Mitigating Wrong-Way Movements near Interchange Areas Using Access Management Techniques

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ABSTRACT
Past studies indicated that interchange configurations, access control, and geometric design are related to wrong-way driving (WWD) and minor ramp geometric changes can be effective in reducing the number of wrong-way entries onto freeways. In this paper, access management techniques and geometric elements, which are capable of discouraging wrong-way maneuvers, are identified and discussed. Additionally, every aspect of these elements, including interchange types, exit ramp terminals, frontage roads, raised medians, channelizing islands, and control radius, and their relationship to WWD is investigated. Furthermore, a survey questionnaire was also designed to ask professionals to rank these elements based on the level of attention they received in different jurisdictions. The aforementioned elements should be given special consideration during the design stage of interchanges and intersections.

Keywords: Wrong-Way Driving, Access Management, Geometric Design, Interchange
INTRODUCTION
Wrong-Way Driving (WWD) is defined as the driving movement against the main direction of traffic flow along high-speed, physically-divided highways (i.e., freeways, expressways, and interstate highways) and their access ramps (I – 4). An analysis on eight years of crash data (2004-2011), extracted from the Fatality Analysis Reporting System (FARS) database, revealed that an average of 359 victims result from 269 fatal WWD crashes in the United States annually (5 and 6). To reduce the possibility and severity of these types of crashes, many efforts have been made and various countermeasures have been implemented by state and local agencies. In addition to traffic signs, pavement markings, traffic signals, and intelligent transportation systems (ITS) technologies, various geometric design and access management techniques have also been found to yield promising results.

One of the primary goals of access management strategies is to provide a safer movement of vehicles while maintaining vehicular throughput and access to adjoining facilities and lands (7 – 11). In other words, a successful access management technique combines both design principles and engineering practices to satisfy movement and safety needs of road users. Therefore, access management techniques that can be applied as WWD countermeasures should also strive for achieving a balance between accessibility and mobility, while caring for safety. Following this effort, WWD requires further studies on various techniques and geometric elements, such as exit and entrance ramp characteristics, frontage roads, control radius, and sight distance. In this paper, these objects of study are identified to help reduce driver confusion near interchange areas, where a high proportion of wrong-way entries occur. Further studies are also conducted to determine their characteristics and to judge their effectiveness in reducing the possibility of wrong-way entries.

RESEARCH BACKGROUND
Several previous studies have addressed the application of access management to reduce WWD at intersections and interchange terminals. They have focused predominately on the effect of roadway geometric characteristics and modifications on the safety of the studied locations.

A recent study by the North Texas Tollway Authority (NTTA) investigated median modifications to reduce WWD incidents at one location in Dallas, Texas. The study location was identified to be the originating point of several WWD incidents, which were caused by the existence of a side street close to an exit ramp. This situation confused drivers turning left from the crossroad toward the side street, causing some of the drivers to enter the nearby exit ramp mistakenly. To mitigate WWD activities, the NTTA proposed closing the median opening to prohibit left turns into the side street from the crossroad. Table 1 shows the effect of median closure on WWD crash statistics at this location before and after improvement (5 and 12). As seen in the table, this modification eliminated the occurrence of WWD incidents associated with this location entirely.

| TABLE 1 Statistics of WWD Incidents before (2010) and after (2011, 2012) |
| Countermeasure Application by the NTTA |
| WWD Incidents | 2010 | 2011 | 2012 |
| Associated with This Location | 2 | 0 | 0 |
| In the Proximity Area without Hard Evidence Linking to This Location | 7 | 3 | 2 |
In their research, Chassande-Mottin and Ganneau (13) proposed to reduce the complexity of intersections connecting to interchanges by using various methods. The presence of more than one island at the exit ramp terminal was identified as an undesirable choice that may cause driver confusion; however, constructing roundabouts became a way to control access, while reducing the possibility of wrong-way entries on interstates.

Zhou et al. (2 and 14) collected and analyzed a six-year period of crash data from 2004 to 2009 in an attempt to identify contributing factors regarding WWD crashes on Illinois freeways. In their study, a total of 217 WWD crashes were used to determine contributing factors, as well as pertinent countermeasures for each specific location. Based on their findings, a series of modification grouped as geometric considerations were offered to control access near interchange areas and to handle the WWD issues. Using raised median and channelizing islands, increasing the distance from the gore of the exit ramp to the entrance ramp for partial cloverleaf interchanges, reducing the turning radius for wrong-way movements and not joining exit ramps to two-way frontage roads were among their suggestions. A guideline (3) for reducing wrong-way movements on freeways was also developed as the second phase of this project. This paper summarizes some key findings from the guideline on the application of access management techniques to reduce wrong-way entries near interchanges. These techniques are fully discussed in the following section.

ACCESS MANAGEMENT TECHNIQUES

Exit/Entrance Ramps

There are various possibilities to enter a freeway system in the wrong direction, such as executing a U-turn on the freeway mainline, crossing the median through an emergency turnaround, or entering from an exit ramp (1). Therefore, when it comes to WWD, exit ramps are critical points to consider for the application of access management techniques. Geometric attributes of exit ramps, such as layout, connecting angles with crossroad, and cross section, can reduce WWD activities at interchange terminals, if designed properly. For instance, adjacent exit and entrance ramps (parallel, side by side) may be more prone to wrong-way maneuvers. A side street or access driveway close to exit ramps may also cause driver confusion. Therefore, special consideration should be given to the geometric characteristics of exit ramps, for the purpose of making them less susceptible to WWD.

Another WWD-related characteristic of the exit ramp is the angle it connects to a roadway (crossroad or frontage), which depends on the functionality of the roadway (15). For example, if left turns from exit ramps are prohibited because of a connecting one-way roadway or the presence of a raised median on the roadway, an acute angle should be used to connect exit ramps to the roadway. Sweeping connections of exit ramps to crossroads, such as outer connections, loops, and some diamond ramps, are less susceptible to WWD. This is primarily due to the inherent capability of the formed acute angles with the crossroads, which causes turning movements in either direction difficult (16). 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.

Reducing ramp-throat width is another access management technique that can be effective in decreasing wrong-way entries. Raised channelizing islands are often used to fulfill this need. This change will make exit ramps uninviting to drivers, especially at multilane exit ramps. Additionally, 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 partial cloverleaf (parclo) interchanges (17 and 18).
In addition to these techniques, several types of exit ramps, their configuration, and nearby access points should be avoided as they are more susceptible to WWD, including:

- Adjacent entrance and exit ramps intersecting a crossroad (e.g., parclo interchanges);
- Isolated exit ramps (19 and 20);
- Left-side exit ramps (drivers usually expect to make right turns to enter freeways) (21);
- One-way exit ramps connected as unchannelized T-intersections (16);
- Exit ramps intersecting two-way frontage roads (22);
- 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 1) (16);
- Temporary ramp terminals at work zones (14);
- Freeway feeders (where exit ramps transition into local roads) (22); and
- Side streets adjacent to exit ramps (16).

![Figure 1 Button-hook ramp connected to parallel frontage road with proper (green) and wrong (red) movements.](image)

**Frontage Roads**

Frontage roads in the National Cooperative Highway Research Program (NCHRP) Report 420 are defined as one of the access management techniques used to reduce the frequency and severity of crashes on roadways (23). However, improper design and connections of frontage roads with freeway exit ramps may cause driver confusion and increase WWD incidents.

The connection of an exit ramp and a two-way frontage road has more safety issues (24) and is more vulnerable to WWD than to a one-way frontage road. A study by Schrock et al. (25) revealed that in cases of having both one-way and two-way frontage roads in a certain region, two-way frontage roads have a higher potential for making drivers confused and leading to wrong-way maneuvers. This result can be traced to the essential complexity of making turning movements at the intersections of exit ramps and two-way frontage roads versus the simplicity at one-way frontage roads.
A study by the Minnesota Department of Transportation (26) found that despite providing more favorable access from controlled-access highways to local streets, continuous multilane frontage roads with numerous intersections may be undesirable and may lead to a high potential for WWD crashes, especially on two-way frontage roads. The study also found that the slip ramps connected to two-way frontage roads at an acute angle offered a higher potential for WWD caused by the exit ramps resembling the extension of a frontage road, thus confusing drivers.

**Raised Median**

According to the AASHTO Green Book (16), a median is an elongated divisional island built as a portion of a highway, which serves primarily to separate opposing directions of traffic on the same roadway. These geometric elements have a fundamental capability for improving safety (27), managing access to freeways, and deterring wrong-way movements. For instance, the presence of raised medians or median barriers between two abutting exit and entrance ramps (i.e., in trumpet interchanges) can help avoid wrong-way entries (28).

A non-traversable median on a crossroad is an effective treatment to discourage wrong-way left-turn entry onto diamond, parclo, and full cloverleaf interchanges (16). This modification is sometimes implemented by narrowing median openings on arterial highways, making left-turn movements onto exit ramps extremely difficult.

Longitudinal channelization devices can also be used as low-cost countermeasures by transportation agencies to fulfill various permanent and temporary channelization needs. Figure 2 depicts a plan view of a location before treatment with longitudinal channelizer as a wrong-way entry countermeasure. This treatment was implemented by the Michigan Department of Transportation (MDOT) after relating approximately one-third of WWD crashes in 2010 to one specific location (29). Since June 2012, no WWD crashes were reported at this location after implementation of longitudinal channelization devices (Figure 3).

**FIGURE 2** Plan view of a treated intersection before treatment with proper (green) and wrong (red) movements.

Despite the benefits in removing undesirable turning movements, elongated raised medians should not be used to divide the same direction of traffic, making an offset channelized turning lane (16). This style may introduce potential WWD incidents because drivers tend to expect the raised median to separate two different directions of travel. Figure 4 shows a raised median installed to separate dual left-turns from thorough movements onto an exit ramp. The crash data
and field study of this location indicated that this type of design is misleading to drivers and has caused three WWD crashes, including one fatal crash, within a three-year time period (14).

FIGURE 3 Application of longitudinal channelization in restriction of left-turn access (29).

FIGURE 4 Raised median for separating same direction of traffic on an exit ramp.

Channelizing Islands
Channelizing islands define the desirable path, separate conflict points, and enhance safety near an intersection (30 and 31). These elements, in addition to their safety benefits (32), can also be used to block the prohibited turns at intersections wherever necessary and practical, including wrong-way turns, or at least discourage their completion.

Raised channelizing islands that are adequately reflectorized 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. Conversely, those channelizing islands that are not properly reflectorized can adversely affect older drivers’ vision and when struck, these islands might be a source of serious injuries and even fatalities (33). Vaswani (34) reported that the combination of channelization and corner radius (which will be discussed in the following subsection) impedes all wrong-way entries onto exit ramps.
When using channelizing islands, a height of at least four inches needs to be considered where it is intended to prohibit or prevent traffic movements, such as WWD. Lower height islands may prove unsatisfactory for their intended purpose and can be easily traversed (22).

Scissors channelization occurs when there is a two-way frontage road adjacent to the freeway and exit and entrance ramps are connected to the frontage road. This arrangement has proven to mislead drivers and has frequently resulted in wrong-way maneuvers (16). For these reasons, it is seldom used by highway designers.

**Control/Corner Radius**

The control radius of an intersection refers to the minimum left-turn path for a design vehicle that affects the radius of the intersection corner as well as the location and opening length of the median (35). The control radius can be used to prevent WWD at exit ramp terminals.

At the intersection of the left edge of exit ramps and the right edge of crossroads, a short-radius curve or angular break discourages wrong-way right turns from the crossroads. While circular curves with larger radii may encourage a wrong-way right turn onto the exit ramp, the angular corner or tight radii make this movement difficult (33). This can also be implemented using pavement markings instead. A study on this countermeasure in Virginia proved promising results after treatment. In other words, an intersection with six wrong-way entries by sober drivers over two years was nominated for improvement. After this change in the configuration, wrong-way movements were completely eliminated in the following 1.5 years (36).

When considering this element, ensuring that the control radius is tangent to the crossroad centerline and not tangent to the edge is critical. Having the control radius tangent to the centerline (and not the edge) makes wrong-way right-turning movements less likely (16). This design element can define the raised median opening and position it to extend far enough to make the wrong-way left turn an awkward move. The red, curved line in Figure 5 is tangent to the centerline of the roadway.

![Figure 5 Control radius (red curve) tangent to the centerline at a ramp-crossroad intersection (Map data: Google).](image-url)
Providing drivers with an 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 also helps them distinguish between entrance and exit ramps (i.e., when they are closely spaced) by the approaching right-way drivers’ headlamps.

Moreover, uniform lighting levels for both entrance ramps and exit ramps facilitate drivers’ vision of intersection, improve their perception of intersection configuration, and lessen, if not eliminate, the possibility of wrong-way movements (14).

Another way to improve crossroad left turns’ sight distance at the intersection of two-way ramps and crossroads (i.e., parclo interchanges) is to move stop lines forward, so that motorists have a better view of the entrance ramp and improve their turning radius. A good practice is to locate the stop line between 50% and 60% of the way through the intersection (Figure 6) to provide an appropriate intersection balance (33).

Excessive grade differentials between ramps (i.e., exit ramp or two-way ramp) and crossroads should be avoided. A large difference between grades of ramps and crossroads can lead to a sight distance problem and increase the likelihood of WWD.

The presence of barriers on interchange ramps may introduce safety hazards to road users (37); therefore, median barriers should not be extended all the way to the stop line on two-way ramps because they might block the drivers’ view of the entrance ramp. A recent study (38) showed that a guardrail installed between two adjacent exit and entrance ramps, as a median barrier, blocked the left-turn drivers’ view of the entrance ramp terminal and increased the possibility of making a wrong turn onto the exit ramps, potentially resulting in an increase in WWD crashes.

**GEOMETRIC DESIGN ELEMENT RANKING**

In addition to these efforts, a survey questionnaire was compiled and distributed to representatives from the states who participated in the 2013 National Wrong-way Driving Summit (39). This survey questionnaire was designed to gather all the relevant information about the most up-to-date WWD countermeasures, as well as the most recent practices; therefore, a part of it was assigned to geometric design elements. In this section, respondents were asked to rank those aforementioned geometric design elements with reference to the level of given attention in their jurisdiction.
Afterward, these individual rankings were combined together using weighted percentage to get to a final, weighted ranking. As would be expected, exit ramps (i.e., their angle with crossroad, their shape such as button-hook or J-shaped, etc.), because they constitute the most frequent origin of wrong-way driving incidents, were ranked the top priority. Channelizing islands were the second most important geometric considerations and control radius at ramp-crossroad intersection and application of medians and their openings were the third and fourth remarkable geometric elements, respectively. Finally, frontage roads (i.e., their continuity, outer separation, one-way vs. two-way, etc.) were also the next geometric considerations for wrong-way mitigation. Sight distance, however, does not receive enough attention in this context, according to the survey questionnaire, ranking it last on the list. Table 2 summarizes these findings with their corresponding weighted ranking.

### TABLE 2 Ranking of Various Geometric Elements based on Weighted Percentage

<table>
<thead>
<tr>
<th>Geometric Element</th>
<th>Weighted Percentage</th>
<th>Weighted Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit Ramps</td>
<td>75.0</td>
<td>1</td>
</tr>
<tr>
<td>Channelizing Islands</td>
<td>58.3</td>
<td>2</td>
</tr>
<tr>
<td>Control Radius</td>
<td>50.9</td>
<td>3</td>
</tr>
<tr>
<td>Medians</td>
<td>47.2</td>
<td>4</td>
</tr>
<tr>
<td>Frontage Roads</td>
<td>37.0</td>
<td>5</td>
</tr>
</tbody>
</table>

**CONCLUSION**

This study identified and summarized various access management techniques and geometric elements, which are often used to reduce WWD incidents near interchange areas. Each of the identified elements plays its own role in the context of WWD. Exit/entrance ramps were found the most important elements according to the survey questionnaire; however, their types, connecting angles with crossroads, and nearby access control are related to WWD activities. A review of the studies has shown promising results in combating WWD using ramp treatments. Channelizing islands, as the second most important geometric element can narrow multilane exit ramp throats to make them less inviting, guiding traffic through the two-way ramps. This element, combined with control/corner radius as the third important element based on the survey, is also observed to diminish the possibility of wrong-way entries completely. Therefore, it can be said that a short-radius curve or an angular break as a control/corner radius not only makes the wrong-way right turn less likely, but it also defines the width of the ramp throat, reducing the appeal. Raised medians, as the next important factors, are effectively capable of controlling/restricting wrong-way left-turn access into exit ramps. The research from Michigan demonstrated the capability of hindering wrong-way maneuvers in an experimental location. Following raised medians, frontage roads do not get sufficient attention, despite being identified as vulnerable to wrong-way entries. This lack of attention persists while previous studies have proven encouraging outcomes after frontage road treatment, such as making a one-way frontage road instead of a two-way, in terms of reducing the frequency of wrong-way movements. Providing an open sight distance at the ramp-crossroad intersection helps drivers to distinguish exit ramps from entrance ramps, especially when they are close in proximity. Avoiding excessive grade differentials and proper stop line placement can be helpful for improving sight distance.
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