Wrong-Way Driving on Freeways: Problems, Issues, and Countermeasures

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Scott A. Cooner, P.E.
Associate Research Engineer/Program Manager
Texas Transportation Institute
110 North Davis Dr. Suite 101
Arlington, Texas 76013
Tel: 817-261-1661 ext. 525
Fax: 817-461-1239
E-mail: s-cooner@tamu.edu

Stephen E. Ranft
Engineering Research Associate
Texas Transportation Institute
110 North Davis Dr. Suite 101
Arlington, Texas 76013
Tel: 817-261-1661
Fax: 817-461-1239
Email: s-ranft@tamu.edu
ABSTRACT

Drivers who make wrong-way entries onto freeways pose a serious risk to the safety of other motorists and themselves. Wrong-way driving often leads to head-on collisions. Wrong-way crashes are relatively infrequent but are more likely to produce serious injuries and fatalities compared to other types of crashes and often result in significant media attention. Driving the wrong way on freeways has been a nagging traffic safety problem since the interstate highway system was started in the 1950s. On average, approximately 350 people are killed each year nationwide in wrong-way freeway crashes according to data from the Fatality Analysis Reporting System (FARS). Despite over forty years of highway design, marking, and signing improvements at freeway interchanges, the problem still persists and annual fatalities are rising.

In response to this issue, the Texas Department of Transportation sponsored a research project to evaluate the most effective traditional and innovative countermeasures throughout the United States to reduce wrong-way movements. Data from previous studies and a detailed study of 4 years of wrong-way crashes on freeways Texas was used to develop a typical wrong-way crash profile. The paper documents best practices nationwide and provides recommended guidelines for use of the most effective wrong-way countermeasures. A checklist for engineers and field crews to use for reviewing wrong-way entry issues or suspected problem locations is also provided.
INTRODUCTION

Drivers who make wrong-way entries onto freeways or other restricted roadways pose a serious risk to the safety of other motorists and themselves. Wrong-way driving often leads to the most feared of traffic crashes, the head-on collision. Wrong-way crashes are relatively infrequent but they are more likely to produce serious injuries and fatalities compared to other types of freeway crashes. Recent statistics from the Fatality Accident Reporting System (FARS) database maintained by the National Highway Traffic Safety Administration (NHTSA) indicate that approximately 350 people are killed each year in wrong-way crashes on freeways in the United States (1) (see FIGURE 1). Driving the wrong way on freeways has been a nagging traffic safety problem since the interstate highway system was started in the late 1950s. Despite over forty years of highway design, marking, and signing improvements at freeway interchanges, the problem of wrong-way driving persists.

Several crashes in the TxDOT Fort Worth District have brought attention to the severity and hazard of wrong-way drivers. A search of newspaper articles revealed that the problem of wrong-way driving is not unique to Fort Worth and occurs throughout the state of Texas. Members of the Fort Worth Traffic Management Team (TMT) identified locations with a history of frequent wrong-way entries and made an assessment of potential countermeasures. During this review process it was determined that research was needed to understand and develop effective countermeasures for wrong-way movements onto freeways and other restricted roads.

TTI was chosen to perform the study and performed the following tasks during the 0-4128 Countermeasures for Wrong-Way Movement research project:

1. **State-of-the-practice literature review:** established state-of-the-practice on safety, design, and operational issues for wrong-way movement on freeways;
2. **Survey of current practice:** surveyed states to get information on typical wrong-way signing and marking and any innovative practices;
3. **Texas freeway wrong-way crash analysis:** quantified the frequency, severity, and other important characteristics of wrong-way crashes in Texas based on a review of crash report;
4. **Available wrong-way countermeasures:** identified available countermeasures to reduce wrong-way movements and crashes and assessed the feasibility/applicability of these countermeasures to address Texas problems;
5. **Typical problem areas:** documented typical situations that were more likely to produce wrong-way entry issues; and
6. **Wrong-way countermeasure guidelines:** Developed guidelines and recommended practices for application of wrong-way countermeasures and treatments.

STATE-OF-THE-PRACTICE LITERATURE REVIEW

The state-of-the-practice literature review revealed that a significant amount of the research associated with wrong-way driving on freeway facilities occurred in the late 1960s to late 1970s. The three states with the most extensive research on the subject of wrong-way driving on freeways were California, Georgia and Washington. Researchers gathered information from previous studies of wrong-way crashes to create a profile of a typical wrong-way crash on freeways. A compilation of previous research findings suggested a profile with six common elements for wrong-way crashes on freeways.
Profile Element #1 – Exit ramps are the most frequent origin of wrong-way entry

One of the most important aspects of studying wrong-way crashes is the attempt to identify where the driver first turned the wrong direction on the roadway. Several studies have utilized information sources such as police crash reports, surveys, and images from camera surveillance systems to determine where a wrong-way movement originated. According to previous studies, the most frequent origin of wrong-way incidents is the freeway exit ramp (i.e., a driver travels the opposite direction on an exit ramp onto the freeway main lanes). The following list highlights some of the wrong-way movement origination study findings:

- A Vaswani study of Virginia interstates (1970-1976) found that about 50 percent of wrong-way entries originated from interchanges; about 15 percent were at crossovers and rest stops or were related to u-turns and median crossings; and the remainder had unknown origins.
- A study of wrong-way driving on Dutch motorways found that information about the locations where the wrong-way movement originated was available in 53 percent of the total wrong-way crashes. Of those whose location was known, about 46 percent started by entering the exit road, 37 percent by making a u-turn on the carriageway or exit road, and the remaining 17 percent by some other maneuver involving turning around.
- The study of 129 wrong-way crashes in Japan determined that 39 percent originated in the vicinity of interchanges/junctions, 27 percent started from service and parking areas, 21 percent occurred on the main road, 10 percent originated in the vicinity of a toll booth, and the remaining 3 percent had an unspecified starting point.

Profile Element #2 – Increased severity

Wrong-way crashes tend to be more severe and have a greater proportion resulting in death or serious injury than most other crash types on freeway facilities. It has been reported that out of 100 wrong-way crashes, 62.7 result in an injury or fatality, versus 44.2 out of 100 for all freeway or expressway crashes. Vaswani found that the fatality rate for wrong-way crashes was 31 times greater on interstates and 10 times greater for all other freeways in Virginia. Similarly, Copelan determined that the fatality rate was 12 times greater for wrong-way crashes compared to all other crashes on California freeways in 1987. These studies highlight and confirm the fact that wrong-way crashes tend to be more severe and have a greater proportion resulting in death or serious injury than most other crash types on freeway facilities.

Profile Element #3 – Elderly drivers are over-represented

Elderly drivers are over-represented compared to their proportion of the driving population and their proportion of involvement in other crashes. Lew reported that drivers ages 70 to 79 experience over twice the number of freeway wrong-way related crashes than would be expected based on their proportion of the driving population. The Older Driver Highway Design Handbook indicates that age-diminished capabilities contributing to wrong-way movements include the cognitive capabilities of selective and divided attention and the sensory/perceptual capabilities of visual acuity and contrast sensitivity.

Profile Element #4 – Males more likely than females

The role of driver sex (i.e., male or female) is also an important factor examined in previous wrong-way crash studies. Several studies have concluded that male drivers are involved in significantly more wrong-way crashes than female drivers.
Profile Element #5 – Drivers are often impaired
The role of alcohol and/or drug involvement by drivers on wrong-way crashes has also received a significant amount of evaluation in previous studies. It seems intuitive that a significant portion of drivers that end up going the wrong-way on freeways would be driving under the influence of drugs or alcohol. The frequency of driver impairment in wrong-way crashes has varied in the studies evaluated during the literature review; however, it is apparent that all suggest that the frequency is higher than for most other crash types on freeway facilities. The following list highlights some of the driver impairment frequency data gathered from previous studies:

- The Copelan study found that impaired drivers were involved in almost 60 percent of all wrong-way crashes and almost 77 percent of fatal wrong-way crashes on California freeways from 1983 to 1987 (5).
- A Washington DOT study indicated that 50 percent of the 30 wrong-way crashes in an interstate corridor were alcohol- or drug-related (7).
- A 1977 study of wrong-way driving in Virginia found that over 50 percent of wrong-way drivers on interstates (152 of 287) were driving under the influence (2).
- An analysis of wrong-way crashes in the state of Indiana during the 1970 to 1972 time period showed that approximately 55 percent (42 of 77) of drivers were impaired (8).

Each of the studies reviewed by the research team suggest that approximately 50 to 75 percent of wrong-way crashes involve impaired drivers that had been drinking or were driving under the influence of alcohol or drugs.

Profile Element #6 – Crashes frequently occur during the early morning hours
Examination of when wrong-way crashes occur is important in determining appropriate engineering and enforcement countermeasures. Several prior studies have investigated the time of day occurrence of wrong-way crashes. The following list summarizes some of the key time of day data gathered from previous studies:

- The Copelan study found that numbers of wrong-way crashes are higher in the evening than in daylight hours and the peaking of fatal wrong-way crashes occurs around 2 a.m. (closing time for bars in California) (5).
- An analysis of wrong-way crashes in the state of Indiana during the 1970 to 1972 time period showed that they occur most frequently on Fridays, Saturdays, and Sundays and also between 6:00 p.m. and 4:00 a.m. (8).

Both studies seem to suggest that wrong-way crashes are more prevalent during non-daylight hours, particularly in the early morning hours.

SURVEY OF CURRENT PRACTICE
A survey gathered information regarding current practices for signing and pavement marking and other treatments to prevent wrong-way driving. Respondents to the survey included 29 state DOTs and 12 TxDOT Districts. Some of the key findings included:
Most state DOTs used the standard DO NOT ENTER (DNE) and WRONG WAY (WW) signs and WW pavement arrows from the Manual on Uniform Traffic Control Devices (MUTCD).

Three states used lowered DNE and WW signs mounted together on the same post. The rationale for this countermeasure was that the vast majority of wrong-way crashes occurred at night and lowered signs are more visible if placed within the area covered by a vehicle’s headlights and visible to the driver from the decision point on each likely approach. The survey also revealed that there were no crash tests to support the safety of the lowered mounting height.

TEXAS FREEWAY WRONG-WAY CRASH ANALYSIS

The research team obtained the original Texas Peace Officer Accident Reports (ST-3s) for wrong-way crashes that occurred in Texas from January 1, 1997, to December 31, 2000. Researchers performed a review of each crash to determine which ones were related to the freeway main lanes and/or ramps (9). This process resulted in the examination of 323 freeway-related wrong-way crashes over the 4-year analysis period (see TABLE 1). The Texas wrong-way crash data profile revealed the following:

- Crashes were five times more likely to occur during early morning hours (i.e., 12:00 to 5:59 a.m.) versus the statewide average for all crashes. Also, the most frequent time for wrong-way crashes (16.7 percent) was the 2:00 to 2:59 a.m. hour that corresponds to closing time of most Texas bars (see TABLE 2).
- Approximately 50 percent of crashes resulted in an incapacitating injury or fatality, which is significantly higher than the statewide severity proportion for all other types of crashes. TABLE 3 provides the severities of the crashes included in the analysis. The data suggest that wrong-way crashes account for a serious economic impact of almost $21 million per year based on the average cost of crashes used by TxDOT.
- Males accounted for slightly over two-thirds of the wrong-way drivers, and almost half of the wrong-way drivers were under the age of 34 (see TABLE 4).
- Almost 61 percent of the wrong-way drivers had some influence of alcohol and/or drugs cited by the investigating officer (see TABLE 5). Further analysis of the frequency of the wrong-way drivers that were under the influence revealed several other notable issues. During the early morning hours (midnight to 6:00 a.m.) the percentage of wrong-way drivers that were under the influence increased to about 73 percent. Seventy-three percent of the wrong-way drivers involved in the fatal crashes were also cited for some involvement of alcohol and/or drugs. Finally, wrong-way drivers with Hispanic surnames were cited slightly over 77 percent of the time as having some influence of alcohol and/or drugs.
- For approximately one out of every three crashes, researchers were able to get some specific information from the investigating officer’s diagram and narrative about where the wrong-way movement first occurred. This information is important because it makes it easier to inventory existing treatments and to develop ideas for other countermeasures based on a specific location.

In addition to the crash statistics from the Department of Public Safety (DPS) database, researchers obtained information from 911 public safety answering points (PSAPs) regarding reports they receive about wrong-way drivers, typically from other drivers with wireless phones.
Officials from three PSAPs provided information (e.g., roadway where wrong-way movement was observed, time of day, direction of travel, etc.) on wrong-way driving reports that occurred on freeways in their jurisdictions. Some of the findings from this effort included:

- The two smaller PSAPs averaged one to two reports of wrong-way drivers on freeways per month over the one-year monitoring period.
- The large PSAP had a range of four to ten reports of wrong-way drivers on freeways per month.
- The common protocol was to dispatch a nearby officer to the location of the reported driver; however, in most cases the officer never encountered the wrong-way vehicle.
- There were only a few cases in which the report was followed by a crash. In most cases the wrong-way drivers eventually corrected themselves and proceeded in the right direction.

AVAILABLE WRONG-WAY COUNTERMEASURES

The research team gathered information on wrong-way countermeasures and treatments using published studies, Internet searches, and the DOT surveys (9). To facilitate the evaluation of feasibility and potential effectiveness, the countermeasures and treatments were divided into four categories: (1) traditional countermeasures, and (2) innovative countermeasures.

Traditional Signing and Pavement Marking Countermeasures

Traditional signing and pavement marking countermeasures included DNE and WW signs on separate posts, oversized DNE and WW signs, red-backed raised pavement markers, WW pavement arrows, yellow edge lines on left sides of exit ramps, one-way signs, and turn restriction signs (see FIGURE 2). Researchers also identified several geometric treatments aimed at discouraging wrong-way entries onto freeway facilities. The two most prominent were offset entrance and exit ramps and off-ramp throat reductions.

Innovative Signing and Pavement Marking Countermeasures

Innovative signing and pavement marking treatments included lowered DNE and WW signs mounted together on the same post, supplemental placards or flashers on the DNE and WW signs, overhead-mounted DNE and WW signs, internally illuminated DNE and WW signs, non-standard WW pavement arrows, WW pavement lights, red reflective tape on the backs of freeway signs, and red delineators on each side of the ramp up to the WW sign (see FIGURE 3). Researchers obtained information on ITS applications for wrong-way detection and warning being used in California, Florida, New Mexico (FIGURE 4), and Washington (FIGURE 5).

TYPICAL PROBLEM AREAS

Based on the review of crashes for which some specific information on wrong-way origin was available, researchers developed a list of typical problem locations (9). This analysis showed:

- Most of the collisions occurred in the inside lane (i.e., leftmost) of the correct direction. This seems logical when you consider that the wrong-way drivers are staying as far to the right as possible just like they normally would if they were going the right way.
• Several locations with left-side exit ramps produced multiple wrong-way crashes during the analysis period — this finding suggests that further countermeasures might need to be considered at locations with left-side exit ramps.
• Another problem type occurs when a one-way street, typically in a downtown area, transitions directly into a freeway section. Several locations with this configuration experienced multiple wrong-way crashes during the analysis period.
• In a few situations, staged construction freeways had wrong-way crashes during the time period when only the frontage roads were in place. The large offset distance between the frontage roads and lack of main lanes may create a confusing situation that needs to be carefully considered for appropriate countermeasures.
• The majority of crashes occurred in major urban areas, with slightly more than 60 percent in the three largest metropolitan areas — Dallas/Fort Worth, Houston, and San Antonio.

GUIDELINES FOR WRONG-WAY COUNTERMEASURES
Based on the results of the literature review, surveys, analysis of freeway-related wrong-way crashes in Texas, and evaluation of available countermeasures, the research team developed some guidelines for wrong-way treatments and countermeasures (10):

• Install reflectorized wrong-way pavement arrows on left-side exit ramps because they are a problem area for wrong-way entry.
• Revise the TxDOT Typical Standard Freeway Pavement Markings with Raised Pavement Markers Standard Plans Sheet FPM (1)–00A wrong-way arrow detail (FIGURE 6). Change “reflectorized wrong-way arrows, not to exceed two, may be placed on exit ramps” to “reflectorized wrong-way arrows, not to exceed two, should be placed on exit ramps for new construction and at locations with multiple wrong-way entries per year.”
• Repair deficient wrong-way pavement arrows (FIGURE 7) and make their maintenance a priority, particularly in the urban districts of Dallas/Fort Worth, Houston, and San Antonio to address urban and alcohol problem locations.
• Consider the use of lowered DO NOT ENTER and WRONG WAY signs mounted together on the same post to address alcohol and nighttime problem locations.
• Develop a wrong-way crash monitoring system and field review similar to the California Department of Transportation (Caltrans) process.

RECOMMENDATIONS
The research team recommends the following actions as a result of this project:

1. Further research on the crashworthiness and alternative designs for DO NOT ENTER and WRONG WAY signs mounted at lower than standard heights together on the same post;
2. Coordination between TxDOT Traffic Management Centers (TMCs) in the urban areas (i.e., Austin, Dallas, Fort Worth, El Paso, Houston, and San Antonio) and the primary 911 public safety answering points to share information on reports of wrong-way movements on freeway facilities (if the information sharing is in real time, further research is needed to examine what, if any, type of warning should be given to motorists traveling in the correct direction in the vicinity of the wrong-way driver); and
3. Consideration of implementing inductive loops or other detectors on exit ramps in future construction (these detectors could be used for wrong-way detection and could also be used for traffic counts). This countermeasure was adopted on the new Westpark Tollway in Houston, Texas following several high-profile wrong-way crashes that produced multiple fatalities (9).

Further information on the research findings and recommendations can be found in the project reports which are available for download at the TTI website – [http://tti.tamu.edu/product/](http://tti.tamu.edu/product/) (10, 11 and 12).

Finally, the research team believes that the application of findings from this research extend beyond Texas. The fatality data summarized in FIGURE 1 show that wrong-way driving is still a significant nationwide issue and many of the Texas problems (alcohol involvement, left hand ramps, etc.) are likely similar to those in other states. This belief has been substantiated somewhat by members of the research team being contacted by representatives from several state DOTs and news media representatives confirming similar issues in their local jurisdictions.

ACKNOWLEDGEMENTS
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- Linden Burgess, TxDOT Dallas District;
- Michael Chacon, TxDOT Traffic Operations Division;
- Wade Odell, TxDOT Research and Technology Implementation Office;
- Grover Schretter, TxDOT Fort Worth District; and
- Ronnie Varnell, City of Fort Worth.

The authors also appreciate the time and contributions of 911 public safety representatives, product vendors, and state department of transportation representatives.
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### TABLE 1  Summary of Wrong-Way Crash Data Obtained from the Department of Public Safety

<table>
<thead>
<tr>
<th>Year</th>
<th>TOTAL</th>
<th>Main Lane and/or Ramp</th>
<th>Other (Arterial, Frontage Road, etc.)</th>
</tr>
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<tbody>
<tr>
<td>1997</td>
<td>194</td>
<td>87</td>
<td>107</td>
</tr>
<tr>
<td>1998</td>
<td>176</td>
<td>83</td>
<td>93</td>
</tr>
<tr>
<td>1999</td>
<td>184</td>
<td>96</td>
<td>88</td>
</tr>
<tr>
<td>2000</td>
<td>96</td>
<td>57</td>
<td>39</td>
</tr>
<tr>
<td>Totals</td>
<td>650</td>
<td>323</td>
<td>327</td>
</tr>
</tbody>
</table>
TABLE 2 Analysis of Wrong-Way Crashes Occurring During Early Morning Hours

<table>
<thead>
<tr>
<th>Time of Day (a.m.)</th>
<th># of Wrong-Way Crashes</th>
<th>Percentage of Total Wrong-Way Crashes</th>
<th>Percentage of Total Crashes Statewide</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 to 12:59</td>
<td>26</td>
<td>8.0</td>
<td>2.2</td>
</tr>
<tr>
<td>1:00 to 1:59</td>
<td>39</td>
<td>12.1</td>
<td>2.0</td>
</tr>
<tr>
<td>2:00 to 2:59</td>
<td>54</td>
<td>16.7</td>
<td>2.5</td>
</tr>
<tr>
<td>3:00 to 3:59</td>
<td>23</td>
<td>7.1</td>
<td>1.5</td>
</tr>
<tr>
<td>4:00 to 4:59</td>
<td>17</td>
<td>5.3</td>
<td>1.0</td>
</tr>
<tr>
<td>5:00 to 5:59</td>
<td>9</td>
<td>2.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Totals</td>
<td>168</td>
<td>52.0</td>
<td>10.4</td>
</tr>
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</table>
### TABLE 3 Crash Severity Distribution for Wrong-Way Crashes in Texas (1997 - 2000)

<table>
<thead>
<tr>
<th>Crash Severity</th>
<th>Number of Crashes</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible Injury</td>
<td>84</td>
<td>26.0</td>
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<tr>
<td>Nonincapacitating</td>
<td>80</td>
<td>24.8</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>96</td>
<td>29.7</td>
</tr>
<tr>
<td>Fatal</td>
<td>63</td>
<td>19.5</td>
</tr>
<tr>
<td>TOTALS</td>
<td>323</td>
<td>100.0</td>
</tr>
</tbody>
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TABLE 4 Wrong-Way Driver Sex and Age Distributions for Crashes in Texas

<table>
<thead>
<tr>
<th>Driver Sex</th>
<th>Number of Drivers</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>216</td>
<td>66.9</td>
</tr>
<tr>
<td>Female</td>
<td>88</td>
<td>27.2</td>
</tr>
<tr>
<td>Unknown</td>
<td>19</td>
<td>5.9</td>
</tr>
<tr>
<td>TOTALS</td>
<td>323</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Number of Drivers</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 to 24</td>
<td>67</td>
<td>20.8</td>
</tr>
<tr>
<td>25 to 34</td>
<td>88</td>
<td>27.2</td>
</tr>
<tr>
<td>35 to 44</td>
<td>55</td>
<td>17.0</td>
</tr>
<tr>
<td>45 to 54</td>
<td>30</td>
<td>9.3</td>
</tr>
<tr>
<td>55 to 64</td>
<td>24</td>
<td>7.4</td>
</tr>
<tr>
<td>Over 65</td>
<td>41</td>
<td>12.7</td>
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<tr>
<td>Unknown</td>
<td>18</td>
<td>5.6</td>
</tr>
<tr>
<td>TOTALS</td>
<td>323</td>
<td>100.0</td>
</tr>
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</table>
TABLE 5 Influence of Alcohol and Drugs on Wrong-Way Drivers

<table>
<thead>
<tr>
<th>Driver Influence</th>
<th>Number of Drivers</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>196</td>
<td>60.7</td>
</tr>
<tr>
<td>No</td>
<td>127</td>
<td>39.3</td>
</tr>
<tr>
<td>TOTALS</td>
<td>323</td>
<td>100.0</td>
</tr>
</tbody>
</table>

1 A wrong-way driver was considered as under the influence of alcohol and/or drugs if one or more of the following items were cited on the crash report by the investigating officer:

- contributing factor code 45: had been drinking, or
- contributing factor code 67: under influence – alcohol, or
- contributing factor code 68: under influence – drugs, or
- the alcohol/drug analysis result indicated a presence of a substance in the driver’s blood.
FIGURE 1 Frequency of Wrong-Way Fatalities for Crashes on United States Freeways (I)
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FIGURE 3 Examples of Innovative Wrong-Way Countermeasures
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