | Sensors |
| Lower-Mounted Signs | Red Raised Pavement Markings | Extended Raised Median or Longitudinal Channelizing Devices | Traffic Management Center to Inform Law Enforcement and Incident Responders |
| Multiple Signs | Stop Lines | Narrowing the Exit Ramp Terminal Throat | |
| Standard Packages of Wrong-Way Signs | Dotted Lane Line Extensions | Widening the Entrance Ramp Terminal Throat | Dynamic Signs to Warn Drivers: LED/RRFBs Illuminated wrong-way Signs, Changeable Message Signs (CMS), In-Pavement Warning Lights |
| "Entrance Freeway" Sign at Entrance Ramps | Delineations | Controlled Corner Radius: Angular Corner at Left-Side of Exit Ramp | |
| Retroreflective Strips, Fluorescent Red Sign Sheeting, or Flashing Beacons | Turn or Through Lane Arrows | | |
| | "ONLY" Marking | Open Sight Distance and Uniform Lighting Levels at Ramp Terminal | |

## 3.1 ENGINEERING COUNTERMEASURES

### 3.1.1 Signs

Signs are low-cost treatments for reducing wrong-way driving crashes. The most common signs used are Wrong Way (WW) and Do Not Enter (DNE) signs, which must be located and positioned properly so that the intended road users will be able to see them clearly (Vaswani 1973). In principle, signs placed for drivers traveling in the right direction should not be seen by drivers traveling in a wrong direction (Figure 3-1) (Baisyet et al. 2015 – note photo is not a U.S. location). Night visibility rather than day visibility should determine the placement of road signs (Vaswani 1977b). Larger signs and additional signs along the roadway will benefit drivers by increasing visibility and giving repeated cues, respectively (Figure 3-2) (Zhou et al. 2012; Baisyet et al. 2015). According to Staplin et al., California standards use larger WW and DNE signs in exit ramps. They recommend the use of signs with fluorescent red sheeting and retroreflective sheeting to improve conspicuity, especially during dawn and dusk conditions (Figure 3-3) (Staplin et al. 2001).


Figure 3-1: Warning Sign for Busway Visible From Off Ramp, (Baisyet et al. 2015)


Figure 3-2: Larger Signs and Additional Signs to Deter Wrong-Way Drivers, (NTSB 2012).

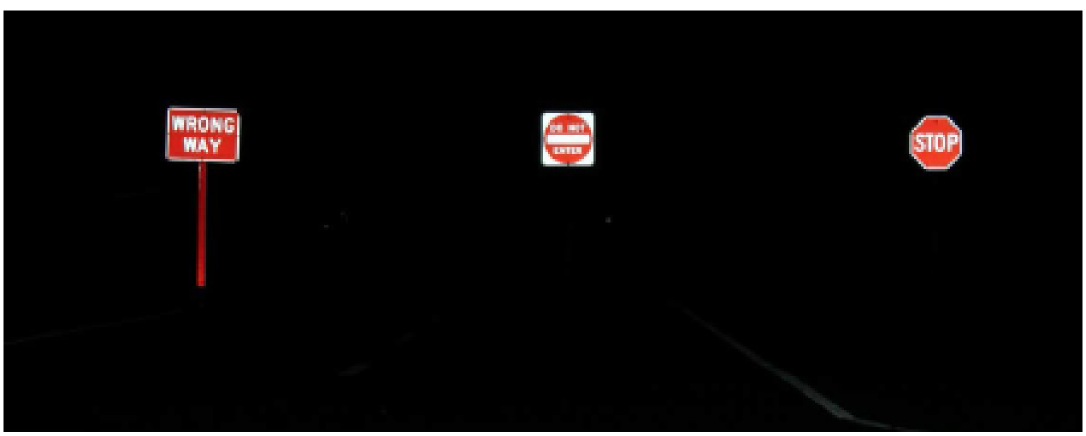



Figure 3-3: Comparing Signs With and Without Red Retroreflective Sheeting on Sign Supports, (Finley et al. 2014).

The use of low-mounted signs improve conspicuity during nighttime under low-beam vehicle headlights (Staplin et al. 2001; Cooner et al. 2004). Because impaired and older drivers focus on the area of the pavement in front of the vehicle, low-mounted signs were intended to target these drivers (Figure 3-4) (Finley et al. 2014; Baisyet et al. 2015). The figure shows the photos as part of a successful crash test under the AASHTO MASH criteria conducted for the North Texas

Tollway Authority. For example, larger DNE and WW low-mounted signs were installed at six exit ramps throughout the Salt River Valley in Arizona to warn drivers traveling in a wrong direction in 2014 (Wince 2014). The minimum mounting height for low-mounted WW and DNE signs is 3-foot from the pavement edge to the bottom of the sign. According to Seitzinger et al., the results of a study utilizing a driving simulator showed that while 3-foot mounted WW signs improved the reaction time of left-turn impaired drivers by 21% (0.888s), it did not significantly improve the reaction time of right-turn impaired drivers (Seitzinger et al. 2016). Ramp and One Way signs might be added to DNE Signs (Figure 3-6) (MUTCD 2009; Cooner et al. 2003). Using "Freeway Entrance" signs for all entrance ramps ensures motorists drive in the right direction (Figure 3-5) (Pour Rouholamin et al. 2015a; Cooner et al. 2003).


Figure 3-4: Lower-Mounted Signs Improve Conspicuity During Nighttime Under Low-Beam Vehicle Headlights, (Finley et al. 2014).


Figure 3-5: Using Freeway Entrance Sign in California, (Cooner et al. 2003).


Figure 3-6: Supplemental One Way (Top) And Ramp (Bottom) Signs To Do Not Enter Signs, (Cooner Et Al. 2003).

MUTCD recommends 48” × 48” inch DNE signs on freeways. The DNE sign is applied where a road is restricted to certain movements such as one-way traffic movement on a ramp or turning lane. This sign should be mounted on the right-hand side of the roadway given road users who might wrongly enter the roadway or ramp, and it should not be visible to traffic to which it does not apply. Figure 3-7 shows the location of wrong-way signing for divided highways. In addition, WW signs may be used further from the DNE sign as a supplement, and at least one WW sign should be placed on the exit ramp toward road users traveling in the wrong direction. MUTCD suggests 42” × 30” inch WW signs on freeways (MUTCD 2009).

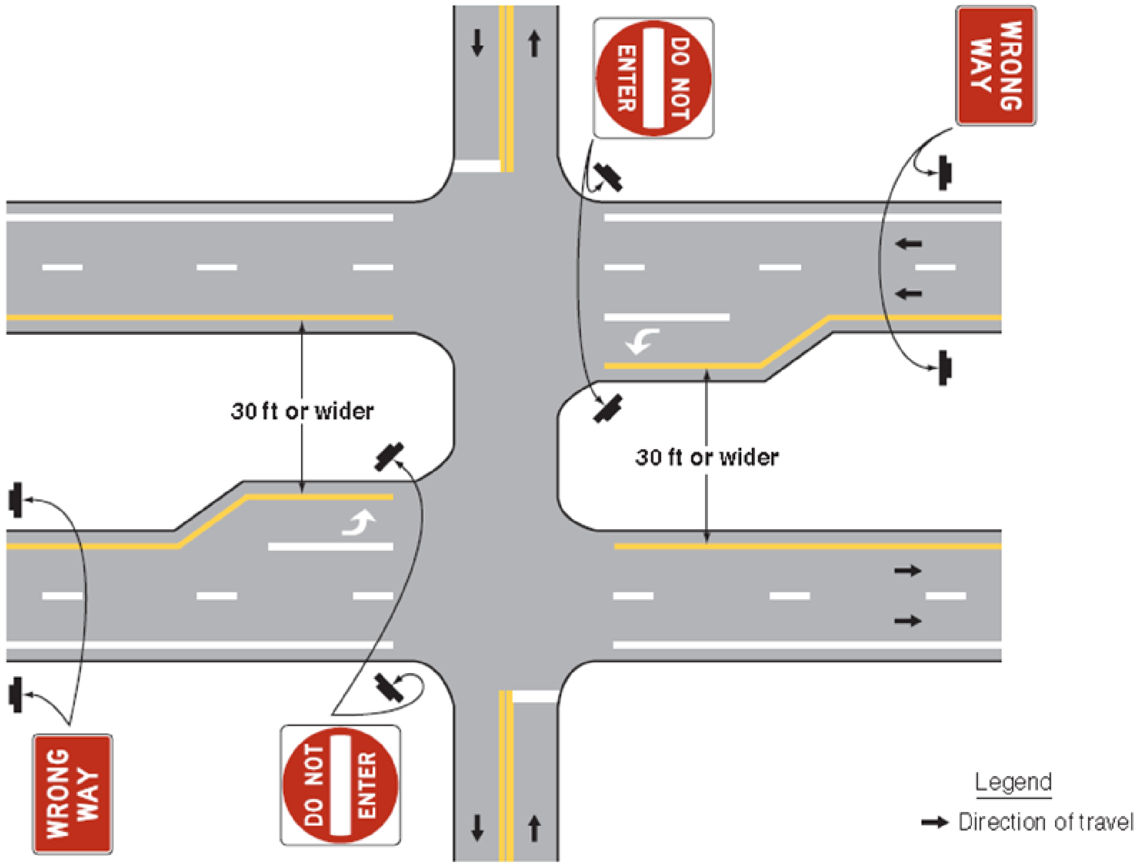



Figure 3-7: Locations of Wrong-Way Signing For Divided Highways, (MUTCD 2009)

According to MUTCD, a One Way sign is used to indicate the direction of traffic vehicles are allowed to travel. One Way signs should be used in all streets with only one traffic direction. In divided highways with a median wider than 30 ft., One Way signs should be placed on each corner of an intersection so that they are visible in each crossroad approach (Figure 3-8). If the median width is less than 30 ft., Keep Right signs should be installed in the median facing approaching traffic from the crossroad (Figure 3-9) (MUTCD 2009). The most commonly used size of One Way signs on freeways is 54” × 18” inches.

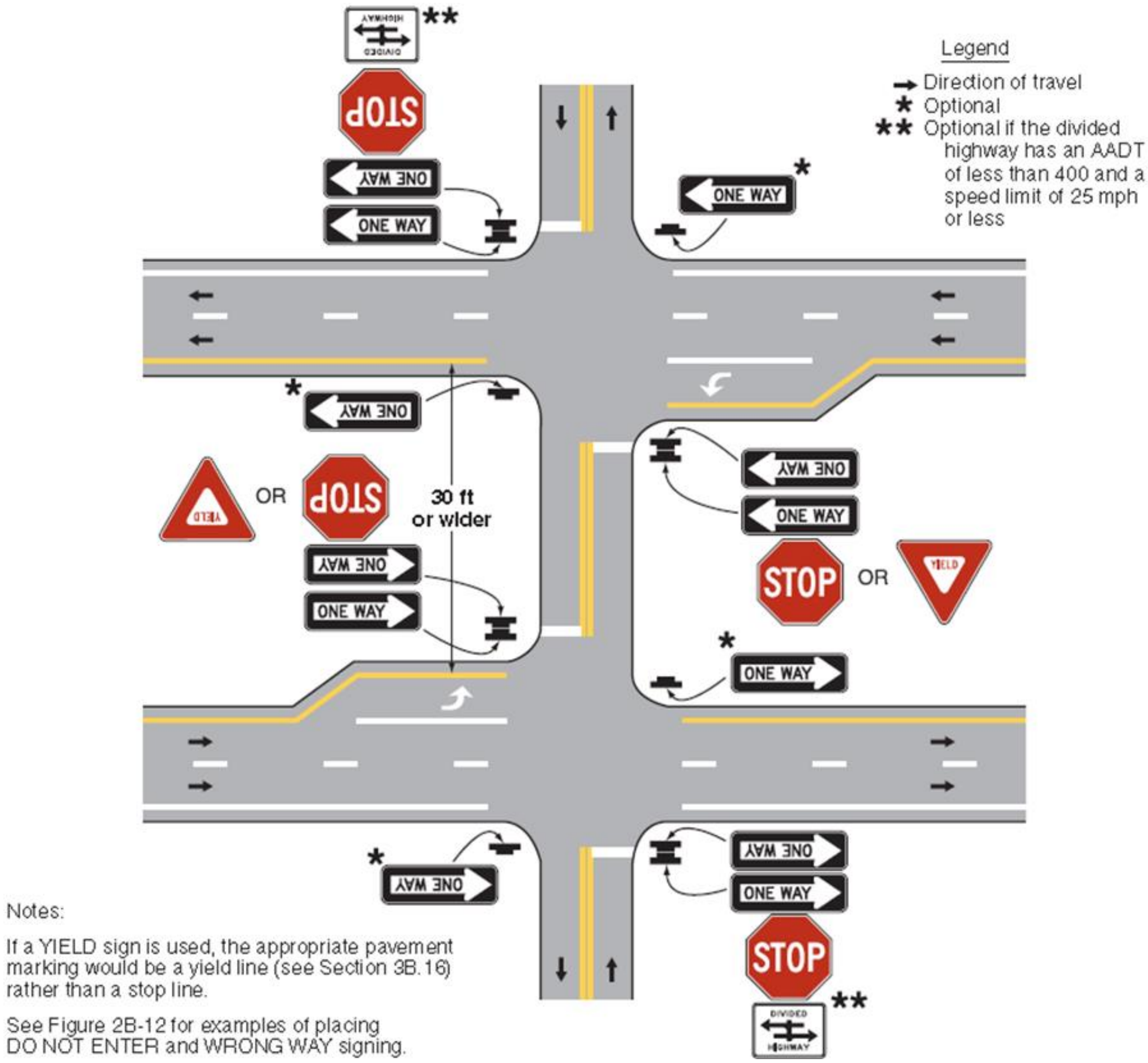



Figure 3-8: ONE-WAY Signing For Divided Highways with Median Wider Than 30 ft., (MUTCD 2009)

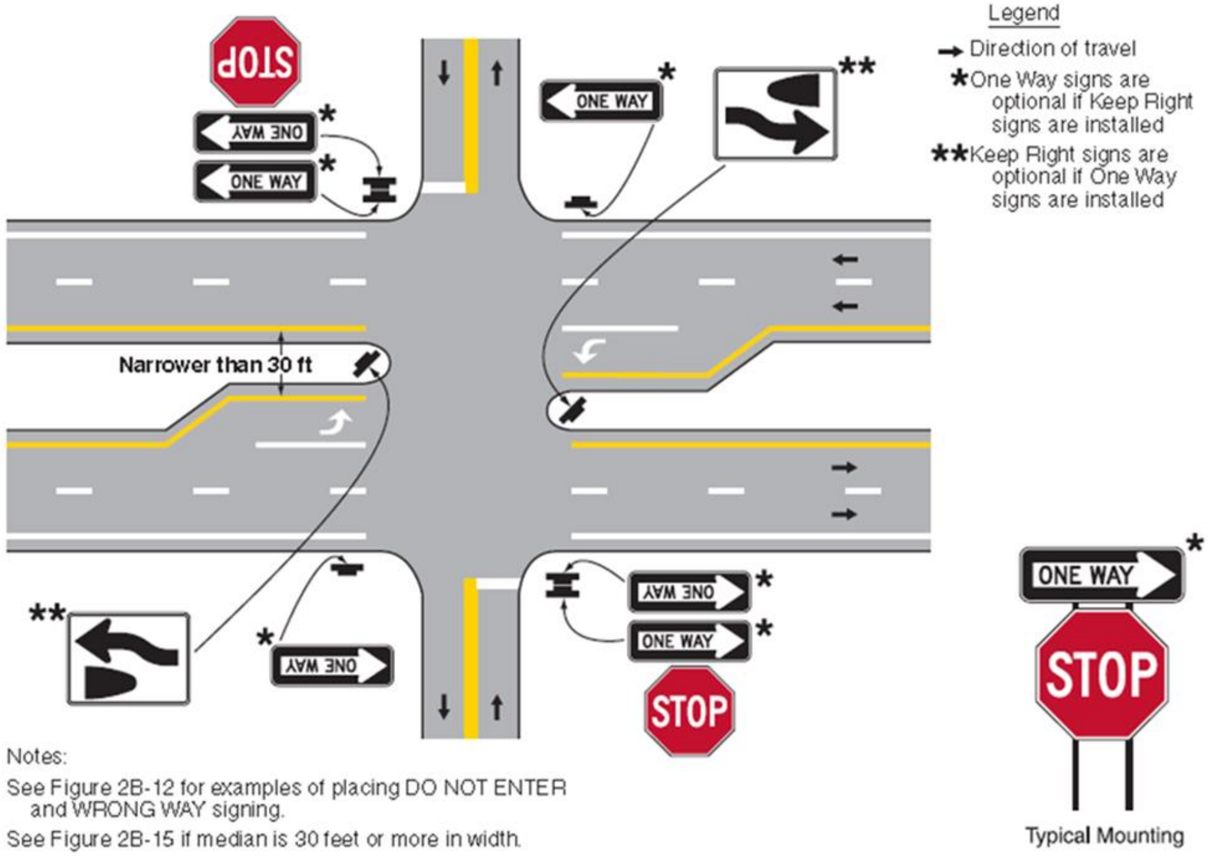



Figure 3-9: ONE-WAY Signing For Divided Highways with Median Width Less Than 30 Ft., (MUTCD 2009)

The "Keep Right" sign should be placed at locations where traffic needs to pass only on the right side of a roadway feature or obstacle, or at locations where it is not clear that traffic must keep to the right. In addition, the sign should be mounted in front of the obstruction separating opposite directions in the center of the highway such as in raised medians, parkways, islands, and underpass piers (MUTCD 2009). MUTCD recommends 48" × 60" inch Keep-Right signs on freeways. No Right/Left Turn signs should be placed at the right/left-hand corner of the intersection or over the roadway. If they are used at signalized intersections, No Right/Left Turn signs should be placed next to the signal face viewed by traffic in the right/left-hand lane, respectively (MUTCD 2009).

### 3.1.2 Pavement Markings

Pavement markings supplement the geometric design of a location by providing road users proper information about the direction of travel (Hawkins et al. 2002). However, this information should be consistent with information provided by signs. Otherwise, road users may be confused. Any enhancement to the visibility of pavement markings can reduce the chance of wrong-way driving crashes (Zhou and Pour Rouholamin 2014a). In a study by Schrock et al., approximately one of every 13 drivers performed a wrong left-turn movement from the freeway to a two-way frontage road at a selected location prior to the installation of lane direction pavement marking arrows, as drivers assumed that the frontage road is a one-way section (Figure 2-11) (Schrock et al. 2005). However, after the installation of two-lane direction pavement marking arrows downstream from the exit ramp, only one of 150 vehicles made a wrong-way movement. The installation of lane direction pavement marking arrows had a significant positive safety effect (Figure 3-15) (Schrock et al. 2005). Wrong-way arrows should be used upstream of the exit ramp and downstream near the crossroad. Also, wrong-way arrow markings may be supplemented by red raised pavement markings (RPMs) and Wrong Way signs along the exit ramp (Figure 3-10) (Caltrans 2014; Vaswani 1977a; Cooner et al. 2004; Zhou and Pour Rouholamin 2014a). Baisyet et al. recommend using straight ahead pavement marking arrows indicating the right direction within a ramp where the ramp is still a single lane because they provide a clue for drivers entering a ramp in the wrong direction, after they have passed signs at the top of the ramp (Figure 3-11) (Baisyet et al., 2015).


Figure 3-10: Wrong-Way Arrows near Supplemented by RPMs and WW Signs, (Zhou and Pour Rouholamin 2014a)

Figure 3-11: Supplemental Direction Arrows Indicating Wright-Way of Travel, (Baisyet et al. 2015)

According to Zhou and Pour Rouholamin a solid yellow line should be installed on the left edge of an exit ramp because it warns wrong-way drivers that a solid yellow line should never be on their right side. Also, where the intersection's geometric design or low visibility do not make wrong-way left-turning movement difficult onto an exit ramp, dotted lane line extensions should be applied. They also suggest using a painted island and a "Keep Right" sign where an exit and entrance ramp are located next to one another (Figure 3-12) (Zhou and Pour Rouholamin 2014a). Additionally, installing stop lines downstream of exit ramps near the crossroad can serve as clues for turning vehicles from the crossroad (Figure 3-12) (Vaswani 1973; Zhou and Pour Rouholamin 2014a; Vaswani 1977b; Vaswani 1977c; Vaswani 1977a).


Figure 3-12: Solid Yellow Line on the Left Edge of an Exit Ramp (Left). Dotted Lane Extension, Pained Island in Ramp Intersection, and Stop Line Downstream of Exit-Ramp (Right), (Zhou and Pour Rouholamin 2014a)

Zhou and Pour Rouholamin suggested that delineations mounted along exit ramp barriers are very effective in catching drivers' attention, especially at night. Yellow delineations should be installed for appropriate traveling direction on the left side of the vehicle, and red delineations should be installed for wrong traveling direction on the right side of the vehicle (Figure 3-13) (Zhou and Pour Rouholamin 2014a).


Figure 3-13: Yellow Delineations in Wright-Way of Travel (Left Image) and Red Delineations in Wrong-Way of Travel (Right Image) along Exit Ramp Barriers, (Zhou and Pour Rouholamin 2014a)

In a study by Miles et al., red retroreflective raised pavement markings (Figure 3-14) (RRPMs) improved drivers' understanding of wrong-way driving on one-way divided roadways. However, the use of pavement marking arrows (Figure 3-10, Figure 3-15) had a stronger impact than RRPMs in improving drivers' understanding of the intended direction of travel (Miles et al. 2008). In Hawaii, red pavement markings (Figure 3-14) (RPMs) or reflectors indicate the wrong direction of travel on undivided highways in order to help drivers from left-side driving countries understand the direction of traffic (HDOT 2006; Miles et al. 2008). Reflectorized pavement arrows in interstate exit and entrance ramps were implemented in Virginia to reduce wrong-way entries on highways (Vaswani 1977a; Vaswani 1977c).

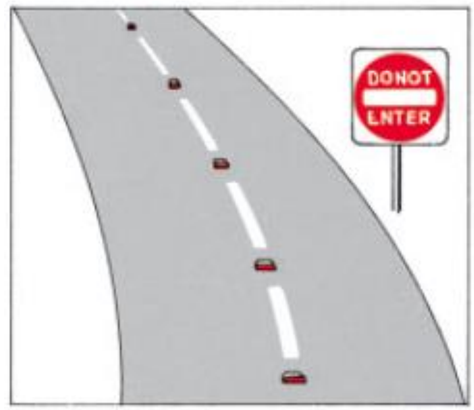



Figure 3-14: Red Retroreflective Pavement Markings, (Leaming 2014; HDOT 2006)

According to MUTCD, the purpose of using pavement markings is to show obligatory and permissive movements in certain lanes, such as in a two-way left turn lane, separate turn lanes, or lanes with permissive movements, which are contrary to the normal rules of the road. If lane-use arrows are used in turn lanes, at least two arrows should be used. One lane-use arrow should be placed downstream near the stop bar or intersection and another one upstream in an appropriate distance from the first one to reduce wrong-way movements. Also, The ONLY word may be added to supplement lane-use arrows in separate turn lanes. Also, in dropped lanes on freeways where a through lane becomes an obligatory exit lane, lane-use markings may be applied. Furthermore, the lane-reduction arrow may be used where a lane-reduction transition occurs. Finally, lane line extension should be used to separate a through lane from an adjacent lane in the interchange, such as entrance ramps with a parallel acceleration lane, exit ramps with a parallel deceleration lane, or in the intersection.  Figure 3-15 shows standard designs for lane-use, lane reduction, and wrong-way arrow markings (MUTCD 2009).

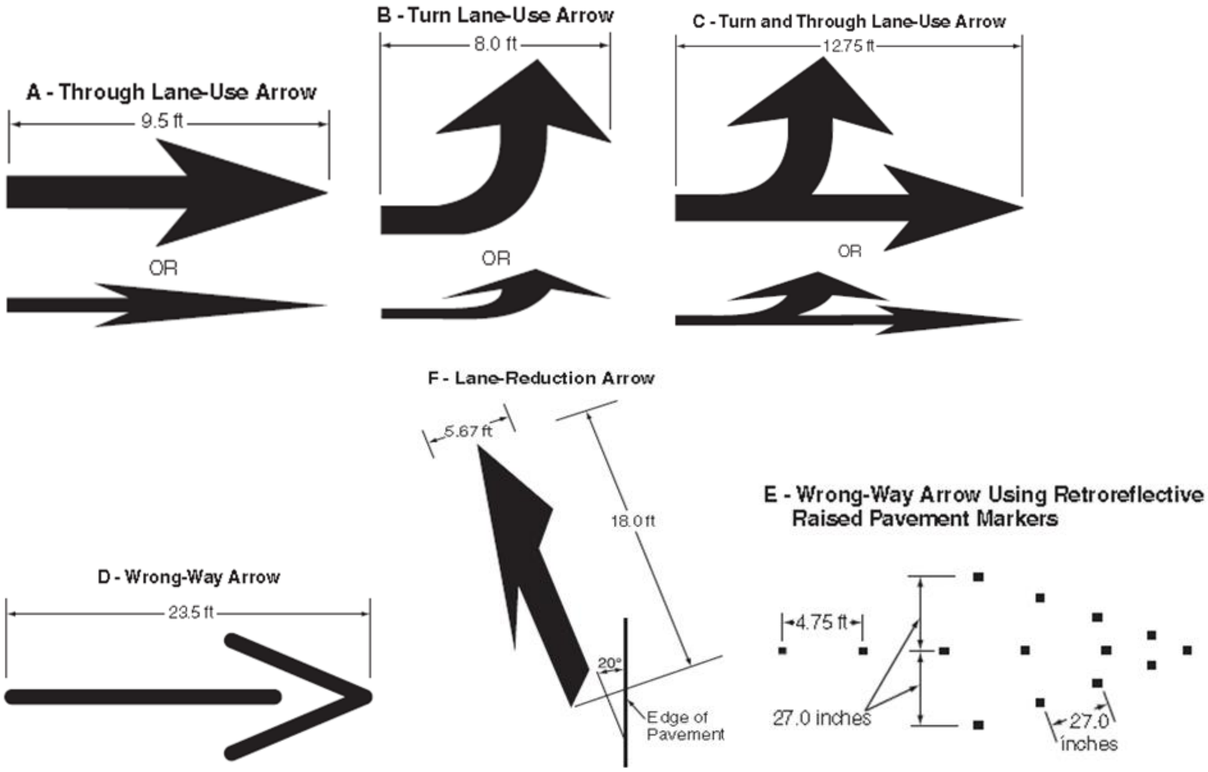



Figure 3-15: Standard Arrows for Pavement Markings, (MUTCD 2009)

MUTCD recommends a combination of signing and pavement markings at an exit ramp and an entrance ramp terminal to deter wrong-way entrance. At an exit ramp terminal, at least one Wrong Way sign, one Do Not Enter sign, and one One-Way sign shall be placed facing road users who may travel in the wrong direction (Figure 3-17). At interchanges where an exit ramp intersects a two-way crossroad, double solid yellow lines should be placed as center lines in the crossroad approaching the ramp intersection for an adequate distance, and lane-use arrows should be placed at exit ramp lanes close to the crossroad terminal (Figure 3-17). At an entrance ramp, a one-way sign should be placed on the entrance ramp close to the roadway terminal facing vehicles traveling in the roadway, and a one-way sign should be placed in the roadway visible to vehicles in the entrance ramp (Figure 3-16). Wrong-way arrow markings should be used downstream of a ramp terminal or where lane-use arrows are not appropriate to guide drivers in a correct direction and prevent them from a wrong-way movement (Figure 3-16, Figure 3-17) (MUTCD 2009).

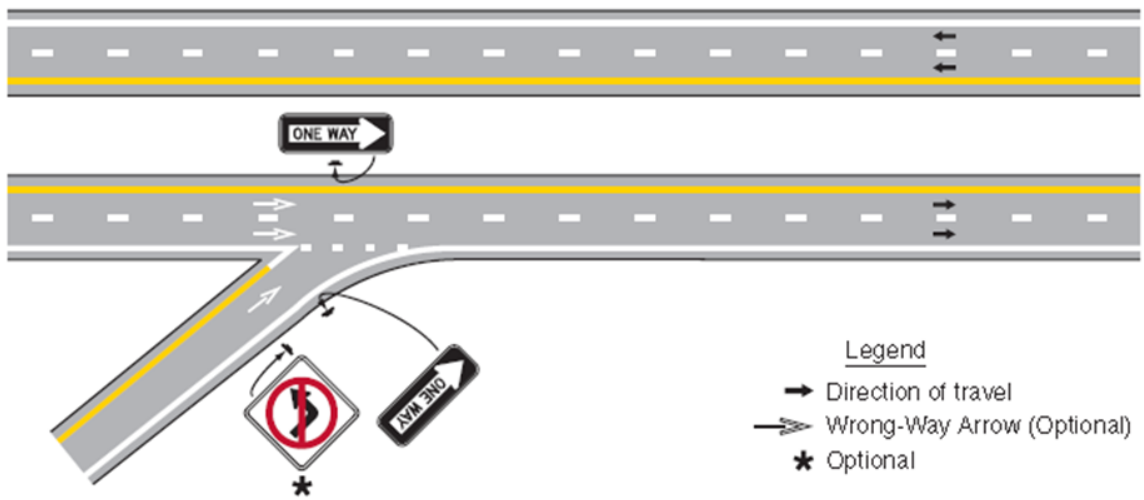



Figure 3-16: Application of Signing and Pavement Markings at an Entrance Ramp, (MUTCD 2009)

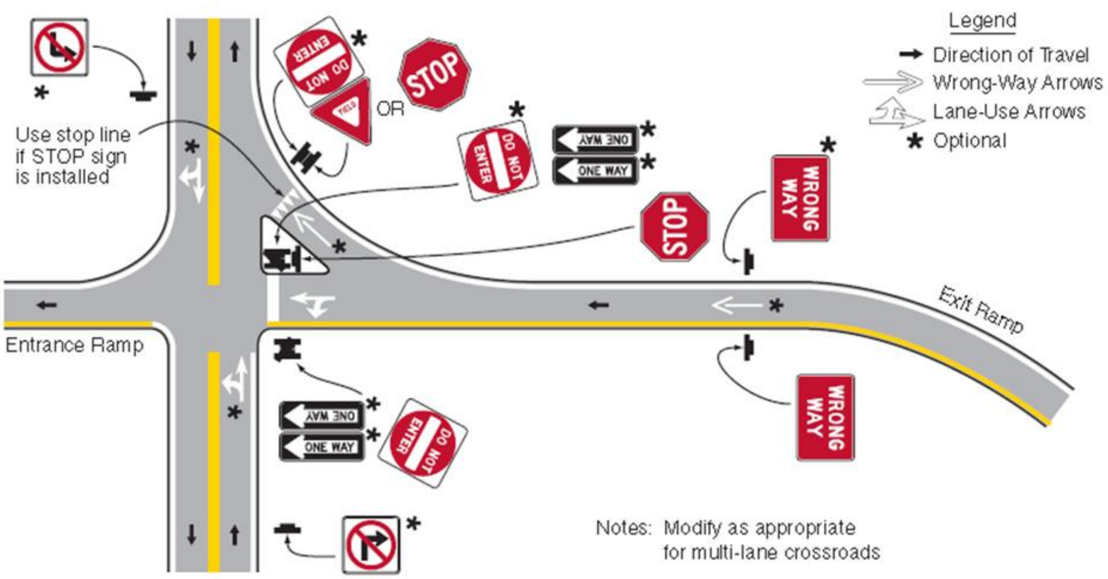



Figure 3-17: Application of Signing and Pavement Markings at an Exit Ramp, (MUTCD 2009).

### 3.1.3 Interchange Signing and Pavement Markings for Interchanges

Zhou and Pour Rouholamin provided wrong-way driving countermeasures for the five types of interchanges. In general, they suggested using red retroreflective strips on sign supports, appropriate lane-use arrows at ramp intersections, additional pairs of WW signs near the ramp terminal, and the word ONLY for emphasizing an exclusive lane. Also, they suggested signing and pavement markings for the following ramp intersection configuration in each interchange (Zhou and Pour Rouholamin 2014a).

#### 3.1.3.1 Partial Cloverleaf Interchange

At partial cloverleaf interchanges, where exit and entrance ramps are adjacent to one another, Zhou and Pour Rouholamin recommend using a painted island with a left-turn line extension marking and installing a Keep Right sign and a DNE sign in the median. If the ramp intersection included a channelizing island, additional DNE and ONE WAY signs can be placed on the island. Figure 3-18 displays pavement markings and signing for a ramp intersection with a channelizing island in a partial clover interchange (Zhou and Pour Rouholamin 2014a).

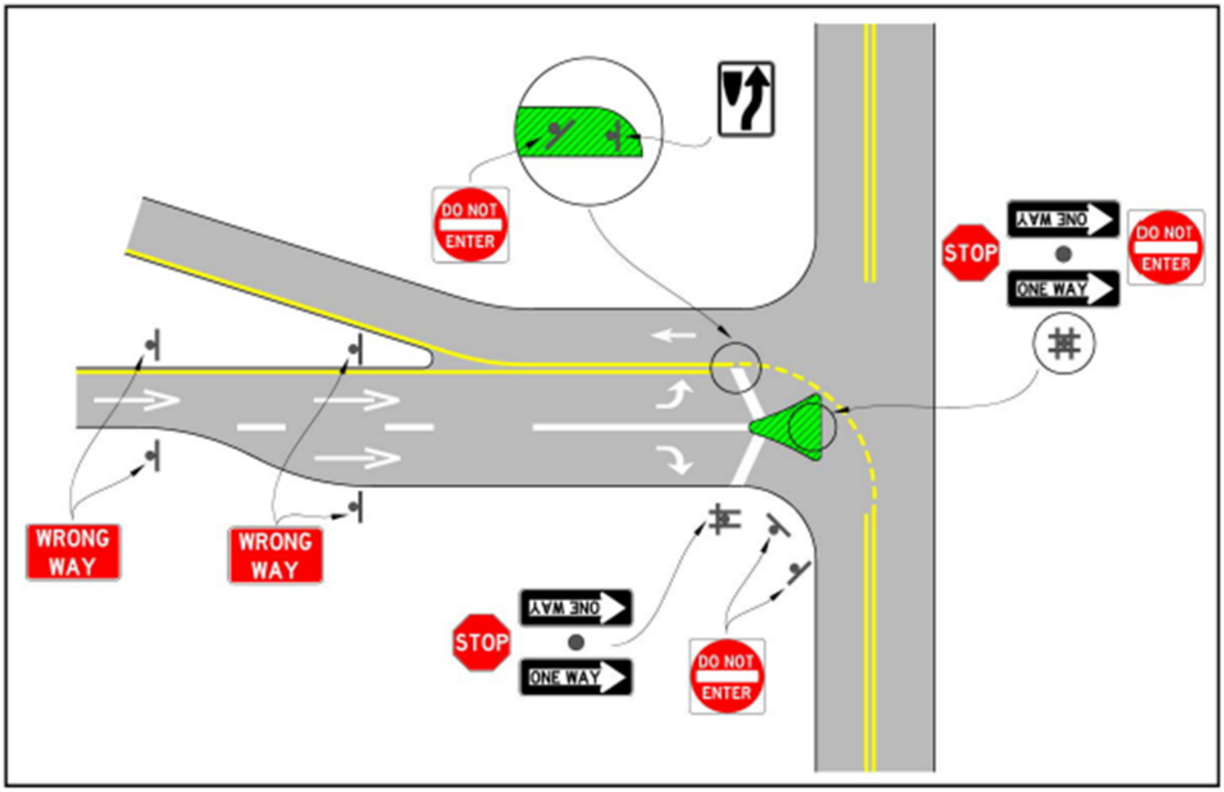



Figure 3-18: Countermeasures in a Parclo Ramp Intersection with a Channelizing Island, (Zhou and Pour Rouholamin 2014a).

According to Illinois Department of Transportation, at two-quadrant partial cloverleaf interchanges, the maximum left-turn radius from the crossroad to the entrance ramp should be 80 ft. and the maximum right-turn radius from the exit ramp onto the crossroad should be 100 ft., to prevent wrong-way movements into the exit ramp (Figure 3-19). Also, in four-quadrant partial clover interchanges, a minimum distance of 200 ft. between the left-turning path of a controlled ramp terminal and the crossroad downstream of the exit ramp gore should be considered to prevent wrong-way movements and provide enough storage lane for vehicles in the crossroad if signalized (Figure 3-19) (IDOT, 2010).

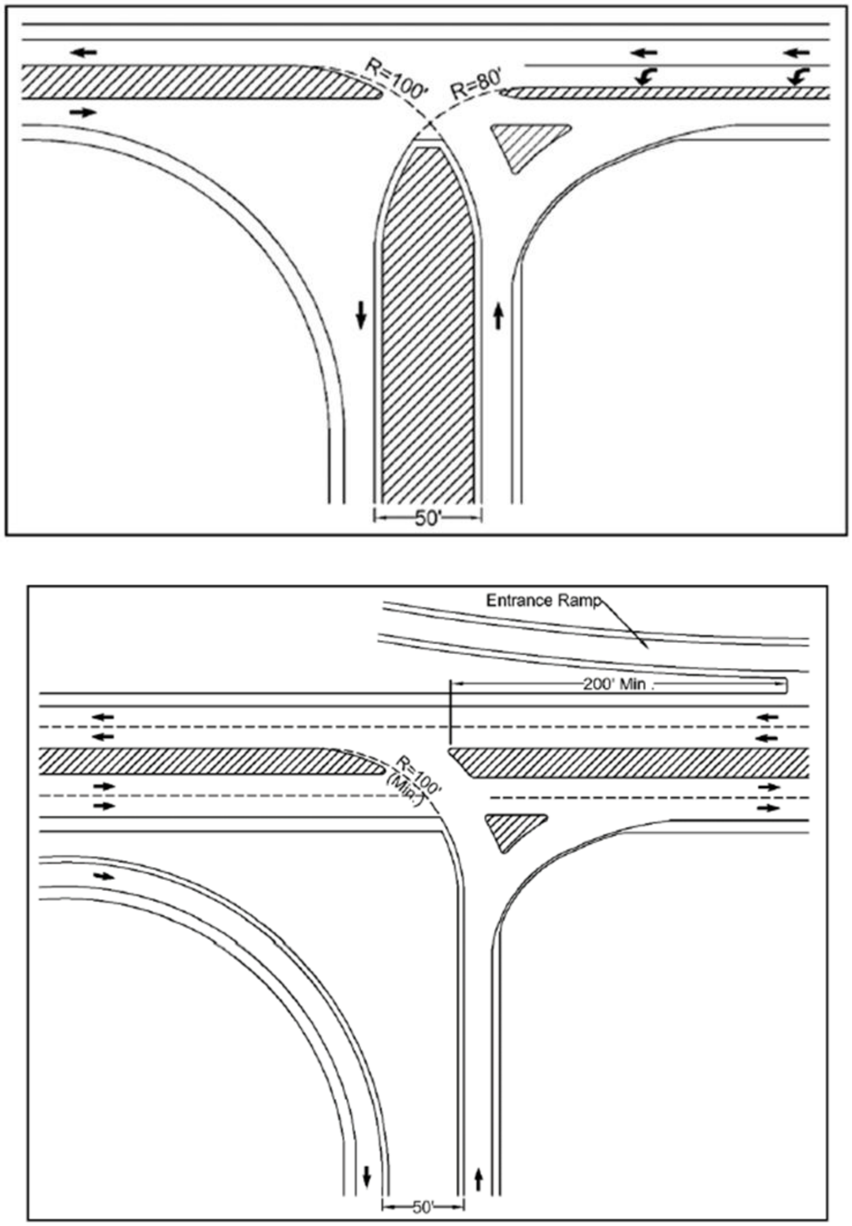



Figure 3-19: Maximum Right and Left Turn Radius for a Typical Two-Quadrant Parclo Interchange (Top), Controlled Terminal for a Four-Quadrant Parclo Interchange (Bottom), (Zhou and Pour Rouholamin 2014a).

#### *3.1.3.2 Diamond Interchange*

The No Left Turn signs should be installed in the near-right and far-left side of the crossroad in a ramp intersection visible to drivers in the crossroad. For half-diamond interchanges, guide signs should be installed to direct drivers to the nearest entrance ramp movement. The second pair of wrong-way signs in the exit ramp may be used for problematic locations with a high crash rate. Figure 3-20 shows countermeasures for a ramp intersection configuration in a diamond interchange (Zhou and Pour Rouholamin 2014a).

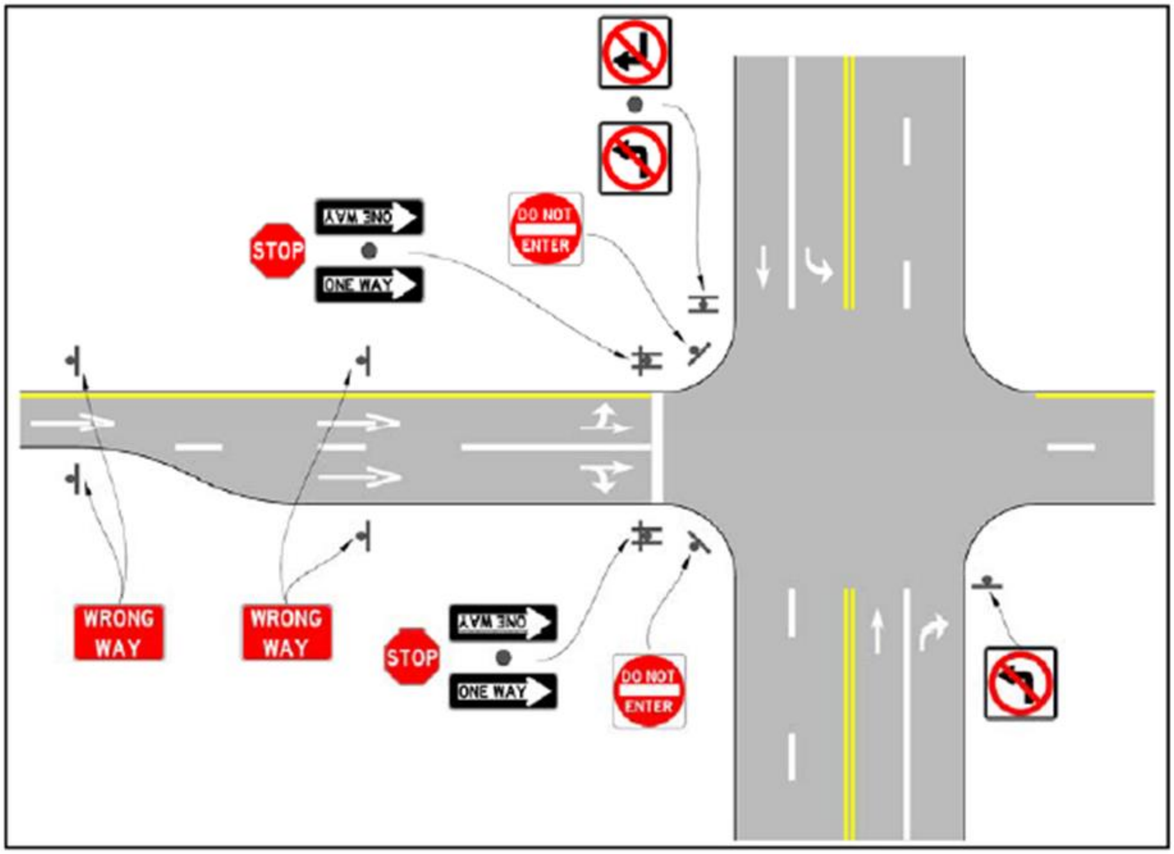



Figure 3-20: Countermeasures for a Ramp Intersection in a Diamond Interchange, (Zhou and Pour Rouholamin 2014a)

According to American Association of State Highway Transportation Officials (AASHTO), for an undivided crossroad, a sharp angle between the left edge of the exit ramp and the right edge of the crossroad discourages right turn wrong-way entry onto the exit ramp. Installing channelizing islands in ramp terminals guides drivers traveling in the right direction, and they can be used for additional signing (Vaswani 1973; AASHTO 2011). Non-traversable medians effectively deter wrong-way left turn movement onto an exit ramp terminal (Figure 3-21) (AASHTO 2011; Pour Rouholamin et al. 2015b).

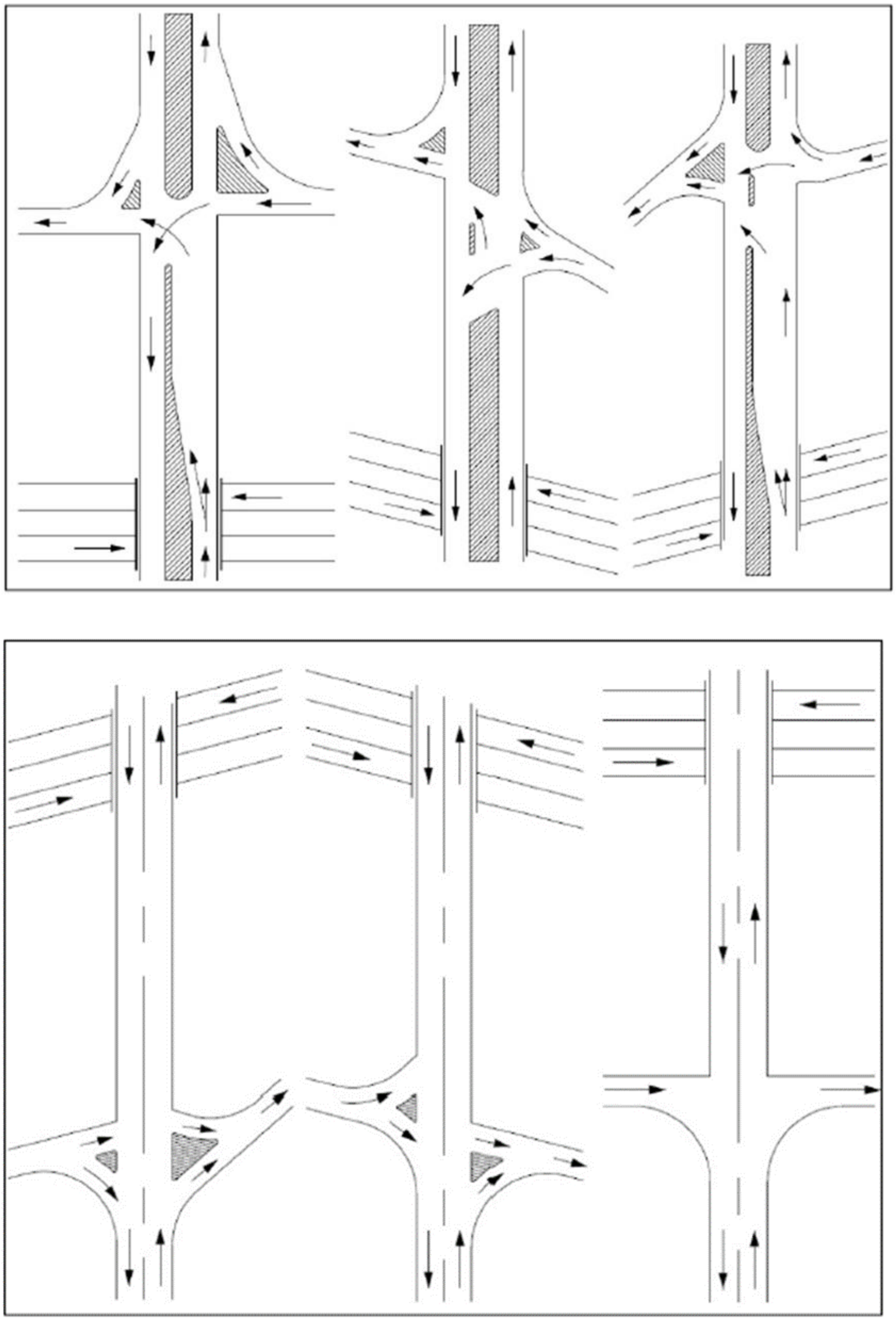


Figure 3-21: Crossroad Designs to Discourage Wrong-Way Entry, (AASHTO 2011)

### *3.1.3.3 Diamond Interchange with Continuous Frontage Roads*

According to Zhou and Pour Rouholamin, a One Way sign should be installed at the end of the frontage road that is visible to drivers in a driveway or crossroad near the exit gore area. They also suggested using a pair of One Way signs upstream of the entrance ramp visible to drivers in the crossroad when unsignalized (Zhou and Pour Rouholamin 2014a). Figure 3-22 shows signing and pavement markings for the configuration of a ramp intersection of a diamond interchange with a continuous frontage road. Raised medians, channelizing islands, and controlled corner radius at the intersection of the frontage road and crossroad are applicable geometric designs for reducing wrong-way movements (Zhou and Pour Rouholamin 2014a).

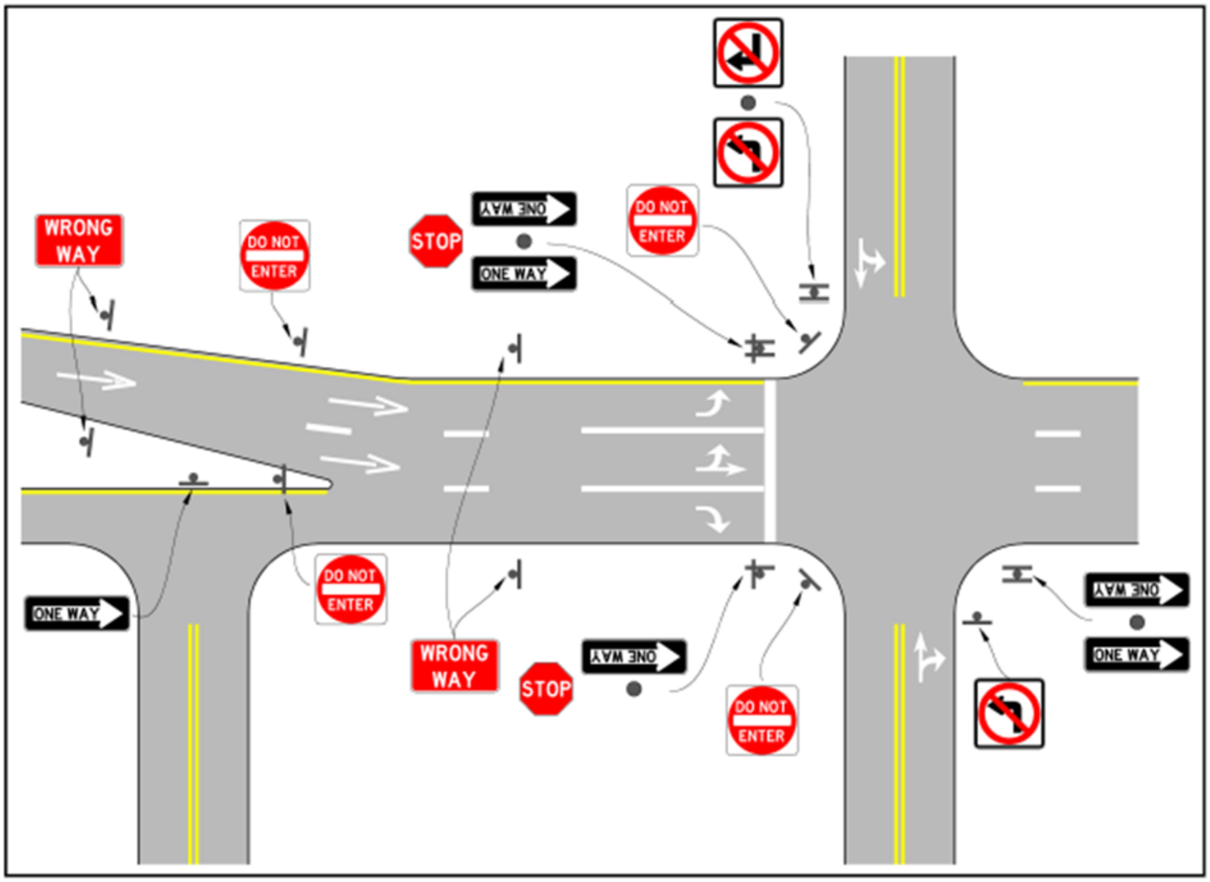



Figure 3-22: Countermeasures for a Ramp Intersection in a Diamond Interchange with A Frontage Road, (Zhou and Pour Rouholamin 2014a).

According to AASHTO, the exit ramp should meet the two-way frontage road at a right angle to discourage wrong-way entry (Figure 3-23). However, for the one-way frontage road, an acute angle between the exit ramp and the frontage road is appropriate (Figure 3-23) (AASHTO 2011).

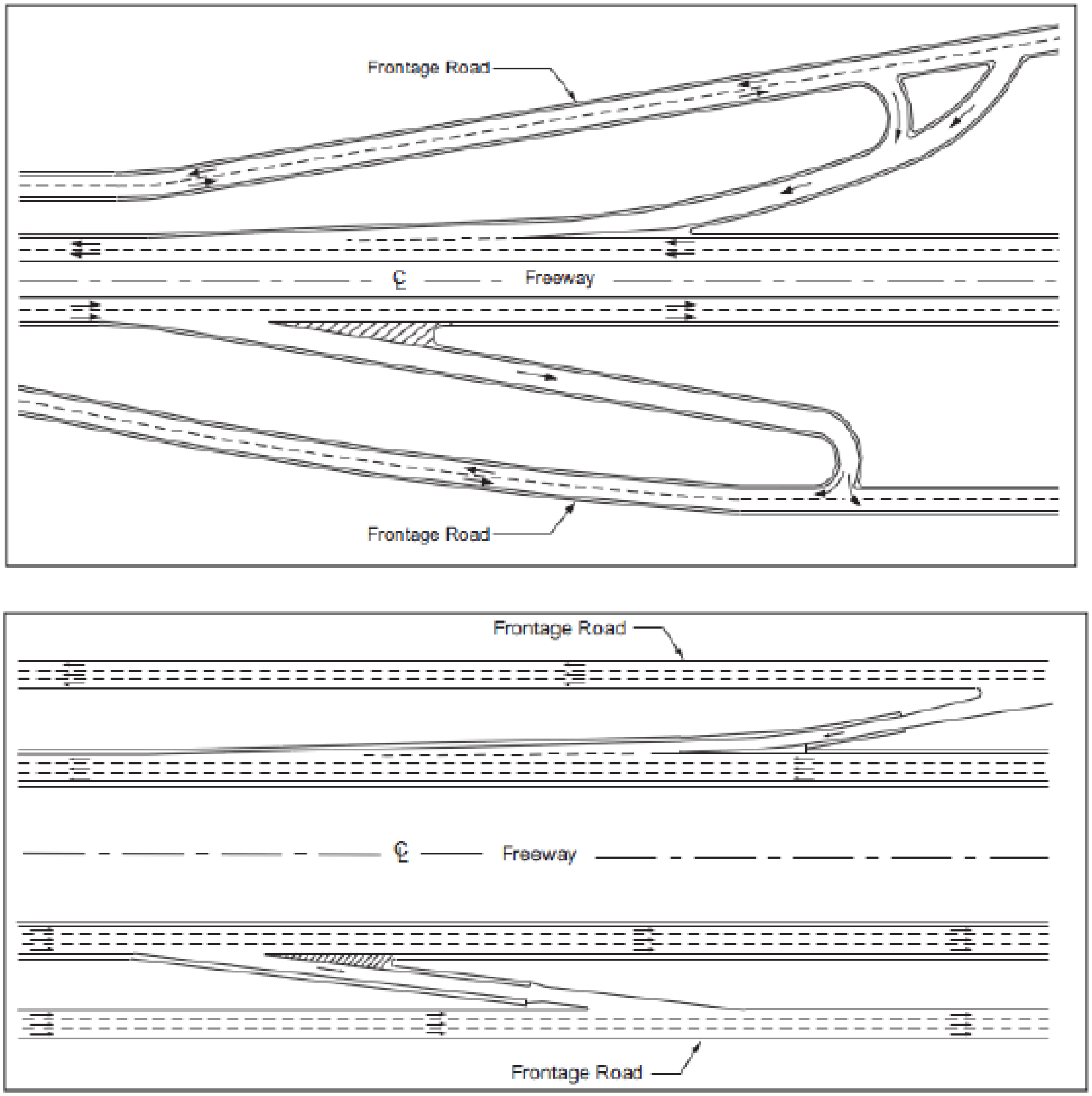



Figure 3-23: A Right Angle between an Exit Ramp and a Two-Way Frontage Road (Top). An Acute Angle between an Exit Ramp and a One-Way Frontage Road (Bottom), (AASHTO 2011).

### *3.1.3.4 Single Point Diamond Interchange (SPDI)*

Zhou and Pour Rouholamin recommend signing and pavement markings shown in Figure 3-24 at one quadrant of an SPDI to mitigate wrong-way driving movements. They noted that the DNE sign should be mounted lower than the Yield sign at the right turning exit ramp near the crossroad terminal (Zhou and Pour Rouholamin 2014a).

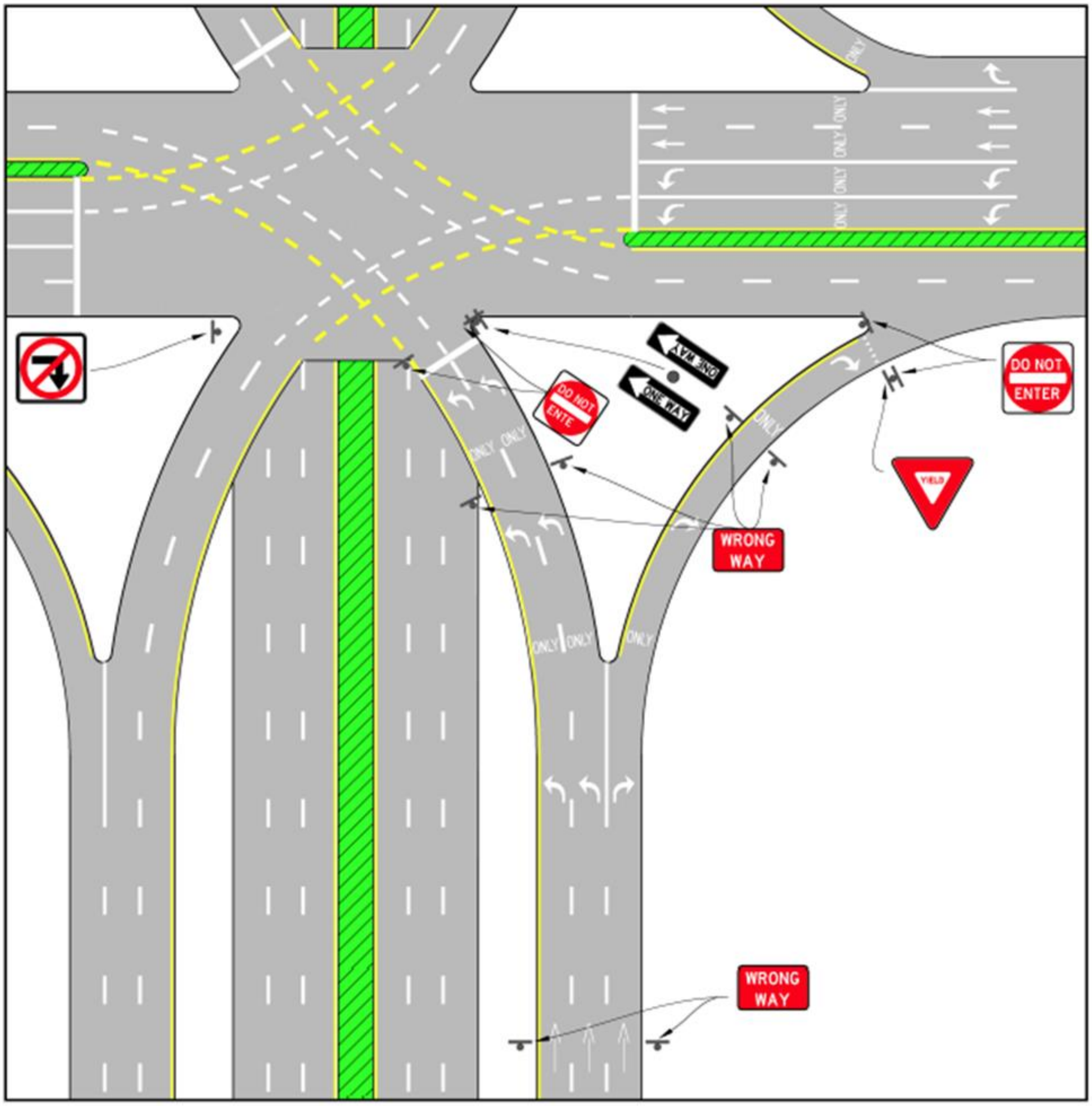



Figure 3-24: Countermeasures at an Exit Ramp of an SPDI, (Zhou and Pour Rouholamin 2014a)

### *3.1.3.5 Freeway Feeder*

A freeway feeder is usually a multilane exit ramp from a freeway to local roads. Zhou and Pour Rouholamin recommended using oversized DNE signs and pairs of wrong-way signs corresponding to the number of exit ramp lanes. They also suggested that pairs of wrong-way signs should be installed at an appropriate distance from one other, and they should be mounted at different heights, such as 3, 5, and 7 feet so that they are all visible from a far distance. They also recommended using wrong-way signs on the other side of existing overhead lane-use signs at an exit ramp where the freeway feeder has more than three lanes (Figure 3-26). Figure 3-25 shows pavement markings and signing at a three-lane freeway feeder (Zhou and Pour Rouholamin 2014a).

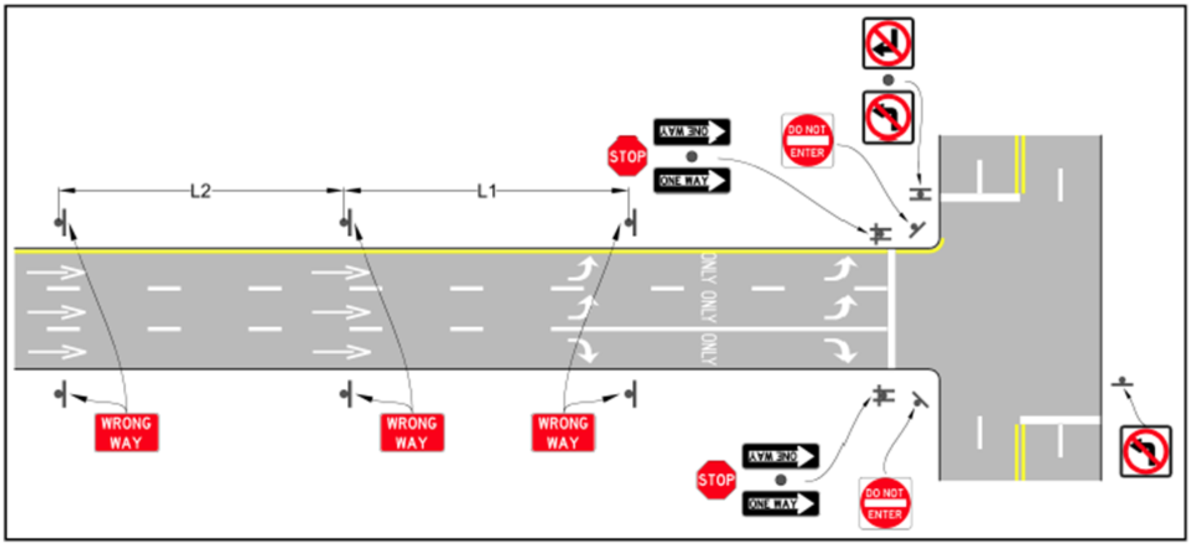



Figure 3-25: Countermeasures at a Three-Lane Freeway Feeder, (Zhou and Pour Rouholamin 2014a)


Figure 3-26: Wrong-Way Signs On the Other Side of Existing Overhead Lane-Use Signs, (Cooner et al. 2003)

### 3.1.4 Traffic Signals

Zhou and Pour Rouholamin suggested that circular green signals supplemented with No Right/Left Turn signs should be used at signalized exit ramp intersections. However, they can be replaced with green arrow signals which convey a more obvious message to drivers (Figure 3-27) (Zhou and Pour Rouholamin 2014a; Baisyet et al. 2015). No Right/Left Turn signs should be placed next to the signal face viewed by traffic in an exclusive through-lane. Figure 3-28 shows traffic signal configuration for a typical exit ramp intersection (Zhou and Pour Rouholamin 2014a).

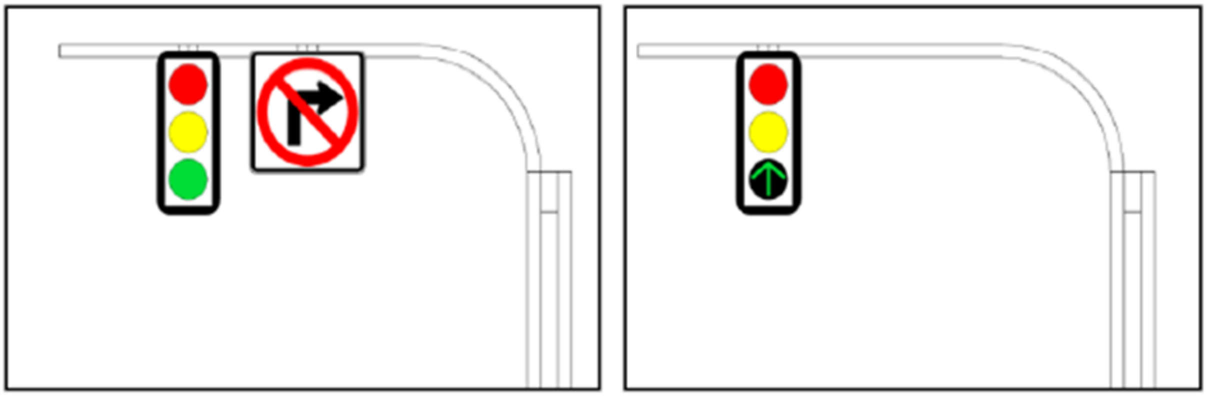


Figure 3-27: Analogous Traffic Signals for Exclusive Through-Lanes, (Zhou and Pour Rouholamin 2014a).

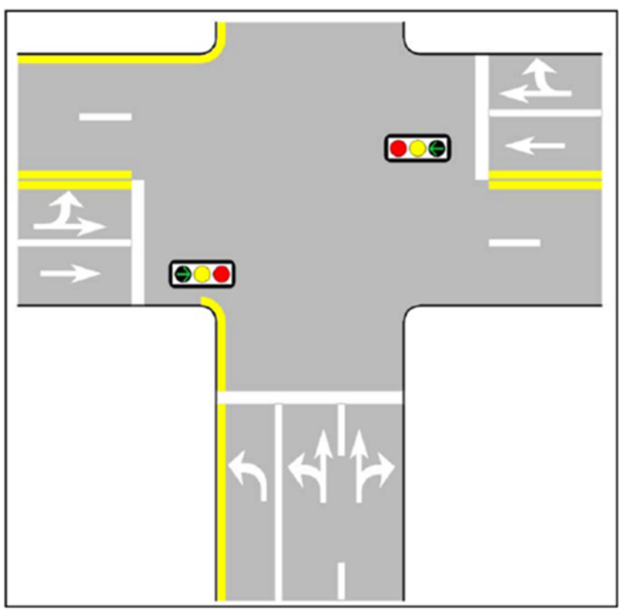


Figure 3-28: Traffic Signal Configuration for a Typical Exit Ramp Intersection, (Zhou and Pour Rouholamin 2014a)

### 3.1.5 Geometric Modifications / Designs

Proper geometric designs, especially in exit and entrance ramps, can reduce wrong-way movements. According to WSDOT, separating adjacent exit and entrance ramps through a raised median can provide additional space for installing proper signage and direct drivers in the correct direction. The minimum width of a raised median is 7 ft. WsDOT suggests reducing the width of the exit ramp terminal throat by installing a raised island (preferred option) or painted island and removing the flared left edge of exit ramps is effective at discouraging wrong-way entry onto the exit ramp (Figure 3-29) (WSDOT 2016; Vaswani 1977a; Vaswani 1977c; Pour Rouholamin et al. 2015b). They also suggest widening the entrance-ramp terminal throat encourages right-way movements (Figure 3-29). Further guidance is that the distance from the ramp median to the left-turn stop line on a crossroad shouldn't be more than 60% of the way through the intersection (L) in order to prevent wrong left-turn movements onto exit ramps (Figure 3-29) (WSDOT 2016; Wang et al. 2017).

Where feasible, an angular corner at the left side of the exit ramp discourages right-turning drivers from going in the wrong direction (Figure 3-30) (WSDOT 2016; Pour Rouholamin et al. 2015b; Zhou and Pour Rouholamin 2014a). An extended raised median into the ramp intersection and proper directional arrows in the diamond interchange are effective at reducing left-turn wrong-way movements onto the exit ramp (Figure 3-31) (WSDOT 2016; Baisyet et al. 2015).

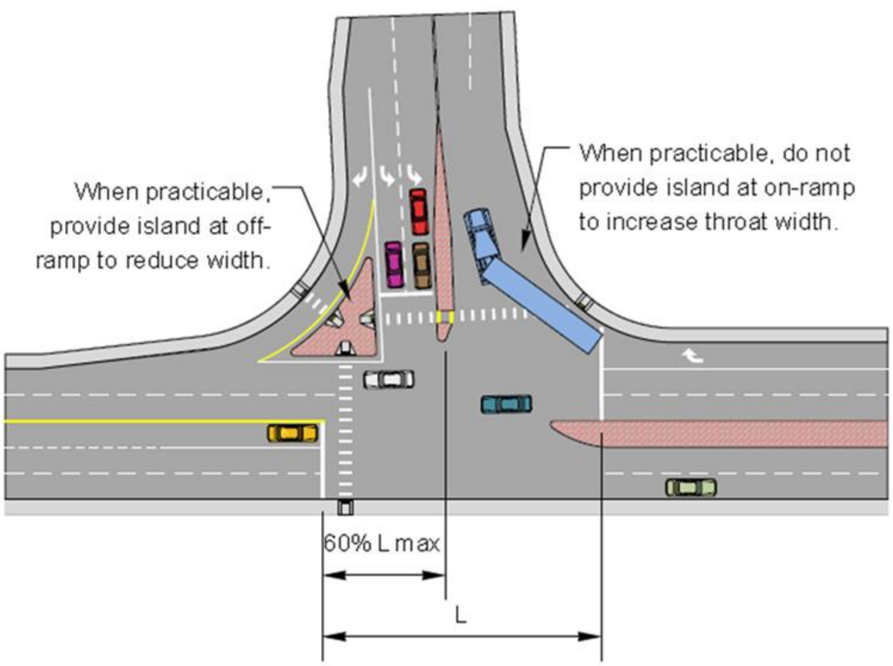



Figure 3-29: Countermeasures for Wrong-Way Movements for Adjacent Entrance and Exit Ramps, (WSDOT 2016)

Figure 3-30: Example Angular Corner at the Left Edge of the Exit Ramp, (Zhou and Pour Rouholamin 2014a)

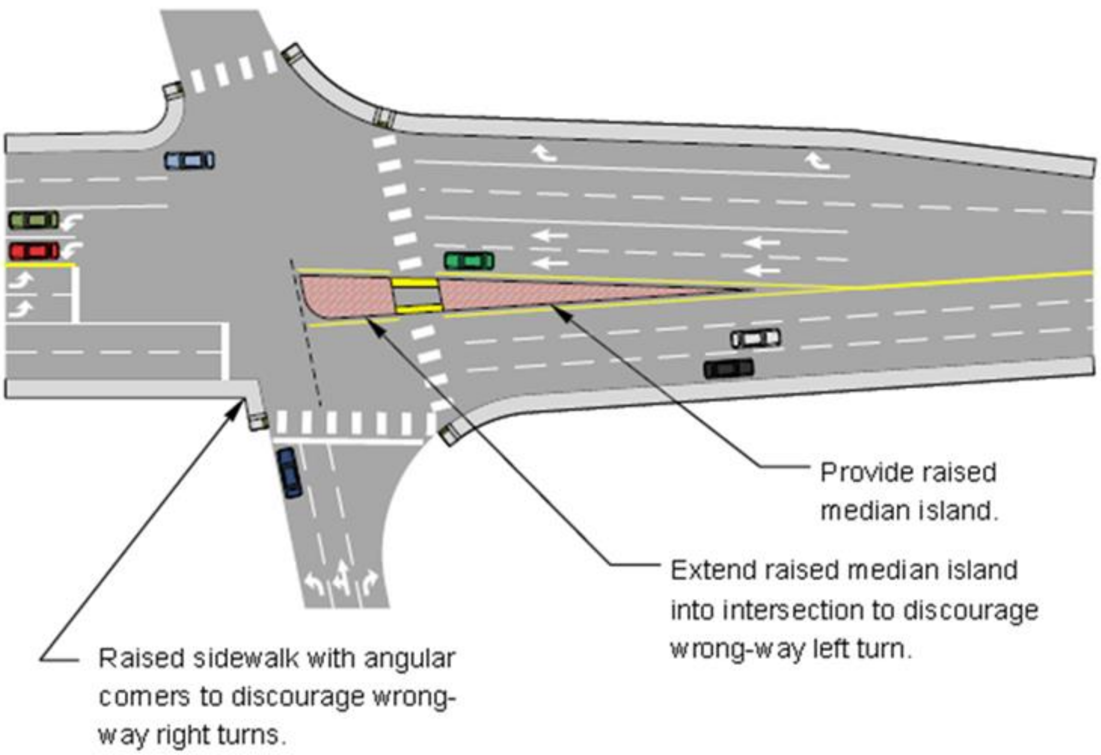



Figure 3-31: An Extended Raised Median into the Ramp Intersection, (WSDOT 2016)

Zhou and Pour Rouholamin suggest that the following geometric designs at exit/entrance ramps are more susceptible to wrong-way driving, and they should be prevented if possible.

- Adjacent entrance and exit ramps intersecting a crossroad (e.g., partial clover interchanges)
- Isolated exit ramps
- Left-side exit ramps: Drivers usually expect to make right turns to enter freeways
- One-way exit ramps connected as unchannelized T-intersections
- Exit ramps intersecting with two-way frontage roads
- Less common arrangements of exit ramps (e.g., button-hook or J-shaped ramp connected to a parallel or diagonal street or frontage road)
- Temporary ramp terminals at work zones
- Freeway feeders (where exit ramps transition into local roads)
- Side streets adjacent to exit ramps (Zhou and Pour Rouholamin 2014a).

According to AASHTO, crossing and turning movements where a two-way frontage road intersects driveways, streets, or exit ramps are complicated, resulting in increasing wrong-way movements. This problem is greatest where an exit-ramp joins a two-way frontage road at an acute angle, which presents as an on-ramp for wrong-way drivers (see also Figure 3-23, top) (AASHTO 2011; Pour Rouholamin et al. 2015b). Longitudinal channelizing devices are an appropriate and low-cost alternative to raised medians so that they prevent left-turn wrong-way entry into exit ramps where a raised median is not present (Figure 3-32) (Morena and Ault 2013). Narrowing median opening on crossroads is effective at reducing left-turn wrong-way movements onto an exit ramp (Zhou and Pour Rouholamin 2014a; Zhou and Pour Rouholamin 2014c).

Figure 3-32: Longitudinal Channelizing Devices Prevent Wrong-Way Left-Turn Movement, (Morena and Ault 2013)


Figure 3-33: Before (left Image) and after (right Image) Narrowing a Median Opening on the Crossroad, (Zhou and Pour Rouholamin 2014c; Zhou 2014d)

Installing double-yellow stripe barriers and reflectors or a concrete median barrier in trumpet interchanges can avoid wrong-way movements (Moler 2002). Medians are used to separate opposing directions, so raised medians should not be used to divide the same direction of traffic, because it may confuse and direct drivers in a wrong direction (AASHTO 2011; Zhou and Pour Rouholamin 2014a). A simple channelization can be very efficient at improving operation and reducing wrong-way entry into freeway ramps, one-way streets, and turning roadways. However, channelization of same direction travel lanes may cause confusion resulting in wrong-way movements into opposing traffic lanes (AASHTO 2011; Neuman et al. 2008). See and example in Figure 3-35.

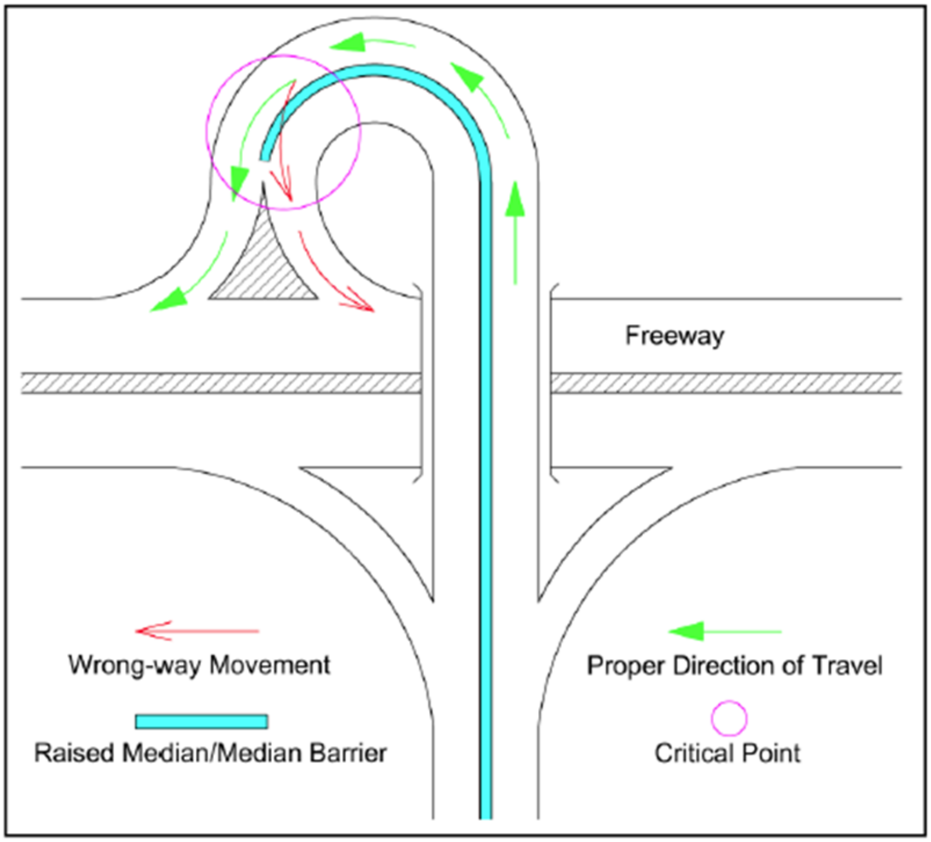



Figure 3-34: Raised Median or Median Barrier in Trumpet Interchanges to Avoid Wrong-Way Movements, (Zhou and Pour Rouholamin 2014a)

Figure 3-35: Use of Median to Divide the Same Direction of Traffic, (Zhou and Pour Rouholamin 2014a)

Wrong-way right-turn movements are less likely where the control radius from the left-side edge of the exit ramp is tangent to the crossroad centerline (AASHTO 2011). According to Zhou and Pour Rouholamin providing an open sight distance and uniform lighting levels at the ramp terminal helps improve driver perception of intersection configuration and reduce possible wrong-way movements (Zhou and Pour Rouholamin 2014a). Vaswani suggests continuing the pavement edge marking across the exit ramp or bringing the stop line closer to the edge of the crossroad at the exit ramp so that it discourages low vision drivers from entering an exit ramp at night (Vaswani 1977b).

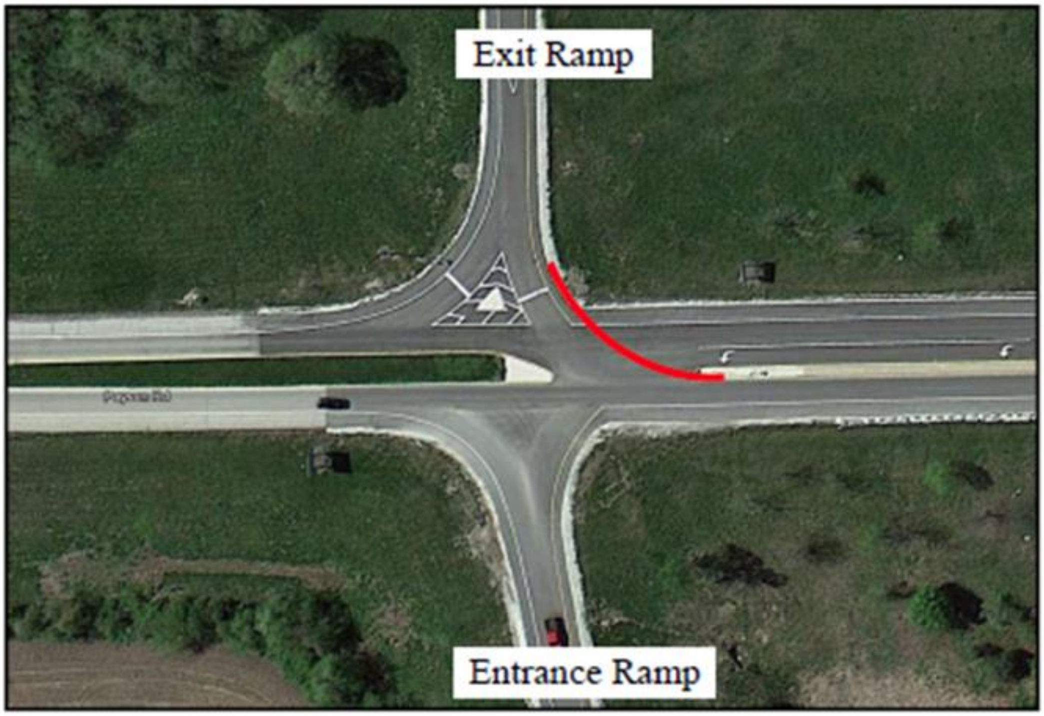



Figure 3-36: Control Radius Tangent to the Crossroad Centerline (Zhou and Pour Rouholamin 2014a)

Extending a median barrier between exit and entrance ramp all the way to the stop line can block left-turning drivers' vision of the entrance ramp and encourage wrong-way movements as shown in Figure 3-37 (Morena and Leix 2012; Zhou and Pour Rouholamin 2014a; Baisyet et al. 2015). This can be mitigated with designs such as shown in Figure 3-38. Further, sharp differences in grades between ramps and crossroads can reduce visibility and increase wrong-way movements (Zhou and Pour Rouholamin 2014a; Baisyet et al. 2015; Pour Rouholamin et al. 2015b).

Figure 3-37: Median Barrier Blocks Conspicuity of the Entrance Ramp, (Morena and Leix 2012)

Figure 3-38: Median Barrier with Improved Visibility of the Entrance Ramp (I-84 Portland OR Google Earth)

### 3.1.6 Advanced Technologies

ITS technologies are effective at identifying wrong-way driving causes by using sensor technologies, and reducing wrong-way incidents by warning both wrong-way and right-way drivers. Sensor technologies consist of inductive loop detectors, magnetic sensors, video image processors, and microwave radar detection. Zhou and Pour Rouholamin compared pros and cons of using each sensor technology displayed in Table 3.3 (Zhou and Pour Rouholamin 2014a). Similarly, Simpson compared the viability of five detector systems in identifying wrong-way entries onto the highway system in Arizona (Table 3.2). Five detector systems including microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors were installed on freeway exit ramps (Simpson 2013). As the accuracy of these detectors is very important, manufacturers have conducted field tests to detect wrong-way driving with near zero false and missing calls (Stiers and Xing 2011). These technologies are used to detect vehicle direction, including wrong-way movements. After a wrong-way movement is detected, traffic management centers (TMCs) receive signals from detectors and activate warning devices such as RRFB/LED WW signs, dynamic message signs (DMSs), and in-pavement warning lights to notify both wrong-way and right-way drivers. Meanwhile, TMCs provide law enforcement officers and other incident responders the location and direction of wrong-way movement to step in and stop the wrong-way driver (Zhou and Pour Rouholamin 2014a; Finley et al. 2016; Ponnaluri 2014; Sandt et al. 2015). Simpson and Karimvand proposed a wrong-way detection system with automated notifications and warnings for the highway system, illustrated in Figure 3-42 (Simpson and Karimvand 2015). Finley et al. proposed a high-level system design utilizing connected vehicle (CV) and infrastructure sensor detection systems (Figure 3-41) to warn other drivers if a vehicle is traveling in the wrong-way on a freeway (Finley et al. 2016).

Finley and Trout conducted a survey to investigate whether motorists understand wrong-way driving dynamic message signs (DMSs). Results showed that whenever a wrong-way driving movement is reported, both dynamic messages consisting of "Warning Wrong Way Driver Reported" and "Warning Wrong Way VEH Reported" are appropriate and they should be displayed in both directions of travel (Figure 3-40). However, the prior message was preferred, as some respondents did not immediately understand the VEH abbreviation. Beacons located on DMSs should be activated, or the message should be flashed (Finley and Trout 2017).

LED and RRFBs WW signs have become popular due to their effectiveness in deterring wrong-way driving maneuvers (Figure 3-39) (Wilson 2013; Lin and Ozkul 2016b; Lin et al. 2016a; Sandt et al. 2016; Finley et al. 2014; Finley et al. 2016; Sorenson et al. 2016). Flashing LED or beacons for wrong-way driving scenarios may be added to WW and DNE signs to improve visibility at night (Zhou and Pour Rouholamin 2014a). In a survey by Sandt et al., 72.1% of respondents preferred two sets of RRFB WW signs to one set of LED WW signs. In addition, 96% of respondents said DMSs were useful for warning right way drivers of wrong-way drivers (Sandt et al. 2016). Also, it was found that non-dimmed red RRFBs at the top and bottom of the "Wrong Way" sign on both sides of the roadway get drivers' attention most, while not adversely affecting driving behaviors on adjacent arterials (Lin and Ozkul 2016b; Lin et al. 2016a).


Figure 3-39: RRFB Wrong-Way Sign (left), LED Wrong-Way Sign (right), (Finley et al. 2014; Lin et al. 2016a)


Figure 3-40: Wrong-Way Dynamic Message Signs, (Finley and Trout 2017)

**Table 3.2: Summary of Detector System Test Results, (Simpson S. A., 2013).**

| Device Type | Detected Wrong-Way Vehicles | Response Time | Non-Intrusive | Minimal Maintenance | Night Operations | Communication | Ease of Installation | No Missed Calls | No False Calls | Dual Function | Low Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Microwave | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| Radar | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | N/A | | |
| Video | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | |
| Thermal Sensor | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | N/A | | |
| Magnetic Detection | ✓ | ✓ | | ✓ | ✓ | ✓ | | | ✓ | ✓ | |

**Table 3.3: Summary of Sensor Technology, (Zhou and Pour Rouholamin 2014a).**

| Detector | Multi-Lane Detection | Maintenance Difficulty | Night Operations | Ease of Installation* | Accuracy | Cost** |
|---|---|---|---|---|---|---|
| Inductive Loop Detectors (ILDs) | | Moderate to High | √ | | Excellent | Low |
| Magnetic Sensors | | Low | √ | | Very Good | Low to Moderate |
| Video Image Processors (VIPs) | √ | Moderate to High | | √ | Good | Moderate to High |
| Microwave Radar Detectors | √ | Low | √ | √ | Very Good | Low |

*Ease of installation: Installation can be done in less than four hours.

**Installation, maintenance, and repair costs are not included. Cost range per detector to be purchased: low (<$5,000), moderate ($5,000~$10,000), high (>$10,000).

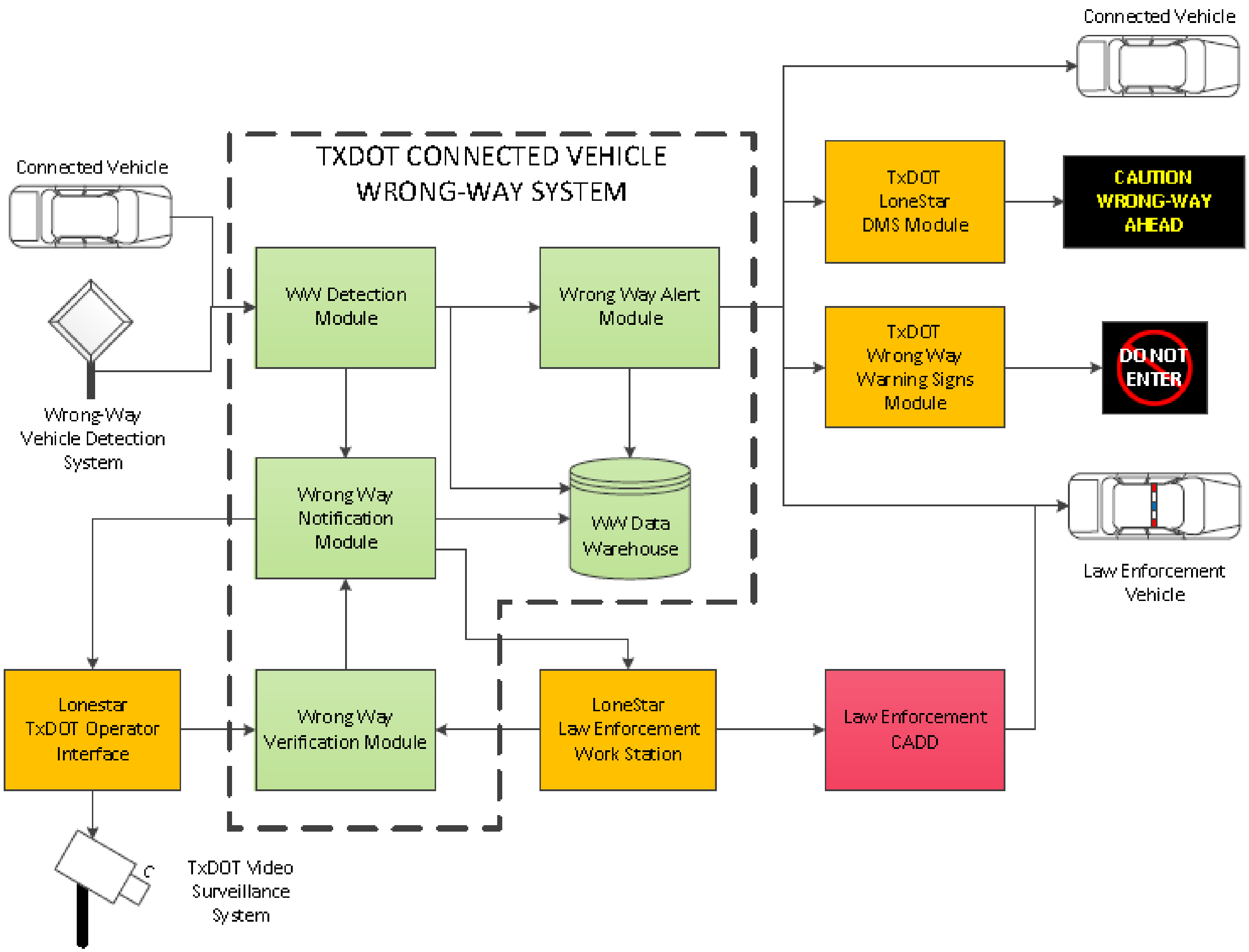



Figure 3-41: High-Level Detection System Design for TXDOT CV WWD Detection and Management System, (Finley et al. 2016)

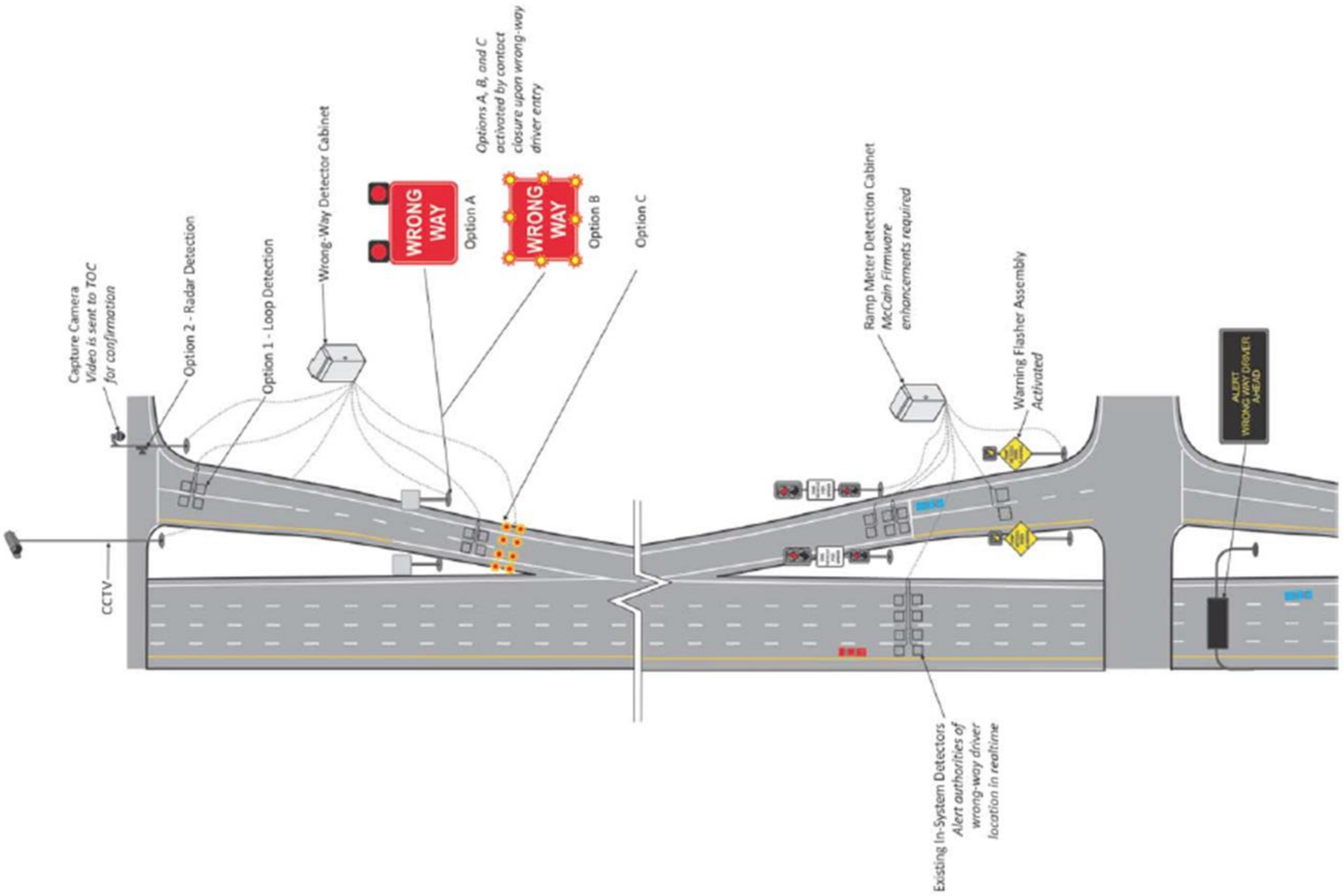



Figure 3-42: Proposed Wrong-Way Detection, Notification, and Warning System (Simpson and Karimvand 2015)

## 3.2 FIELD DEPLOYMENT STUDIES

### 3.2.1 Wang et al. (2017)

Wang, et al. used 3D traffic simulation models to investigate the effect of different lengths of median barrier and left-turn stop line position on the crossroad on drivers' perception of the correct driving path when turning left from a crossroad to an adjacent two-way ramp (Figure 3-43). Table 3.4 shows the percentage of "right way" information that can be seen by a driver by different ending points of a median barrier. Quoting from the study, the authors state "*For example, to maximize the right-way information in the driver's view when stop line positioning was 60%, the median barrier should be placed at least 21.0 m (68.90 ft.) away from the stop line on ramps.*" The stop line positioning indicates the distance from the left-turn stop line on a crossroad to the extension of the ramp median into the intersection as a percentage of the way through the intersection (L in Figure 22) (Wang et al. 2017).

**Table 3.4: Right-Way Information Based on Median Barrier Length and Stop Line Positioning, (Wang et al. 2017).**

| | **Distance From The Median Barrier Ending Point To The Stop Line On Ramps** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Percent of Stop Line Positioning | 3.0 m (9.84ft) | 6.0 m (19.68ft) | 9.0 m (29.52ft) | 12.0 m (39.37ft) | 15.0 m (49.21ft) | 18.0 m (59.05ft) | 21.0 m (68.89ft) | 24.0 m (78.74m) |
| 30% | 1.408 | **1.691** | **1.691** | **1.691** | **1.691** | **1.691** | **1.691** | **1.691** |
| 40% | 0.607 | 0.895 | 1.167 | **1.236** | **1.236** | **1.236** | **1.236** | **1.236** |
| 50% | 0.571 | 0.621 | 0.764 | 0.876 | 0.967 | **1.034** | **1.034** | **1.034** |
| 60% | 0.402 | 0.498 | 0.498 | 0.564 | 0.636 | 0.700 | **0.754** | **0.754** |

Note: values in bold are the maximum that can be achieved.

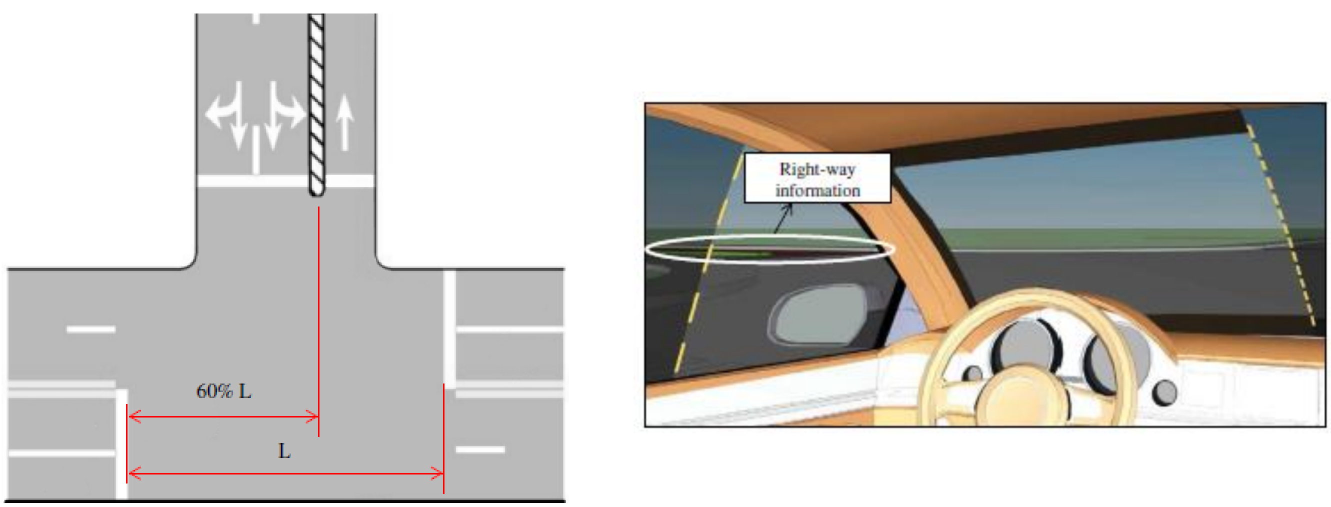



Figure 3-43: Stop Line Positioning on the Crossroad (60%L) (Top), Driver's Perception of The Correct Driving Path (Bottom), (Wang et al. 2017)

### 3.2.2 Zhou and Pour Rouholamin (2015)

Zhou et al. evaluated the efficiency of countermeasures implemented at the top ten potential locations for wrong-way driving crashes identified during the first phase of the project (Zhou et al. 2012). Countermeasures included larger DNE and WW signs, red retroreflective strips on DNE and WW sign supports, and the addition of wrong-way pavement arrows along the exit ramps. Wrong way driving crash data after treatments from 2012 to 2013 was compared to wrong-way driving crash data collected before treatments were implemented. A simple before-after analysis showed nearly a 40% reduction in the total number of wrong-way driving crashes and an almost 13% reduction in the number of wrong-way driving-related fatal crashes (Zhou and Pour Rouholamin 2015).

### 3.2.3 Kockelman et al. (2016)

The Southwest Research Institute (SwRI) installed roadside equipment, on SwRI's campus and in three locations along Interstate 410 between Culebra Road and US-281 in San Antonio in June 2016. SwRI equipped vehicles with a portable onboard device (POD) system, which enabled vehicles and transmit basic safety messages (BSMs) at 10 Hz. The roadside equipment received the vehicle BSMs and were able to compare vehicle direction against the road segment correct direction. Once a connected vehicle traveling in a wrong direction is detected, the roadside equipment, can send warning messages to both wrong-way vehicles and other vehicles within communication range (Figure 3-44), (Kockelman et al. 2016).


Figure 3-44: Connected Vehicle WWD Messages Sent By RSE, (Kockelman et al. 2016)

### 3.2.4 Jalayer et al. (2016)

Jalayer et al. investigated the contribution of GPS devices to wrong-way entries where an access point is close to an exit ramp at 10 common interchanges terminals in Alabama. Results indicated that GPS device voice commands were not able to guide drivers precisely where the distance between an access point and an exit ramp was less than 100 feet. It was also found that traveling in a wrong direction was very likely when the distance between a nearby access point and an exit ramp was less than 350 feet. They suggested that GPS companies improve the accuracy of their GPS navigation systems and add new features to warn drivers when driving in a wrong direction such as "no turn right/left at next intersection" or "driving wrong-way, please turn back." (Jalayer et al. 2016).

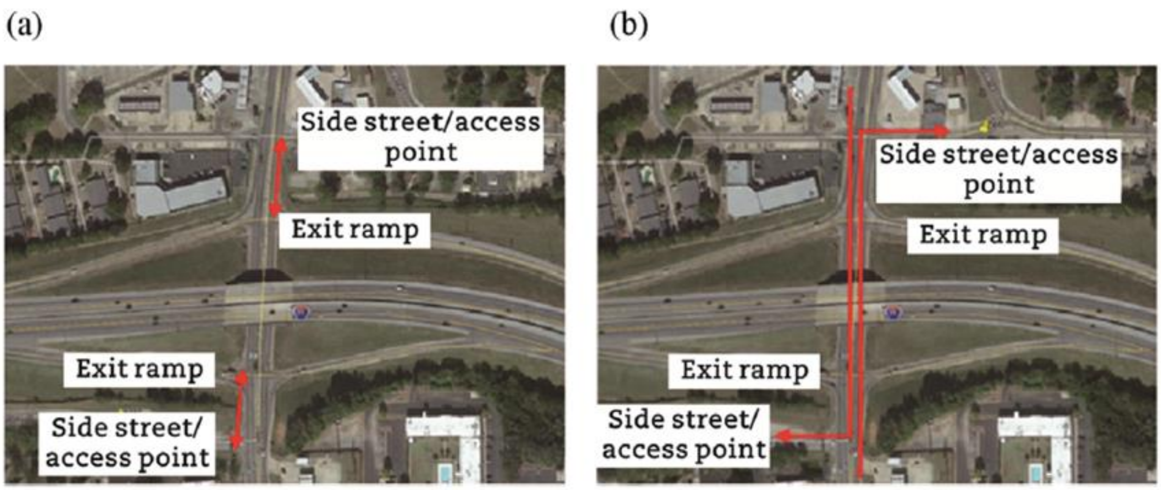



Figure 3-45: (A) Spacing between Side Streets and Exit Ramps. (B) Field Test Driving Routes, (Jalayer et al. 2016)

### 3.2.5 Sorenson et al. (2016)

Athey Creek Consultants conducted an online literature search and contacted different agencies across the US to prepare a comprehensive summary of active wrong-way driving countermeasure deployments with/out ITS technologies. They provided an information matrix of these countermeasures implemented by June 2015. They tracked these deployments from June 2015 to July 2016 by conducting interviews with agency contacts to evaluate these countermeasures. Agencies consisted of State DOTs including Arizona, Connecticut, Florida, Iowa, Michigan, Missouri, Ohio, Rhode Island, Texas, Washington, and Wisconsin DOTs, Central Florida Expressway Authority, Florida Turnpike Enterprise, and Harris County Toll Road Authority. While many agencies were not able to evaluate the effectiveness of deployed wrong-way driving countermeasures due to insufficient "after" crash data during the tracking period, main findings indicated that enhanced signing such as flashing LED wrong-way signs and RFFBs on wrong-way signs were very effective in reducing wrong-way driving events (Sorenson et al. 2016).

### 3.2.6 Boot et al. (2015)

Boot et al. found that the effectiveness of countermeasures could not be determined in previous studies of problematic locations because there was not a clear association between the reduction of wrong-way entries and the number of countermeasures implemented. Biased samples of interchanges under investigation and unique factors at specific interchanges were main drawbacks of observational data in the real world. Therefore, they utilized a driving simulator to gain insight into the effectiveness of countermeasures for wrong-way entries. In total, 120 participants consisting of 40 older drivers, 40 unimpaired young drivers, and 40 young impaired drivers drove a driving simulator. Results indicated that implementing more countermeasures at potential locations for wrong-way movements is effective at reducing wrong-way entries. The vehicle speed, braking behavior, and lane change behavior of a driver may indicate their measure of confusion (Boot et al. 2015).

### 3.2.7 Finely et al. (2014)

Finley et al. conducted research to evaluate the effectiveness of wrong-way driving countermeasures on alcohol-impaired drivers. They used 30 participants, ranged from 21 to 42 years old, driving on a closed-course using two instrumented vehicles equipped with GPS, an eye tracker, two cameras and an infrared pod. Each participant drove the closed-course four times, each time with a different level of BAC consisting of 0.00, 0.04, 0.08, and 0.12 (g/dl). Results indicated that, as opposed to non-impaired drivers (BAC 0.0), alcohol-impaired drivers did not pay much attention to surrounding areas and focused on a small area of the pavement in front of the vehicle (region 4 in Figure 3-46). They needed to be closer to sign to recognize the background color and read the legend. They also needed to be closer to flashing LED-illuminated signs, compared to signs without flashing LEDs, to read the legend. They increasingly misidentified the red background color of signs as orange, as the level of BAC increased. Lower-mounted signs did not improve their ability to locate the sign, recognize the background color, or read the legend. Although larger signs with a red retroreflective strip on the sign support, or flashing LEDs around a sign's border helped alcohol-impaired drivers to see WW signs, these countermeasures did not improve their ability to locate signs. Alcohol-impaired drivers did not pay attention to lower-mounted and normal-sized WW signs as much as other countermeasures with an increased visibility element.

As the BAC level increased, participants needed more time to determine wrong-way arrow pavement markings compared to other markings. In sum, results suggest that although these countermeasures had a positive effect on reducing wrong-way driving events, highly alcohol-impaired drivers were not helped by these countermeasures. Researchers recommend that a wrong-way detection system is necessary to reduce wrong-way driving events and gain insight into countermeasures (Finley et al. 2014). Lathrop et al. proposed prevention strategies including lowering the legal limit for BAC to 0.05 gm/dl, sobriety checkpoints, mandatory blood testing following a crash, and quick suspension of driver's licenses of DUI drivers (Lathrop et al. 2010).

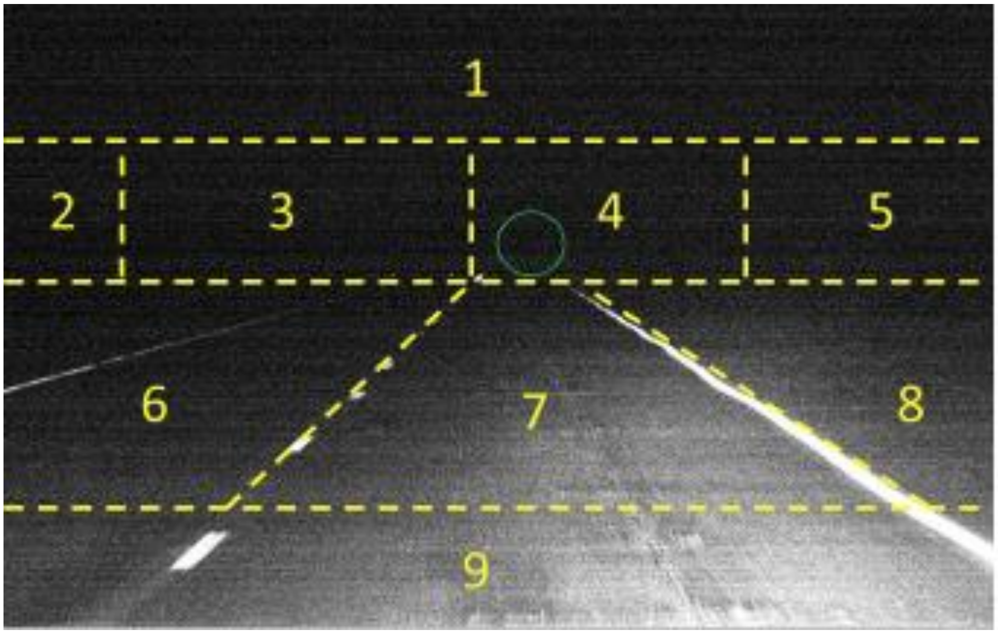



Figure 3-46: A Participant's Glance Location among Nine Regions Overlaid on the Video Screenshot, (Finley et al. 2014)

### 3.2.8 Gianotti (2014)

The Texas Department of Transportation applied two LED-illuminated wrong-way signs and a radar detection unit at 28 off-ramps within 15 miles, along with the US 281 corridor in San Antonio, Texas. Statistics showed a 28% reduction in the frequency of wrong-way crashes with a benefit-cost ratio 12.5:1 over a period of 18 months (Gianotti 2014). They also found that 80% of wrong-way crashes occurred at night, and drivers were intoxicated in the majority of those crashes (TxDOT 2011)

### 3.2.9 Zhou and Pour Rouholamin (2014)

The Harris County Toll Road Authority (HCTRA) applied a wrong-way detection system in 2008 (Finley et al. 2014). Doppler radar detection sensors with in-pavement loop sensors were applied at 14 locations along a 13.2-mile portion of the West Park Tollway in Houston. Incident management center personnel always monitor the tollway through CCTV cameras integrated with GIS wrong-way detection map software. After detection of a wrong-way movement, they warn other motorists with dynamic message signs (DMSs). HCTRA enhanced the system with new countermeasures in 2011. (1) After detection of wrong-way movement, an alarm is activated, and the nearest CCTV camera is directed toward the detection place so that dispatchers can inform responding units. (2) Warning messages are automatically displayed on dynamic message signs to warn other drivers at the detection site. (3) LED in-ground lighting and illuminated wrong-way signs were installed to warn motorists. (4) Lastly, radar sensors were replaced with in-ground puck loop systems in some locations. According to Pour Rouholamin, since 2008, law enforcement units were able to stop 19 wrong-way driving motorists, 11 of whom were impaired. These results showed that technologies are effective strategies in controlling wrong-way driving at the system level (Zhou and Pour Rouholamin 2014a).

## 3.3 EDUCATION COUNTERMEASURES

Special education programs have been developed to educate drivers about the dangers of drinking and driving. The California Highway Patrol (CHP) partnered with student groups, local individuals, and organizations during May and June of 1985 to spread the "don't drink and drive" message through young drivers, television, and radio public service announcements. They also distributed posters, bumper stickers, decals, key chains, and book covers. Results indicated that fatal crashes were reduced by 25% and injury crashes were reduced by 19% in May and June of 1985 (Copelan 1989). Other education programs include development of a comprehensive safety plan and initiation of wrong-way monitoring programs to collect information on wrong-way driving behaviors (NTTA 2009; Moler 2002). In a survey conducted by Sandt et al., 49.8% of survey respondents did not know the meaning of a wrong-way pavement arrow and 26.1% could not identify the correct color of the edge line on the right side as white. As a result, educating drivers would reduce wrong-way driving maneuvers (Sandt et al. 2016). Jalayer et al. concluded that educational countermeasures such as general awareness programs and mass communication campaigns should focus on older and DUI drivers, as they are at greatest risk of wrong-way crashes (Jalayer et al. 2017). Zhang et al. reached the same conclusion, confirming that older and DUI drivers should be targets of educational programs (Zhang et al. 2017).

## 3.4 SUMMARY

Commonly used engineering, emergency, education, and enforcement countermeasures were also examined. Engineering countermeasures consisted of signs, pavement markings, traffic signals and geometric design. Emergency countermeasures included using advanced technologies such as ITS, sensor detection systems, and traffic management centers. Primary education and enforcement countermeasures found in the literature involved the use of general awareness programs, mass communication campaigns. In general, engineering countermeasures, especially signage and pavement markings are low-cost while emerging countermeasures like ITS are costly.

# 4 CRASH DATA REVIEW

A review of wrong-way crashes on interstate highways was conducted with Oregon crash data for the years 2006–2014. The objective of this analysis was to understand the crash and driver characteristics associated with wrong-way crashes in the Oregon reported crash data. Additionally, dispatch logs from District 7 and 8 in Region 3 were reviewed to provide further insight in wrong-way crash patterns.

## 4.1 CRASH OVERVIEW

Table 4.1 shows the crash summary derived from ODOT crash data for the years 2006 - 2014. The wrong-way crashes on interstate highways (I-5, I-84, I-205, I-82, and I-105) were filtered from the crash data set using the error code for wrong-way driving (046). The initial filter includes cross median crashes. Since the objective of this study is to focus crashes resulting from wrong-way entries, the cross median crashes were filtered out using the crash cause code for wrong-way crashes (015). For the nine year period from 2006-2014, there were 66 total and 7.3 crashes per year on average on interstate highways (around 0.20% of all interstate crashes).

**Table 4.1: Oregon Interstate Crash Summary 2006-2014**

| Category | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| Wrong-way Crashes | 11 | 10 | 6 | 6 | 2 | 6 | 9 | 10 | 6 |
| All Interstate Crashes | 3,453 | 3,427 | 3,169 | 3,302 | 3,547 | 3,798 | 3,925 | 4,058 | 4,496 |
| Percent of Interstate Crashes | 0.32% | 0.29% | 0.19% | 0.18% | 0.06% | 0.16% | 0.23% | 0.25% | 0.13% |

Figure 4-1 shows the wrong-way crash distribution by year of crash and the Oregon interstate freeway vehicle miles travelled (VMT). As shown, the wrong-way crash distribution generally tracks the VMT pattern. Figure 4-2 shows the distribution of wrong-way driving crashes by route. Most of the wrong-way crashes occurred on I-5, followed by I-84 and I-205. Figure 4-3 shows the location of the wrong-way crashes from 2006 to 2014 on the interstates highways in Oregon.

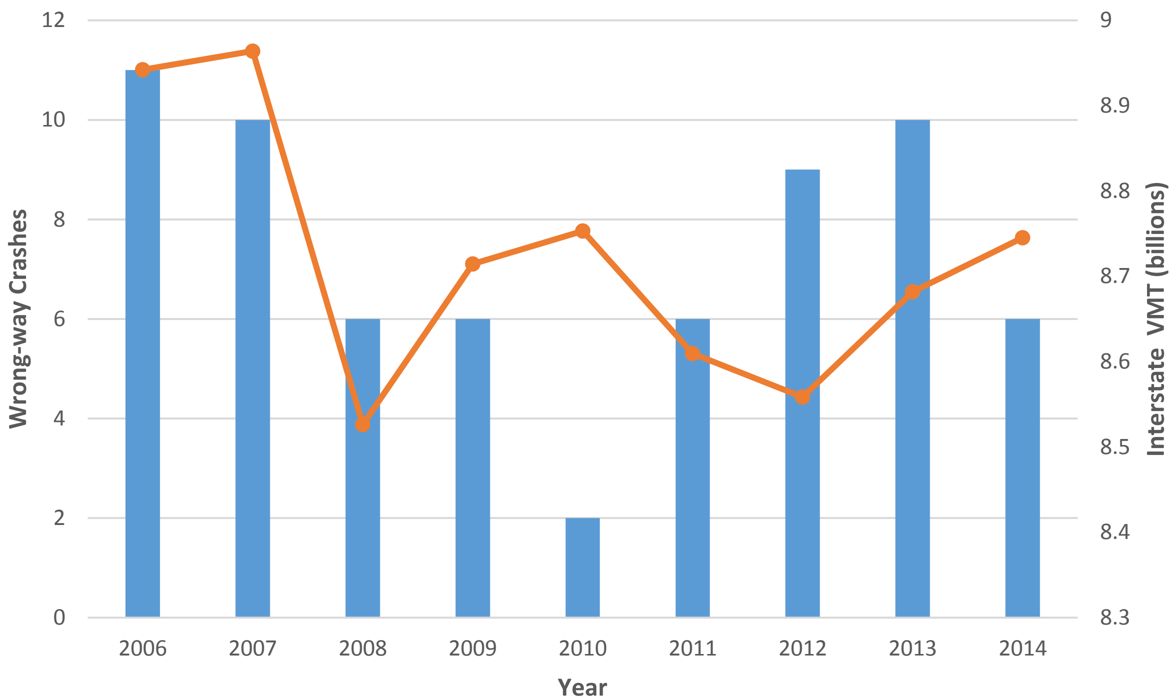



Figure 4-1 Wrong-way Crash Distribution by Year and Interstate VMT

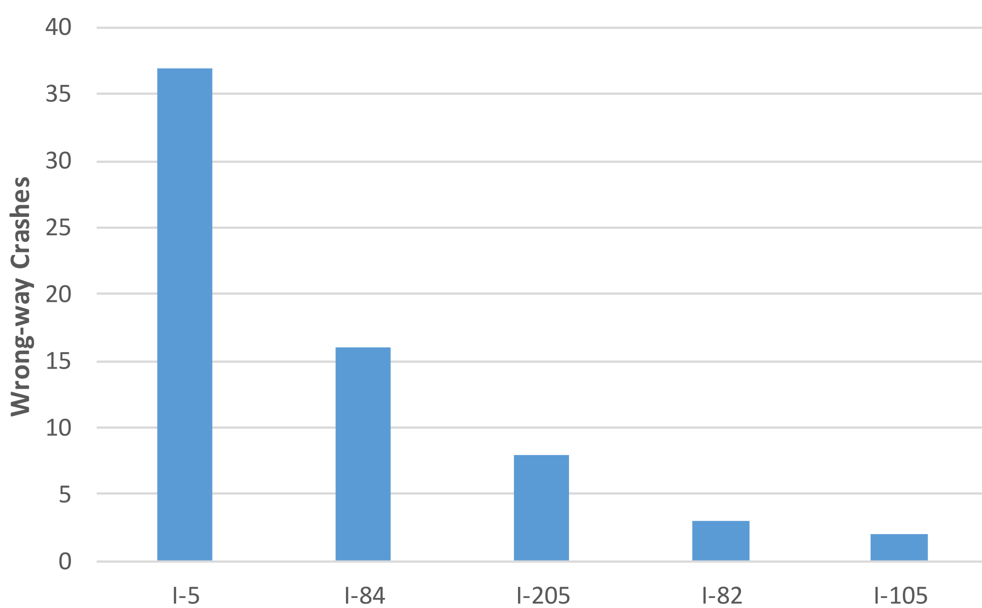



Figure 4-2 Wrong-way Driving Crashes by Interstate Highway

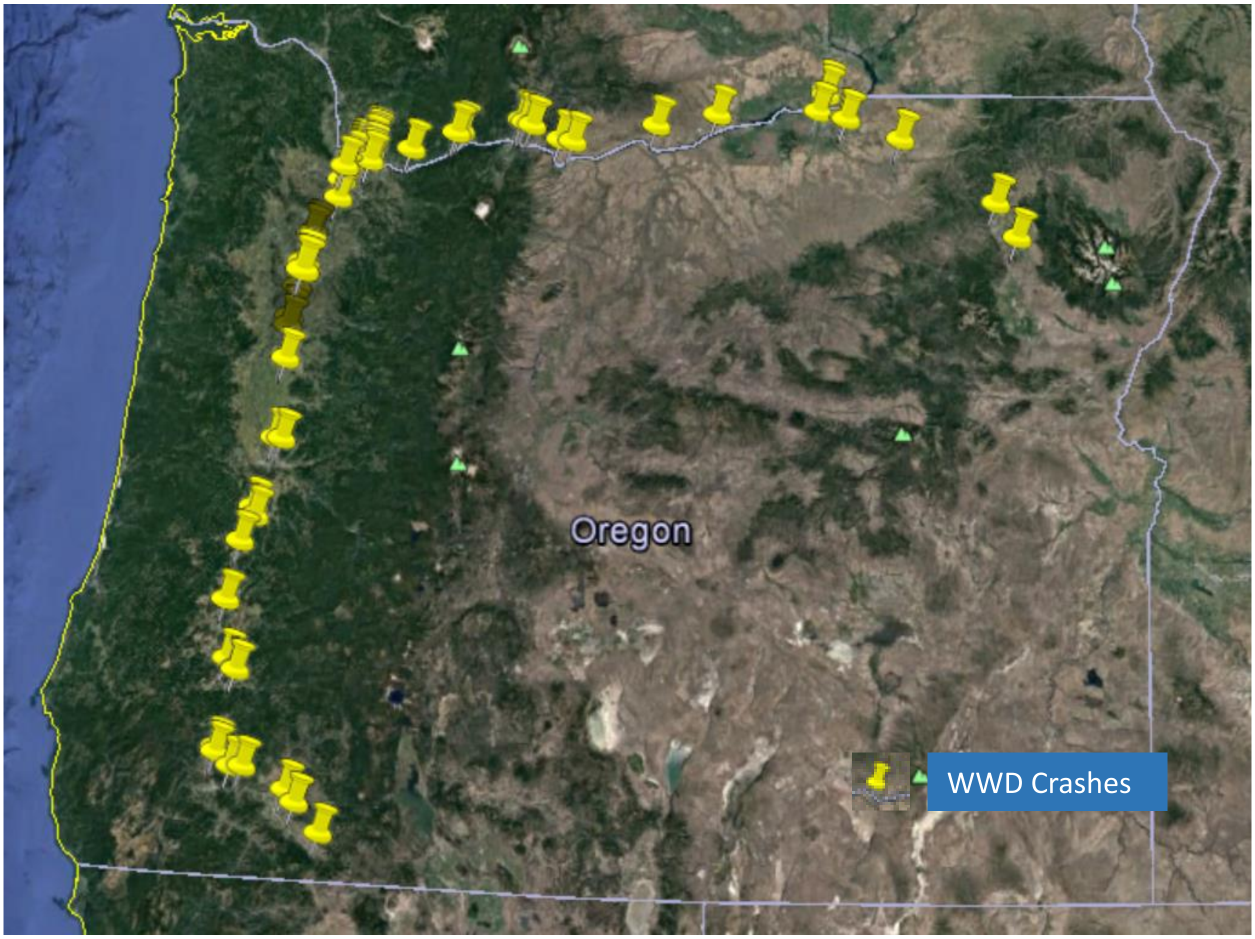



Figure 4-3 Wrong-way Crashes Locations in OR

Table 4.2 provides a breakdown of the wrong-way crashes on highways and all rural interstate crashes based on crash severity. The proportion of fatal and injury wrong-way driving crashes is far greater than the proportion of fatal and injury rural interstate crashes, illustrating that wrong-way crashes are associated with higher crash severity. Fatal and injury crashes combined accounted for 85% of all wrong-way crashes on interstate highways.

**Table 4.2: Oregon DOT Wrong-way Crash Severity Summary, 2006-2014**

| Crash Type | Wrong-way Driving Crashes | Rural Interstate Crashes |
|---|---:|---:|
| Fatal | 19 (28.8%) | 3.7% |
| Injury | 37 (56.0%) | 39.0% |
| PDO | 10 (15.2%) | 57.3% |
| Total | 66 (100%) | 100% |

Figure 4-4 shows wrong-way crash distribution by time of day for wrong-way and rural interstate crashes. For all rural interstate crashes (proportions taken from the Oregon DOT SIM worksheets updated in 2016), the highest proportion of all crashes on rural interstates occur between 3- 6 PM. For wrong-way driving crashes, the highest proportion of wrong-way crashes occur between 9 PM – midnight, followed by midnight – 3 AM. This time was also identified in the literature as the primary risk time.

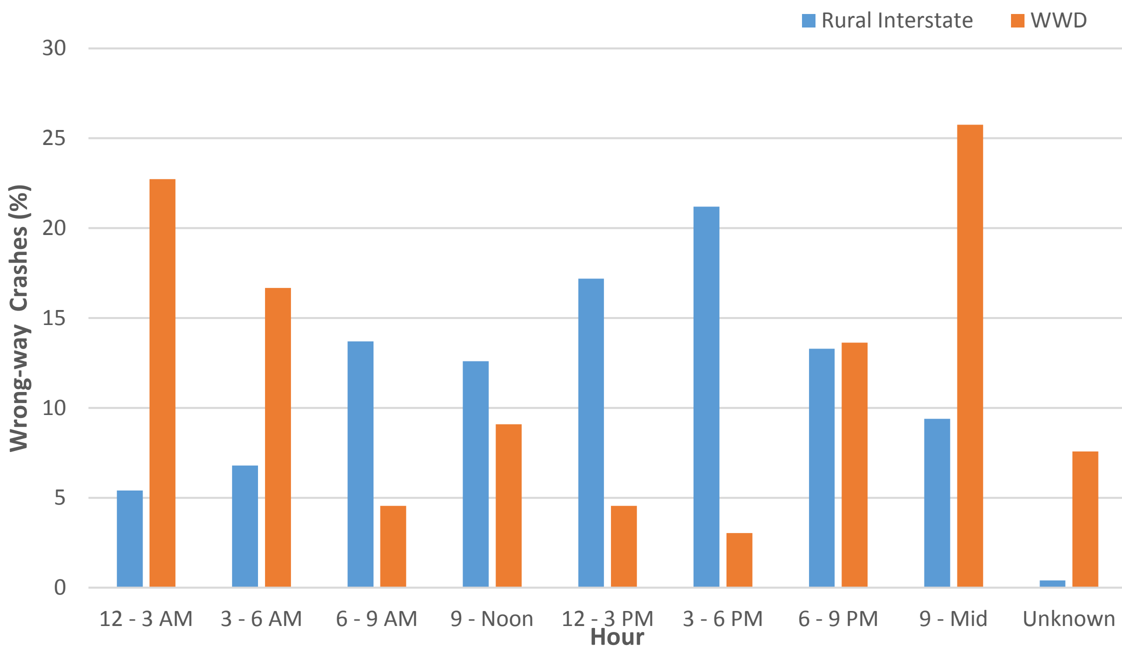



Figure 4-4 Wrong-way Crash Distribution by Time of Day

Table 4.3 shows the road, weather, and lighting characteristics associated with wrong-way crashes and all crashes on rural interstate highways. The majority of both types of crashes occurred on straight, dry roads during clear weather conditions. While a majority of wrong-way crashes occurred during dark hours in the absence of streetlights, most of the rural interstate crashes occurred during daylight hours.

**Table 4.3: Characteristics Associated with Wrong-Way Crashes**

| Descriptor | Wrong-way | Rural Interstate |
|---|---|---|
| **Road Characteristics** | | |
| Intersection | 3.0% | 0.3% |
| Alley | 0.0% | 0.0% |
| Straight | 68.2% | 36.0% |
| Transition | 0.0% | 0.6% |
| Curve | 13.6% | 4.7% |
| Open Access | 0.0% | 0.0% |
| Grade | 7.6% | 4.1% |
| Bridge | 7.6% | 0.7% |
| Tunnel | 0.0% | 0.0% |
| Unknown | 0.0% | 0.1% |
| **Road Surface Characteristics** | | |
| Dry | 68.2% | 50.6% |
| Ice | 0.0% | 23.1% |
| Wet | 31.8% | 20.4% |
| Snow | 0.0% | 4.6% |
| Unknown | 0.0% | 1.3% |
| **Weather Characteristics** | | |
| Clear | 51.5% | 46.4% |
| Cloudy | 25.8% | 18.4% |
| Rain | 19.7% | 16.2% |
| Sleet/Freezing Rain/Hail | 0.0% | 1.5% |
| Fog | 1.5% | 3.3% |
| Snow | 0.0% | 12.3% |
| Dust | 0.0% | 0.1% |
| Smoke | 0.0% | 0.1% |
| Ash | 0.0% | 0.0% |
| Unknown | 1.5% | 1.6% |
| **Lighting Characteristics** | | |
| Daylight | 18.2% | 59.1% |
| Darkness – with Street Lights | 34.9% | 2.3% |
| Darkness –without Street Lights | 42.4% | 30.3% |
| Dawn | 3.0% | 3.5% |
| Dusk | 1.5% | 4.6% |
| Unknown | 0.0% | 0.2% |

Table 4.4 shows the collision types associated with wrong-way and rural interstate crashes. While majority of the wrong-way crashes were head-on crashes (63.64%), followed by sideswipe meeting and turning movement crashes, majority of the crashes on rural interstates were fixed object or other object crashes.

**Table 4.4: Types of Collisions Associated with Wrong-way Crashes**

| Collision Type | Wrong-way | Rural Interstate |
|---|---|---|
| Angle | 0.0% | 0.3% |
| Head-on | 63.6% | 0.4% |
| Rear | 0.0% | 22.0% |
| Sideswipe-Meeting | 16.7% | 0.4% |
| Sideswipe-Over | 0.0% | 13.2% |
| Turning Movement | 9.1% | 0.4% |
| Parked | 0.0% | 0.1% |
| Non Collision | 0.0% | 11.8% |
| Backing | 0.0% | 0.1% |
| Pedestrian | 0.0% | 0.2% |
| Fixed-Object or Other-Object | 10.6% | 43.6% |
| Other | 0.0% | 7.6% |

## 4.2 PARTICIPANT CHARACTERISTICS

In addition to the crash characteristics, characteristics of the driver involved in the wrong-way crashes were also mined. Only those drivers who had an error code associated with wrong-way crashes (046) were considered for this analysis. Figure 4-5 shows the age characteristics of wrong-way drivers compared to the age of drivers involved in all crashes on rural interstate facilities. Large differences between the two groups were observed especially in the older driver (75+ years of age) category. A higher proportion of older drivers were involved in wrong-way crashes, a finding that was corroborated by past literature.

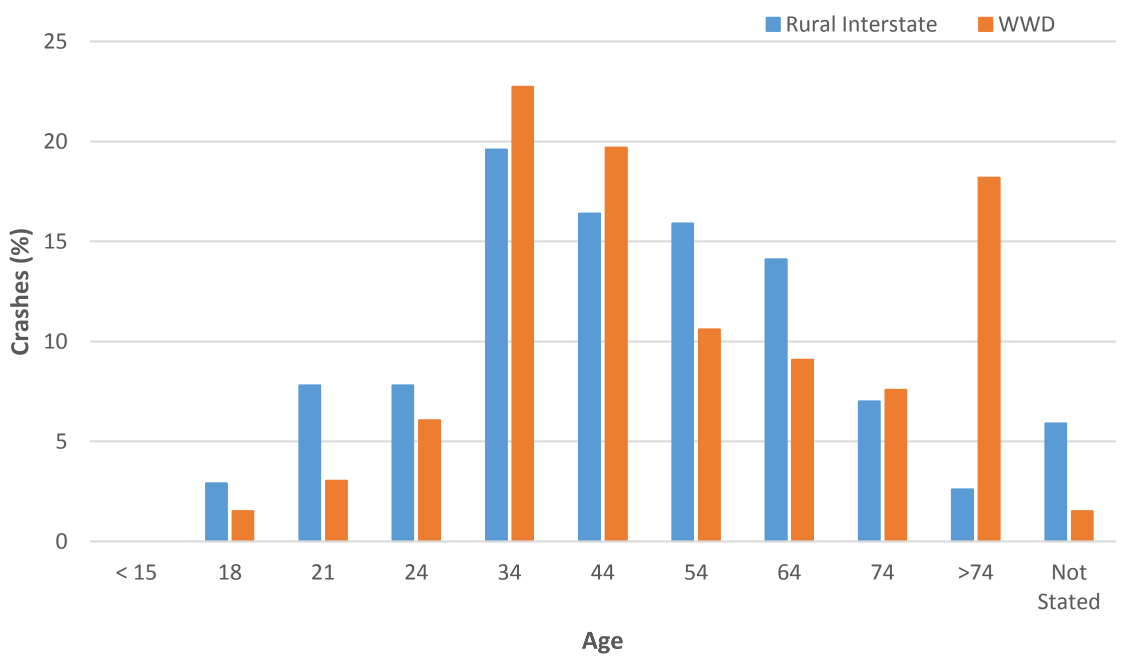



Figure 4-5 Age Characteristics of Wrong-way Drivers

Figure 4-6 shows that majority of the drivers involved in wrong-way crashes were male, corroborating a trend observed in previously published literature. However, the proportions with respect to gender were very similar to those observed for all rural interstate crashes.

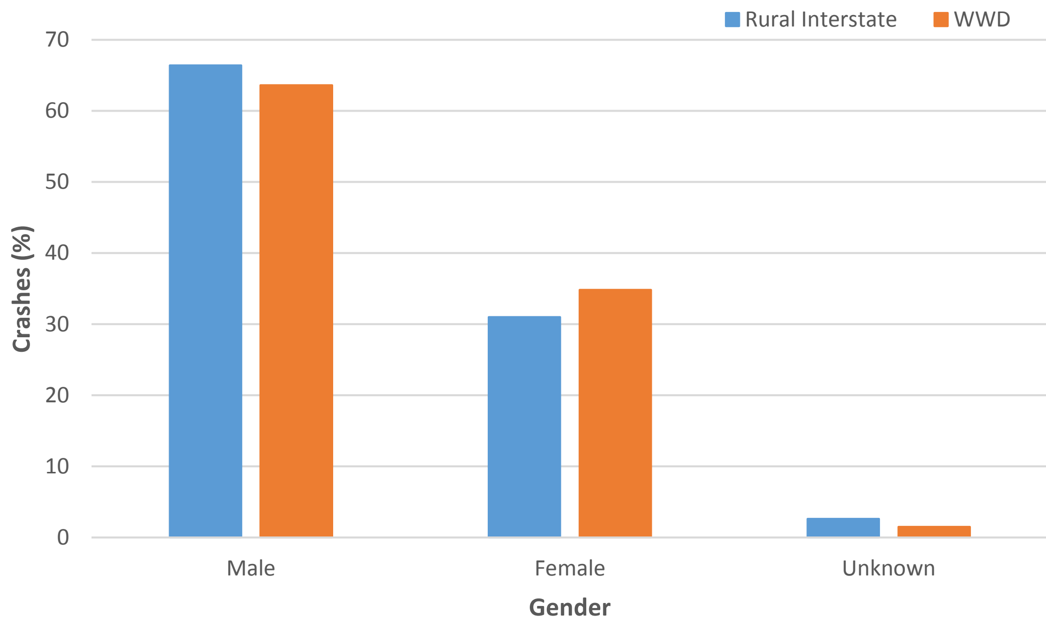



Figure 4-6 Gender of Wrong-way Drivers

Figure 4-7 shows the resident status of drivers involved in wrong-way and all rural interstate crashes. Majority of the drivers that were involved in wrong-way crashes were Oregon residents whose residence was less than 25 miles from the location of the crash and this proportion was higher than the proportion of local drivers involved in rural interstate crashes. Differences in proportions were also observed in the non-resident category between the two groups.

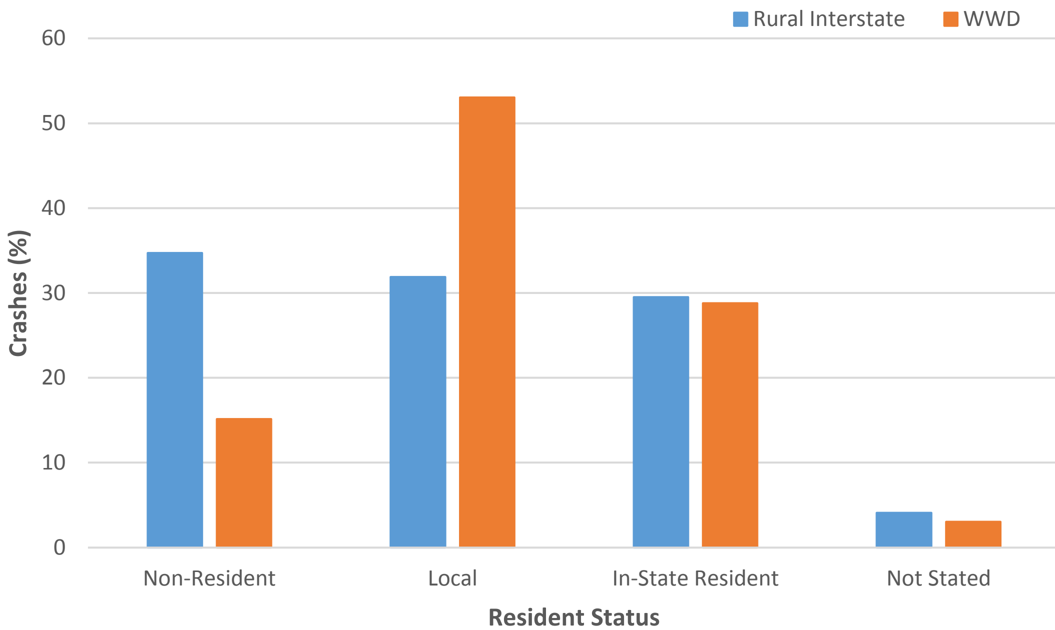



Figure 4-7 Resident Status of Wrong-way Drivers

## 4.3 Dispatch Logs

Dispatch logs that reported wrong-way incidents were obtained from ODOT along I-5 corridor for Districts 7 and 8 for January 2014 to March 2017. These are shown along with wrong-way crashes in Figure 4-8. These logs were analyzed. The logs for wrong-way driving on Region 3 of I-5 indicated that 25 wrong-way events were reported between January 2014 and March 2017 in District 7. Eleven wrong-way movements and three wrong-way crashes were confirmed. Ten of twenty-five reported wrong-way events, including two crashes, occurred after midnight (12:00 - 8:00 am), and five wrong-way events, including one crash, occurred at night (7 pm - 12 am). In District 8, 37 wrong-way events were reported between February 2014 and December 2016. Of these, 18 wrong-way movements and 3 wrong-way crashes were confirmed. Six of thirty-seven reported wrong-way events occurred after midnight (12:00 - 8:00 am) and eight wrong-way events, including two crashes, occurred at night (7 pm - 12 am). No fatal crashes were reported during these periods in District 7 or 8.

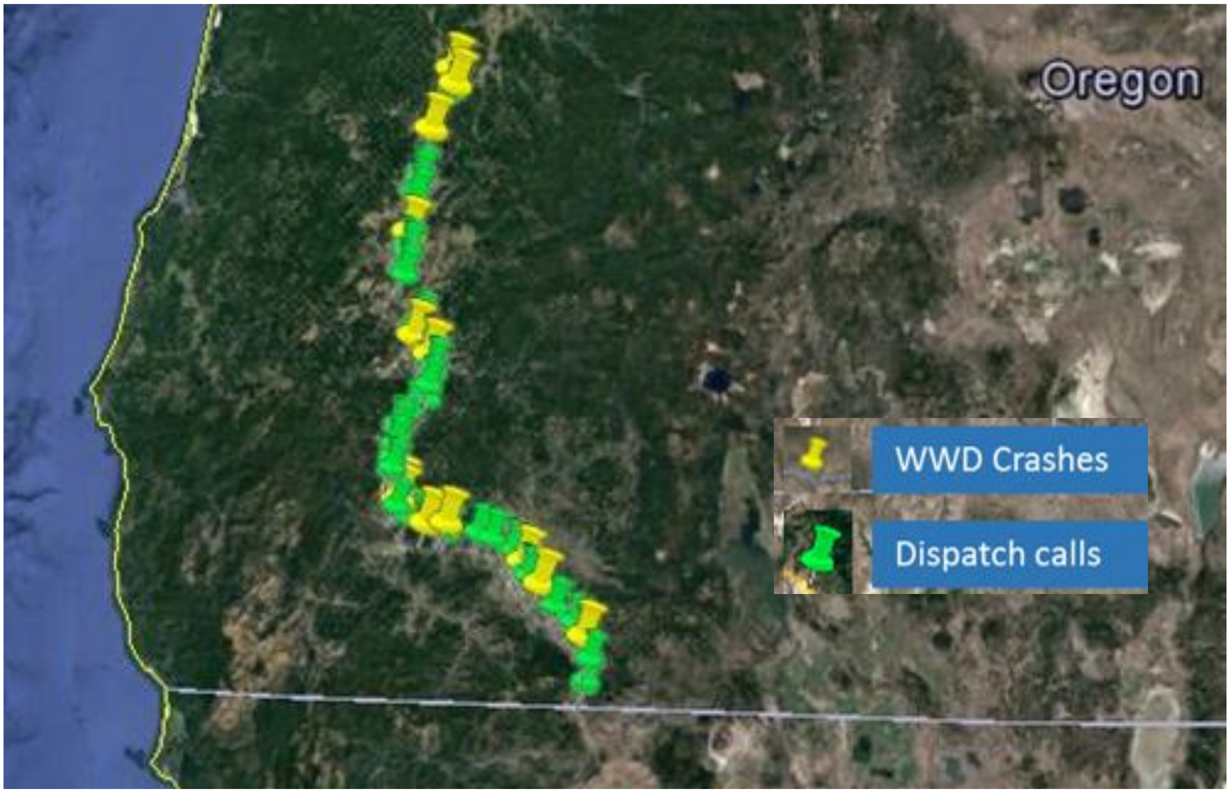



Figure 4-8 Wrong-way Crashes and Locations of Reported Wrong-way Drivers (Region 3 only)

## 4.4 Summary

A review of the Oregon crash data for 2006 to 2014 found 66 wrong-way crashes on interstates. Although these crashes form a very small proportion of the total crashes, according the literature, the severity level of these crashes is higher compared to other crashes. Of the crashes that were analyzed, 29% were fatal crashes and 56% resulted in an injury. Thus, 85% of all wrong-way crashes resulted in either a fatality or injury as compared to 43% of all rural interstate crashes. A majority of the crashes occurred on I-5. The profile of the wrong-way driver and crash in Oregon was similar to the trends identified in the literature. Almost half of these crashes also occurred between 9 PM – 3 AM (49%). With respect to driver characteristics, majority of the drivers involved with wrong-way crashes were male, older drivers (75+) were over-represented in wrong-way driving crashes.

# 5 RECOMMENDED SYSTEMIC APPROACH

The profile of the typical wrong-way driver -- often impaired or disoriented, older, local, and driving in the dark conditions -- suggests that eliminating wrong-way movements will be challenging with engineering countermeasures only. However, the literature and human factors work reviewed suggest that a careful review of each interchange and a systemic approach to enhancing traffic control devices may prevent some events.

The following recommendations are based on the review of literature regarding countermeasures employed by different states, current ODOT policies and the team's field visit to interchanges on I-5 in Region 3. Unlike other engineering countermeasures, quality CMFs for the expected crash reductions for the wrong-way driving improvements do not exist. This study recommends a package for a systemic application of interchange ramps by Region or District on interstate exit ramps and interchanges. These recommendations are summarized in Table 5.1. A brief description and justification for each recommended treatment follows.

**Table 5.1: Summary of wrong-way driving Engineering Recommendations**

| SYSTEMIC EXIT RAMP APPROACH | ADDITIONAL TREATMENTS FOR HIGH-RISK LOCATIONS |
|---|---|
| **Signing**<br>• Confirm all DNE and WW signs have wide-angle prismatic sheeting (ASTM Type IX or better).<br>• Modify DNE signs such that installation angle is optimal for potential wrong-way driver.<br>• Add additional WW sign below DNE sign assembly where feasible.<br>• Add Keep Right sign where entrance and exit ramps are close together.<br>• In rural areas with low or no lighting, add red reflective material to DNE sign post(s).<br>• Add additional DNE and WW sign to long ramps.<br>• Add turn movement prohibition (s) signs where appropriate (OPTIONAL).<br>• Add ONE WAY sign to DNE assembly (OPTIONAL).<br><br>**Pavement Markings**<br>• Confirm that wrong-way arrows are properly placed on single lane exit ramps or lane use arrows are present.<br>• For locations where exit and entrance ramps are co-located, add dotted lane extension lines for turning guidance.<br>• Add additional WWA to long ramps. | **Active Warning Signs**<br>• Add automated red LED/RRFB to WW sign.<br>**Signing**<br>• Review guide and route signing.<br>**Geometric Modifications**<br>• Add channelizing islands.<br>• Extend raised median.<br>• Narrow the exit ramp terminal throat.<br>• Widen the entrance ramp terminal throat.<br>**Lighting**<br>• Review existing lighting. |

## 5.1 SYSTEMIC EXIT RAMP RECOMMENDATIONS

The objective of the recommended systemic package is to present the potential wrong-way driver with as many cues as possible to the wrong-way movement through enhanced signs and markings.

It is assumed that all interchange exit ramps meet the minimum MUTCD and ODOT requirements for signing and pavement markings. However, exit ramps should be reviewed for compliance with the current minimum recommendations for WRONG WAY (WW), DO NOT ENTER (DNE), and ONE WAY signing and wrong-way arrows (WWA). Appendix A includes a sample field investigation questionnaire that the research team modified from FHWA documents for a field review.

### 5.1.1 Confirm Prismatic Sheeting for Wrong Way Signs

The use of signs with fluorescent red sheeting and retroreflective sheeting improves conspicuity, especially during low light conditions (Staplin et al. 2001). The ODOT sign manual requires that all installations for wrong-way entrance signing use wide-angle prismatic sheeting (ASTM Type IX or better). As part of the systemic review process, all associated wrong-way signing (DNE, WW, and ONE WAY etc.) should be upgraded if the sheeting requirement is not met.

### 5.1.2 Improve DNE Sign Installation Angle

The DO NOT ENTER (DNE) is the primary regulatory sign for wrong-way crash prevention and is placed at the point where a road user could wrongly enter a one-way roadway or ramp. Most ODOT exit ramps have a pair of DNE signs unless geometry prohibits this placement. Figure 5-1 shows an example of a DNE sign along the exit ramp on I-5 NB in southern Oregon. Guidance in the MUTCD and ODOT suggest these signs should be angled appropriately so that they are optimally visible to the potential wrong-way driver. For low mount signs, ODOT recommends these signs should be placed at 45-degree angle to the approaching traffic. However, for many exit ramps in Oregon at least one of the DNE sign posts is being multi-purposed for exiting freeway traffic (often the STOP sign). Since it is difficult to optimize the orientation for both signs, the DNE is often not optimally oriented. As part of the systemic process, the orientation of the DNE signs should be confirmed and if necessary, be retrofitted with angling brackets such that the orientation is optimal for the potential wrong-way movement.


Figure 5-1: DO NOT ENTER (DNE) Sign Pair at Exit Ramp Terminal

### 5.1.3 Add Supplemental wrong-way Signs to DNE Sign Post

The literature and the MUTCD suggest that the low mounted DNE/WW sign assembly (mounted at 3 ft. from the bottom of the sign to the elevation of the near edge of the pavement) may improve conspicuity during nighttime driving conditions because it is in the low-beam vehicle headlights range (Staplin et al. 2001). Because impaired and older drivers focus on the area of the pavement in front of the vehicle, low-mounted signs were intended to target these drivers (Finley et al. 2014; Baisyet et al. 2015). Figure 5-2 shows an example of low mounted signs used by CalTrans and shows Figure 5-3 shows ODOT's typical drawing from the sign policy.

If installing new low-mount sign assemblies is not feasible some of the benefit of the low-mount sign can be obtained by installing the supplemental WW sign on the DNE sign assembly. The additional red background of the WW sign enhances the conspicuity of the DNE assembly. The WW sign should be angled in the same manner as the DNE sign. Note that some features such as guardrail may limit the placement of an additional WW sign due to maintenance activities.


Figure 5-2: Low Mounted DO NOT ENTER (DNE) and WRONG WAY (WW) Signs Used by CalTrans (FHWA)

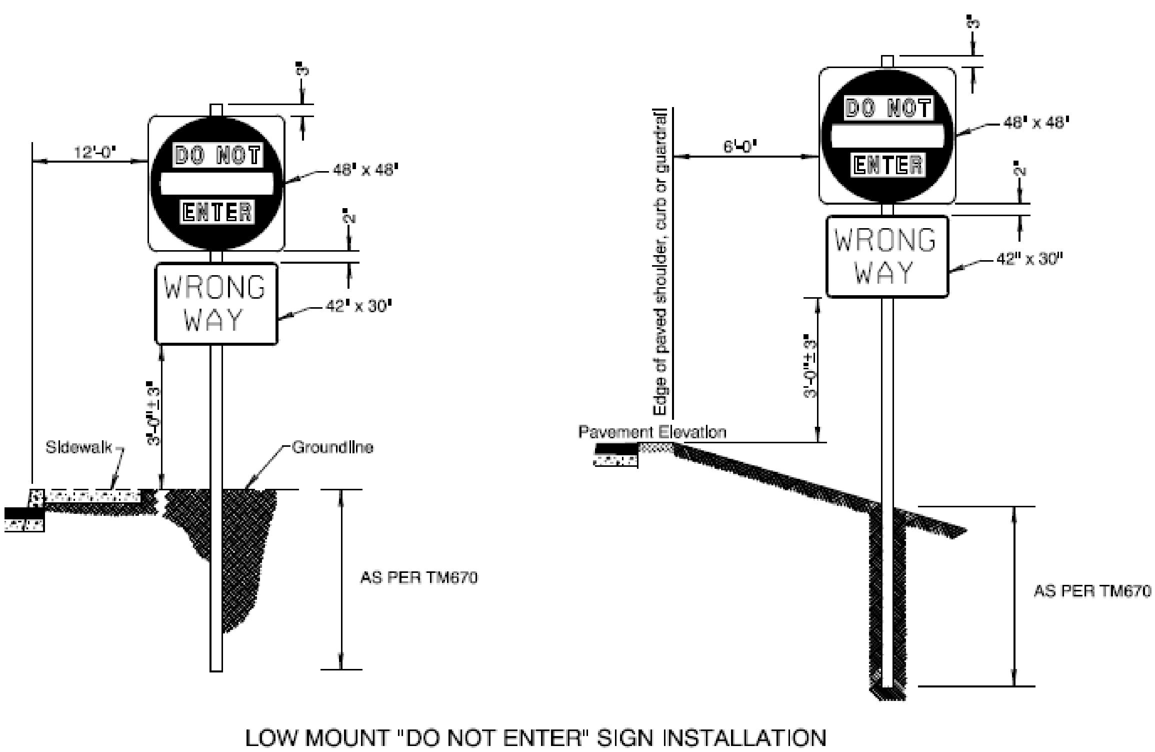



Figure 5-3: Low Mount DNE and WW Signs (ODOT Sign Policy)

### 5.1.4 Add Reflective Material to DNE Sign Post

For exit ramps located in rural or low-light areas, it is recommended to add reflective red material to the DNE sign post. This will further enhance the sign conspicuity for the potential wrong-way driver. The MUTCD allows the use of a strip of retroreflective material on the sign support if it is least 2 inches in width and placed for the full length of the support from the sign to within 2 feet above the edge of the roadway. For wrong-way applications, the material must be RED.


Figure 5-4 Red Reflective Material on STOP Sign Post

### 5.1.5 Add ONE WAY sign to DNE/WW Assembly (OPTIONAL)

According to the MUTCD, ONE WAY signs shall be used to indicate streets or roadways where traffic flows in one direction only.  ONE WAY signs on top of the DNE signs at ramp terminals is noted as typical in the ODOT sign policy but not all exit ramps in the field review consistently used these signs. As a systemic approach, it is recommended that each exit ramp be reviewed and, if feasible, that the ONE WAY sign be added. Figure 5-5 shows an example of the use of ONE WAY signs on the DNE/WW sign assembly.


Figure 5-5: ONE WAY Signs placed on top of the DNE Sign Assembly

### 5.1.6 Add Turn Prohibition or Lane Control Signing (OPTIONAL)

In addition to the standard signs (DO NOT ENTER, WRONG WAY and ONE WAY), additional movement prohibition sign can be added. These signs are considered optional by MUTCD and ODOT for exit ramp wrong-way movements signing package. Figure 5-6 shows the right turn prohibited sign placed on an approach to an exit ramp. For each exit ramp, it is recommended that a review be conducted to determine whether additional turn prohibition signs should be added.


Figure 5-6 Turn Movement Prohibition Sign

### 5.1.7 Add or Modify Wrong Way Arrow or Lane Use Arrow

Slender, elongated wrong-way arrow (WWA) pavement markings are intended primarily to warn wrong-way road users that they are traveling in the wrong direction and are placed upstream from the ramp terminus to indicate the correct direction of traffic flow (MUTCD 2009). These are particularly critical when other lane use arrows are absent and the ramp has only one approach lane. The ODOT Traffic Line Manual states that wrong-way arrows are used in specialized locations where an engineering investigation shows that there is a need (ODOT 2012). Figure 5-7 shows an example of the wrong-way arrow placed near the stop bar of an exit ramp.

It is recommended that the WWA be placed on all single lane exit ramps lacking lane control arrows. Guidance suggests that the WWAs should be placed as close to the stop bar as possible and within 50 feet of the DNE signs or in a location where an engineering study demonstrates the wrong-way arrow will be clearly visible to potential wrong-way road users. Lane-use arrows can also serve a similar function of communicating to the drivers about the appropriate travel direction. ODOT's Traffic Line Manual currently requires lane use arrows (standard left/right/thru intersection turn arrows) at ramp terminals when there is more than one ramp lane approaching the intersection as a wrong-way countermeasure (ODOT 2012). Figure 5-8 shows an example of the lane use arrows clearly showing the intended position for left and right turning movements at an exit ramp. If lane arrows are present, additional WWA may be considered further upstream the ramp.


Figure 5-7: Wrong Way Arrow Placed Near DNE Signs at an Exit Ramp

Figure 5-8: Lane Use Arrows on an Exit Ramp

### 5.1.8 Add Additional WW Sign Pair and WW Arrow to Long Exit Ramps

The placement of additional WW signs and WWA when exit ramps are long can provide more cues to the wrong-way driver that they are making a wrong-way entry before merging onto the freeway, especially if they miss seeing the first set of signs. The second pair of wrong-way signs in the exit ramp may be used for problematic locations with a high crash rate, giving drivers repeated cues (Baisyet et al. 2015).

### 5.1.9 Add Dotted Lane Line Extensions

According to ODOT Traffic Line Manual, the dotted lines are used in situations where the intended path is uncertain to the drivers (ODOT 2012). According to literature, these are useful in situations where the intersection's geometric design or low visibility do not make wrong-way left-turning movement difficult onto an exit ramp. Figure 5-9 shows an example of an added dotted lane line extension (though this particular location is very low turning volume).

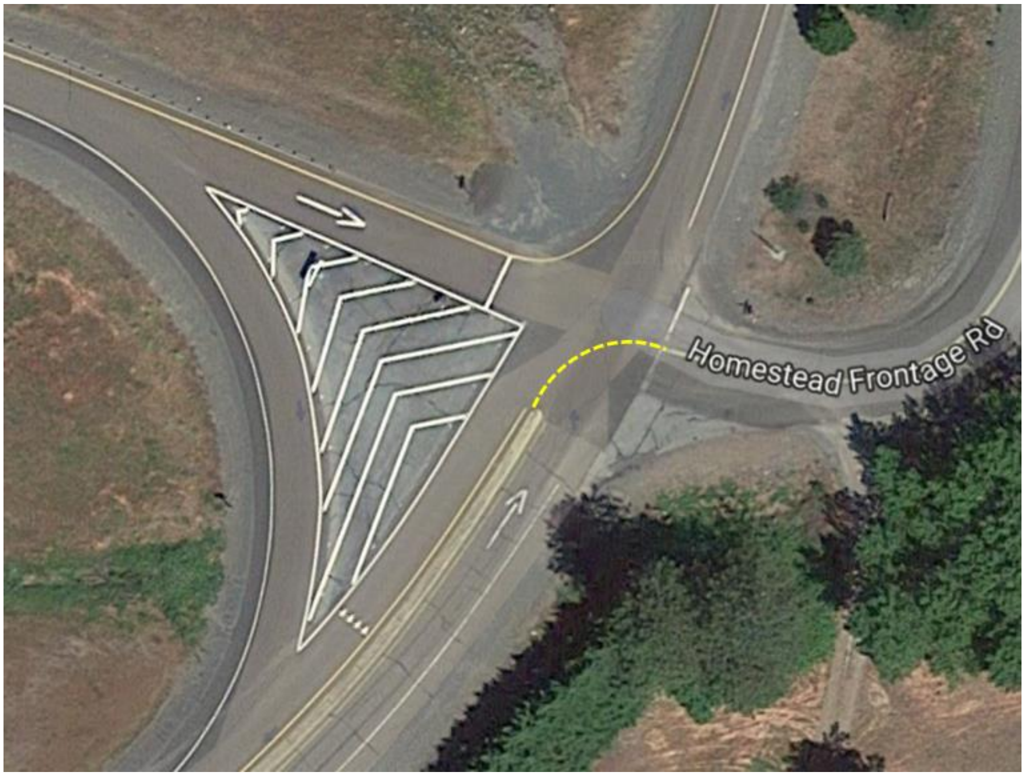



Figure 5-9: Example Dotted Lane Line Extensions

### 5.1.10 Review/Add Keep Right Sign

Because co-located on and off ramps have high potential for wrong-way movements, additional treatments may be considered. When used, the Keep Right sign should be installed as close as possible to the approach end of a raised median such that traffic will have always pass to the right of the sign (MUTCD 2009). Zhou et al. suggest that these are most useful in locations with channelization or obstruction or at locations where it is not clear that traffic should stay to the right (Zhou and Pour Rouholamin 2014). The recommended size of this sign varies by facility type as outlined in the MUTCD. As part of the systemic review, it is recommended that these signs be placed at locations where the entrance and exit ramps are adjacent to each other. Figure 5-10 shows an example of a Keep Right sign that has been installed in the raised median separating the entry and exit ramps.


Figure 5-10 Keep Right Sign in Raised Median Separating the Entry and Exit Ramps

## 5.2 Additional Treatments For High-Risk Locations

For locations that are considered high-risk due to geometry or past wrong-way entrances events, additional countermeasures are presented as options to be considered on a case-by-case basis. The following countermeasures are available at these locations and are described further below.

### 5.2.1 LED and RRFB Beacons on Wrong Way Sign

LED and RRFB wrong-way signs are considered as moderate cost countermeasures that have become popular due to their effectiveness in deterring wrong-way driving maneuvers (Lin and Ozkul 2016b; Lin et al. 2016a; Finley et al. 2014; Sorenson et al. 2016). Flashing LED or beacons for wrong-way driving scenarios may be added to WW and DNE signs to improve visibility at night (Zhou and Pour Rouholamin 2014). Figure 5-11 shows an example of LEDs added to a WW sign. The findings of the literature review showed that non-dimmed red RRFBs at the top and bottom of the "Wrong Way" sign on both sides of the roadway get drivers' attention most while not adversely affecting driving behaviors on adjacent roadways (Lin and Ozkul 2016b; Lin et al. 2016a). It should be noted that some DOTs have reported an issue with false-calls from some of the systems.



Figure 5-11: LED and RRFB on WW Sign

### 5.2.2 Modify and Enhance Guide and Route Finding Signing

According to the MUTCD, guide signs are essential in providing information to road users that will enable them during their trip (MUTCD 2009). As such, it may be beneficial to ensure that appropriate guide signs are present at ramp terminals, entrance and exit ramps to clearly inform the drivers about the correct routes. It is recommended that the guide signing/route finding be reviewed at each exit ramp with a high priority. Figure 5-12 shows an example of guide signs that inform the driver about the direction of the routes.


Figure 5-12: Guide Signs

### 5.2.3 Lighting

Wrong-way crashes often occur late at night and in rural areas, where low-light conditions may prevail. Zhou and Pour-Rouhalamin suggest that non-uniform lighting may affect drivers' perceptions of intersection configurations and lead to confusion and potential wrong-way driving (Zhou and Pour Rouholamin 2014). It is therefore recommended to review existing lighting configurations and provide uniform lighting levels at the entrance and exit ramps especially at locations prone to wrong-way entries.

### 5.2.4 Geometric Modifications

Geometric modifications include the use of channelizing islands, raised medians, narrowing the exit ramp terminal throat or widening the entrance ramp terminal throat. These recommendations describe minor geometric improvements, which, when used in conjunction with other improvements may address the wrong-way entry problem. Many of these treatments are discussed in AASHTO 2011 Chapter 10, pages 10-83 to 10-87 and can be referenced for more details (AASHTO 2011). When evaluating individual locations, the full range of ideas should be considered including modifications that are more substantial to address the root problem.

#### *5.2.4.1 Channelizing Islands*

According to AASHTO, installing channelizing islands in ramp terminals guides drivers traveling in the right direction, and they can be used for additional signing (AASHTO 2011). Figure 5-13 shows an example of the use of a channelizing island off an exit ramp. The addition of these islands at locations with wide paved areas can be considered.

Figure 5-13: Channelizing Island off an Exit Ramp

#### *5.2.4.2 Raised Medians*

For co-located exit and on-ramp locations, Zhou and Pour Rouholamin recommend the use of raised medians as an appropriate geometric countermeasure for reducing wrong-way movements (Zhou and Pour Rouholamin 2014). According to WSDOT, separating adjacent exit and entrance ramps through a raised median can provide additional space for installing proper signage and direct drivers in the correct direction (WSDOT 2016). The recommended minimum width of a raised median is seven ft.


Figure 5-14: Raised Median at Folded Diamond Ramp Terminal

#### *5.2.4.3 Narrowing Exit Ramp and Widening Entrance Ramp Throat*

According to AASHTO (2011), for an undivided crossroad, a reduced radius between the left edge of the exit ramp and the right edge of the crossroad discourages right turn wrong-way entry onto the exit ramp. Where feasible, consider reducing the width of the exit ramp terminal throat by installing a raised island (preferred option) or painted island, removing the flared left edge of exit ramps, and or widening the entrance-ramp terminal throat encourages right-way movements as discussed in Section 3.1.5.

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## APPENDIX A – FIELD INSPECTION PROMPTS

Field inspections and reviews are often critical in identifying deficiencies that may lead to wrong-way entries. During the field visits, inspection of signage, pavement markings and geometric design at each interchange can be conducted. Regular inspections are necessary to ensure that signage, pavement markings and geometric design are effective in preventing wrong-way driving crashes. Many states have their own checklists for conducting field inspections. FHWA has also developed a Wrong Way Driving road safety audit prompt list that is intended to focus specific attention on wrong-way driving issues and contributing factors (FHWA, 2013).

The first step in the process is to identify locations for site visit. These may be identified based on a review of the crash data and/or wrong-way driving logs. Once the sites have been shortlisted, it is helpful to identify all potential wrong-way movements that can occur at each interchange. Note locations of DO NOT ENTER, WRONG WAY, ONE WAY and MOVEMENT PROHIBITION signs and pavement markings such as wrong-way arrows, turning guide lines, stop bars, and lane arrows for each ramp interchange at each site. Additionally, reviewing the presence of wayfinding and guide signs may also be warranted. Following are some of the things to review at each interchange. This list has been compiled using the FHWA's road safety audit prompt list, research team observations following a field study and conversations with ODOT engineers. While this list is intended to help in the identification of potential deficiencies, there may be site-specific characteristics that may be not be included here. Engineers are encouraged to use this list along with other resources that may be helpful in identifying causes.

### Signs

- Are DNE, WW, ONE WAY and Movement Prohibition signs present at all ramp interchanges?
- Are these signs visible during day and night to the potential wrong-way driver? Do they have retro-reflective sheeting?
- Are the signs in adequate condition?
- Are the sizes and the heights of the signs appropriate?
- Are the signs angled appropriately to face the potential wrong-way driver?
- Are wayfinding and guide signs provided?
- Do the other non-warning and non-regulatory signs that are present, contribute to sign clutter and/or driver confusion?

### Pavement Markings

- Are wrong-way arrows present? Are they located near the stop bar and DNE signs?
- Are other markings such as turning guidelines, stop bars, and lane markings present?
- Are these markings in adequate condition?
- Are they visible during day and night?

**Geometric Design**

- Are exit ramps located close to entrance ramps?
- Is the spacing between ramps adequate?
- Are medians, channelizing islands or other design features present to separate entrance and exit ramps?
- Are sight lines on ramps and ramp terminals adequate?
- Do guardrail or other traffic barriers obstruct ramp visibility?
- Is corner radius at exit ramp such that it would deter wrong-way entry?
- Does horizontal or vertical curvature affect ramp visibility?
- Are traffic signals or other control devices configured to reinforce proper travel direction for ramps?

**Other**

- Is lighting present and functional at exit ramp locations?
- Does inclement weather affect the visibility of signs or geometric conditions at or approaching ramps?
- Is the study area located in proximity to or along a corridor with drinking establishments?

APPENDIX B – SUMMARY OF NEWS ARTICLES ON WRONG-WAY DRIVING

| Date | Route | MP | Region | F | A | Fatal? | DUII? | Age | Driver Age | Nighttime? | Link |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/7/2014 | I-82 | 3.8 | 5 | 1 | 1 | Yes | Yes | 66 | 31 | Yes | http://www.oregon.gov/osp/NEWSRL/Pages/news/03_07_2014_prelim_fatal_i82_mp4.aspx |
| 3/27/2014 | I-5 | 23.5 | 3 | 1 | 1 | Yes | Yes | 58 | 42 | Yes | http://www.oregon.gov/osp/NEWSRL/Pages/news/03_27_2014_update_fatal_i5_mp24.aspx |
| 11/13/2014 | I-5 | 96.7 | 3 | 1 | 0 | No | Yes | 64 | 64 | Yes | http://www.oregonlive.com/news/index.ssf/2014/11/wrong-way_driver_killed_near_c.html |
| 11/25/2014 | I-5 | 266.41 | 2 | 1 | 2 | Yes | Yes | 49 | 49 | Yes | http://www.kptv.com/story/27477170/southbound-lanes-of-i-5-blocked-near-woodburn-after-deadly-wrong-way-crash |
| 3/3/2013 | I-5 | 102.65 | 3 | 1 | 1 | Yes | Yes | 44 | 26 | Yes | http://www.oregonlive.com/pacific-northwest-news/index.ssf/2013/03/driver_arrested_after_fatal_wr.html |
| 5/3/2013 | I-5 | 9.75 | 3 | 1 | 1 | No | Yes | 41 | 41 | yes | http://www.cbnb.info/index.php/Regional-News/i-5-wrong-way-driver-near-medford-may-6.html |
| 7/6/2012 | I-84 | 23.3 | 1 | 1 | 0 | No | No | 36 | 53 | Yes | http://www.oregonlive.com/pacific-northwest-news/index.ssf/2012/07/woman_driving_the_wrong_way_di.html |
| 9/10/2011 | I-5 | 221.68 | 2 | 1 | 0 | No | Yes | 71 | 71 | Yes | http://www.gazettetimes.com/news/local/one-dead-in-wrong-way-crash-on-i/article_025d6930-dc2f-11e0-b0e7-001cc4c03286.html |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/8/2011 | I-105 | 0.95 | 2 | 1 | 0 | No | Yes | 57 | 75 | Yes | https://portlandattorney.wordpress.com/tag/eugene-oregon/ |