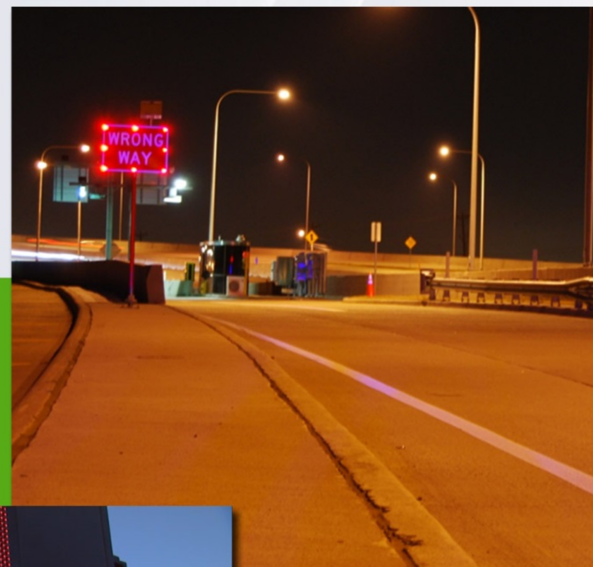
ILLINOIS CENTER FOR TRANSPORTATION

Illinois Department of Transportation

GUIDELINES FOR REDUCING WRONG-WAY CRASHES ON FREEWAYS



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May 2014

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16. Abstract

Each year, hundreds of fatal wrong-way driving (WWD) crashes occur across the United States, and thousands of injuries are reported in traffic crashes caused by wrong-way drivers. Although WWD crashes have been a concern since the advent of access-controlled, divided roadways, the problem persists despite efforts to address it over time. The objective of this book is to provide guidance for implementing traditional and advanced safety countermeasures to achieve a significant reduction in the number of WWD incidents and crashes on freeways.

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EXECUTIVE SUMMARY

Each year, hundreds of fatal wrong-way driving (WWD) crashes occur across the United States, and thousands of injuries are reported in traffic crashes caused by wrong-way drivers. Although WWD crashes have been a concern since the advent of access-controlled, divided roadways, the problem persists despite efforts to address it over time. The objective of this book is to provide guidance for implementing traditional and advanced safety countermeasures to achieve a significant reduction in the number of WWD incidents and crashes on freeways.

Past studies identified several common issues associated with the high WWD crash-prone intersections, based on field reviews of numerous locations and analysis of multiple years of crash data. Issues with signing and pavement markings, including inadequate or missing devices, poor location or placement, and insufficient conspicuity, were commonly cited. Some geometric features also correlated to WWD crashes, such as interchange or intersection layout, presence of raised median or channelizing islands, turning radii, and large median openings.

This guidebook was compiled from reviewing previously conducted studies, assessing current documented practices, and reviewing national and state-level design standards or manuals that pertain to WWD. The authors were also provided with significant input and information from the National Wrong-Way Driving Summit held in Edwardsville, Illinois, on July 18–19, 2013. This guidebook is intended to serve state and local agencies as an informational resource to supplement, not to replace or supersede, existing standards and manuals, with a comprehensive discussion of strategies and countermeasures to mitigate WWD in their jurisdictions. The target audiences for this guidebook are transportation professionals, highway designers, traffic engineers, law enforcement officers, and safety specialists who may be involved in efforts to reduce WWD crashes.

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

The organization of this guidebook is as follows:

- Chapter 1 is an introduction to the problem; it begins with a definition of WWD, summarizes safety data that demonstrate the importance of the issue, and discusses how WWD efforts can fit into a state highway safety improvement program.

- Chapter 2 covers the three most common categories of countermeasures: signs, pavement markings, and traffic signals. This chapter covers important fundamentals of applying these devices, as well as options to enhance them when appropriate. Photos, figures, and tables illustrate the discussion whenever possible.

- Chapter 3 elaborates on various geometric elements and related design considerations that can affect WWD. These elements include basic interchange layout, different arrangements of exit ramps and their connections with crossroads or frontage roads, and specific components of intersections (e.g., raised median, control radius, channelizing island).

- Finally, Chapter 4 discusses aspects of human factors and behavior, covering advanced technologies, enforcement, and education strategies.

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ATSSA	American Traffic Safety Services Association
Caltrans	California Department of Transportation
CCTV	closed-circuit television
CHP	California Highway Patrol
CMS	changeable message sign
DNE	do not enter
DUI	driving under the influence
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
HCTRA	Harris County Toll Road Authority
ICT	Illinois Center for Transportation
IDOT	Illinois Department of Transportation
IID	ignition interlock device
ILD	inductive loop detector
IMS	incident management system
ISP	Illinois State Police
ISTHA	Illinois State Toll Highway Authority
ITS	intelligent transportation system
LED	light-emitting diode
MADD	Mothers Against Drunk Driving
MUTCD	*Manual on Uniform Traffic Control Devices*
NHTSA	National Highway Traffic Safety Administration
NSA	National Sheriff's Association
NTSB	National Transportation Safety Board
NTTA	North Texas Tollway Authority
RPM	raised pavement marker
TMC	traffic management center
USDOT	United States Department of Transportation
VIP	video image processing
WSDOT	Washington State Department of Transportation
WW	wrong way
WWD	wrong-way driving

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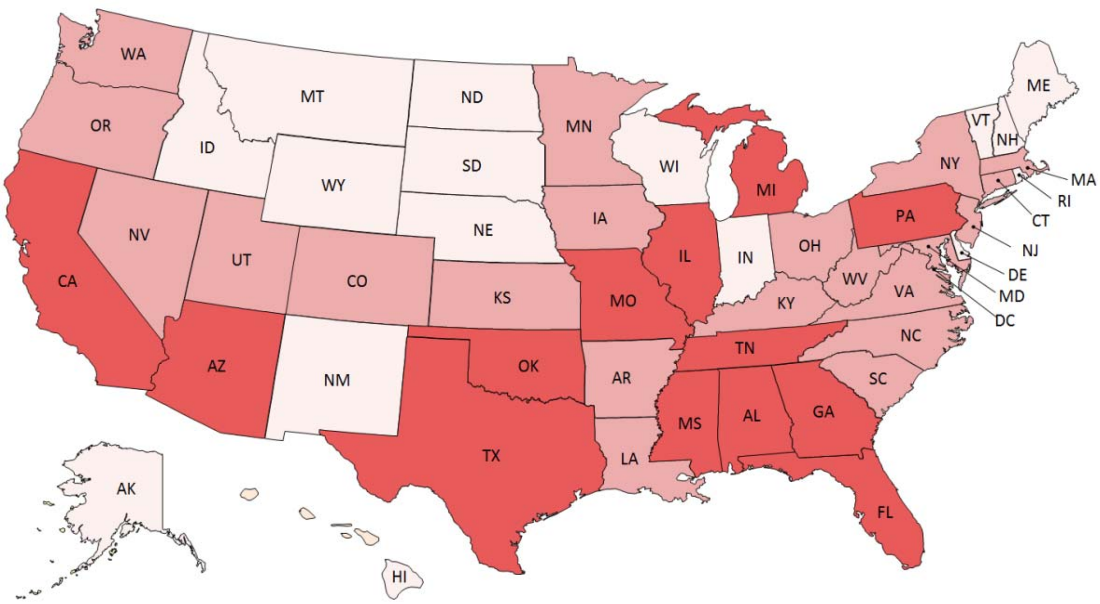
CHAPTER 1

INTRODUCTION

Wrong-way driving (WWD), by definition, happens when a driver, inadvertently or deliberately, drives against the main direction of flow along physically divided highways or their access ramps. A recent study (Zhou et al. 2012) shows that freeway exit ramps are the main entry points for most recorded WWD crashes. Because WWD crashes are mainly head-on or opposite-direction sideswipes, the outcome tends to be more severe and cause more incapacitating injuries (A-injuries) and fatalities than non-WWD crashes.

An analysis of the data from 2004 to 2011 derived from the National Highway Traffic Safety Administration (NHTSA)'s Fatality Analysis Reporting System (FARS) database revealed that on average there were 261 WWD fatal crashes annually on high-speed divided highways (out of around 9,400 of all types of fatal crashes on these facilities) in which roughly 360 people were killed. Figure 1-1 depicts the annual average frequency of WWD fatalities across all 50 U.S. states. In this figure, Group 1 includes 13 states with more than 2% of WWD fatalities, Group 2 represents states with less than 2% but more than 1%, and Group 3 consists of the states with less than 1% WWD fatalities. The three states with the highest frequency—Texas, California, and Florida—comprise approximately one-third of total WWD fatalities in the United States.



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 1-1. Annual average frequency of WWD fatalities across the United States (2004–2011).

Several states, including California, Texas, Illinois, Michigan, and Arizona, have existing WWD programs in place to identify and address problematic locations with different types of countermeasures or strategies. For example, a related study sponsored by the Illinois Center for Transportation (ICT) reported that there were 217 WWD crashes on Illinois freeways from 2004 through 2009 resulting in 44 fatalities and 248 injuries. The study identified possible contributing factors, determined the top locations in the state for WWD, and suggested general and site-specific mitigation treatments (Zhou et al. 2012). This guidebook brings together and builds on these efforts in Illinois and other states to provide comprehensive guidance to practitioners in order to achieve a significant reduction in the number of WWD crashes and fatalities in the future.

Efforts to reduce WWD-related fatalities can be a good fit within a state's Highway Safety Improvement Program (HSIP). The HSIP is a core federal aid highway program created to significantly reduce traffic-related fatalities and serious injuries on all public roads in the United States. More information about the HSIP can be found at http://safety.fhwa.dot.gov/hsip/. In short, the HSIP is a data-driven, strategic program to improve safety. Because WWD crashes are very sporadic, it is rare for specific sites to emerge as high crash or "hot spot" locations. However, when data from a statewide, regional, or system level over a sufficient period of time are analyzed, certain risk characteristics become evident. This is referred to by the Federal Highway Administration (FHWA) as the systemic process or approach. Details about and examples of the systemic approach can be found at http://safety.fhwa.dot.gov/systemic/. According to the FHWA, "the systemic approach to safety involves widely implemented improvements based on high-risk roadway features correlated with specific severe crash types. The approach provides a more comprehensive method for safety planning and implementation that supplements and compliments traditional site analysis. It helps agencies broaden their traffic safety efforts and consider risk as well as crash history when identifying where to make low cost safety improvement locations."

Taking a systemic approach to WWD can help identify the higher risk characteristics associated with this problem, which in turn leads to identification of strategies and countermeasures to mitigate or reduce these risks. The Michigan Department of Transportation (MDOT) used a systemic approach to addressing WWD and found that while partial cloverleaf (parclo) interchanges represented about 20% of the interchanges across the state, the data showed that 60% of WWD crashes involved a parclo. Using this information, MDOT developed a package of enhanced signing and marking treatments to be deployed at parclo interchanges across the entire state over a multi-year period, using HSIP funds, based on availability from year to year. They have also revised and modified some of their standards for interchange ramp signing, resulting in incremental improvements with all interchange projects.

A systemic process to address WWD is not limited to engineering countermeasures. It can also inform strategies for enforcement, such as campaigns or locations to reduce impaired driving; and education, by targeting older and younger driver audiences.

As for roadway characteristics, past studies (Moler 2002; Braam 2006; Leduc 2008; Morena and Leix 2012) have demonstrated that some kinds of interchange/intersection layouts are prone to wrong-way movements. The first phase of the current project found that the top five interchange types with relatively high WWD crashes are diamond interchanges with continuous frontage roads, diamond interchanges without continuous frontage roads, parclo interchanges, single point diamond interchanges (SPDI), and freeway feeders. This guidebook incorporates engineering countermeasures and application guidelines for each of the five aforementioned interchanges to deter potential wrong-way movements. Although this book was developed based on the study of Illinois WWD crashes, researchers received information from other state agencies at the National Wrong Way Driving Summit held in Edwardsville, Illinois, on July 18–19, 2013. Hence, the guidelines are also intended for use by other state and local agencies. These guidelines are categorized in three separate chapters:

- Chapter 2: Signs, Pavement Markings, and Traffic Signals
- Chapter 3: Geometric Design Elements
- Chapter 4: Advanced Technologies, Enforcement, and Education

CHAPTER 2

SIGNS,

PAVEMENT MARKINGS, AND

TRAFFIC SIGNALS

SECTION 2.1: SIGNS

Signs are among the more traditional and least expensive WWD countermeasures. They are meant to guide, warn, or regulate drivers, and, in the WWD context, deter them from making wrong-way maneuvers at the intersection of exit ramps and crossroads. Proper signage can notify the wrong-way driver that he or she is traveling in the wrong direction should it occur. In this section, signs intended to prevent WWD, including DO NOT ENTER (DNE), WRONG WAY (WW), and ONE WAY, are discussed along with information about appropriate location, orientation, size, and enhancement to maximize their effectiveness.

Design Guidelines	
General Considerations	
• Ensure that signs are positioned to face, and are clearly visible to, the driver for whom signs are placed. • Consider optional use of oversized and/or supplemental signs to enhance their visibility and conspicuity. • Evaluate use of lower mounting height of DNE and WW signs where appropriate. • Consider various optional enhancements to increase conspicuity of signs (particularly at night), including red retroreflective strips on sign supports, flashing LED borders, or flashing beacons.	
Sign	**Guidelines**
DO NOT ENTER	• Place DNE signs for potential wrong-way drivers. • Place DNE signs at the end of one-way frontage roads that lead from freeway exit ramps.
WRONG WAY	• Place at least one WW sign along exit ramps, ensuring that it faces potential wrong-way drivers. • Place WW sign(s) along one-way frontage roads that lead from freeway exit ramps. • Consider using a second set of WW signs or additional WW signs on the backside of existing signage along exit ramps closer to the freeway mainline at high crash locations.
ONE WAY	• Place at least one set of ONE WAY signs at intersections of exit ramps and crossroads parallel to one-way ramps facing each direction of travel on crossroads. • Use the R6-1 ONE WAY sign rather than the R6-2 for a higher visibility at night.
Keep Right	• Use Keep Right signs at the median between exit and entrance ramps at parclo interchanges.
Turn Prohibition (No Right/Left Turn)	• Place No Right/Left Turn signs where they will be most easily seen by road users who might be intending to make wrong-way movements. • Add No Right/Left Turn signs adjacent to traffic signal indications where appropriate. • Install additional No Right/Left Turn signs at right/left corner facing potential right/left-turning wrong-way drivers.

DISCUSSION

General Considerations

- **Ensure that signs are positioned to face, and are clearly visible to, the driver for whom signs are placed.**

  Once the appropriate location for a sign is determined, check that the sign face is oriented toward intended road users so that the highest visibility can be attained (Figure 2-1). Signs visible to non-intended users that might cause a conflict between the messages being conveyed should be adjusted, screened, or relocated to avoid confusion.

Figure 2-1. Signs facing potential wrong-way drivers at a SPDI.

- **Consider optional use of oversized and/or supplemental signs to enhance their visibility and conspicuity.**

  Based on engineering judgment, the use of signs beyond minimum size, number, and location requirements may be considered in order to make critical information stand out to drivers. The use of larger signs is suggested in various publications (FHWA 2001; Potts et al. 2004) to be advantageous in increasing sign visibility, especially for older drivers at night. Adding supplemental signs along the roadsides (left and right sides), or repeating signs longitudinally along the roadway, provides redundancy in case a driver does not see one instance. Supplemental warning plaques can also be added below warning and regulatory signs, such as a DNE sign, to convey a complementary message about the existing condition. According to the MUTCD (FHWA 2009), these plaques, if combined with regulatory signs, must be black on yellow (black legend and border on yellow background). RAMP (Figure 2-2) and ONE WAY (Figure 2-3) signs are two signs that can be added to DNE signs. Appendix C provides a table containing other combined signs currently being used.

Figure 2-2. Supplemental RAMP placards on DNE signs (Cooner et al. 2004).

Figure 2-3. Supplemental ONE WAY sign on DNE sign (Cooner et al. 2004).

- **Evaluate use of lower mounting height of DNE and WW signs where appropriate.**

  Per the MUTCD, DNE and WW signs may be mounted at a height of 3 feet from the edge of pavement to the bottom of sign (Figure 2-4). A lower-mounted sign targets impaired and older drivers, two categories of drivers that many studies have associated with WWD, who have a tendency to look for visual cues near the pavement surface (Cooner et al. 2004). The lower height also places the signs more directly in the area illuminated by vehicle headlights. When considering a lower mounting height, keep in mind that concerns such as snow accumulation, parked vehicles, pedestrian activity, vegetation and other possible obstructions should be evaluated. To alleviate these concerns where they may exist, some states simply add the lower-mounted sign to an existing, normally mounted one, resulting in a "double" sign.

Figure 2-4. Lower-mounted DNE and WW signs along exit ramp (Ouyang 2013).

- **Consider various optional enhancements to increase conspicuity of signs (particularly at night), including red retroreflective strips on sign supports, flashing LED borders, or flashing beacons.**

  There are many optional enhancements that serve to make signs more conspicuous, most of which are low cost. Increasing the nighttime visibility of sign supports by applying red retroreflective strips on the supports of DNE (Figure 2-5) and WW (Figure 2-6) signs adds visual target value to the overall sign installation. When used, the strip of retroreflective material must be at least 2 inches in width and placed from the sign to within 2 feet above the edge of the roadway (FHWA 2009).

Figure 2-5. Red retroreflective strips on DNE sign supports (Image: Huaguo Zhou).

Figure 2-6. Red retroreflective strips on WW sign supports (Image: Yang Ouyang).

Flashing LED borders along the edges of WW (Figure 2-7) and DNE signs add a dynamic visual cue to a static sign and may be seen more easily at night or in low-visibility conditions. LED lights can also make the signs visible to drivers before the vehicle headlights illuminate the retroreflective sign sheeting. Finally, flashing LEDs can be dynamic—set to activate only when a WWD incident is detected.

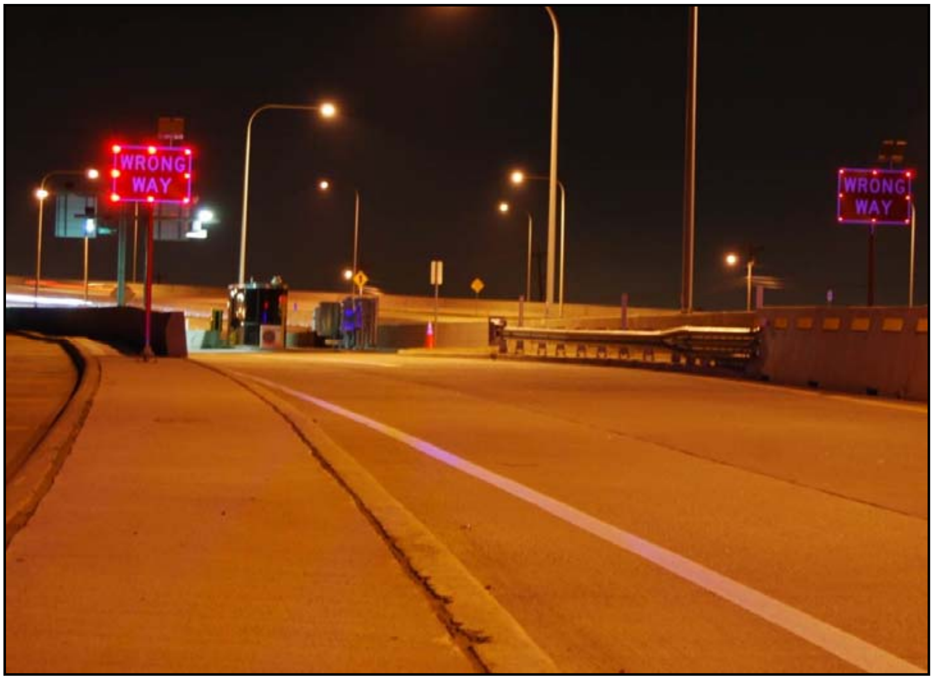


Figure 2-7. LED-enhanced WW signs (Ouyang 2013).

Although just a few states use flashing beacons for WWD scenarios, such devices can also supplement DNE and WW signs to enhance nighttime visibility of these signs. MUTCD Section 4L.03 discusses them in more detail.

DO NOT ENTER Sign

Where motor vehicles are prohibited from entering a restricted road, DNE signs must be used. The signs should be placed on the right-hand side of roads in positions appropriate for full view of a road user to avoid entering a restricted facility. It can also be installed on the left-hand side, where the vehicles approach from an intersecting roadway. Table 2-1 summarizes the sizes of the sign, based on the facility type (2009 MUTCD). The dimensions shown in this table are inches.

Table 2-1. DO NOT ENTER Sign (R5-1) Sizes by Facility Type

	Conventional Road		Expressway	Freeway	Minimum	Oversized
	Single Lane	Multi-Lane				
	30 × 30	36 × 36	36 × 36	**48 × 48**	—	36 × 36

- **Place DNE signs for potential wrong-way drivers.**

  Placement and number of DNE signs differ according to the conditions where they apply. At least one DNE sign should be installed at an exit ramp terminal, next to the intersection, facing potential wrong-way drivers. Additional DNE signs may be used for traffic approaching from an intersecting roadway (MUTCD Section 2B.37).

- **Place DNE signs at the end of one-way frontage roads that lead from freeway exit ramps.**

  One-way frontage roads parallel to freeways and connected to exit ramps can result in wrong-way maneuvers. Placement of DNE signs at the intersection of the frontage road, crossroad, and beyond can warn drivers against entering the one-way frontage road and the one-way exit ramp.

WRONG WAY Sign

WW signs may be used to supplement DNE signs. They are installed along the exit ramp farther from the crossroad than DNE signs and directly face would-be wrong-way drivers. Table 2-2 summarizes different sizes of this sign according to facility type (2009 MUTCD). The dimensions shown in this table are inches.

Table 2-2. WRONG WAY Sign (R5-1a) Sizes by Facility Type

	Conventional Road		Expressway	Freeway	Minimum	Oversized
	Single Lane	Multi-Lane				
	36 × 24	42 × 30	36 × 24	**42 × 30**	30 × 18	42 × 30

- **Place at least one WW sign along exit ramps, ensuring that it faces potential wrong-way drivers.**

  At least one WW sign should be placed along exit ramps, facing possible wrong-way drivers, to provide additional warning after a wrong-way maneuver has occurred. The back of the ramp exit signs where the ramp deviates from the freeway mainline is another place to consider placing WW signs (Figure 2-8). These signs can be placed approximately 125 feet apart from DNE signs.

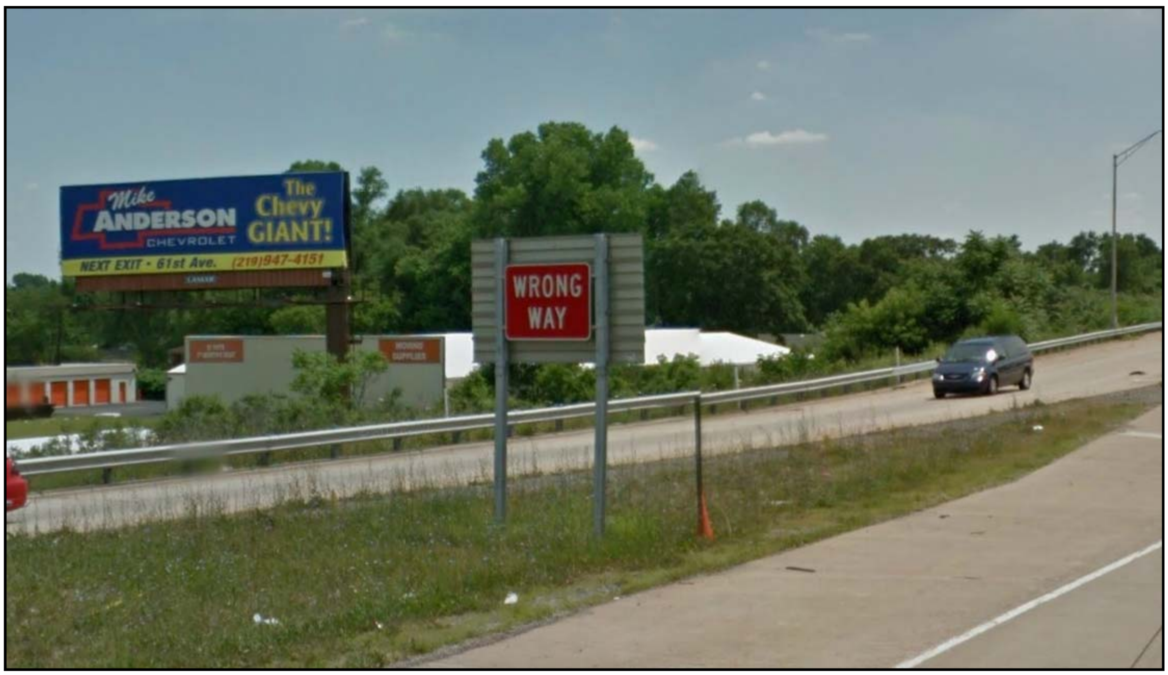


Figure 2-8. WW sign on the back of a ramp exit sign (Image: Google Maps).

- **Place WW sign(s) along one-way frontage roads that lead from freeway exit ramps.**

  At the intersection of one-way frontage roads and crossroads, WW signs installed along one-way frontage roads in advance of exit ramps can help drivers correct their movements before entering exit ramps and freeways.

- **Consider using a second set of WW signs or additional WW signs on the backside of existing signage along exit ramps closer to the freeway mainline at high crash locations.**

  Where an engineering study or judgment suggests they would be effective, additional WW signs may be installed along exit ramps. A field review of exit ramps with more than one set of WW signs showed that a distance of approximately 350 feet was commonly used between two consecutive sets of WW signs.

ONE WAY Sign

ONE WAY signs should be installed parallel to the intended roadways at the intersections where the traffic movement is allowed in only one direction. Table 2-3 summarizes various sizes of these signs based on facility type (2009 MUTCD). The dimensions shown in this table are inches. As shown in this table, two types of ONE WAY signs (R6-1 and R6-2) may be used, based on visibility needs and where lateral space is limited (e.g., on mast arms).

Table 2-3. ONE WAY Signs (R6-1 and R6-2) Sizes by Facility Type

	Conventional Road		Expressway	Freeway	Minimum	Oversized
	Single Lane	Multi-Lane				
 (R6-1)	36 × 12	54 × 18	54 × 18	**54 × 18**	—	54 × 18
 (R6-2)	24 × 30	30 × 36	36 × 48	**48 × 60**	18 × 24	36 × 48

- **Place at least one set of ONE WAY signs at intersections of exit ramps and crossroads parallel to one-way ramps facing each direction of travel on crossroads.**

  This sign should be installed at the end of exit ramps on the side with the highest visibility to potential wrong-way drivers. Additional ONE WAY signs may be considered in advance of ramp intersections to supplement existing ONE WAY signs (MUTCD Section 2B.41). For divided highways with median widths of 30 feet or wider, ONE WAY signs may be installed at the near right and far left corners of each intersection with one-way streets.

- **Use R6-1 ONE WAY signs rather than R6-2 for higher visibility at night.**

  The choice to use R6-1 or R6-2 should be based on engineering judgment and local agency policies. Some literature suggests that R6-1 is more easily understood than R6-2, potentially because of the shape and visual appearance.

Keep Right Sign

Keep Right signs guide traffic to pass only to the right-hand side of a roadway where there is channelization or an obstruction or when it is otherwise not apparent that traffic should keep to the right. Such signs should be placed on the ends of raised medians, parkways, or islands, or in front of obstructions that separate two directions of traffic. Table 2-4 summarizes the basic sizes of this sign (2009 MUTCD). The dimensions shown in this table are inches.

Table 2-4. Keep Right Sign (R4-7) Sizes by Facility Type

	Conventional Road		Expressway	Freeway	Minimum	Oversized
	Single Lane	Multi-Lane				
	24 × 30	24 × 30	36 × 48	48 × 60	18 × 24	36 × 48

- **Use Keep Right signs at the median between exit and entrance ramps at parclo interchanges.**

  At certain types of interchanges where exit and entrance ramps are adjacent to one another and where the separation is less than 30 feet, Keep Right signs should be installed to guide traffic pass from the right side of the median (Figure 2-9). Interchange configuration and intersection geometry are discussed in more detail in Chapter 3.

Figure 2-9. Keep Right sign at the median of parclo interchange (Image: Huaguo Zhou).

Turn Prohibition (No Right/Left Turn) Signs

Turn prohibition signs warn road users of required, permitted, or prohibited traffic movements. A No Right Turn sign should be placed at a right-hand corner of the intersection if right-turn movements are prohibited. A No Left Turn sign should be placed at the left-hand corner of the intersection, on a median, or with a STOP sign or YIELD sign if left turns are prohibited. Both No Right/Left Turn signs can be placed in conjunction with traffic control signals (adjacent to a signal face for a better view by road users). However, these signs may be omitted where ONE WAY signs are present. Table 2-5 summarizes different sizes of these two signs based on facility type (2009 MUTCD). The dimensions shown in this table are inches.

Table 2-5. No Right Turn Sign (R3-1) and No Left Turn Sign (R3-2) Sizes by Facility Type

	Conventional Road		Expressway	Freeway	Minimum	Oversized
	Single Lane	Multi-Lane				
	24 × 24	36 × 36	36 × 36	—	—	48 × 48

- **Place No Right/Left Turn signs where they will be most easily seen by road users who might be intending to make wrong-way movements.**

  According to the MUTCD, these turn prohibition signs should be installed so that they provide the highest visibility (MUTCD Section 2B.18).

- **Add No Right/Left Turn signs adjacent to traffic signal indications where appropriate.**

  Turn prohibition signs, if used in combination with traffic control signals, may be post-mounted as a supplement to the traffic signal head (MUTCD Section 2B.18) (Figure 2-10).

Figure 2-10. No Right Turn sign mounted on mast arm to increase visibility (Image: Huaguo Zhou).

- **Install additional No Right/Left Turn signs at right/left corner facing potential right/left-turning wrong-way drivers (Figure 2-11).**

Figure 2-11. Additional No Left Turn sign facing to potential wrong-way drivers (Image: Huaguo Zhou).

SECTION 2.2: PAVEMENT MARKINGS

Pavement markings, like other traffic control devices, are a way of communicating with drivers and can convey important messages about proper and safe road use. Types of pavement markings used to address WWD include longitudinal lines, lane line extensions, lane-use arrows, wrong-way arrows, and delineation (arrows are shown in Table 2-6 on the following page). Detailed information about designing these arrows and their dimensions can be found in *Standard Highway Signs and Markings* (FHWA 2004, 2012).

Design Guidelines	
General Considerations	
• Ensure that pavement markings complement the geometry of the location and provide positive guidance to drivers about proper direction and movement. • Ensure that pavement markings and signs are consistent with one another so they reinforce the information conveyed to drivers. • Consider various optional enhancements to pavement markings to increase conspicuity (particularly at night).	
Marking	**Guidelines**
In-Lane Arrows	• Place appropriate lane-use arrows on the approach to and at intersections with ramps. • Avoid placing lane-use arrows where they can be misunderstood and possibly result in wrong-way maneuvers. • Consider using the wrong-way arrow along exit ramps.
Longitudinal Lines	• Use longitudinal lines to help drivers recognize the appropriate directions for travel. • Use lane line extensions to guide vehicles through ramp terminals with large turning radii. • Use painted islands between entrance and exit ramps.
Stop Lines	• Consider placing stop lines at the end of exit ramps.
Enhanced Delineation	• Use red retroreflective raised pavement markers (RPM) to enhance the visibility of pavement markings (lines, arrows, etc.) on exit ramps. • Use barrier delineators to warn wrong-way drivers.

DISCUSSION

General Considerations

- **Ensure that pavement markings complement the geometry of the location and provide positive guidance to drivers about proper direction and movement.**

  Use of longitudinal lines can help drivers recognize their appropriate directions of travel, especially solid yellow lines along the left edge of exit ramps.

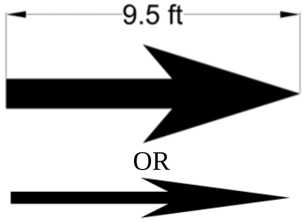
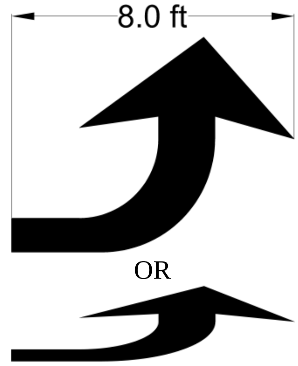
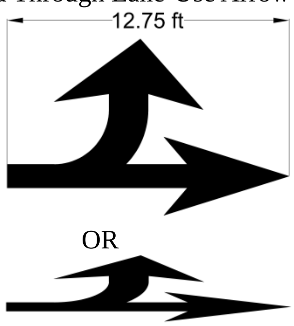
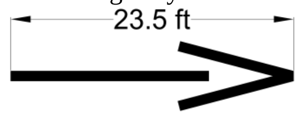
- **Ensure that pavement markings and signs are consistent with one another so they reinforce the information conveyed to drivers.**

  Road users try to get the information about the facility (lane use, restrictions, etc.) and, if possible, match the information with the existing pavement marking and vice versa. Therefore, any inconsistency between pavement markings and signs could lead to driver confusion.

- **Consider various optional enhancements of pavement markings to increase conspicuity (particularly at night).**

  Because the majority of wrong-way driving crashes happen during night and early mornings under dark conditions (Zhou et al. 2014), any optional enhancements to pavement markings that improve their visibility can help decrease the likelihood of WWD incidents.

Table 2-6. Wrong-Way and Lane-Use Arrows (FHWA 2009)

Through Lane-Use Arrow 	Turn Lane-Use Arrow 
Turn and Through Lane-Use Arrow 	Wrong-Way Arrow 

In-Lane Arrows

- **Place appropriate lane-use arrows on approach to and at intersections with ramps.**

  Painting lane-use arrows at the ramp–crossroad intersection (on both crossroad and exit ramp pavements) makes drivers aware of the permissible movement in the specific lane (Figure 2-12). At least two lane-use arrows should be placed as follows:
    - One near the stop line or intersection; and
    - One upstream of the intersection at the end of the full-width turn lane.

  Additional arrow(s) may also be used if necessary. The longitudinal spacing between two consecutive lane-use arrows should be at least four times and no more than ten times of the height of the arrow (MUTCD Section 3B.20).

Figure 2-12. Directional pavement arrows at intersection (Image: Huaguo Zhou).

- **Avoid placing lane-use arrows where they can be misunderstood and possibly result in wrong-way maneuvers.**

  As mentioned earlier, lane-use arrows should complement the geometry of roadway while strengthening the message of existing signs without causing confusion. A study by NTTA (2012) addressed issues related to how pavement markings were typically applied at exit ramps of diamond interchanges. One issue involved locations where a left-turn lane extended beyond the limits of the ramps due to heavy turning movement queue storage. Typically, left-turn arrows were used along the entirety of the left-turn lane, including the portion beyond the far-side ramps. The study showed that replacing the left-turn arrows beyond far-side ramps with through lane-use arrows can mitigate WWD issues at diamond interchanges.

- **Consider using the wrong-way arrow along exit ramps.**

  These types of pavement markings warn drivers who are traveling in the wrong direction. They may be placed on the exit ramps where lane-use arrows are not appropriate as well in the following locations:
    - Upstream from the ramp terminus; and
    - At an appropriate location near the crossroad junction.

  Wrong-way pavement markings may be supplemented as follows (Figure 2-13):
    - Bidirectional red-and-white raised pavement markers (RPM) or any other means with the red side facing wrong-way drivers where high visibility is required and there is no risk of RPM damage by snow removal operations; and
    - Supplemental WW signs along the exit ramp.

Figure 2-13. Supplemental WW signs and a WW arrow with RPMs (Image: Yang Ouyang).

Longitudinal Lines

These types of pavement markings are used to communicate appropriate directions of travel and to guide vehicles traveling through or turning across intersections.

- **Use longitudinal lines to help drivers recognize the appropriate directions for travel.**

  Longitudinal lines, especially solid yellow lines on the left edge of exit ramps, help drivers discern their correct directions of travel. It lets drivers know that under no circumstances should the solid yellow line be on their right side as they travel along an exit ramp.

- **Use lane line extensions to guide vehicles through ramp terminals with large turning radii.**

  Dotted lane line extension markings (2-foot line segments with 2- to 6-foot gaps) should be used where the intersection’s geometric condition (complex design, multi-legged intersection, presence of offset left-turn lanes, large turning radii, etc.) or insufficient visibility can lead to driver confusion and undesirable left-turning movements onto exit ramps (MUTCD Section 3B.08).

- **Use painted islands between entrance and exit ramps.**

  This countermeasure (Figure 2-14) shows drivers that there are two ramps next to each other and guides them to pass the island along its left side (i.e., the right side of the ramp from driver's point of view). To give drivers even more guidance, a Keep Right sign can be used with a painted island (Morena and Ault 2013).

Figure 2-14. Painted island between exit and entrance ramps (Morena and Ault 2013).

Stop Lines

- **Consider placing stop lines at the end of exit ramps.**

  Stop lines should be 12 to 24 inches wide. Stop lines should consist of solid white lines extending across approach lanes to indicate the point at which the stop is intended or required to be made (MUTCD Section 3B.16). An additional benefit of this countermeasure is that vehicles stopped behind the stop line serve as visual cues for vehicles turning from the crossroad, especially when two-way ramps are used.

Enhanced Delineation

Evaluate potential delineation options, including the use of red retroreflective raised pavement markers (RPMs), along the roadway, roadside barriers, raised channelization features, or in flush median areas.

- **Use red retroreflective RPMs to enhance the visibility of pavement markings (lines, arrows, etc.) on exit ramps.**

  RPMs may be used to enhance delineation where damage that could be caused by snow removal operations is not a major concern. RPMs are especially effective under dark, wet conditions when pavement markings are difficult for drivers to see.

- **Use barrier delineators to warn wrong-way drivers.**

  Delineations can be mounted along exit ramp barriers (if any) so that if a driver is traveling in the appropriate direction, yellow delineation is visible to the left of the vehicle (Figure 2-15) and red delineation is visible to the right (Figure 2-16). Barrier delineation combined with WW signs catches driver attention effectively, especially at night (Morena and Ault 2013).

Figure 2-15. Barrier delineators visible while traveling in the correct direction (Morena and Ault 2013).

Figure 2-16. Barrier delineators visible while traveling
in the wrong direction (Morena and Ault 2013).

SECTION 2.3: TRAFFIC SIGNALS

Most exit ramp terminals currently use circular green signals supplemented with No Right/Left Turn signs. Some locations use green arrow signals. Field observations show that green arrow signals send a more obvious message to drivers and can replace a circular green signal with a No Right/Left Turn sign. As shown in Figure 2-17, the combination of a circular green indication and a turn prohibition sign (No Right Turn shown in the figure) mounted on the mast arm traffic signal for an exclusive through-lane has the same meaning as a green arrow indication (through only). An example of a green arrow configuration for a traffic signal head on a typical interchange exit ramp terminal is shown in Figure 2-18. Green arrows are assigned to exclusive through-travel to discourage potential wrong-way right/left-turning movements.

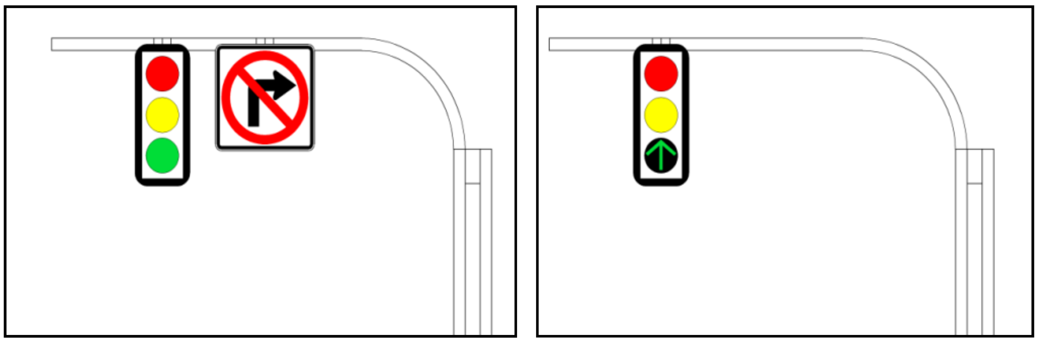


Figure 2-17. Analogous traffic signals for exclusive through-lanes.

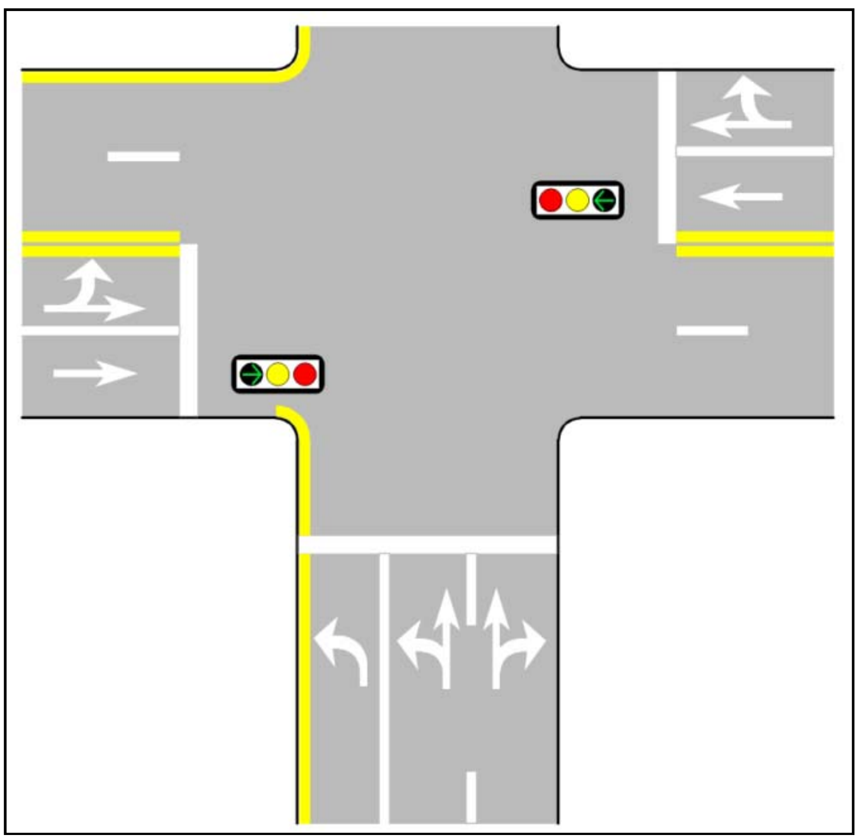


Figure 2-18. Proposed traffic signal configuration for a typical exit ramp terminal.

SECTION 2.4: SIGNING AND PAVEMENT MARKINGS AT EXIT RAMP TERMINALS FOR DIFFERENT INTERCHANGE TYPES

The following subsections provide guidelines for signage and pavement marking design for the five types of interchanges identified in previous studies as the most susceptible to WWD crashes. Designers should consider the following before implementing these countermeasures at interchanges:

- Signs must be field verified and adjusted by engineers as necessary to provide clear visibility of signs.
- Red retroreflective strips can be used on supports for DNE and WW signs.
- Lane-use arrows should be placed as appropriate for intersection lane configuration.
- Additional pairs of WW signs may be installed near the beginning of the ramp.
- The word ONLY can be used to emphasize that the lane use is exclusive.

Partial Cloverleaf Interchange

Parclo interchanges may or may not have channelizing islands separating left-turn and right-turn movements at exit ramps. These two scenarios are depicted in Figure 2-19 (with an island) and Figure 2-20 (without an island). For parclo interchanges with islands, additional DNE and ONE WAY signs can be placed on the island.

Design Guidelines
• Install Keep Right sign if median width is greater than 8 feet. • Install DNE sign if median width is greater than 12 feet.

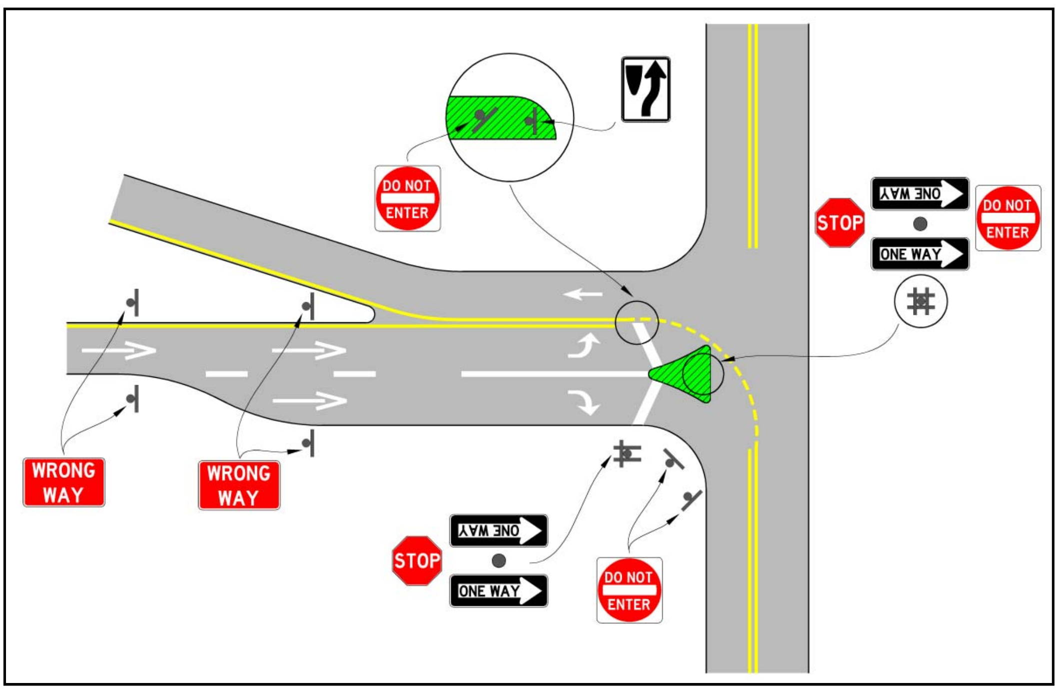


Figure 2-19. Example of signing and pavement markings at an exit ramp of parclo interchange (with island).

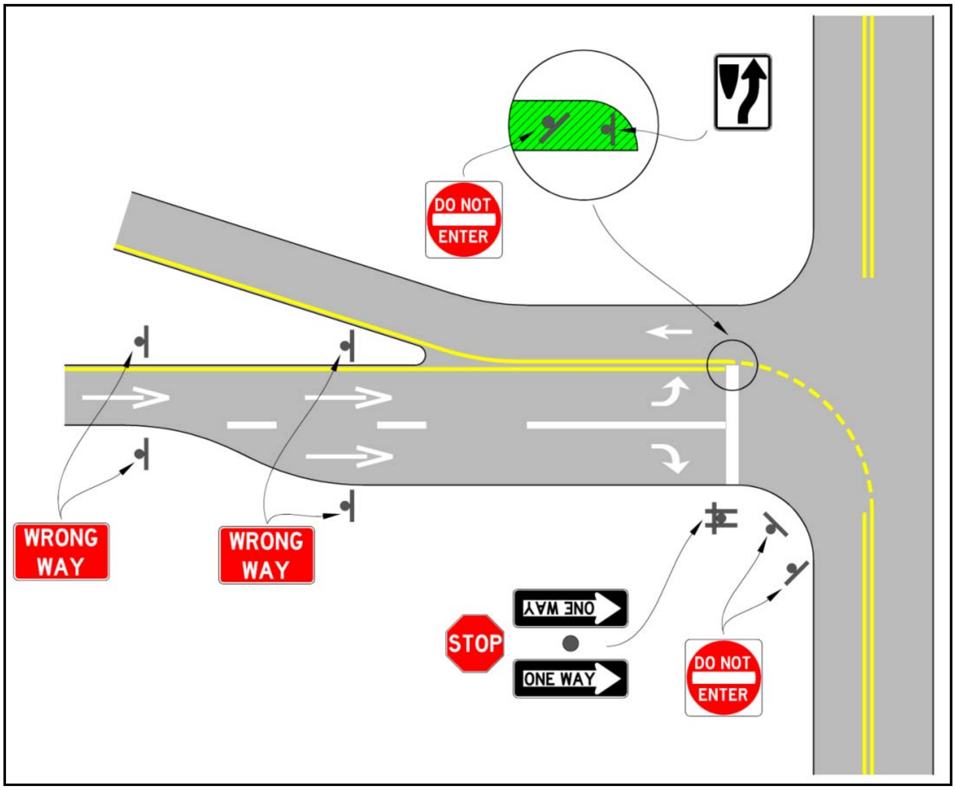


Figure 2-20. Example of signing and pavement markings at an exit ramp of parclo interchange (without island).

At parclo exit ramps, or generally at any other paired controlled-access highway ramps, a painted island combined with a left-turn marking extension is recommended (Figure 2-21).

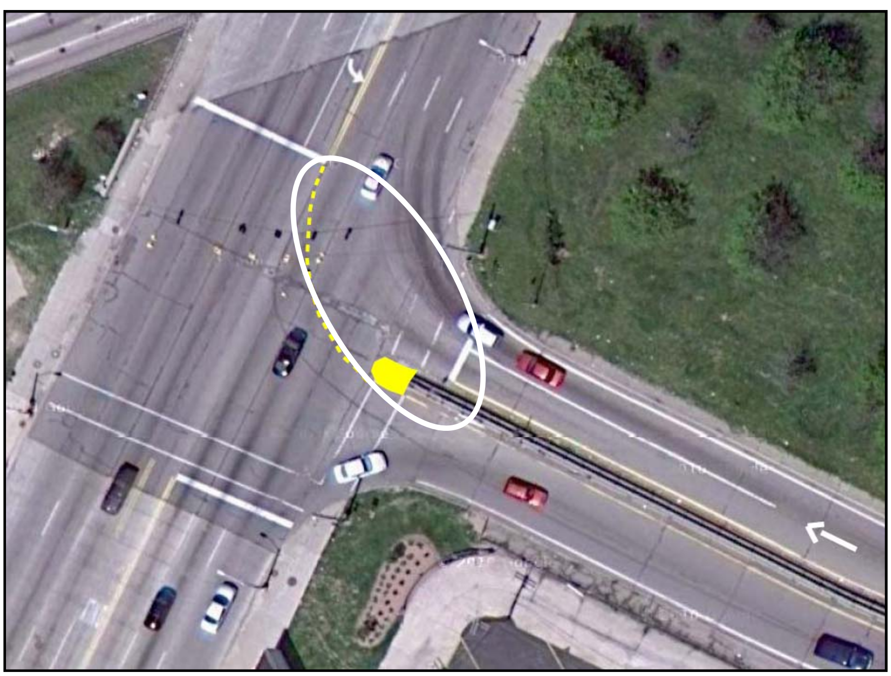


Figure 2-21. A painted island combined with lane line extension (NTSB 2012).

Diamond Interchange with Continuous Frontage Roads

The proposed signage and pavement markings for diamond interchanges connected to frontage roads are depicted in Figure 2-22. It should be noted that the signage and pavement markings at the intersection of frontage roads and crossroad are usually managed by the local city or county.

Design Guidelines
• If there is an existing cross street or driveway near the exit gore area, a ONE WAY sign as shown should be installed. • A pair of ONE WAY signs at the beginning of the entrance ramp is recommended if the intersection is unsignalized.

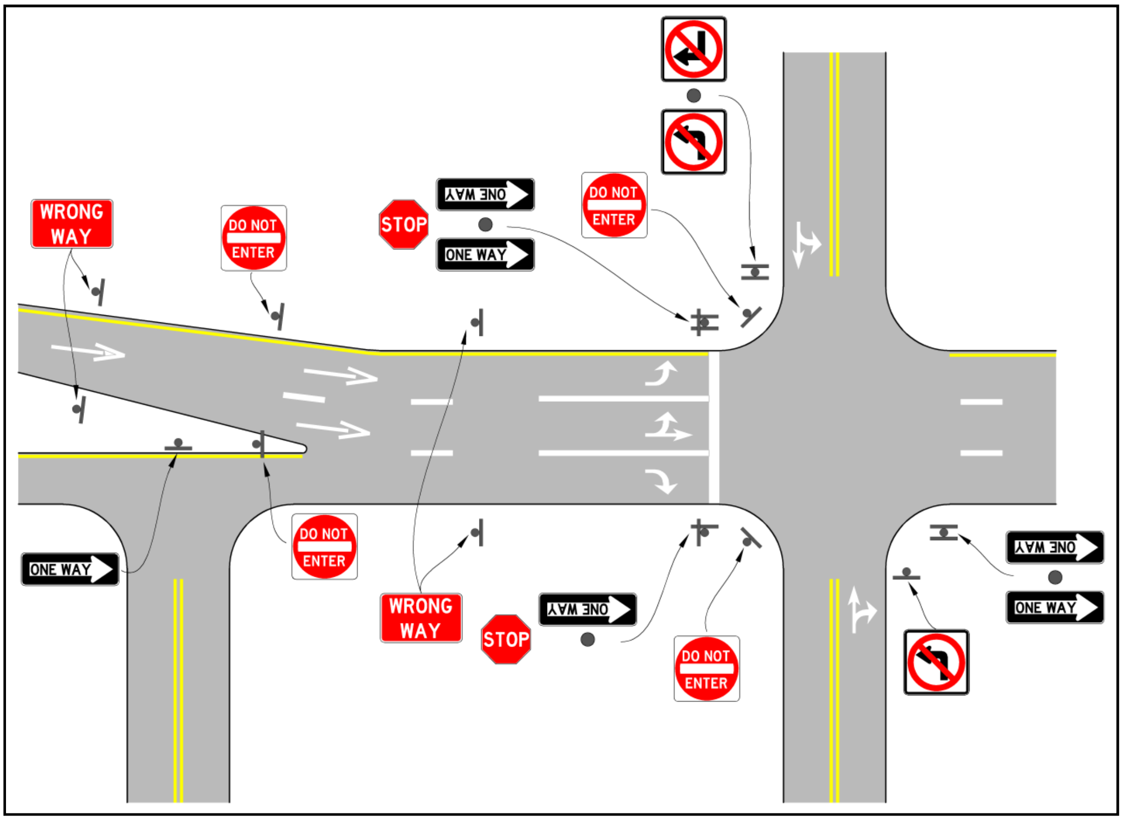


Figure 2-22. Example of signage and pavement markings at an exit ramp of a diamond interchange with a continuous frontage road in an urban area.

Diamond Interchange

Two types of diamond interchanges are addressed in this section: a diamond interchange with ramps meeting at the same intersection (Figure 2-23) and a half-diamond interchange that has only two diagonal ramps (one entrance and one exit). Logically, these ramps are located in adjacent quarters and not opposite each other (Figure 2-24). For the diamond interchanges (whether full or half), a No Left Turn sign near the entrance ramp can also be placed in the median, if present. For the half-diamond interchange, trailblazing signs should be provided to direct drivers to the closest entrance for ramp movements not provided at this interchange. The second set of WW signs is optional and can be placed at high crash locations.

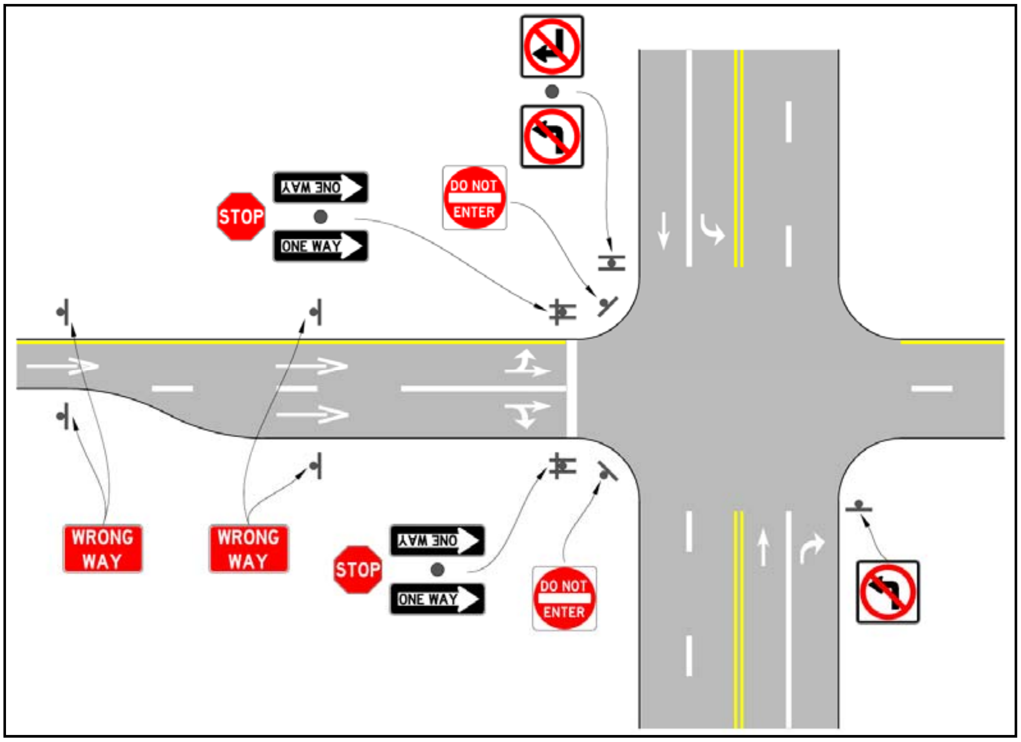


Figure 2-23. Example of signage and pavement markings at an exit ramp of a diamond interchange.

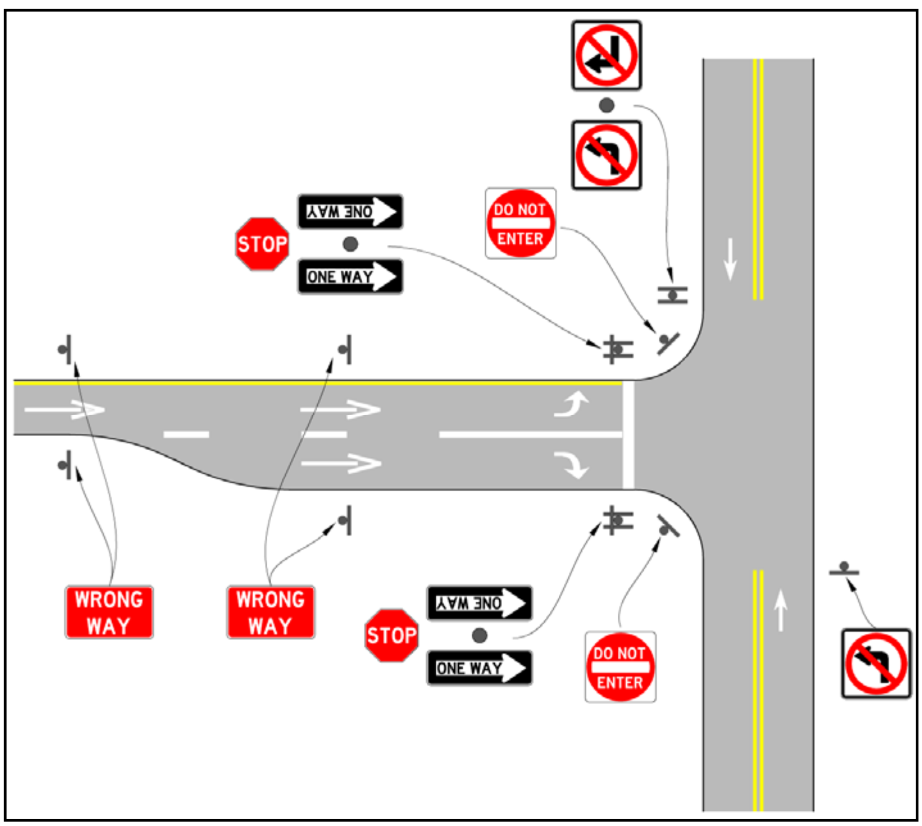


Figure 2-24. Example of signage and pavement markings at an exit ramp of a half-diamond interchange.

Single Point Diamond Interchange (SPDI)

Figure 2-25 shows signage and pavement markings that can be used to mitigate WWD issues at one quadrant of an SPDI. It should be noted that the DNE sign is to be mounted lower than the Yield sign at the end of the right-turning exit ramp.

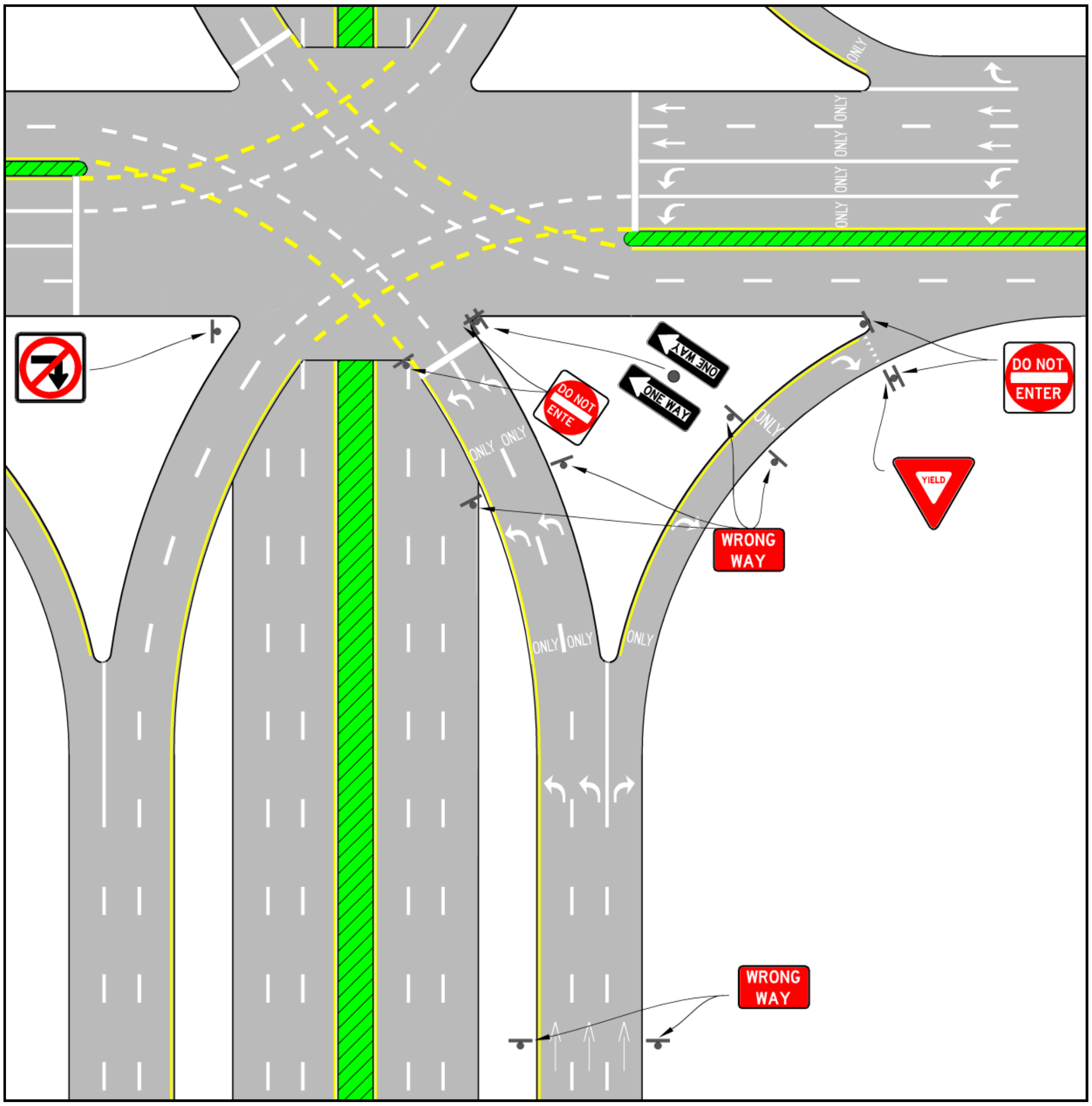


Figure 2-25. Example of signage and pavement markings at an exit ramp of an SPDI.

Freeway Feeder

A freeway feeder, which usually has a multi-lane cross section, is where exit ramps transition into local roads. The recommended signage layout for freeway feeders depends on the width of cross sections. Oversized DNE signs are recommended at the end of the ramps. An additional pair of WW signs should be considered for each additional lane of ramps. For instance, for approaches with three lanes, three pairs of WW signs could be placed along the roadway at an appropriate distance from each other (for example, 350 feet for L1 and L2 shown in Figure 2-26). The best results are achieved when these three pairs are mounted at different heights. For example, the first pair can be mounted 3 feet from bottom of the sign to the near edge of the pavement. The second and third pairs can be mounted at 5 feet and 7 feet, respectively (Figure 2-26). This combination will make all the WW signs visible at the same time from a longer distance.

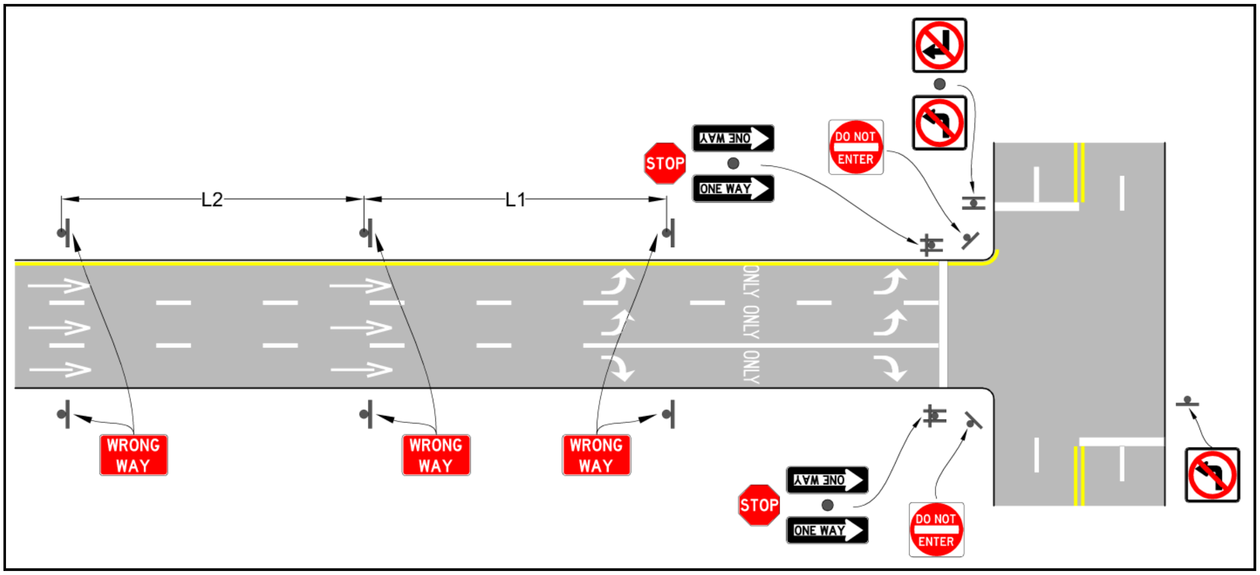


Figure 2-26. Example of signage and pavement markings at a three-lane freeway feeder.

For freeway feeders with more than three lanes, additional WW signs can be placed on the other side of existing overhead lane-use signs. Figure 2-27 shows the overhead sign support that can be used for this purpose.

Figure 2-27. Overhead lane-use signs at exit ramps (Image: Huaguo Zhou).

CHAPTER 3

GEOMETRIC DESIGN ELEMENTS

SECTION 3.1: GEOMETRIC DESIGN ELEMENTS

Past studies (Copelan 1989; Moler 2002; Braam 2006; Leduc 2008; Zhou et al. 2012; Zhou et al. 2014) have indicated that certain interchange configurations and geometric design elements may be more susceptible to WWD and that minor geometric changes to ramps can reduce wrong-way maneuvers onto freeways. In this section, geometric elements that are capable of discouraging wrong-way maneuvers are identified. Those elements should be given special consideration during the design stage of interchanges and ramp intersections. To illustrate the right and possible wrong movements in the top five interchange types with relatively high WWD crashes, the wrong-way movements (red arrows) as well as right-way movements (green arrows) are presented in the figures below. As a reminder, these interchanges include diamond interchanges with continuous frontage roads (Figure 3-1), diamond interchanges without continuous frontage roads (Figure 3-2), parclo interchanges (Figure 3-3), SPDI (Figure 3-4), and freeway feeders (Figure 3-5).

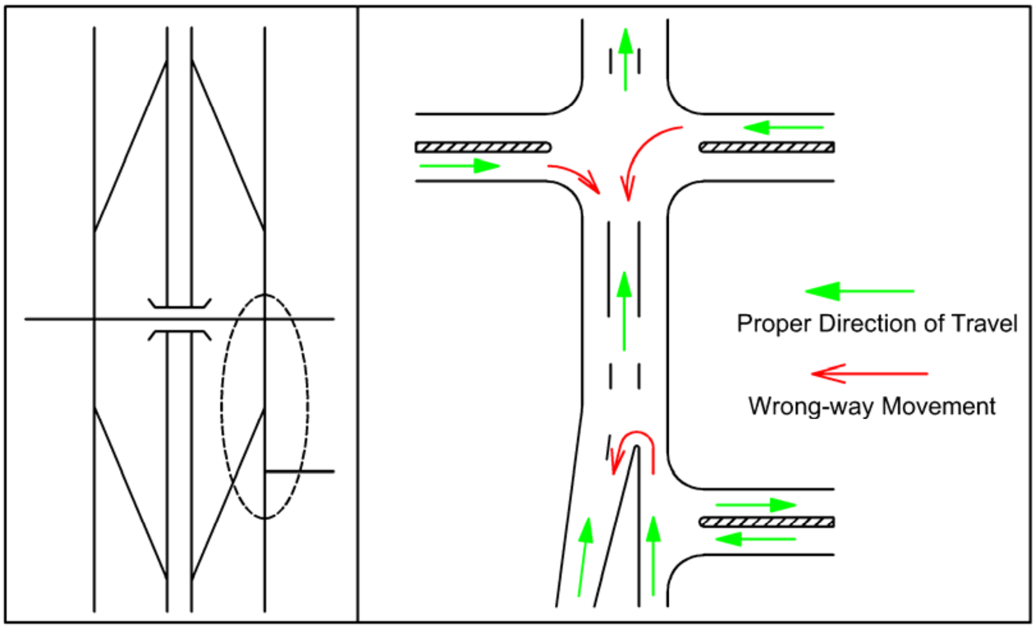


Figure 3-1. Possible WWD movements in diamond interchanges with continuous frontage road.

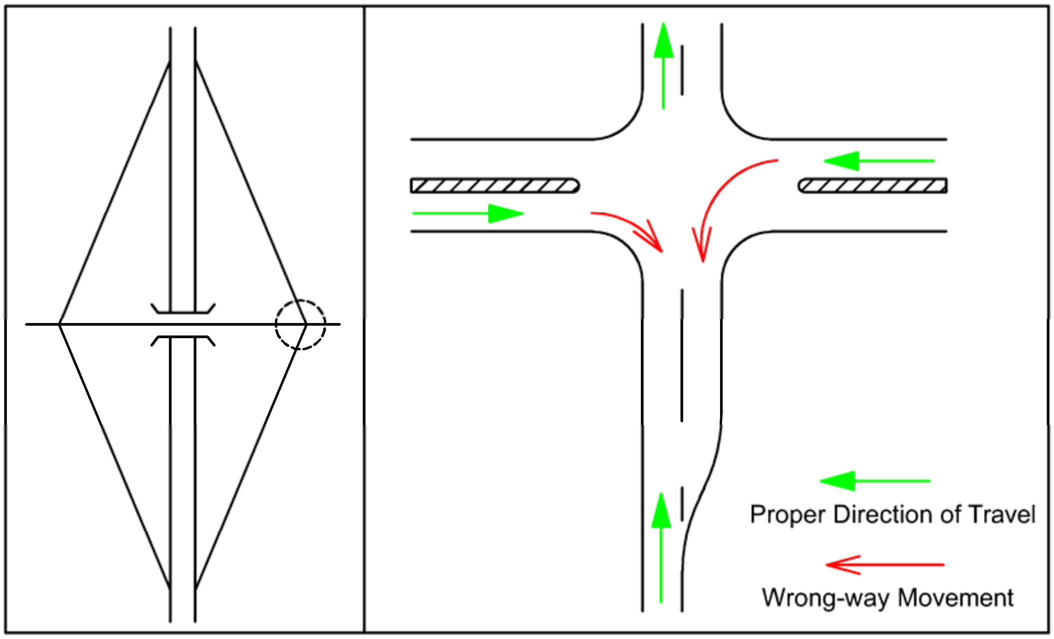


Figure 3-2. Possible WWD movements in diamond interchanges without continuous frontage road.

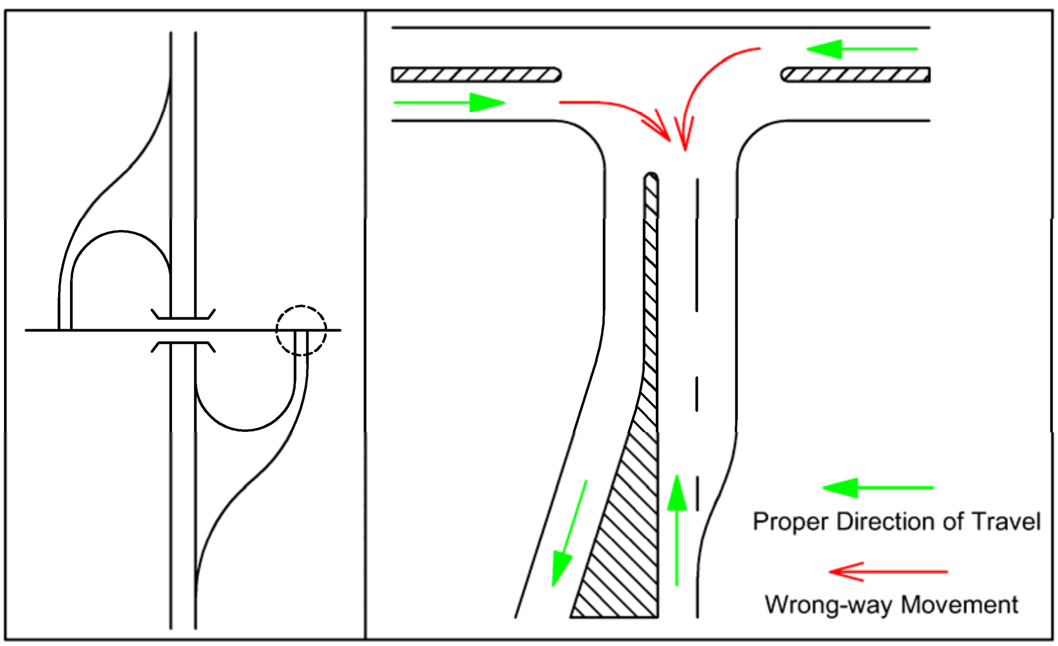


Figure 3-3. Possible WWD movements in partial cloverleaf interchanges.

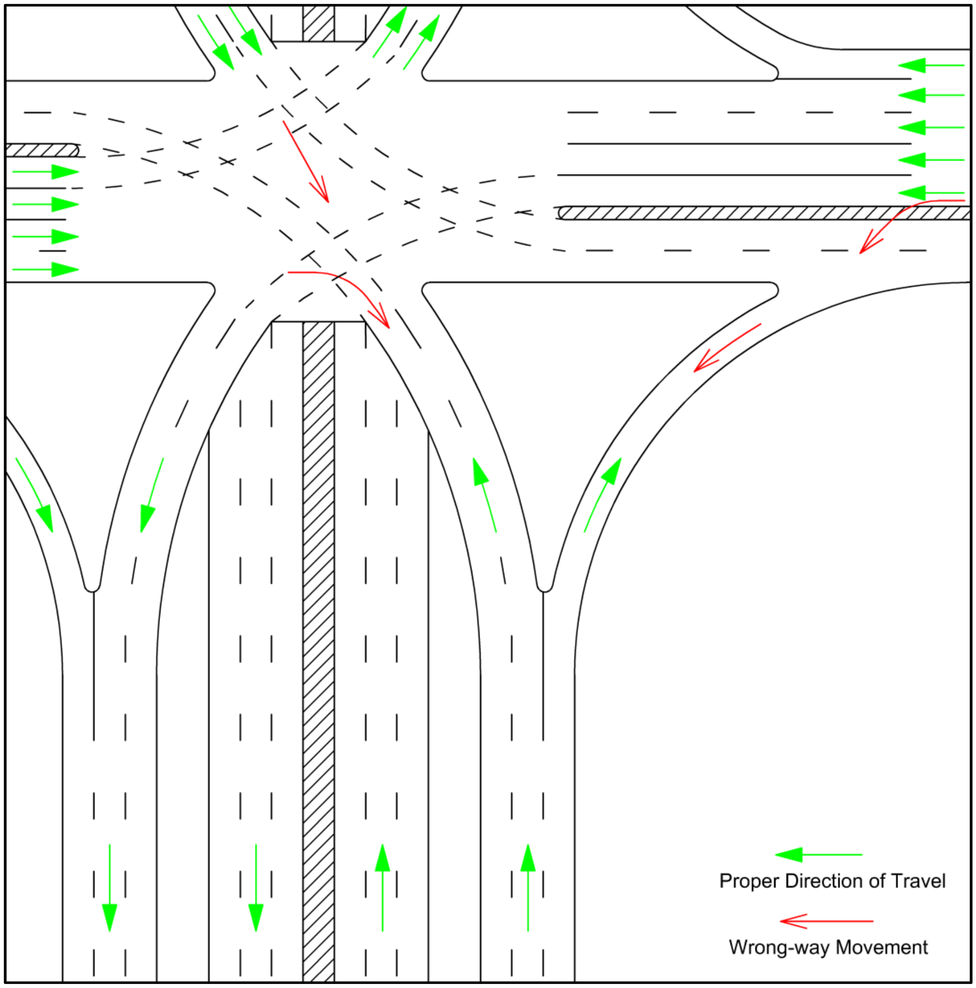


Figure 3-4. Possible WWD movements in SPDI.

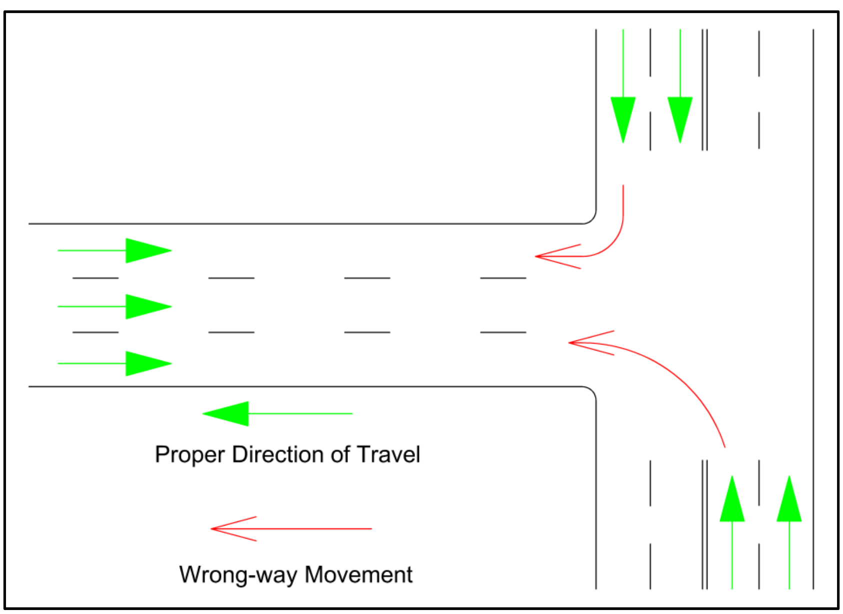


Figure 3-5. Possible WWD movements in freeway feeder.

Design Guidelines	
Geometric Element	**Guidelines**
Exit/Entrance Ramps	• *Less* susceptible to WWD o Use acute angles to connect exit ramps to one-way streets and right angles to two-way roadways to better convey direction of travel (AASHTO 2011; WSDOT 2013). o Use sweeping connections to cross streets (such as outer connection, loop, and some diamond ramps) (AASHTO 2011). o Reduce the width of exit ramp throats where entrance and exit ramps are closely spaced, and increase the width of entrance ramp throats by removing islands or using large radii (WSDOT 2013). • *More* susceptible to WWD o Adjacent entrance and exit ramps intersecting a crossroad (e.g., parclo interchanges) (Cooner et al. 2004) o Isolated exit ramps (Caltrans 2012) o Left-side exit ramps (Cooner et al. 2004) o One-way exit ramps connected as unchannelized T-intersections (AASHTO 2011) o Exit ramps intersecting with two-way frontage roads (IDOT 2010) o Less common arrangements of exit ramps (e.g., button-hook or J-shaped ramp connected to a parallel or diagonal street or frontage road) (AASHTO 2011) o Temporary ramp terminals at work zones o Freeway feeders (IDOT 2010) o Side streets adjacent to exit ramps (AASHTO 2011)
Frontage Road	• *More* susceptible to WWD o Two-way frontage roads result in more WWD than one-way frontage roads (AASHTO 2011). o Multi-lane frontage roads with numerous driveways or side streets are conducive to WWD (AASHTO 2011). o Acute angles between exit ramps and two-way frontage roads are more susceptible to WWD (AASHTO 2011).
Raised Median	• *Less* susceptible to WWD o Use non-traversable medians to discourage left-turn wrong-way entry onto exit ramps (AASHTO 2011). o Use longitudinal channelizers to prohibit left-turn wrong-way entry when no raised medians are present (Morena and Ault 2013). o Use narrow median openings on arterial highways to prevent left-turn wrong-way movements (AASHTO 2011). o Install raised medians or median barriers between ramps of trumpet interchanges (Moler 2002). • *More* susceptible to WWD o Do not use raised medians to separate vehicles traveling in the same direction on exit ramps (AASHTO 2011).
Channelizing Island	• *Less* susceptible to WWD o Use raised channelizing islands to reduce WWD, especially for older drivers (AASHTO 2011). o Use channelizing islands to reduce the width of exit ramps (WSDOT 2013). o Use a height of at least 4 inches where the island is intended to prohibit or prevent traffic movements such as WWD (IDOT 2010). • *More* susceptible to WWD o Do not use scissors channelization because it can confuse motorists and result in WWD (AASHTO 2011).

Design Guidelines	
Geometric Element	**Guidelines**
Control/Corner Radius	• *Less* susceptible to WWD o Use a short-radius curve or angular break at the intersection of the left edge of exit ramps and the right edge of crossroads to discourage wrong-way right turns from crossroads (AASHTO 2011). o Ensure that the control radius is tangent to the crossroad centerline, not tangent to the edge (AASHTO 2011).
Sight Distance	• *Less* susceptible to WWD o Provide an open sight distance throughout the entire length of ramps, especially at the ramp terminal on crossroads where wrong-way entries start (AASHTO 2011). o Provide uniform lighting levels for both entrance ramps and exit ramps (Zhou et al. 2012). o At the intersection of two-way ramps and crossroads (parclo interchanges), move stop lines for left turns from crossroads forward so motorists have a better view of the entrance ramp and a better turning radius (WSDOT 2013). • *More* susceptible to WWD o Do not extend median barriers to block left-turn drivers' view of the entrance ramp where the entrance ramp and exit ramp are adjacent (WSDOT 2013). o Avoid excessive grade differentials between ramps (exit ramp or two-way ramp) and crossroads (Caltrans 2012; WSDOT 2013).

DISCUSSION

Exit/Entrance Ramps

When it comes to WWD, exit ramps are highly critical points because they can be the entry location from which a wrong-way maneuver originates. Their geometric characteristics (arrangement, angle with crossroad, cross section, etc.) are of high importance. For instance, adjacent exit and entrance ramps (parallel, side by side) may be more prone to wrong-way maneuvers when there is a nearby side street. Therefore, care should be taken to consider how each geometric characteristic can make a location more susceptible or less susceptible to WWD.

- **Use acute angles to connect exit ramps to one-way streets and right angles to two-way roadways to better convey direction of travel.**

  The angle at which an exit ramp connects to a roadway (crossroad or frontage) depends on the functionality of the crossroads. If left turns from exit ramps are prohibited because of connecting one-way roadway or the presence of a raised median on roadway, an acute angle should be used to connect exit ramps to crossroads. On the other hand, when exit ramps cross two-way roadways where left turns are allowed, a right angle should be used to connect exit ramps to crossroads.

- **Use sweeping connections to cross streets (such as outer connection, loop, and some diamond ramps).**

  Sweeping connections of exit ramps to streets, which are seen in exit ramps such as outer connection, loop, and some diamond ramps, are less susceptible to WWD because they form acute angles with crossroads where turning movements in either direction are not allowed (Figure 3-6) (AASHTO 2011).

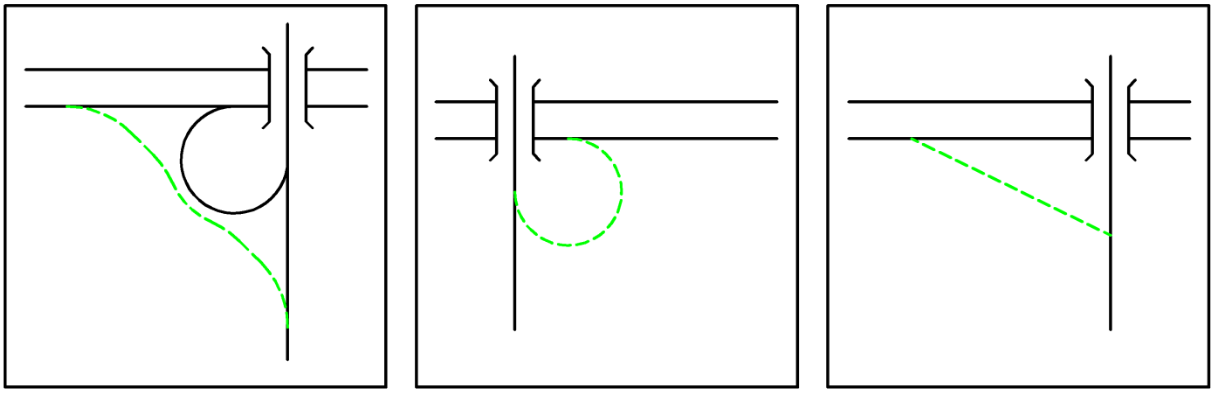


Figure 3-6. From left to right: Outer connection, loop, and diamond exit ramp are indicated by green dashed lines.

- **Reduce the width of exit ramp throats where entrance and exit ramps are closely spaced, and increase the width of entrance ramp throats by removing islands or using large radii.**

  Right-way movements are encouraged by providing a wider entrance ramp throat using either flat radii or removing raised islands that separate adjacent entrance and exit ramps at parclo interchanges. Likewise, reducing the width of exit ramp terminals by the application of raised channelizing island can help decrease WWD.

- **Reduce the use of the following geometric features that are more susceptible to WWD.**
  - Adjacent entrance and exit ramps intersecting a crossroad (e.g., parclo interchanges)
  - Isolated exit ramps
  - Left-side exit ramps: Drivers usually expect to make right turns to enter freeways (Figure 3-7)
  - 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) (Figure 3-8).
  - Temporary ramp terminals at work zones
  - Freeway feeders (where exit ramps transition into local roads)
  - Side streets adjacent to exit ramps (Figure 3-9)

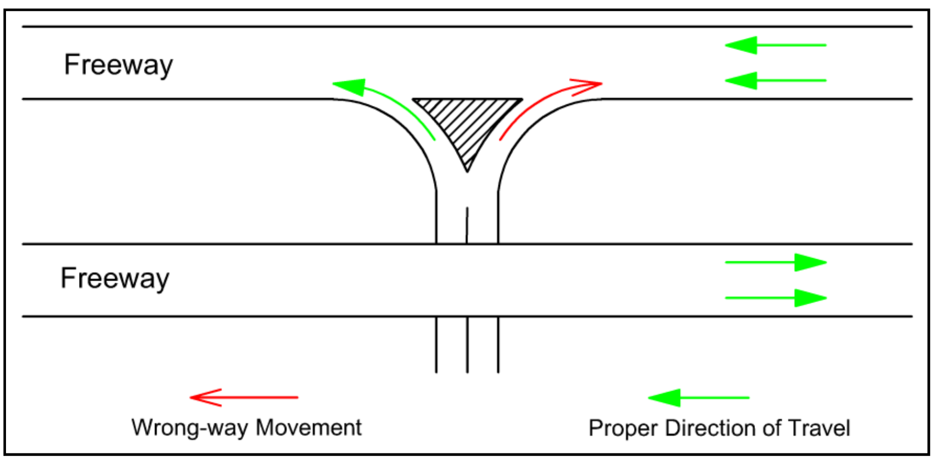


Figure 3-7. Left-side exit ramps.

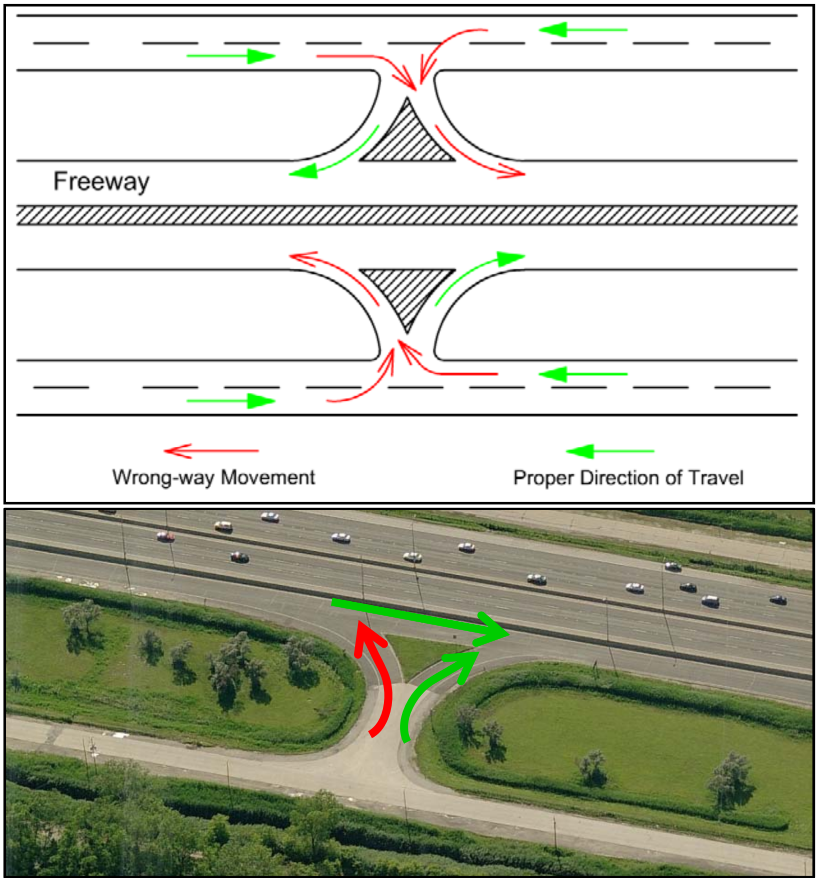


Figure 3-8. Button-hook ramp connected to parallel frontage road (Bottom image: Bing).

Figure 3-9. A side street located next to an exit ramp (Image: Google Earth).

Frontage Road

The connections between frontage roads and freeways should be given special consideration at design stages. The number of lanes, traffic flow on frontage roads, and types of connections with ramps can increase or decrease the likelihood of WWD.

- **Two-way frontage roads result in more WWD than one-way frontage roads.**

  The joint points of exit ramps and two-way frontage roads are more vulnerable to WWD than one-way frontage roads. Turning movements at intersections of exit ramps and two-way frontage roads are much more complicated than on one-way frontage roads.

- **Multi-lane frontage roads with numerous driveways or side streets are conducive to WWD.**

  Despite providing more favorable access from controlled-access highway to local streets, continuous multi-lane frontage roads with numerous intersections may be undesirable and lead to a high potential for WWD crashes.

- **Acute angles between exit ramps and two-way frontage roads are more susceptible to WWD.**

  The acute angle between exit ramps and two-way frontage roads may make exit ramps resemble the extension of a frontage road, thus causing driver confusion.

Raised Median

According to the AASHTO 2011 Green Book, a median is an elongated divisional island built as a portion of highway, which serves primarily to separate opposing directions of traffic on the same roadway. The following points should be considered when using medians to discourage WWD.

- **Use non-traversable medians to discourage left-turn wrong-way entry onto exit ramps.**

  A non-traversable median on crossroads is an effective treatment to deter wrong-way left-turn entry onto diamond (Figure 3-10), parclo, and full cloverleaf interchanges (AASHTO 2011). This geometric element makes left-turn movements onto exit ramps very difficult.

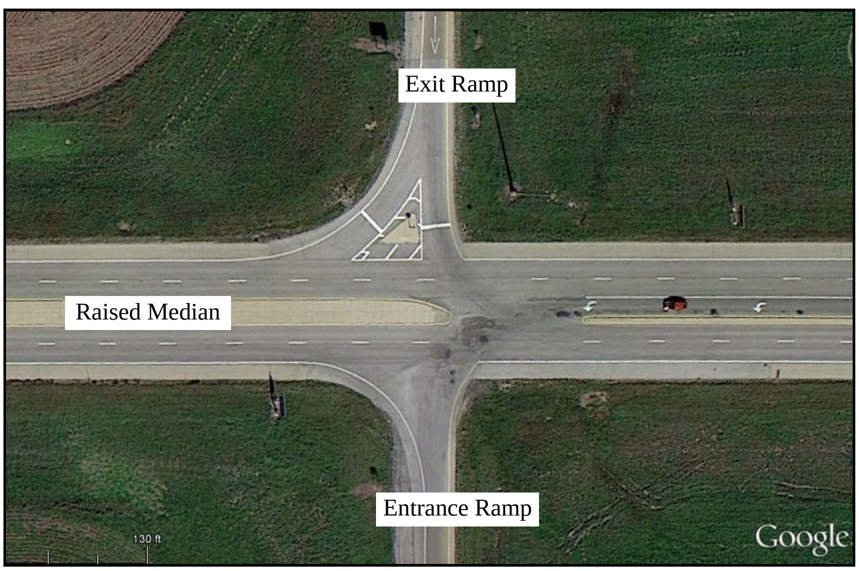


Figure 3-10. A non-traversable raised median at the ramp-crossroad intersection of a diamond interchange (Image: Google Earth).

- **Use longitudinal channelizers to prohibit left-turn wrong-way entry when no raised medians are present.**

  Longitudinal channelization devices can be used as low-cost countermeasures by transportation agencies to fulfill various permanent and temporary channelization needs. Figure 3-11 depicts a plan view of a location before treatment with longitudinal channelizer as a wrong-way entry countermeasure. Preliminary results after this improvement (Figure 3-12) demonstrated that there were no WWD incidents recorded at this site after implementation of longitudinal channelization devices (Morena and Ault 2013).

Figure 3-11. Plan view of a treated intersection before treatment with proper (white) and wrong (red) movements (Image: Bing).

Figure 3-12. Application of longitudinal channelization in restriction of left-turn access (Morena and Ault 2013).

- **Use narrow median openings on arterial highways to prevent left-turn wrong-way movements.**

  Extending raised medians on crossroads and thereby narrowing median openings has recently been implemented by an agency to prevent future recurrence of wrong-way left-turns onto an exit ramp (Figure 3-13). Since the completion of this project, no wrong-way incidents have been recorded at this location (Ouyang 2013).

Figure 3-13. Before (left) and after (right) application of raised median to prevent wrong-way maneuvers (Ouyang 2013; Zhou et al. 2012).

- **Install raised medians or median barriers between ramps of trumpet interchanges.**

  WWD can be avoided in trumpet interchanges by installing raised medians or median barriers between entrance and exit ramps (Moler 2002). Figure 3-14 shows a typical trumpet interchange layout and the potential WWD movement as well as the critical point where wrong-way maneuver may originate.

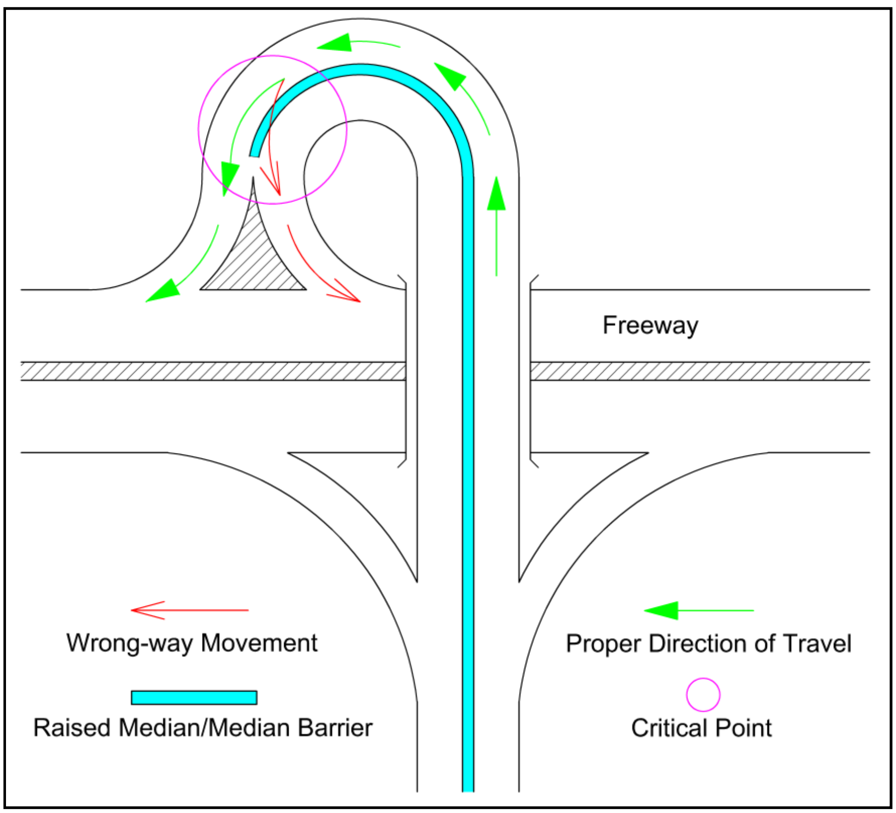


Figure 3-14. Application of raised median/median barrier for trumpet interchanges.

- **Do not use raised medians to separate vehicles traveling in the same direction on exit ramps.**

  Elongated raised medians should not be used to divide the same direction of traffic (AASHTO 2011). It may introduce potential WWD incidents because drivers usually expect a raised median to separate two different directions of travel. Figure 3-15 shows a raised median installed to separate dual left-turns from through movements on an exit ramp. The crash data and field study indicated that this type of design can be confusing to drivers and has already caused a high number of WWD incidents (Zhou et al. 2012).

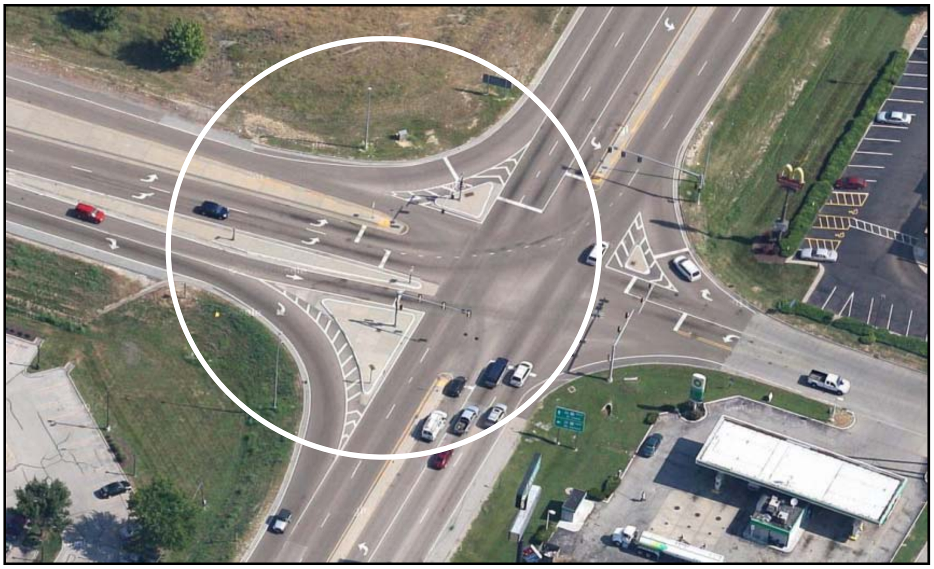


Figure 3-15. Raised median for separating same direction of traffic on an exit ramp (Image: Google Maps).

Channelizing Island

This geometric element can serve various functions other than defining desirable paths and separating conflict points (FHWA 2013). In other words, a channelizing island can also be used to block the prohibited turns at intersections wherever necessary and practical. The applications of using channelizing islands as effective WWD countermeasures are described as follows.

- **Use raised channelizing islands to reduce WWD, especially for older drivers.**

  Adequately reflectorized raised channelizing islands can impede wrong-way movements effectively. These elements exclusively target older drivers' poor contrast visibility by providing greater contrast and, therefore, making geometric characteristics of the downstream intersection more visible. Indeed, inadequately reflectorized raised channelizing islands can adversely affect older drivers' vision and when struck, these islands might be a source of serious injuries and even fatalities (WSDOT 2013).

- **Use channelizing islands to reduce the width of exit ramps.**

  The narrower the width of exit ramps, the lower the probability a WWD movement occurring. Wider ramp throats tend to encourage vehicle entry; therefore, by reducing the width of the exit ramp throats with channelizing islands, WWD is discouraged.

- **Use a height of at least 4 inches where the island is intended to prohibit or prevent traffic movements such as WWD.**

  Lower height islands may fall short of satisfying the intended needs and can be traversed easily (IDOT 2010).

- **Do not use scissors channelization because it can confuse motorists and result in WWD.**

  This type of channelization occurs when there is a two-way frontage road adjacent to freeway and exit and entrance ramps are connected to frontage roads. Figure 3-16 shows scissors channelization with right- and wrong-way movements. Figure 3-17 illustrates a real-world example of scissors channelization. This type of design can confuse drivers and result in WWD maneuvers (AASHTO 2011). It currently is seldom used by designers.

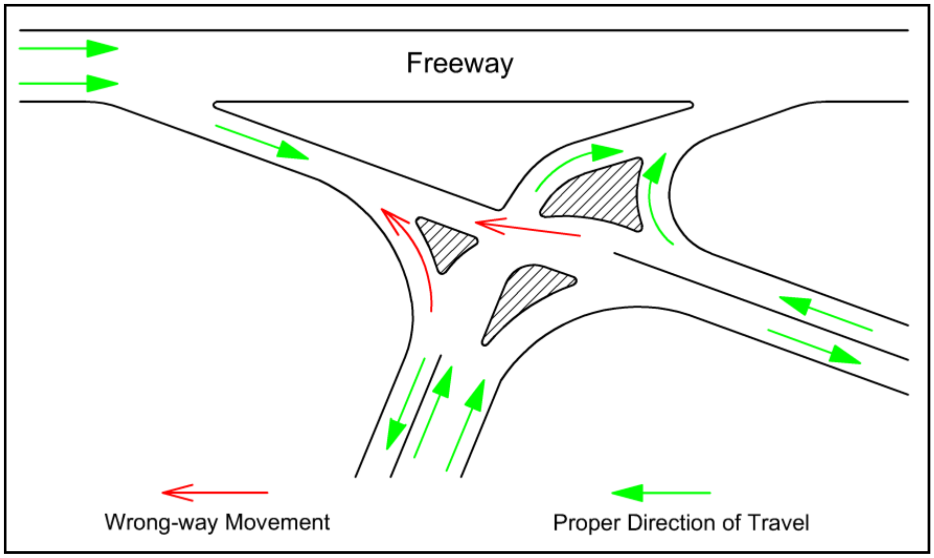


Figure 3-16. Scheme of scissors channelization with possible movements.

Figure 3-17. Scissors channelization (Image: Google Earth).

Control/Corner Radius

The control radius at intersections refers to the minimum left-turn path for a particular vehicle that affects the radius of the intersection corner, as well as the location and opening length of the median (Harwood and Glauz 2000). The control radius can be used to restrict WWD at exit ramp terminals.

- **Use a short-radius curve or angular break at the intersection of the left edge of exit ramps and the right edge of crossroads to discourage wrong-way right turns from crossroads.**

  While circular curves with larger radii may encourage a wrong-way right turn onto the exit ramp, the angular corner (Figure 3-18) or tight radii make this movement difficult (WSDOT 2013).

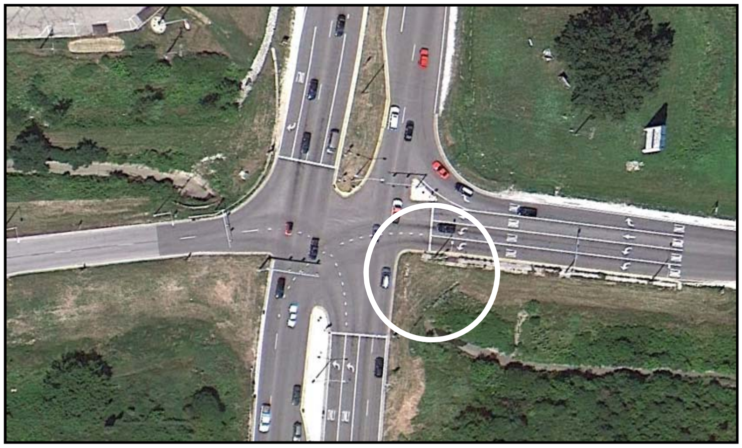


Figure 3-18. Angular corner between the left edge of exit ramp and right edge of crossroad (Image: Google Earth).

- **Ensure that the control radius is tangent to the crossroad centerline, not tangent to the edge.**

  Having the control radius tangent to the centerline (and not the edge) makes wrong-way right-turning movements less likely (AASHTO 2011). This design consideration can define the raised median opening and position to extend far enough to make the wrong-way left turn an awkward move. The red curved line in Figure 3-19 is tangent to the centerline of roadway.

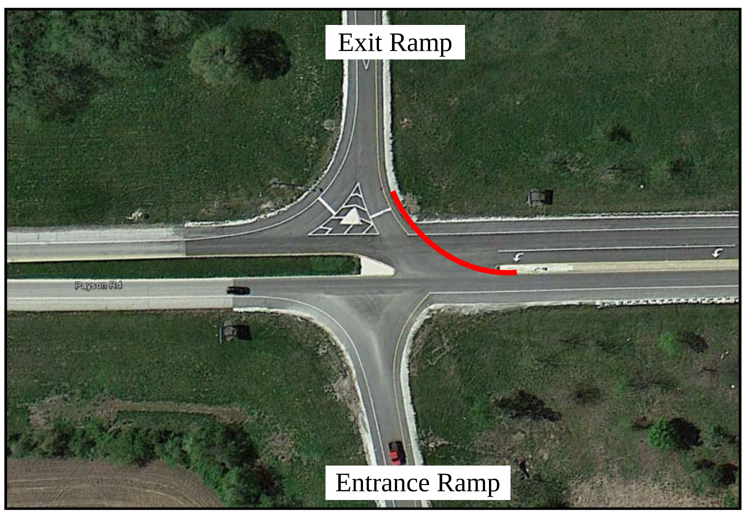


Figure 3-19. Control radius tangent to the centerline at a ramp-crossroad intersection (Image: Google Earth).

Sight Distance

Providing drivers with open sight distance of entrance ramps can help reduce WWD. An adequate sight distance not only provides drivers on crossroads with a better view of ramp terminals, but it also helps them distinguish between entrance and exit ramps (when closely spaced) by the approaching right-way drivers' headlamps.

- **Provide an open sight distance throughout the entire length of ramps, especially at the ramp terminal on crossroads where wrong-way entries start.**

- **Provide uniform lighting levels for both entrance ramps and exit ramps.**

  Non-uniform lighting can affect the drivers' perception of intersection configurations and lead to confusion and possibly WWD (Zhou et al. 2012).

- **At the intersection of two-way ramps and crossroads (parclo interchanges), move stop lines for left turns from crossroads forward so motorists have a better view of the entrance ramp and a better turning radius.**

  A good practice is to locate the stop line between 50% and 60% of the way through the intersection (Figure 3-20) to provide an appropriate intersection balance.

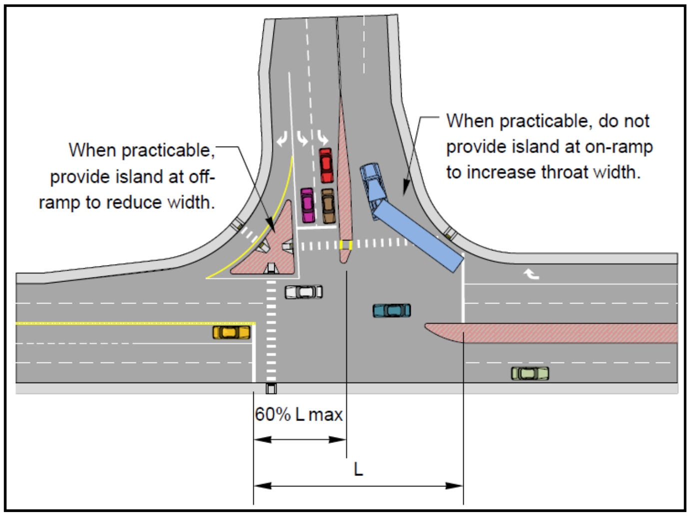


Figure 3-20. Intersection balance for two-way ramps
to address wrong-way issues (WSDOT 2013).

- **Do not extend median barriers to block left-turn drivers' view of the entrance ramp where the entrance ramp and exit ramp are adjacent.**

  Designers should not extend median barriers on two-way ramps all the way to stop line because it blocks the drivers' view of entrance ramp. A recent study (Morena and Leix 2012) showed that a guardrail installed between two adjacent exit and entrance ramps, as a median barrier, will block left-turn drivers' view of the entrance ramp terminal and increase the possibility of making a wrong turn onto the exit ramps (Figure 3-21). That study also found a high number of WWD crashes recorded at this location. Figure 3-22 illustrates an example of the proper length for a concrete barrier.

Figure 3-21. Median barrier (guardrail) blocking view of throat of entrance ramp (Morena and Leix 2012).

Figure 3-22. Short concrete barrier for a better view of throat of entrance ramp (Image: Google Maps).

- **Avoid excessive grade differentials between ramps (exit ramp or two-way ramp) and crossroads.**
  A large difference between grades of ramps and crossroads can lead to a sight distance problem and increase the likelihood of WWD.

SECTION 3.2: GEOMETRIC DESIGN ELEMENTS AT EXIT RAMP TERMINALS FOR DIFFERENT INTERCHANGE TYPES

PARTIAL CLOVERLEAF INTERCHANGE

Various studies have found that parclo interchanges have a high number of WWD incidents and crashes (Copelan 1989; Moler 2002; Leduc 2008; Zhou et al. 2012; Zhou et al. 2014). These interchanges use loop ramps that bring traffic around, connecting to the crossroad on the opposite side of the connection of a diagonal ramp of a diamond interchange. Loop ramps can replace a left-turn movement with a right turn. This type of interchange can have ramps in only two or in all four of the quadrants of the interchange. Design guidelines below summarize the previously discussed geometric elements that can deter WWD at parclo interchanges.

Design Guidelines

- Applicable geometric elements at exit ramp terminals:
  - Raised median
  - Channelizing island
  - Control/corner radius
- For the ramp–crossroad intersection at two-quadrant parclo interchanges:
  - The maximum left-turn control radius from the crossroad into the entrance ramp should be limited to 80 feet (IDOT 2010) (Figure 3-24).
  - The maximum left-turn control radius from the exit ramp onto the crossroad should be limited to 100 feet (IDOT 2010) (Figure 3-24).
  - A minimum median width of 50 feet should be considered between two adjacent entrance and exit ramps (IDOT 2010) (Figure 3-24).
- For four-quadrant parclo interchanges, type A, a minimum distance of 200 feet should be considered from the gore of the exit terminal to the left-turning path of the controlled ramp terminal to discourage wrong-way movements (Figure 3-25) (IDOT 2010).

Discussion

Figure 3-23 shows the different types of parclo interchanges discussed in this document. Please note that despite the existence of other types of parclos, the configurations of intersections formed at the crossroad are similar.

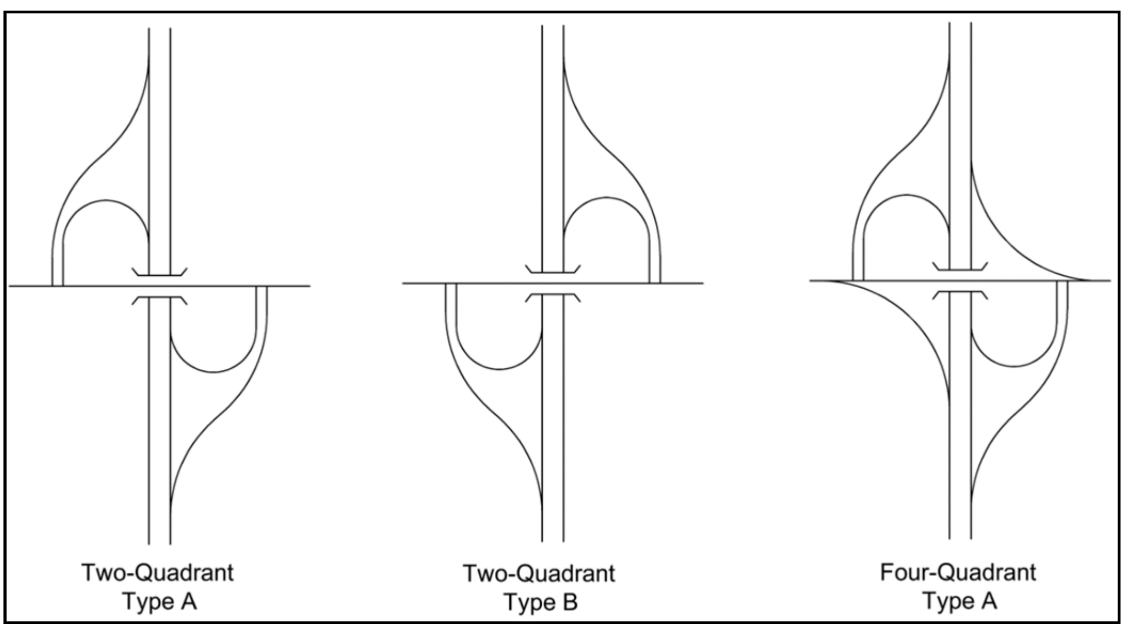


Figure 3-23. Common types of parclo interchanges.

Figure 3-24 shows a typical application of control radius, raised median, and channelizing island at a ramp–crossroad intersection for two-quadrant parclo interchange, type A.

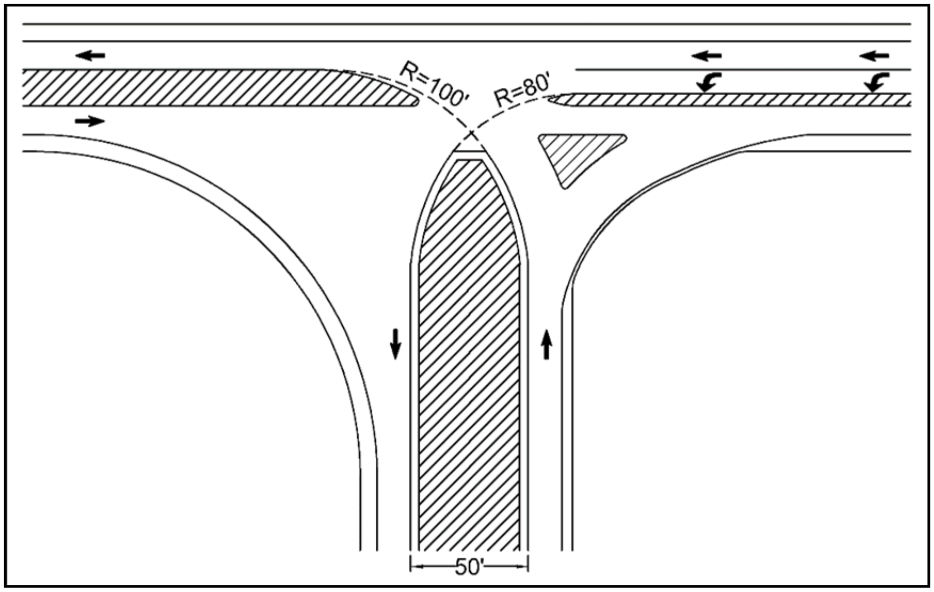


Figure 3-24. Typical ramp-crossroad design for a two-quadrant parclo, type A.

Figure 3-25 depicts a typical application of control radius, raised median, and channelizing island at a ramp–crossroad intersection proposed for four-quadrant parclo, type A, to discourage wrong-way maneuvers.

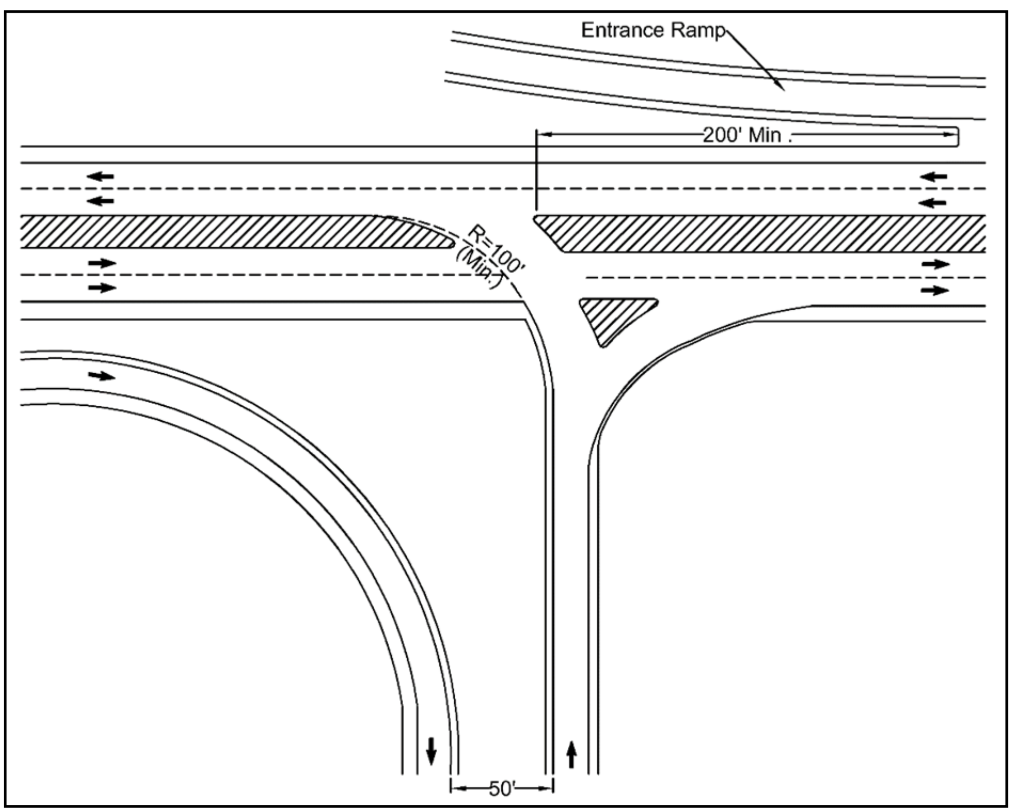


Figure 3-25. Controlled terminal for a four-quadrant parclo, type A.

DIAMOND INTERCHANGE WITH CONTINUOUS FRONTAGE ROAD

In this variation of diamond interchange, the diagonal ramp connects with a frontage road parallel to freeway mainlines. The intersecting frontage road that makes a connection between the exit ramp and crossroad creates two intersections where potential wrong-way entries originate. This type of interchange introduces a higher potential than conventional diamond interchanges for WWD. A previous study (Cooner et al. 2004) showed that two-way frontage roads are more conducive than one-way frontage roads to WWD. The following design guidelines include various geometric elements to be considered as ways to reduce the possibilities of WWD at these interchanges.

Design Guidelines
• Applicable geometric elements at the intersection of the frontage road and crossroad: o Raised median o Channelizing island o Control/corner radius • Connection with frontage road (AASHTO 2011): o Use acute angle to connect exit ramp with one-way frontage road. o Use right angle to connect exit ramp with two-way frontage road.

Discussion

At diamond interchange with continuous frontage roads, WWDs often originate at the intersections between the frontage road and crossroad. Raised medians, channelizing islands, and control/corner radii should be applied at these intersections following the same design guidelines provided for use at conventional diamond interchanges. Wrong-way signage and pavement markings, which are discussed in detail in the Chapter 2 of this guidebook, should also be considered at these two types of intersection. Channelizing islands should also be installed at side streets that connect to the one-way frontage road.

An acute angle for the intersection is recommended between an exit ramp and one-way frontage road to avoid possible wrong-way turning movements (Figure 3-26).

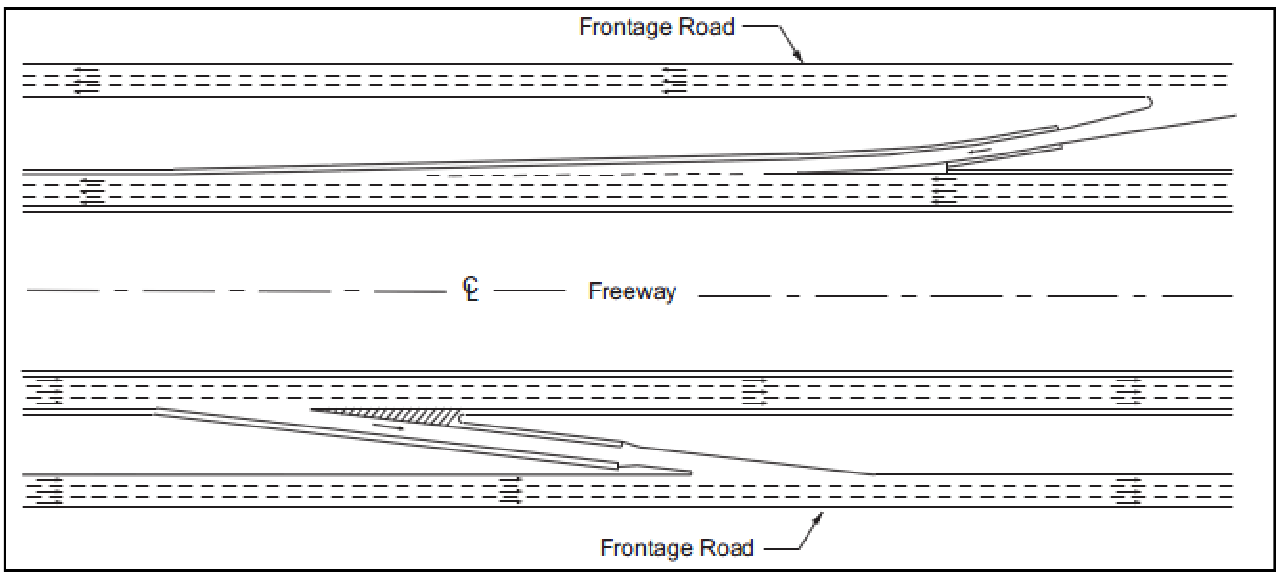


Figure 3-26. Intersections between ramps and one-way frontage roads (AASHTO 2011).

On the other hand, the intersection of an exit ramp and two-way frontage road should be designed using right angles to prevent vehicles on the rightmost lane of the frontage road from entering the exit ramp (Figure 3-27).

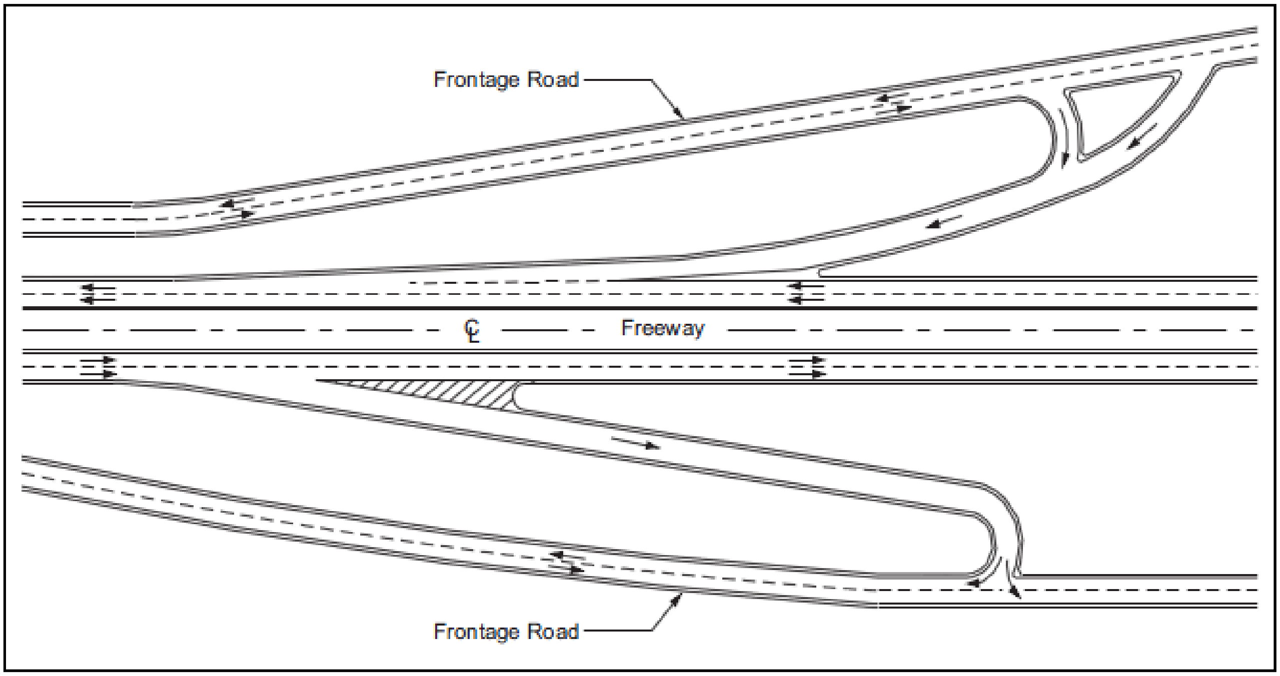


Figure 3-27. Intersections between ramps and two-way frontage roads (AASHTO 2011).

CONVENTIONAL DIAMOND INTERCHANGE

Conventional diamond interchanges, which are used where a freeway crosses a minor road, provide a one-way diagonal ramp in each quadrant. These interchanges have a greater potential for wrong-way maneuvers compared with, for example, a full cloverleaf (AASHTO 2011). The reason is that the intersections of the ramps and the crossroad, although having four legs, function as T-intersections and should be designed similarly. This combination (i.e., having four legs while following the characteristics of T-intersections) with two one-way legs introduces challenges for the engineer in order to prevent any wrong-way maneuvers. The following design guidelines incorporate previously discussed elements applicable to this type of interchange to deter WWD.

Design Guidelines

- Applicable geometric elements at exit ramp terminals:
  - Raised median
  - Channelizing island
  - Control/corner radius
- Appropriate use of channelizing island at the intersection of undivided crossroad and ramp (Figure 3-28) and use of a raised median and channelizing island together where the crossroad is divided (Figure 3-29) help prevent WWD.

Discussion

On undivided crossroads, channelizing island and a sharp turn radius are often used to discourage wrong-way left and right turns at exit ramp terminals. Figure 3-28 shows three examples of the intersection of ramps and undivided crossroads to discourage WWD maneuvers. The application of a sharp turn radius and channelizing islands at entrance and exit ramps that have the potential for wrong-way right-turn movements can be identified in these layouts. For divided crossroads, a raised median should be considered to prevent the wrong-way left turns. Figure 3-29 shows the application of control radius, channelizing island, and raised median for divided crossroads.

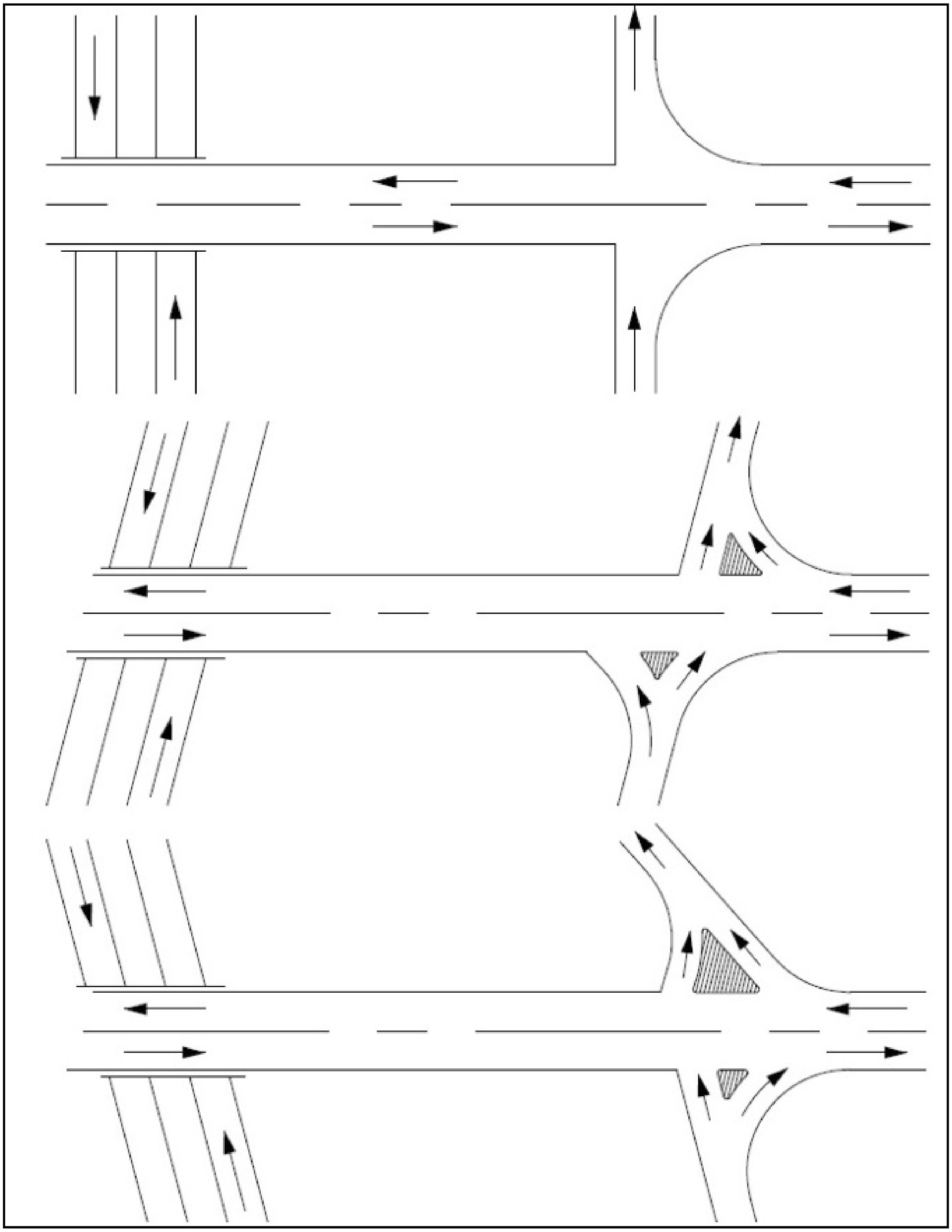


Figure 3-28. Undivided crossroad designs to discourage wrong-way entry (AASHTO 2011).

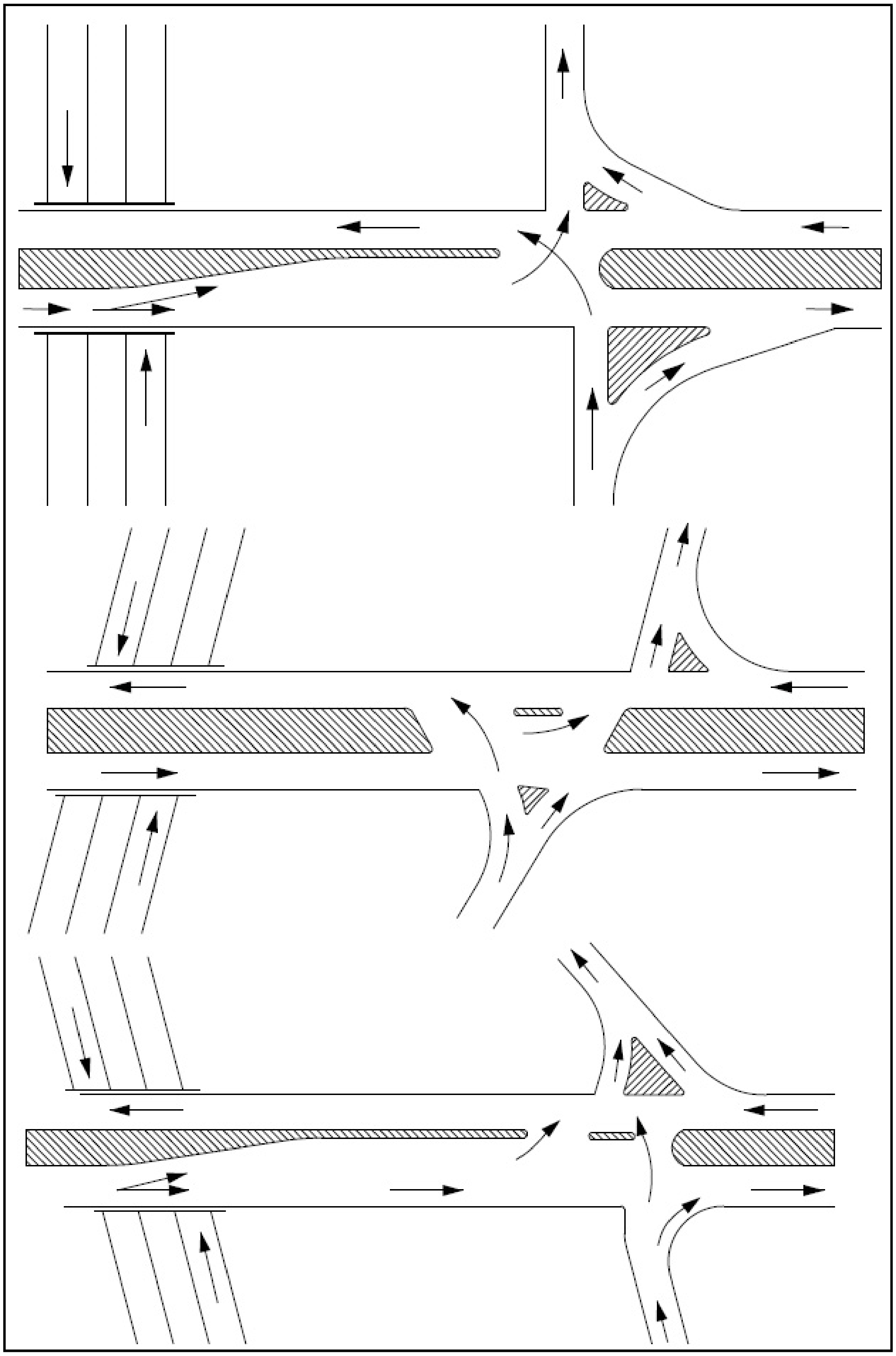


Figure 3-29. Divided crossroad designs to discourage wrong-way entry (AASHTO 2011).

CHAPTER 4

ADVANCED TECHNOLOGIES, ENFORCEMENT, AND EDUCATION

SECTION 4.1: ADVANCED TECHNOLOGIES

INTRODUCTION

This section of the guidebook presents applications of advanced technologies to reduce WWD incidents. These technologies, which are based mainly on intelligent transportation system (ITS) technologies, use detectors to sense and verify the presence of wrong-way vehicles and warn both wrong-way and right-way drivers.

Design Guidelines
• Use ITS technologies to detect the WWD, send alerts to traffic management centers (TMCs), and warn both wrong-way and right-way drivers. 1. Detection o In-roadway sensor technologies o Over-roadway sensor technologies 2. Warning o LED WW signs o Changeable message signs (CMSs) o In-pavement warning lights. 3. Example of application of ITS technologies

DISCUSSION

- **Use ITS technologies to detect WWD, send alerts to traffic management centers (TMCs), and warn both wrong-way and right-way drivers.**

  The application of ITS technologies and detectors has been implemented and studied over past few decades to address WWD issues (Parsonson and Marks 1979; Moler 2002; Wiley 2011). These devices are capable of identifying vehicle movement direction. If vehicle movement is detected in the wrong direction, a signal can be transmitted to warning devices and TMCs to take further actions. The two major parts of this process are detection and warning. A typical scheme of ITS detection and warning systems can be found in Figure 4-1. As shown, a wrong-way driver is first detected using sensor technologies, and he/she is immediately notified of the mistake by means of warning devices such as LED WW signs. These work well in rural areas where modern TMCs and quick responses by police are not available. In some large metropolitan areas, TMCs can receive the signals from field detectors and sensors and further verify WWD using video cameras. After the incident is verified, law enforcement officers will be provided with the location and direction of the wrong-way driver through dispatch centers. Law enforcement officers and other incident responders can either help at-fault vehicles correct their directions or stop them. Meanwhile, pertinent messages can be posted on CMSs to notify right-way (RW) drivers of the presence of errant drivers.

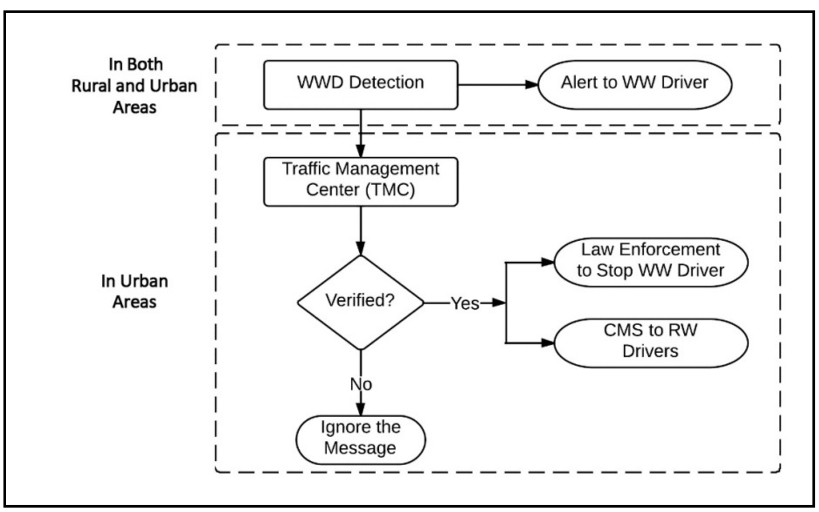


Figure 4-1. Typical scheme of WWD detection and warning system.

1. Detection

Wrong-way movements can be sensed by various detection systems as a part of ITS technologies. These detection systems fall into two main categories (Mimbela and Klein 2007): in-roadway sensor technologies and over-roadway sensor technologies.

In-Roadway Sensor Technologies

These sensors are embedded or installed below the roadway surface and include inductive loop detectors (ILDs) and magnetic sensors.

Inductive Loop Detectors (ILDs)

Inductive loop detectors (ILDs) detect vehicles by sensing a reduction in loop inductance as a result of inducing currents into the conductive metal object while the vehicle is passing over the inductive loop. An ILD system is a combination of four major parts: (1) a wire loop consisting of one or more turns of wire placed at a specific depth in roadway pavement, (2) a lead-in wire that connects the wire loop to a pull box, (3) a lead-in cable that connects the lead-in wire at the pull box to the controller, and (4) a detector (electronics unit channel in the cabinet) that powers loops and detects the change in loop inductance caused by the presence of a conductive metal object (Figure 4-2) (FHWA 2006a).

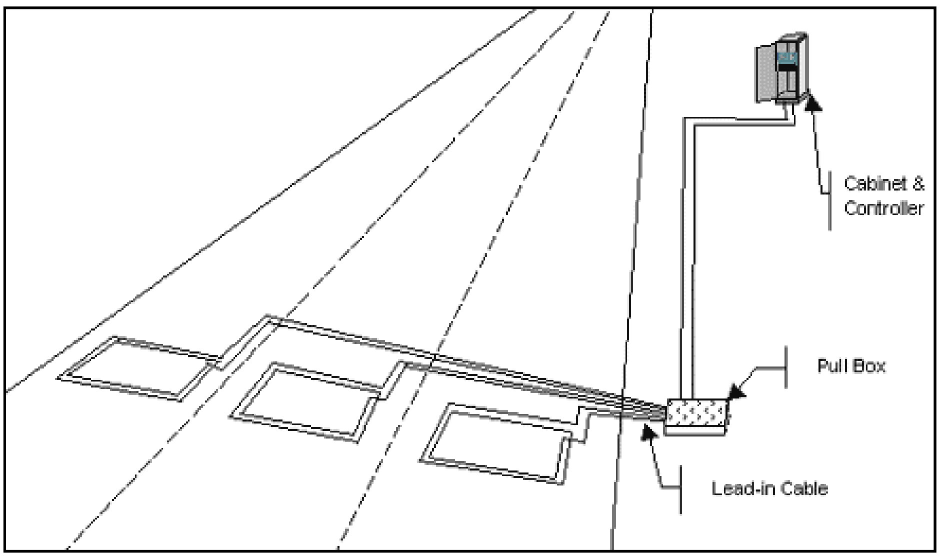


Figure 4-2. Typical inductive loop detector (ILD) system (FHWA 2003).

When it is necessary for ILDs to distinguish between the directions of different movements, such as wrong-way movements, directional logic becomes applicable. In such cases, two loops located near each other at a specific distance or slightly overlapped (Figure 4-3) are used.

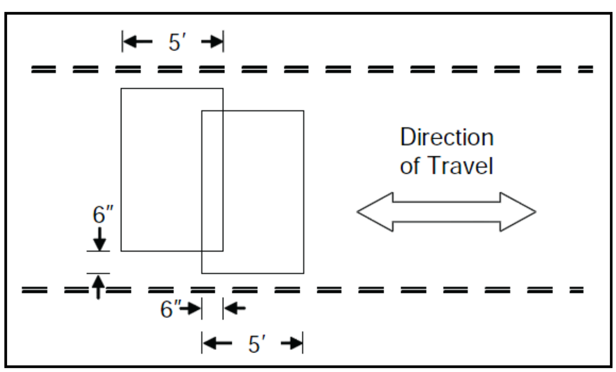


Figure 4-3. Directional detection using ILDs (FHWA 2006a).

One of the main strengths of ILDs is that these devices can operate under all weather conditions and are insensitive to time of day (i.e., no problems with lighting). One of the main disadvantages is that installation and maintenance require lane closure and pavement cutting.

Magnetic Sensors

Like ILDs, magnetic sensors are embedded into the pavement to detect vehicles. Vehicles can be detected by measuring the change in the Earth's magnetic field caused by the presence of a vehicle near the sensor. When a change in the magnetic field is detected, the sensors send their data via radio to an access point near the field sensors. The vehicles' speed and direction can be determined by the roadside controller (Simpson 2013).

Because these systems register the vehicles passage when they are traveling at a speed of 5 mph and higher, the detectors should be placed far enough back from the stop line at the end of exit ramp. A distance of at least 50 feet from the stop line is recommended. Moreover, detectors must be appropriately placed across the lane to ensure enough signal strength to detect the vehicle. Figure 4-4 depicts a magnetic detector implemented on a freeway exit ramp, with a cabinet and controller, as well as a camera to videotape the scene. The sensors are placed in the pavement at a distance of approximately 70 feet from the crosswalk.

These devices can work all day long and under all weather conditions. The main disadvantage of these sensors, as with to ILDs, is that installation and maintenance require lane closure and pavement cutting.

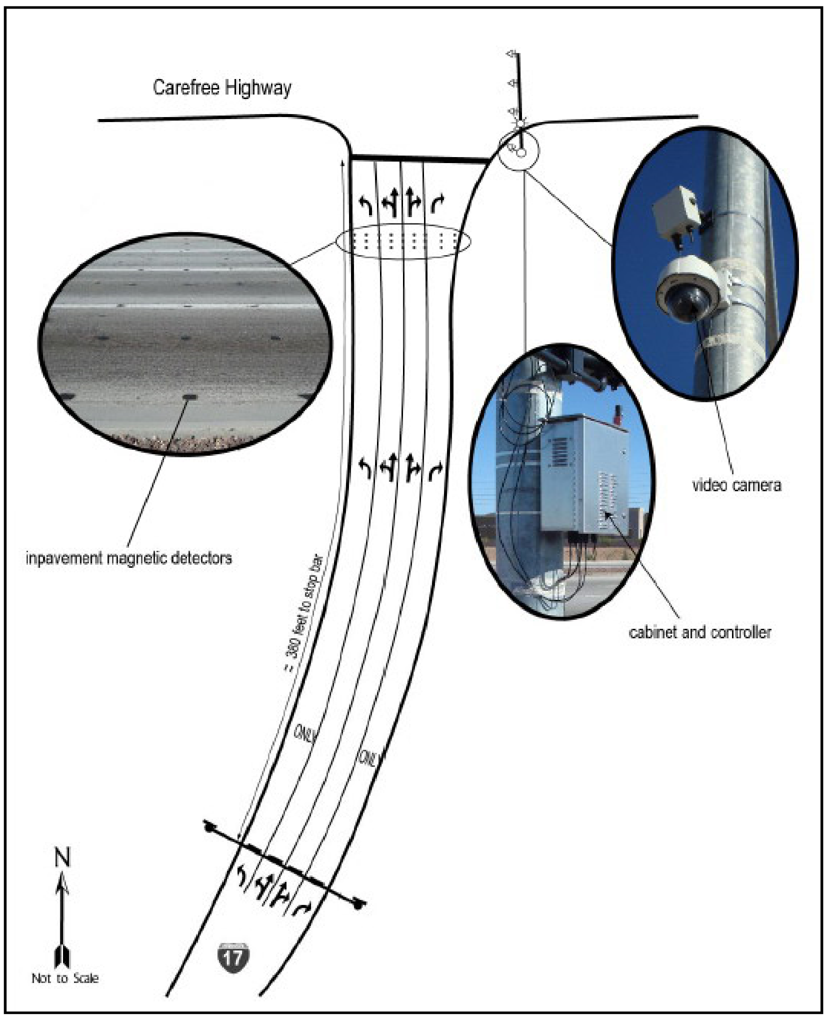


Figure 4-4. In-roadway magnetic detection system along exit ramp (Simpson 2013).

Over-Roadway Sensor Technologies

These sensors are mounted over the roadway surface, on the side of roadway or in the middle. The technologies include video image processor (VIP) systems and microwave radar detectors. Their capability to collect data for multiple lanes using a single sensor has made them a popular choice. Moreover, they usually are much safer for installation personnel and provide more data than ILDs and magnetic sensors.

Video Image Processors (VIPs)

These systems use fixed-position video cameras mounted over the roadway or on a side pole to detect the presence of a vehicle as well as its direction of travel. A VIP system typically consists of one or more cameras, a computer for digitizing and analyzing the imagery, and software for interpreting the images and converting them into traffic flow data (FHWA 2006a).

The cameras are recommended to be mounted at least 40 feet or higher if they are placed over the roadway. For side-mounted cameras, higher mounting heights (50 feet or more) are typically required. On the basis of the 5:1 aspect ratio of the spot on the pavement directly below the camera to the camera mounting height, a camera mounted 40 feet high can detect vehicles up to 200 feet from the installation point along the camera's target direction. The performance of a low-mounted camera can be affected by headlight beams of approaching vehicles and may result in false detection. For best performance, the cameras should be mounted where they will experience the least vibration and motion.

The performance of VIPs can be affected by inclement weather conditions (fog, rain, snow, etc.), vehicle headlight beams, and nighttime conditions. Their lenses must be cleaned periodically to reduce the effects of water, salt grime, icicles, and cobwebs on the detection process (Mimbela and Klein 2007).

Microwave Radar Detection

Microwave radar detectors sense the presence of a vehicle as well as its direction by transmitting a high-frequency microwave signal back and forth to the object. There are two types of microwave radars: (1) continuous wave (CW) Doppler that detects vehicles traveling at a speed of at least 3 to 5 mph but cannot detect motionless vehicles, and (2) frequency-modulated continuous wave (FMCW) presence-detecting sensors that detect moving vehicles as well as stopped ones. Both types are applicable for detecting WWD movements because moving vehicles are targeted (FHWA 2006a).

To detect the direction of travel, the sensors may be mounted over the middle of a lane in the forward-looking direction. Figure 4-5 illustrates typical placement of a microwave radar detector along a roadway.

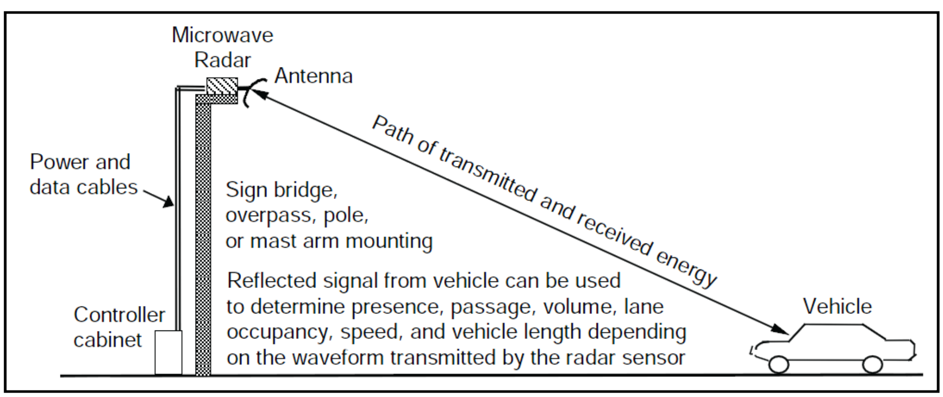


Figure 4-5. Microwave radar operation (FHWA 2006a).

In terms of detector placement, some manufacturers provide diagrams along with their products to help users with the appropriate placement. Figure 4-6 depicts an example of such a diagram for proper detector placement. For instance, by looking at this diagram, it can be inferred that if the detector (TC-20 model) with a 16-degree beam width is going to be used along a single-lane exit ramp (12 feet wide), the detector must be placed 40 feet or more from the ramp terminal. Figure 4-7 illustrates a microwave detector mounted on a utility pole on the side of an exit ramp for detecting possible wrong-way entries.

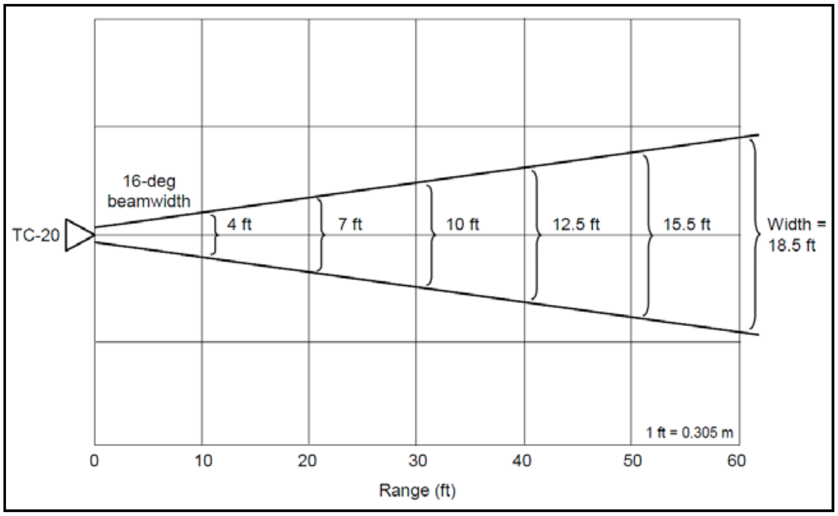


Figure 4-6. Approximate detection pattern for a sample microwave radar sensor (FHWA 2006b).

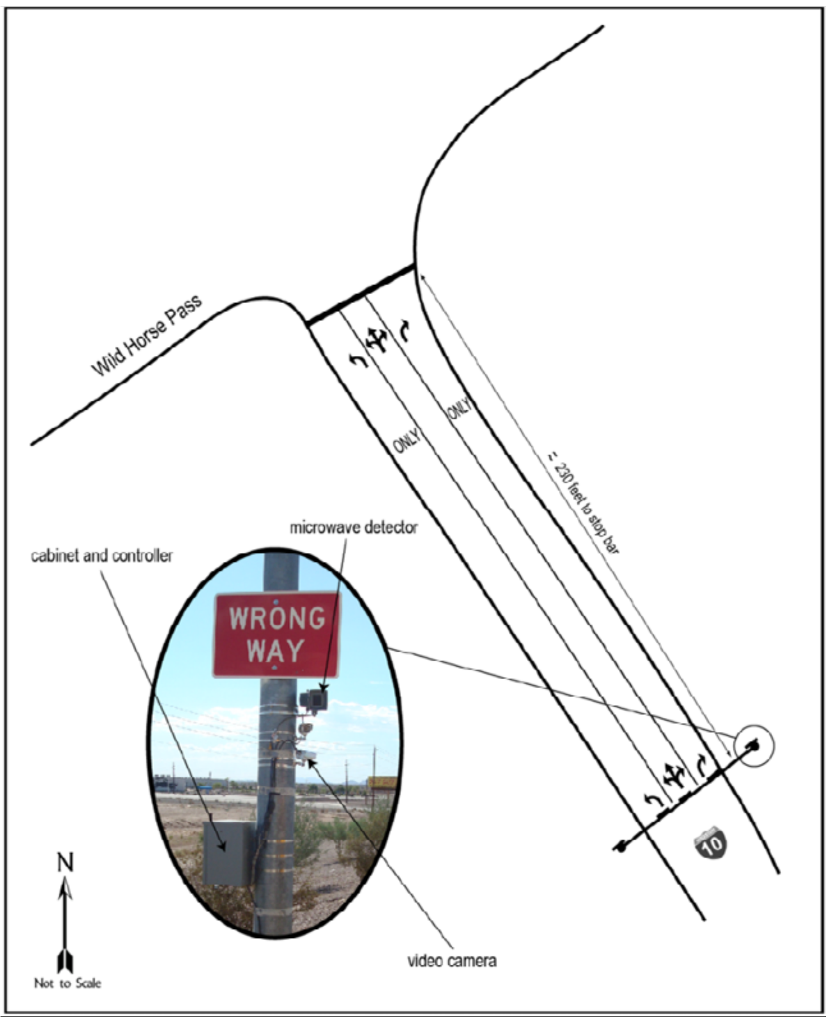


Figure 4-7. Microwave radar detection system along exit ramp (Simpson 2013).

Like ILDs and magnetic detectors, microwave radar sensors are insensitive to inclement weather conditions. Benefits of microwave radar detectors include multi-lane detection and low maintenance.

In general, all these systems provide for early detection of WWD using different technologies. Table 4-1 summarizes the characteristics of each of these devices.

Table 4-1. Characteristics of Various Detection Technologies

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).

2. Warning

After a WWD movement has been detected, different alerts can be transmitted to both wrong-way drivers and right-way drivers by means of LED WW signs, CMSs, and in-pavement warning lights.

LED WW Signs

LED WW signs can be activated after receiving any signal from detectors about the presence of a wrong-way vehicle on the facility. Otherwise, there will be no message on the sign. Figure 4-8 shows this sign in both blank and activated conditions.

Figure 4-8. LED wrong-way sign to alert wrong-way drivers (Cooner et al. 2004).

Changeable Message Signs (CMSs)

A CMS can be used to convey warning messages to right-way drivers about a wrong-way driver. While some agencies use more general messages such as “Wrong Way Driver Reported—Use Extreme Caution” (Figure 4-9), others have tried messages that direct drivers to take a specific action like “Wrong Way Driver Ahead—All Traffic Move to Shoulder and Stop” (Figure 4-10).

Figure 4-9. Changeable message sign (CMS) to alert right-way drivers (TxDOT 2011).

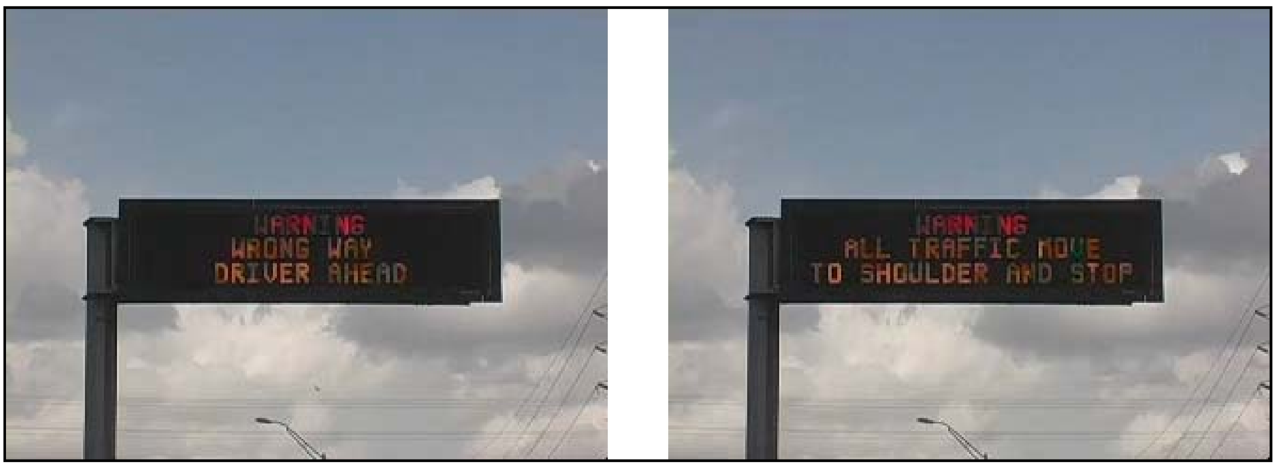


Figure 4-10. Changeable message sign (CMS) to alert right-way drivers (Thurman 2013).

In-Pavement Warning Lights

These types of devices (Figure 4-11) can be applied to exit ramps susceptible to WWD (Cooner et al. 2004). In-pavement warning lights are used to reduce the frequency of wrong-way incidents, especially at night (Moler 2002). Upon detecting a wrong-way driver (by means of any type of detector), these lights can be activated to alert the wrong-way driver that he/she is going the wrong direction. Very few agencies have implemented these types of devices.

Figure 4-11. In-pavement Warning lights (Cooner et al. 2004).

3. Example of Application of ITS Technologies

Harris County Toll Road Authority (HCTRA) in Texas recently implemented a WWD radar detection system. The system includes four parts:

1. Detection: When a wrong-way vehicle is detected, an audible alert comes through the speakers at the TMC and simultaneously an automated call slip with the location of the wrong-way driver is sent to dispatchers by the incident management system (IMS).
2. Verification: GIS maps, shown on a big screen at the TMC, zoom in automatically to the WWD location, determine the direction of travel, and display the direction using a message such as "Exit 57 Eastbound Going Westbound." The closest law enforcement vehicle is then notified while dispatch confirms the presence of a wrong-way driver by closed-circuit television (CCTV) roadway software to automatically pan, tilt, and zoom adjacent cameras to the alert location and obtain a vehicle description.
3. Warning: After verification, dispatchers post the most appropriate (pre-determined) message, such as "Wrong Way Driver Ahead" and "All Traffic Move to Shoulder and Stop" on full-color CMSs, warning motorists of the incident.
4. Action: Dispatchers using GPS technology coordinate with law enforcement to position officers ahead of the wrong-way driver and force him/her to pull over. Once the officers are not positioned ahead of the at-fault driver, responding units attempt to intercept the vehicle by deploying tire deflation devices (portable spikes) to slow or stop the wrong-way driver (HCTRA 2012).

SECTION 4.2: ENFORCEMENT

Apart from roadway configurations, most studies have found that human factors account for the most roadway incidents—75% to 90% (Van Elslande and Fouquet 2007). When it comes to WWD, two behavioral factors of high importance can cause drivers confusion: those that cause a reduction in driving capabilities on a long-term basis (e.g., inexperience and aging) and those that reduce driving capabilities on a short-term basis (e.g., alcohol and drug use) (Petridou and Moustaki 2000). Past studies (NTSB 2012; Zhou et al. 2012; Zhou et al. 2014) have shown that more than 60% of wrong-way crashes were caused by DUI drivers and that older drivers (> 65 years old) are overrepresented in WWD crashes. Therefore, a comprehensive WWD mitigation program should consider enforcement and education components as essential parts of a "4E" (engineering, enforcement, education, and emergency response) approach.

Many WWD crashes can be prevented by enforcement and response strategies. An advanced detection and warning system can be implemented and coordinated with law enforcement and other incident responders to ensure quick action to stop a WWD before a crash occurs. Even the most sophisticated ITS countermeasures, however, may fall short of notifying and warning wrong-way drivers to help them stop on their own, especially in the case of a severely impaired driver. It is essential that law enforcement officers step in and take appropriate action to correct the wrong-way driver or stop the vehicle. Effective enforcement often relies on quick detection and notification by advanced ITS techniques and modern TMCs. It is therefore important that law enforcement officers and other responders understand the various ITS techniques used for WWD detection and notification described in this chapter.

The enforcement discussion in this guidebook was developed based on previous research results and best practices by different agencies. It includes four topics: (1) data-driven enforcement, (2) methods to stop wrong-way vehicles, (3) WWD crash reporting, and (4) techniques for use with DUI offenders.

DATA-DRIVEN ENFORCEMENT

A past study by IDOT (Zhou et al. 2012; Zhou et al. 2014) showed that the most significant human factors involved in WWD incidents were alcohol impairment, driver age (> 65 years old), drug impairment, physical condition, and driver skills, knowledge, and experience. There were significantly more WWD crashes on weekends and during early morning hours (12 midnight to 5 A.M.) than other weekdays and time periods. To combat freeway WWD crashes, it is important to keep DUI drivers away from freeways, possibly by establishing more DUI checkpoints near freeway entrances. These checkpoints can be established from midnight until early morning and during weekends at high crash locations.

METHODS TO STOP WRONG-WAY VEHICLES

Current practice for stopping wrong-way vehicles by law enforcement officers include (1) driving in the correct location, parallel with the wrong-way driver and notify him/her by using emergency lights, siren, spotlight, etc. or (2) getting ahead of the driver and forcing him/her to pull over. Other suggested methods are as follows:

- Deploying tire deflation (e.g., portable spike tools) or entangler stopping systems
- Conducting a traffic break to reduce the closing speed
- Using a patrol car to "ram" a wrong-way violator or using the patrol car to serve as a stationary or moving roadblock
- Employing patrol car contact to execute a pursuit intervention technique maneuver
- Pinning a wrong-way vehicle against a continuous median barrier (NTSB 2012; NSA 2013)

Agencies should review local laws and their own policies before considering use of some type of these techniques because they might be considered use of deadly force.

Some agencies use radio and CMSs to warn right-way drivers of oncoming wrong-way drivers to provide extra response time for law enforcement officers to stop wrong-way vehicles before crashes occur.

WWD CRASH REPORTING

The most important information in WWD crash reports is the wrong-way entry point, which is defined as the starting point of the WWD maneuver. Therefore, after stopping wrong-way drivers, law enforcement officers can ask at-fault drivers where they are coming from and where they entered the route in a wrong-way direction. This information can be recorded and analyzed to identify the locations with a high potential for WWD entries, and it can inform road-owning agencies about the locations where countermeasures should possibly be implemented.

TECHNIQUES FOR USE WITH DUI OFFENDERS

A survey of law enforcement officers showed that enforcement of DUI laws is one of the countermeasures they perceive to be most effective at preventing WWD events (Zhou et al. 2012). A recent study by NTSB (2012) recommended the ignition interlock devices (IIDs) (Figure 4-12) be required for convicted DUI offenders. IIDs are designed to control the ignition circuit of the vehicle and run a test on the driver's breath sample to ensure that the amount of alcohol in the sample is below the pre-set limits (which vary from state to state). If the amount exceeds the limit, the engine will not start. The procedure requires the driver to exhale into the device for analysis of alcohol content in the breath before starting the engine. Many of these systems require the driver to retake the test at specific time intervals during the trip to make certain that not only is the amount of alcohol still within the safe level but also that nobody else other than the driver is providing the sample (NTSB 2012). Studies have shown promising results with the use of IIDs in reducing the recidivism rate among alcohol-impaired drivers (Raub et al. 2003; Willis et al. 2004; Elder et al. 2011; Rauch et al. 2011).

Figure 4-12. Ignition interlock system detects the alcohol content in a driver's breath before the engine can be started (CNRL 2012).

SECTION 4.3: EDUCATION

Education strategies can be implemented to improve public awareness and understanding of (1) the basics of road designs and interchange types, (2) potential risks, (3) what to do when witnessing a wrong-way driver, and (4) possible harm to family and/or society. Education programs should focus especially on younger drivers, older drivers, and DUI drivers.

Past studies have identified specific education programs developed for special age groups of drivers to help prevent wrong-way crashes (Copelan 1989; NTTA 2009). For instance, the California Highway Patrol (CHP), working with student groups, local individuals, and local organizations such as Mothers Against Drunk Driving (MADD), started the Sober Graduation Program in 1985 to reduce drinking and driving among young people. It was conducted during May and June 1985. The community-based effort involved 15 to 19-year-old drivers who abided by the “don’t drink and drive” message and agreed to deliver it to their peers. The CHP ran television and radio public service announcements and distributed posters, bumper stickers, decals, key chains, and book covers. The results of this program were rewarding. In May and June of 1985 alone, fatal crashes in that age group dropped by 25%, and injury crashes decreased by 19%.

In 2009, the North Texas Tollway Authority (NTTA) developed a comprehensive public safety plan to educate the public about WWD (NTTA 2009). A major component of the plan was to reduce impaired driving and publicize the ramifications of drinking and driving. The plan included quarterly safety forums for the public, co-sponsored by MADD.

To help guide their own educational programs, several states, including California and Washington, initiated a WWD monitoring program to collect information about WWD behaviors, such as real-world WWD incidents and correct ways to avoid WWD crashes.

Education components should also include materials that foster the public’s understanding of engineering countermeasures such as signage, pavement markings, geometric elements, and ITS technologies.

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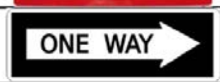
APPENDICES

APPENDIX A: WRONG-WAY ENTRY CHECKLIST FIELD INSPECTION SHEET

Inspector:		
Route Information:		Date:
Ramp Description:		Time:

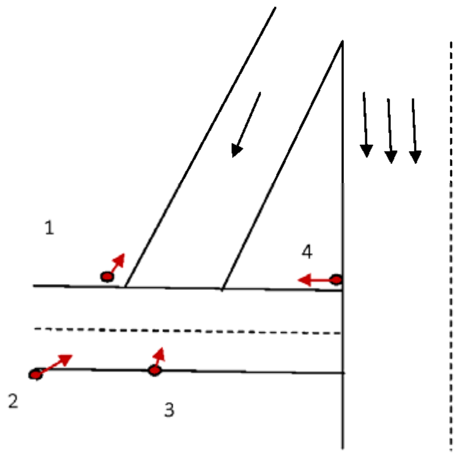
SIGN	CHECK IF	YES	NO	COMMENTS
	At least one present			
	In good condition			
	At least one present			
	In good condition			
	Present at location for cross under/over traffic			
	NO RIGHT TURN			
	NO LEFT TURN			
	NO U-TURN			

PAVEMENT MARKNG	CHECK IF	YES	NO	COMMENTS
WRONG-WAY ARROWS	Present			
	Pieces in good condition			
Other Markings	Elephant tracks (turning guide line)			
	Stopping lines at end of exit ramp			
	Left/Right Turn Only Arrow			

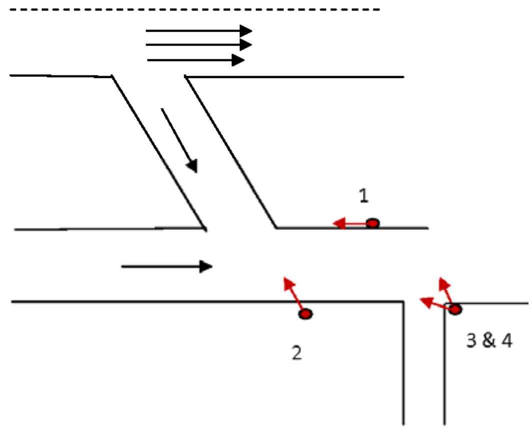
GEOMETRC DESIGN FEATURES	CHECK IF	YES	NO	COMMENTS
Raised Curb Median on the crossroad	Present			
	Present			
	Present			
Design to Discourage Wrong-Way Entry	Present			

DESCRIBE ANY CONFUSING ROAD LAYOUT NEAR POSSIBLE WRONG-WAY ENTRY:

Picture Locations



OR



APPENDIX B: WRONG-WAY DRIVING ROAD SAFETY AUDIT PROMPT LIST

September 2013

Wrong-Way Driving

Road Safety Audit Prompt List

Purpose

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

U.S. Department of Transportation
Federal Highway Administration

Office of Safety
Publication No.: FHWA-SA-13-032

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

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

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

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

Wrong-Way Driving RSA Prompt List

Master Prompt List

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

Detailed Prompt Lists

Scope of Project, Function, Traffic Mix, Road Users

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

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

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

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

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

Design

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

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

Do local roadways or driveways intersect near interchange ramps?

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

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

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

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

Wrong-Way Driving RSA Prompt List (continued)

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

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

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

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

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

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

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

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

Signs and Markings

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

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

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

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

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

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

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

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

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

Wrong-Way Driving RSA Prompt List (continued)

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

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

Time of Day Conditions

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

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

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

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

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

Seasonal and Temporary Conditions

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

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

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

For more information on Road Safety Audits

Federal Highway Administration
FHWA Road Safety Audit Guidelines
Publication No. 33 FHWA-SA-06-06
Washington, DC, 2006

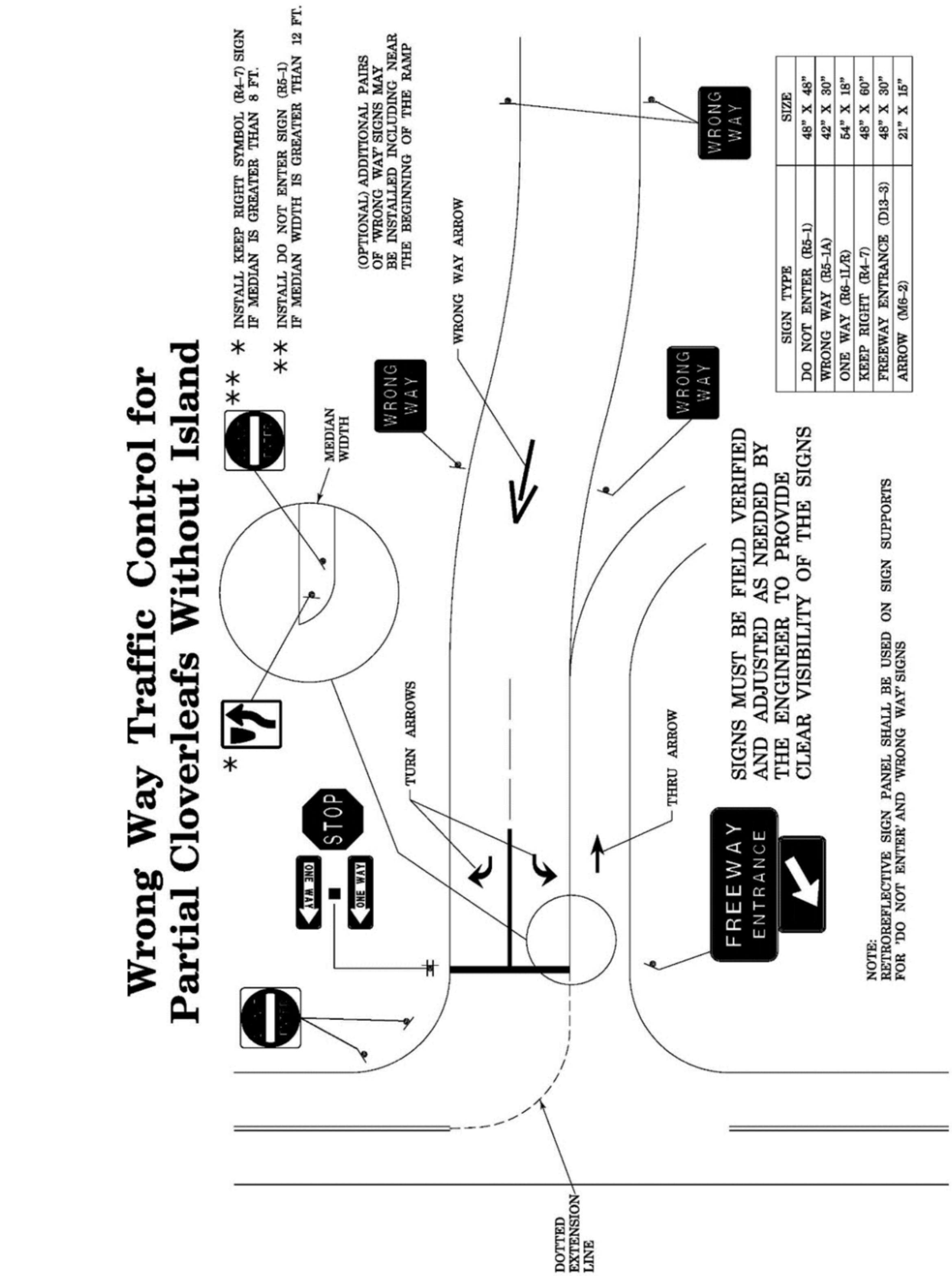
http://safety.fhwa.dot.gov/rsa/guidelines

RSA Making Your Roads Safer

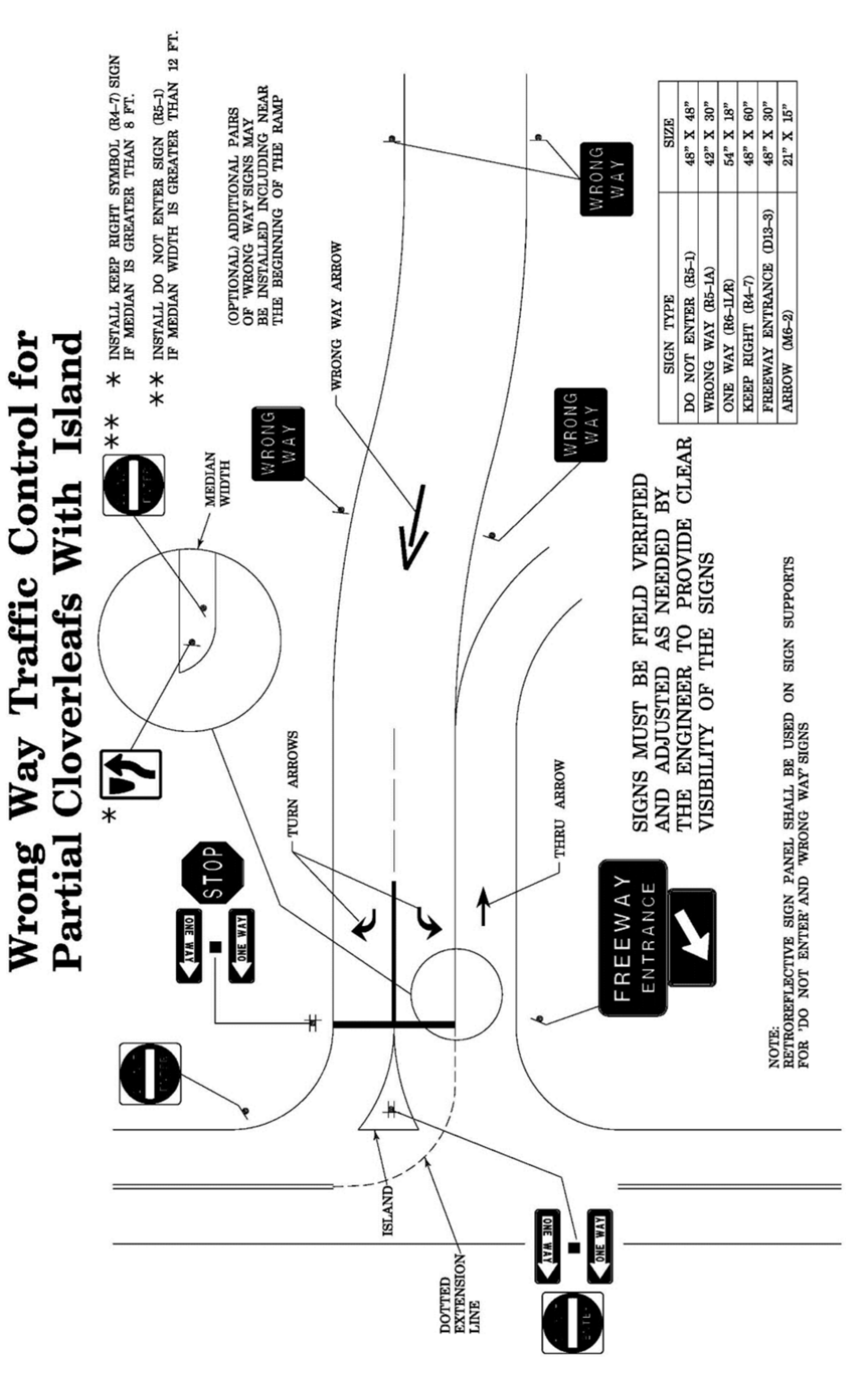
APPENDIX C: SIGN COMBINATIONS USED BY DIFFERENT AGENCIES

Sign(s)	Proposed/Used By
	Caltrans Virginia DOT Texas DOT Georgia DOT Ohio DOT Michigan DOT
	Caltrans
	New York State DOT
	New York State DOT Ohio DOT

APPENDIX D: WRONG-WAY TRAFFIC CONTROL FOR COMMON INTERCHANGE TYPES

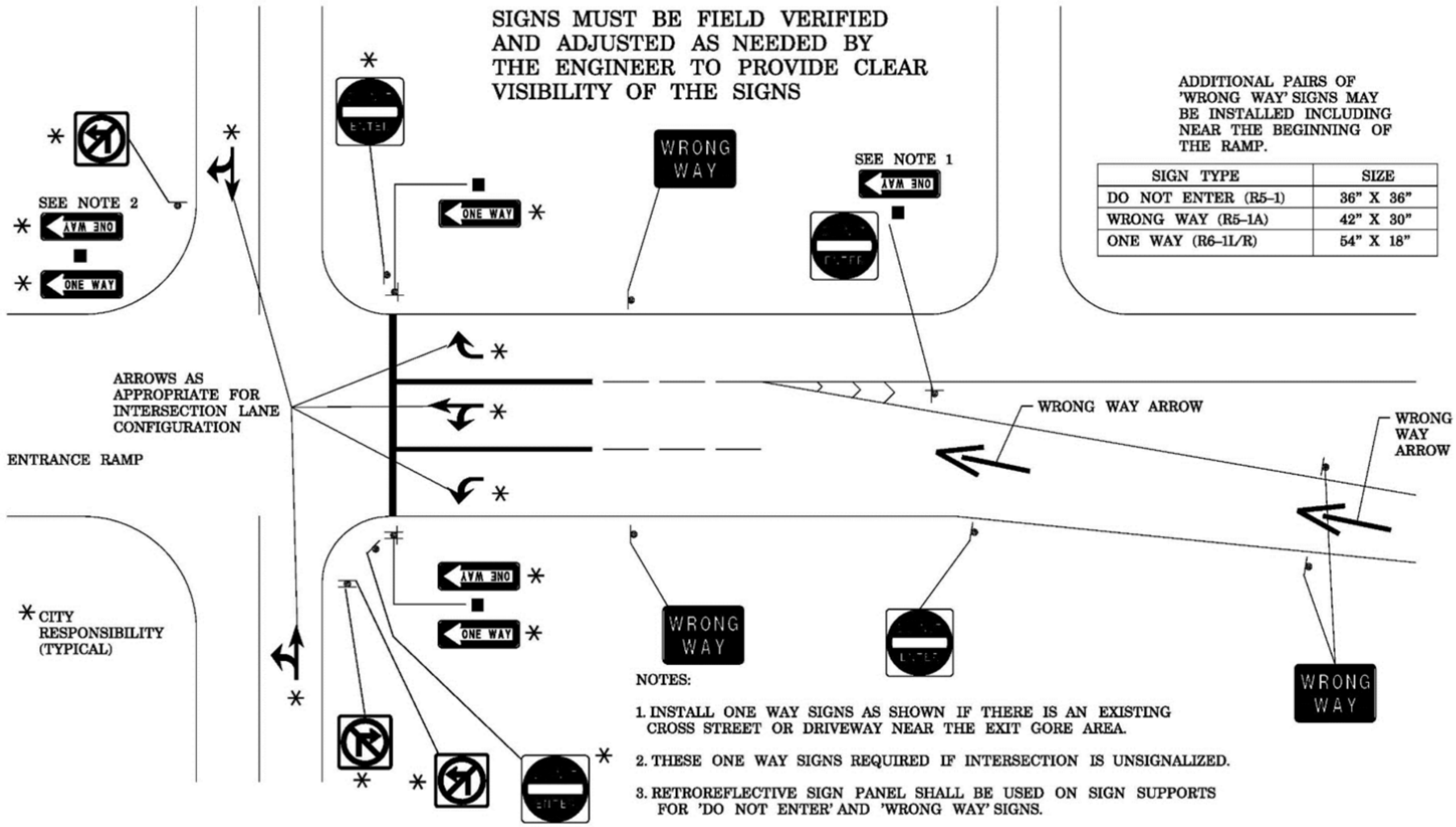


SIGN TYPE	SIZE
DO NOT ENTER (R5-1)	48" X 48"
WRONG WAY (R5-1A)	42" X 30"
ONE WAY (R6-1L/R)	54" X 18"
KEEP RIGHT (R4-7)	48" X 60"
FREEWAY ENTRANCE (D13-3)	48" X 30"
ARROW (M6-2)	21" X 15"



SIGN TYPE	SIZE
DO NOT ENTER (R5–1)	48" X 48"
WRONG WAY (R5–1A)	42" X 30"
ONE WAY (R6–1L/R)	54" X 18"
KEEP RIGHT (R4–7)	48" X 60"
FREEWAY ENTRANCE (D13–3)	48" X 30"
ARROW (M6–2)	21" X 15"

Wrong Way Traffic Control for Compressed Diamond Interchange



SIGN TYPE	SIZE
DO NOT ENTER (R5–1)	36" X 36"
WRONG WAY (R5–1A)	42" X 30"
ONE WAY (R6–1L/R)	54" X 18"

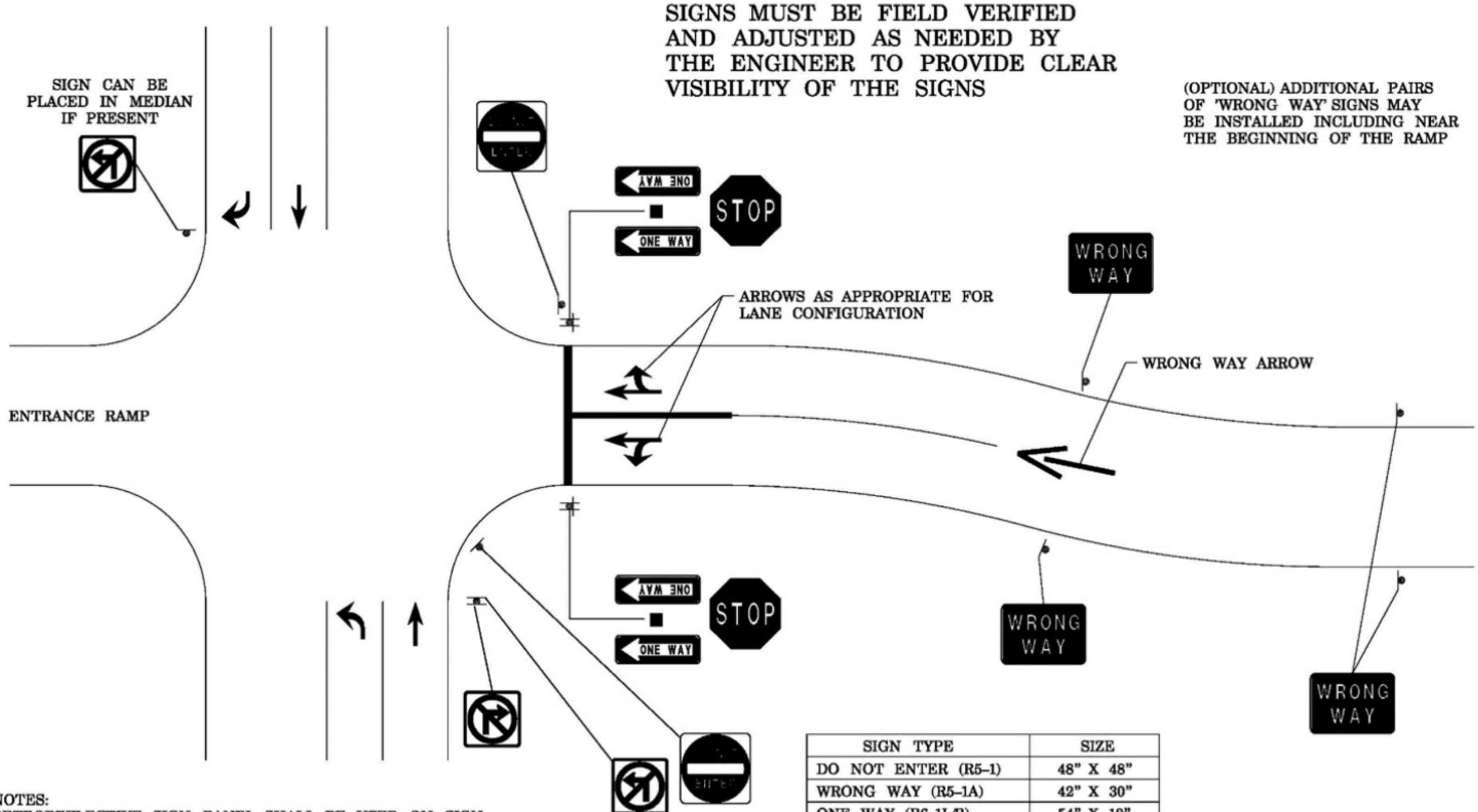
NOTES:

1. INSTALL ONE WAY SIGNS AS SHOWN IF THERE IS AN EXISTING CROSS STREET OR DRIVEWAY NEAR THE EXIT GORE AREA.
2. THESE ONE WAY SIGNS REQUIRED IF INTERSECTION IS UNSIGNALIZED.
3. RETROREFLECTIVE SIGN PANEL SHALL BE USED ON SIGN SUPPORTS FOR 'DO NOT ENTER' AND 'WRONG WAY' SIGNS.

Wrong Way Traffic Control for Diamond Interchange Exit Ramp

SIGNS MUST BE FIELD VERIFIED AND ADJUSTED AS NEEDED BY THE ENGINEER TO PROVIDE CLEAR VISIBILITY OF THE SIGNS

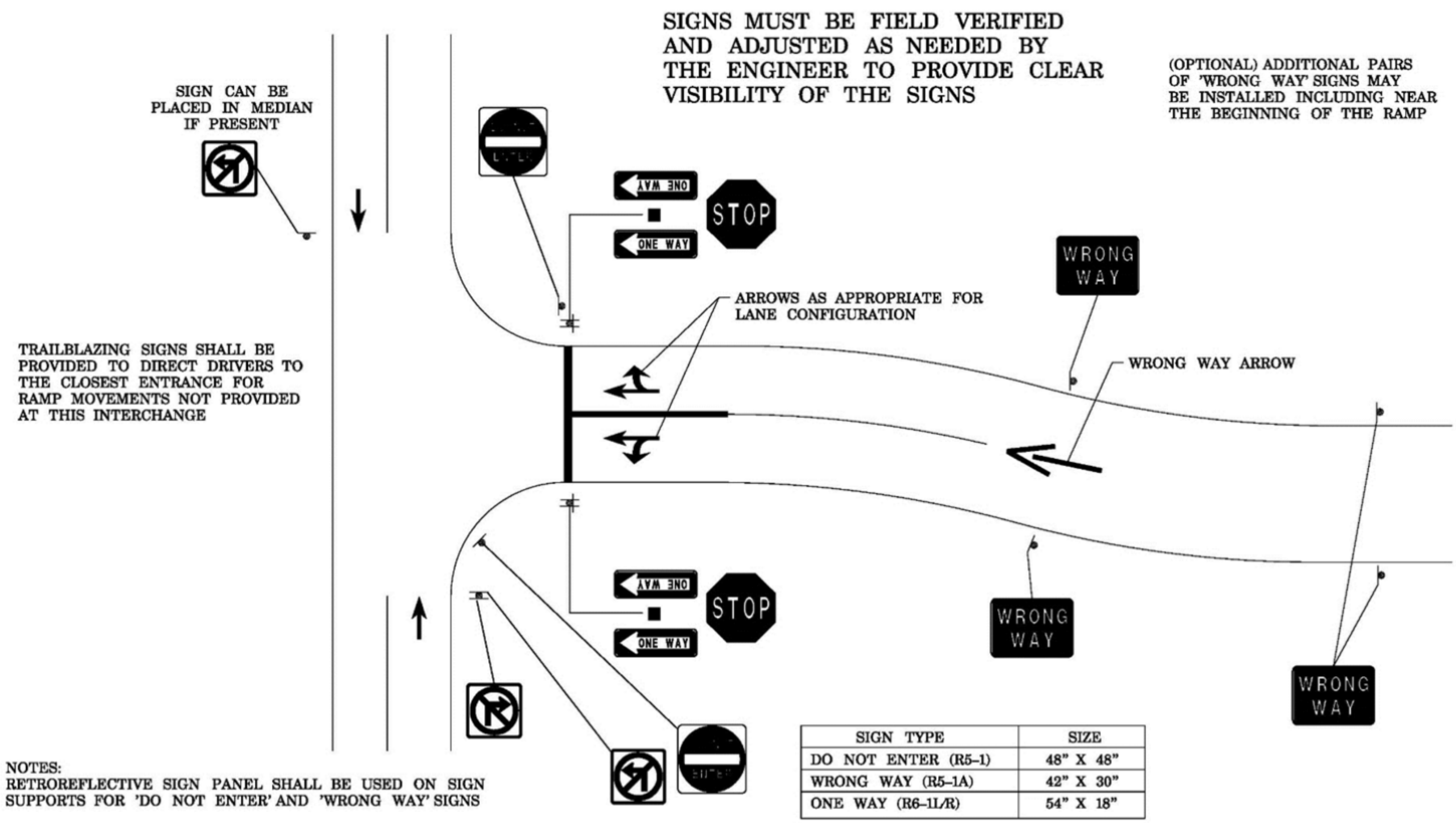
(OPTIONAL) ADDITIONAL PAIRS OF 'WRONG WAY' SIGNS MAY BE INSTALLED INCLUDING NEAR THE BEGINNING OF THE RAMP



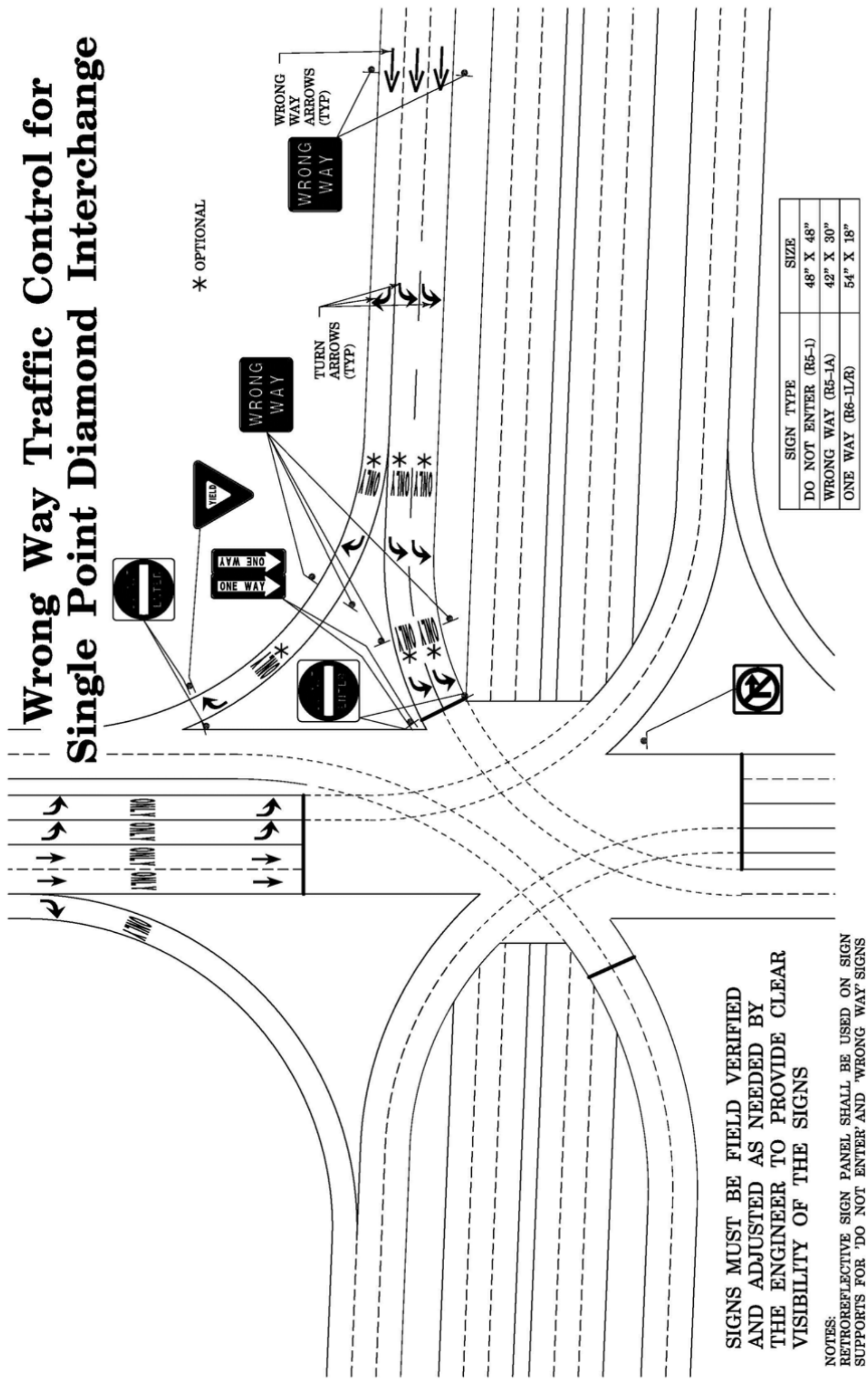
SIGN TYPE	SIZE
DO NOT ENTER (R5-1)	48" X 48"
WRONG WAY (R5-1A)	42" X 30"
ONE WAY (R6-1L/R)	54" X 18"

NOTES:
RETROREFLECTIVE SIGN PANEL SHALL BE USED ON SIGN SUPPORTS FOR 'DO NOT ENTER' AND 'WRONG WAY' SIGNS

Wrong Way Traffic Control for Half Diamond Interchange Exit Ramp



SIGN TYPE	SIZE
DO NOT ENTER (R5–1)	48" X 48"
WRONG WAY (R5–1A)	42" X 30"
ONE WAY (R6–1L/R)	54" X 18"



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