Investigation of Wrong-Way Driving

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16. Abstract

Wrong-way driving (WWD) is an area of high concern across the United States, particularly due to the fact that such collisions involving wrong-way drivers tend to be among the most severe crashes in terms of occupant injuries and resultant crash costs. Recently, significant research, documentation, and countermeasure installation has been conducted nationally to prevent WWD as well as a series of research projects sponsored by various state departments of transportation (DOTs).

WWD is also a significant threat to traffic safety as the act exacerbates the crash and fatality risks among occupants in the wrong-way vehicle, as well as those occupants of the vehicles traveling in the correct direction.

Most of the research to date has focused on high-speed divided highways, particularly interstate and full-access control freeways. While these facilities require grade separations, a particular concern in Iowa is the presence of expressways, where access from the crossroads occurs at-grade. This represents an area where additional investigation was necessary. In addition, the Iowa Department of Transportation (DOT) has collected valuable data as to the prevalence of wrong-way driving on the US 30 corridor near Ames, Iowa since 2014.

The objectives of this project were to assess the state-of-the-art and state-of-the-practice as it relates to countermeasures to address wrong-way driving and investigate the nature and magnitude of wrong-way driving issues occurring in Iowa and along the US 30 corridor near Ames, Iowa.

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INVESTIGATION OF WRONG-WAY DRIVING

Final Report
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EXECUTIVE SUMMARY

Data collected by the Iowa Department of Transportation (DOT) on the prevalence of wrong-way driving in Iowa has the potential to address crashes and other safety concerns at at-grade intersections. The primary objective of this project was to investigate the nature and magnitude of wrong-way driving issues occurring in Iowa, including a corridor-level study of US 30 between Boone and Nevada.

Background

Wrong-way driving (WWD) is an area of high concern across the US, particularly due to the fact that crashes involving wrong-way drivers tend to be among the most severe crashes in terms of occupant injuries and resultant crash costs.

WWD is also a significant threat to traffic safety as the act exacerbates the crash and fatality risks among occupants in the wrong-way vehicle, as well as those of occupants in the vehicles traveling in the correct direction.

Most of the research to date has focused on high-speed divided highways, particularly interstate and full-access control freeways, both of which require grade separations. However, a particular concern in Iowa is the presence of expressways, where access from the crossroads occurs at-grade.

Project Description

The research team conducted a statewide analysis of WWD crash data to examine trends based on driver and roadway characteristics. In addition, the team did a corridor-level review to determine all WWD events that occurred along the US 30 corridor near Ames using data collected by the Iowa DOT.

The statewide analysis of current wrong-way crashes in Iowa involved extensive collection and integration of a diverse range of data, including roadway characteristics, traffic information, and historical weather measurements, among others. From the analysis, the team constructed a database of all wrong-way crashes.

The corridor-level study of US 30 between Boone and Nevada included data analysis from a plethora of video camera imagery and recorded 911 calls about wrong-way drivers. The team analyzed the data provided by the Iowa DOT about WWD incidents based upon various known characteristics that included information from law enforcement records.

Statewide Study Findings

A total of 718 unique wrong-way crash events, 25 of them fatal, were reported from 2008 to 2017 in Iowa. Other findings included the following:

- Younger and older drivers had increased involvement in WWD crashes
- Male drivers were over-represented in the WWD crashes
- Impaired drivers accounted for 24% of all at-fault drivers involved in WWD crashes, which is higher than the rate of impairment in other types of crashes in Iowa for the same period
- WWD was also more likely among those who were driving alone (76%), which suggests passenger presence is likely to reduce the propensity for WWD events

US 30 Corridor Study Findings

A total of 87 incidents of WWD, although no crashes, occurred on the US 30 corridor between Boone and Nevada from 2014 to 2017. Other findings included the following:

- A majority of the WWD events occurred at-grade intersections
- Most of the WWD incidents occurred on Friday and Saturday
- A majority of the WWD incidents occurred from 9:00 p.m. to 5:00 a.m.
- Of the occurrences, 19 wrong-way drivers were stopped by a law enforcement officer
- WWD incidents with a 911 call traveled on average 3.03 miles and passed 9.31 vehicles, whereas incidents without a 911 call averaged 2.17 miles and passed 3.65 vehicles

Recommendations

- Wider implementation of high-visibility pavement markings and traffic signs could help reduce the frequency of WWD
- Site-specific improvements, such as installing rumble strips and subtle changes to turning radii at ramps and median crossings, can also be considered at ramp entries and for at-grade intersections on divided highways
- Each site requires a different approach to mitigate the nature of the WWD events, and the solutions should consider practicality, large-scale applicability, and associated cost
- Traffic enforcement also can play several important roles, which include surveillance and monitoring of WWD events, in combatting Iowa's WWD issues
- Careful coordination between law enforcement agencies, local agencies, and the DOT can supplement available monitoring devices such as roadside sensors and cameras
- Educational programs that focus on the demographic groups most prone to WWD, as well as on problem behaviors such as impaired driving, can be broadcast on digital, electronic, and print media

1. INTRODUCTION

Wrong-way driving (WWD) is defined as a vehicular movement along a travel lane in a direction opposing the legal flow of traffic on high-speed divided roadways or access ramps (NTSB 2012). WWD is an area of high concern across the United States, particularly due to the fact that such collisions involving wrong-way drivers tend to be among the most severe crashes in terms of occupant injuries and resultant crash costs. Recently, significant research, documentation, and countermeasure installation has been conducted nationally to prevent WWD, including a 2012 National Transportation Safety Board (NTSB) Special Investigation Report (NTSB 2012), as well as a series of research projects sponsored by various state departments of transportation (DOTs).

The NTSB reports that, on average, 360 people are killed each year in WWD crashes (NTSB 2012). This accounts for about 2.8% of all fatal crashes on divided highways each year. One research study determined that the fatality rate for wrong-way collisions on controlled-access highways was 27 times that of all other crash types (Vaswani 1973). WWD is also a significant threat to traffic safety as the act exacerbates the crash and fatality risks among occupants in the wrong-way vehicle, as well as those occupants of the vehicles traveling in the correct direction. A study in New Mexico determined that among 49 fatal wrong-way crashes on the interstate system between 1990 and 2004, 35 drivers and 11 passengers in the at-fault wrong-way vehicle suffered fatal injuries, while 18 drivers and 15 passengers of the vehicles traveling in the correct direction were also fatally injured (Lathrop et al. 2010).

Most of the research to date has focused on high-speed divided highways, particularly interstate and full-access control freeways. While these facilities require grade separations, a particular concern in Iowa is the presence of expressways, where access from the crossroads occurs at-grade. This represents one area where additional investigation is necessary. In addition, the Iowa Department of Transportation (DOT) has collected valuable data as to the prevalence of wrong-way driving on the US 30 corridor near Ames, Iowa since 2014. This information has the potential to address the at-grade intersection concerns as numerous intersections with US 30 near this location are at-grade. Consequently, the objectives of this project were as follows:

- Assess the state-of-the-art and state-of-the-practice as it relates to countermeasures to address wrong-way driving
- Investigate the nature and magnitude of wrong-way driving issues occurring along the US 30 corridor near Ames, Iowa

To address these objectives, this report is comprised of five chapters. Chapter 2 provides a review of the extant research literature. Chapter 3 and Chapter 4 contain the methods and results from a statewide analysis of the WWD crash data, respectively. Chapter 5 is a disaggregate summary of the WWD along the US 30 corridor near Ames, Iowa. Lastly, Chapter 6 provides conclusions and recommendations as well as opportunities for subsequent WWD research.

2. LITERATURE REVIEW

An extensive amount of WWD-focused research literature has been generated over recent years due to the significant threat that WWD has on resultant traffic safety. This research has generally focused on three topics: (1) identifying contributing factors associated with WWD events, (2) examining the types of roadway facilities and circumstances that are most prone to WWD, and (3) developing design policies, traffic control practices, and other countermeasures that decrease the frequency of WWD. This chapter summarizes the available research literature that has focused on these topics.

2.1 Contributing Factors

The common variables associated with the prevalence of WWD events or crashes can be categorized into three primary areas: (1) driver characteristics, (2) temporal/environmental characteristics, and (3) countermeasures that are used to combat the occurrence of WWD. Each of these areas is discussed at greater length below.

2.1.1 Driver Factors

WWD events are often attributable to driver confusion resulting from difficult-to-navigate roadway environments. Considering specific driver characteristics, age has been shown to be a primary determinant of the likelihood of an individual to be involved in a WWD event. Older drivers have been shown to be particularly susceptible to involvement in WWD crashes. Previous research studies conducted in Illinois and Alabama have determined that drivers above age 65 were significantly more likely to cause a WWD crash in a study that examined 15 years of crash data (Jalayer et al. 2018). Additional research from Florida focused exclusively on the frequency of county-level WWD 911 calls, citations, and crashes using data from 2011 through 2015 (Faruk et al. 2018). The results demonstrated that urban counties, counties with a higher percentage of drivers ages 15–30 and 50–65, and counties with a higher percentage of Hispanic populations tended to experience more WWD crashes and citations. Similarly, research from Alabama focused on divided highways estimated that the likelihood of being involved in a WWD crash was 2.3 times greater among drivers aged 55 to 64 years (as compared to younger drivers), while drivers who are aged 65 years or older were 6.9 times more likely to be involved in a WWD crash (Zhang et al. 2017). These findings are also consistent with international research, which has also shown WWD crashes to be more prevalent among drivers age 65 and older (Kemel 2015). For example, 52% of WWD crashes in Japan were caused by drivers aged 65 and older, while an additional 21% were attributable to drivers aged 50 to 64 (Xing 2014). In contrast, additional studies in Florida have determined that 42% of WWD drivers were under 30 years of age, and only 4.6% were older drivers (Ponnaluri 2015). Likewise, other studies from Illinois have noted that both younger (under 25) and older (above 65 years) drivers are overrepresented in WWD crashes (Zhou and Pour-Rouholamin 2014).

Driver impairment has also been established as a critical factor associated with WWD events. One analysis that considered five years of data determined that 45% of 280 WWD crashes involved drug or alcohol impairment (Ponnaluri 2015). A 2012 investigative report by the NTSB used data from the Fatality Analysis Reporting System (FARS) and estimated that 60% of wrong-way drivers had indications of alcohol impairment based on resultant blood-alcohol content (BAC) levels (NTSB 2012). Further, the FARS data analysis determined that 9% of wrong-way drivers had been convicted of driving while intoxicated or impaired within three years prior to the WWD crash. Similarly, an analysis of WWD crash data in Illinois from 2004 to 2009 found nearly 50% of drivers were impaired by alcohol during the crash event, while an additional 5% were impaired by drugs (Zhou et al. 2014).

Further research on the subject of WWD determined that drivers under the influence of alcohol were significantly more likely to be involved in a WWD crash as compared to non-impaired drivers (Jalayer et al. 2018). In a similar analysis, crash rates for drivers under the influence of alcohol or drugs in Alabama were 4.2 times higher than unimpaired drivers on divided highways (Zhang et al. 2017). Similarly, an additional study in Florida determined that drivers under the influence of alcohol or drugs were 400% and 1,200% more likely to be involved in a WWD crash on an arterial or freeway, respectively (Ponnaluri 2018). Further research determined that when the BAC level of the driver was twice to over four times that of the legal limit, the probability of involvement in a WWD crash was 5 to 15 times higher than their unimpaired counterparts (Ponnaluri 2016).

An investigation of WWD crashes on divided highways in France from 2008 to 2012 indicated BAC was more frequently over the legal limit for wrong-way drivers as compared to all drivers who were involved in a crash. This was also true for motorists who were involved in a WWD crash while drugged driving (Kemel 2015). Table 1 provides a comparison of the percentages of WWD crashes that were attributed to alcohol intoxication in six states, as well as the Netherlands and Japan (Lin et al. 2017).

Table 1. Percentage of wrong-way crashes attributed to driver intoxication

Region	**Year**	**Percentage**
California	1983–1987	59.4%
Virginia	1977	50%
Indiana	1970–1972	55%
Texas	1997–2000	60.7%
New Mexico	1990–2004	63%
North Carolina	2000–2005	43%
Netherlands	1983–1990	45%
Netherlands	1991–1998	20%
Japan	1997–2000	15%

Source: Lin et al. 2017

In the United States, these rates ranged from 43% to 63% and have remained consistent since the 1970s. In contrast, the international data show significantly lower rates of driving while intoxicated among wrong-way drivers, which may be reflective of less severe penalties for drunk driving in the United States as compared to other countries across the world.

2.1.2 Temporal and Environmental Factors

Temporal characteristics are also commonly associated with the frequency of WWD crashes. A study conducted by the Florida DOT focused on the frequency of WWD crashes and the day of the week on which they occurred determined that about 61% of WWD crashes happened during weekend days (Ponnaluri 2015). Regarding the time of day, 55% of all WWD crashes and 70% of fatal WWD crashes occurred between 12:00 a.m. and 6:00 a.m. A similar study that utilized six years of WWD data in Illinois from 2004 to 2009 determined that 29% of WWD crashes occurred on weekends between 12:00 a.m. and 5:00 a.m. Further research on the topic has identified the night period as the most prone for WWD crashes, as incidents on divided roadways were more likely to occur during the evening (6:00 p.m. to 12:00 a.m.) and night (12:00 a.m. to 6:00 a.m.) in France (Kemel 2015). This result was reflected in other domestic studies in Illinois and Alabama (Jalayer et al. 2018). Furthermore, a study conducted by the Florida DOT observed that while only 29% of all crashes that occurred on freeways/expressways happened during the night, 71% of these crashes were due to WWD (Ponnaluri 2015). Further research in Alabama noted that 80% of WWD crashes on statewide interstates were in the evening or night periods (Pour-Rouholamin et al. 2016). A similar study found that the probabilities for all WWD crashes and fatal WWD crashes were increased during the nighttime period when compared to the daytime (Ponnaluri 2016).

In addition to temporal factors, environmental factors also impact the probability of WWD frequency and crashes as well. For example, one research study analyzed 15 years of WWD crashes in the state of Illinois and Alabama by conducting a multiple correspondence analysis. The results determined that most WWD crashes occurred on dry roadway surfaces and under clear weather conditions (Jalayer et al. 2018). An additional study using the Alabama data also had similar results; clear weather conditions and dry roadway surfaces had the highest probabilities of contributing to WWD crashes (Zhang et al. 2017).

2.2 Locations

Understanding the locations that are prone to WWD and WWD crashes is an important aspect in reducing the frequency of these crash types. Because of this, many studies have examined the types of facilities that are more prone to WWD. A French study used logistic regression models to determine that highways and secondary roadways had higher probabilities of WWD crashes when compared to freeways (Kemel 2015). Further analysis in Florida considered one million crash records between 2003 and 2010 and determined that WWD and fatal WWD crashes had a greater likelihood to occur on arterials and limited access facilities (Ponnaluri 2016). Additional research determined that two-way frontage roads were more likely to become WWD entries than one-way frontage roads (Pour-Rouholamin et al. 2014).

Besides facility types, the location of facilities has also been determined to affect the likelihood of engaging in WWD. The Florida DOT determined that 76% of 280 WWD crashes from 2009 to 2013 occurred in urban areas, with 24% occurring in rural areas (Ponnaluri 2015). Converse results were determined in Illinois, with 26% of WWD incidents occurring in the city of Chicago based on data between 2005 and 2009. Research from France also documented this trend and noted that the familiarity of drivers with the infrastructure was likely to increase the risk of WWD (Kemel 2015). This was theorized because the drivers who lived in rural areas and visited urban areas were more likely to be involved in a WWD crash. Unlike others, Zhang et al. (2017) found the 2009 to 2013 WWD crashes did not differ from urban and rural area on Alabama divided highways. Research in California (Coplean 1989) and Texas (Cooner et al. 2004) has found that most WWD crashes occur in the urban areas rather than rural areas. The collision also tends to occur on the inside lane of the correct direction and the side closest to the median (Cooner et al.2004). Although wrong-way crashes occur randomly, it was rather hard to identify high-frequency locations for engineering improvement (Braam 2006, Cooner et al. 2004, NTTA 2009). The California Department of Transportation (Caltrans) has developed an analysis tool to identify locations where wrong-way collision concentrations have occurred on expressways and freeways (Coplean 1989).

Moreover, the types of interchanges and specific points that have higher probabilities of WWD and WWD crashes is worthy of further study as well. Based on six years of crash data from Illinois DOT, Zhou et al. (2012) identified several other factors contributing to WWD crashes on Illinois freeways. They concluded that on freeways, most entry points for WWD are exit ramps at interchange areas (Zhou, et al. 2015). Compressed diamond and diamond interchanges were the top two interchange types for wrong-way crash entry points (Zhou et al. 2012). Morena and Leix (2012) investigated the characteristics of WWD crashes on Michigan freeways. The study results determined that partial cloverleaf interchanges were the origination points for 60% of WWD crashes with known entry points but represented only 21% of all interchanges in Michigan (Morena and Leix 2012).

Atiquzzaman and Zhou (2018a) conducted a comparative analysis to determine why wrong-way (WW) entry rates were significantly higher in Alabama than in Illinois. Specifically, differences in exit ramp terminal designs for full diamond and partial cloverleaf interchanges were compared between the two states. Crash data collected from 2009–2013 show that for full diamond interchanges, 40% of the exit ramps studied in Alabama had WW entries, compared to 14% in Illinois. For partial cloverleaf interchanges, WW vehicles entered 24% of the exit ramps studied in Alabama and 14% in Illinois (Atiquzzaman and Zhou 2018a).

Another study from Atiquzzaman and Zhou (2018b) created logistic regression models to predict WW entries based on factors like geometric design features and traffic control device (TCD) usage at exit ramps of full diamond interchanges. WWD crash data from 2009–2013 on freeways in Alabama and Illinois were collected for this study. Findings showed that an exit ramp connected to a crossroad by an obtuse angle has the least probability of WW entry, which challenges the American Association of State Highway and Transportation Officials' (AASHTO's) recommendation of using a right angle. Results also showed that signalized exit ramp terminals have a lower risk of WW entry. Conversely, locations with low exit ramp annual average daily traffic (AADT) and high crossroad AADT have a higher risk of WW entry, and deserve higher priority. Note that the sample sizes from each state were relatively small, a common problem considering the rarity of WWD crashes (Atiquzzaman and Zhou 2018b).

2.3 Countermeasures

The common countermeasures for WWD include engineering (signage, roadway geometry, intelligent transportation systems (ITS), and pavement marking), education (training), and enforcement (emergency response, confinement, and radio messages) (Braam 2006, Vicedo 2006). Table 2 lists several of the most common countermeasures implemented to reduce the WWD crashes in different states.

Table 2. Wrong-way driving countermeasures

<table>
<tr><th>Signs</th><th>Pavement markings</th><th>Geometric designs</th><th>ITS technologies</th></tr>
<tr><td>Oversized signs</td><td>Wrong-way arrows</td><td>Channelizing islands</td><td>Sensors</td></tr>
<tr><td>Lower-mounted signs</td><td>Red raised pavement markings</td><td>Extended raised median or longitudinal channelizing devices</td><td rowspan="2">Traffic management venter to inform law enforcement and incident responders</td></tr>
<tr><td>Multiple signs</td><td>Stop lines</td><td>Narrowing the exit ramp terminal throat</td></tr>
<tr><td>Standard packages of wrong-way signs</td><td>Dotted lane line extensions</td><td>Widening the entrance ramp terminal throat</td><td rowspan="4">Dynamic signs to warn drivers: LED/RRFBs illuminated wrong-way signs, changeable message signs (CMS) in-pavement warning lights</td></tr>
<tr><td>Entrance Freeway sign at entrance ramps</td><td>Delineations</td><td rowspan="2">Controlled corner radius: Angular corner at left-side of exit ramp</td></tr>
<tr><td rowspan="2">Retroreflective strips, fluorescent red sign sheeting, or flashing beacons</td><td>Turn or through lane arrows</td></tr>
<tr><td>ONLY marking</td><td>Open sight distance and uniform lighting levels at ramp terminal</td></tr>
</table>

Source: Monsere et al. 2017

There is no one-size-fits-all approach to mitigating WWD at every location. Each proposed solution must be designed to suit a particular jurisdiction by carefully observing the feasibility, applicability, implementation, and associated cost. A combined approach of education campaigns, taking proactive steps to modify human behavior, and enforcement may prove to be a more viable solution in some cases (NTTA 2009).

2.3.1 Engineering

Engineering countermeasures provide advance warning to drivers at the earliest point of decision or in some cases feedback to the drivers once they have begun traversing the roadway in the wrong direction (NTTA 2009). The Texas Transportation Institute (TTI) classified engineering countermeasures into four basic categories:

- Traditional signing and pavement marking techniques
- Innovative signing and pavement marking techniques
- Geometric modifications
- Intelligent transportation systems (ITS) applications

Improvement to signing and pavement markings are often a feasible option compared to geometric modifications, which in most cases are very costly. The use of intelligent wrong-way detection and warning systems are also expensive and are often used at the most problematic interchanges (Braam 2006).

2.3.1.1 Traffic Signs and Pavement Markings

Signs

The most common countermeasure for wrong-way driving is the use of a DO NOT ENTER sign. The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA 2009) asserts that DO NOT ENTER signs shall be placed wherever traffic is prohibited from entering a restricted roadway. It also recommended to put WRONG WAY signs in addition to the DO NOT ENTER signs where an exit ramp intersects a crossroad but one-way roadway farther from the crossroad than a DO NOT ENTER sign. However, a TTI report suggested to put both a WRONG WAY sign and a DO NOT ENTER sign on the same post so as to be easily perceivable (Kaminski Leduc 2008).

The DO NOT ENTER and WRONG WAY signs were lowered to 2 ft above the pavement in California in 1973, which was an effective countermeasure for preventing drivers to enter the wrong way. Caltrans again evaluated their low-mounted signs in 1989, and they still were found out to be effective. This study also suggested to use the oversized DO NOT ENTER signs for locations with repeated wrong-way accidents (Coplean 1989, Cooner et al. 2004). These improvements to the package reduced the frequency of wrong-way moves from 50–60 to 2–6 per month at problematic ramps and completely removed them at majority of the ramps (Coplean 1989). In addition to this, the number of wrong-way crashes decreased at the south end of the Dallas North Tollway after installing additional WRONG WAY and DO NOT ENTER signs (NTTA 2009).

The North Texas Tollway Authority (NTTA) recommended using flashing, internally illuminated signs or using small light-emitting diode (LED) units along the borders to catch the attention of wrong-way drivers. A TTI report stated that 10% of the 28 states that replied to their survey used internally illuminated signs (Cooner et al. 2004). Except LED, a rectangular flashing beacon (RFB) also can be used to reduce the WWD. A study in Florida compared the performance of LED and RFB signs in reducing WWD events. The results showed a 38% reduction in WWD citations and 911 calls at sites where LEDs were installed. Also, at the RFB sign locations, over 77% of wrong-way vehicles self-corrected, compared to 14% at the LED signs (Kayes et al. 2018). In Ohio, DO NOT ENTER signs were installed at the ramp throat and double WRONG WAY signs were installed partway down the ramp. DO NOT ENTER and WRONG WAY signs were also mounted closer to the highway farther along the ramp (Cooner et al. 2004). Similarly, after Central Florida agencies identified the segments with the most WWD crashes, they have decided to install WRONG WAY signs with rapid rectangular flashing beacons (RRFBs) on those segments (Sandt et al. 2017).

Pavement Markings

Pavement arrows are also considered to be a good countermeasure for discouraging wrong-way movements. MUTCD suggests that where crossroad channelization or ramp geometrics do not make wrong-way movements difficult, a lane arrow should be marked in each lane of an exit ramp (Kaminski Leduc 2008). NTTA also installed pavement arrows on each exit ramp (NTTA 2009). However, the pavement arrow used by Texas DOT (TXDOT) is slightly longer than the national standard in use (Cooner et al. 2004). A TTI report suggested to install reflective and raised pavement arrow markers on exit ramps, particularly at left-side exits, newly constructed ramps and at locations with a history of wrong-way crashes (Kaminski Leduc 2008).

2.3.1.2 Geometric Modifications

Geometric modifications can also be used to reduce wrong-way crashes (AASHTO 2011, IDOT 2010). These include the following:

- Use raised curb medians
- Use channelizing islands
- Use rumble strips (Xue 2018, Yang et al. 2017)
- Increase the distance from the gore of the exit ramp to the entry ramp for partial cloverleaf interchanges
- Reduce the wrong-way turning radius
- Do not use off-ramps that join two-way frontage roads

2.3.1.3 ITS Technologies to Prevent Wrong-Way Driving

Several transportation agencies have used ITS technologies to develop countermeasures for wrong-way driving. An ITS system comprises of a detection subsystem using Doppler radar or a loop detector and a warning system with light barriers, luminous signaling, and a sound alarm.

Caltrans installed airport-type red pavement lights together with induction loops and extra wrong-way sign packages (Coplean 1989). The idea was that when a driver enters the wrong-way and drives over the induction loop detector, the warning lights would be activated to alert the driver of entering the wrong-way. However, this improvement was relatively expensive and required constant maintenance (Coplean 1989). The New Mexico State Highway and Transportation Department (NMSHTD) introduced a wrong-way traffic sensor system in 1998 (Moler 2002). The system detects wrong-way drivers with loop detectors and turns on two sets of warning lights, one red set of lights to warn wrong-way drivers of the oncoming danger and one yellow sets of lights facing the other side to warn the other drivers of possible incoming wrong-way traffic.

The Florida DOT (FDOT) installed a wrong-way driving detection and warning system that uses microwave radar to detect wrong-way vehicles and activates overhead flashing lights to warn oncoming vehicles. The system also informs the nearby police substation of the incident (Cooner et al. 2004). Similar microwave radar detectors were installed by Harris County Toll Road Authority in Houston, Texas, to detect wrong-way incidents. The system sends a message to a traffic management center after detecting a wrong-way driving that is then verified manually through closed-circuit television. The manager can send the warning messages to the right-way drivers through dynamic message signs (DMS) and can also notify law enforcement officers to stop wrong-way driver (NTTA 2009).

To mitigate the WWD and WWD crashes, Japan also applied the advanced ITS technologies: the roadside wrong-way warning system with different types of sensors, wrong-way navigation alert system using global positioning systems (GPS) and digital map, and wrong-way warning system with road-to-vehicle communications such as dedicated short-range communications (DSRC). The roadside WW warning system was composed by microwave radar, infrared sensor, ultrasonic sensor, photoelectric sensor and video image process. It is able to detect and warn the WWD drivers through variable message signs (VMS) with flashing lights. Wrong-way navigation alert systems were installed into the onboard navigation system to warn drivers of WWD. It detects WWD vehicles based on GPS coordinates, digital maps, travelling speeds, and other relevant data. A WW warning system with road-to-vehicle communication notified the drivers about WWD through ITS spot service (DSRC) beacons (Xing 2014).

2.3.2 Enforcement

Enforcement and emergency responses play a major role in reducing wrong-way crashes. Using proper enforcement strategies can help avoid wrong-way accidents by taking measures before severe crashes occur. Some of these strategies include setting up driving under the influence (DUI) checkpoints, using portable spike tools, responding to alerting systems, warning right-way drivers, and confining wrong-way drivers. Many enforcement countermeasures have focused on enhanced legislation and DUI checkpoint programs in the past (Coplean 1989, NTTA 2009). The success of a wrong-way detection and warning system is possible only when there is sufficient staff to respond to the incident (NTTA 2009).

Various agencies have tried incident response strategies in the past that have been ineffective. Caltrans experimented with parking-lot spike barriers at freeway off-ramps to see if they could be used to stop wrong-way movements (Coplean 1989). This strategy was unsuccessful because the spikes could not deflate tires quickly enough to stop the vehicle from entering the freeway, the spikes broke under high-volume traffic, and some right-way drives braked when they saw the spikes. The Georgia DOT (GDOT) also tested a device that raised a physical barrier to stop the wrong-way driver, but it was ineffective due to the similar reasons as the directional in-pavement spike (Coplean 1989).

The study from Atiquzzaman and Zhou (2018a) also revealed that geometric modifications can be used to decrease wrong-way crashes. For example, Illinois had non-traversable crossroad medians near the exit ramp terminals and non-traversable channelizing islands at the exit ramp terminals. This was the one of reasons that Illinois had fewer wrong-way driving entries in full diamond and partial cloverleaf interchanges than Alabama had (Atiquzzaman and Zhou 2018a).

In Switzerland, radio stations were used to broadcast location, direction, and time of a wrong-way incident so as to alert drivers of a wrong-way movement. However, it was seen that the location and time rarely matched up. Nevertheless, it still had some effect in reducing the wrong-way crashes because wrong-way driving incidents warned by radio rarely resulted in accidents (Scaramuzza and Cavegn 2007).

2.3.3 Education

Several specific education programs have been effective in preventing wrong-way crashes. The California Highway Patrol (CHP) collaborated with student groups and local organizations such as Mothers Against Drunk Driving to start a program called Sober Graduation Program in 1985 to reduce drinking and driving among young people (Coplean 1989, NTTA 2009). The CHP broadcasted television and public service announcements and distributed posters, key chains, and book covers. The efforts turned out to be fruitful as the fatal crashes in the 15–19 year age group reduced by 25% and injury crashes reduced by 19%.

The study in Illinois and Alabama suggested the educational countermeasures should focus on the groups that had the highest likelihood of being involved in WWD crashes, such as older and impaired drivers. General awareness programs, a general deterrence policy, mass communication campaigns, as well as the use of ignition interlock devices (IIDs) are able to reduce the WWD crashes involving DUI drivers. Since there were a lot of older drivers involved WWD crashes, older drivers should be given special attention, because as age increased, sensory and cognitive abilities decreased. In order to mitigate WWD crashes among such drivers, well-maintained signage, pavement marking, as well as safety programs could be developed (Jalayer et al. 2018).

Several states, such as California and Washington, started a wrong-way monitoring program to gather information regarding wrong-way driving behaviors. Caltrans developed a wrong-way camera system in 1967 to detect wrong-way movements using a pair of road tubes and a camera to count and record wrong-way entries on exit ramps. The data was collected at 4,000 exit ramps for at least 30 days (Cooner et al. 2004).

The Washington State DOT (WSDOT) used different types of technologies to monitor wrong-way driving, such as cameras and videocassette recorders. This constituted two 6-ft induction loops, a loop detector, and a digital recorder to detect and record wrong-way movements (Moler 2002). Another system comprised of electromagnets embedded in the ramp, a closed-circuit video camera, and a videocassette recorder that was used to detect wrong-way movements using the electromagnetic detectors and then record it (Moler 2002). The various techniques used by California and Washington are summarized in Table 3 (Coplean 1989, Moler 2002).

Table 3. Wrong-way monitoring systems in the United States

Location	Wrong-way detection	Wrong-way recording	Performance
California	Paired road tube	Camera	Excellent
Washington	Loop detector	Digital recorder	Poor
Washington	Electromagnetic sensor	VCR	Poor
Washington	Video detection system	VCR	Poor

Sources: Copelan 1989, Moler 2002

3. CRASH DATA COLLECTION AND INTEGRATION

From an investigative standpoint, it is often challenging to distinguish between wrong-way driving and cross-median crashes as typical police crash report codes do not allow for a clear definition as to whether a crash is due to a vehicle crossing the median or a driver inadvertently driving the wrong way. Consequently, wrong-way collisions are often analyzed in conjunction with median crossover crashes because the two types of crashes are difficult to distinguish (NTSB 2011).

This analysis of current wrong-way crashes in Iowa involved extensive collection and integration of a diverse range of data, including roadway characteristics, traffic information, and historical weather measurements, among others. This chapter outlines each of the data sources utilized for this study, as well as the necessary processes used to obtain disaggregate information when appropriate.

3.1 Roadway Information

The baseline interstate roadway network was provided by the Iowa DOT through the online Geographic Information Management System (GIMS) portal. This portal contains annually updated operational and geometric characteristics for roadways within the state. All of the roadway management resources are maintained in a georeferenced format. Figure 1 displays a sample georeferenced segment collected from the GIMS database (in orange) as it relates to aerial imagery from this interstate.

Image © 2016 Google (from Google Earth)

Figure 1. GIMS georeferencing example

3.2 Crash Information

A statewide crash database is maintained by the Iowa DOT that includes detailed information regarding all crashes reported to law enforcement on an annual basis. Crashes occurring from 2008 to 2017 were collected for this study. The location of each crash was provided in a georeferenced format similar to that used for the GIMS data. Additionally, vehicular information, roadway characteristics, and environmental factors present during the crash, as described by the responding police officer, were included. A total of 85 individual data elements related to the scene of the incident were either collected or derived and matched with each crash as appropriate. This information was collected using three independent methods that were manually checked for reliability:

- Application of a filter to identify target wrong-way crashes based on the "contributing circumstances" field in the crash database
- A manual review of relevant crash narratives using a keyword search based on a police officer's description of the crash events
- Spatial joined with GIMS data to determine the types of roadway segments (i.e., one-way street, divided roadway, undivided roadway, etc.)

3.2.1 Crash Code Methodology

The crash database consists of three level of information related to each crash, which are crash-level, vehicle-level, and person-level. To obtain the wrong-way driving crashes, the "contributing circumstances" attribute field from the vehicle-level was utilized. This attribute describes the driver actions that immediately preceded and contributed to the crash event. The crash report form allows for up to two contributing circumstances for each vehicle. A filter was applied to the vehicle-level data for all crashes with contributing circumstance code of 13 for both fields. According to the 2015 crash report form, code 13 indicates crashes that involved vehicles traveling the wrong way or wrong side of traffic. Based on this filter, a total of 3,573 unique crashes were identified for a period between 2008 and 2017 as potential wrong-way driving crashes. These crashes were then reviewed using the crash narrative to confirm whether or not they actually involved wrong-way driving. Based on this review, crashes with contributing circumstances code 13 included a variety of other types of crashes that were not correctly classified as involving a wrong-way driver. These included the following:

- Crashes involving vehicles in the wrong lane of traffic (e.g., a vehicle intending to go through the intersection, but is using the left turn lane – being in the wrong lane, normally resulting in a rear end collision). These crashes comprise 2.4% of the initial sample.
- Collisions involving a vehicle backing up in the travel lane. Approximately 3.4% of these crashes were identified from the 3,573 crashes that were initially identified.
- Cross-centerline crashes. These crashes were the largest portion of the crashes where the contributing circumstance code was equal to 13. These crashes comprised 48.1% of the sample and illustrate a major issue with respect to exclusive use of this field for identification of WWD crashes.
- Vehicle U-turning into a passing vehicle after a missing an exit or turn, on a two-lane road (0.2% of sample).
- Head-on collision or sideswipe with a legally parked vehicle in tight corridors (3.1% of sample).

- Other types of crashes, including crashes involving animal, vehicles failing to yield right of way, vehicles running a stop sign, vehicles failing to give a turning signal, and vehicles running a red traffic signal, among others (11.1%).

Ultimately, the target crashes of interest in this study are those involving vehicles traveling the wrong way on a one-way road or a divided highway. Approximately 20.8% (739 crashes) of the filtered crashes were identified as target crashes. As mentioned before, almost 50% of the filtered crashes were identified as cross centerline crashes. One possible reason is that each crash allows for two contributing circumstances, which will include traveling in the wrong way, and other contributing circumstances that may include crossing the centerline. However, based on the narratives, these crashes actually involved vehicles crossing the centerline. The remaining 11% of filtered crashes were crashes without narratives.

3.2.2 Crash Narrative Review Methodology

In addition to identifying potential WWD crashes based on crash report codes, an alternate approach is to use a series of keywords identified from the narrative sections of the police-reported crashes. Using data from the 3,573 crash sample where the contributing circumstance field was equal to 13, a series of common keywords were identified that could be used as an alternative to simply using this crash report code (3,573 crashes).

Two groups of keywords were identified during the process, which include keywords for target crashes, as well as other keywords for non-target crashes. A logic statement was developed to identify the potential target crashes using several keywords, which include “wrong direction,” “wrong way,” “wrong way” AND “one way,” and “wrong direction” AND “one way.” To identify potential non-target crashes, six keywords used were “parked” AND “facing the wrong way,” “parked” AND “facing the wrong direction,” “spun,” “spin,” “reversing,” and “backing up”. Mistyped such as “wrong” written as “*worng*” and variations of words such as “one way” written as one word, “oneway,” were also checked during the filtering process to capture potential target crashes. A list of examples of mistyped words that were checked are shown in Table 4.

Table 4. Examples of mistyped words

Actual word	**Mistyped/Misspelled**
Wrong	Worng
One way	Oneway, one-way
Wrong way	Wrongway, wrong-way, worngway

Table 5 shows how the identified keywords were used to classify three unique crashes.

Table 5. Example of possible WWD

Crash ID	Wrong direction	Wrong way	Wrong way + One way	Wrong direction + One way	WWD	Parked + Facing the wrong way	Parked + Facing the wrong direction	Spun	Spin	Reversing	Backing up	NonWWD	Possible WWD
1	1	0	0	0	1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	1	0	0	1	-1
3	0	0	0	1	1	0	0	0	0	0	1	1	0

If any of the keywords for possible target crashes were present in the narrative, column "WWD" was marked as 1 (Crash ID 1 and 3 each included one of these keyword combinations). Similarly, for non-target crashes, if any of the keywords were present, column "NonWWD" was marked as 1. As for the final review, column "WWD" was subtracted with column "NonWWD", which gave the results on column "Possible WWD". Any crashes with "Possible WWD" equal to 1 were reviewed. After reviewing the narratives of possible wrong-way driving crashes using the keywords, 171 additional crashes were identified. Consequently, a total of 906 wrong-way driving crashes were identified using these two methods.

3.2.3 Location Confirmation through Spatial Data

Based on the total 906 wrong-way driving crashes, types of roadway segment that crashes occurred on were indistinguishable in some of these crash reports. As mentioned previously, the target crashes in this study focused on crashes due to drivers driving on one-way roads or driving on the wrong way of divided roads. Consequently, some these crashes may have occurred on undivided roadways. To determine the target crashes, each crash was spatially linked with GIMS data to obtain information regarding the segment where the crash occurred. Using the information from GIMS data, crashes were filtered using INTERSTATE (interstate system), MEDTYPE (present of median), and TYPESECTION (two-way or one-way roads) to determine the target crashes, where a total of 560 (out of 906) crashes were determined. The remaining 344 crashes were manually reviewed using satellite imagery, and 158 crashes were found to be occurred on either one-way or undivided roads. Ultimately, a total of 718 crashes were identified as target crashes.

3.3 Wrong-Way Drivers

The crash database contains information pertaining to each vehicle involved in a crash. These vehicles were assigned with a coded reference (unit number) in the crash report form (i.e., two vehicles that were involved in a crash will have a coded reference of 1 for Unit 1 and 2 for Unit 2), and it is used to identify vehicles that were involved in the crashes. Each crash narrative explains the action made by each driver by referring to them using the coded reference. An example of a crash narrative is, Unit 1 was traveling on the wrong way of traffic on I-80 and caused a head-on collision with Unit 2. In this case, Unit 1 was the wrong-way driver. Ultimately, the wrong-way drivers were identified using the crash narratives.

Once the wrong-way drivers were identified, the characteristics of each driver were collected. These characteristics include the age of drivers, condition of drivers (intoxicated), gender, and state of registration, among others. However, for a number of cases, some of these characteristics were not available from the crash code. This happened when hit and run crashes occurred where the wrong-way driver was unavailable to be tracked down. Usually, other drivers involved in the crash were able to describe the characteristics of the vehicle (i.e., color, model, make, etc.) to the law enforcement, but the characteristics of the driver remain unknown. A similar case was observed for crashes involving contactless vehicles (wrong-way drivers that cause the incident but was not physically involved in it). However, these crashes were still considered as target crashes as it gave useful information regarding the crash characteristics.

For wrong-way drivers, data was extracted only for drivers above age 13. Driver ages of 99 were investigated to determine if they were unknown drivers. Total drivers with age coded as 99 and NR Gender (no registered gender) was 73. About 53% of these drivers were the hit and run drivers. Essentially, 707 drivers (including hit and run drivers) from 718 crashes were found to be at fault in driving on the wrong way of traffic. Among these 718 crashes, there were 11 crashes that where the driver of a vehicle not involved in the crash was found to be at fault. Note that information about these uncontacted vehicles was not included in the crash report form.

3.4 Database Construction

Ultimately, the crash narratives review methodology was seen as a better approach to extract target crashes and resulted in 906 unique crash events with 707 known at-fault drivers over the course of the study period.

Each crash event had a unique crash key with all the vehicles involved in that crash event having the same crash key. Each individual vehicle involved in the crash event was distinguished using the unit number from the crash database.

Once all target crashes were identified, various crash and person-level characteristics, such as vehicle type, level of injury severity, weather conditions, and lighting conditions, driver age and gender, driver condition, and level of alcohol or drug impairment were identified in the database.

3.5 Data Summary

As mentioned previously, there were a total of 718 unique wrong-way crash events occurring between 2008 and 2017, and 17% of these crashes occurred on the interstates, 40% were located on the US and Iowa route, and approximately 43% on the secondary, municipal, or institutional roads. During the study period, 37 people were recorded to be involved in a fatal crash while 4,247 people were involved in an injury or property damage only (PDO) crash as a result of wrong-way driving. Fourteen percent of these crashes were single vehicle crashes while 86% of these crashes were multivehicle crashes. The wrong-way crashes recorded six different types of collisions (manner of crash), where 15% of these incidents were single vehicle crashes, 26% were head-on collisions or rear-end collisions, 34% were angle and broadside crashes, and 18% were sideswipe collisions. About 84% of the WWD crashes were in urban areas.

Figure 2 shows the locations of wrong-way driving crashes on Iowa roads.

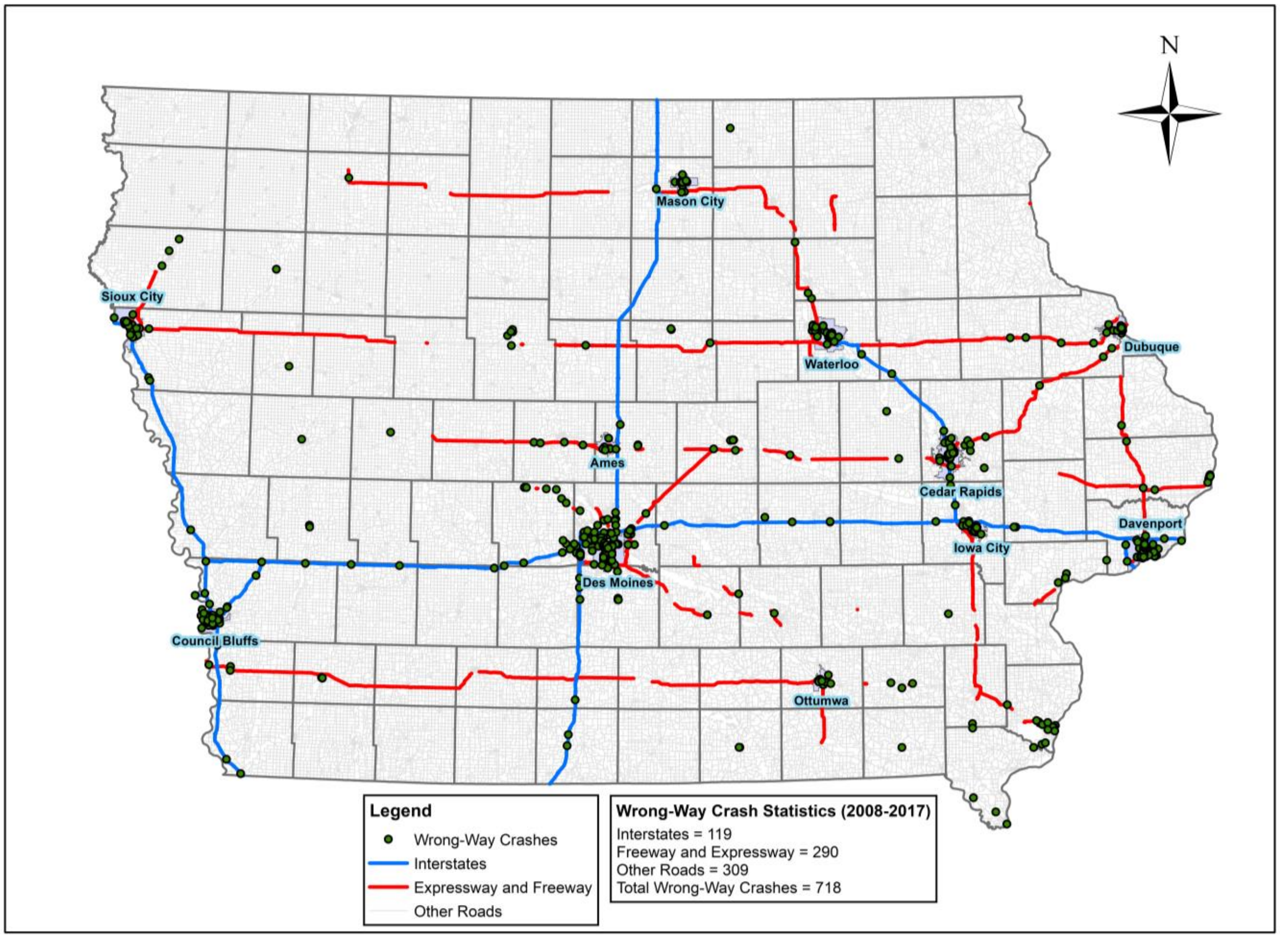

Figure 2. Location of wrong-way driving crashes on Iowa roads (2008–2017)

4. CRASH DATA TRENDS

In the state of Iowa, wrong-way driving crashes are relatively infrequent as Table 6 shows an average of 12 crashes per year on the interstate system and 29 crasher per year on other freeways and expressways.

Table 6. Wrong-way crashes by road type

	Interstate		Freeway/Expressway		Secondary/Municipal/ Institutional road	
Year	**Total crashes**	**Fatal crashes**	**Total crashes**	**Fatal crashes**	**Total crashes**	**Fatal crashes**
2008	7	1	25	1	25	0
2009	13	3	24	1	27	0
2010	12	1	23	0	25	0
2011	11	2	30	0	31	0
2012	11	2	33	2	29	0
2013	10	1	20	1	26	0
2014	13	1	32	0	34	0
2015	9	2	34	2	35	0
2016	21	2	39	2	40	0
2017	12	1	30	0	37	0
TOTAL	**119**	**16**	**290**	**9**	**309**	**0**

In total, crashes caused by driving in a wrong direction of traffic accounted for 0.13% of the total crashes between 2008 and 2017.

Despite these relatively low frequencies, the rate of wrong-way crashes that result in fatalities is 13.4% on the interstates. This percentage is 22 times the fatality rate for all crashes in the state of Iowa over this same period. In total, 25 cases were recoded as fatal crashes involving wrong-way drivers on all different types of facilities within the 10 years of study period. Moreover, the rate of severe injuries is also markedly higher among wrong-way driving crashes. Consequently, if even a subset of such crashes can be prevented, this would represent substantial crash cost savings to the state of Iowa.

This section compares the distribution of WWD crashes to total statewide crashes (exclusive of those involving WWD) to determine where substantive differences existed. Various potential factors that may result in WWD crashes were analyzed. Demographic factors such as age groups and gender, behavioral factors such as driver condition, and environmental factors such as weather and lighting conditions were analyzed to see how they differ in comparison to the total crash distribution.

Table 7 contains the number of drivers involved in crashes in the state of Iowa between the period of 2008 and 2017 with different driver's characteristics.

Table 7. Drivers involved in crashes

Variable	Category	At-fault WWD		Other drivers in WWC		Other drivers	
		Count	Percent	Count	Percent	Count	Percent
Age	<25	174	24.6%	157	22.3%	232,866	25.5%
	25-34	145	20.5%	141	20.1%	162,718	17.8%
	35-44	81	11.5%	104	14.8%	127,292	13.9%
	45-54	65	9.2%	128	18.2%	125,299	13.7%
	55-64	65	9.2%	71	10.1%	100,600	11.0%
	65+	133	18.8%	56	8.0%	89,434	9.8%
	Unknown	44	6.2%	46	6.5%	76,220	8.3%
Gender	Male	375	53.0%	374	53.2%	460,547	50.4%
	Female	262	37.1%	274	39.0%	363098	39.7%
	Unknown	70	9.9%	55	7.8%	90,784	9.9%
Impairment	None	370	52.3%	647	92.0%	734,687	80.3%
	Alcohol	169	23.9%	9	1.3%	24,023	2.6%
	Other	46	6.5%	2	0.3%	15,200	1.7%
	Unknown	122	17.3%	45	6.4%	140,519	15.4%
Occupants	1	539	76.2%	453	64.4%	624,377	68.3%
	2	121	17.1%	135	19.2%	162,001	17.7%
	2+	47	6.6%	79	11.2%	72,774	8.0%
	Unknown	0	0.0%	36	5.1%	55,277	6.0%
State registration	Iowa	531	75.1%	573	81.5%	740,971	81.0%
	Other	96	13.6%	78	11.1%	75,437	8.3%
	Unknown	80	11.3%	52	7.4%	98,021	10.7%

Three different drivers' classes were recorded in this table: wrong-way drivers (identified from crash narratives and GIMS information), other drivers involved in the wrong-way crashes, and the rest of drivers involved in other types of crashes.

Based on these results, approximately 19% of the wrong-way drivers were more than 65 years old, which is two times the percentage of drivers involved in the total crashes across Iowa within the same age group. According to a study conducted by Lathrop et al. (2010), older drivers were associated with an increase of likelihood to be involved in the wrong-way crashes. Similar results were found from several other studies where older drivers were one of the primary factors of the wrong-way crashes (Braam 2006, Zhou et al. 2015, Kemel 2015). However, the distribution of the wrong-way driver's age shows that both younger drivers and older drivers tend to have the highest percentage when compared to the middle age groups (25 to 64 year olds). Additionally, other drivers showed a different trend where the number of drivers involved in crashes decreased as the age of driver increases.

During the study period, the number of at-fault male drivers involved in the wrong-way crashes was approximately 1.5 times the number of female drivers as shown in Table 7. A similar trend was found for other drivers where about 50% of the drivers were male and 40% were female drivers. According to several studies, male drivers are usually over-represented in the wrong-way crashes when compared to female drivers (Lathrop et al. 2010, Kemel 2015, Zhou et al. 2016). However, there is no significant results showed that male drivers were more likely to be involved in the wrong-way crashes when compared to female drivers based on these study.

According to the previous literature, drivers under the influence of alcohol were also found to have a significant effect on the wrong-way crashes, where these drivers are more likely to be involved in wrong-way crashes (Lathrop et al. 2010). Based on Table 7, intoxicated wrong-way drivers accounted for 24% of the overall wrong-way drivers; more than nine times the number of intoxicated drivers involved in other types of crashes across Iowa over the same period. However, approximately 17% of wrong-way drivers had an unknown impairment condition during the crash. This could be attributed to the drivers' refusal to be administered the sobriety test. Consequently, the number of at-fault drivers under the influence of alcohol might be higher than the reported crashes. Gender comparison shows that intoxicated male drivers outnumbered female drivers under the influence of alcohol by more than two times. Additionally, when compared the number of wrong-way drivers under the influence of alcohol by age groups, younger drivers have the highest percentage (40%) involvement in this type of crash. According to Scaramuzza and Cavegn (2007), younger drivers under the influence of alcohol that perform risky maneuvers are at risk to be involved in crashes.

The number of occupants in vehicles was also recorded in Table 7. The wrong-way drivers that drove alone had the highest percentage (76%) involvement in the wrong-way crashes when compared to drivers with passengers in their vehicle. Among the 76% of the wrong-way lone drivers, 26% of the drivers were found to be impaired. Moreover, for the state registration, Iowan drivers had the highest percent involved in wrong-way crashes compared to drivers from other states.

As for the crash characteristics, Table 8 shows the number of crashes due to wrong-way driving and the total crashes in Iowa for the period between 2008 and 2017.

Table 8. Wrong-way driving crashes and total crashes

Variable	Category	Total crashes		WWD crashes	
		Count	Percent	Count	Percent
Location	Urban	361,996	67.8%	604	84.1%
	Rural	168,568	31.6%	110	15.3%
	Unknown	3,534	0.7%	4	0.6%
Lighting	Daylight	332,449	62.2%	322	44.8%
	Dusk/Dawn	22,041	4.1%	15	2.1%
	Dark	127,075	23.8%	380	52.9%
	Unknown	52,533	9.8%	1	0.1%
Crash type	Head-on	11,547	2.2%	186	25.9%
	Rear end	131,476	24.6%	45	6.3%
	Angle	29,742	5.6%	26	3.6%
	Broadside	97,125	18.2%	216	30.1%
	Side-swipe	64,578	12.1%	129	18.0%
	Single vehicle	154,457	28.9%	110	15.3%
	Unknown	45,173	8.5%	9	0.8%
Weather	Clear/Cloudy	394,579	73.9%	619	86.2%
	Rain	36,425	6.8%	65	9.1%
	Fog/Standing snow	41,582	7.8%	32	4.5%
	Severe	5,990	1.1%	1	0.1%
	Unknown	55,522	10.4%	1	0.1%
Day of week	Weekday	403,752	75.6%	497	69.2%
	Weekend	130,346	24.4%	221	30.8%
Season	Spring	114,421	21.4%	158	22.0%
	Summer	120,905	22.6%	177	24.7%
	Fall	142,784	26.7%	194	27.0%
	Winter	155,988	29.2%	189	26.3%
Vehicles involved	1	187,618	35.1%	99	13.8%
	1+	346,480	64.9%	619	86.2%

Based on this table, it is recorded that wrong-way crashes occurred frequently in urban areas (84%) as compared to rural areas (15%). This finding is supported by previous studies observing the same trend of higher wrong-way crashes in urban areas (Coplean 1989, Cooner et al. 2004, Zhou et al. 2016). The findings also show that about 53% of wrong-way crashes occurred during dark conditions, out of which 17 were fatal crashes; this accounts for 68% of overall fatal wrong-way crashes. The percentage of wrong-way crashes that occurred during dark condition is more than two times the percentage of total crashes in Iowa with the same condition (24%).

Six different types of crashes were also recorded for the wrong-way driving as shown in Table 8. Broadside crashes accounted for the highest percentage (30%), followed by head-on crashes (26%). Angle crashes had the least occurrence (3.6%) as compared to other types of crashes. Based on these percentages, some had approximately similar number of crashes based on type.

However, when compared to the total crashes in Iowa, some of the types of crashes had significantly larger percentage. The wrong-way driving that resulted in a head-on collision was 12 times higher than the percentage of head-on collision for the total crashes in Iowa. The head-on wrong-way crashes have resulted in 25 fatal crashes, which was 100% of the total number of fatal crashes that caused from wrong-way driving.

The weather conditions during the crashes were also recorded from the police reported crashes. Most of the wrong-way crashes occurred during a clear or cloudy day, which was 86% of the overall wrong-way crashes. The remaining 14% of the crashes occurred due to limited visibility condition such as rain, snow, and fog. As compared with the total crashes in Iowa, a similar trend was found where most of the crashes occurred during a clear or cloudy day. For day of the week, the majority of the wrong-way crashes occurred during the weekdays as compared to the weekend. Approximately 69% of the crashes occurred during weekdays, and about 31% happened on the weekend. While for seasonal impact, no significant difference was found between all four seasons, where approximately the same percentage of wrong-way crashes were observed among the seasons. Additionally, most of the wrong-way crashes involved with more than one vehicle. Around 86% of the wrong-way crashes were recorded as multiple vehicle crashes.

5. REVIEW OF CORRIDOR-LEVEL WRONG-WAY DRIVING DATA

As mentioned previously, the Iowa DOT has collected detailed WWD data along the US 30 corridor near Ames since 2014. This data included a plethora of video camera imagery and recorded 911 calls about wrong-way drivers. The segment of interest that had video coverage was the US 30 corridor between Boone and Nevada. Ames is located in the middle of this corridor. The data provided by the Iowa DOT about WWD incidents has been analyzed based upon various known characteristics. The results of these disaggregate analyses are contained in Table 9.

Table 9. Proportion of data available for WWD incidents

Type of supplemental information	Count	Percentage
Video recording	70	80%
Known point of entry (POE)	60	69%
Associated 911 call	47	54%
Stopped by law enforcement	19	22%
Total	**87**	**100%**

Based on the Iowa DOT provided data in Table 9, there were 87 total occurrences of WWD that happened on the US 30 corridor between Boone and Nevada between 2014 and 2017. Of these 87 incidents, 70 were captured on video by the Iowa DOT traffic cameras. By using the roadside cameras, the Iowa DOT was able to visually confirm the frequency of WWD without relying on a 911 call from other motorists. This also eliminated a scenario where any driver was driving the wrong way without any other motorists around, which would otherwise result in an undocumented WWD incident. From the 87 total WWD events, 69% (n = 60) had a known point of entry (POE). The POE was determined by watching the WWD incident on the recorded video and locating the point along the roadway that the driver ultimately proceeded in the wrong direction of travel. Furthermore, 54% (n = 47) of these WWD incidents had a corresponding 911 call made by another motorist. These 911 calls were matched with the WWD behavior by comparing the time and day on which the call was placed and the recorded video imagery. Lastly, 22% (n = 19) of the WWD occurrences ended with an officer stopping the vehicle while traveling in the wrong direction.

The number of 911 calls related to WWD occurrences are displayed in Figure 3, with a total of 157 calls occurring over the 10-year analysis period.

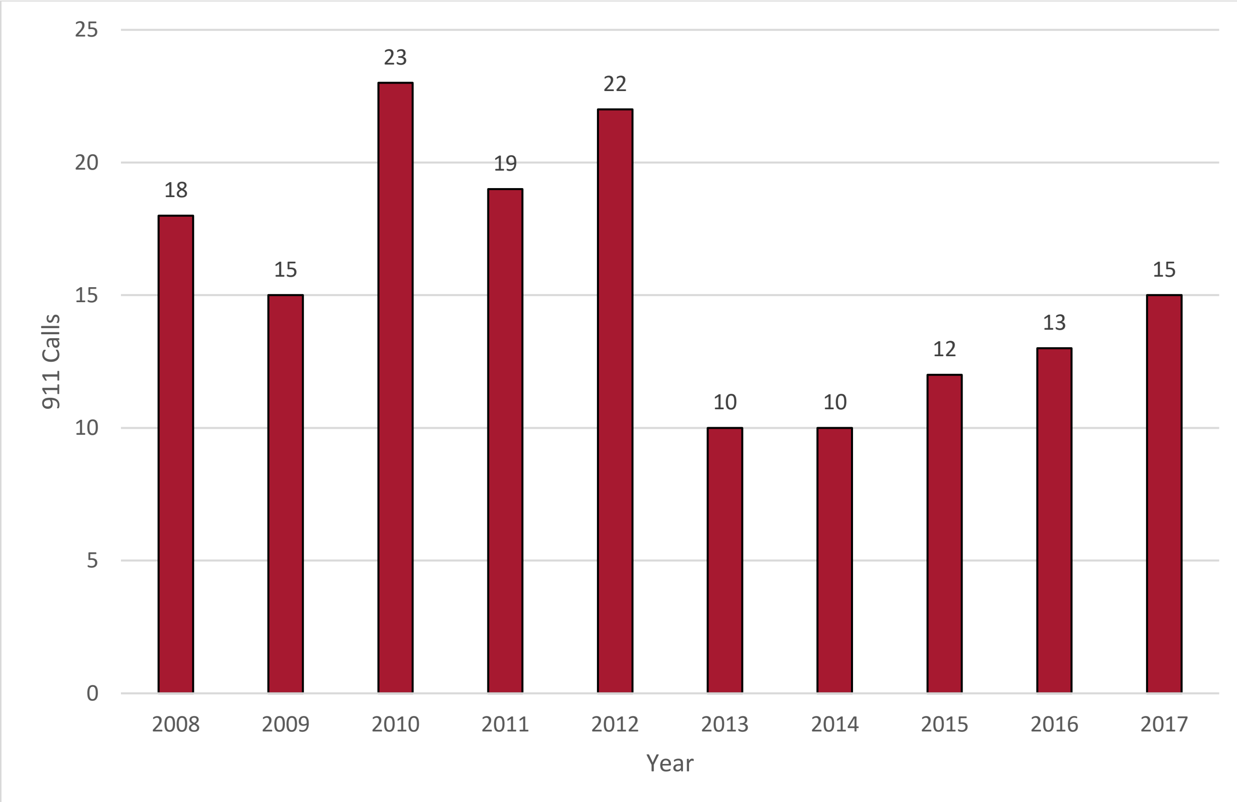

Figure 3. Number of 911 calls about WWD incidents per year

Note that the 911 calls are presented annually, with 2010 having the most calls related to WWD events. In 2010, 23 911 calls were completed by motorists that detailed a WWD incident, while the minimal amount of calls occurred in 2013 and 2014 (n = 10). The trend in the frequency of 911 calls related to WWD varies significantly between 2008 and 2017, with call frequency initially decreasing between 2008 and 2009, then increasing in 2010 to a maximum. After this peak, the frequency of 911 calls had a decreasing trend until 2013, where the frequency of 911 calls again began to increase until 2017. Based on this varying pattern, there was no significant increase or decrease in WWD frequency, as the varying pattern suggests that the WWD incidents varied widely over the 10-year period.

Figure 4 contains the average distance traveled and the average number of cars passed per WWD event.

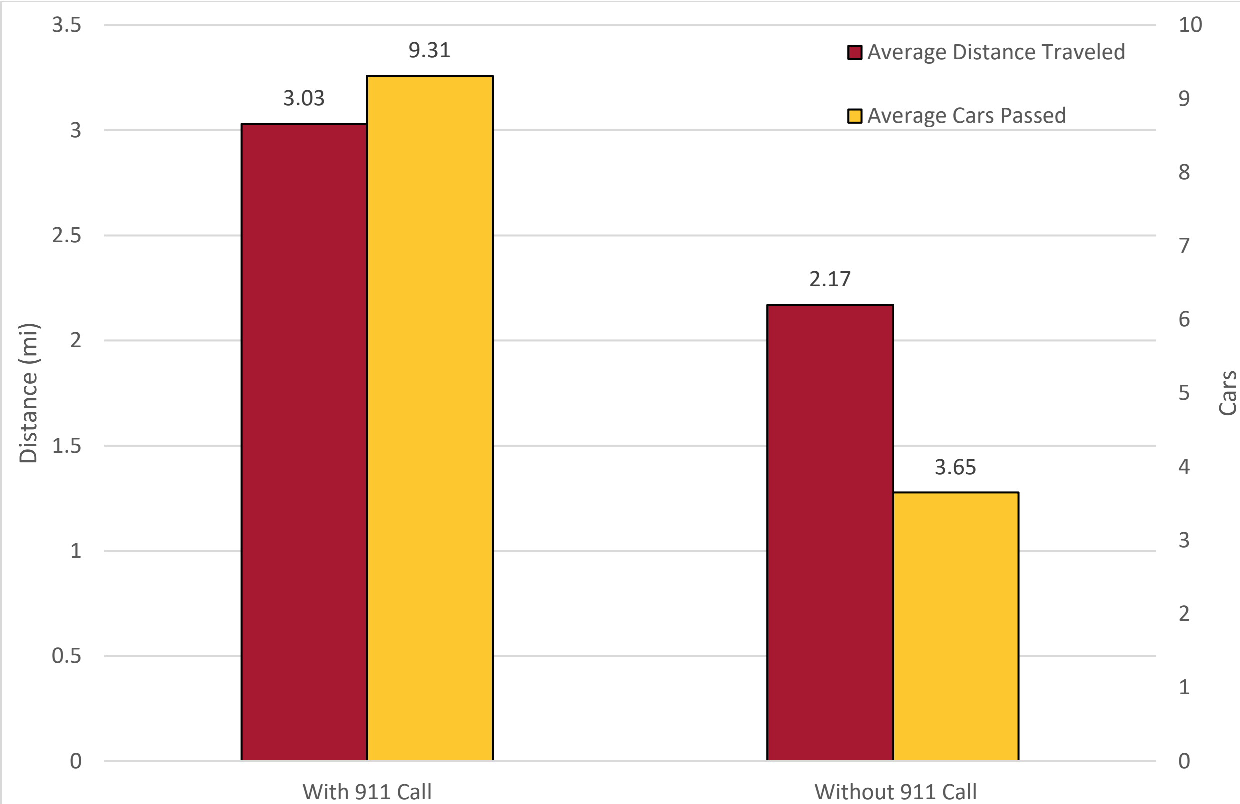

Figure 4. Average distance traveled and average cars passed per WWD incident

Note that this information is divided into two categories: (1) those that had a 911 call related to the WWD incident and (2) those that did not have a related 911 call. Intuitively, the WWD occurrences that had an associated 911 call involved motorists that traveled a farther distance on average in comparison to those WWD incidents that did not have an associated 911 call. As the wrong-way driver covered more distance along the US 30 corridor, it is likely that they would be exposed to more motorists traveling in either direction on US 30. Because of this, it is more likely that one of these other motorists will report the wrong-way driving behavior with a 911 call. This is also reflected in the average cars passed metric also captured in Figure 4. The WWD incidents that received a 911 call passed more motorists on average than those that did not receive a 911 call.

The WWD incidents provided by the Iowa DOT are segregated by the day of the week on which they initially occurred in Figure 5.

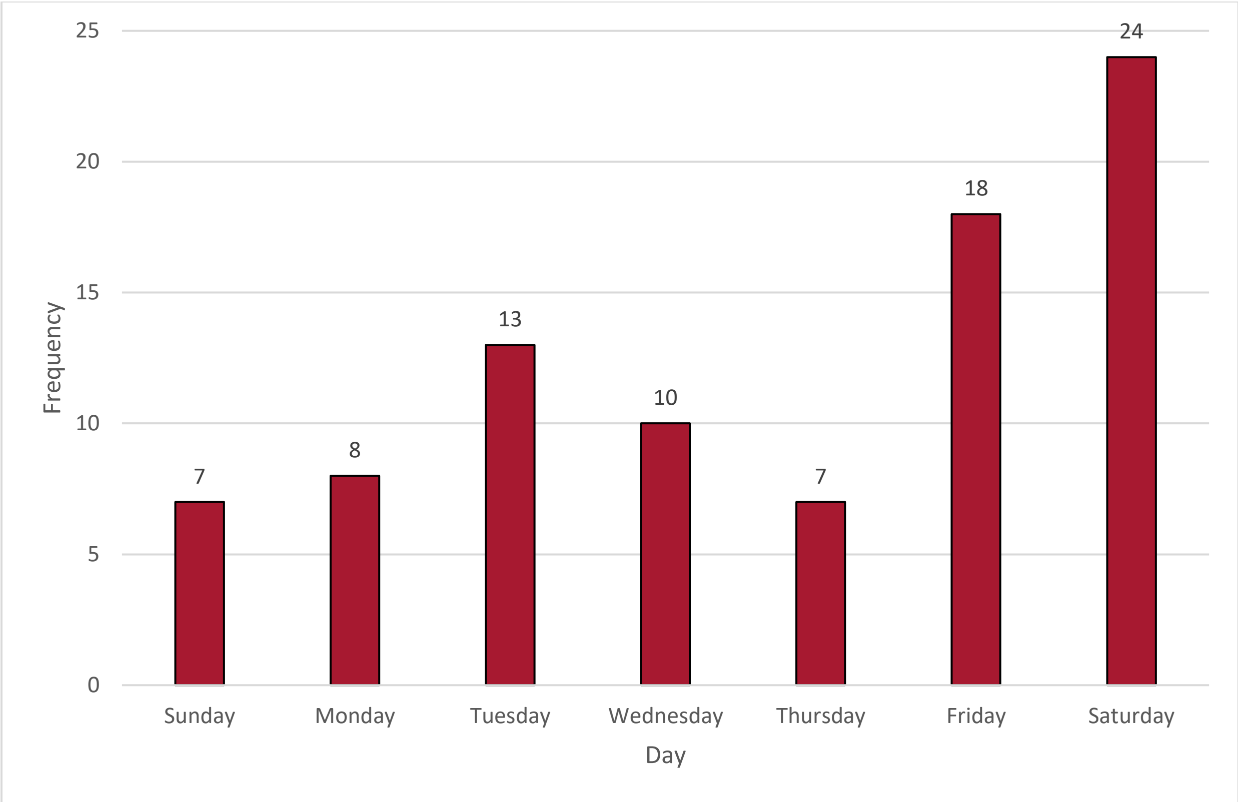

Figure 5. WWD incidents by day of week

As expected, most of the WWD events happened on Friday and Saturday, with Saturday having 28% (n = 24) of the 87 total WWD incidents. As mentioned in the literature review, driving while intoxicated increases the likelihood of being involved in a WWD event, and both Friday and Saturday are candidates for this driving behavior as both are time periods during which drunk driving frequency is likely to increase. The days with the lowest number of WWD events were Sunday and Thursday (n = 7). Again, this is not surprising as both of these days are followed by a traditional work day. Because of this, motorists may be less likely to engage in drunk driving activities, which leads to a corresponding reduction in WWD occurrences.

Figure 6 separates the 87 WWD events by the time of day during which they occurred.

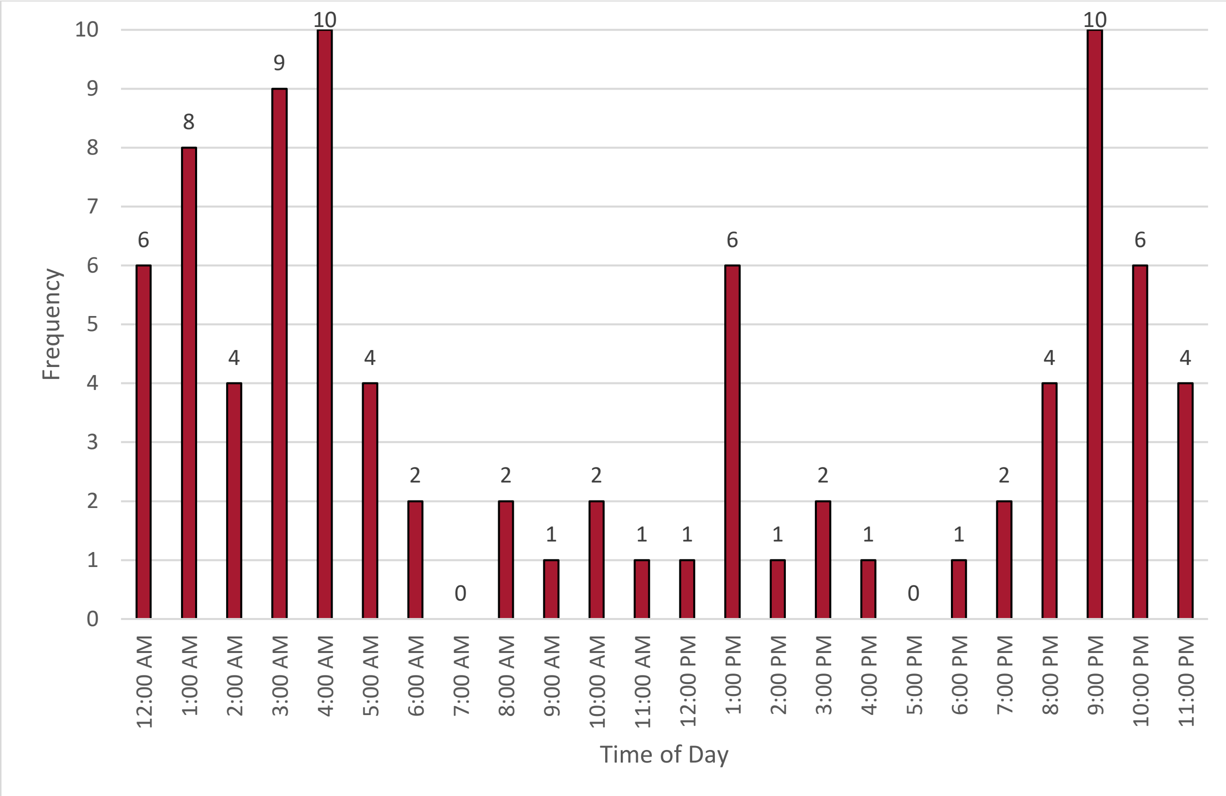

Figure 6. WWD incidents by time of day

As expected from the extant literature, a majority of the events happened during evening and nighttime periods. As expected, these are time periods during which drunk driving is more likely to occur. Because of this, it is expected that WWD incidents would be more prevalent during these time frames. Interestingly, there were two hours within the day that had zero WWD incidents: 7:00 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m. These are during traditional peak hour periods. Because of this, the motorists traveling during this time may be very familiar with the roadway network that they often travel; therefore, WWD may not be an issue during these times. There were two one-hour time periods during the evening and nighttime periods that had the greatest frequency of WWD activities (n = 10). These periods were between 9:00 p.m. to 10:00 p.m. and 4:00 a.m. to 5:00 a.m.

The WWD incidents are categorized by their initial POE in Figure 7.

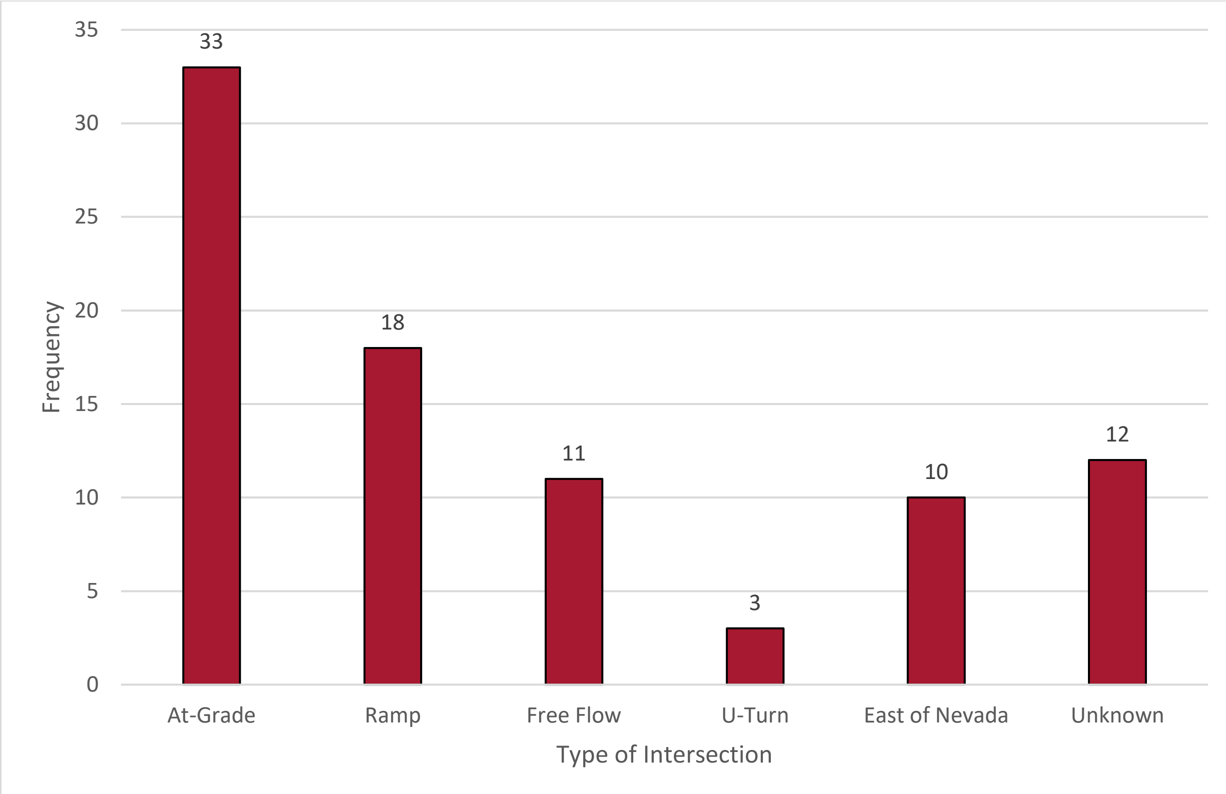

Figure 7. WWD incidents by point of entry

A majority of the WWD events occurred at at-grade intersections within the US 30 corridor. As mentioned previously, research on this topic has been limited in the past and represents an area of significant importance in future WWD research. The next most common POE for WWD was at ramp terminals to enter the US route. The median crossover (U-turn) segments between the two directions of travel had the fewest WWD events, as only 3% (n = 3) WWD incidents happened at these locations during the study period. The category "East of Nevada" in Figure 7 denotes the WWD events that began outside of the field of view of the traffic cameras. Because of this, the POE could not be recorded.

Of the 19 wrong-way drivers stopped by law enforcement officers, 68% (n = 13) had a common condition that has traditionally been demonstrated to increase the likelihood of a WWD incident. As determined by the literature, impaired motorists, elderly drivers, and those unfamiliar with the local roadway network (i.e., confused drivers) are more likely to be involved in a WWD event. Based on Figure 8, impaired operators and confused motorists accounted for 53% (n = 10) of the 19 WWD events.

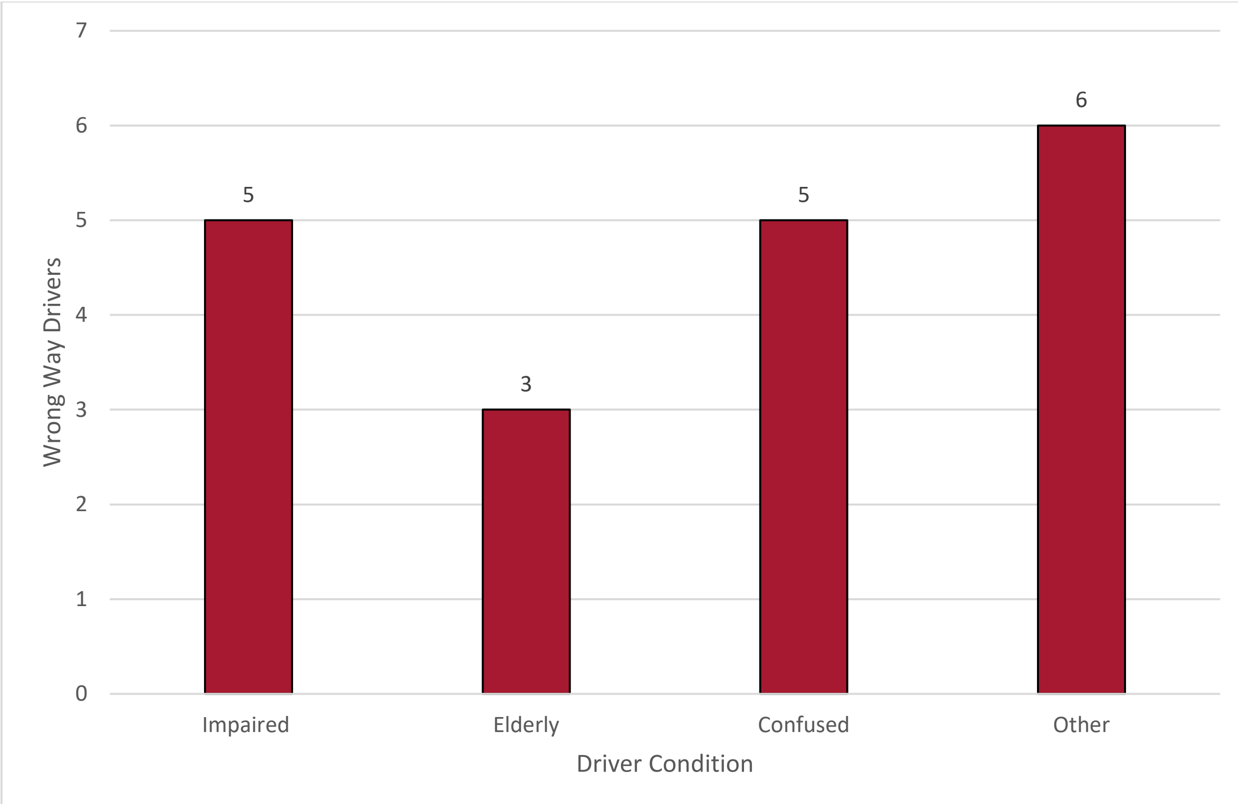

Figure 8. WWD incidents by driver condition

Sixteen percent (n = 3) of the WWD occurrences were due to old age, as determined by the responding police officer. Aside from the three major conditions, all other WWD events were due to other reasons, as depicted in Figure 8.

The following three figures depict the spatial frequency of WWD crashes along the US 30 corridor between Boone and Nevada. Note that the entire corridor for which data was provided is documented in the three separate figures, with the western most point of the corridor on the left of Figure 9, the middle segment in Figure 10, and the eastern most point of the corridor on the right of Figure 11.

The break points of the corridors are consistent between the data frames depicted in the figures. To generate this information, the WWD incidents were spatially located based on the data provided by the Iowa DOT and the traffic cameras that recorded the actions of motorists who traveled in the wrong direction.

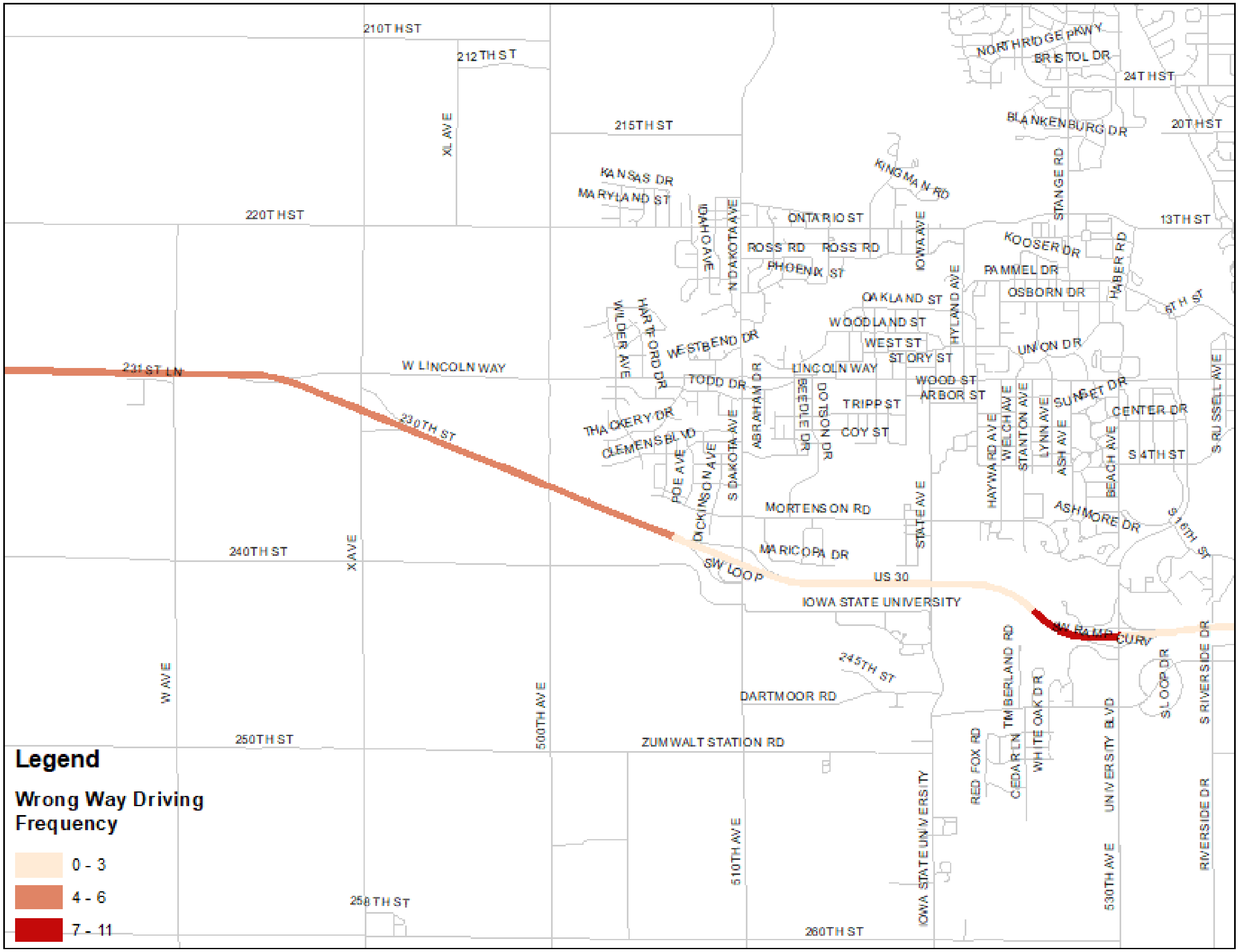

Figure 9. WWD frequency along US 30 (Part 1)

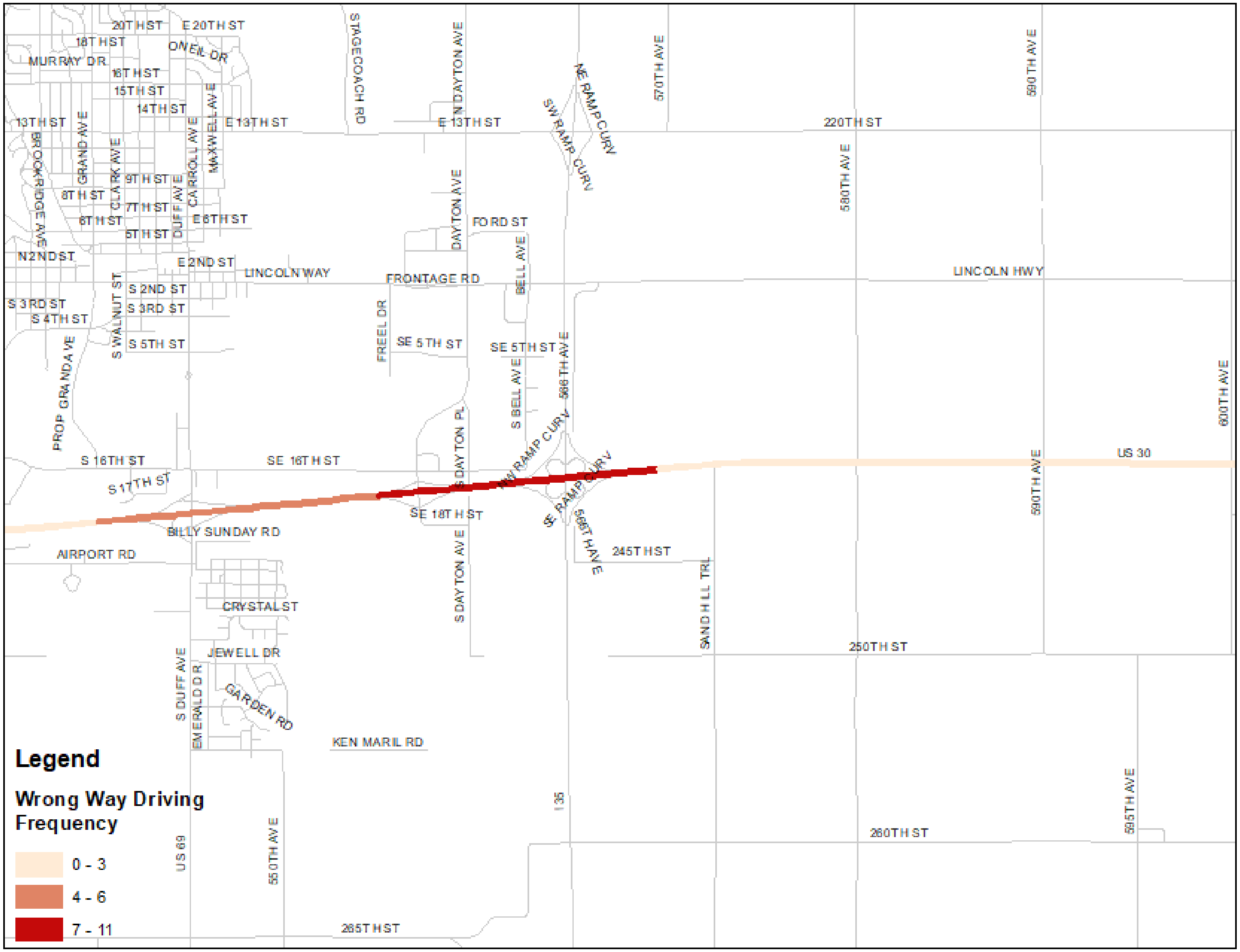

Figure 10. WWD frequency along US 30 (Part 2)

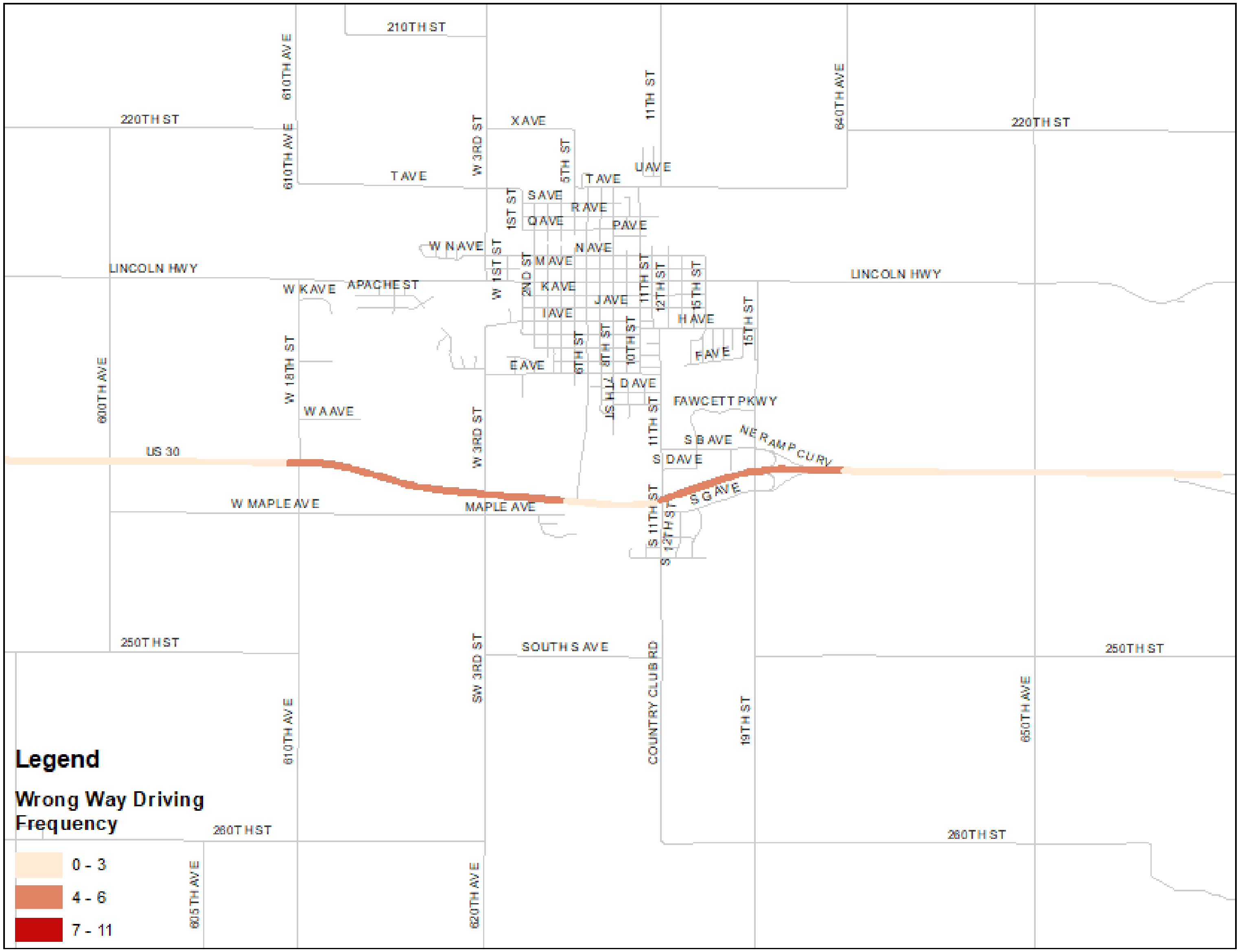

Figure 11. WWD frequency along US 30 (Part 3)

6. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this project was to investigate the nature and magnitude of wrong-way driving issues occurring in the state of Iowa. A statewide analysis of WWD crash data was conducted to examine trends based on driver and roadway characteristics. In addition, a corridor-level review was conducted as to all WWD events that were found to occur along the US 30 corridor near Ames, Iowa using data collected by the Iowa DOT.

6.1 Statewide Analysis of Wrong-Way Driving Crash Data

A total of 718 unique wrong-way crash events were reported between 2008 and 2017 in Iowa, with 17% of these crashes on interstates, 40% on US and Iowa routes, and about 43% on secondary, municipal, or institutional roads. During the study period, 25 fatal crashes were recorded with 64% reported to have occurred on an interstate highway, and the remaining were on freeway or expressway systems. The vast majority of these crashes (84%) occurred in urban environments. The findings also show that approximately 53% of WWD crashes occurred under dark conditions, with 17 of these crashes resulting in fatalities. Among all WWD crashes, 69% occurred on weekdays, and there were no significant differences with respect to the season of the year.

The crash data review also showed that several driver characteristics tended to be over-represented among WWD crashes, with these results being largely consistent with findings from the extant literature. A few of these key findings are summarized here:

- Younger and older drivers had increased involvement in WWD crashes as compared to the middle age groups. The reasons for these increased risks are varied. For younger drivers, inexperience is likely to play a role while for older drivers, cognitive issues are a concern.
- Male drivers were over-represented in the WWD crashes. Approximately 53% of the wrong-way drivers were male and 37% were female, while the gender of the remaining 10% was unknown.
- Impaired drivers accounted for 24% of all at-fault drivers involved in WWD crashes. This is significantly higher than the rate of impairment in other types of crashes across Iowa over the same period. Impaired wrong-way drivers contributed to 25 fatal crashes during the study period.
- WWD was also more likely among those who were driving alone (76%), which suggests passenger presence is likely to reduce the propensity for WWD events.

6.2 Corridor-Level Wrong-Way Driving Data

The Iowa DOT has collected detailed WWD data along the US 30 corridor between Boone and Nevada since 2014 using video camera imagery and recorded 911 calls concerning wrong-way drivers. There were 87 total occurrences of WWD that occurred on this corridor between 2014 and 2017. Based on the results of reviewing the corridor-level of US 30 WWD data, the findings revealed the following:

- Most of the WWD incidents occurred on Friday and Saturday, which covered almost 50% of the 87 total occurrences of WWD on this corridor.
- The WWD data from Iowa DOT also disaggregated by time of day which the WWD events occurred. Based on the findings, a majority of the WWD incidents occurred from 9:00 p.m. to 5:00 a.m. (n = 57).
- The WWD incidents are categorized by their initial point of entry, where a majority of the WWD events occurred at-grade intersections (n = 33), followed by ramp terminals to enter the US route (n = 18).
- From 87 events, 19 wrong-way drivers were stopped by a law enforcement officer. Based on the characteristics of these drivers, 68% had a common condition that has traditionally been demonstrated to increase the likelihood of a WWD incident (impaired, elderly, and confused).
- The average distance traveled by wrong-way drivers with a 911 call was 3.03 miles with the average of 9.31 vehicles passed by the wrong-way drivers. For wrong-way drivers without a 911 call, the average distance travelled and the average number of vehicles passed per WWD event were 2.17 miles and 3.65 vehicles, respectively.

6.3 Recommendations

Ultimately, the vast majority of WWD events tend to occur in urban and suburban areas, with wrong-way entry occurring at ramp terminals on limited access freeways, as well as at-grade intersections on the expressway system. Consequently, these are the areas that are the best candidates for countermeasure implementation. Ultimately, each site requires a different approach to mitigate the nature of the WWD events. These solutions must be designed in consideration of practicality, large-scale applicability, and associated cost.

Traffic enforcement can play several important roles in combatting Iowa's WWD issues. This includes surveillance and monitoring of WWD events, which can be identified through active enforcement programs, as well as utilization of data from 911 calls. Increasing the frequency of law enforcement during specific times of day, particularly after 9:00 p.m. could also help to mitigate wrong-way driving in areas where WWD crashes or non-crash events have been identified with considerable frequency. In addition, as many of these crashes involve alcohol, high-visibility enforcement focused on reducing impaired driving represents another potential opportunity area.

Both younger drivers and older drivers were prone to involvement in WWD crashes. For younger drivers, graduated licensing programs that limit driving after dark are likely to provide ancillary benefits by limiting these risks. For older drivers, these results reinforce the importance of monitoring driver cognitive function and introducing transportation alternatives for drivers who are no longer capable of driving safely under some or all conditions. In addition, educational programs that focus on these demographic groups, as well as on problem behaviors such as impaired driving, can be broadcast on digital, electronic, and print media.

From an engineering standpoint, wider implementation of high-visibility pavement markings and traffic signs could help reduce the frequency of WWD. These traffic control devices would be likely to provide particular assistance for older drivers who have experienced degradation in sensory and cognitive abilities. Site-specific improvements can also be considered at ramp entries and at-grade intersections on divided highways. For example, rumble strips can be used at the entry of ramp terminals to alert drivers who are traveling the wrong-way (these strips can be designed such that drivers traveling in the correct direction would not sense the vibration or sound generated by the rumble strips). In addition, subtle changes to turning radii at ramps and median crossings can be introduced at relatively modest cost in order to make it more difficult for drivers to inadvertently travel in the wrong direction.

6.4 Future Research

The data from the US 30 corridor suggest that the magnitude of the WWD issue is significantly larger than what would be expected based upon pertinent crash data. While this corridor did not experience any crashes during the study period, there were at least 87 events identified since 2014. Additional data from other areas of the state would help to further quantify the extent of this problem. The stakeholders involved in the US 30 corridor provide an exemplary case study that can be followed in other areas. Careful coordination between law enforcement agencies, local agencies, and the state DOT can supplement available monitoring devices such as roadside sensors and cameras.

The results of this study provide important insights that provide motivation for further research in this area. Recently, the Iowa DOT has begun installing treatments at various locations throughout the state in an effort to combat WWD. These countermeasures include the increased installation of high-visibility signs and pavements markings, as well as geometric modifications to make wrong-way movements more difficult for drivers to execute. Given the relative infrequency of WWD events, evaluations of the effectiveness of such countermeasures would be best investigated through human factors studies to discern how these measures affect driver cognition and decision-making.

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