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16. 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. Driving the wrong way on freeways has been a nagging traffic safety problem since the interstate highway system was started in the 1950s. Despite over forty years of highway design, marking, and signing improvements at freeway interchanges, the problem still persists.

Several crashes in the Texas Department of Transportation (TxDOT) Fort Worth District have brought attention to the 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 Texas. Members of the Fort Worth Traffic Management Team (TMT) identified locations with a history of wrong-way entries and assessed 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. This research provides TxDOT staff with preventative measures for reducing the frequency and severity of wrong-way entries onto freeway facilities throughout Texas. Researchers performed the following tasks during the project:

- Established state-of-the-practice on safety, design, and operational issues for wrong-way movement on freeways;
- surveyed state DOTs to get information on typical wrong-way signing and marking and any innovative practices;
- quantified the frequency, severity, and other important characteristics of wrong-way crashes in Texas based on a review of crash reports and coordination with 911 public safety answering points;
- identified available countermeasures to reduce wrong-way movements and crashes;
- evaluated the feasibility and applicability of the available countermeasures to address Texas problems;
- documented typical situations that were more likely to produce wrong-way entry issues;
- developed guidelines/recommended practices for application of wrong-way countermeasures and treatments; and
- developed a checklist for field crews to use for reviewing wrong-way entry issues or suspected problem locations.

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COUNTERMEASURES FOR WRONG-WAY MOVEMENT ON FREEWAYS: OVERVIEW OF PROJECT ACTIVITIES AND FINDINGS

by

Scott A. Cooner, P.E.
Associate Research Engineer
Texas Transportation Institute

A. Scott Cothron
Associate Transportation Researcher
Texas Transportation Institute

and

Steven E. Ranft
Engineering Research Associate
Texas Transportation Institute

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The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

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- 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.

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LIST OF ABBREVIATIONS

AC	Alternating Current
ARS	Active Road Signs
ATR	Alliance for Transportation Research
BAC	Blood Alcohol Concentration
BPD	Beaumont Police Department
CAD	Computer Aided Dispatch
Caltrans	California Department of Transportation
CCTV	Closed Circuit Television
DC	Direct Current
DFW	Dallas/Fort Worth
DOT	Department of Transportation
DPS	Department of Public Safety
DTSS	Directional Traffic Sensor System
DWI	Driving While Intoxicated
FARS	Fatality Accident Reporting System
FHWA	Federal Highway Administration
FWPD	Fort Worth Police Department
HES	Hazard Elimination Program
IITS	Internally Illuminated Traffic Signs
ITARDA	Institute for Traffic Accident Research and Data Analysis
ITS	Intelligent Transportation System
LED	Light Emitting Diode
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
PMC	Project Monitoring Committee
PSAP	Public Safety Answering Point
RPD	Richardson Police Department
RPM	Raised Pavement Marker
SCRI	Southern California Research Institute
TDL	Texas Driver License
TMC	Traffic Management Center
TMT	Traffic Management Team
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
VCR	Videocassette Recorder
VHTRC	Virginia Highway Transportation Research Council
UMass	University of Massachusetts
US	United States
VMS	Variable Message Sign
WsDOT	Washington Department of Transportation

CHAPTER 1. INTRODUCTION

BACKGROUND AND SIGNIFICANCE OF RESEARCH

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 (see Figure 1). Wrong-way crashes are relatively infrequent but they are more likely to produce serious injuries and fatalities compared to other types of freeway crashes. 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. This research will provide TxDOT staff with preventative measures for reducing the frequency and severity of wrong-way entries onto freeway facilities throughout the state of Texas.

Figure 1. Picture of Vehicle Involved in Wrong-Way Crash.

RESEARCH EFFORTS

The research team developed a work plan for this project with the goal of producing guidelines and recommended practices to reduce wrong-way crashes and movements in Texas. Based on this goal, researchers performed the following tasks:

- established the state-of-the-practice on safety, design, and operational issues related to wrong-way movement on freeways based on review of previous and ongoing studies;
- surveyed state Departments of Transportation (DOT) representatives to gather information on typical wrong-way signing and marking plans and any innovative practices or countermeasures;
- quantified the frequency, severity, and other important characteristics of wrong-way crashes in Texas based on a review of Department of Public Safety (DPS) crash reports and coordination with 911 public safety answering points (PSAPs);
- documented typical situations that were more likely to produce wrong-way entry issues;
- identified available countermeasures to reduce wrong-way movements and crashes;
- evaluated the feasibility and applicability of the available countermeasures to address Texas problems;
- developed guidelines and recommended practices for the application of wrong-way countermeasures and treatments; and
- developed a checklist for engineers and field crews to use for reviewing wrong-way entry issues or suspected problem locations.

REPORT ORGANIZATION

This report is divided into six chapters. Chapter 1 contains the background and significance of this research and the summary of the primary research efforts.

Chapter 2 (State-of-the-Practice Literature Review) documents the review of literature on issues associated with wrong-way driving on freeway facilities. This chapter concentrates on studies that have quantified the problem of wrong-way driving with monitoring programs and by analyzing crash data.

Chapter 3 (Synthesis of National and Texas Surveys) summarizes the results of surveys of state DOTs to gather information on typical wrong-way signing and marking plans and use of any innovative practices or countermeasures.

Chapter 4 (Analysis of Freeway-Related Wrong-Way Crashes in Texas) contains the results of the wrong-way crash analysis. This chapter documents the frequency, severity, and other important characteristics of each freeway-related wrong-way crash in Texas during the 1997 through 2000 time period. This chapter also gives some insight on typical situations that are more likely to produce wrong-way entry issues based on the analysis of wrong-way origination data.

Chapter 5 (Identification and Assessment of Wrong-Way Driving Countermeasures) outlines the available countermeasures and treatments designed to reduce wrong-way entries and crashes.

This chapter also provides information on the feasibility and applicability of the available countermeasures and treatments based on cost information and potential to address Texas problems.

Chapter 6 (Guidelines and Recommended Practices for Application of Wrong-Way Countermeasures) provides the guidelines and recommended practices for the most applicable wrong-way countermeasures and treatments for TxDOT. This chapter also contains a checklist tool developed for engineers and field crews to use for reviewing wrong-way entry issues or suspected problem locations.

CHAPTER 2. STATE-OF-THE-PRACTICE LITERATURE REVIEW

This chapter summarizes important research conducted on wrong-way driving issues in published studies. The first section addresses studies that have quantified the problem of wrong-way driving with monitoring programs. The second section describes some of the studies that have quantified the problem of wrong-way driving by analyzing crash data.

MONITORING OF WRONG-WAY MOVEMENTS

The research team found several studies that documented wrong-way movements, primarily on freeway exit ramps. In each study, researchers monitored and documented wrong-way movements at exit ramps using either still or video-based camera systems.

California

In 1967 the California Department of Transportation (Caltrans) developed a wrong-way camera which, when installed on an exit ramp, counted and took a snapshot of every wrong-way entry (*1*, *2*). The typical wrong-way camera system consisted of a Kodak Instamatic camera, a steel box that rested on the ground chained to a pole, and a pair of closely-spaced road tubes stretched across the ramp (see Figure 2). The pair of road tubes was used to detect wrong-way vehicles. Right-way vehicles crossing the tubes in the correct sequence were ignored by the system. However, when a wrong-way vehicle crossed the tubes it triggered the camera and a digital counter. The wrong-way camera system was designed to appear to be an ordinary volume-count station. The only visible differences in the wrong-way camera system and a volume-count station were the small glass window in the steel box for the camera and the presence of two tubes instead of one.

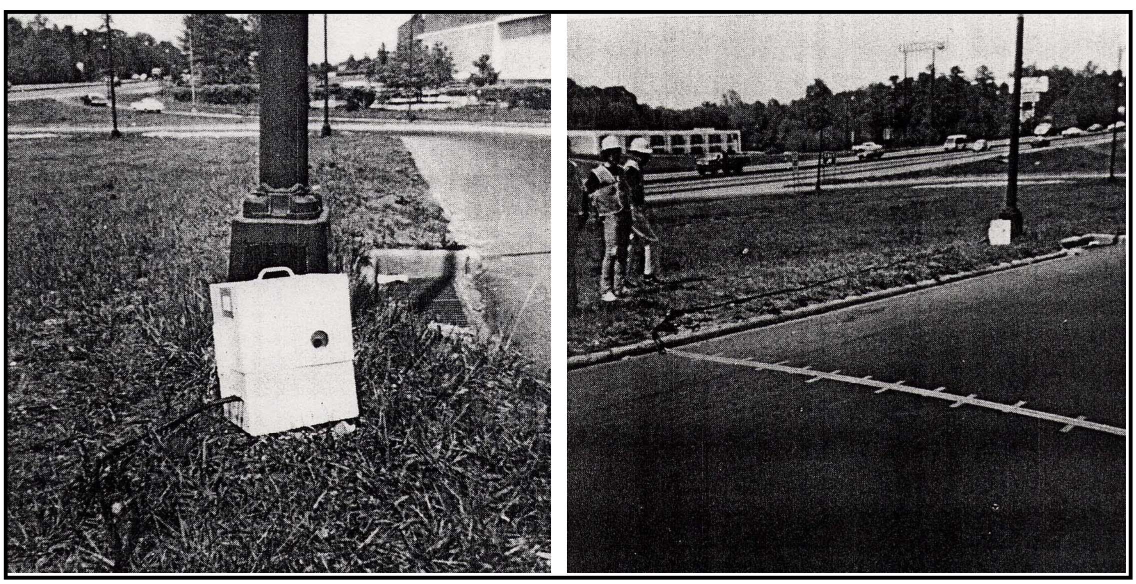

Figure 2. California Wrong-Way Camera System (*1*).

In the late 1960s Caltrans refined the design of the wrong-way camera system and from 1971 to 1977 used 150 of them as part of a monitoring program for wrong-way entries at almost every exit ramp in the state. A 1971 study found that the wrong-way camera system was consistent, reliable, and accurate in detecting wrong-way entries (*3*). The following list highlights some of the results of the monitoring program (*2*).

- Approximately 4000 exit ramps each had at least 30 days of camera surveillance.
- About 7 percent of the ramps monitored (257 out of 3954) had a significant wrong-way entry problem (five or more wrong-way entries per month) – with a few ramps as high as 50 to 60 entries per month.
- Wrong-way crashes remained relatively level during the program (1971-1977).
- The standard DO NOT ENTER and FREEWAY ENTRANCE sign packages changed format for color, mounting height, and location in 1973. The changes included:
    - The bottom of the lower portion of the DO NOT ENTER package (i.e., wrong-way sign mounted below a DO NOT ENTER sign on the same post) is placed two feet (0.6 m) above the edge of the pavement (see Figure 3) (*4*).
    - ONE WAY arrows are mounted 1.5 feet (0.46 m) above the pavement.
    - At least one DO NOT ENTER package is placed within the area covered by a car's headlights and visible to drivers from the decision point on all approaches.
    - FREEWAY ENTRANCE signs are placed as near the intersection of the entrance ramp and cross street as possible (see Figure 4).
    - Symbol right or left turn prohibition signs are not used at ramp terminals because of the potential for being misunderstood by drunks as a directional arrow.
- The improved standard sign packages for entrance and exit ramp terminals instituted in 1973 were effective in reducing wrong-way entries (entries were reduced to an acceptable level – two or fewer per month – at 90 percent of the ramps identified as having a significant wrong-way entry problem).

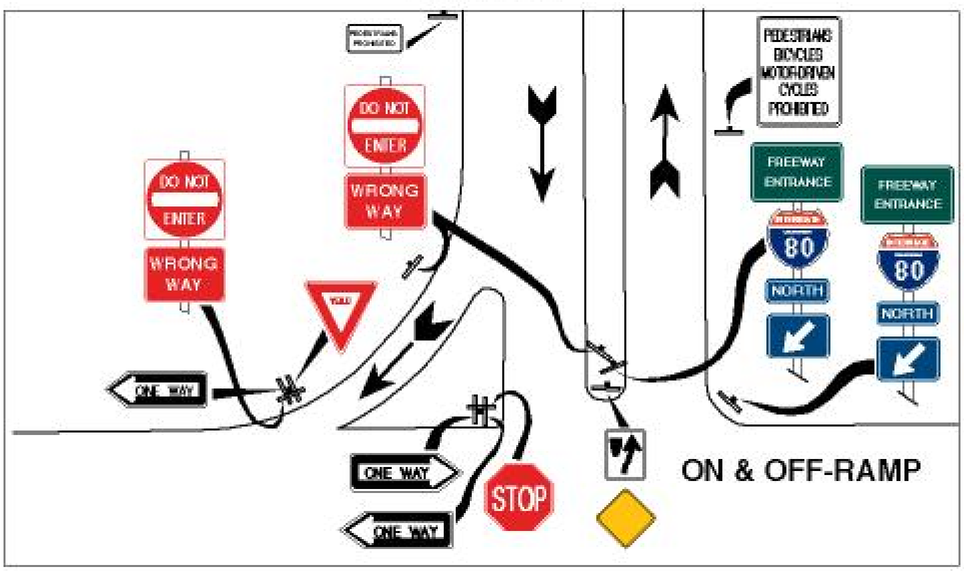

Figure 3. Standard Signing and Marking Layout in California (*4*).

Figure 4. Freeway Entrance Signs in California.

Georgia

The Georgia Institute of Technology, in cooperation with the Georgia DOT, purchased 18 wrong-way camera systems from Caltrans to monitor exit ramps in the Greater Atlanta metropolitan area (*1*). The camera systems were installed at 44 freeway exit ramps based on a sampling technique designed to monitor enough of each type of exit ramp (e.g., diamond, diagonal, parclo, cloverleaf, etc.) to permit an evaluation of the associated hazard based on wrong-way entries. As in California, Georgia Institute of Technology researchers placed the cameras for approximately one month at each ramp to gather data on the frequency of wrong-way entry. The wrong-way entry rates ranged from 0 to as high as 14 per month.

Washington

The Washington State Department of Transportation (WsDOT) recently implemented video monitoring systems on three exit ramps as part of a federal intelligent transportation system (ITS) grant project (*5*). Figure 5 shows photographs of the three major components of the video monitoring system. The left frame of Figure 5 includes the closed circuit television (CCTV) component of the video monitoring system. The center frame of Figure 5 shows the solar power assembly used to provide electricity to the system. The right frame of Figure 5 shows the television monitor and videocassette recorder (VCR) unit that are housed in the controller cabinet. The video monitoring system is activated when a wrong-way vehicle is detected on the exit ramp. At the same time, the VCR records the wrong-way incident so that WsDOT engineers can observe the vehicle’s movements and the driver’s behavior. The video recording can also be reviewed to analyze whether or not the cause is driver error, interchange deficiencies, or a combination of both.

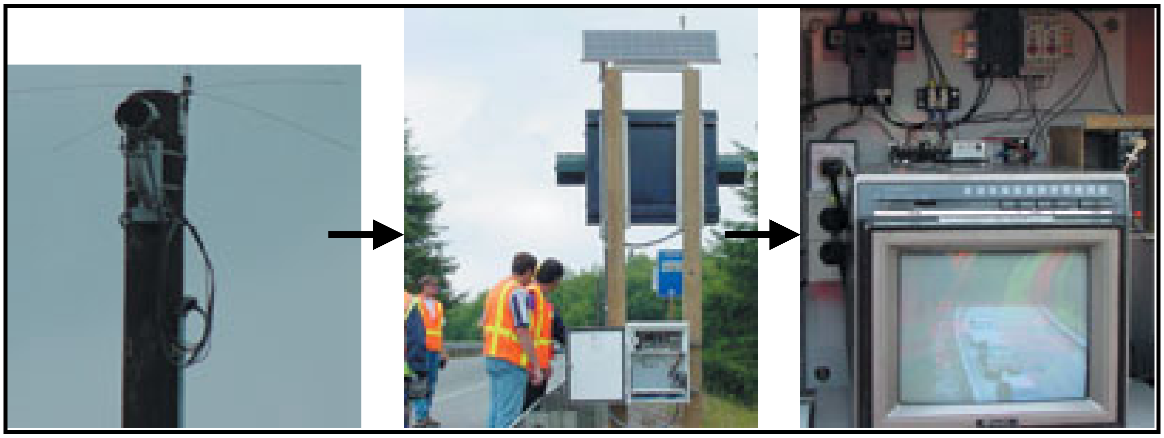

Figure 5. Video Monitoring System on Exit Ramp in Washington State (*5*).

WRONG-WAY CRASH CHARACTERISTICS

The research team found that many studies have quantified the problem of wrong-way driving by analyzing crash data. The studies have analyzed wrong-way rates, characteristics, and correlation to geometric design features. The research team reviewed these studies and the following text describes some of the significant findings and trends of wrong-way crashes. This narrative also provides a profile of typical characteristics of wrong-way crashes based on previous research.

Severity Characteristics of Wrong-Way 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 (*5*). Figure 6 provides a graphical representation of the number of fatalities per year between 1996 and 2000 attributed to wrong-way movement on freeways. Over a five-year period, 1753 people died in crashes where a vehicle was driven the wrong-way on freeway facilities (ramps, main lanes, etc.).

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 (*6*). A 1977 Vaswani study 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 (*7*). Similarly, a 1989 Copelan study determined that the fatality rate was 12 times greater for wrong-way crashes compared to all other crashes on California freeways in 1987 (*8*). 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.

Driver Age Characteristics of Wrong-Way Crashes

Driver age is an important characteristic identified in previous studies of wrong-way crashes on freeways. Lew reported on an analysis of 168 wrong-way crashes on California freeways that (*9*):

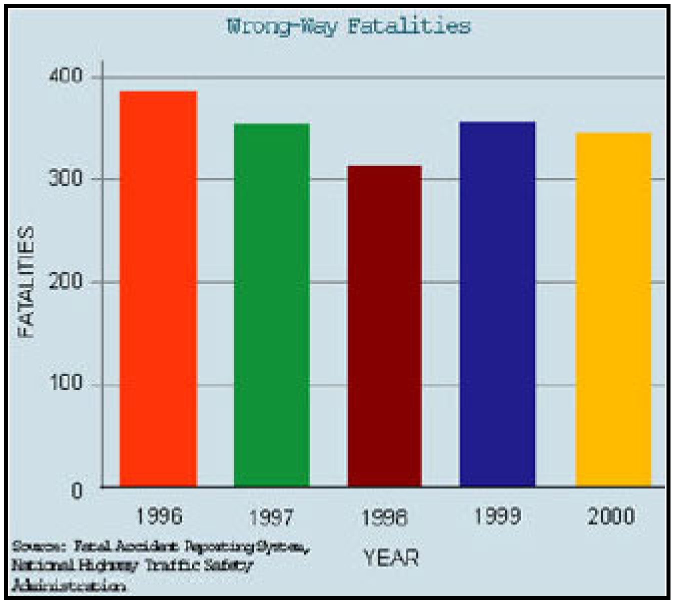

Figure 6. Number of Wrong-Way Fatalities for Crashes on United States Freeways (*5*).

- The 30-39, 50-59, and 60-69 age groups were represented in these crashes at a rate closely corresponding to their proportion of the driving population in California.
- Drivers ages 16-19 experienced approximately one-half of the wrong-way crashes expected for their age group.
- Drivers ages 40-49 experienced approximately three-quarters of the rate expected.
- Drivers ages 70-79 experienced over twice the number of freeway wrong-way 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 (*10*).

A study performed by the Japanese Institute for Traffic Accident Research and Data Analysis (ITARDA) determined that as many as 29 percent of the wrong-way crashes on highways involving injury or death were caused by senior citizens (over 65 years old) (*11*). The same study found that only 4 percent of the total crashes on highways involving injury or death were attributed to senior citizens.

It appears that several studies have found that **elderly drivers are over represented in wrong-way crashes** compared to their proportion of the driving population and their proportion of involvement in other crashes.

Driver Sex Characteristics of Wrong-Way Crashes

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.

Driver Impairment Characteristics of Wrong-Way Crashes

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 (*8*).
- A WsDOT study indicated that 50 percent of the 30 wrong-way crashes in an interstate corridor were alcohol- or drug-related (*5*).
- A study of wrong-way driving on Dutch motorways found that alcohol use was relatively frequent (the exception was drivers 70 years and older where it was extremely rare) (*12*).
- 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 (*7*).
- 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 (*13*).

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.

Role of Driver Race in Wrong-Way Crashes Involving Driver Impairment

Another factor related to driver impairment that was of interest to the research team was previous research on the role of driver race in crashes involving impaired drivers. This interest was initiated by representatives of the Fort Worth Police Department (FWPD) who proposed the hypothesis that male Hispanic/Mexican American drivers seemed to have more involvement in wrong-way crashes where driver impairment was a contributing factor. This hypothesis was based on the experience of officers in the traffic division who were called to work several high-profile crashes involving impaired male Hispanic drivers.

Study of Hispanic Drivers in California. A recently published study by Ferguson et al. investigated drinking and driving among Mexican American and non-Hispanic white males in Long Beach, California (*14*). Researchers at the Southern California Research Institute (SCRI) conducted surveys to investigate the role of driver race on driving under the influence. A total of 300 Mexican American and Mexican national males (the Mexican American group) and 300 non-Hispanic white males were included in the surveys. Within each group, half were current driving while intoxicated (DWI) arrestees, and the other half were residents of the local community. SCRI chose Long Beach as the location for the study because southern California has a large Mexican American population and because of its convenience and ready access to DWI arrestees.

SCRI compared the survey results to ascertain alcohol use, attitudes towards drinking and driving, and knowledge of DWI laws. SCRI analysts found that Mexican American males, both DWIs and those from the community, reported heavier drinking than non-Hispanic white males. All four groups of respondents tended to underestimate the number of drinks needed to achieve the blood alcohol concentration (BAC) threshold at or above which it is illegal to drive under California law. SCRI concluded that estimations were around two to three drinks rather than a more realistic estimate of four to five drinks. However, Mexican American DWIs and their comparison group vastly overestimated the number of drinks to make them unsafe drivers (8–10 drinks). Furthermore, the surveys revealed that fewer than half of the Mexican American group were aware of the BAC threshold in California (0.08 percent) compared with between 60 and 78 percent on non-Hispanic whites. The SCRI research team made the following two important conclusions based on their study in Long Beach, California:

- The study was limited in scope and needs to be replicated in other communities with other racial/ethnic groups.
- The clear lack of knowledge of the DWI law in California and a lack of understanding of the relationship between the number of drinks and BAC point to the need for culturally sensitive programs that are developed and implemented within the Mexican American community.

Other Studies of Hispanic Drivers. The research team was also able to find some other studies into the relationship between Hispanic drivers and driving under the influence. The following list highlights some of the significant findings regarding the relationship of Hispanic drivers and driving under the influence:

- A 1998 study by Voas et al. indicated that the number of drinking drivers on roadways in the United States fell significantly between 1986 and 1996 (*15*). However, this study determined that there was no evidence of a decline in drinking and driving among Hispanic drivers.
- Tashima and Helander examined California DWI arrest data and found that 46 percent of those arrested for DWI were Hispanic, about twice as high as the proportion of Hispanics in the population (*16*).
- Caetano and Clark also found higher self-reported arrest rates for DWI among Hispanic men than non-Hispanic whites (*17*).
- Recent evidence compiled by Voas et al. indicated that some Hispanic drivers are over-represented in alcohol-related fatal crashes. For example, among Mexican Americans, about 65 percent of all motor vehicle deaths were alcohol related, compared with 46 percent among non-Hispanic whites (*18*).
- Traffic crashes have steadily increased their ranking as a leading cause of death for Hispanic males, ranking fifth in 1992 and third in 1997 according to the National Highway Traffic Safety Administration (*19*).

All of these studies suggest that **Hispanic males are involved in higher rates of arrests and DWI-related crashes than their corresponding proportion of the population**. It appears that these studies support the FWPD hypothesis, if they are transferable to wrong-way crashes.

Time of Day Characteristics of Wrong-Way Crashes

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 highlights some of the 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) (*8*).
- 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. (*13*).

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

Origination of Wrong-Way Movement

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 previous 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. The following list emphasizes some of the general studies of where wrong-way movements originated:

- A Vaswani study of data on Virginia interstates from 1970-1976 found that about 50 percent of wrong-way entries originated from interchanges; about 15 percent were associated at crossovers and rest stops or were related to u-turns and median crossings; and approximately 35 percent had unknown origins. On non-interstate four-lane divided highways, about 40 percent of drivers making wrong-way entries emerged from intersections with crossroads or exit ramps connecting with interstate roads; about 25 percent originated from business establishments such as gas stations and motels; and about 20 percent originated from residential areas, crossovers, beginnings of divided sections, and construction sites or were associated with u-turns and median openings. The origins of the remaining 15 percent were unknown (*7*).
- 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 (*12*).
- The study of 129 wrong-way crashes in Japan determined that 39 percent originated in the vicinity of interchanges and 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 (*11*).

Several studies have concluded that **the most frequent origin of wrong-way incidents is the freeway exit ramp** (*10*). Research has shown that some ramp and interchange types are more problematic and susceptible to wrong-way movements:

- Tamburri and Theobald (1966) analyzed 400 wrong-way incidents where entry was made to the freeway via an exit ramp and found that the trumpet interchange category had the highest wrong-way entry rate, with approximately 14 incidents per 100 ramp-years, and the full cloverleaf interchanges had the lowest wrong-way entry rate, with 2 incidents per 100 ramp-years (*6*).
- Parsonson and Marks (1979) also determined that the half-diamond (3.9 per month), partial cloverleaf ("parclo") loop ramp (11.0 per month), and parclo AB loop ramp (6.7 per month) had the highest wrong-way entry rates. They concluded that the parclo loop ramp and parclo AB loop ramp shared the same problem, which is an entrance and exit ramp in close proximity. They also concluded that because half-diamonds are incomplete interchanges drivers often made intentional wrong-way entries at them (*1*).
- Copelan (1989) concluded that **left-hand exit ramps are obsolete and should be avoided in new construction** because they appear to be entrance ramps to the wrong-way driver (a driver naturally expects to enter the freeway using a right turn and may mistakenly make this turn and travel the wrong-way). Figure 7 shows a typical interchange with a left-hand exit ramp. Furthermore, Copelan stated that scissors-style exit ramps are also obsolete and can be confusing for some drivers who head straight ahead onto the exit ramp instead of turning left (*8*). Figure 8 depicts an interchange with a scissors-style exit ramp.

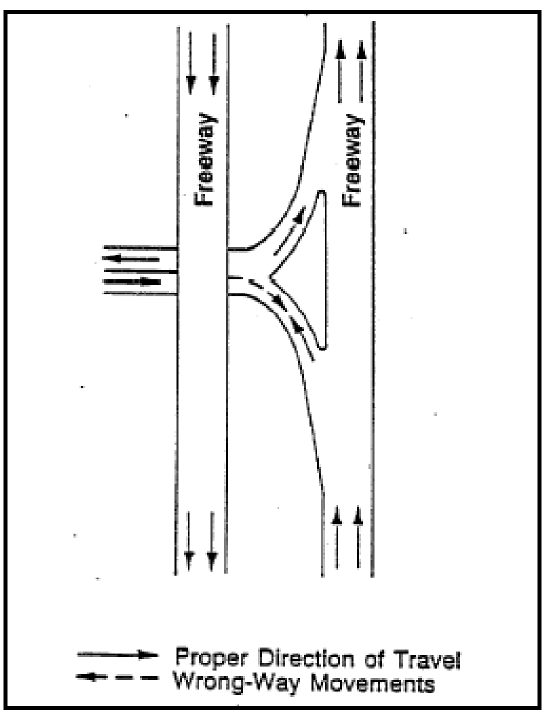

Figure 7. Proper and Wrong-Way Movements for Left-Hand Freeway Exit Ramp (*8*).

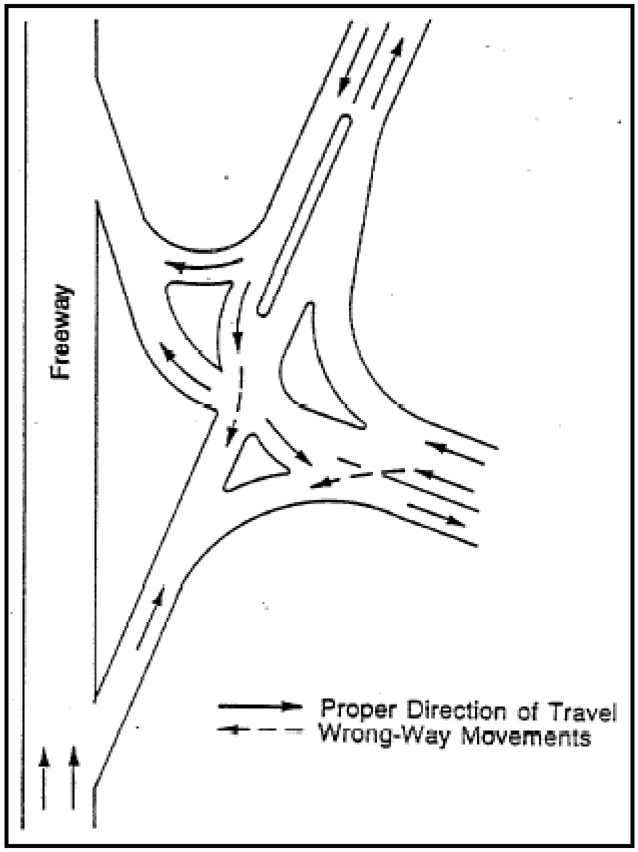

Figure 8. Proper and Wrong-Way Movements at Scissors-Style Freeway Exit Ramp (8).

CHAPTER 3. SYNTHESIS OF NATIONAL AND TEXAS SURVEYS

SURVEY DISTRIBUTION

In order to supplement the information obtained during the state-of-the-practice literature review, the research team developed two survey instruments to gather information on typical wrong-way signing and marking plans and use of any other innovative practices or countermeasures. Researchers developed the first survey instrument (Appendix A) for distribution to other state DOT representatives. The research team created the second survey instrument for delivery to each of the 25 TxDOT districts (Appendix B).

Researchers designed both surveys to be similar so that comparisons could be drawn between Texas and national responses. The research team distributed the national survey via electronic mail (e-mail) to one representative of each state DOT. The state DOT representatives were selected from the list of current members of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Traffic Engineering. The Texas survey was e-mailed to the Director of Transportation Operations at each TxDOT District.

The research team utilized distribution via e-mail to control costs and make it easier for respondents to complete and return the survey. Researchers used the Perseus survey software to distribute and compile the survey results.

SURVEY RESULTS

TTI distributed surveys to the 50 state DOTs and received responses from 28 states, a 56 percent response rate. Table 1 provides the list of state DOT respondents. The results for the survey of TxDOT district offices produced similar results. Surveys were distributed to each of the 25 TxDOT districts and 12 responses were received, a 48 percent response rate. Table 2 lists the TxDOT district respondents.

DO NOT ENTER Sign Survey Results

The national survey results showed that all but one of the respondents (97 percent) use DO NOT ENTER signs to discourage wrong-way movements on exit ramps. The percentage of states that used DO NOT ENTER signs on frontage roads (72 percent) and divided highways (86 percent) was also high. Survey respondents were also asked which standard-sized DO NOT ENTER signs were used in their jurisdiction. The results are listed below:

- 30 inch by 30 inch – 83 percent,
- 36 inch by 36 inch – 79 percent, and
- 48 inch by 48 inch – 55 percent.

Table 1. National Survey Respondents—28.

State Department of Transportation
Arizona
Arkansas
Colorado
Connecticut
Georgia
Hawaii
Illinois
Indiana
Iowa
Kansas
Kentucky
Michigan
Minnesota
Mississippi
Nevada
New Hampshire
New Jersey
New York
North Dakota
Ohio
Oregon
Pennsylvania
Rhode Island
South Carolina
Tennessee
Washington
West Virginia
Vermont

Table 2. TxDOT District Survey Respondents—12.

TxDOT District
Amarillo
Atlanta
Austin
Beaumont
Childress
Corpus Christi
Dallas
Houston
Laredo
Paris
Waco
Yoakum

One respondent indicated that their state uses a 42-inch by 42-inch sign, which is not one of the standard sizes in the list above. Another respondent indicated that they have size guidelines based on the type of roadway. Finally, almost all respondents (86 percent) indicated that they use the standard *Manual on Uniform Traffic Control Devices* (MUTCD) mounting height for the DO NOT ENTER sign.

The two primary differences in the national and Texas surveys with respect to the DO NOT ENTER sign were:

- more usage of the DO NOT ENTER sign on frontage roads, and
- significantly more usage of the largest (48 inch by 48 inch) DO NOT ENTER sign.

WRONG WAY Sign Survey Results

The national survey results showed that all but one of the 29 states (97 percent) used WRONG WAY signs to discourage wrong-way movements on exit ramps. The percentage of states that used WRONG WAY signs on frontage roads (59 percent) and divided highways (76 percent) was also high. Survey respondents were also asked which standard-sized WRONG WAY signs were used in their jurisdiction. The results are listed below:

- 30 inch by 18 inch – 28 percent,
- 36 inch by 24 inch – 93 percent,
- 42 inch by 30 inch – 38 percent, and
- 48 inch by 36 inch – 17 percent.

The results for the survey of TxDOT district offices produced similar results. Similar to previous results, the two primary differences in the national and Texas surveys with respect to the WRONG WAY sign were:

- more usage of WRONG WAY signs on frontage roads, and
- significantly more usage of the largest (48 inch by 36 inch) WRONG WAY sign.

The research team also surveyed DOT representatives regarding the use of supplemental items on either the DO NOT ENTER or WRONG WAY signs. The results are listed below:

- word plaque with ‘RAMP’ – 0 percent,
- word plaque with ‘FREEWAY’ – 3 percent,
- ONE WAY sign – 62 percent,
- red flashing beacons – 3 percent,
- yellow flashing beacons – 3 percent, and
- flags – 3 percent.

Several other states indicated the use of other supplemental items not on the survey list including turn restriction signs and the use of retro reflective u-channel post inserts. Finally, almost all respondents (86 percent) indicated that they use the standard MUTCD mounting height for the WRONG WAY sign.

Red-Backed Pavement Markers

The results of the national survey showed that approximately 38 percent of the state DOT respondents used some type of red-backed raised pavement marker (RPM) on the freeway main lanes on a standard basis. In comparison, Texas has significantly more use of this countermeasure as eleven of the twelve TxDOT districts (92 percent) indicated standard use of these RPMs.

Wrong-Way Pavement Arrows

Both surveys contained several questions related to the use of wrong-way pavement arrows. Table 3 lists the responses for the circumstances wrong-way pavement arrows are used on exit ramps. It is difficult to draw many definitive conclusions from this data; however, it seems apparent that most respondents do not use wrong-way pavement arrows on all or the majority of exit ramps. Several respondents provided additional comments on this question including:

- arrows used occasionally,
- looking at new wrong-way pavement arrow designs,
- use standard lane use pavement arrows instead of wrong-way,
- wrong-way pavement arrows are not maintained, and
- wrong-way pavement arrows are installed routinely for new construction.

Table 3. Circumstances for the Use of Wrong-Way Pavement Arrows on Exit Ramps.

Q: Under what circumstances do you use wrong-way pavement arrows on exit ramps?		
Response	**Percentage of Respondents**	
	National Survey	**Texas Survey**
Arrows are standard on all exit ramps	24.1	8.3
Arrows are installed on the majority of exit ramps	10.3	33.3
Arrows are installed on known or suspected problem locations	27.6	8.3
Do not use these arrows	27.6	25.0
Other response	6.9	16.7

Edge Lines on Exit Ramps

Almost all survey respondents (93 percent of national and 100 percent in Texas) indicated that they typically use yellow edge lines on the left and white edge lines on the right side of exit ramps as a countermeasure for wrong-way driving.

Other Movement Restriction Signs

Researchers also asked survey respondents if any other signs, in addition to the DO NOT ENTER and WRONG WAY, are used to prevent wrong-way movements. Several other signs were listed as wrong-way countermeasures including:

- ONE WAY sign, and
- turn restriction signs – symbol and text versions (e.g., NO LEFT TURN).

Supplemental Sign Placards

None of the national survey respondents indicated use of the RAMP supplemental placard; however, almost 42 percent of the Texas respondents have used this placard. The ONE WAY sign had the most utilization as a supplement (62 percent of states in the national survey and 25 percent of the TxDOT districts). Only one state DOT and one TxDOT district have used a FREEWAY supplemental placard.

Internally Illuminated Traffic Signs (IITS)

Three of the national survey respondents (10 percent) indicated that they use internally illuminated DO NOT ENTER and WRONG WAY signs as a countermeasure against wrong-way movements. None of the TxDOT survey respondents currently use this type of technology.

CHAPTER 4. ANALYSIS OF FREEWAY-RELATED WRONG-WAY CRASHES IN TEXAS

In Task 2 of project 4128, the research team performed studies to quantify the problems and issues associated with wrong-way driving in Texas. The major effort included in this task involved an analysis of wrong-way crashes using the Department of Public Safety crash records database. The secondary effort of this task involved coordination with 911 public safety answering point representatives regarding reports they receive on wrong-way driving on freeway facilities.

STATEWIDE WRONG-WAY CRASH ANALYSIS

The objective of the statewide wrong-way crash analysis was to quantify the frequency, severity, and other important characteristics of wrong-way crashes in Texas. The focus of the 4128 research is to develop countermeasures for wrong-way movements on freeways; therefore, only those crashes related to the freeway main lanes and/or ramps were of particular interest.

The first step in the crash analysis was to define a screening methodology to identify crashes in the DPS database likely to involve a wrong-way driver. The research team agreed that the best determinant of a wrong-way crash was code 71 (wrong way-one way road) in the factors/conditions contributing portion of the ST-3 form filed by the investigating officer. This was the only screening technique used by the research team and all crash reports in the database with this code were requested from DPS.

Researchers requested copies of the original ST-3 reports for wrong-way crashes that occurred in Texas from January 1, 1997, to December 31, 2000. Table 4 provides a list of the total number of reports for each of the years that were obtained from the DPS Accident Records Bureau. After receiving these reports, the research team performed a review of each crash to determine which ones were related to the freeway main lanes and/or ramps (see Table 4). Analysis of the individual reports revealed that approximately half were related to the freeway main lanes and/or ramps.

Table 4. Summary of Wrong-Way Crash Data Obtained from the DPS.

	Number of Wrong-Way Crashes		
Year	**Total**	**Main Lane and/or Ramp**	**Other (Arterial, Frontage Road, etc.)**
1997	194	87	107
1998	176	83	93
1999	184	96	88
2000	96	57	39
Totals	650	323	327

Freeway-Related Crash Analysis

After the determination of whether or not the wrong-way crash was freeway-related (i.e., occurred on the main lanes and/or an entrance or exit ramp), the research team performed a clinical analysis of the following key factors:

- Time of day – What time of day did the crash occur and what were the light conditions?
- Severity – What were the injuries to the parties involved in the crash?
- Driver profile – What were the age, sex, and race of the wrong-way driver?
- Driver influence – Did the officer cite any influence of drugs and/or alcohol by the wrong-way driver?
- Wrong-way origination – Does the officer narrative or diagram provide any information on the location where the wrong-way entry originally occurred?

Time of Day Characteristics of Wrong-Way Crashes in Texas

Examination of when wrong-way crashes occur is important in determining appropriate engineering and enforcement countermeasures. The analysis of the 323 freeway-related wrong-way crashes indicated that 52 percent occurred during the 12:00 a.m. to 5:59 a.m. time period. Table 5 provides a listing of the number of crashes that happened during the early morning hours and the corresponding frequencies compared to the total of wrong-way and total statewide crashes.

Table 5. Analysis of Wrong-Way Crashes Occurring During Early Morning Hours.

Time of Day (a.m.)	# of Wrong-Way Crashes	Percentage of Total Wrong-Way Crashes	Percentage of Total Crashes Statewide
12:00 to 12:59	26	8.0	2.2
1:00 to 1:59	39	12.1	2.0
2:00 to 2:59	54	16.7	2.5
3:00 to 3:59	23	7.1	1.5
4:00 to 4:59	17	5.3	1.0
5:00 to 5:59	9	2.8	1.2
Totals	168	52.0	10.4

The data in Table 5 suggest that there is a significant difference between the frequencies at which wrong-way crashes occur during the 12:00 a.m. to 5:59 a.m. time period versus the statewide average for all crashes. In fact, **wrong-way crashes are five times more likely to occur during the early morning hours**. It is also interesting to note that there is a definite spike in the 2:00 a.m. to 2:59 a.m. hour that corresponds to the closing time of most bars in Texas.

These findings closely resemble data published in several previous studies that concluded that **wrong-way crashes are more prevalent during non-daylight hours, particularly in the early morning hours**.

Severity Characteristics of Wrong-Way Crashes in Texas

Recent statistics from the Fatality Accident Reporting System database maintained by the National Highway Traffic Safety Administration indicate that approximately 350 people have been killed each year between 1997 and 2000 in wrong-way crashes on freeways in the United States (*5*, *20*). Fatalities as a result of wrong-way drivers comprise a very small percentage of the overall fatal crashes in this country.

The analysis of the 323 freeway-related wrong-way crashes in Texas confirmed that wrong-way crashes tend to be more severe and have a greater proportion resulting in death or serious injury than other types of crashes. Table 6 shows the crash severities for the Texas crashes.

Table 6. Crash Severity Distribution for Wrong-Way Crashes in Texas (1997 - 2000).

Crash Severity	Number of Crashes	Percentage of Total
Possible Injury	84	26.0
Nonincapacitating	80	24.8
Incapacitating	96	29.7
Fatal	63	19.5
TOTALS	323	100.0

There were approximately 16 fatal and 24 incapacitating wrong-way crashes per year during the four-year study period. Wrong-way crashes account for a serious economic impact of approximately **$21 million per year** based on the average cost of accidents used by TxDOT's Traffic Operations Division for the Federal Hazard Elimination (HES) Program.

Profile of Drivers Involved in Wrong-Way Crashes in Texas

The research team developed a profile of drivers involved in freeway-related wrong-way crashes in Texas. The major elements of the driver profile were driver sex, age, race, and involvement of alcohol and/or drugs.

Driver Sex

Researchers gathered data on the sex (i.e., male versus female) of the wrong-way drivers involved in the 323 crashes. Table 7 shows the results of this analysis. It was apparent that a significant portion (67 percent) of wrong-way crashes in Texas involved a male driver.

Table 7. Wrong-Way Driver Sex for Crashes in Texas.

Driver Sex	Number of Drivers	Percentage of Total
Male	216	66.9
Female	88	27.2
Unknown	19	5.9
TOTALS	323	100.0

Driver Age

Researchers gathered data on the age of the wrong-way drivers involved in the 323 crashes. Table 8 shows the results of this analysis. Interestingly, almost half (48 percent) of the wrong-way drivers were in the two youngest age groups – 16 to 24 and 25 to 34. The percentage of drivers over the age of 65 involved in wrong-way crashes was also higher (almost 13 percent) compared to their involvement in other types of crashes.

Table 8. Age of Wrong-Way Drivers for Crashes in Texas.

Age Group	Number of Drivers	Percentage of Total
16 to 24	67	20.8
25 to 34	88	27.2
35 to 44	55	17.0
45 to 54	30	9.3
55 to 64	24	7.4
Over 65	41	12.7
Unknown	18	5.6
TOTALS	323	100.0

Driver Race

One of the secondary issues of interest to the research team was the problem associated with drivers unfamiliar with the English language, particularly Hispanic drivers. Previous TTI research has indicated that Hispanic drivers have a high level of understanding (approximately 90 percent comprehension) of both the DO NOT ENTER and WRONG WAY traffic signs (*21*). A municipal police department traffic officer has previously expressed the hypothesis that Hispanic drivers seem to be over represented in wrong-way crashes.

In order to test this hypothesis, researchers attempted to use a non-scientific method to determine the number of Hispanic drivers involved in the 323 freeway-related wrong-way crashes. The ST-3 crash report contains information on driver race (W = White, B = Black, A = Asian/Pacific Islander, and H = Hispanic). This information is somewhat subjective and is often based on the investigating officer's judgment because there is no information on the Texas Driver License (TDL) regarding driver race. Since each individual crash report was being analyzed, the research team needed a methodology to estimate Hispanic driver involvement. Researchers decided that they would consider a driver as Hispanic based on their surname (i.e., last name). For example, if the wrong-way driver had a last name of Gonzalez, Hernandez, or Martinez they were considered to be Hispanic. This methodology is not considered to be definitive and may actually overestimate Hispanic involvement but is considered to be better than just race code on the ST-3.

Based on this methodology, data was gathered on race of wrong-way drivers involved in the 323 crashes. This analysis determined that approximately one-third (31.3 percent) of the wrong-way drivers had a Hispanic surname.

Driver Influence

The influence of alcohol and/or drugs on drivers involved in 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 freeway facilities would be driving under the influence of drugs or alcohol.

Researchers gathered data on the influence of alcohol and/or drugs on the wrong-way drivers in the 323 freeway-related crashes included in this study. 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.

Table 9 provides the results of the driver influence analysis. Almost 61 percent of all of the crashes studied had some influence of alcohol and/or drugs cited by the investigating officer. This is a significantly higher proportion than for other types of crashes and points to driver influence being a primary contributor to the majority of freeway-related wrong-way crashes.

Table 9. Influence of Alcohol and Drugs on Wrong-Way Drivers.

Driver Influence	Number of Drivers	Percentage of Total
Yes	196	60.7
No	127	39.3
TOTALS	323	100.0

Researchers performed further analysis of the frequency of the wrong-way drivers that were under the influence and found that several other findings were reinforced. 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.

Origination of Wrong-Way Movement for Crashes in Texas

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. If the location of the original wrong-way movement is known, it makes it easier to inventory existing treatments and also to develop ideas for other countermeasures if deemed necessary. Several previous 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 (*1*, *2*, and *3*).

Researchers gathered data on the location where the wrong way movement originated for each of the 323 freeway-related crashes studied. This data was obtained primarily in the crash reports from the investigating officer's narrative opinion of what happened and the corresponding diagram. The research classified the wrong-way origination information into four categories, described in the list below:

- Good idea – This category was for crashes where there was very specific information on where the wrong-way entry occurred. These locations were almost exclusively exit ramps like the example given in Figure 9.
- Some idea – This category was for crashes where there was some general information about the wrong-way movement location but it was not tied to a specific exit ramp or cross street.
- Driver u-turn – This category was for crashes where the driver was going in the right direction and made a u-turn to end up going the wrong way.
- Unknown – This category was for crashes where there was no conclusive information available about where the wrong-way entry occurred.

Table 10 gives the wrong-way frequency distribution for the four categories for the wrong-way origination data obtained from the ST-3 forms. This analysis revealed that for about one out of every three crashes there was at least some idea of where the wrong-way movement first occurred. The origination of the wrong-way entry was unknown for the other two-thirds of the crashes studied. This points to the fact that wrong-way movements are often difficult to pinpoint, even with the benefit of having the original crash reports.

Table 10. Quality Assessment of Wrong-Way Origin Information for Crashes.

Wrong-Way Origin Information	Number of Crashes	Percentage of Total
Good idea	63	19.5
Some idea	28	8.7
Driver u-turn	12	3.7
Unknown	220	68.1
TOTALS	323	100.0

Examples of Typical Crashes for Wrong-Way Origin Information

This section provides some examples of text and diagrams from actual wrong-way crashes for each of the four categories listed in Table 10. This information helps clarify how the research team categorized the wrong-way origin information. Each of the figures has the investigating officer's narrative and a representation of the collision diagram. In all cases the wrong-way driver is referred to as Unit #1 in the narrative and labeled with a number 1 in the collision diagram. The path of the wrong-way driver is also depicted in the diagrams by a dashed line.

Example of Good Idea Category for Wrong-Way Origin Information. Figure 9 provides an example from one of the wrong-way crashes that was categorized as having good wrong-way origin information. In the crash described in Figure 9, the wrong-way driver entered the freeway main lanes going the wrong direction from a left-hand exit ramp. The information provided by the investigator's narrative and collision diagram clearly provides the name of the exit ramp where the initial wrong-way movement occurred.

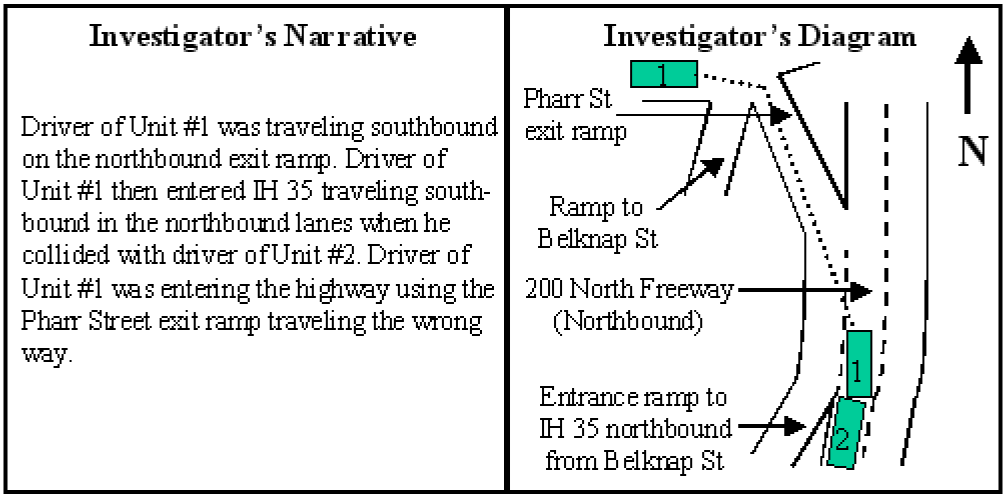

Figure 9. Example of Good Idea Category of Wrong-Way Origin Information.

Example of Some Idea Category for Wrong-Way Origin Information. Figure 10 shows an example from a wrong-way crash that was categorized as having some wrong-way origin information. In the crash described in Figure 10, the wrong-way driver was traveling southbound in the northbound lanes of the International Parkway on the south side of the Dallas/Fort Worth (DFW) International Airport. The information provided by the narrative and collision diagram provides enough information to know that the wrong-way movement occurred somewhere in the DFW Airport, likely between the first set of tollbooths and the crash location. However, the crash report does not provide any specific information on the exact location where the first wrong-way movement occurred.

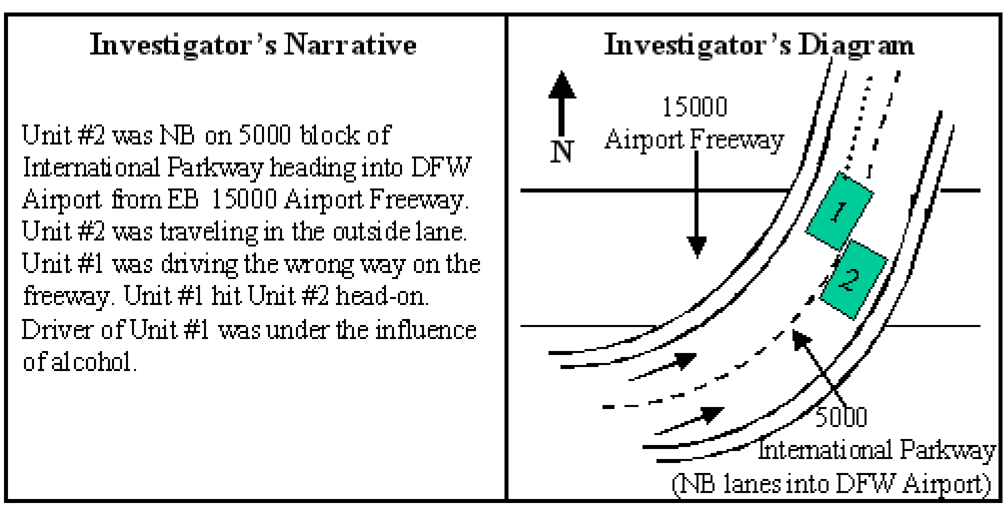

Figure 10. Example of Some Idea Category of Wrong-Way Origin Information.

Example of U-turn Category for Wrong-Way Origin Information. Figure 11 shows an example from a wrong-way crash that was categorized in the u-turn category for wrong-way origin information. In the crash described in Figure 11, the wrong-way driver entered the freeway main lanes going the correct direction (northbound) on an entrance ramp and then turned around and started going the wrong direction before colliding with another vehicle. Almost all of the wrong-way drivers that made a u-turn maneuver similar to this were under the influence of alcohol and/or drugs.

Investigator's Narrative

Unit #2 was NB in the inside lane of the 3400 block of N IH 35. Unit #1 was on the entrance ramp to N IH 35. Unit #1 turned around and drove SB in the NB lanes of IH 35. Unit #2 swerved to the left to avoid Unit #1 but was unable to do so.

Investigator's Diagram

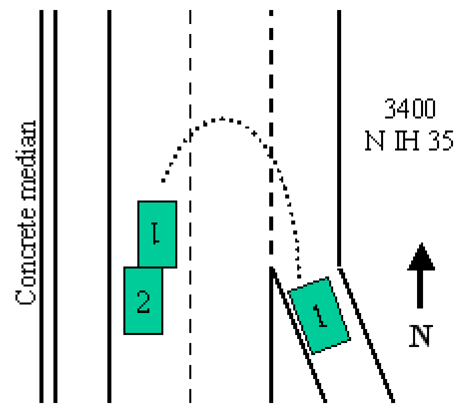

Figure 11. Example of U-turn Category of Wrong-Way Origin Information.

Example of Unknown Category for Wrong-Way Origin Information. Figure 12 shows an example from a wrong-way crash that was categorized in the unknown category for wrong-way origin information. In the crash described in Figure 12, the wrong-way driver was southbound in the northbound lanes of the freeway. The only specific information provided by the crash report was the block number on the freeway where the collision occurred.

Investigator's Narrative

Unit #1 was southbound in the northbound lane of IH 45. Unit #2 was northbound in the northbound inside lane of IH 45. Unit #1's front strikes Unit #2's front. Unit #2 came to rest on its side in the median. Unit #1 came to rest in the inside northbound traffic lane.

Investigator's Diagram

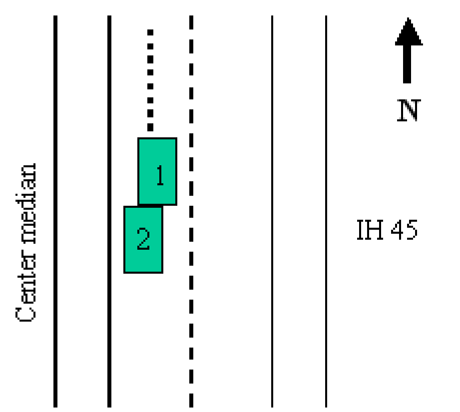

Figure 12. Example of Unknown Category of Wrong-Way Origin Information.

Other Important Characteristics Regarding Wrong-Way Origins

Researchers noticed several other important characteristics for the wrong-way crashes included in this study. The list below summarizes some of the other important observations after reviewing the crash reports:

- 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 driver is staying as far to the right as possible 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 suggests that further countermeasures might need to be considered at locations with left-side exit ramps.
- Another problem type according to the crash data is the situation 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.
- There were a few situations where staged construction freeways had wrong-way crashes and during the time period when only the frontage roads were in place. The large offset between the frontage roads and lack of main lanes may create a confusing situation for drivers that needs to be carefully considered for appropriate wrong-way countermeasures.
- The majority of wrong-way crashes analyzed happened in the major urban areas. Over 60 percent happened in the three largest metropolitan areas – Dallas/Fort Worth, Houston, and San Antonio.
- For the four-year analysis period, only five locations with good wrong-way origin information experienced multiple crashes. The location with the highest number of crashes only experienced an average of one wrong-way crash per year.

911 WRONG-WAY DRIVING REPORTS

To supplement the information extracted from the DPS database, researchers attempted to further quantify the problems and issues associated with wrong-way driving on freeways by coordination with 911 PSAP regarding reports they receive about wrong-way drivers, typically from other drivers with wireless phones. Researchers contacted and solicited the assistance of approximately forty PSAPs in Texas to collect and store information (e.g., roadway wrong-way movement was observed on, time of day, direction of travel, etc.) for wrong-way related reports on freeways in their jurisdiction during the course of the research project (i.e., September 2002 to August 2003).

This process proved to be frustrating as only three PSAPs (Beaumont Police Department [BPD], Fort Worth Police Department, and Richardson Police Department [RPD]) shared data regarding wrong-way driving reports. Many of the PSAPs would have liked to assist in the effort; however, the most popular reason for not participating was that their 911 computer aided dispatch (CAD) equipment and software had no code for capturing wrong-way driver reports. Liability concerns about sharing data with “outside” agencies may have also been an impediment.

Some of the key findings from the three PSAPs included:

- The two smaller PSAPs averaged one to two reports of wrong-way drivers on freeways per month over the yearlong 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 where the report was followed by a crash. In most cases the wrong-way drivers eventually corrected themselves and proceeded in the right direction.

CHAPTER 5. IDENTIFICATION AND ASSESSMENT OF WRONG-WAY DRIVING COUNTERMEASURES

Drivers who make wrong-way entries onto freeways or other restricted roads are at serious risk of injuring themselves and others. Wrong-way driving often leads to the most feared of traffic crashes, the head-on collision. In Task 3 of Research Project 0-4128, TTI identified and collected information on countermeasures and treatments designed to reduce wrong-way driving and crashes on freeway facilities. The research team used a variety of methods to gather information on wrong-way countermeasures and treatments including:

- review of published studies,
- Internet searches, and
- surveys (see Chapter 3).

In order to facilitate the assessment of feasibility and potential effectiveness as part of Task 4, the research team divided the countermeasures and treatments into four separate categories:

- category 1: traditional signing and pavement marking techniques (e.g., signs, pavement arrows, pavement markers, etc.);
- category 2: innovative signing and pavement marking techniques;
- category 3: geometric modifications (e.g., changes to ramps, medians, islands, or other design features); and
- category 4: intelligent transportation system applications.

The remainder of this document will summarize the information on countermeasures and treatments collected by the research team.

TRADITIONAL SIGNING AND PAVEMENT MARKING TECHNIQUES

This section reports on the traditional signing and pavement marking techniques used as countermeasures for wrong-way movements on freeway facilities. The following list summarizes the countermeasures within this category:

- DO NOT ENTER and WRONG WAY signs on separate posts,
- oversized DO NOT ENTER and WRONG WAY signs,
- red-backed raised pavement markers on the freeway main lanes,
- wrong-way pavement arrows,
- yellow edge line on left and white edge line on right side of exit ramps,
- ONE WAY signs, and
- turn restriction signs.
  - ✓ symbol signs for no left turn and no right turn, and
  - ✓ text signs for no left turn and no right turn.

DO NOT ENTER Signs

The DO NOT ENTER sign (Figure 13), designated as R5-1 in the *Manual on Uniform Traffic Control Devices,* is probably the most universal and recognizable countermeasure for wrong-way driving. The Millennium Edition of the MUTCD provides the following guidance on the use of the DO NOT ENTER sign (*19*):

- *Standard*:
The DO NOT ENTER (R5-1) sign shall be used where traffic is prohibited from entering a restricted roadway.
- *Guidance*:
The DO NOT ENTER sign, if used, should be placed at the point where a road user could wrongly enter a one-way roadway or ramp. The sign should be mounted on the right side of the roadway, facing traffic that might enter the roadway or ramp in the wrong direction. If the DO NOT ENTER sign would be visible to traffic to which it does not apply, the sign should be turned away from, or shielded from, the view of that traffic.
- *Option*:
The DO NOT ENTER sign may be installed where it is necessary to emphasize the one-way traffic movement on a ramp or turning lane. A second DO NOT ENTER sign on the left side of the roadway may be used, particularly where traffic approaches from an intersecting roadway.

Figure 13. DO NOT ENTER Sign.

Mexican Driver Understanding

TTI performed research on Mexican driver understanding of traffic control devices in the mid-nineties (*21*). The target population was Mexican drivers coming into Texas driving either automobiles or commercial trucks. Researchers administered surveys at international port crossings in El Paso, McAllen, and Pharr in August of 1996 while drivers were waiting in queue. The survey used a flashcard format, where the surveyor would present to a driver a flashcard with an image of a traffic control device and ask a question about the meaning of the device. The driver's response was recorded on audiotape for analysis. The traffic control devices evaluated related to the 4128 project were the standard DO NOT ENTER and ONE WAY signs.

The results, shown in Table 11, indicate that a high percentage of Mexican drivers have high comprehension of the meanings for the DO NOT ENTER and ONE WAY signs. Over 90 percent of the 581 survey respondents provided correct responses when shown the flashcard of the DO NOT ENTER sign. The percentage of correct responses, 83 percent, was almost as high for the ONE WAY sign as the DO NOT ENTER. These findings seem to suggest that if Mexican drivers are involved in wrong-way driving it probably is not related to their comprehension or understanding of traditional traffic signs such as the DO NOT ENTER and ONE WAY signs. There was no assessment of Mexican driver understanding of the WRONG WAY sign.

International DO NOT ENTER Signs

Based on information obtained in Internet searches, the research team concluded that the United States version of the DO NOT ENTER sign is relatively the same as in other countries, with the primary exception being the use of the DO NOT ENTER text on the sign. Most international transportation agencies use only the symbol portion of the sign. Figure 14 provides pictures of international DO NOT ENTER signs from the French West Indies, Australia, Japan, and The Netherlands.

Table 11. Mexican Driver Comprehension of DO NOT ENTER and ONE WAY Signs (*21*).

Device	Question	Correct Response Concept	Partially Correct Response Concept	C	PC	I	NS	U	SS
	What does this sign mean?	Must not enter the roadway from this direction, wrong way, or no entry	No acceptable responses	91	0	5	3	1	581
	What does this sign mean?	Left-only or one-way	No acceptable responses	83	0	14	2	1	558

C = correct response
PC = partially correct response
I = incorrect response
NS = analyst not sure
U = unknown or inaudible response
SS = sample size of survey respondents who were shown this sign

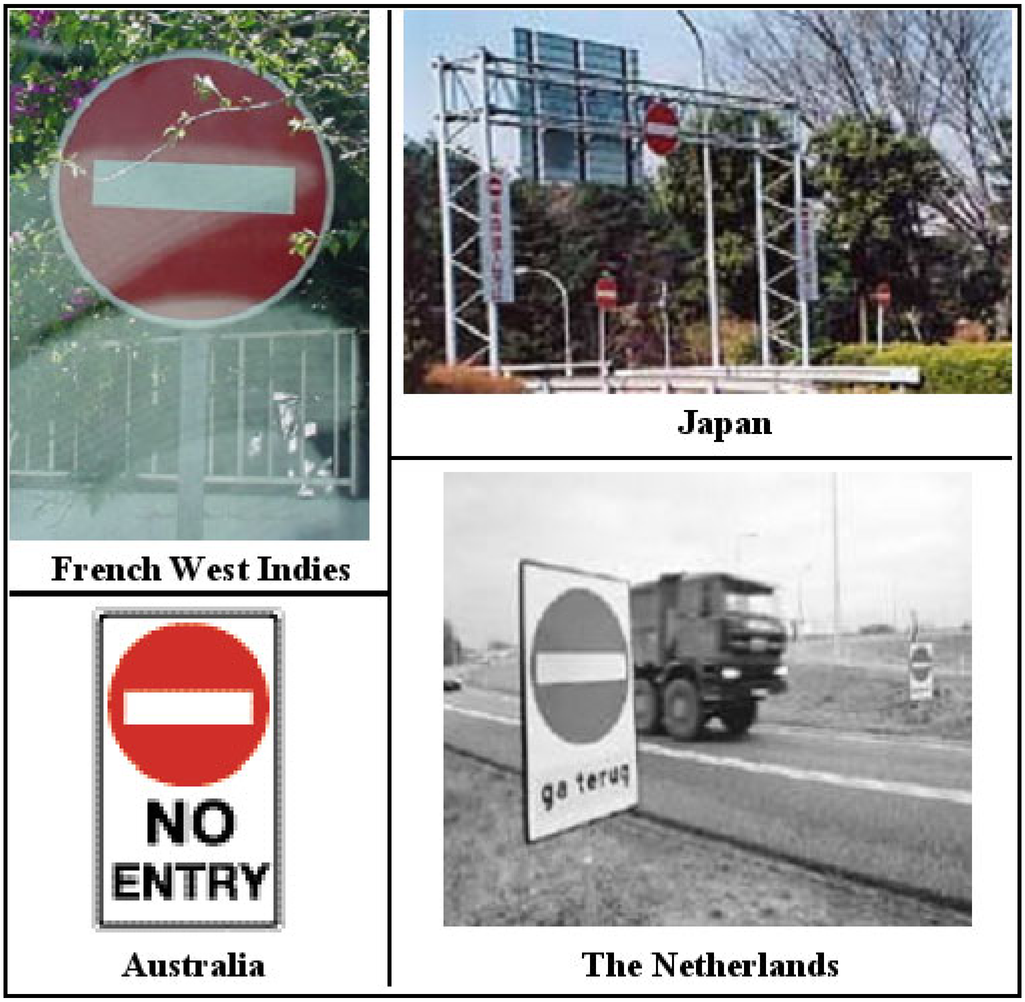

Figure 14. Examples of International DO NOT ENTER Signs.

WRONG WAY Signs

The WRONG WAY sign (Figure 15), designated as R5-1a in the MUTCD, is probably the second most recognizable countermeasure in the United States for wrong-way driving. The Millennium Edition MUTCD provides the following guidance on the use of the WRONG WAY sign (*19*):

- *Option*:
  The WRONG WAY (R5-1a) sign may be used as a supplement to the DO NOT ENTER sign where an exit ramp intersects a crossroad or a crossroad intersects a one-way roadway in a manner that does not physically discourage or prevent wrong-way entry.

- *Guidance*:
  If used, the WRONG WAY sign should be placed at a location along the exit ramp or the one-way roadway farther from the crossroad than the DO NOT ENTER sign.

Figure 15. WRONG WAY Sign.

International WRONG WAY Signs

Based on information obtained in Internet searches, the research team concluded that the U.S. version of the WRONG WAY sign is not used in other countries. The only country found with a similar sign was Australia. The province of Victoria has signs with white text 'WRONG WAY GO BACK' on a red background (see Figure 16). Transportation officials also display this same message on variable message signs (VMS) on the Southern Expressway—a reversible freeway facility into downtown Melbourne in the morning and back out in the evening (see Figure 17).

Figure 16. WRONG WAY GO BACK Sign in Australia.

Figure 17. WRONG WAY GO BACK Message on Electronic Sign in Australia.

Red-Backed Pavement Markers

Red reflective raised pavement markers are another widely used countermeasure. These RPMs are used as a countermeasure on freeway main lanes and also by some agencies on exit ramps, either along the edge lines and/or as part of the wrong-way pavement arrow. Type II-R is the common RPM placed on freeway main lanes with the red side facing in the wrong-way direction. Type I-R is the common RPM placed on edge lines and in wrong-way pavement arrows. Figure 18 provides a picture of a typical wrong-way RPM.

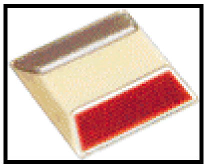

Figure 18. Typical Wrong-Way Raised Pavement Marker.

Wrong-Way Pavement Arrows

Wrong-way pavement arrows are another traditional countermeasure for discouraging wrong-way entry onto restricted facilities. The MUTCD provides the following advice on the use of wrong-way pavement arrows (see Figure 19) (*19*):

- *Standard*:
  Where through traffic lanes approaching an intersection become mandatory turn lanes, lane-use arrow markings shall be used and shall be accompanied by standard signs. Lane use, lane reduction, and wrong-way arrow markings shall be designed as shown in Figure 19.

- *Guidance*:
  Where crossroad channelization or ramp geometrics do not make wrong-way movements difficult, a lane-use arrow should be placed in each lane of an exit ramp near the crossroad terminal where it will be clearly visible to a potential wrong-way road user.

- *Option*:
  The wrong-way arrow markings may be placed near the downstream terminus of a ramp to indicate the correct direction of traffic flow and to discourage drivers from traveling in the wrong direction.

TxDOT has a slightly different standard wrong-way pavement arrow than what is contained in the national MUTCD (*22*). Figure 20 provides the detailed drawing for the standard TxDOT wrong-way arrow that is slightly longer and wider than the national standard.

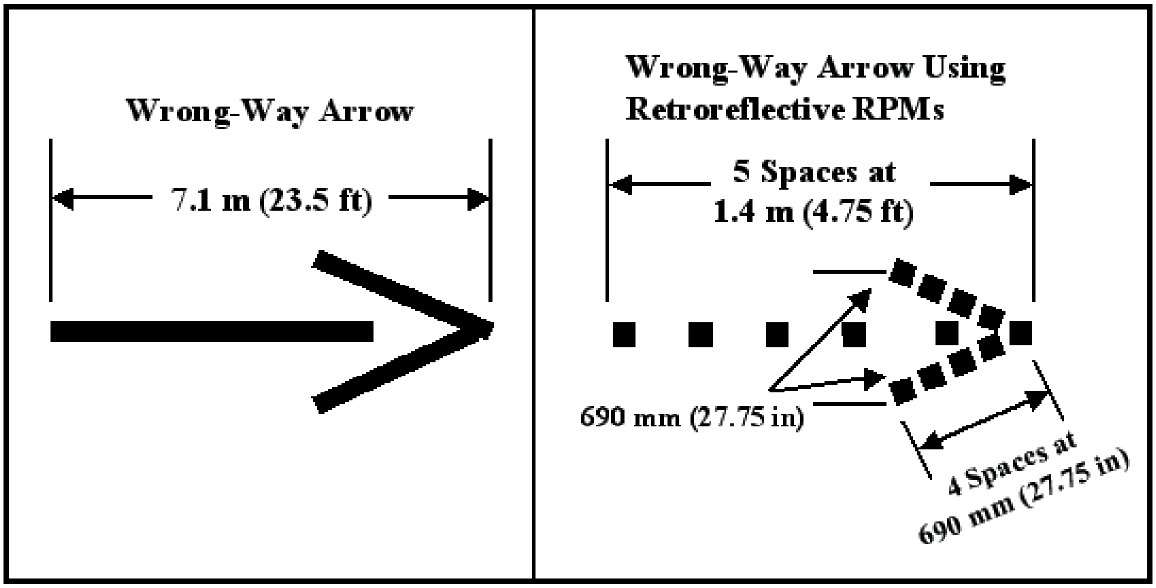

Figure 19. Wrong-Way Pavement Arrow Details Found in Figure 3B-20 of the MUTCD.

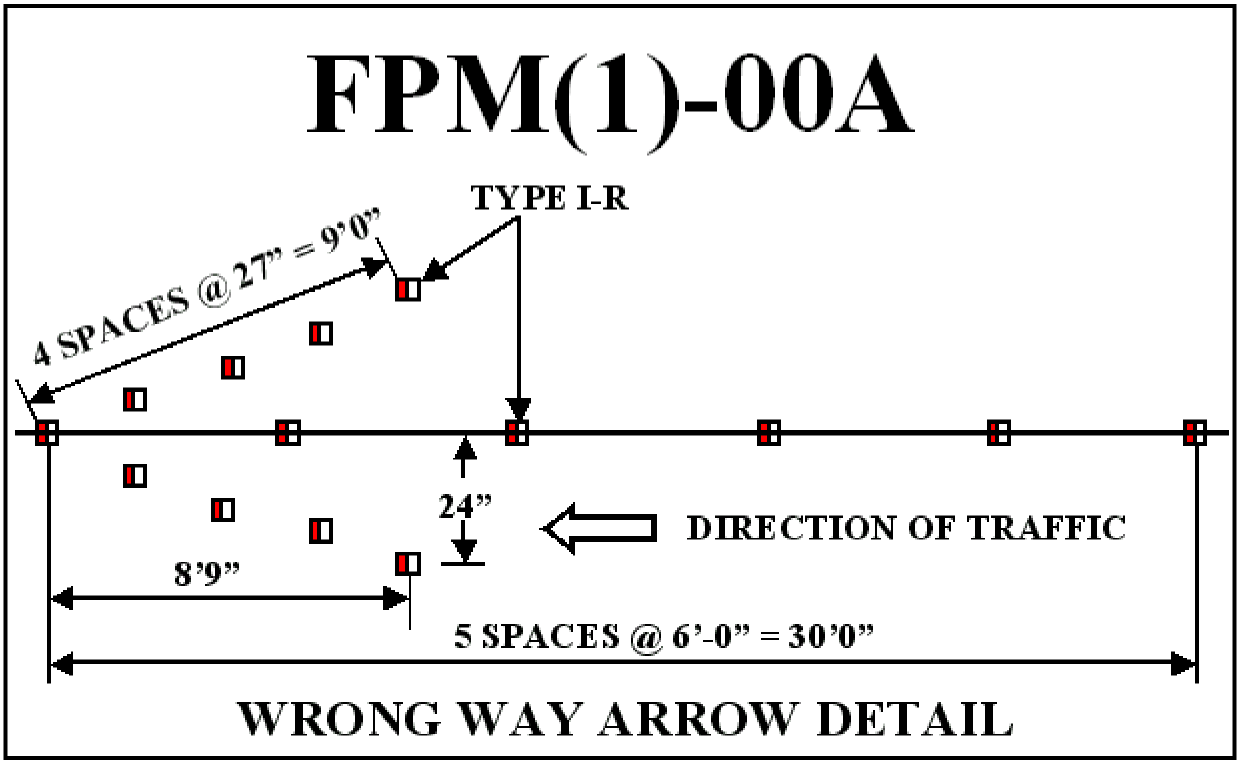

Figure 20. TxDOT Wrong-Way Pavement Arrow Detail (*22*).

Edge Lines on Exit Ramps

The use of colored pavement edge lines on exit ramps is another traditional wrong-way countermeasure. A yellow edge line is typically used on the left side and a white edge line on the right side of exit ramps to provide drivers with further indication of the correct direction of travel (Figure 21). Some agencies, notably Caltrans, supplement the yellow edge line with yellow RPMs to provide further delineation and visibility at night (*4*).

Figure 21. Example of Yellow Edge Line Wrong-Way Countermeasure.

INNOVATIVE SIGNING AND PAVEMENT MARKING TECHNIQUES

This section reports on some of the innovative signing and pavement marking techniques used as countermeasures for wrong-way movements on freeway facilities. The following list summarizes the countermeasures within this category:

- lowered DO NOT ENTER/WRONG WAY signs,
- supplemental sign placards on the DO NOT ENTER or WRONG WAY signs,
- supplemental flashers on the DO NOT ENTER or WRONG WAY signs,
- overhead-mounted DO NOT ENTER and WRONG WAY signs,
- internally-illuminated DO NOT ENTER and WRONG WAY signs,
- GO BACK YOU ARE GOING THE WRONG WAY signs (60 inches by 36 inches),
- non-standard wrong-way pavement arrows,
- red reflective tape on the back of freeway signs,
- extra overhead lighting, and
- red delineators on each side of the ramp up to the WRONG WAY sign.

Modifications to the DO NOT ENTER and WRONG WAY Signs

The research team found several countermeasures that involved slight modification and/or enhancement of either the DO NOT ENTER or WRONG WAY sign. The six primary countermeasures of this type were: lowered mounting height, supplemental sign placards, flashing beacons, three-dimensional signs, internal illumination, and overhead-mounted signs.

Lowered Mounting Height

The MUTCD specifies a standard mounting height (i.e., distance from ground to bottom edge) of 7 feet for urban signs and 5 feet for rural signs (*19*). Several research studies on wrong-way driving determined that lowering the DO NOT ENTER, WRONG WAY, and ONE WAY signs was an effective countermeasure for deterring wrong-way entries (*1*, *2*, *6*, *9*). These studies concluded that lowering the mounting height:

- avoids sight restrictions,
- makes the signs more visible at night because they are in the path of low beam headlights (wrong-way crashes and entries are more problematic in dark light conditions), and
- makes the signs potentially more visible to impaired drivers because they tend to drive with their eyes low looking for visual cues from the pavement.

California Standards for Lowered Mounting Height. The state of California uses lowered DO NOT ENTER and WRONG-WAY signs mounted together as standard practice (see Figure 22). The justification for doing this is provided in two studies on the topic of preventing wrong-way driving. The first study conducted by Caltrans is titled *Off-Ramp Surveillance: Wrong-Way Driving* – August 1978 (*2*). The second study, also by Caltrans, is titled *Prevention of Wrong-Way Accidents on Freeways* – June 1989 (*8*).

Figure 22. Lowered DO NOT ENTER/WRONG WAY Sign Package Used in California.

The earlier report describes the surveillance of all off-ramps in California using a traffic counter and camera. The traffic counter would detect the wrong-way movement and the camera verified the movement. The wrong-way entries into the off-ramp were found to be between 50-60 entries per month at some locations. The lowered DO NOT ENTER and WRONG WAY signs were used to lower the number of wrong-way movements. The lowered signs were thought to work better because they were positioned at headlight height.

The report indicated that although there are a variety of movements that result in wrong-way driving, two of the most common are the wrong-way entry via the off-ramp and u-turns on the main roadway. The wrong-way surveillance program actually began in 1971. The improved standard for the wrong-way sign package was originally instituted in 1973 by an administrative circular letter. The installation of the wrong-way sign package lowered the number of wrong-way entries to an acceptable level of two to six per month for 90 percent of the locations that had a problem with wrong-way entries. The remaining locations required additional attention. The new sign standard included the following changes:

- The bottom of the lower DO NOT ENTER and WRONG WAY sign packages are placed two feet (0.6 m) above the edge of pavement.
- ONE WAY arrows are mounted 1.5 feet (0.46 m) above the pavement (Figure 23).
- At least one DO NOT ENTER and WRONG WAY sign package is placed to fall within the area covered by a car's headlights and visible to the driver from the decision point on each likely wrong-way approach.
- FREEWAY ENTRANCE signs are placed as near the intersection of the on-ramp and cross street as possible.
- Caltrans does not use symbol right or left prohibition signs at ramps because of possible misunderstandings by intoxicated drivers as directional arrows (Figure 23).

Figure 23. Lowered ONE-WAY and Turn Restriction Signs in California.

The 1989 study revisited the topic of wrong-way crashes and critically reviewed Caltrans efforts to reduce this crash type (*8*). The lowered DO NOT ENTER and WRONG WAY sign packages were still considered to be effective. The use of oversized DO NOT ENTER signs was suggested for locations with a recurring wrong-way problem. Also offered as a consideration was the use of a second set of DO NOT ENTER and WRONG WAY signs to give drivers a second chance to realize that they are headed the wrong way before they enter the freeway.

Today, California has 175 wrong-way incidents per year. This number seems to remain constant from year to year and is thought to be a direct result of the lowered signs. Also, California continually monitors wrong-way incidents and information on locations that appear to be a problem. This information is forwarded to responsible districts so that adjustments are possible for the signing, pavement markings, or general operation.

Georgia Standards for Lowered Mounting Height. The Georgia DOT uses lowered DO NOT ENTER and WRONG WAY signs mounted together as standard practice. The justification for doing so was in a 1979 study by the Georgia Institute of Technology entitled *Wrong-Way Traffic Movement on Freeway Ramps* (*1*). The study recommended that the Georgia DOT adopt California's freeway ramp terminal standard sign package, with the addition of a 24-inch wide painted stop bar at the crossroad end of the ramp. The standard sign package includes the 24-foot painted arrow pavement marking.

Virginia Standards for Lowered Mounting Height. The state of Virginia uses lowered DO NOT ENTER and WRONG WAY signs mounted together as standard practice. The justification for doing so was in a 1980 study by the Virginia Highway and Transportation Research Council (VHTRC) entitled *Wrong-Way Driving at Selected Interstate Highway Off-Ramps*, which recommended that the Virginia DOT adopt the use of California's sign placement criteria for deterring wrong-way drivers (*23*). Virginia acknowledges the importance of having the DO NOT ENTER and WRONG WAY signs visible in the area covered by a car's headlights and visible to the driver from the decision point on each likely wrong-way approach. In 1981, two Traffic Safety Division memorandums were issued adopting the California criteria.

The VHTRC report discusses the two basic criteria used to judge measures for preventing wrong-way entries at off-ramps. These criteria are the effectiveness in deterring wrong-way movements and insuring that countermeasures do not impede or endanger the right-way motorists. The author concluded that California's program against wrong-way driving has been successful in satisfying both requirements.

Supplemental Sign Items

In some cases supplemental items such as placards, flashing beacons, or flags have been added to either DO NOT ENTER or WRONG WAY signs as an enhancement to the traditional approach. In the case of supplemental sign placards, the research team identified the following:

- the word RAMP (Figure 24),
- the word FREEWAY, and
- ONE WAY sign (Figure 25).

Figure 24. DO NOT ENTER Signs with RAMP Supplemental Placards.

Figure 25. DO NOT ENTER Sign with Supplemental ONE WAY Sign.

Flashing Beacons

The survey results also showed that only one of the national survey respondents has used yellow and red flashing beacon assemblies to enhance the visibility of DO NOT ENTER and WRONG WAY signs. Figure 26 provides an example of a DO NOT ENTER sign with flasher assembly.

The research team also discovered a vendor who offers a product called Active Road Signs (ARS) (*24*). One of the ARS is a standard WRONG WAY sign with red flashing beacons that is solar powered. Figure 27 shows a graphical representation of a WRONG WAY ARS. The basic cost is $3100 for an ARS with 12-volt direct current (DC) or 110-volt alternating current (AC) power and $4500 for a 75-watt solar-powered setup.

Figure 26. DO NOT ENTER Sign with Flasher Assembly.

Figure 27. WRONG WAY Active Road Sign (*24*).

Three-Dimensional DO NOT ENTER Sign

Researchers at the University of Massachusetts (UMass) developed and evaluated a three-dimensional (3D) DO NOT ENTER sign as a method to reduced wrong-way entries (*25*). Researchers developed the 3D technique to draw attention to the DO NOT ENTER sign by having a cone protruding from the sign face so it is visible to approaching cars before turning into an exit ramp. The UMass research team tested the three alternative 3D sign panels pictured in Figure 28. The evaluation was performed using a driving simulator under daylight conditions.

Internally Illuminated Signs

Internally illuminated traffic signs have become a fairly common sight in many cities throughout the United States. Most of the IITS deployed in the field are street name signs that help provide greater visibility, especially in areas frequented by tourists or other unfamiliar drivers. The research team also found several vendors who offer both the DO NOT ENTER and WRONG WAY signs with internal illumination capabilities. Figure 29 shows an example of an internally illuminated DO NOT ENTER sign.

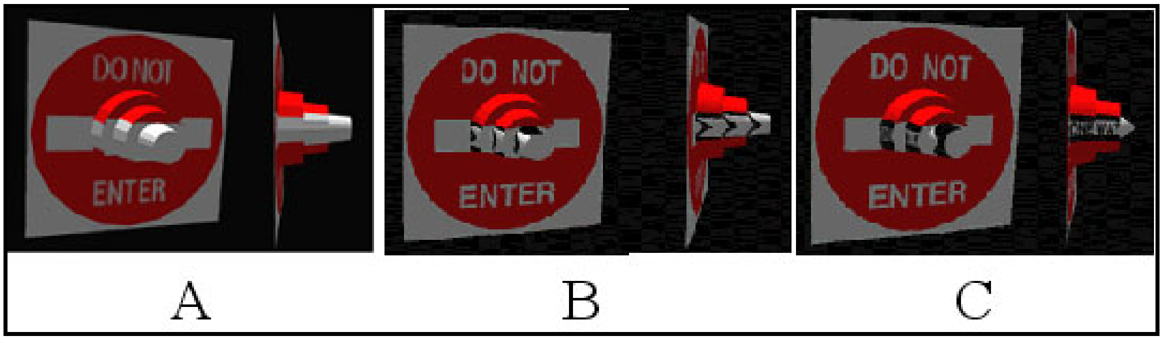

Figure 28. Massachusetts 3D DO NOT ENTER Signs: Panel A – Plain 3D Sign, Panel B – 3D Sign with Chevrons, Panel C – 3D Sign with ONE WAY Sign Embedded (*25*).

Figure 29. Internally Illuminated DO NOT ENTER Sign.

Overhead-Mounted Signs

Researchers found several agencies that mount DO NOT ENTER and WRONG WAY signs overhead as a wrong-way entry countermeasure. Based on the survey results and Internet search, this treatment has not received widespread deployment as a wrong-way countermeasure. The research team found several examples of overhead-mounted signs in Texas (see Figure 30 and Figure 31).

In the Phoenix, Arizona, metropolitan area, WRONG WAY signs are mounted on overhead sign bridge structures on freeway frontage roads. A single WRONG WAY (36 inch by 24 inch) sign is placed on the back of overhead lane use sign structures, which are located a minimum of 250 feet upstream of the cross street on many of the freeway facilities (*26*). The main purpose of these sign structures is the provision of lane use assignment information for drivers on the frontage road going in the proper direction of travel. A similar treatment can be seen in Figure 14 where a Japanese DO NOT ENTER sign is mounted on an overhead sign bridge structure.

Figure 30. Overhead-Mounted WRONG WAY Signs in Texas.

Figure 31. Overhead-Mounted Red Flashers on Span Wire in Texas.

Non-Standard Wrong-Way Pavement Arrows

Based on the survey results, several state DOTs use wrong-way pavement arrows that are different from the MUTCD standards shown in Figure 19. Agencies that are using non-standard wrong-way arrows are using the standard lane use arrows instead. One survey respondent indicated that they are in the process of designing a new wrong-way arrow.

GEOMETRIC TREATMENTS

The research team identified a number of geometric treatments aimed at discouraging wrong-way entries onto freeway facilities. The following list describes two of the more prominent geometric treatments used as wrong-way countermeasures:

- Offset entrance and exit ramps – Proper separation of entrance and exit ramp terminals is an important treatment to consider, particularly at interchanges where the terminals are closely spaced (e.g., loop ramps).
- Off-ramp throat reductions – Reducing the size of the off-ramp throat using dikes, curbs, delineator posts, and painted islands is considered a successful method of discouraging wrong-way movements. This countermeasure makes the wrong-way entry less inviting by reducing the size of the opening for the movement.

INTELLIGENT TRANSPORTATION SYSTEM APPLICATIONS

Researchers collected information regarding ongoing projects related to wrong-way driving that use ITS technologies. The following two sections highlight wrong-way detection and warning systems in New Mexico and Washington.

New Mexico Wrong-Way Detection and Warning System

The Alliance for Transportation Research (ATR), in conjunction with the New Mexico State Highway and Transportation Department and New Mexico State University, has developed a Directional Traffic Sensor System (DTSS). A DTSS was installed on an Interstate 40 exit ramp near Albuquerque in 1998 for wrong-way detection and warning. The DTSS uses loop sensors, a modified 3M Canoga TMI C400 vehicle detector, and standard warning signs (*27*, *28*).

When wrong-way traffic is detected entering the exit ramp, the DTSS illuminates two sets of warning lights. Each set of lights will flash for a period of one minute. The red set of lights faces the wrong-way traffic and is mounted on both sides of a conventional WRONG WAY sign. This is designed to warn the driver of imminent danger of entering the freeway going the wrong-way. On the opposite side of the DTSS sign structure, a yellow set of lights faces the exiting freeway traffic and is mounted on the top and bottom of a STOP AHEAD warning sign. This is designed to warn the traffic of a possible exit ramp obstacle and the upcoming STOP SIGN. Figure 32 shows a diagram of how the DTSS appears to drivers traveling in both directions. The DTSS is designed to be an effective warning system in bad weather conditions and is also effective with disoriented and confused drivers. A picture of the DTSS is provided in Figure 33.

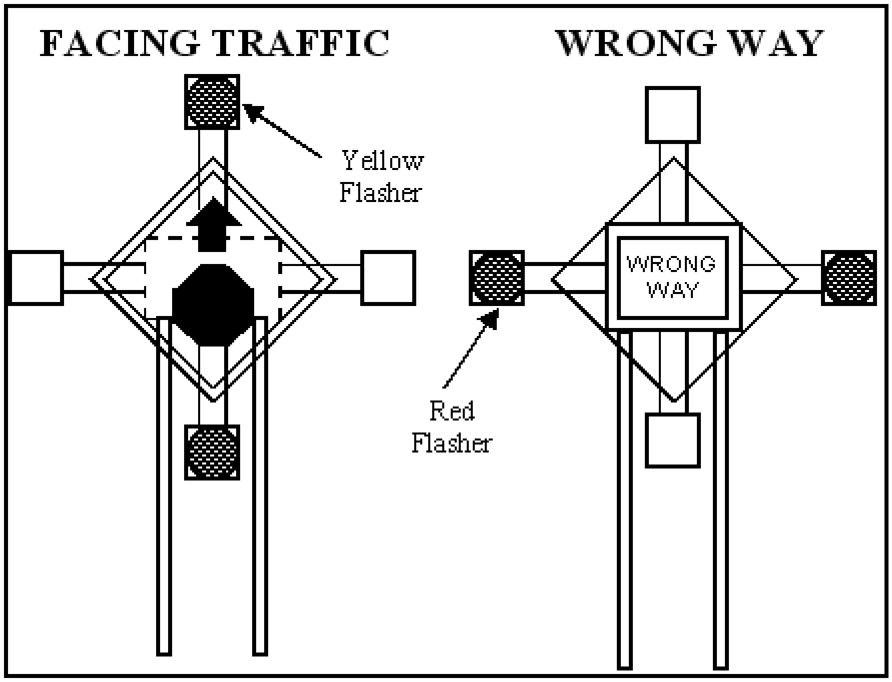

Figure 32. Diagram of the New Mexico Directional Traffic Sensor System.

Figure 33. Picture of the New Mexico Directional Traffic Sensor System.

Washington Experimental ITS Wrong-Way Detection and Warning System

The Washington State Department of Transportation is currently involved in several safety projects related to wrong-way driving on freeways. WsDOT has a $90,000 ITS Safety Earmark project, $50,000 funded by the FHWA, that is using technology to address crashes involving motorists who drive the wrong way on freeway interchange ramps (*29*, *30*).

Two freeway ramp locations will be using different technologies to demonstrate the safety benefits of ITS wrong-way signing. The first location is a rural exit ramp off of Interstate 5 that uses a self-powered vehicle detection system with solar powered batteries that provide power to the electronic light emitting diode (LED) signs, flashers, video camera, and VCR. Figure 34 shows the LED wrong-way sign in both activated and blank status and also the ramp installation. The second location, which is still being determined, will be an urban exit ramp. The primary difference in this system is that it uses traditional power sources. Both warning systems will only be visible when an errant vehicle activates the video detectors. Once activated by a wrong-way vehicle, the detectors transmit a message to the electronic signs, flasher, and VCR - flashing a red “WRONG WAY” message to the driver. The VCR will record incidents involving wrong-way vehicles so that WsDOT engineers can study the tape to assess whether the problem occurred because of driver behavior or engineering-related flaws (signing, striping, geometric, etc.) in the interchange.

Figure 34. Washington State Wrong-Way ITS System on an Exit Ramp.

Vendor Advertised Wrong-Way Products

The research team found several products related to wrong-way vehicle detection and warning during Internet searches. The following subsections highlight a few of these products.

SmarTek Acoustic Sensors

SmarTek Systems Incorporated is currently marking the SAS-1 acoustic traffic sensor for wrong-way traffic detection on exit ramps (*31*). The SAS-1 detector is designed based on passive acoustic detection of motor vehicles, which minimizes the effect on performance due to variation in environmental conditions such as rain and fog. This type of detector is considered non-intrusive because it is not embedded in the pavement like a loop detector system.

The company website provides a diagram of a typical wrong-way detection system installation, as shown in Figure 35, where the maximum number of zones monitored is set at five. For the configuration shown in Figure 35, a vehicle traveling in the proper direction will be detected in the following sequence: zone 1, then 2, then 3, then 4, and finally zone 5. A wrong-way vehicle will be detected in the opposite sequence: zone 5, then 4, then 3, then 2, and finally zone 1. The relative spacing between the detection zones will determine wrong-way detection response time. The use of five detection zones improves on performance and ability to accurately detect wrong-way entries. Figure 36 provides a picture of a SAS-1 detector installed on an exit ramp.

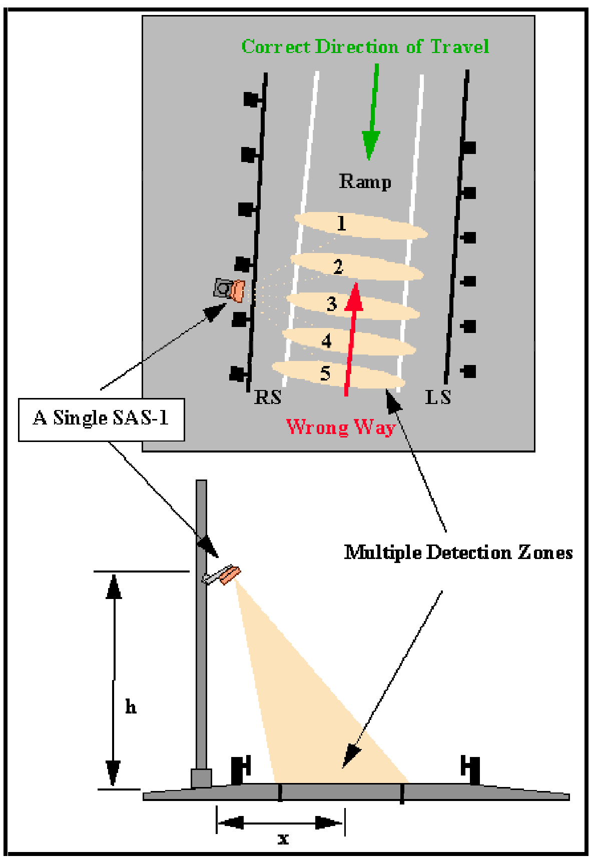

Figure 35. Diagram of SmarTek System Acoustic Wrong-Way Detection System.

Figure 36. SAS-1 Acoustic Detector Installed on an Exit Ramp.

Video-Based Wrong-Way Detection Systems

The research team found a few video detection systems being marketed for wrong-way detection. The Internet search revealed the following vendors that currently market wrong-way video-based detection systems:

- ASCOM – based in Switzerland (*32*);
- Traficon – based in Belgium (*33*, *34*); and
- Peek – based in the United States (*35*).

The two European companies' wrong-way detection products have primarily been applied in motorway tunnels.

Other Wrong-Way Applications Using Advanced Technologies

Researchers discovered several other advanced technologies being used as wrong-way countermeasures. One system on a bridge in Florida utilizes loop detectors for wrong-way vehicle detection. The bridge had experienced several high profile fatal wrong-way crashes in a short time period that prompted the installation of the wrong-way detection and warning system. The warning portion of the system is twofold:

- a nearby police substation is notified when a wrong-way driver is detected, and
- a signal system on a span-wire warns motorists going in the proper direction that a wrong-way driver may be approaching – see Figure 37.

Caltrans has also utilized in-pavement warning lights activated by wrong-way vehicles as a countermeasure on problem exit ramps. Figure 38 provides a picture of this type of installation.

Figure 37. Florida Bridge Wrong-Way Signal System.

Figure 38. In-Pavement Warning Lights for Wrong-Way Vehicles.

CHAPTER 6. GUIDELINES AND RECOMMENDED PRACTICES FOR APPLICATION OF WRONG-WAY COUNTERMEASURES

This chapter provides the guidelines and recommended practices for application of wrong-way countermeasures and treatments. The research team developed the guidelines and recommended practices based on the results of the literature review, surveys, analysis of freeway-related wrong-way crashes in Texas, and evaluation of available countermeasures.

GUIDELINES

Guideline #1: Existing left-side exit ramps on freeways shall have reflectorized wrong-way pavement arrows installed.

The analysis of freeway-related wrong-way crashes in Texas revealed that several locations with existing left-side exit ramps experienced multiple crashes during the four-year analysis period. This confirms that left-side exit ramps in Texas, while rare, were one of the few problem location types substantiated by the analysis of wrong-way originations.

Guideline #2: Left-side exit ramps on freeways should be avoided in future freeway construction.

This guideline supports previous research in California, which stated that left-hand exit ramps were obsolete and must be avoided in new construction. The basic rationale for this guideline is that drivers naturally expect to enter the freeway using a right turn and may mistakenly make this turn and travel the wrong-way onto a left-side exit ramp.

Guideline #3: Revise the Typical Standard Freeway Pavement Markings with Raised Pavement Markers Standards Plan Sheet FPM (1) – 00A.

This guideline calls for TxDOT to revise the Typical Standard Freeway Pavement Markings with Raised Pavement Markers Standard Plans Sheet FPM (1) – 00A wrong-way arrow detail from:

- "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**."

This revision would make the installation of wrong-way pavement arrows a more standard practice, particularly at known or suspected problem locations.

Guideline #4: Repair deficient wrong-way pavement arrows and make their maintenance a priority, particularly in the urban districts of Dallas/Fort Worth, Houston, and San Antonio.

TxDOT's standard wrong-way pavement arrow is comprised of raised pavement markers, which create good visibility and reflectivity at night. The use of RPMs also can be a maintenance concern because they are often run over, especially on high-volume exit ramps in urban areas. Field inspections by the research team revealed that wrong-way pavement arrows sometimes had markers missing or were very worn in appearance. Researchers believe that it is important to repair deficient wrong-way pavement arrows and make their maintenance a priority, particularly in the urban districts of Dallas/Fort Worth, Houston, and San Antonio. The singling out of these three districts is based on the crash analysis, which found that approximately 60 percent of all the freeway-related wrong-way crashes occurred in the urban districts of Dallas/Fort Worth, Houston, and San Antonio.

Guideline #5: 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.

TxDOT standard wrong-way signing involves the use of gatepost sets of DO NOT ENTER and WRONG WAY signs mounted at the standard mounting height (i.e., distance from ground to bottom edge) of 7 feet for urban signs and 5 feet for rural signs. Several states, most notably California, have used lowered DO NOT ENTER, WRONG WAY, and ONE WAY signs as an effective countermeasure for deterring wrong-way entries onto freeway facilities. The lowered mounting height was based on the following:

- avoids sight restrictions,
- makes the signs more visible at night because they are in the path of low beam headlights (wrong-way crashes and entries are more problematic in dark light conditions), and
- makes the signs potentially more visible to impaired drivers because they tend to drive with their eyes low looking for visual cues from the pavement (a significant portion of wrong-way crashes involve impaired drivers).

The analysis of wrong-way crashes in Texas revealed that almost 61 percent had some influence of alcohol and/or drugs cited by the investigating officer. This is a significantly higher proportion than for other types of crashes and points to driver influence being a primary contributor to the majority of freeway-related wrong-way crashes. Furthermore, approximately 80 percent of the wrong-way crashes in Texas happened at night (i.e., dark light conditions). Both of these findings suggest that lowered DO NOT ENTER and WRONG WAY signs like those used in

California should be considered to address the problems of alcohol-involvement and darkness in creating wrong-way crashes.

Below are some of the issues that need to be addressed while considering implementation issues with lowered DO NOT ENTER and WRONG WAY signs:

1. Crashworthiness – The survey revealed that there have been no crash testing or other analyses to support the safety of lowered sign mounting height. This is potentially a barrier to implementation in Texas and crash tests would likely need to be performed to assess the performance and safety of a lowered DO NOT ENTER/WRONG WAY sign package.

2. Financial – There are a number of financial issues associated with using lowered signs. The first is that the Federal Highway Administration does not pay for lowered signs because they do not meet the MUTCD standard. Caltrans uses state funds to pay for all of their DO NOT ENTER sign packages. Texas has a high number of exit ramp, frontage road, and divided highway locations that would be potential sites for retrofitting with lowered signs.

3. Design – The Georgia and Virginia DOTs have adopted the California standards (i.e., the bottom of the lower DO NOT ENTER and WRONGWAY package placed two feet (0.6 m) above the edge of pavement. TxDOT could adopt the California standards or consider research on alternative designs using different materials (e.g., plastic signs, metal posts instead of wood posts, etc.).

RECOMMENDED PRACTICES

Recommended Practice #1: Coordinate with the primary 911 public safety answering points to share information on reports of wrong-way movements on freeway facilities.

This recommended practice can take one of the following two approaches:

- Approach #1 – Coordinate with the 911 public safety answering point representatives as the research team did by receiving a list of wrong-way driving reports on a monthly basis. TxDOT would likely receive more cooperation from 911 representatives than what the research team experienced. The monthly lists could be used to track areas and corridors where wrong-way movements have occurred and could be compared with historical crash data.

- Approach #2 – TxDOT Traffic Management Centers (TMCs) in the urban areas (i.e., Austin, Dallas, Fort Worth, El Paso, Houston, and San Antonio) share information with the 911 PSAPs in real-time. Further research would be needed to develop protocols and procedures for TMC operators on how to respond to wrong-way driving reports (e.g., what, if any, type of warning should be given to motorists traveling in the correct direction in the vicinity of the wrong-way driver.

The research team recommends that TxDOT initially take Approach #1 and work towards Approach #2 as the relationship with the PSAPs solidifies.

Recommended Practice #2: Implement inductive loops or other detectors on exit ramps in future construction.

Installation of inductive loops or other detectors on exit ramps during future construction, particularly on urban freeways, would allow for the implementation of wrong-way detection and warning systems. In addition to wrong-way application, the detectors could also be used for other purposes such as traffic counts and detection of queues before they spill back onto the freeway mainlanes. The detector installation would be relatively inexpensive when done as part of major freeway reconstruction projects.

Recommended Practice #3: Utilize the wrong-way entry checklist for reviewing wrong-way entry issues and suspected problem locations.

The wrong-way entry checklist contained in Appendix C is designed for engineers and field crews to use for reviewing wrong-way entry issues or suspected problem locations. The research team based the checklist on one currently used by Caltrans with some additions and modifications based on project findings.

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APPENDIX A

NATIONAL WRONG-WAY COUNTERMEASURES SURVEY

Wrong Way Countermeasures Survey

A. Introduction

Drivers who make wrong-way entries onto freeways or other restricted roadways are at a serious risk of injuring themselves or others. The Texas Transportation Institute is currently performing a research project to study wrong-way driving issues and potential countermeasures. FHWA and TxDOT sponsored this study. This survey is intended to obtain information on current practices for signing and pavement marking related to wrong-way movements and any efforts by your agency to countermeasure this problem. Please forward the survey to the appropriate member(s) of your agency for completion. The estimated amount of time to finish the survey is 10 minutes.

Respondent ID Information (For Internal Use Only):

Agency Name:	
City:	
State:	(Click here to choose)
Person Completing Survey:	
Telephone Number:	
E-mail Address:	

B. Signing Issues

1. What signs does your state typically use to discourage wrong-way movements? **(Check all that apply)**

	DO NOT ENTER (R5-1)	WRONG WAY (R5-1a)
On Exit Ramps	☐	☐
On Frontage Roads	☐	☐
On Divided Highways	☐	☐

2. If both the 'DO NOT ENTER' and 'WRONG WAY' signs are used, indicate whether they are mounted together on the same post or on separate posts? **(Check all that apply)**

	Same	Separate	Do Not Use Both
On Exit Ramps	☐	☐	☐
On Frontage Roads	☐	☐	☐
On Divided Highways	☐	☐	☐

3a. What dimensions does your state use for the 'DO NOT ENTER' sign? **(Check all that apply)**

- ☐ 30 inch by 30 inch
- ☐ 36 inch by 36 inch
- ☐ 48 inch by 48 inch
- ☐ 72 inch by 72 inch
- ☐ Other(s) (List below)

3b. Other(s) or Comments:

4a. What dimensions does your state use for the 'WRONG WAY' sign? **(Check all that apply)**

- ☐ 30 inch by 18 inch
- ☐ 36 inch by 24 inch
- ☐ 42 inch by 30 inch
- ☐ 48 inch by 36 inch
- ☐ Other(s) (List below)

4b. Other(s) or Comments:

5. Does your state use the standard MUTCD mounting height (7 ft urban/5 ft rural) for the 'DO NOT ENTER' and 'WRONG WAY' signs?

	DO NOT ENTER	**WRONG WAY**
Yes	○	○
No	○	○

6. If the answer above is 'No', please specify the typical mounting height (in feet) above the pavement surface for the 'DO NOT ENTER' and 'WRONG WAY' signs.

DO NOT ENTER: None

WRONG WAY: None

7a. Has there been any crash testing or other analyses in your state to support the safety of the lowered mounting height?

- Yes (Explain below)
- No
- Do not have any lowered signs

7b. Explain:

8a. Has your state used any of the following supplemental items on either the 'DO NOT ENTER' or 'WRONG WAY' signs? **(Check all that apply)**

- The word 'RAMP' on supplemental plaque
- The word 'FREEWAY' on supplemental plaque
- 'ONE WAY' sign
- Red flashing beacons
- Yellow flashing beacons
- Flags
- Other(s) (List below)

8b. Other(s):

9a. Has your state used any other signs besides the 'DO NOT ENTER' or 'WRONG WAY' to prevent wrong-way movements?

- ☐ Yes (Explain below)
- ☐ No

9b. Explain:

C. Pavement Marking Issues

10a. Under what circumstances does your state use wrong-way arrow pavement markings on exit ramps to discourage wrong-way movements?

- ☐ Arrows are standard on all exit ramps
- ☐ Arrows are installed on the majority of exit ramps
- ☐ Arrows are placed on known or suspected problem locations
- ☐ Do not use wrong-way arrows
- ☐ Other (Explain below):

10b. Other:

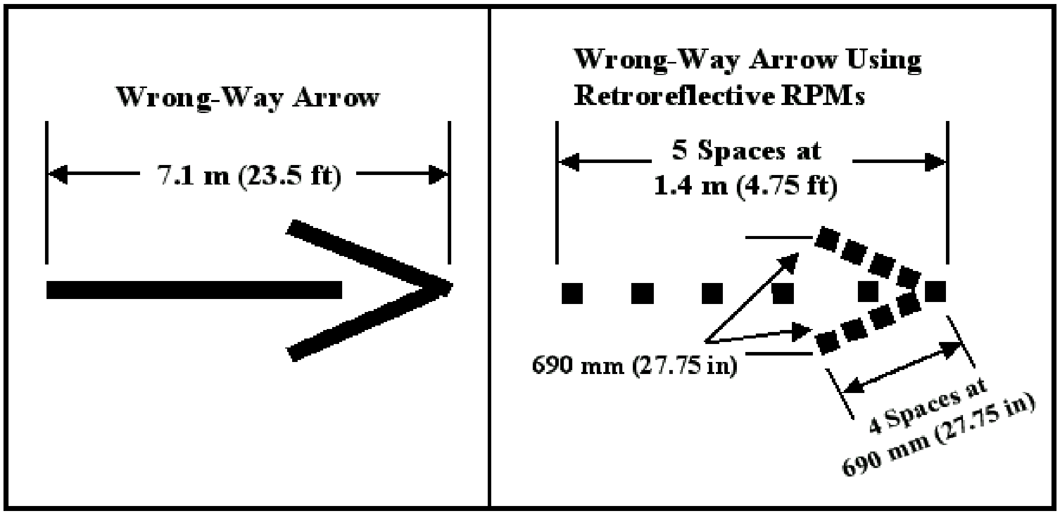


Figure 3B-20 from Millenium Edition Manual on Uniform Traffic Control Devices

11. Are the wrong-way arrows in the Millennium Edition MUTCD (shown above) the ones typically used?

- Yes
- No

12a. Has your state used other types of wrong-way arrows other than those in the Millennium Edition MUTCD?

- Yes
- No

12b. If Yes, please describe:

13. Does your state typically use a yellow edgeline on the left and white edgeline on the right of freeway exit ramps?

- Yes
- No

14. Are red-backed raised pavement markers (Type II-C-R) visible to wrong-way drivers a standard item installed on freeway main lanes and wrong-way arrows in your state?

	Main Lanes	Wrong-Way Arrow
Yes	◯	◯
No	◯	◯

D. Other Wrong-Way Movement Countermeasures

15a. Has your state used any of the following countermeasures for wrong-way movements? **(Check all that apply)**

- ☐ Airport-type in-pavement lights activated by wrong-way drivers
- ☐ Positive barriers (e.g., gates, spikes, etc.)
- ☐ Internally illuminated 'DO NOT ENTER' and/or 'WRONG WAY' signs
- ☐ Overhead-mounted 'DO NOT ENTER' and/or 'WRONG WAY' signs
- ☐ Red reflective tape on the back of freeway signs
- ☐ Supplemental flashing beacons and/or strobe lights on 'DO NOT ENTER' and/or 'WRONG WAY' signs
- ☐ Extra overhead lighting
- ☐ Devices that produce an audible warning when activated by wrong-way drivers
- ☐ Special ITS wrong-way detection and warning system
- ☐ Other (Please specify below):

15b. Other:

E. Wrong-Way Crash Issues

16. How does your state identify problematic wrong-way crash locations?

None

17. If known, please indicate which statements are true, based on your experience, for a majority (i.e., greater than 50 percent) of the wrong-way crashes in your state. **(Check all that apply)**

- ☐ Occur at night
- ☐ Alcohol and/or drugs are a contributing factor
- ☐ Drivers over 55 years old were involved
- ☐ Resulted in fatal and/or incapacitating injuries
- ☐ Do not know

18a. Does your state have guidelines for countermeasures based on the frequency of wrong-way crashes and/or movements?

- ○ Yes
- ○ No

18b. If yes, please describe:

19. Additional comments about wrong-way driving issues and/or countermeasures:

None

Submit Survey

APPENDIX B

TEXAS WRONG-WAY COUNTERMEASURES SURVEY

Wrong-Way Movement Survey

A. Introduction

Drivers who make wrong-way entries onto freeways or other restricted roadways are at a serious risk of injuring themselves or others. The Texas Transportation Institute is currently conducting research for the Texas Department of Transportation research project 0-4128, Countermeasures for Wrong-Way Movements on Freeways, to study wrong-way driving issues and potential countermeasures. Mr. Roy Parikh of the Fort Worth District is the Project Director of this study.

This survey is intended to obtain information on current practices for signing and pavement marking related to wrong-way movements and any efforts by your district to countermeasure this problem. This survey is being distributed to each Director of Transportation Operations for the 25 TxDOT Districts. Please help by completing this survey or by forwarding the survey to the appropriate member(s) of your agency for completion. The estimated amount of time to complete this survey is 10 minutes. Respondent ID Information (For Internal Use Only):

TxDOT District:	
Person Completing Survey:	
Telephone Number:	
E-mail Address:	

B. Signing Issues

1. What signs does your district typically use to discourage wrong-way movements? **(Check all that apply)**

	DO NOT ENTER (R5-1)	WRONG WAY (R5-1a)
On Exit Ramps	☐	☐
On Frontage Roads	☐	☐
On Divided Highways	☐	☐

2. If both the 'DO NOT ENTER' and 'WRONG WAY' signs are used, indicate whether they are mounted together on the same post or on separate posts. **(Check all that apply)**

	Same	Separate	Do Not Use Both
On Exit Ramps	☐	☐	☐
On Frontage Roads	☐	☐	☐
On Divided Highways	☐	☐	☐

3a. What dimensions does your district use for the 'DO NOT ENTER' sign? **(Check all that apply)**

- ☐ 30 inch by 30 inch
- ☐ 36 inch by 36 inch
- ☐ 48 inch by 48 inch
- ☐ 72 inch by 72 inch
- ☐ Other(s) or Comments (Describe below)

3b. Other(s) or Comments:

4a. What dimensions does your district use for the 'WRONG WAY' sign? **(Check all that apply)**

- ☐ 30 inch by 18 inch
- ☐ 36 inch by 24 inch
- ☐ 42 inch by 30 inch
- ☐ 48 inch by 36 inch
- ☐ Other(s) or Comments (List below)

4b. Other(s) or Comments:

5. Does your district use the standard MUTCD mounting height (7 ft urban/5 ft rural) for the 'DO NOT ENTER' and 'WRONG WAY' signs?

	DO NOT ENTER	**WRONG WAY**
Yes	○	○
No	○	○

6. If the answer above is 'No', please specify the typical mounting height (in feet) above the pavement surface for the 'DO NOT ENTER' and 'WRONG WAY' signs.

DO NOT ENTER: None

WRONG WAY: None

7a. Has your district used any of the following supplemental items on either the 'DO NOT ENTER' or 'WRONG WAY' signs? **(Check all that apply)**

- ☐ The word 'RAMP' on supplemental plaque
- ☐ The word 'FREEWAY' on supplemental plaque
- ☐ 'ONE WAY' sign
- ☐ Red flashing beacons
- ☐ Yellow flashing beacons
- ☐ Flags
- ☐ Other(s) (Describe below)

7b. Other(s):

8a. Has your district used any other signs besides the 'DO NOT ENTER' or 'WRONG WAY' to prevent wrong-way movements?

- ○ Yes (Explain below)
- ○ No

8b. Explain:

C. Pavement Marking Issues

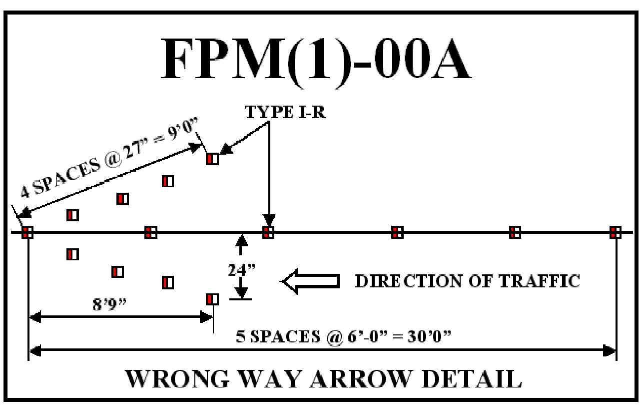
9a. Under what circumstances does your district use wrong-way arrow pavement markings on exit ramps to discourage wrong-way movements?

- Arrows are standard on all exit ramps
- Arrows are installed on the majority of exit ramps
- Arrows are placed on known or suspected problem locations
- Do not use wrong-way arrows
- Other (Explain below):

9b. Other:

10. Is the wrong-way arrow detail on FPM(1)-00A (Typical Standard Freeway Pavement Markings with Raised Pavement Markers) the one typically used in your district?

- Yes
- No



11a. Has your district used other types of wrong-way arrow pavement markings other than the TxDOT standard?

- Yes
- No

11b. If Yes, please describe:

12. Does your district typically use a yellow edgeline on the left and white edgeline on the right of freeway exit ramps?

- Yes
- No

13. Are red-backed raised pavement markers (Type II-C-R) visible to wrong-way drivers a standard item installed on freeway main lanes and wrong-way arrows in your district?

	Main Lanes	Wrong-Way Arrow
Yes		
No		

D. Other Wrong-Way Movement Countermeasures

14a. Has your district used any of the following countermeasures for wrong-way movements? **(Check all that apply)**

- Airport-type in-pavement lights activated by wrong-way drivers
- Positive barriers (e.g., gates, spikes, etc.)
- Internally illuminated 'DO NOT ENTER' and/or 'WRONG WAY' signs
- Overhead-mounted 'DO NOT ENTER' and/or 'WRONG WAY' signs
- Red reflective tape on the back of freeway signs
- Supplemental flashing beacons and/or strobe lights on 'DO NOT ENTER' and/or 'WRONG WAY' signs
- Extra overhead lighting
- Devices that produce an audible warning when activated by wrong-way drivers
- Special ITS wrong-way detection and warning system
- Other(s) (Describe below):

14b. Other (s):

E. Wrong-Way Crash Issues

15a. Does your district have an existing monitoring program to identify and evaluate wrong-way crashes and/or suspected problem locations?

- Yes
- No

15b. If yes, please explain:

16. In your district, please indicate which statements are true, based on your experience, for a majority (i.e., greater than 50 percent) of the wrong-way crashes. **(Check all that apply)**

- Occur at night
- Alcohol and/or drugs are a contributing factor
- Drivers over 55 years old were involved
- Resulted in fatal and/or incapacitating injuries
- Do not know

17a. Does your district have guidelines for countermeasures based on the frequency of wrong-way crashes and/or movements?

- Yes
- No

17b. If Yes, please describe:

18. Would your district be willing to have locations considered for field testing of wrong-way countermeasures developed during this research project?

- Yes
- No

19. Please list and describe any known and/or suspected locations in your district with wrong-way movement problems:

None

20. Additional comments about wrong-way driving issues and/or countermeasures:

Submit Survey

This questionnaire was created using Perseus SurveySolutions.

APPENDIX C

TEXAS WRONG-WAY ENTRY ANALYSIS PROCEDURES AND CHECKLIST

TEXAS WRONG-WAY ENTRY ANALYSIS PROCEDURES

This document was developed for TxDOT engineers and field crews to use for reviewing wrong-way entry issues or suspected problem locations. The research team based the checklist on one currently used by Caltrans with some additions and modifications based on project findings. The checklist was developed as part of the **0-4128 Countermeasures for Wrong-Way Movement on Freeways** research project performed by the Texas Transportation Institute.

STEP 1: Review pertinent Department of Public Safety crash reports.

Obtain copies of the original ST-3 crash reports from the DPS or local police agencies to have the officer's crash diagram and narrative of events. The best screening variable for wrong-way crashes is contributing factor code 71 (*wrong way – one way road*). Some of the crash reports with contributing factor code 71 will not be freeway-related crashes.

STEP 2: Analyze crash reports to determine wrong-way entry locations.

The information contained in the crash diagram and narrative is the best way to determine where the wrong-way entry occurred. Review the diagram and narrative and try to determine the location where the wrong-way entry occurred.

Other tools such as recent aerial photographs and online maps can be useful in determining wrong-way entry locations. The analyst should use the aerial photographs to review ramps, cross roads, and median openings approximately three miles upstream (can be less in urban and more in rural areas) from the actual location of the wrong-way crash.

STEP 3: Perform field inspections.

Field investigation of ramps located within three miles may also be necessary to inspect the condition of signing and marking. Field inspection should occur during both daylight and dark conditions, particularly if the crash occurred at night. Using proper safety procedures, inspectors should get out of the vehicle and view the scene from the wrong-way driver's perspective. Use the WRONG-WAY ENTRY CHECKLIST – FIELD INSPECTION SHEET to complete the field inspection.

STEP 4: Make recommendations.

Any recommendations for improvements that result from the field investigation should verbally be communicated to a management level engineer. Do not initially put these recommendations in writing to prevent tort liability.

WRONG-WAY ENTRY CHECKLIST
FIELD INSPECTION SHEET

Inspector name: ___________________________

Location description: ____
____
____

Crash Report ID Number: ____________________

SIGNING CHECKLIST

Sign	Check if	Yes	No	Comments
DO NOT ENTER	Present in minimum quantity			
	Visible from entry decision point			
	Night time visibility is sufficient			
	Mounted at standard MUTCD height			
	High intensity sheeting			
	In good repair and free of graffiti			
WRONG WAY	Present in minimum quantity			
	Mounted at standard MUTCD height			
	Night time visibility is sufficient			
	High intensity sheeting			
	In good repair and free of graffiti			
ONE-WAY	Present at the location			
	Supplement to DO NOT ENTER sign			
TURN RESTRICTION SIGNS	NO RIGHT TURN			
	NO LEFT TURN			
	NO U-TURN			
	KEEP RIGHT			
	DIVIDED HIGHWAY			

PAVEMENT MARKINGS CHECKLIST

Pavement Marking	Check if	Yes	No	Comments
WRONG-WAY ARROWS	Present at the location			
	RPMs in arrow in good condition			
	Thermoplastic arrow in good condition			
RED-CLEAR MARKERS	Present on the freeway main lanes			
	In good condition			
OTHER MARKINGS	Elephant tracks (turning guide lines)			
	Stop lines at end of exit ramp			
	Other: _________________________			
	Other: _________________________			
	Other: _________________________			

Other items to review and note include:

- location of nearby businesses (particularly bars);
- geometry near the wrong-way entry point that might be confusing (driveways, islands, etc.); and
- any other factors that the inspector feels might contribute to wrong-way movements.