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A Study of Wrong-Way Driving Crashes in Alabama

Volume 1: Freeways

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A STUDY OF WRONG-WAY DRIVING CRASHES IN ALABAMA

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Final Report
Volume 1: Freeways

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1. INTRODUCTION

The National Transportation Safety Board (NTSB) assigned the Office of Safety Operations of the Alabama Department of Transportation (ALDOT) to develop a comprehensive highway safety program for older drivers that incorporates, at a minimum, the program elements outlined in the National Highway Traffic Safety Administration (NHTSA) Highway Safety Program Guidelines (H-12-46) with a special focus on wrong-way driving (WWD) crashes.

Accordingly, the ALDOT decided that an in-depth investigation of WWD crashes on Alabama freeways and multilane divided highways could provide a better understanding of such events. The purpose of this research was to review these severe crashes in depth, to determine the contributing factors that are most commonly involved, and to generate ideas to consider in reducing the frequency and severity of these crashes. The ultimate objective of this research is to develop a plan to mitigate WWD crashes and activities on freeways and multilane divided highways in Alabama. This project includes two parts: (1) WWD crashes on freeways; and (2) WWD crashes on divided highways.

This report summarizes the research activities and findings in part 1: WWD crashes on freeways, and it includes six chapters. Chapter 2 is a review of the current and past studies conducted in different states in the U.S. as well as other countries. This chapter also synthesizes previous findings on WWD countermeasures, mostly from engineering viewpoints. The database used as well as WWD crash data collection and verification is elaborated on in Chapter 3. Chapter 4 identifies spatiotemporal characteristics of WWD crashes and analyzes the WWD crash data using Haddon matrices and a logistic regression method. Using these methods, contributing factors regarding WWD crashes on Alabama freeways are identified. As the next step and using the crash data, 49 locations (exit ramp terminals) were selected for further field review in order to identify other variables that might cause WWD crashes, but could not be determined from crash data analysis. Through the extensive field review, researchers determined general issues and current practices in Alabama to mitigate this kind of problem. The results of these field observations and general countermeasures are summarized in Chapter 5. Chapter 6 provides the final conclusions and recommendations.

2. LITERATURE REVIEW

WWD crashes tend to be more severe and have a greater likelihood to result in death or injury when compared to other types of crashes. Past studies (Copelan, 1989; Cooner et al., 2004a; Cooner et al., 2004b) showed that although a very small percentage of overall traffic crashes were caused by WWD, they result in a relatively large percentage of fatal crashes. Drivers and passengers in both wrong-way and right-way vehicles can be killed in WWD crashes. For example, of the 49 fatal WWD crashes on the New Mexico interstate highway system between 1990 and 2004, 35 drivers and 11 passengers in the wrong-way vehicles were killed, 18 drivers and 15 passengers in vehicles traveling in the correct direction were killed as well (Lathrop, 2010).

WWD crashes are more prevalent during non-daylight hours, particularly in the early morning. In Texas, 52 percent of all WWD crashes occurred during the six hours from 12:00 midnight to 6:00 a.m.; however, only 10.4 percent of overall freeway crashes occurred during that time period. Past studies (Copelan, 1989; Cooner et al., 2004a; Braam, 2006; NTTA, 2009; Zhou et al., 2012) indicated that WWD crashes occurred more frequently during the weekends. The monthly distribution of WWD crashes varies among different states (Braam, 2006; Cooner, 2008; Zhou et al., 2012) and countries (ITARDA, 2002), showing no consistent trend.

Past researches conducted in both Illinois (Zhou et al., 2012) and Texas (Cooner et al., 2004a; Cooner et al., 2004b) have found that WWD crashes occur in urban areas more often than in rural areas. Studies in Texas (Cooner et al., 2004a; Cooner et al., 2004b) also found that most of the WWD collisions occurred in the inside lane of the correct direction and at locations with left-side exit ramps or one-way streets that transitioned into a freeway section. A study in the Netherlands from 1983 to 1998 found that 79 percent of WWD crashes took place on the main line of the freeway, 5 percent on merge/diverge lanes, and 17 percent on ramps (SWOV, 2009).

The characteristics of wrong-way drivers, such as driver sobriety, age, and gender, have been discussed in many past studies. A significant portion of WWD crashes on freeways was caused by driving under the influence (DUI) of alcohol or drugs. Most past studies concluded that young drivers and older drivers are overrepresented in the WWD crashes. Most of the crashes caused by drivers in the young and middle-age range were brought about by inattention, while most crashes caused by drivers in the senior age range occurred because of some physical illnesses such as dementia or confusion (ITARDA, 2002). The findings of a study by Gibbons (2012) established a relationship between aging and nighttime driving behaviors signifying that older drivers have more difficulty detecting objects than younger drivers when the roadway is not lit. The overwhelming majority of WWD crashes involved male drivers, and most of the female drivers were in young age groups (ITARDA, 2002).

Finding WWD entry points can be a challenging process but can lead to a more comprehensive understanding of general causal factors. To this end, Zhou et al. (2012) proposed a method to identify WWD entry points which could be used to develop site-specific countermeasures and rank several interchange types based on their entry point rates.

To overcome the issue of WWD crashes, various countermeasures, ranged from low-cost (signs and pavement markings), to more expensive (geometric modification and Intelligent Transportation System (ITS) technologies), have been applied to minimize frequency and severity of the problem. All these countermeasures fall under the 4 E's approach which includes engineering, education, enforcement, and emergency response. Table 2.1 represents various WWD countermeasures under engineering group that have been implemented by different agencies (Pour-Rouholamin et al., 2015) and were identified through an extensive literature review (Zhou and Pour-Rouholamin, 2014b) and discussions at the 2013 National WWD Summit (Zhou and Pour-Rouholamin, 2014b). It should be noted that DO NOT ENTER (DNE) and WRONG WAY (WW) signs are the two widely used engineering countermeasures for WWD mitigation purposes.

Table 2.1 Various WWD Countermeasures Implemented by Different Agencies

Signing	Pavement Marking	Geometric Improvement	ITS Technologies
• Implementing Standard Wrong-way Sign Package • Improved Static Signs • Lowering Sign Height • Using Oversized Signs • Mounting Multiple Signs on the Same Post • Applying Red Retroreflective Strip to the Vertical Posts • "Freeway Entrance" Sign for All Entrance Ramps (Ensure the Right Way)	• Stop Line • Wrong-way arrow • Turn/Through Lane Only Arrow • Red Raised Pavement Markers • Short Dashed Lane Delineation Through Turns	• Entrance/Exit Ramp Separation • Raised Curb Median • Longitudinal Channelizers • Change in Ramp Geometrics: - Obtuse Angle - Sharp Corner Radii • Roundabouts	• LED Illuminated Signs • Dynamic Signs – Warn Other Drivers • Use Existing GPS Navigation Technologies to Provide Wrong-way Movement Alerts • Provide Consistent Messages or Alerts That Are Intuitive to the Driver

2.1 WWD Studies in the U.S.

Many states have conducted studies on WWD crashes, including California, New Mexico, North Carolina, Texas, Illinois, Michigan, Florida, etc. The results of these efforts are summarized in Table 2.2.

2.2 WWD Studies in Other Countries

In addition to studies in the U.S., other countries such as Switzerland, France, Netherlands, Finland, and Japan have also worked on WWD issues. The studies by these countries are summarized in Table 2.3.

Table 2.2 Summary of Some of the WWD Studies Conducted in the U.S.

State	Study Period	Contributing Factors	Countermeasures Recommended	References
California	1983-1987	Darkness; Intoxicated drivers; Half and full diamond interchanges; Trumpet interchanges	Continue monitoring of WW incidents; Periodic review of exit ramps; Use of detectors and cameras; Pavement Lights; Training for designers; Edge lines across exit ramps; Using second set of WW signs along exit ramps	Copelan 1989
New Mexico	1990-2004	Darkness; Intoxicated drivers; older drivers; Male drivers; Passenger cars	Intervention strategies to reduce the prevalence of impaired driving; Using physical barriers to prevent entry onto interstates; Improved lighting and signage at interstate entry points	Lathrop et al., 2010
North Carolina	2000-2005	Alcohol-related; Older drivers; Two-quadrant parclo interchanges; Full diamond interchanges	Embedded sensors; Video detection systems and flashing lights; Spikes and other barriers; Sensor video information for making modifications; Stricter laws for intoxicated drivers	Braam, 2006
Texas	1997-2000	Early morning hours; Male drivers; Drivers less than 34 years old; Intoxicated drivers; Left-side exit ramps; Urban areas	Traditional signage and pavement marking (DNE and WW signs, WW arrows, etc.); Innovative signage (lowered DNE and WW signs, supplemental placards, red retroreflective strips on signs supports, etc.); Geometric treatments (offset entrance and exit ramps, exit ramp throat reduction); Advanced technologies (detectors and warning signs)	Cooner et al., 2004a; Cooner et al. 2004b
Illinois	2004-2009	Darkness; Older Drivers; Male drivers; Intoxicated drivers; Time of day; Weekends; Urban areas; Parclo interchanges; Compressed diamond interchanges; Freeway feeders	Statewide improvement of WW-related traffic control devices, including DNE, WW, ONE WAY, Keep Right, and Turn Prohibition signs; Use of larger signs for multi-lane exit ramps; Red retroreflective tape on sign supports; Lane-line extensions for complex intersections; and Stop lines at the end of exit ramps; Transform recommendations and best practice into new guidelines	Zhou et al., 2012
Michigan	2005-2009	Darkness; Intoxicated drivers; Younger drivers; Parclo interchanges	Lowered DNE and WW signs; Red retroreflective strips on sign supports; Stop lines at the end of exit ramps; WW pavement arrow at exit ramps; Pavement marking (lane-line) extensions; Painted island between exit and entrance ramps; Red delineators along the exit ramps	Morena and Leix, 2012

A recent paper by Ponnaluri (2016) from the FDOT presents a policy–oriented framework toward addressing WWD in a systematic manner and to suggest a systemic discipline for transforming policy objectives to actionable outcomes. *To accomplish this goal, the leadership of the FDOT played a pivotal role in converting strategy to reality by promoting organizational linkages and active collaboration. The method included: (a) implementing pilot projects; (b) conducting a statewide study with crash evaluation and field reviews, identifying interchange types, and developing countermeasures; (c) evaluating and deploying experimental devices specifically approved by the Federal Highway Administration; (d) conceptualizing a human factors study; (e) transforming recommendations to design guidance; (f) discussing with planners on interchange types susceptible to WWD; (g) retrofitting exit ramps with the recommended countermeasures; and (h) leveraging the media to promote awareness and to educate the public about the dangers of driving under the influence.*

Table 2.3 Summary of Some of the WWD Studies Conducted in Other Countries

Country	Study Period	Contributing Factors	Countermeasures Recommended	References
Switzerland	2003-2005	Young drivers; Intoxicated drivers; Older drivers; Darkness; Female drivers	Radio warning messages; Directional arrows at exit ramps; Double sided No Entry signs; Interchange layout modification	Scaramuzza and Cavegn, 2007
France	2008-2012	Darkness; Older drivers; Intoxicated drivers; Local drivers; Driving older vehicles; Passenger cars; Driving alone without any passengers	Sign-based countermeasures; Changes in the infrastructure geometry; Monitoring divided roads	Kemel, 2015
Netherlands	1996-1998	Older drivers; Younger drivers; Intoxicated drivers	Use of traditional DNE and WW signs; Placing extra arrows on the road surface to show the correct direction; Additional "Go Back" sign installed at the bottom of the DNE sign	SWOV, 2009
Finland	1999-2002	Older drivers; Intoxicated drivers; Ramp configuration	Appropriate use of guidance and signing; Intersection design using islands and roundabouts; Use of physical barriers	Karhunen, 2003
Japan	2005-2009	Older drivers; Younger drivers; Darkness; Type of interchange	Appropriate guide signs; ITS applications such as onboard navigation systems and advanced sensing technologies; Road-vehicle communication technologies; Pavement arrow markings; Enhanced driver education; Enforcement on drunken driving; Alcohol ignition interlock devices	Xing, 2015

A recent study by Kemel (2015) is the first to use a more robust statistical analysis to delineate between WWD crashes and non-WWD crashes on French divided highways. In his study, a database was used to identify 266 crashes that involved WW drivers from 2008 to 2012 on French divided highways, and their characteristics were compared to those of other crashes (22,120 crashes) on the same highways during the same time period. This empirical research was then complemented by a binary logistic regression to make it possible to account for the effect of all the variables simultaneously. The results showed that rare, severe WWD crashes are more likely to occur during nighttime conditions (12-6 AM). Regarding the driver's age, this type of crash is more prevalent among drivers 65 and older, which is consistent with the findings of the majority of existing research. Other characteristics of WW drivers that contribute to their likelihood of becoming involved in a WWD crash were identified, including whether they are intoxicated, are local drivers (and not long distance), and are driving passenger cars alone (without any passengers). However, the database used only shows around 1.2% of events (266 WWD vs. 22,120 non-WWD crashes), which may bias the results of a regular logistic regression method.

2.3 Summary of the Literature Review

As can be seen from the reviewed literature, several factors have been found to commonly affect WWD crashes, including driver age, lighting condition, and driver condition. However, there seem to be variations in the effect of these factors in the studies. For example, in terms of age, while older drivers are found to be a significant contributing factor for WWD crashes in the majority of studies, some others have emphasized the role of young drivers as the contributing factor to WWD crashes. Regarding the time of day, it is generally accepted that darkness influences the WWD crashes. There are two reasons associated with this finding. Besides drivers' visibility of the exit ramp and crossroad intersections being reduced (which are the most prevalent entry points of WWD crashes), drinking and driving is more prevalent during nighttime. These factors both increase the likelihood of turning in the wrong direction. Other than human and temporal factors, some interchange types – and specifically their geometric design features – are found to affect the possibility and occurrence of WWD. As is implied by some studies, diamond (full or half) and partial cloverleaf (parclo) interchanges are overrepresented when it comes to WWD.

3. CRASH DATA COLLECTION

The approach used to identify WWD crashes consists of two steps: (1) use pertinent variables to separate possible WWD crashes from the total crashes in the database; and (2) identify true WWD crashes by reviewing the crash narratives in the crash reports. The following sections elaborate upon the WWD crash identification and verification process.

3.1 Crash Database

Crash data on Alabama freeways were collected across a five-year time period from 2009 to 2013. The data source used in this project is the Alabama crash records database accessed through the Critical Analysis Reporting Environment software, also known as CARE (CAPS, 2014). This software was designed to help identify inherent statistical characteristics of various kinds of crashes from different perspectives, such as driver, roadway, and vehicle. This software also enables researchers to use filters to narrow their study focus to specific kinds of crashes.

3.2 WWD Crash Identification

Table 3.1 summarizes the variables as well as the corresponding values used to identify possible WWD crashes for further examination. The filter includes contributing circumstances, vehicle maneuvers, and citations issued for the causal unit (CU) and the second vehicle (V2).

Table 3.1 Summary of Variables and Their Values to Identify Possible WWD Crashes

Variable	Value(s)
Primary Contributing Circumstance	- Traveling Wrong Way/Wrong Side - Wrong Side of Road
CU Contributing Circumstance	- Traveling Wrong Way/Wrong Side - Wrong Side of Road
V2 Contributing Circumstance	- Traveling Wrong Way/Wrong Side - Wrong Side of Road
CU Vehicle Maneuvers	- Wrong Side of Road - Wrong Way on One Way
V2 Vehicle Maneuvers	- Wrong Side of Road - Wrong Way on One Way
CU Citation Issued	- Wrong Side of Road
V2 Citation Issued	- Wrong Side of Road

This filter was then applied to interstate, federal, and state highways in the hierarchy of highway classification in CARE, resulting in 132, 525, and 799 possible WWD crashes (1,456 altogether), respectively. The reason this filter was also applied to federal and state highways (as non-interstate highways) was that the study on WWD crashes revealed that some true WWD crashes happened on exit ramps were coded as crashes on non-interstate highways (depending on the classification of the crossroad connected to the exit ramp). Therefore, it was necessary to include these highways in WWD crash identification.

3.3 WWD Crash Verification

To verify actual WWD crashes on freeways and their access ramps, hardcopy reports for those 1,456 possible WWD crashes were requested from ALDOT. The first step was to confirm if the crashes had occurred on freeways or ramp terminals by checking crash diagrams or locating these crashes using Google Maps as a supplementary tool.

Crash locations can be identified using several variables under the "Location and Time" section in the crash reports. These variables include facility name and description, node codes, and coordinates. Not all the crashes have all the location information; however, at least one of the three abovementioned variables should be available to locate the crash on the map. Figure 3.1 depicts an example of the "Location and Time" portion of a crash report. As can be seen in this figure, other information can be of use to correctly pinpoint the crash on the map, such as Mile Post, and distance from nodes.

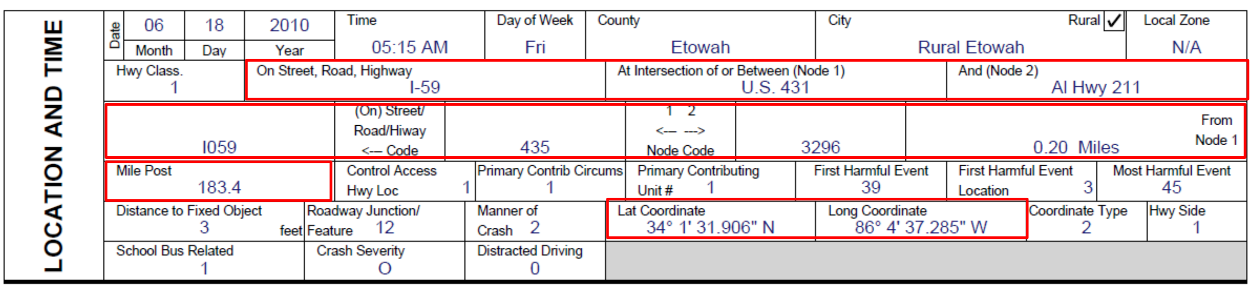
LOCATION AND TIME
Date: 06 Month / 18 Day / 2010 Year | Time 05:15 AM | Day of Week Fri | County Etowah | City Rural Etowah | Rural ✓ | Local Zone N/A
Hwy Class. 1 | On Street, Road, Highway I-59 | At Intersection of or Between (Node 1) U.S. 431 | And (Node 2) Al Hwy 211
I059 | (On) Street/ Road/Hiway <— Code 435 | 1 2 <— —> Node Code 3296 | 0.20 Miles From Node 1
Mile Post 183.4 | Control Access Hwy Loc 1 | Primary Contrib Circums 1 | Primary Contributing Unit # 1 | First Harmful Event 39 | First Harmful Event Location 3 | Most Harmful Event 45
Distance to Fixed Object 3 feet | Roadway Junction/ Feature 12 | Manner of Crash 2 | Lat Coordinate 34° 1' 31.906" N | Long Coordinate 86° 4' 37.285" W | Coordinate Type 2 | Hwy Side 1
School Bus Related 1 | Crash Severity O | Distracted Driving 0

Figure 3.1 Location and Time Portion of Crash Report

Figure 3.2 shows a WWD crash location in a satellite image that can be used to confirm that the crash occurred on a freeway. The second step was to review the narrative description in crash reports to confirm that each crash was truly the result of a WWD maneuver. The actual WWD crashes were confirmed with respect to key phrases in the narratives such as "traveling the wrong way," "traveling northbound on the southbound lanes," or "turned right on the northbound exit ramp." Altogether, 93 crashes were verified as true WWD crashes on freeways. Table 3.2 lists the number of total crashes, freeway crashes, possible WWD crashes, and actual WWD crashes from 2009 through 2013 in Alabama.

Figure 3.2 An Example to Verify the Location of Possible WWD Crash (Google Earth)

Table 3.2 Number of Crashes under Different Categories in Alabama (2009-2013)

Year	2009	2010	2011	2012	2013	Total
Total crashes	123,999	129,608	128,583	128,420	126,634	513,245
Freeway Crashes	11,023	11,433	11,967	11,258	11,358	57,039
Possible WWD crashes	494	269	242	231	220	1,456
Actual WWD crashes	17	16	25	16	19	93

Table 3.3 presents the percentage of total and fatal crashes on freeways that were caused by WWD in Alabama from 2009 to 2013. Approximately 4% of all fatal freeway crashes were due to WWD even though WWD crashes comprised less than 0.2% of all interstate crashes (indicating a rare event).

Table 3.3 Percentage of WWD Crashes on Freeways

Year	2009	2010	2011	2012	2013	Total
Freeway Crashes	11,023	11,433	11,967	11,258	11,358	57,039
WWD Crashes	17	16	25	16	19	93
Percent	0.15%	0.14%	0.21%	0.14%	0.17%	0.16%
Freeway Fatal Crashes	64	79	76	73	69	361
WWD Fatal Crashes	4	2	4	2	2	14
Percent	6.3%	2.5%	5.3%	2.7%	2.9%	3.9%

3.4 Additional Information from Crash Reports

A spreadsheet of the 93 true WWD crash data with rows representing each crash record and columns representing each attribute in the crash record was created. All the attributes for the database entries of each crash were double-checked against the original crash hardcopy report for accuracy. The typical problems found in this step include:

1. Some variables were miscoded, such as lighting condition, vehicle being towed, airbag deployment, and seatbelt usage;
2. Causal Unit (CU) driver condition was checked and revised based on the narratives. It was found that the variable BAC (Blood Alcohol Concentration) for some crashes was miscoded as showing "Apparently Normal" when the narratives indicated that the driver had positive alcohol/drug test results above the allowed levels.
3. The alcohol test column was also revised based on the hardcopies, as a number of test results were not mentioned in the electronic version, and the column did not identify if the driver refused to take a test.
4. The information for the type of injury along with the number of persons injured could not be found in the electronic data file. So, the researchers reviewed all the hardcopy reports one-by-one to include this information in the final dataset.
5. The variable for "Manner of Crash" for some crashes was recorded from the report manually.

In addition to verifying the information in the electronic crash data file, entry points for each WWD crash were also identified by reviewing hardcopy reports. The WWD entry point was defined as the starting point of the WWD maneuver. WWD maneuvers usually start at a freeway interchange area, a freeway segment (e.g., WW driver made a U-turn on a freeway and then drove in the wrong direction), or a freeway median (WW driver crossed the median and drove in the wrong direction). For 24 of the 93 WWD crashes, the entry points were already documented in the narrative description of the crash reports; however, for the remaining 69 WWD crashes, no information about the entry points was available in the crash reports. For those cases, the method identified in Zhou et al. (2012) was used to estimate the possible entry points as the first two closest possible entry points, such as the nearest freeway exits. Accordingly, 65 possible first and second entry points were identified for those crashes without the recorded entry points. Four WWD crashes were found to have occurred after a U-turn was made on a freeway mainline.

4. CRASH DATA ANALYSIS

The purpose of the data analysis was to investigate factors contributing to WWD crashes and propose corresponding countermeasures. The data analysis is composed of four parts: (1) Spatiotemporal distributions and characteristics of WWD crashes compared to other freeway crashes; (2) Haddon matrix analysis to identify contributing factors in three categories: human, vehicle, and environment during pre-crash, during-crash, and post-crash time periods; (3) Logistic regression analysis to find statistically significant factors based on both crash data and geometric data and quantify their effects using odds ratio (OR); and (4) Additional data analysis including econometric loss, WWD entry point analysis, and interchange ranking.

4.1 Spatiotemporal Distributions and General Characteristics

In this section, the analysis of crash data is presented in terms of crash severity, WW driver characteristics, crash time, vehicle information, and environmental conditions. These characteristics of WWD crashes were then compared with other crashes on freeways to identify the variables that are over-represented in WWD crashes. Detailed tables and figures are presented in Appendices A and B.

4.1.1 *Crash Severity*

Table 4.1 summarizes the frequency and percentage of WWD crashes by severity on freeways each year from 2009 to 2013. The severity used throughout this document is in the 5-level scale of KABCO in which fatal injury are coded as “K”, incapacitating injury as “A”, non-incapacitating injury as “B”, possible (but not evident) injury as “C”, and no injury as “O”.

Table 4.1 Frequency and Percentage of WWD Crashes by Severity per Year

Crash Severity	Total		2009		2010		2011		2012		2013	
K-Fatal Crash	14	15.1%	4	23.5%	2	12.5%	4	16.0%	2	12.5%	2	10.5%
A Injury Crash	25	26.9%	5	29.4%	2	12.5%	9	36.0%	2	12.5%	7	36.8%
B Injury Crash	11	11.8%	1	5.9%	3	18.8%	4	16.0%	2	12.5%	1	5.3%
C Injury Crash	4	4.3%	1	5.9%	1	6.3%	0	0.0%	0	0.0%	2	10.5%
O-No Injuries	37	39.8%	6	35.3%	8	50.0%	8	32.0%	10	62.5%	5	26.3%
Unknown	2	2.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	10.5%

Table 4.2 gives a general scheme of the WWD crashes compared to non-WWD crashes on freeways in terms of severity and the involvement of the persons and vehicles. According to Table 4.2, the percentage of severe injuries (Fatal and A-injury crashes) is more than 40%, while this number for all crashes on freeways in Alabama within the same time period is less than 7%. The variables in red in this table and the following tables show those that have a significant difference in percentage distribution between WWD and other freeway crashes.

Table 4.2 General Characteristics of WWD and other Freeway Crashes

Variable	Category	WWD Crashes (n=93)		Other Crashes (n=57,039)	
		Frequency	Percentage	Frequency	Percentage
Crash Severity	Fatal Crash	14	15.1	347	0.6
	Incapacitating	25	26.9	3,403	6
	Non-Incapacitating	11	11.8	4,091	7.2
	Possible Injury	4	4.3	3,469	6.1
	PDO	37	39.8	45,205	79.3
	Unknown	2	2.2	524	0.9
Number of Persons	One	15	16.1	15,523	27.2
	Two	43	46.2	20,968	36.8
	Three and More	35	37.6	20,548	36
Number of Vehicles	One	12	12.9	21,643	37.9
	Two	66	71	31,614	55.4
	Three and More	15	16.1	3,782	6.6

In addition, WWD crashes resulted in 18 fatalities in 14 fatal crashes (1.29 fatalities per fatal crashes), while this number for all freeway fatal crashes was 1.13 (392 fatalities in 348 fatal crashes), which translates to 16 more fatalities per 100 fatal crashes. The statistics also show that 88% of WWD crashes involve two or more vehicles, which is higher than the average 62% of overall freeway crashes involving two or more vehicles.

4.1.2 *WW Driver*

The responsible driver group contains essential information regarding the driver who is primarily responsible for the crash (also known as 'WW driver'). This information includes the driver's age, gender (male or female), race, and condition, as well as the proximity of the crash location to the driver's place of residence (Table 4.3). The last factor was obtained from a variable in the crash reports that defined if the driver's dwelling place was within 25 miles of the crash location. After comparing the WW driver characteristics with other freeway crash drivers, the key findings are as follows:

- Drivers older than 65 years are over-represented in WWD crashes.
- Males accounted for a larger percentage of drivers involved in WWD crashes than other freeway crashes.
- Nearly half of the WW drivers were DUI, whereas less than 4% of drivers in non-WWD crashes were intoxicated.
- A large percentage of WW drivers live within 25 miles of the crash locations.

Table 4.3 Responsible Driver Characteristics of WWD and other Freeway Crashes

Variable	Category	WWD Crashes (n=93)		Other Crashes (n=57,039)	
		Frequency	Percentage	Frequency	Percentage
Driver Age	Less than 24	17	18.3	14,642	25.7
	25 to 34 years	21	22.6	12,967	22.7
	35 to 44 years	14	15.1	9,303	16.3
	45 to 54 years	8	8.6	7,875	13.8
	55 to 64 years	4	4.3	5,296	9.3
	65 years of over	24	25.8	4,524	7.9
	Other/Unknown	5	5.4	2,432	4.3
Driver Gender	Male	62	66.7	32,970	57.8
	Female	22	23.7	20,823	36.5
	Other/Unknown	9	9.7	3,246	5.7
Driver Race	White/Caucasian	44	47.3	35,016	61.4
	African American	34	36.6	15,905	27.9
	Hispanic	5	5.4	1,806	3.2
	Asian/Pacific Islander	0	0	631	1.1
	American Indian	0	0	47	0.1
	Other/Unknown	10	10.8	3,634	6.4
Driver Condition	Apparently Normal	23	24.7	48,191	84.5
	DUI	43	46.2	2,210	3.9
	Physical Impairment	4	4.3	58	0.1
	Asleep/Fainted/Fatigued	1	1.1	1,711	3
	Illness	1	1.1	205	0.4
	Emotional	0	0	68	0.1
	Other/Unknown	21	22.6	4,596	8.1
Driver Residency Distance	Less than 25 Miles	55	59.1	27,876	48.9
	Greater than 25 Miles	26	28	25,238	44.2
	Other/Unknown	12	12.9	3,925	6.9

4.1.3 *Crash Time*

Table 4.4 lists the frequency and percentage distribution of WWD crashes and other freeway crashes by the month, day, and hour of the day that they occurred. As indicated, it can be ascertained that

- WWD crashes are more prevalent and likely to happen during weekends, while other freeway crashes are almost evenly distributed throughout the week.
- The hourly distribution was also varied within the entire day but with the late night and early morning hours encompassing the highest frequency of WWD crashes. Accordingly,

the hours of 9:00 PM to 6:00 AM accounts for two-thirds of the WWD crashes. Figure 4.1 shows the detailed hourly distribution of WWD crashes during the day.

- The number of WWD crashes range between 4 and 15 per month. May, March, and November are considered as the peak months with nearly half of the total WWD crashes.
- The yearly distribution of WWD crash frequencies for the study years of 2009 to 2013 ranged from 16 to 25, with the year of 2011 having the highest number of WWD crashes and an average frequency of about 19 crashes per year (Table 3.3).

Table 4.4 Temporal Information of WWD and other Freeway Crashes

Variable	Category	WWD Crashes (n=93)		Other Crashes (n=57,039)	
		Frequency	Percentage	Frequency	Percentage
Month	January	4	4.3	4,523	7.9
	February	8	8.6	4,428	7.8
	March	13	14	4,939	8.7
	April	3	3.2	4,346	7.6
	May	15	16.1	5,007	8.8
	June	6	6.5	4,801	8.4
	July	6	6.5	5,176	9.1
	August	4	4.3	4,629	8.1
	September	6	6.5	4,576	8
	October	6	6.5	4,573	8
	November	13	14	4,891	8.6
	December	9	9.7	5,150	9
Day	Monday	15	16.1	8,280	14.5
	Tuesday	6	6.5	8,127	14.2
	Wednesday	7	7.5	7,789	13.7
	Thursday	5	5.4	8,243	14.5
	Friday	16	17.2	10,133	17.8
	Saturday	20	21.5	7,500	13.1
	Sunday	24	25.8	6,967	12.2
Time	Morning (6-12)	12	12.9	16,733	29.3
	Afternoon (12-18)	7	7.5	23,917	41.9
	Evening (18-24)	31	33.3	10,509	18.4
	Night (0-6)	43	46.2	5,880	10.3

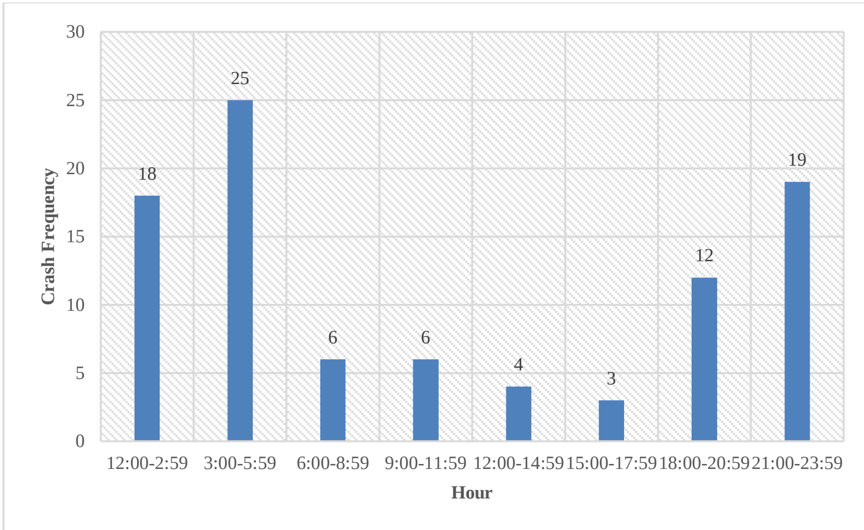

Figure 4.1 Hourly Distribution of WWD Crashes on Alabama Freeways

4.1.4 *Vehicle Information*

The vehicle information reflects type of vehicle, vehicle age, type/extent of damage, towing information, and safety equipment in use (seatbelt and airbag). Table 4.5 lists a comparison between vehicle information for WWD crashes and other freeway crashes during the same time period. The results indicate that:

- More than 95% of WWD vehicles are passenger cars.
- Approximately 70% of the WWD vehicles become disabled after the crash, while this percentage for other freeway crashes is only 44%, resulting in more vehicles being towed after WWD crashes (81.7% of WWD vehicles vs. 48.8% of other vehicles).
- Approximately 66.7% of WW drivers used their seat belts, which is lower than the 89.4% of other freeway drivers that were belted.
- Airbag deployment is also more prevalent among WWD crashes (48.4%) than other non-WWD crashes (14.8%).

4.1.5 *Environmental Conditions*

The environmental conditions refer to area type, lighting, weather, and roadway conditions. Table 4.6 lists a comparison of environmental conditions between WWD crashes and other freeway crashes. The results show that:

- WWD crashes had a similar percentage distribution between rural and urban areas as other freeway crashes.
- The percentage of WWD crashes during dark conditions (whether roadway is lit or not) is much higher than other freeway crashes (71.0% vs. 26.5%).
- Most WWD crashes occurred under clear weather conditions and on dry roadway surfaces.

Table 4.5 Vehicle Information of WWD and other Freeway Crashes

Variable	Category	WWD Crashes (n=93)		Other Crashes (n=57,039)	
		Frequency	Percentage	Frequency	Percentage
Causal Unit (CU) Type	Passenger Car	89	95.7	51,306	89.9
	Truck	1	1.1	5,047	8.8
	Bus	0	0	55	0.1
	Motorcycle	0	0	18	0
	Other/Unknown	3	3.2	613	1.1
Vehicle Age	Less than 5 years	15	16.1	14,680	25.7
	5 to 15 years	56	60.2	33,175	58.2
	More than 15 years	16	17.2	5,915	10.4
	Unknown	6	6.5	3,269	5.7
CU Vehicle Damage	Minor/None Visible	9	9.7	16,346	28.7
	Major Not Disabled	11	11.8	13,222	23.2
	Major and Disabled	65	69.9	25,310	44.4
	Other/Unknown	8	8.6	2,161	3.8
Vehicle Towed?	No	14	15.1	28,210	49.5
	Yes	76	81.7	27,828	48.8
	Other/Unknown	3	3.2	1,001	1.8
CU Driver Seatbelt Use	Belt Used	62	66.7	51,017	89.4
	Belt Not Used	8	8.6	1,216	2.1
	Other/Unknown	23	24.7	4,806	8.4
CU Driver Airbag Status	Not Deployed	30	32.3	39,498	69.2
	Deployed	45	48.4	8,460	14.8
	Other/Unknown	18	19.4	9,081	15.9

Table 4.6 Environmental Conditions of WWD and other Freeway Crashes

Variable	Category	WWD Crashes (n=93)		Other Crashes (n=57,039)	
		Frequency	Percentage	Frequency	Percentage
Setting	Rural	35	37.6	23,479	41.2
	Urban	58	62.4	33,560	58.8
Lighting Condition	Daylight	22	23.7	39,456	69.2
	Dark, Road Lit	25	26.9	5,592	9.8
	Dark, Road Not Lit	41	44.1	9,541	16.7
	Dawn	2	2.2	861	1.5
	Dusk	2	2.2	1,483	2.6
	Other/Unknown	1	1.1	106	0.2
Weather Condition	Clear/Cloudy	84	90.3	44,411	77.9
	Fog/Mist	3	3.2	1,276	2.2
	Precipitation	6	6.5	11,170	19.6
	Other/Unknown	0	0	182	0.3
Roadway Condition	Dry	84	90.3	41,236	72.3
	Wet	9	9.7	15,478	27.1
	Snow/Slush	0	0	184	0.3
	Other/Unknown	0	0	141	0.2

4.2 Haddon Matrices

Developed by William Haddon in 1970, a Haddon matrix is used to identify various contributing factors in terms of personal attributes, agent (vehicle) attributes, and environmental (road) attributes, representing columns of the matrix. To this end, this matrix separates the information pertaining to each crash record into three categories of pre-crash, during crash, and post-crash (representing the rows of the matrix). This matrix can be developed for all crashes, one-by-one, and the cumulative frequencies and percentages for each category can be used for further analysis.

In this project, a Haddon matrix was developed for each fatal, A-injury and B-injury WWD crash based on the information in the hardcopy report of each WWD crash. These Haddon matrices contain information about all drivers and vehicles involved in the crash as well as the environmental factors, the noted causes to the crash, and the entry point for the crash. The matrices helped determine the frequency of the contributing factors. Because these accounted for each human, vehicle, and environmental factor at the pre-crash, during crash, and post-crash stages, all contributing factors were divided into nine groups: pre-crash human, pre-crash vehicle, pre-crash environment; during-crash human, during-crash vehicle, during-crash environment; post-crash human, post-crash vehicle, and post-crash environment. The pre-crash environment cell in the matrix contained information about the entry point. The frequency of each contributing factor was counted to identify the prevalent factors for all injuries and for each category: fatal, A-injury, and B-injury severity types.

For the pre-crash human category, drivers aged 25-34 accounted for the largest percentage of fatal (43%) and A-injury (32%) WWD crashes. The prevalent age group for B-injury WWD crashes was older drivers (65 years old and above) with more than 45% of total drivers in this category. While these drivers were ranked second in fatal and A-injury crashes, the drivers aged 35-44 were the second-most prevalent drivers involved in B-injury crashes. Male drivers were over-represented for all the studied crash types accounting for 64%, 76%, and 73% of fatal, A-injury, and B-injury crashes, respectively. Without considering the Other/Unknown category for driver condition, being under the influence of alcohol/drugs was the most common condition of drivers involved in each severity type. As could be expected, traveling wrong way/wrong side was the most prevalent driver contributing circumstance for all severity levels.

Regarding the pre-crash vehicle category, 57%, 60%, and 55% of the vehicles involved in fatal, A-injury, and B-injury crashes, respectively, were passenger cars. The prevalent maneuver type for both the at-fault vehicle and second vehicle was essentially straight (leading to the common crash type for WWD crashes, which is head-on). This fact could easily be seen in the during-crash vehicle category, as 93% of fatal crashes, 72% of A-injury crashes, and 55% of B-injury crashes were head-on. For the majority of crashes in all severity levels, the air bags had been deployed as a result of the crash. In other words, in 57% of fatal crashes, 84% of A-injury crashes, and 64% of B-injury crashes, airbag deployment was observed. Using a seatbelt shows a decreasing trend with increasing severity type. Specifically, seatbelts were used in only 57% of fatal crashes while this number for A-injury and B-injury crashes are 72% and 82% respectively. This parameter shows the active role of seatbelt use in providing safety for the vehicle occupants.

In terms of environmental factors during WWD crashes, almost all crashes in all severity levels happened on dry pavement surfaces. Darkness was the contributing factor for 93%, 72%, and 82% of fatal, A-injury, and B-injury crashes, respectively. The weather condition was also clear/cloudy for the majority of WWD crashes at all levels. In other words, this number is 93% for fatal crashes, 92% for A-injury crashes, and 82% for B-injury crashes. The detailed frequency tables can be found in Appendix C.

4.3 Logistic Regression Analysis

4.3.1 *Crash Data Analysis*

The literature review showed that the most recent studies use simple descriptive statistics to identify the contributing factors to WWD crashes. Few have focused on comparing WWD crashes with non-WWD crashes to test the significance of the identified contributing factors. So far in this study, the relationships between each variable and the type of crash on interstates were calculated individually; however, these variables must be put into one model for multivariate analysis in order to identify the effect of the explanatory variables (contributing factors) on the type of crash altogether. Numerous methods could have been considered; however, the choice of the appropriate model(s) depends on the type and nature of the data available. Logistic regression models were more appropriate than regular regression models here because it was important to find the probability of having either WWD or other types of crashes in this case [as the outcome in this problem is dichotomous (WWD or not)] and not to predict a numerical value for the outcome.

When looking at the data, two conditions are apparent: the rarity phenomenon and unbalanced data. In other words, not only is our event (WWD) rare and the rate of the event low, but also some categories for WWD crashes have zero frequency, which can cause problems in computations (Hosmer et al., 2013). This phenomenon limits the applicability of the regular logistic regression, as it uses the maximum likelihood estimation (MLE), which is known to suffer heavily from the small-sample bias. As a result, the probability of the rare event will be underestimated sharply (King and Zeng, 2001). In this situation, a penalized-likelihood approach is proposed (i.e., Firth's logistic regression), which reduces the small-sample bias of the MLE method (Firth, 1993; Heinze and Schemper, 2002).

The R software package "logistf" was used as a comprehensive tool to estimate the effect of various contributing factors on the probability of WWD crashes (Heinze et al., 2013). First, a model was fit with all possible contributing factors. Subsequently, a backward elimination procedure based on the penalized-likelihood ratio test (as is the suitable procedure for nested models) was employed to produce a final model that best explains the dependent variable. Table 4.7 summarizes the results of the backward elimination of Firth's model.

Table 4.7 Final Firth's Penalized-Likelihood Regression Model for WWD Crashes

Variable	Category	Est. Coef.	Est. S.E. of Coef.	OR
Intercept	–	-8.38	0.46	–
Time of the Day	Morning (6-12)	–	–	Reference
	Afternoon (12-18)	-0.83	0.44	0.44
	Evening (18-24)	0.92	0.33	2.51
	Night (0-6)	1.49	0.33	4.45
Driver Age	Less than 24	–	–	Reference
	25 to 34 years	0.01	0.32	1.01
	35 to 44 years	0.20	0.35	1.23
	45 to 54 years	0.05	0.41	1.05
	55 to 64 years	0.12	0.52	1.12
	65 years of over	2.16	0.36	8.71
Driver Condition	Apparently Normal	–	–	Reference
	DUI	2.78	0.28	16.09
	Physical Impairment	4.31	0.61	74.29
	Asleep/Fainted/Fatigued	-0.28	0.82	0.75
Driver Residency Distance	Less than 25 Miles	–	–	Reference
	Greater than 25 Miles	-0.51	0.23	0.60
Vehicle Age	Less than 5 years	–	–	Reference
	5 to 15 years	0.40	0.28	1.50
	More than 15 years	0.64	0.36	1.90
CU Driver Airbag Status	Not Deployed	–	–	Reference
	Deployed	1.14	0.24	3.12
Roadway Condition	Dry	–	–	Reference
	Wet	-0.90	0.33	0.41
Penalized Likelihood Ratio Test: χ^2=376.4352 on 25 d.f., *p*-value<0.001 Wald Test = 348.546 on 25 d.f., *p*-value<0.001 AIC= -326.4352				

Looking at the obtained model (as shown in Table 4.7), it can be inferred that all of the included parameters have been previously found to explain WWD crashes, except vehicle age. The penalized-likelihood ratio test statistic of 376.43 with corresponding p-value of less than 0.001 (with 25 degrees of freedom) indicates that the alternative hypothesis (i.e., "the current model is true") is accepted. Consequently, the predictor variables given in the model affect the type of crash, or the model with independent variables is statistically better than the model with only the intercept (the null model).

OR, as a relative measure of effectiveness, was calculated and used in this study to interpret the results. It should be noted that when OR is greater than one, the study group is more likely to have the specific characteristic (defined in the category) than the reference category. A similar explanation is applied to OR of less than one. According to results from the fit model, drivers who cause WWD crashes are more likely to be 65 and older (OR=8.71), to be physically impaired (OR=74.29), to be under the influence of alcohol and drugs (OR=16.09), to drive during the nighttime (OR=4.45) or evening (OR=2.51) when there will probably not be ample lighting, to reside in the vicinity of the crash scene (OR=Reference, which is higher among other categories under the variable), and to drive vehicles older than five years ($OR_{5\text{-}15years}$=1.50; $OR_{more\ than\ 15\ years}$=1.90). Moreover, WWD crashes can be characterized by airbag deployment (OR=3.12) and by an occurrence on dry roadways (OR=Reference).

4.3.2 *Geometric Design Elements Analysis*

The standard binary logistic regression approach was also applied to identify the role of various geometric design features in the probability of WWD crashes at partial cloverleaf (parclo) interchanges. Parclo interchanges are notorious as one of the most WWD-prone interchanges, mainly due to the vicinity of the exit and entrance ramps. The studied geometric features include intersection angle, control/corner radius, median, channelizing island, and distance to access point in the vicinity of the interchange. Figure 4.2 depicts these geometric design features.

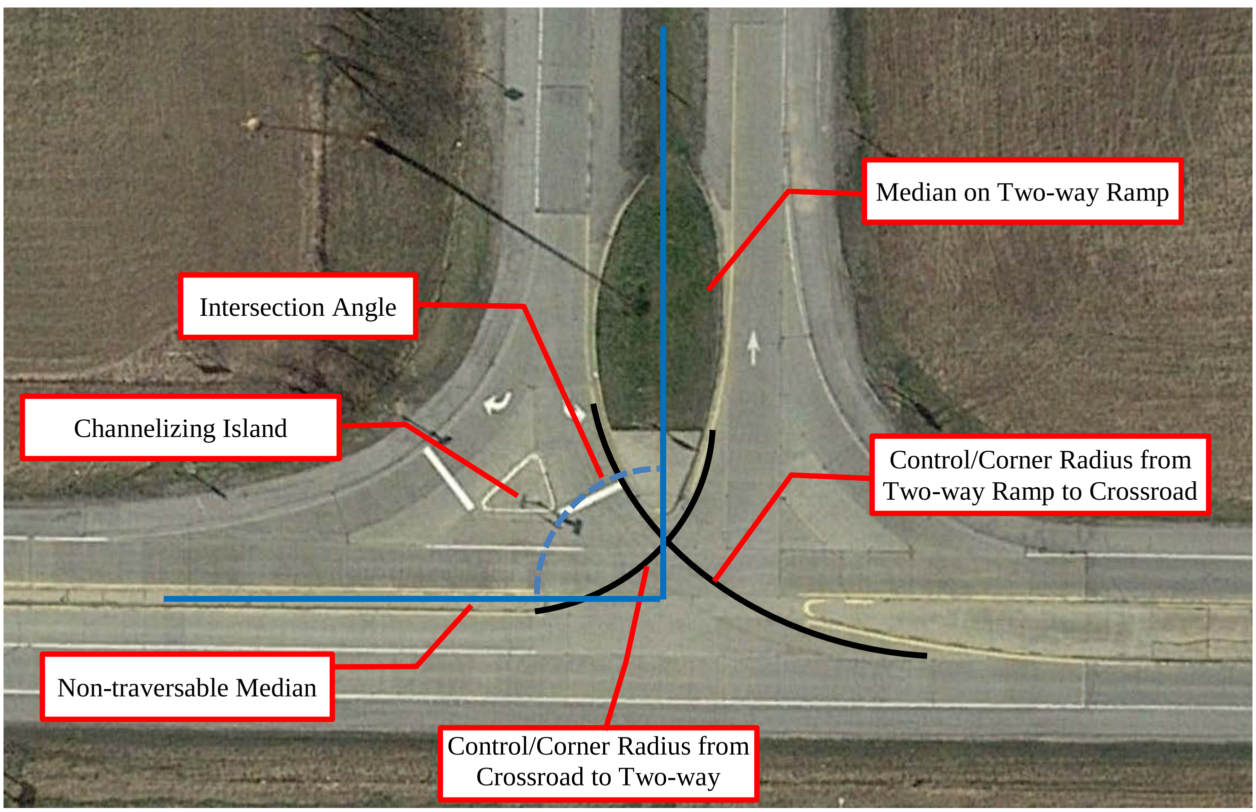

Figure 4.2 Studied Geometric Design Features of the Parclo Interchanges

- Intersection angle is defined as the angle at which the ramp connects to the crossroad, and it depends primarily on the functionality of the crossroad. This angle is measured between the centerlines of the crossroad and the ramp, from the right side of the ramp, so it theoretically can range from 0 to 180 degrees.

- The control/corner radius of an intersection refers to the minimum left-turn path for a design vehicle that affects the radius of the intersection corner as well as the location and opening length of the median.
- Median is defined as an elongated divisional island built as a portion of highway that primarily serves as a means of separating opposing traffic flow on the same roadway. Three characteristics of medians are critical to their role in WWD mitigation, i.e., their type (traversable or non-traversable), their opening, and their width. While the first two characteristics are important for medians on a crossroad, the latter is of importance for the medians between two abutting exit and entrance ramps at parclo interchanges.
- Channelizing islands, in addition to their benefit in defining desirable paths and separating conflict points at intersections, can be utilized to prohibit or at least discourage undesirable movements, such as WWD. Two types of channelizing islands can be considered, i.e., flush (traversable) and raised (non-traversable). Raised channelizing islands can reduce the width of an exit ramp appropriately compared to the width of adjacent entrance ramp, make WWD movements less probable and, in case of possible WWD maneuvers, potentially stop at-fault drivers. A height of at least four inches is required for raised channelizing islands to physically reduce WWD maneuvers.

One of the most important challenges in access management literature is the immediate vicinity of access points/side streets and exit ramps. This spacing should be optimized because short spacing disturbs vehicular movements and affects the service life of the interchange. Some design manuals specify a minimum distance from the interchange to the first connection along the crossroad. However, the extent to which this spacing can lead to possible WWD maneuvers is unknown.

In order to improve the accuracy of analysis and the quality of the results, the WWD crash data from Alabama was supplemented with data from a 10-year (2004-2013) WWD crash study from Illinois. Altogether, the study examined 172 two-way (adjacent exit and entrance) ramps, at 97 parclo interchanges. It revealed that 65 WWD crashes originated from 54 of these locations (11 locations had two WWD entries during the studied time period), and the remaining 118 locations had no history of WWD crashes.

Table 4.8 summarizes the obtained results for the geometric features analysis as well as the OR for the variables. As can be seen in this table, several variables can significantly affect the probability of WWD crashes at parclo interchanges, specifically the control/corner radius from the crossroad onto a two-way ramp, the distance to the access point in the vicinity of the interchange, the type of median on the crossroad, and the median width between the exit and entrance ramp. According to results from the fitted model, having a control/corner radius (from crossroad) of more than 80 feet can considerably increase the probability of WWD crashes (OR=4.67). Furthermore, access points within 600 feet of the exit ramps appeared to be problematic, resulting in a higher likelihood of WWD entries than other categories in the final model. WWD crash entries are also almost twice (OR=1.94) as likely to occur at non-traversable medians on a crossroad. However, a median of more than 30 feet wide on a two-way ramp can considerably decrease the likelihood of WWD crash entries at parclo interchanges. Appendix F of this report provides some examples of parclo interchanges that include all of these features that help to reduce WWD issues. For more details on the variables and statistical analysis method, please refer to a technical paper by Pour-Rouholamin and Zhou (2016).

Table 4.8 Summary of the Final Analysis of Geometric Design Features

Variable	Category	Est. Coef.	Est. S.E. of Coef.	OR
Intercept	–	-0.86	0.97	–
Control/Corner Radius from Crossroad	50 ft and less	Reference		
	51 to 60 ft	0.57	0.89	1.76
	61 to 70 ft	0.44	0.77	1.55
	71 to 80 ft	0.68	0.76	1.97
	81 to 90 ft	1.54	0.86	4.67
	91 to 100 ft	1.22	0.90	3.39
	More than 100 ft	0.82	0.97	2.27
Type of Median on Crossroad	Non-traversable	Reference		
	Traversable	0.66	0.43	1.94
Median Width between Exit and Entrance Ramps	10 ft and less	Reference		
	11 to 20 ft	0.12	0.62	1.13
	21 to 30 ft	0.63	0.72	1.89
	31 to 40 ft	-1.40	0.59	0.25
	41 to 50 ft	-0.23	0.63	0.79
	51 to 60 ft	-1.26	0.96	0.28
	More than 60 ft	-1.64	1.18	0.19
Distance to Access Point in the vicinity of the Interchange	300 ft and less	Reference		
	301 to 600 ft	0.15	0.61	1.16
	601 to 900 ft	-0.39	0.59	0.68
	901 to 1,200 ft	-0.37	0.69	0.69
	1,201 to 1,500 ft	-0.51	1.06	0.60
	More than 1,500 ft	-0.46	0.71	0.63
Number of Observations = 172 Log Likelihood at Convergence = -97.91 (d.f. = 24) McFadden's Pseudo-R^2 = 0.131				

Additionally, in case of having two closely-spaced entrance and exit ramps, providing drivers on the crossroad with a better view of the two-way ramp terminals can help drivers distinguish between entrance and exit ramps, thereby alleviating the WWD problem. At these locations, intersection balance requirements can be satisfied with the proper placement of stop lines so that vehicles intending to enter the intersection and proceed to entrance ramps have already entered some percentage of the way into the intersection. Figure 4.3 also shows the intersection balance requirement according to the Washington State DOT (WSDOT, 2015) design manual. It recommends that the distance between the stop line for left turns from a crossroad and the middle of the median separating exit and entrance ramps be no more than 60% of the entire intersection width. It also suggests providing on island at the off-ramp to reduce width and not providing on island at the on-ramp to increase throat width for better view of entrance ramps. A further study is recommended to evaluate the effectiveness of the intersection balance in reducing WWD activities.

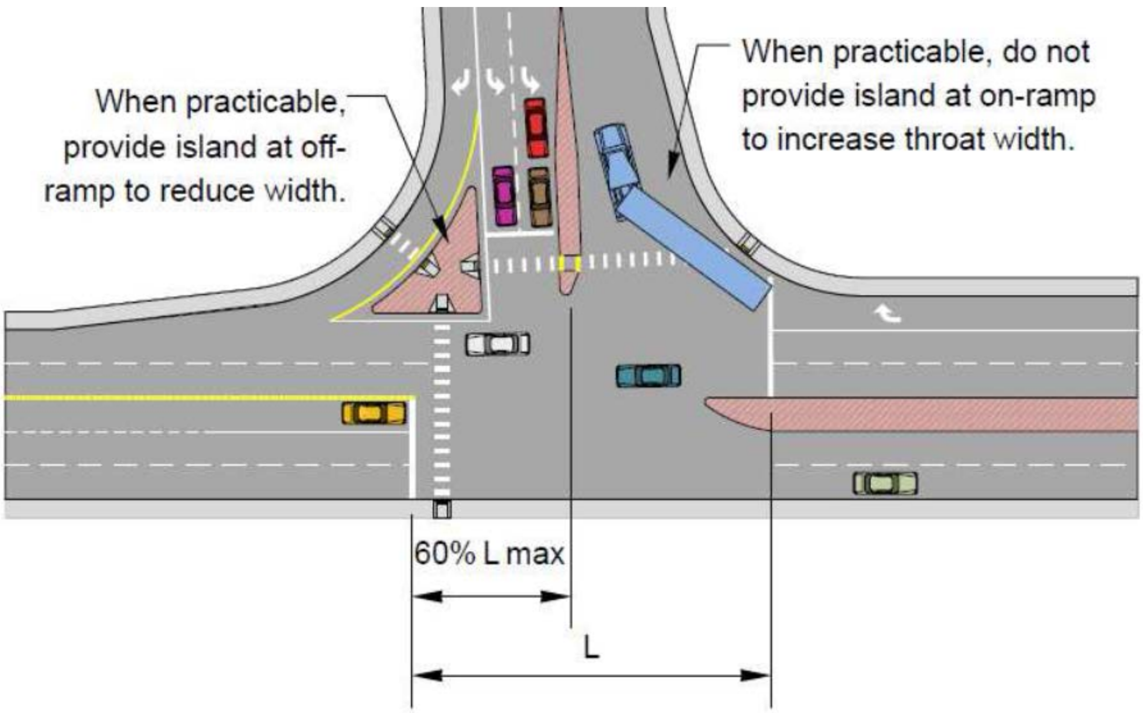

Figure 4.3 Intersection Balance Definition Based on the WSDOT Manual

4.4 Additional Data Analysis

4.4.1 *Economic Loss Due to WWD Crashes*

The economic cost of the WWD crashes is not only the cost that is imposed to the property (vehicles) and medical costs for the involved persons but also includes the loss of productivity, legal and court costs, emergency medical service (EMS) costs, insurance administration costs, congestion costs, and workplace losses. Table 4.9 shows the average comprehensive costs on a per-injured-person basis for 2012 as reported by the National Safety Council (2014).

Table 4.10 also summarizes the number of fatalities, injuries, and other persons without suffering from injuries for each of the studied WWD crashes. By multiplying the numbers in Table 4.9 with those in Table 4.10, the aggregated costs are obtained. These estimates, as well as summations by severity and year, are all listed in Table 4.11. From 2009 through 2013, the annual economic costs of WWD crashes ranged from $10.7 million to $32.0 million, averaging at $19.0 million per year for the studied period. When considering the costs by severity, it can be found that fatalities account for 86% of total costs imposed by WWD crashes. Consequently, reducing the number of WWD fatal crashes and fatalities can reduce societal costs substantially.

Table 4.9 Crash Costs per Person

Severity	Cost per Fatality/Injury ($)
Killed	4,538,000
A-Injury	230,000
B-Injury	58,700
C-Injury	28,000
PDO	2,500

Table 4.10 Number of WWD Fatalities, Injuries, and PDO (person)

Type	2009	2010	2011	2012	2013	Sum
Killed	4	2	6	2	4	18
A-Injury	7	4	18	7	11	47
B-Injury	2	10	6	7	3	28
C-Injury	3	1	6	2	5	17
PDO	22	27	44	38	24	155
Total	38	44	80	56	47	265

Table 4.11 Aggregated Costs of WWD Crashes in Alabama (2009-2013)

Type	2009	2010	2011	2012	2013	Sum by Severity	% of Total
Killed	18,152,000	9,076,000	27,228,000	9,076,000	18,152,000	81,684,000	86.0%
A-Injury	1,610,000	920,000	4,140,000	1,610,000	2,530,000	10,810,000	11.4%
B-Injury	117,400	587,000	352,200	410,900	176,100	1,643,600	1.7%
C-Injury	84,000	28,000	168,000	56,000	140,000	476,000	0.5%
PDO	55,000	67,500	110,000	95,000	60,000	387,500	0.4%
Sum by Year	20,018,400	10,678,500	31,998,200	11,247,900	21,058,100	95,001,100	100%

4.4.2 *WW Entry Points*

The information about WWD entry points is not usually found in the crash reports, as in this study, only 26% of crashes have recorded entry points. A previous similar study by the Illinois Department of Transportation (IDOT) had a comparable percentage of 22% for recorded entry points (Zhou et al., 2012). The identification of WWD crash entry points can serve as a basis for developing proper general and site-specific countermeasures to mitigate the problem. As mentioned earlier, the narratives and aerial images were used to estimate the possible entry points that were not recorded in the crash reports.

Table 4.12 summarizes the number of entry points (recorded, first estimated, and second estimated) and the corresponding interchange type within the studied time period. There were 4 confirmed U-turns on freeways leading to the WWD crashes; therefore, the number of recorded plus either first or second estimated point does not sum up to 93 – the total number of verified WWD crashes. According to this table, diamond (58.3%, 55.4%, 49.2%, 53.2%), modified diamond/parclo (12.5%, 15.4%, 13.8%, 14.3%), and parclo (20.8%, 7.7%, 10.8%, 11.0%) interchanges were the top three interchange types for the recorded, first, second, and total WWD entry points.

Table 4.12 Entry Points and Corresponding Interchange Types for WWD Crashes

Interchange Type	Rec		1st		2nd		Total	
	#	%	#	%	#	%	#	%
Parclo	5	20.8%	5	7.7%	7	10.8%	17	11.0%
Half Diamond	0	0.0%	7	10.8%	5	7.7%	12	7.8%
Cloverleaf	0	0.0%	2	3.1%	2	3.1%	4	2.6%
Modified Diamond/Parclo	3	12.5%	10	15.4%	9	13.8%	22	14.3%
Diamond	14	58.3%	36	55.4%	32	49.2%	82	53.2%
Freeway Feeder	2	8.3%	2	3.1%	5	7.7%	9	5.8%
Diamond with Frontage Road	0	0.0%	1	1.5%	1	1.5%	2	1.3%
Directional	0	0.0%	1	1.5%	2	3.1%	3	1.9%
Rest Area	0	0.0%	1	1.5%	2	3.1%	3	1.9%
Total	24	100.0%	65	100.0%	65	100.0%	154	100.0%

For each of the 89 crashes with entry points, the distance between the entry point and crash location was measured and the cumulative WWD distance distribution for each of the entry point categories (recorded, first estimated, and second estimated) was plotted in Figure 4.4. This plot will help to make comparisons between the entry points and establish the weighting factors for interchange ranking purposes. This figure shows that more than 80% of WWD crashes happened within one mile from the point that the at-fault driver started driving in the wrong direction. Furthermore, 90% and 80% of WWD crashes happened within 4 miles of the recorded and first estimated entry points, respectively. The average driving distance for recorded entry points is about 1.1 miles while this number for the first and second estimated entry points is 3.1 miles and 5.7 miles, respectively. Table 4.13 summarizes some statistics about these entry points.

Table 4.13 Average Driving Distance for WWD Crashes

Statistic	Recorded Entry Points	Estimated Entry Points
Total Number	24	130
Mean (in miles)	1.13	4.38
Maximum (in miles)	11.23	29.00
Minimum (in miles)	0.05	0.20
Standard Deviation	2.51	4.90
Variance	6.28	24.02
Median	0.19	2.60

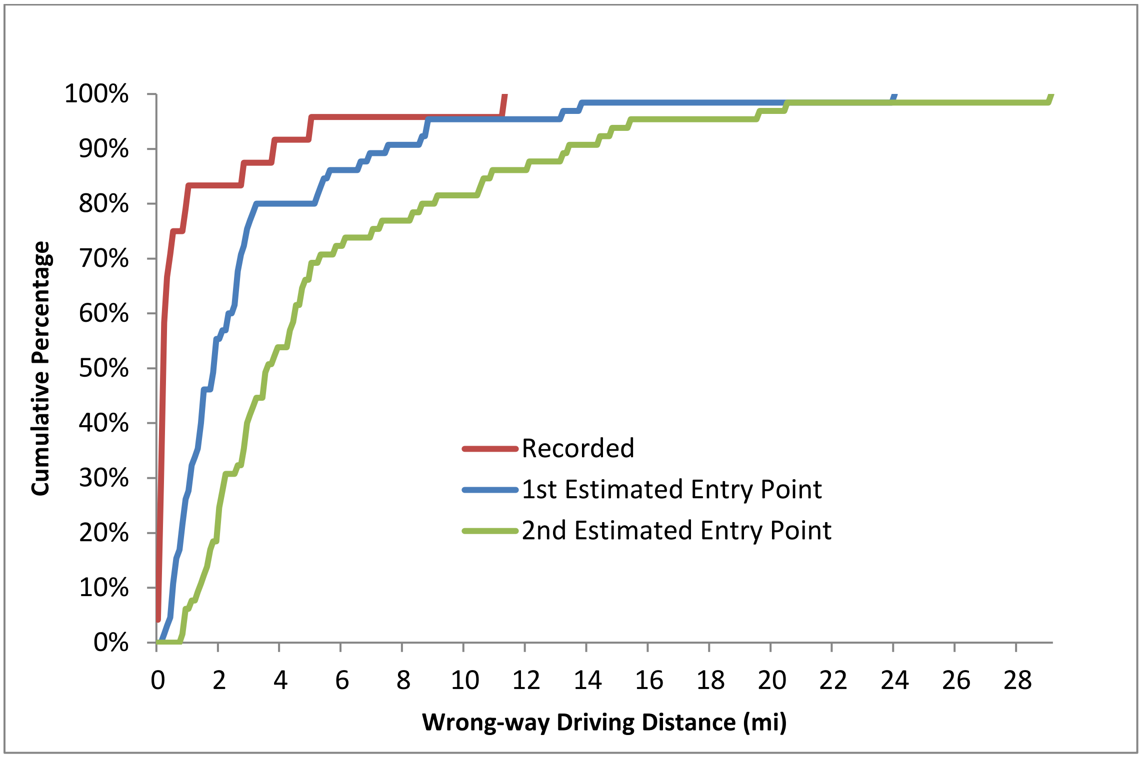

Figure 4.4 Cumulative Distribution for WWD Distance

4.4.3 *Interchange Ranking*

The recorded, first, and second estimated WWD entry points were used to rank the top locations based on the summation of the weighted recorded, first, and second estimated WWD entry frequencies. The weighting factors imply the relative importance of entry points and were identified using the 95% confidence interval for each of the entry point categories. These confidence intervals are depicted in Figure 4.5.

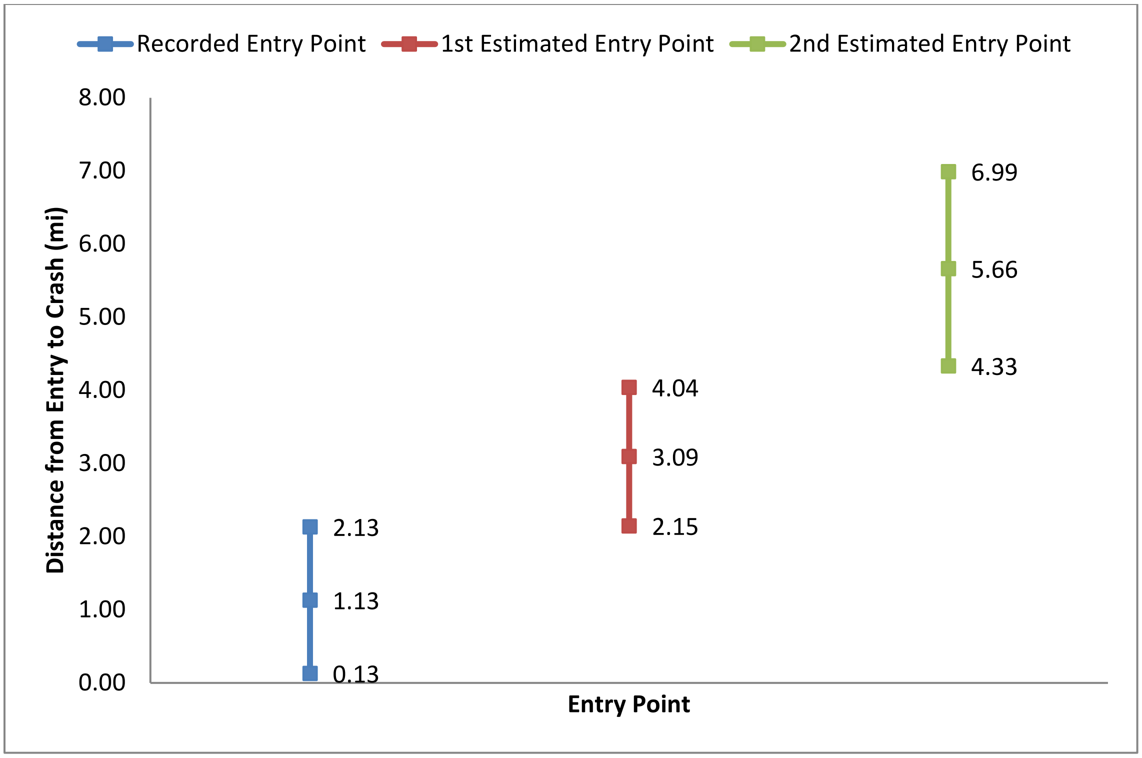

Figure4.5 95% Confidence Intervals of Mean Distances between Entry Points and Crash Locations

Accordingly, a weight of 1.0 was assigned to the recorded entry point. Whereby the mean WWD distance is the key difference between the recorded and estimated entry points, the percentage decrease in the mean driving distance between the estimated and recorded entry points was used to define the weight for the first and second estimated entry points. Consequently, a weight of 0.40 was calculated for the first estimated entry point, and 0.20 for the second estimated entry point. Applying the weight of the first and second estimated entry points to their corresponding mean WWD distances in Figure 4.5 produces the same weighted mean distances depicted in Figure 4.6.

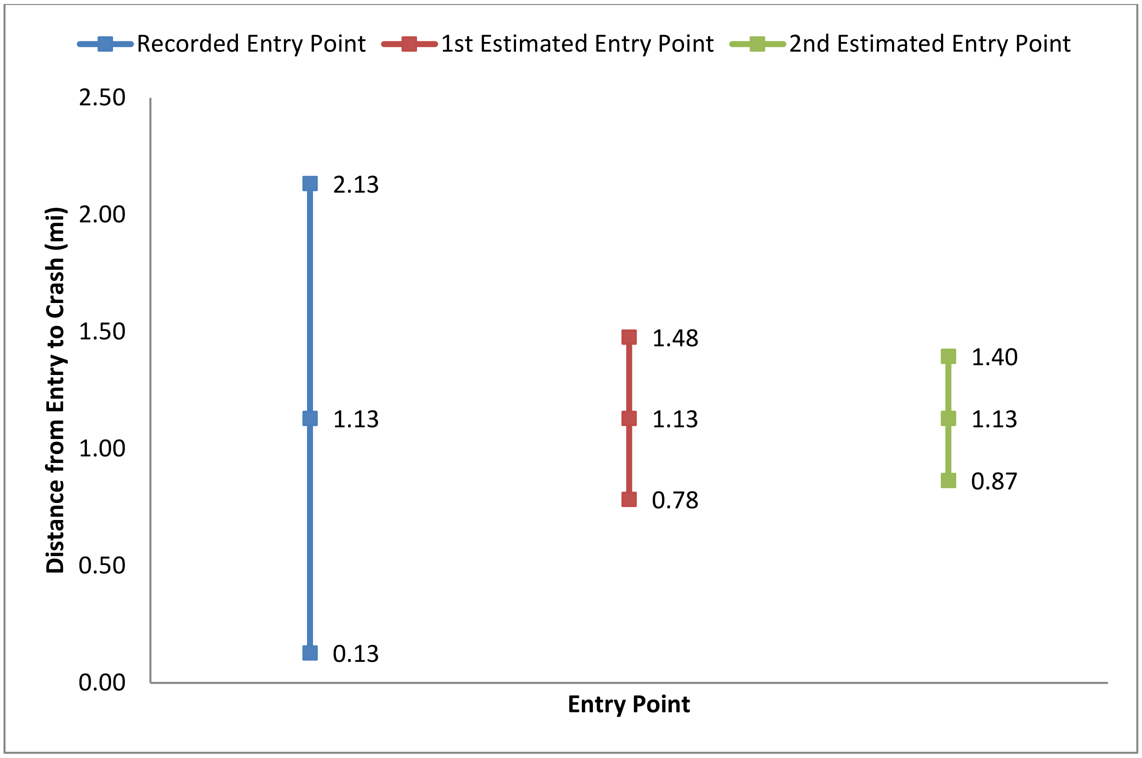

Figure 4.6 Weighted Confidence Intervals of Mean Distances between Entry Points and Crash Locations

When considering the exposure (total number of each type of interchange in Alabama), the WWD crash rate (total number of weighted wrong-way entries per 100 interchanges per year) can be calculated for all the interchange types using the Eq. (1):

$$CR_{int} = \frac{100 \sum_{i=0}^{2} w_i E_i}{N_{int}.T} \quad (1)$$

Where
CR_{int}: WWD crash rate for each interchange type
w_i: Assigned weight for specific type of entry point (1.00, 0.40, and 0.20)
E_i: Number of specific type of entry point (Table 4.12)
N_{int}: Total number of interchange by type in Alabama (Table 4.12)
T: Study time period.

For example, the WWD crash rate (CR) for partial cloverleaf (parclo) interchanges during the studied time period (2009-2013) is calculated as follows:

$$CR = \frac{100 \times (1 \times 5 + 0.40 \times 5 + 0.20 \times 7)}{25 \times 5} = 6.72$$

All the calculations are presented in Table 4.14, and interchanges are ranked using the calculated CR. Accordingly, parclo, half diamond, cloverleaf, and modified diamond/parclo interchanges are the top four interchange types for the potential WWD entries in Alabama.

Table 4.14 Interchange Ranking by Type Using WWD Crash Rate

Interchange Type	Recorded (E_0)	1st Estimated Entry Point (E_1)	2nd Estimated Entry Point (E_2)	Total No. of Int. in AL (N_{int})	WWD Crash Rate (CR_{int})	Rank
Parclo	5	5	7	25	6.72	1
Half Diamond	0	7	5	15	5.07	2
Cloverleaf	0	2	2	5	4.80	3
Modified Diamond/Parclo	3	10	9	37	4.76	4
Diamond	14	36	32	173	4.02	5
Freeway Feeder	2	2	5	19	4.00	6
Diamond with Frontage Road	0	1	1	4	3.00	7
Directional	0	1	2	16	1.00	8
Rest Area	0	1	2	19	0.84	9
Total	24	65	65	313	4.03	–

This method was applied to the statewide study in Alabama to identify high crash locations (specific location instead of specific type of interchange). Altogether there were 104 unique locations with 154 entries, of which 16 percent were recorded, 42 percent accounted for the first estimated, and 42 percent for the second estimated. WWD entry was a sparse event, and the entry frequencies for most locations were relatively low, varying from one to five. Among the 104 entry points, approximately 66 percent experienced one wrong-way entry and the remaining experienced two to five entries. Based on the WWD entries and engineering judgment, several locations were identified for field review. During the field review, researchers identified improvements for WW-related signage, pavement markings and geometric elements. Chapter 5 presents details about the field review.

5. FIELD OBSERVATIONS AND COUNTERMEASURES

The crash data analysis highlighted temporal, human, and environmental factors that delineate WWD crashes; however, another look at the crash reports and narratives demonstrates that not all of the WWD crashes can be identified by these factors, suggesting the role of other possible factors not mentioned in the crash reports. In other words, these crash reports lack essential site-specific features that may either confuse drivers and lead to a WWD maneuver or help mitigate the issue. The main reason is that crash reports contain information about the overall crash scene and not entry points, which may be of equal if not greater importance. To better characterize WWD crashes and detect those contributing factors, such as traffic control devices and geometric features, the researchers conducted field reviews at 49 ramp-crossroad intersections in Alabama. Table 5.1 summarizes the geographical locations and the time of observations for each planned field review. The detailed map of these locations can be found in Appendix D.

Table 5.1 Time and Location of the Studied Intersections

Geographic Location	No. of Locations Visited	Date
Rural I-85 and I-65	13	June 2014
Mobile	6	September 2014
Birmingham	17	December 2014
Huntsville	3	December 2014
Montgomery	10	March 2015

These locations were selected based on having a history of WWD entries identified through narratives of the WWD crashes and the method proposed in Zhou et al. (2012). To identify the problems at these locations, a field inspection checklist was used, which was introduced in IDOT's *Guidelines for Reducing Wrong-way Crashes on Freeways* (Zhou and Pour-Rouholamin, 2014a). This checklist, which is presented in Appendix E, provides a tool to assess the potential for WWD entry problems at possible problematic locations identified through an analysis of crash histories. Moreover, after combining the information from each field inspection checklist, it is possible to assess general issues in terms of signage, pavement marking, and geometric design throughout Alabama. Table 5.2 summarizes the aggregated field review results.

5.1 General Issues

In terms of the signage, "DO NOT ENTER" (DNE) signs were found to be present at almost 96% of the locations, two of which were found to be faded. "WRONG WAY" (WW) signs were also noticed at 92% of the locations along the exit ramps, while almost 20% of exit ramps lack WW signs on their right side. Although it is preferable to have the DNE and WW signs face potential WW drivers, very few of these signs are oriented towards the target driver. Moreover, optional retroreflective strips can be added to these sign supports to improve visibility during darkness.

Given the overrepresentation of WWD crashes at nighttime, adding these strips should help alleviate the problem. "ONE WAY" signs were consistently placed at the proper locations, as well. In contrast, the placement of turn prohibition signs near the ramp-crossroad junction does not seem to be a general practice in Alabama, as just four locations were equipped with such signs, all mounted over the roadway near the traffic signal face.

Table 5.2 Aggregated Field Observation Results

	Check if	Yes (%)	No (%)	Comments
DO NOT ENTER Sign	At least one present	96	4	More than half of them are not faced toward the target drivers. Few locations lack DNE signs on both sides. Optional red retroreflective strips on sign supports are not considered.
	In good condition	96	4	
WRONG WAY Sign	At least one present	92	8	Almost 20% of exit ramps lack WW signs on the right side.
	In good condition	91	9	Size of some WW signs can be increased based on the width of exit ramp. Optional red retroreflective strips can be used to improve visibility.
ONE WAY Sign	At least one present	90	10	Some of the One Way Signs are pointing to different directions or bending. Some of them are not close enough to the entry. There are some retroreflective tapes on sign support.
No Turning Sign	No Right Turn	8	92	More No Turn signs can be installed to restrict WW turning movements.
	No Left Turn	18	82	
	No U-Turn	2	98	
Wrong Way Arrows	Present	14	86	Implement more WW arrows
	Pieces in good condition	57	43	Improve the condition of existing WW arrows
Other Markings	Lane-line Extensions	12	88	Add lane-line extensions to direct traffic onto the on-ramps
	Stop lines at the end of exit ramp	92	8	RRPMs were found at some locations. Almost 30% stop lines are not in good condition and need repainting.
	Left/Right Turn Only Arrow	53	47	Some of the Left/Right Turn Only Arrows are also not in good condition.
Raised Curb Median on the crossroad	Present	29	71	About 35% raised median are extended to prevent WW movements.
Keep Right Sign	Present	8	92	Suggest to use at proper locations
Some other comments				Channelizing island to reduce exit ramp throat is a common practice. Angular break for turning radius was also found to be common. At some locations, exit ramp and adjacent side streets are very close to each other and there are lots of activities and driveways near the interchange areas. This kind of geometric design is inherently confusing.

Regarding pavement markings, WW arrows − one of the primary pavement markings designed to help drivers distinguish their errors after entering the wrong way (Pour-Rouholamin et al., 2015; Zhou and Pour-Rouholamin, 2014a) − were found along seven (14%) of the visited exit ramps, while just three were in good condition and the remaining were faded. Lane-line extensions designed to guide drivers through complicated intersections were painted in only six locations. During the field observations, it was noted that the majority of stop lines and lane-use arrows needed repainting. Bi-directional retroreflective raised pavement markers (RRPMs) had been applied at approximately 20% of the locations, especially at stop lines, to make these markings more visible when insufficient lighting was provided (Figure 5.1).

Figure 5.1 Bi-directional RRPMs to Enhance the Nighttime Visibility of Pavement Marking

As for geometric design features, having channelizing islands to reduce exit ramp throat width and angular break for right-turn WWD movements appears to be common practice. Although the proximity of side streets and exit ramps is reported to increase the possibility of WWD movements, several exit ramps have side streets in the vicinity, some less than 300 feet away. In these situations, raised medians on crossroads that can hinder wrong-way left-turn movements are suggested (Pour-Rouholamin and Zhou, 2015).

5.2 General Countermeasures

In order to reduce the frequency and probability of WWD crashes on freeways in Alabama, regular inspections of the condition of existing signage and pavement markings are necessary to ensure that these traffic control devices are working effectively at preventing WWD incidents in Alabama. Furthermore, enhanced signage should be considered at high crash locations to reduce the probability of WWD. This enhancement includes techniques such as using larger WWD-related signs (DNE and WW signs), adding red retroreflective strips on sign supports, and orienting the existing signs towards potential WW drivers. General countermeasures for signage, pavement markings, and geometric designs are listed in Table 5.3. Most of these countermeasures are the standard methods in the MUTCD (2009) or AASHTO Green Book (2011), or they are proven to be effective by past studies.

Table 5.3 General Countermeasures for WWD Mitigation on Alabama Freeways

Item	General Countermeasures
DO NOT ENTER signs	• Place one **DO NOT ENTER** sign for potential one-direction wrong-way drivers. • Reorient **DO NOT ENTER** signs to face potential wrong-way drivers. • Use a larger sign (35 × 35 inches) for multi-lane off-ramps. • Use red retroreflective strip on sign support(s) to increase nighttime visibility • Use low-mounted **DO NOT ENTER** signs where they cannot be blocked by parked vehicles, pedestrian activities and other blocking objectives.
WRONG WAY signs	• Place at least one **WRONG WAY** sign at the end of ramp terminals, ensuring that it faces potential wrong-way drivers. • Use a larger sign (42 × 30 inches) for multi-lane off-ramps. • Use red retroreflective strips on sign support(s) to increase nighttime visibility. • Consider using a second set of **WRONG WAY** signs or additional **WRONG WAY** signs on the backside of existing signage along the main line at high crash locations. • Use LED-illuminated **WRONG WAY** signs at high crash locations. • Use low-mounted **WRONG WAY** signs where they cannot be blocked by parked vehicles, pedestrian activities and other blocking objectives.
ONE WAY signs	• Use **ONE WAY** signs at the end of the off-ramp on the side with the highest visibility to potential wrong-way drivers. • Use a larger sign (54 × 18 inches) along multi-lane frontage roads that connect to freeway off-ramps.
KEEP RIGHT signs	• Use **KEEP RIGHT** signs at the median between the on and off-ramps at partial cloverleaf interchanges where the median width is less than 30 ft.
NO RIGHT TURN or **NO LEFT TURN** signs	• Add **NO RIGHT TURN** or **NO LEFT TURN** sign next to overhanging traffic signals to increase the sight distance. • Install additional **NO RIGHT TURN** signs at right corner facing potential right-turning wrong-way drivers. • Install additional **NO LEFT TURN** signs at left corner facing potential left-turning wrong-way drivers.
Pavement markings	• Use pavement marking for guiding traffic (through-arrows, turning arrows, elephant tracks). • Add RRPM to stop lines at the end of exit ramps to improve the nighttime visibility.

Item	General Countermeasures
	• Paint new or repaint existing stop lines at the end of exit ramps.
Geometric design	• Use raised curb median and extend it into the intersection (if possible) and use channelizing islands at the exit ramp throat. • Reduce the corner radius for possible wrong-way movements. • Consider implementing roundabouts.
Traffic signals	• Use green arrow instead of circular green for through-only travel lanes.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study attempted to identify the factors that contribute to WWD crashes on freeways in Alabama. The ALDOT crash database, along with the hardcopy of possible WWD crashes, was used to identify the crashes that were caused by WW drivers. Different methods were then used to characterize WWD crashes and identify contributing factors. At first, spatiotemporal distributions and general characteristics of WWD crashes were identified. To get a better understanding of the WWD crashes on freeways, these distributions were compared to other crashes on freeways. These analyses were then completed with a Haddon matrix analysis that further separates the data and contributing factors according to human, vehicle, and environmental characteristics for pre-crash, during-crash, and post-crash time periods. Consequently, drivers of age 25-34, older drivers, male drivers, being under the influence of alcohol/drugs, and driving passenger cars were found as notable factors with higher frequency in fatal, A-injury and B-injury crashes. A logistic regression model between WWD and other freeway crashes was developed to quantify the effect of the contributing factors and to further improve the conclusions. In addition to analyzing crash data, a standard binary logistic model was also used to identify the role of various geometric design elements at parclo interchanges (as one of the most WWD-prone interchange type). To this end, the geometric feature data was used from the state of Alabama and was supplemented with the corresponding data from Illinois.

Based on the results of the crash data analysis, factors including time of day, driver age, driver condition, driver residency distance, vehicle age, and roadway conditions were found to distinguish between WWD crashes and other freeway crashes. Odds ratios (OR) as a measure of relative effectiveness were estimated to quantify the effect of these variables. Accordingly, drivers of 65 years and older are more likely to cause WWD crashes (OR=8.71), to be physically impaired (OR=74.29), to be under the influence of alcohol and drugs (OR=16.09), to drive during the nighttime (OR=4.45) or evening (OR=2.51) when there will probably not be ample lighting, to reside in the vicinity of the crash scene (OR=Reference, which is higher among other categories under the variable), and to drive vehicles older than five years ($OR_{5\text{-}15years}$=1.50; $OR_{more\ than\ 15\ years}$=1.90). Moreover, WWD crashes can be characterized by airbag deployment (OR=3.12) and by their occurrence on dry roadways (OR=Reference). Regarding the geometric design element analysis, it was found that having a control/corner radius (from crossroad) of more than 80 feet can considerably increase the probability of WWD crashes (OR=4.67). Non-traversable medians on crossroad are also almost twice (OR=1.94) more likely to experience WWD crash entries. As for median width on two-way ramps, medians of more than 30 feet can considerably decrease the likelihood of WWD crash entries at parclo interchanges. Regarding the vicinity of access points to the investigated locations, the access points within 600 feet of the exit ramps appeared to be problematic, having a higher likelihood of resulting in WWD entries than other categories in the final model. The method proposed by Zhou et al. (2012) was used to find entry points for various

WWD crashes. The method developed by Zhou et al. (2015) was also used to find weighting factors for different entry points (recorded, first estimated, and second estimated) and rank interchanges in Alabama. Accordingly, parclo, half diamond, and cloverleaf interchanges with 6.72, 5.07, and 4.80 WW entries per 100 interchanges, respectively, from 2009 to 2013 were identified as the interchanges with the highest WWD entry rates.

A comprehensive field review was conducted at 49 locations selected based on the history of WWD entries. The field inspection checklist proposed by Zhou et al. (2012) was completed for each of the studied locations and the results were aggregated. Common practices and general issues and countermeasures were found based on the aggregated results of the field observations. Accordingly, some DNE signs were found to not face towards the potential WW drivers. Use of optional signs (e.g., turn prohibition signs) was also observed to not be a common practice in Alabama. Furthermore, optional visibility enhancements for nighttime conditions (such as red retroreflective strips on sign supports) when the WWD crashes are disproportionally high are recommended for short-term low-cost countermeasures. WW arrows were found at 15% of the studied locations and are suggested to be implemented at more locations as an effective countermeasure to mitigate WWD. WW arrows can be equipped with RRPMs that appropriately enhance the visibility during nighttime conditions. In terms of geometric design features, channelizing islands and angular breaks at exit ramp terminals were found to be a common practice in Alabama. However, the presence of side streets near interchange areas was found to be common as well. As these side streets might increase the probability of WW entries onto the freeway exit ramps when they are located in less than 600 feet from off ramps, it is suggested to install longitudinal channelizers or extend the raised median (if any) into the intersection to impede WW left-turn movements and use angular break and channelizing island to reduce WW right-turn movements.

6.2 Recommendations

The results of this study identified the significant contributing factors to WWD crashes based on crash data analysis and general issues through extensive field reviews in terms of signage, pavement markings, and geometric design elements. The general countermeasures can be recommended to be implemented in two phases. Phase one focuses on short-term, low-cost countermeasures, such as regular maintenance and inspection of the existing signage and pavement markings. Phase two is a long-term, systematic approach on improving geometric design elements and implementing advanced ITS technologies.

6.2.1 *Short-term, low-cost countermeasures*

A potential WW maneuver might occur due to lack of supplemental signage for preventing such a maneuver, lack of proper supplemental pavement markings, or lack of a directional traffic signal head for guiding the driver in the correct direction. These types of countermeasures are mainly related to traditional signage, pavement markings, and traffic signal indications. For instance, given the fact that WWD crashes are more likely to happen during evening and night, the use of optional visual enhancement, such as red retroreflective strips on sign supports, is suggested. As for the traffic signal for the intersection of an exit ramp and crossroad, changing the signal indication from circular green to green arrow for through traffic only lanes might be helpful. More general issues and corresponding low-cost countermeasures are summarized in Table 5.3. Detailed guidelines on improving WW-related signs, pavement markings, and traffic signal indications can be found in a recent publication by Zhou and Pour-Rouholamin (2014a).

6.2.2 *Long-term, systematic countermeasures*

Long-term countermeasures can entail a more comprehensive 4 E's approach (engineering, education, enforcement, and emergency response). It is recommended that a multidisciplinary WW inspection team conduct further field reviews of the confirmed WWD entry points and develop site specific countermeasures. In addition to improving WW-related traffic control devices, some geometric design improvements can also be recommended at parclo and diamond interchanges. One of the recommendations regarding interchange design is to avoid parclo interchanges in the future design, where possible. However, if not practically feasible, following recommendations and considerations may help confront the issue based on this study results. It is suggested to use a raised median and extend it into the intersection (if possible), as it is shown to help mitigate WWD entries. Furthermore, use of channelizing islands is proposed at the exit ramp throat. The data analysis indicates the proper control/corner radius from the crossroad into two-way ramps can reduce the probability of WWD crash entries at parclo interchanges. Accordingly, radii of more than 80 feet for left turns from crossroads are not recommended as they are associated with higher probability of WWD entries. Although the vicinity of access points to the exit ramps is shown to increase the probability of WWD crashes, relocating these access points may be difficult, as this is governed by factors such as accessibility and vehicular movement and throughput as well as availability of right-of-way. However, the increased probability of WWD crashes when the access point is within 600 feet of the two-way ramp of parclo interchanges should be kept in mind. Another suggestion under geometric improvement is the use of roundabouts at the exit ramp-crossroad intersection as a roundabout has a directional movement geometric form which is very effective at reducing the occurrence of WW entries.

Education strategies can be implemented to improve public awareness and understanding of (1) the basics of road designs and interchange types, (2) potential risks, (3) what to do when witnessing a WW driver, and (4) possible damages to family and/or society. Education programs should emphasize young drivers, older drivers, and DUI drivers. These programs can focus on the driving abilities of senior drivers and be supplemented with a self-assessment questionnaire to help senior drivers identify their challenges and abilities to drive safely. In terms of driver's condition, specifically drunk driving as one of the contributing factors, campaigns to raise awareness of drunk driving can reduce the frequency and severity of WWD crashes.

Enforcement strategies that could be implemented include data-driven DUI checkpoints, stopping WW drivers by using portable spike barriers, and using radio and DMS to warn right-way drivers of oncoming WW drivers. An advanced detection and warning system can be implemented by coordinating with traffic management centers and incident responders to enable quick actions to stop WWD before crashes occur. Some ITS automatic WW monitoring and warning systems were found to be effective because they quickly notify law enforcement, who can respond immediately.

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APPENDIX A
FIGURES FOR WWD CRASH DATA ANALYSIS

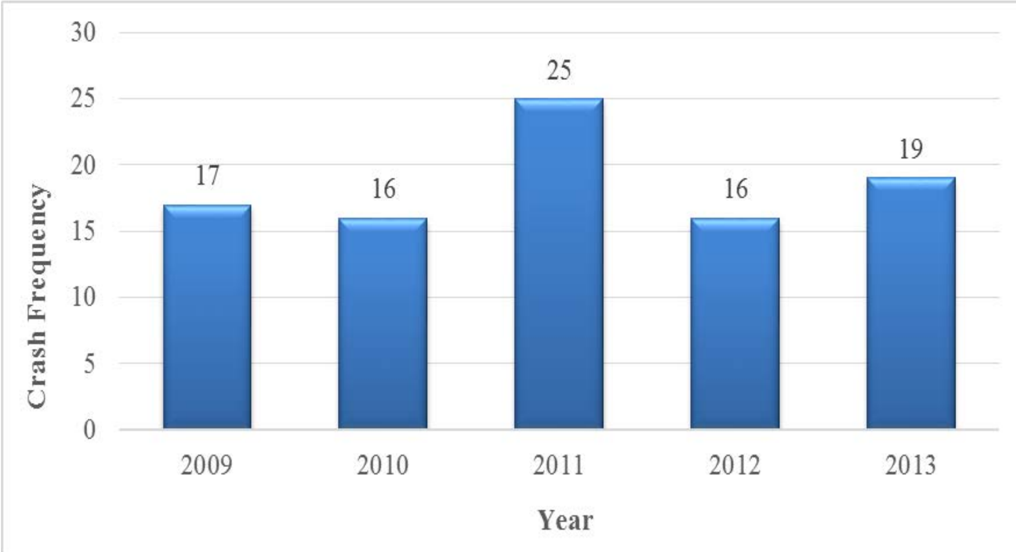

Figure A.1. Annual distribution of wrong-way crashes.

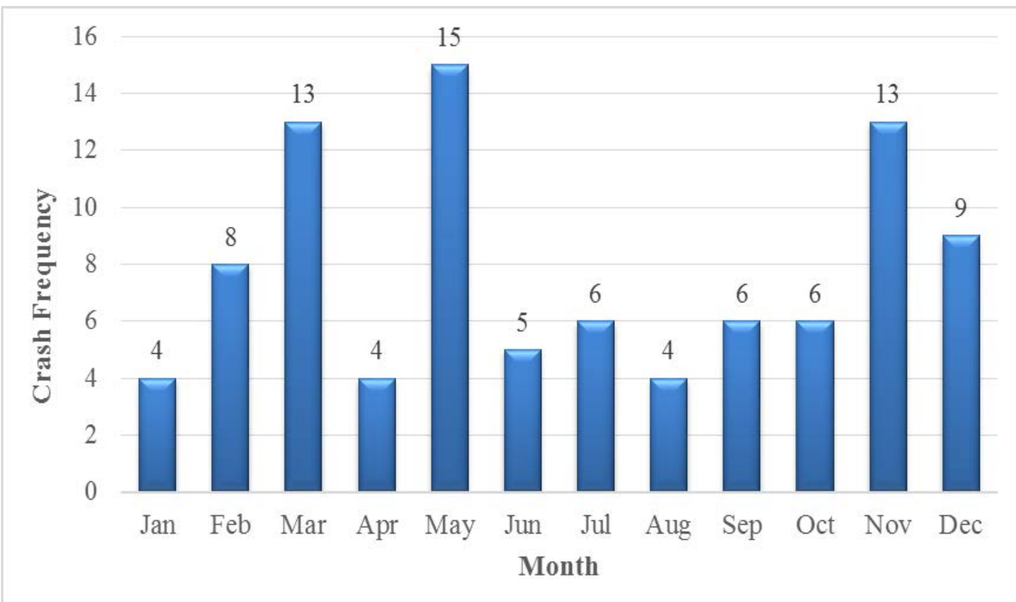

Figure A.2. Monthly distribution of wrong-way crashes.

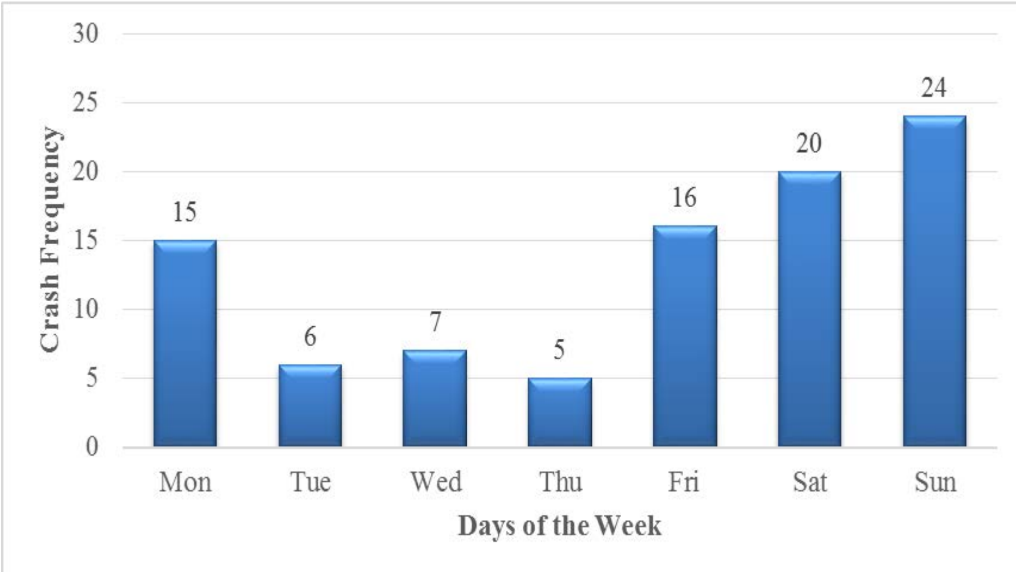

Figure A.3. Weekly distribution of wrong-way crashes.

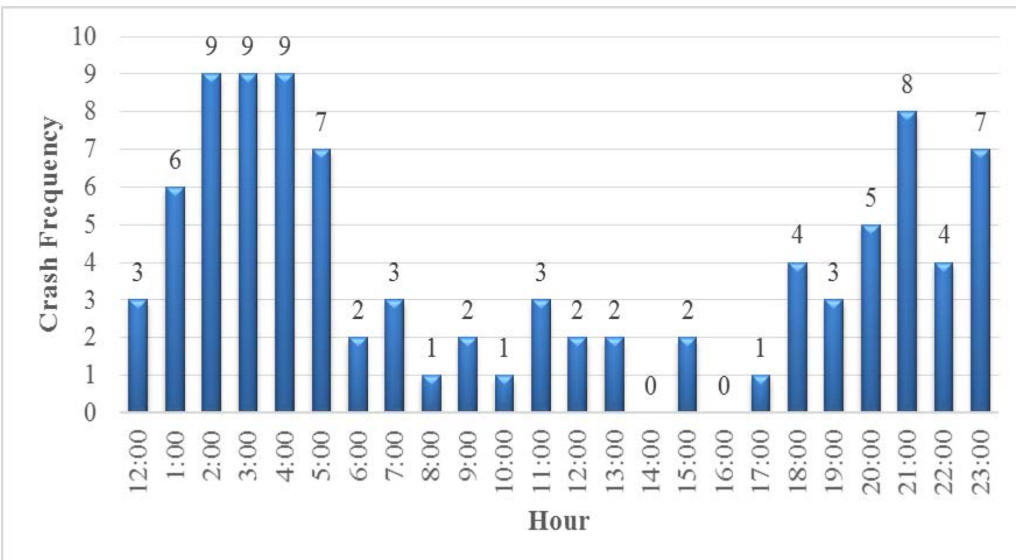

Figure A.4. Hourly distribution of wrong-way crashes.

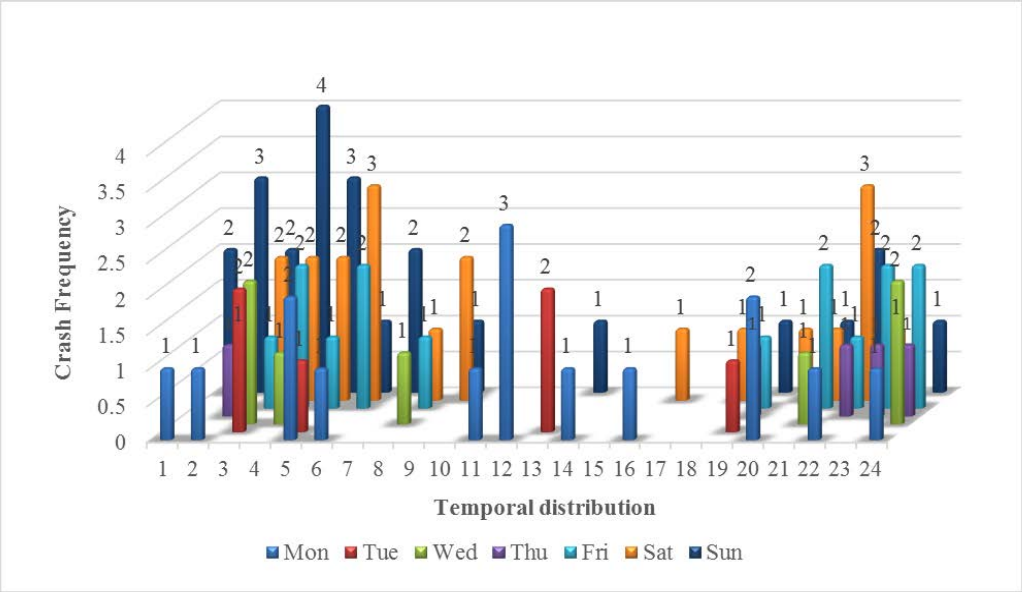

Figure A.5. Temporal distribution of wrong-way crashes.

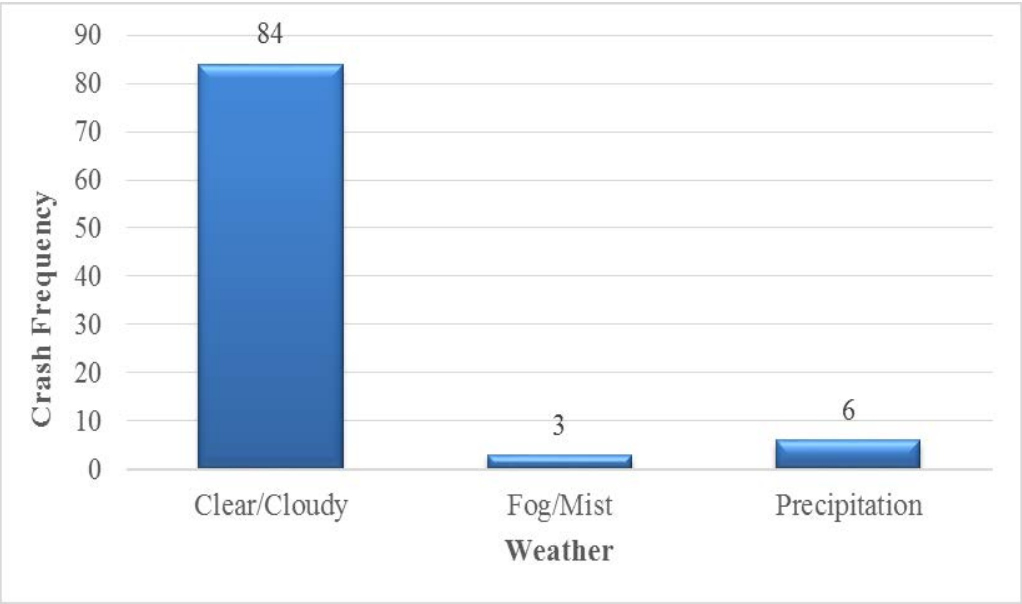

Figure A.6. Weather condition for wrong-way crashes.

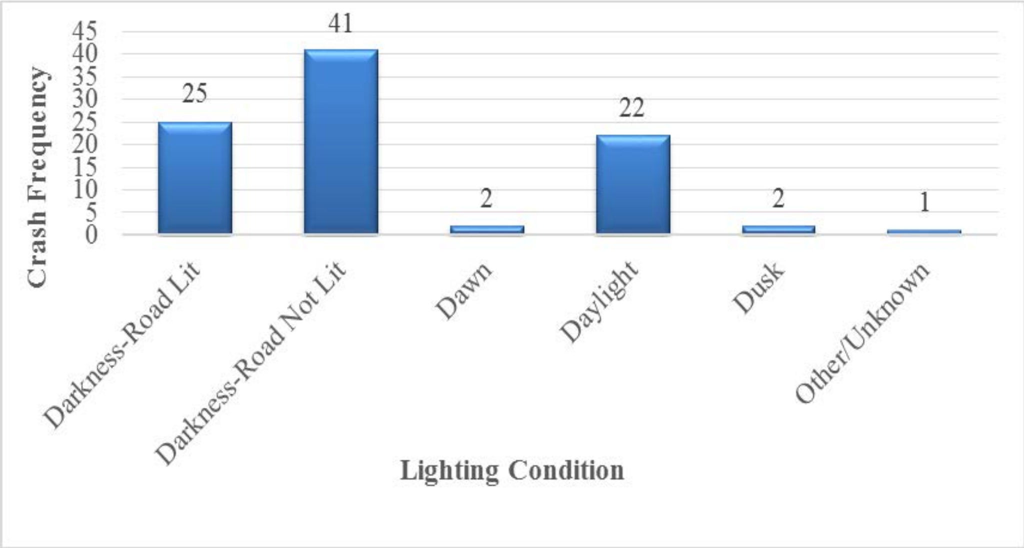

Figure A.7. Lighting condition for wrong-way crashes.

Figure A.8. Class of traffic way for wrong-way crashes.

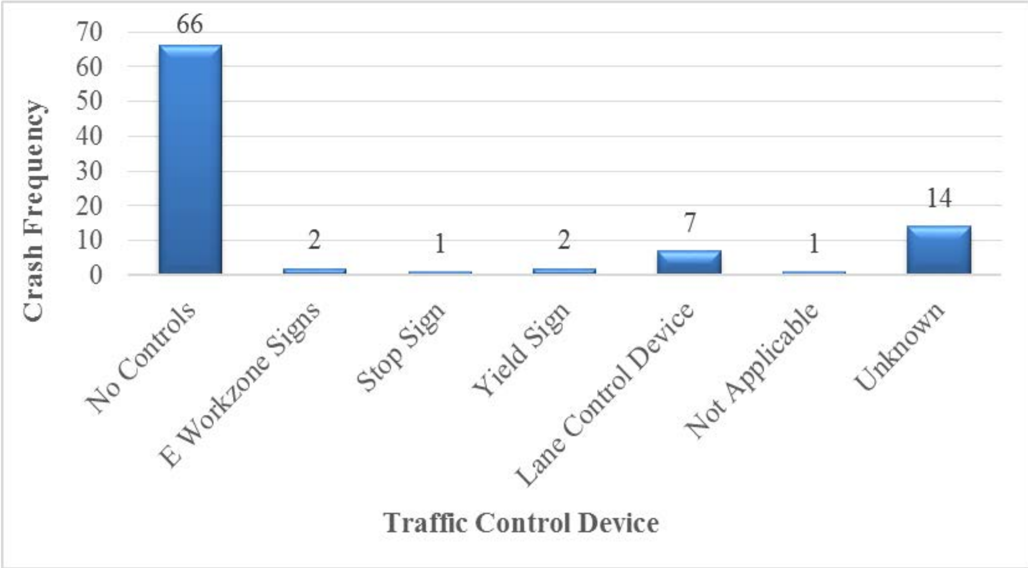

Figure A.9. Traffic control device presence for wrong-way crashes.

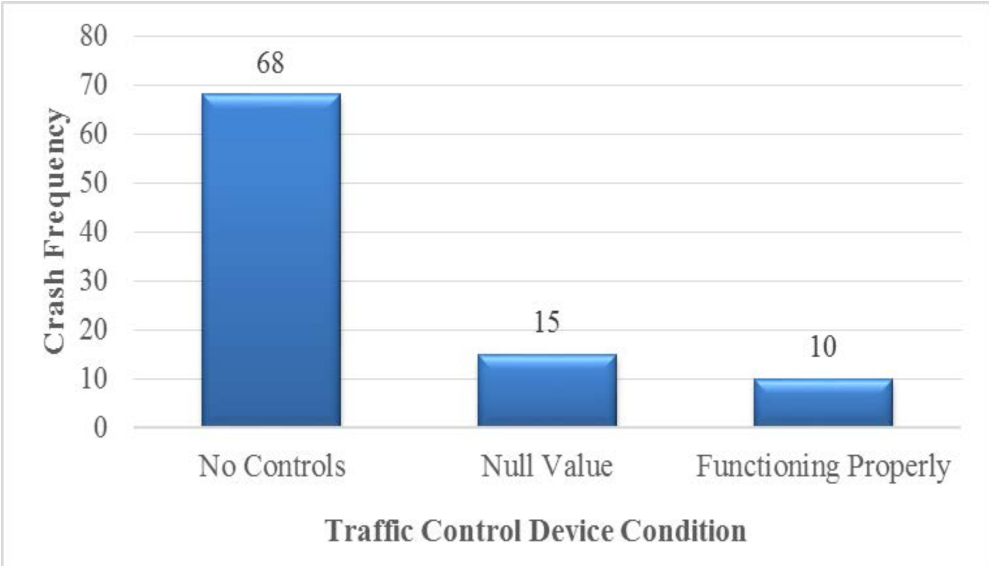

Figure A.10. Traffic control device operating condition for wrong-way crashes.

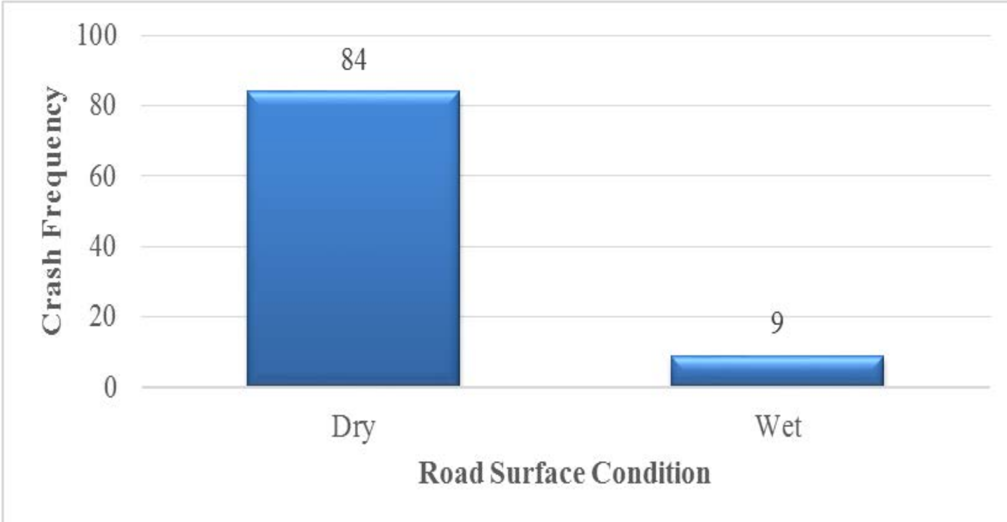

Figure A.11. Road surface condition for wrong-way crashes.

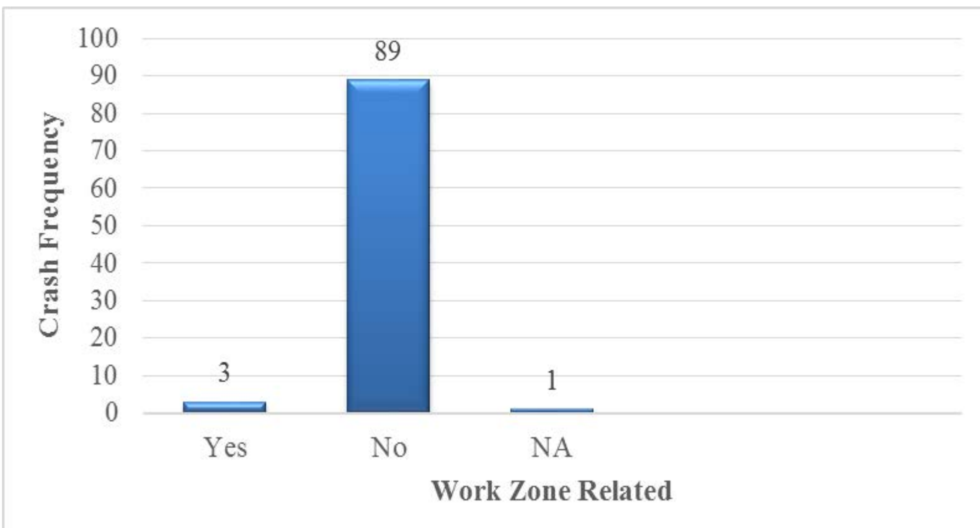

Figure A.12. Work zone–related wrong-way crashes.

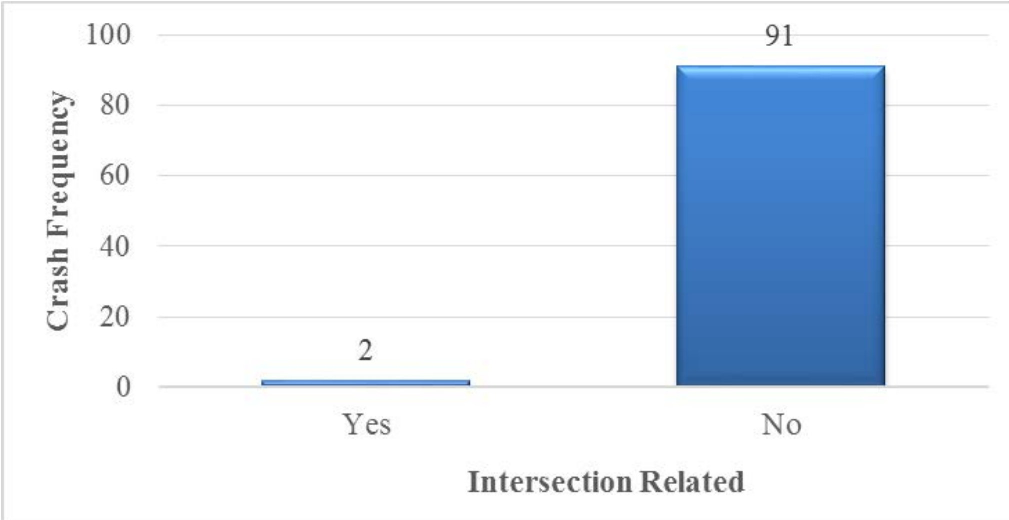

Figure A.13. Relationship between intersections and wrong-way crashes.

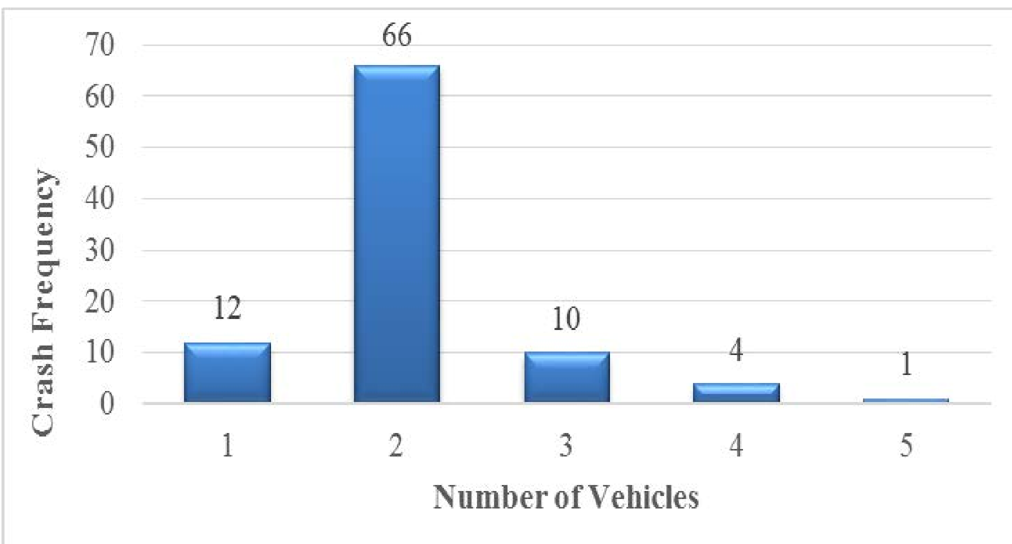

Figure A.14. Number of vehicles involved in wrong-way crashes.

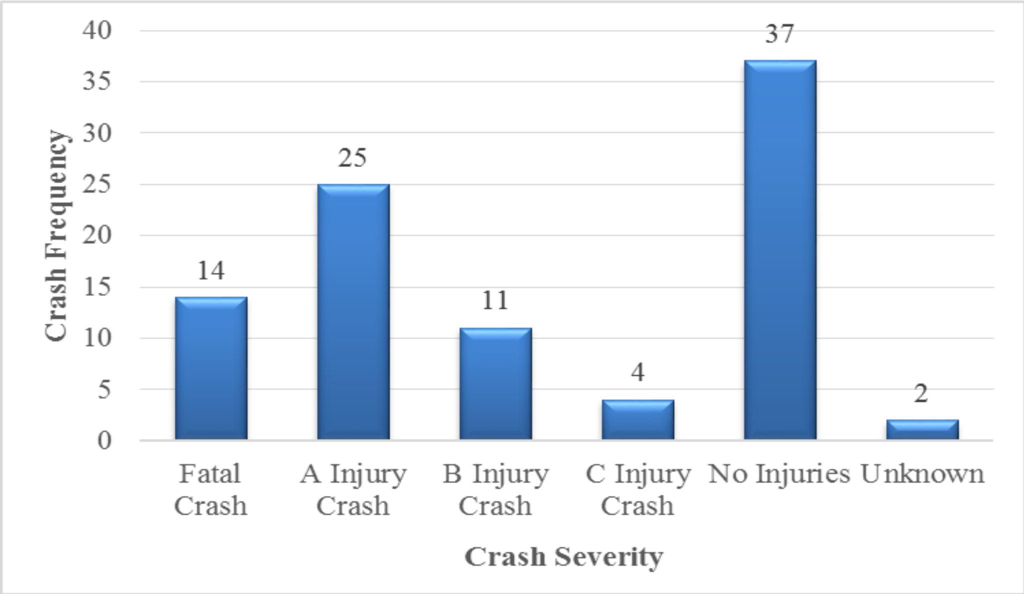

Figure A.15. Wrong-way crash severity.

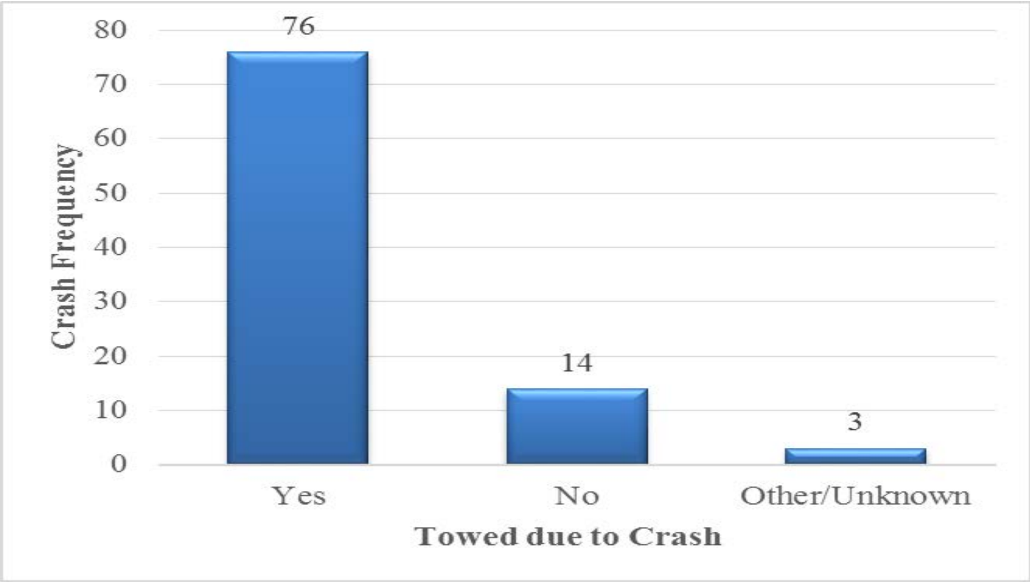

Figure A.16. Towed due to crash for wrong-way crashes.

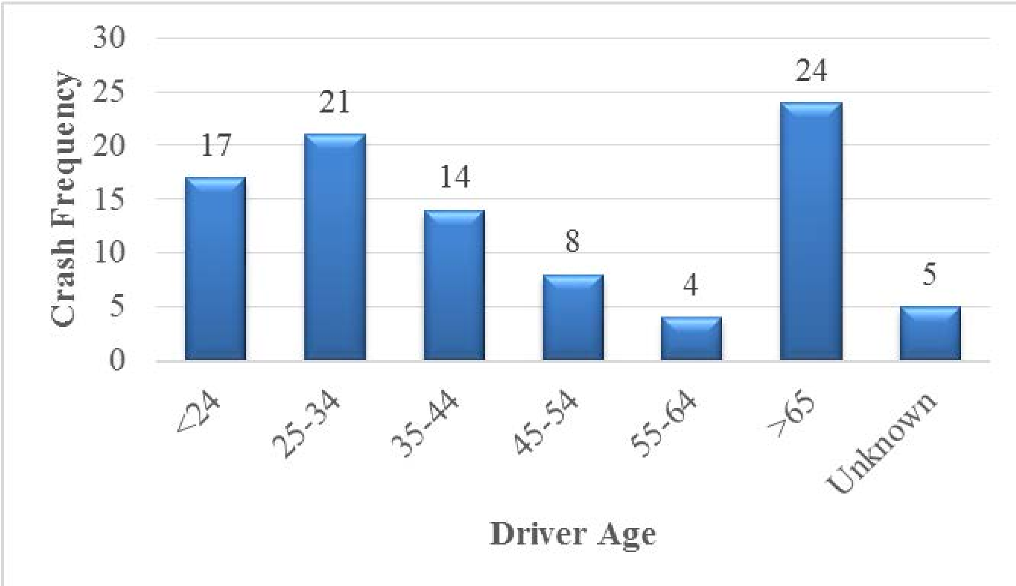

Figure A.17. Wrong-way driver age group.

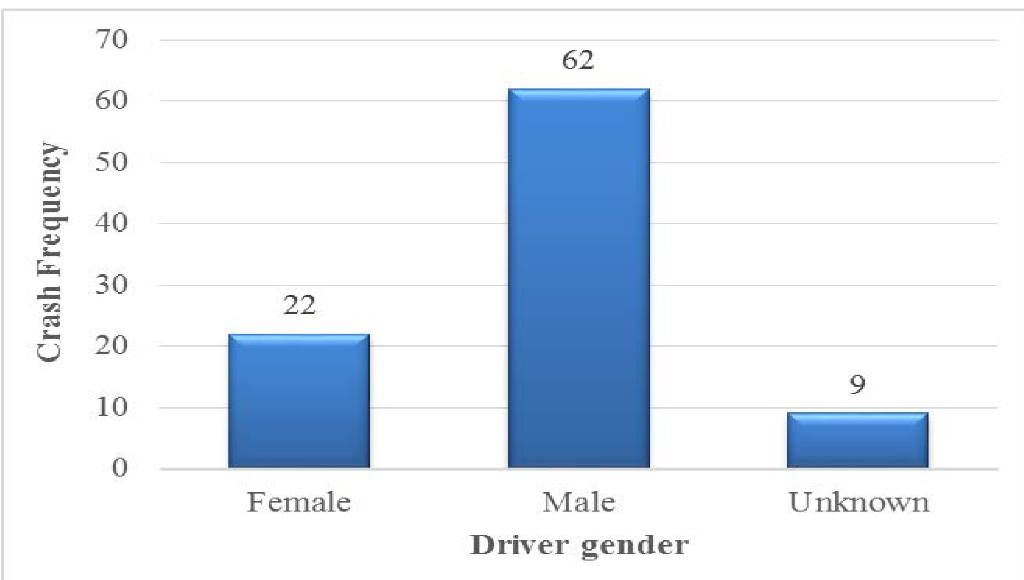

Figure A.18. Wrong-way driver gender distribution.

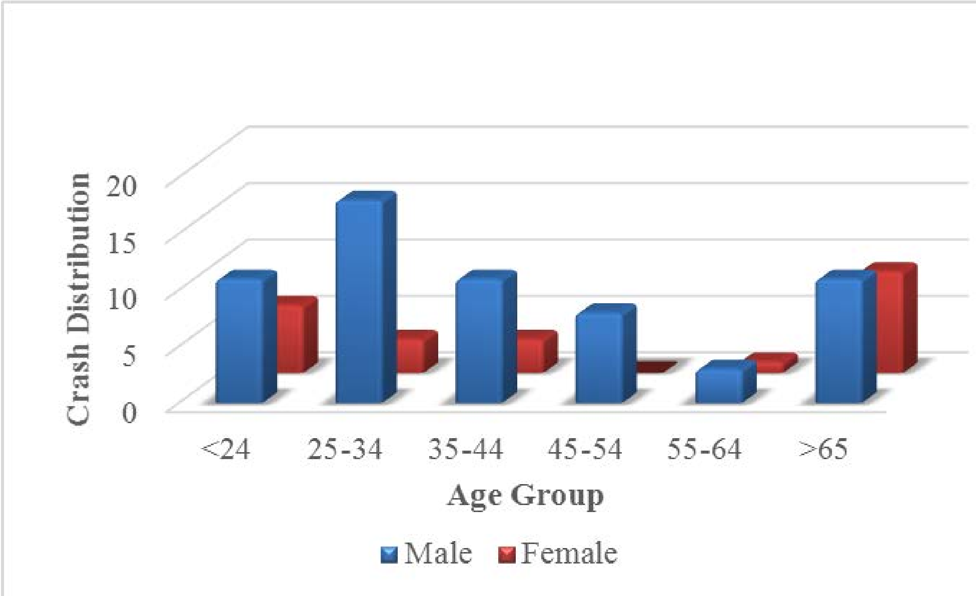

Figure A.19. Relationship between wrong-way driver age group and gender.

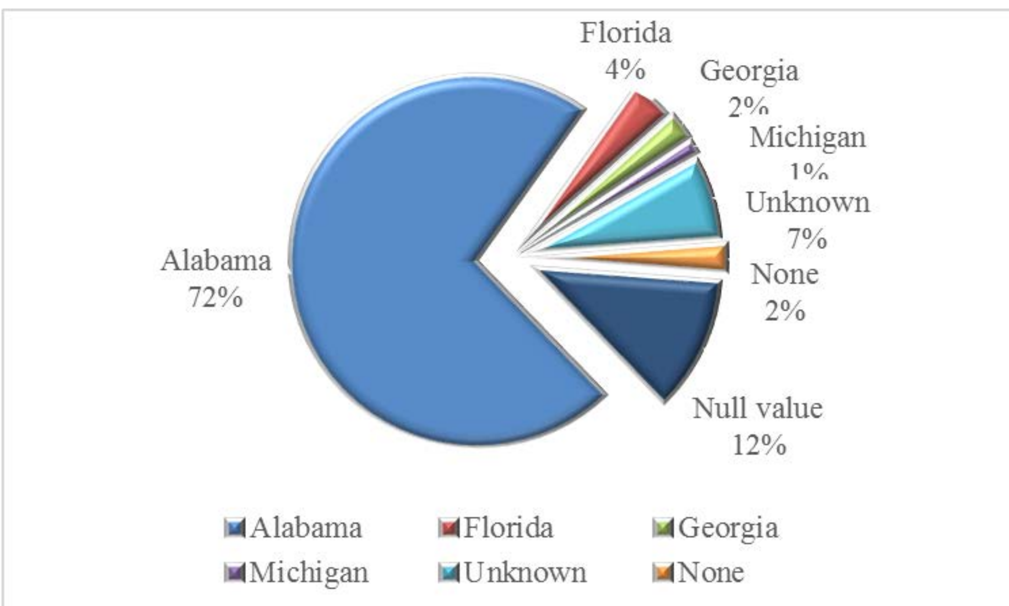

Figure A.20. Licensed state for wrong-way drivers.

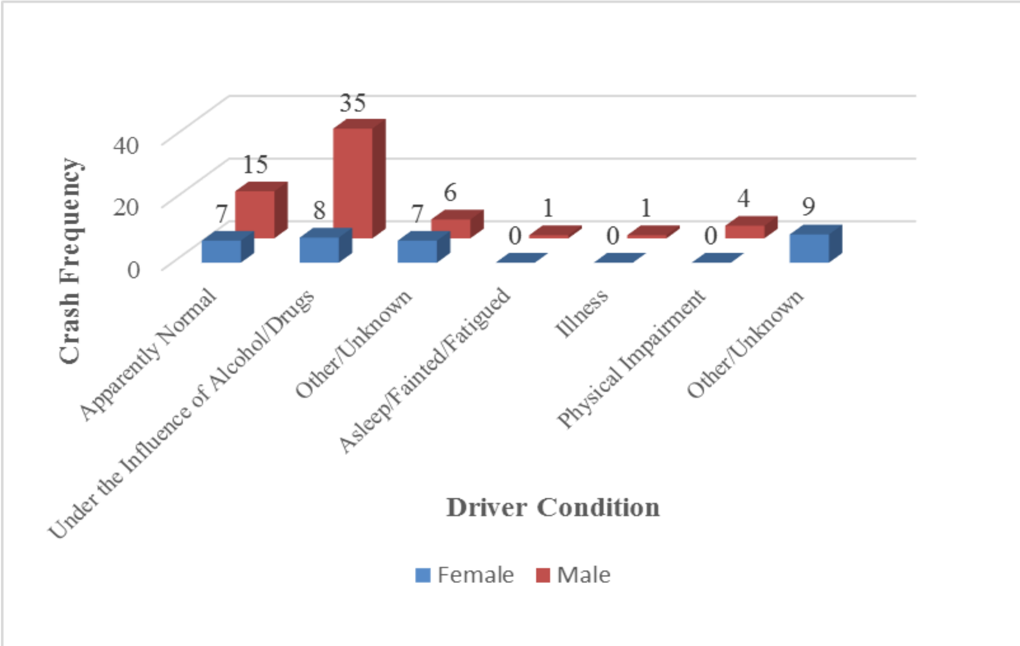

Figure A.21. Relationship between driver gender and condition.

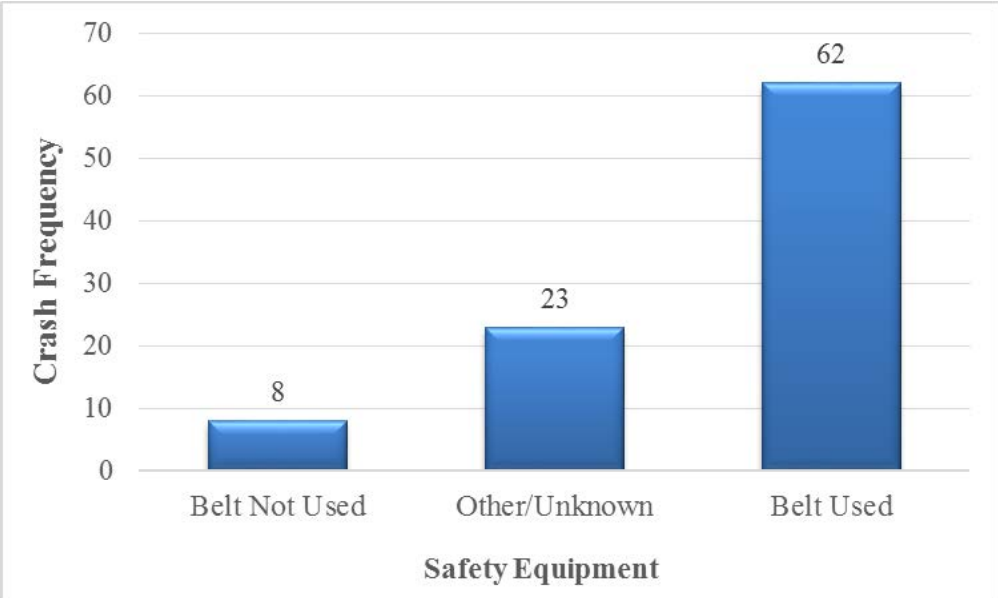

Figure A.22. Safety equipment used by wrong-way drivers.

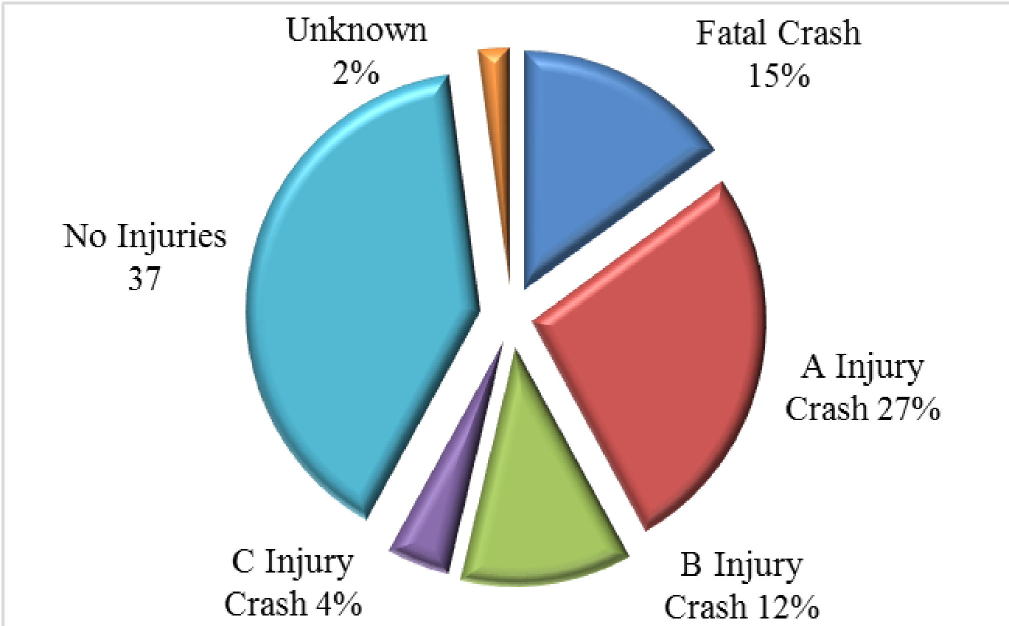

Figure A.23. Injury severity level for wrong-way drivers.

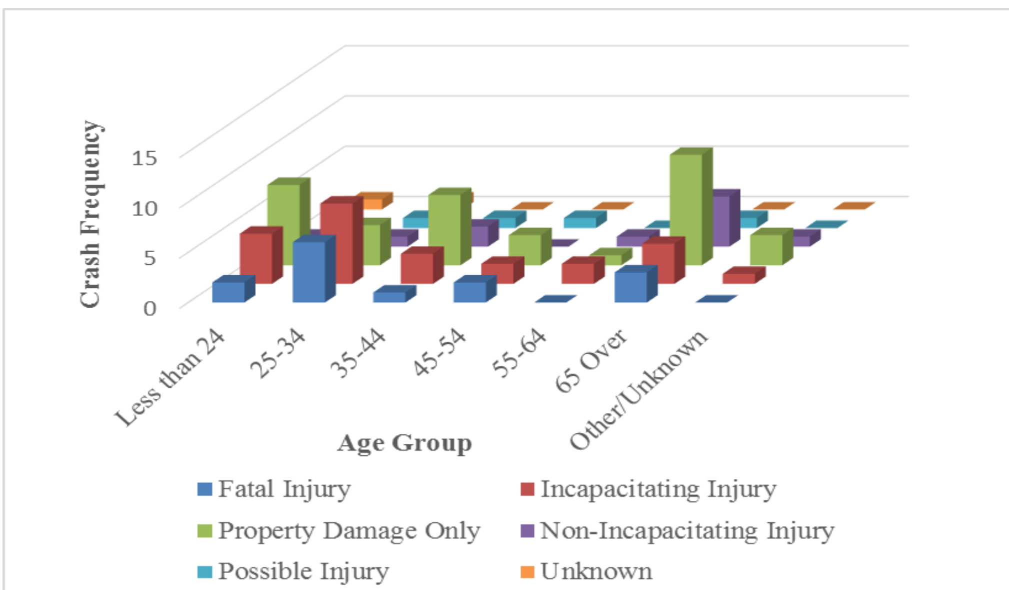

Figure A.24. Relationship between driver injury severity level and driver age group

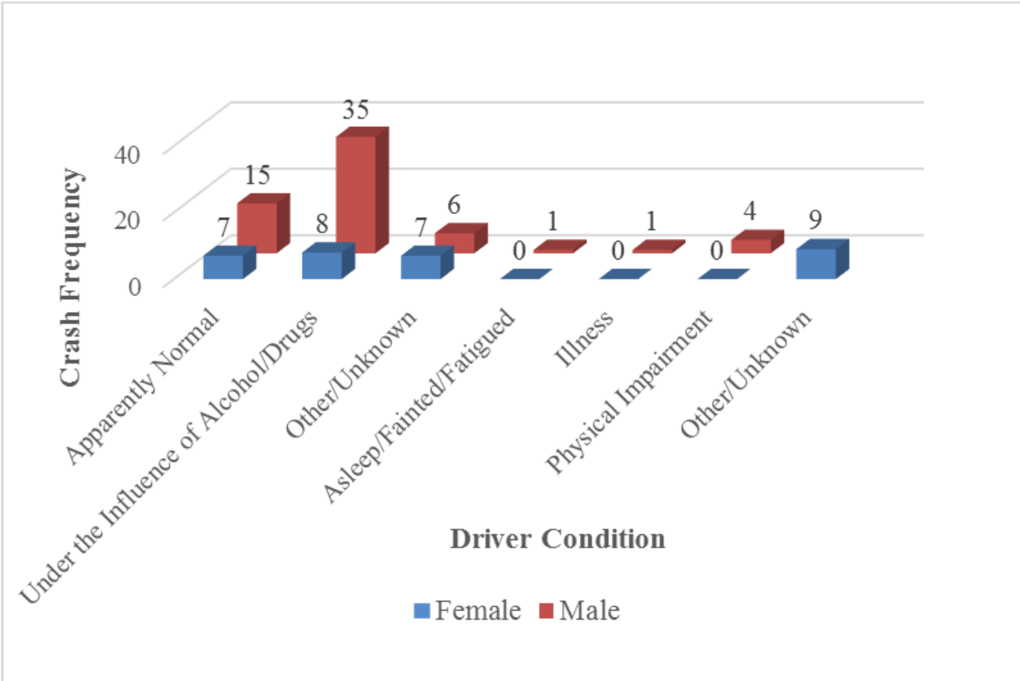

Figure A.25. Relationship between driver injury severity level and driver gender

APPENDIX B
TABLES FOR WWD CRASH DATA ANALYSIS

Table B.1. Route Distribution for Wrong-Way Crashes

Route	Frequency	Percent	Length (mi)
I-65	29	31.2%	367
I-59	25	26.9%	241.36
I-10	10	10.8%	66.31
I-20	7	7.5%	214.7
I-85	6	6.5%	80
I-565	6	6.5%	21.4
I-459	3	3.2%	32.8
AL-3	2	2.2%	-
I-165	2	2.2%	4.9
I-22	2	2.2%	-
AL-106	1	1.1%	-
Total	93	100.0%	-
Total Interstate Mileage in AL			1035.27

Table B.2. County Distribution of Wrong-Way Crashes

Ranking	County	No. of WWD Crashes	Percent
1	Jefferson	31	33.3%
2	Mobile	14	15.1%
3	Baldwin	5	5.4%
4	Madison	5	5.4%
5	Montgomery	4	4.3%
6	St. Clair	4	4.3%
7	Butler	3	3.2%
8	Macon	3	3.2%
9	Tuscaloosa	3	3.2%
10	Blount	2	2.2%
11	Cullman	2	2.2%
12	Limestone	2	2.2%
13	Shelby	2	2.2%
14	Sumter	2	2.2%
15	Walker	2	2.2%
16	Autauga	1	1.1%
17	Calhoun	1	1.1%
18	Chilton	1	1.1%
19	Cleburne	1	1.1%
20	Conecuh	1	1.1%
21	Elmore	1	1.1%
22	Etowah	1	1.1%
23	Lee	1	1.1%
24	Lowndes	1	1.1%
	Total	93	100.0%

Table B.3. City Distribution of Wrong-Way Crashes

Ranking	City Name	Frequency	Percentage	Ranking	City Name	Frequency	Percentage
1	Birmingham	19	20%	16	Rural Blount	1	1%
2	Huntsville	7	8%	16	Georgiana	1	1%
2	Mobile	7	8%	16	Dodge City	1	1%
4	Rural Baldwin	5	5%	16	Rural Calhoun	1	1%
5	Hoover	4	4%	16	Auburn	1	1%
5	Rural Jefferson	4	4%	16	Rural Cullman	1	1%
7	Bessemer	3	3%	16	Fort Deposit	1	1%
7	Rural St. Clair	3	3%	16	Saraland	1	1%
7	Rural Mobile	3	3%	16	Trussville	1	1%
7	Rural Tuscaloosa	3	3%	16	Hayden	1	1%
7	Rural Macon	3	3%	16	Alabaster	1	1%
12	Rural Montgomery	2	2%	16	Heflin	1	1%
12	Rural Conecuh	2	2%	16	Rural Autauga	1	1%
12	Rural Walker	2	2%	16	Rural Elmore	1	1%
12	Montgomery	2	2%	16	Greenville	1	1%
16	Homewood	1	1%	16	Prichard	1	1%
16	Calera	1	1%	16	Chickasaw	1	1%
16	Clanton	1	1%	16	Rural Butler	1	1%
16	Rural Etowah	1	1%	39	York	0	0%
16	Rural Sumter	1	1%				

Table B.4. Collision Type for Wrong-Way Crashes

Collision Type	Frequency
Angle Same Direction	1
Angle Oncoming (Frontal)	4
Head-on	45
Angle Opposite Direction	8
Sideswipe, opposite direction	13
Single Vehicle Crash	11
Side Impact (Angled)	5
Non-Collision	2
Rear End (front to rear)	3
Other	1

Table B.5. Crash Injury Severity for Wrong-Way Crashes

Crash Severity	Total	2009	2010	2011	2012	2013
Killed	14	4	2	4	2	2
A Injury Crash	25	7	2	9	2	7
B Injury Crash	11	2	3	4	2	1
C Injury Crash	4	3	1	0	0	2
No Injuries	37	22	8	8	10	5
Unknown	2	0	0	0	0	2
Subtotal	93	17	16	25	16	19

Table B.6. Crash Severity and Collision Type for Wrong-Way Crashes

Collision Type	Crash Severity Level						
	Fatal	A Injury	B Injury	C Injury	No Injuries	Unknown	Total
Head-on	11	18	6	2	8	0	45
Angle Oncoming (Frontal)	0	1	0	1	2	0	4
Angle Opposite Direction	1	1	0	0	6	0	8
Angle Same Direction	0	0	0	0	1	0	1
Non-collision	0	0	0	0	2	0	2
Other	0	0	1	0	0	0	1
Rear End (front to rear)	0	0	0	1	2	0	3
Side Impact (Angled)	0	1	1	0	3	0	5
Sideswipe, opposite direction	1	1	2	0	7	2	13
Single Vehicle Crash	1	3	1	0	6	0	11
Total	14	25	11	4	37	2	93

Table B.7. Collision Type and Number of Vehicles Involved

	# of Vehicles					Total
Collision Type	1	2	3	4	5	
Head-on	1	35	6	3	0	45
Angle Oncoming (Frontal)	0	4	0	0	0	4
Angle Opposite Direction	1	7	0	0	0	8
Angle Same Direction	0	1	0	0	0	1
Non-collision	1	1	0	0	0	2
Other	1	0	0	0	0	1
Rear End (front to rear)	0	2	1	0	0	3
Side Impact (Angled)	0	5	0	0	0	5
Sideswipe, opposite direction	0	9	3	0	1	13
Single Vehicle Crash	8	2	0	1	0	11
Total	13	68	13	8	6	93

Table B.8. Contributory Cause for Wrong-Way Crashes

Contributory Cause	
Avoid Vehicle/Object/Non-Motorist	2
DUI	32
Failed to Yield the Right-of-Way	1
Traveling Wrong Way/Wrong Side	58

Table B.9. Number of Vehicles Involved and Crash Severity

Crash Severity	Number of Vehicles					
	1	2	3	4	5	Total
Fatal Injury	0	10	4	0	0	14
Incapacitating Injury	3	18	2	2	0	25
Non-Incapacitating Injury	1	8	2	0	0	11
Possible Injury	0	1	2	1	0	4
Property Damage Only	8	27	0	1	1	37
Unknown	0	2	0	0	0	2
Total	12	66	10	4	1	93

Table B.10. Vehicle Type for Wrong-Way Vehicles

Vehicle Type	Crash Frequency	Percent
Passenger Car	55	59%
Pick-up	28	30%
SUV	5	5%
UNK	3	3%
Van	2	2%
Total	93	100%

Table B.11. Vehicle Use for Wrong-Way Vehicles

CU Commercial Motor Vehicle Indicator	Crash Frequency	Percent
CU is CMV	2	2.2%
CU is Not CMV	91	97.8%
Total	93	100.0%

Table B.12. Number of Occupants in Wrong-Way Vehicles

Number of Occupants	Crash Frequency	Total Occupants
1	173	173
2	23	46
3	5	15
4	1	4
5	1	5
Total	203	243

Table B.13. Driver Condition for Wrong-Way Drivers

Driver Condition	Frequency	Percent
Apparently Normal	23	24.7%
Asleep, fainted, fatigued, etc.	1	1.1%
Illness	2	2.2%
Physical Impairment	4	4.3%
Under the Influence of Alcohol/Drugs	29	31.2%
Other/unknown	34	36.6%
Total	93	100.0%

Table B.14. BAC Test Results for Wrong-Way Drivers

Driver BAC Test	Crash Frequency	Percent (%)
0	1	1.08%
1-5	2	2.15%
6-10	0	0.00%
11-15	1	1.08%
16-20	7	7.53%
21-25	4	4.30%
Above25	1	1.08%
NA	68	73.12%
Refused	9	9.68%
Total	93	100%

Table B.15. Air Bag Deployment for Wrong-Way Drivers

Air Bag Deployment	Crash Frequency	Percent (%)
Deployed	45	48.39%
Other/Unknown	18	19.35%
Not Deployed	30	32.26%
Total	93	100%

Table B.16. Relationship Between Safety Equipment and Driver Severity Level

	Driver Severity Level						
Safety Equipment	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Belt Used	8	18	9	4	23	1	63
Belt Not Used	2	1	1	0	3	0	7
Other/Unknown	4	6	1	0	11	1	23
Total	14	25	11	4	37	2	93

Table B.17. Relationship Between Driver Condition and Driver Severity Level

	Driver Severity Level						
Driver Condition	Fatalit y	A Injury	B Injury	C Injury	No Injury	Unknow n	Tota l
Apparently Normal	1	3	3	2	13	1	23
Asleep/Fainted/Fatigued	0	1	0	0	0	0	1
Illness	1	0	0	0	0	0	1
Other/Unknown	6	6	1	1	7	0	21
Physical Impairment	0	1	2	1	0	0	4
Under the Influence of Alcohol/Drugs	6	14	5	1	16	1	43
Total	14	25	11	5	36	2	93

Table B.18. Relationship Between Air Bag Deployment and Driver Severity Level

Airbag Status	Crash Severity						
Airbag Deployment	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Deployed	8	21	7	1	8	0	45
Not Deployed	2	2	4	3	18	1	30
Other/Unknown	4	2	0	0	11	1	18
Total	14	25	11	4	37	2	93

Table B.19. Relationship Between Driver BAC Test Results and Driver Severity Level

	Crash Severity						
Driver BAC Test	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
0	1	0	0	0	0	0	1
1-5	0	0	0	0	2	0	2
6-10	0	0	0	0	0	0	0
11-15	1	0	0	0	0	0	1
16-20	3	0	0	0	4	0	7
21-25	1	1	0	0	2	0	4
Above25	0	1	0	0	0	0	1
NA	8	21	9	4	24	2	68
Reject	0	2	2	5	0	0	9
Total	14	25	11	9	32	2	93

Table B.20. Relationship Between Driver Age Group and Crash Severity Level

	Crash Severity						
Age	Fatality	A Injury	B Injury	C Injury	Possible Injury	Unknown	Total
Less than 24	2	5	8	1	0	1	17
25-34	6	8	4	1	1	1	21
35-44	1	3	7	2	1	0	14
45-54	2	2	3	0	1	0	8
55-64	0	2	1	1	0	0	4
65 Over	3	4	11	5	1	0	24
Other/Unknown	0	1	3	1	0	0	5
Total	14	25	37	11	4	2	93

Table B.21. Relationship Between Driver Gender and Crash Severity Level

	Crash Severity						
Gender	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Male	9	19	8	3	21	2	62
Female	5	4	2	1	10	0	22
Other/Unknown	0	2	1	0	6	0	9
Total	14	25	11	4	37	2	93

Table B.22. Relationship Between Driver Condition and Crash Severity Level

	Crash Severity						
CU Driver Condition	Fatality	A Injury	B Injury	C Injury	Possible Injury	Unknown	Total
Apparently Normal	1	3	3	2	13	1	23
Asleep/Fainted/Fatigued	0	1	0	0	0	0	1
Illness	1	0	0	0	0	0	1
Other/Unknown	6	6	1	1	7	0	21
Physical Impairment	0	1	2	0	1	0	4
Under the Influence of Alcohol/Drugs	6	14	5	1	16	1	43
Total	14	25	11	4	37	2	93

Table B.23. Relationship Between Light Condition and Crash Severity Level

	Crash Severity						
Lighting Conditions	Fatality	A Injury	B Injury	C Injury	PDO	Other	Total
Darkness-Road Lit	5	6	1	2	10	1	25
Darkness-Road Not Lit	8	12	8	0	13	0	41
Dawn	0	1	0	0	1	0	2
Daylight	1	5	2	2	11	1	22
Dusk	1	0	0	0	1	0	2
Other/Unknown	0	0	0	0	1	0	1
Total	15	24	11	4	37	2	93

Table B.24. Relationship Between Weather and Crash Severity Level

	Crash Severity						
Weather	Fatal	A Injury	B Injury	C Injury	No Injuries	Unknown	Total
Clear/Cloudy	13	23	11	4	31	2	84
Fog/Mist	0	1	0	0	2	0	3
Precipitation	1	1	0	0	4	0	6
Total	14	25	11	4	37	2	93

Table B.25. Relationship Between Vehicle Type and Crash Severity Level

	Crash Severity						
Vehicle Type	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Passenger Car	9	15	4	3	22	2	55
Pick-up	3	10	5	1	9	0	28
SUV	2	0	2	0	1	0	5
UNK	0	0	0	0	3	0	3
Van	0	0	0	0	2	0	2
Total	14	25	11	4	37	2	93

Table B.26. Wrong-Way Entry Point Distribution

Entry Point Type	Frequency	Percentage
Recorded Only	25	27.78%
1st Possible Entry Only	0	0.00%
2nd Possible Entry Only	1	1.11%
Recorded and 1st Possible Entry	0	0.00%
Recorded and 2nd Possible Entry	2	2.22%
1st and 2nd Possible Entry	62	68.89%
Recorded, 1st and 2nd Possible	0	0.00%
Total	90	100.00%

Table B.27 Wrong-Way Entry Point Locations

Rank	Major Route	Minor Route	Entry Point			Total
			Recorded	1st Est.	2nd Est.	
1	US-31/280	University Blvd	2	0	0	2
2	I-65	AL-106	1	2	0	3
3	I-59	20th Street Ensley	1	0	4	5
4	I-10	Theodore Dawes Rd	1	1	0	2
5	I-10	Co Rd 64	1	1	0	2
6	I-65	1st St S	1	1	0	2
7	I-59	Arkadelphia Rd	1	1	0	2
8	I-59	AL-17	1	0	1	2
9	I-65	AL-3	1	0	1	2
10	I-165	Beauregard St	1	0	0	1
11	I-65	Dauphin St	1	0	0	1
12	I-65	Spring Hill Ave	1	0	0	1
13	I-65	US-31	1	0	0	1
14	I-65	Lake Mitchell Rd	1	0	0	1
15	I-65	Mobile Hwy	1	0	0	1
16	I-59	AL-7	1	0	0	1
17	I-59	McAsahn Dr	1	0	0	1
18	I-20	AL-1	1	0	0	1
19	I-20	AL-9	1	0	0	1
20	I-59	Co Rd 10	1	0	0	1
21	I-65	AL-74	1	0	0	1
22	I-565	Wall Triana Hwy SW	1	0	0	1
23	I-565	Pratt Ave NW	1	0	0	1
24	I-59	19th St	0	4	0	4
25	I-59	40th St	0	3	2	5
26	I-20	Messer Airport Hwy	0	2	1	3

27	I-65	6th Ave N	0	2	1	3
28	I-65	Government Blvd	0	2	0	2
29	AL-255	Old Madison Pike NW	0	2	0	2
30	I-565	Madison Pike	0	2	0	2
31	I-85	Co Rd 53	0	1	2	3
32	I-459	US 280	0	1	2	3
33	I-20	AL 79	0	1	2	3
34	I-10	Government St	0	1	1	2
35	I-165	Whistler St	0	1	1	2
36	I-65	AL 97	0	1	1	2
37	I-65	Co Rd 6	0	1	1	2
38	I-59	Co Rd 36	0	1	1	2
39	I-59	26th St N	0	1	1	2
40	I-20	AL 53	0	1	1	2
41	I-20	Co Rd 29	0	1	1	2
42	I-59	AL 75	0	1	1	2
43	I-65	Cobbs Ford Rd	0	1	1	2
44	I-10	Franklin Creek Road	0	1	0	1
45	I-10	Old Spanish Trail	0	1	0	1
46	I-65	N Beltline Hwy	0	1	0	1
47	I-65	W Lee St	0	1	0	1
48	I-165	S Wilsen Ave	0	1	0	1
49	I-10	W-9 Mile Rd	0	1	0	1
50	I-65	AL 59	0	1	0	1
51	I-65	AL 21	0	1	0	1
52	I-65	US 84	0	1	0	1
53	I-85	AL 97	0	1	0	1
54	I-85	Perry Hill Rd	0	1	0	1
55	I-85	Rest Area (MP 44)	0	1	0	1
56	I-20	AL 28	0	1	0	1
57	I-20	AL 7	0	1	0	1
58	I-20	Co Rd 10	0	1	0	1
59	I-20	18th St N	0	1	0	1
60	I-459	US 31	0	1	0	1
61	I-65	AL 3	0	1	0	1
62	I-459	Acton Rd	0	1	0	1
63	I-459	Co Rd 143	0	1	0	1
64	I-20	Montevallo Rd	0	1	0	1
65	I-65	3rd Ave N	0	1	0	1
66	I-59	4th Ave S	0	1	0	1

67	I-59	AL 23	0	1	0	1
68	I-65	US 31	0	1	0	1
69	I-22	Co Rd 11	0	1	0	1
70	I-565	Co Rd 115	0	1	0	1
71	I-65	AL 14	0	1	0	1
72	I-10	Dauphin Island Pkwy	0	0	2	2
73	I-65	St. Stephens Rd	0	0	2	2
74	I-65	Hank Williams Rd	0	0	2	2
75	I-85	Notasulga Rd	0	0	2	2
76	I-65	Valleydale Rd	0	0	2	2
77	I-565	Sparkman Dr NW	0	0	2	2
78	I-10	Rest Area (MP 75)	0	0	1	1
79	I-10	Government Blvd	0	0	1	1
80	I-10	Texas St	0	0	1	1
81	I-165	New Bay Bridge Rd	0	0	1	1
82	I-10	Rest Area (MP 1)	0	0	1	1
83	I-10	Pine Forest Rd	0	0	1	1
84	I-65	AL 225	0	0	1	1
85	I-65	Co Rd 1	0	0	1	1
86	I-65	AL 83	0	0	1	1
87	I-85	S Decatur St	0	0	1	1
88	I-65	Clay St	0	0	1	1
89	I-85	Ann St	0	0	1	1
90	I-65	Co Rd 52 E	0	0	1	1
91	I-20	Co Rd 208	0	0	1	1
92	I-20	19th St N	0	0	1	1
93	I-459	Derby Pkwy	0	0	1	1
94	I-20	1st Ave S	0	0	1	1
95	I-20	26th St N	0	0	1	1
96	I-65	12th St S	0	0	1	1
97	I-65	4th Ave N	0	0	1	1
98	I-65	16th St N	0	0	1	1
99	I-59	AL 7	0	0	1	1
100	I-59	AL 53	0	0	1	1
101	I-22	AL 13	0	0	1	1
102	I-565	AL 20	0	0	1	1
103	I-565	Rideout Rd	0	0	1	1
104	AL-255	Bradford Dr	0	0	1	1

APPENDIX C
CONTRIBUTING FACTORS FREQUENCY

Table C.1 Pre-Crash/Human – Fatal Crashes

Pre-Crash: Human			
Age of Driver	16-24	2	14.3%
	25-34	6	42.9%
	35-44	2	14.3%
	45-54	1	7.1%
	55-64	0	0.0%
	Above 65	3	21.4%
Gender of Driver	Male	9	64.3%
	Female	5	35.7%
Driver Condition	Under the Influence of Alcohol/Drugs	4	28.6%
	Illness	1	7.1%
	Other/Unknown	9	64.3%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	6	42.9%
	Wrong Side of Road	1	7.1%
	Other/Unknown	5	35.7%
	Improper Lane Change/Use	1	7.1%
	DUI	1	7.1%

Table C.2 Pre-Crash/Human – A-Injury Crashes

Pre-Crash: Human			
Age of Driver	16-24	5	20.0%
	25-34	8	32.0%
	35-44	3	12.0%
	45-54	2	8.0%
	55-64	2	8.0%
	Above 65	3	12.0%
	NA	2	8.0%
Gender of Driver	Male	19	76.0%
	Female	4	16.0%
	NA	2	8.0%
Driver Condition	Under the Influence of Alcohol/Drugs	8	32.0%
	Apparently Normal	4	16.0%
	Asleep, fainted, fatigued, etc.	1	4.0%
	Physical Impairment	1	4.0%
	Illness	1	4.0%
	Other/Unknown	10	40.0%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	16	64.0%
	Unseen Object/Person/Vehicle	1	4.0%
	Other/Unknown	3	12.0%
	Disregarded Traffic Sign other than Stop Sign	1	4.0%
	Vehicle Left in Road	1	4.0%
	DUI	3	12.0%

Table C.3 Pre-Crash/Human – B-Injury Crashes

Pre-Crash: Human			
Age of Driver	16-24	1	9.1%
	25-34	1	9.1%
	35-44	2	18.2%
	45-54	0	0.0%
	55-64	1	9.1%
	Above 65	5	45.5%
	NA	1	9.1%
Gender of Driver	Male	8	72.7%
	Female	2	18.2%
	NA	1	9.1%
Driver Condition	Under the Influence of Alcohol/Drugs	4	36.4%
	Apparently Normal	3	27.3%
	Physical Impairment	2	18.2%
	Other/Unknown	2	18.2%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	9	81.8%
	Wrong Side of Road	2	18.2%

Table C.4 Pre-Crash/Vehicle – Fatal Crashes

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	7	50.0%
	Wrong Side of Road	5	35.7%
	Entering Main Road	1	7.1%
	Other/Unknown	1	7.1%
Vehicle 1 Type	Passenger Car	8	57.1%
	Pick-up	4	28.6%
	SUV	2	14.3%
Vehicle 2 Maneuver	Movement Essentially Straight	13	92.9%
	Changing Lanes	1	7.1%
Vehicle 2 Type	Passenger Car	7	50.0%
	SUV	1	7.1%
	Tractor/semi-trailer	3	21.4%
	Truck Tractor	3	21.4%

Table C.5 Pre-Crash/Vehicle – A-Injury Crashes

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	13	52.0%
	Entering Main Road	2	8.0%
	Negotiating a Curve	2	8.0%
	Wrong Side of Road	6	24.0%
	Other/Unknown	2	8.0%
Vehicle 1 Type	Passenger Car	15	60.0%
	Pick-up	9	36.0%
	Tractor/semi-trailer	1	4.0%
Vehicle 2 Maneuver	Movement Essentially Straight	18	72.0%
	Negotiating a Curve	2	8.0%
	Slowing/Stopping	2	8.0%
	No Second Vehicle	3	12.0%
Vehicle 2 Type	Passenger Car	9	36.0%
	Pick-up	4	16.0%
	SUV	1	4.0%
	Tractor/semi-trailer	4	16.0%
	Truck Tractor	2	8.0%
	Van	2	8.0%
	No Second Vehicle	3	12.0%

Table C.6 Pre-Crash/Vehicle – B-Injury Crashes

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	10	90.9%
	Wrong Side of Road	1	9.1%
Vehicle 1 Type	Passenger Car	6	54.6%
	Pick-up	3	27.3%
	SUV	2	18.2%
Vehicle 2 Maneuver	Movement Essentially Straight	10	90.9%
	No Second Vehicle	1	9.1%
Vehicle 2 Type	Passenger Car	6	54.6%
	Pick-up	3	27.3%
	Tractor/semi-trailer	1	9.1%
	No Second Vehicle	1	9.1%

Table C.7 Crash/Human – Fatal Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	10	71.4%
	DUI	4	28.6%

Table C.8 Crash/Human – A-Injury Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	16	64.0%
	DUI	9	36.0%

Table C.9 Crash/Human – B-Injury Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	6	54.6%
	DUI	5	45.5%

Table C.10 Crash/Vehicle – Fatal Crashes

Crash: Vehicle			
Type of Crash	Head-on	13	92.9%
	Angle Opposite Direction	1	7.1%
Air Bag	Deployed Airbag Front	8	57.1%
	Not Deployed	3	21.4%
	Not Applicable (vehicle cannot contain airbags)	1	7.1%
	NA	2	14.3%
Safety Equipment	Seat Belts Used	8	57.1%
	Seat Belts Not Used	4	28.6%
	NA	2	14.3%

Table C.11 Crash/Vehicle – A-Injury Crashes

Crash: Vehicle			
Type of Crash	Head-on	18	72.0%
	Single Vehicle Crash	3	12.0%
	Side Impact (Angled)	1	4.0%
	Angle Oncoming (Frontal)	1	4.0%
	Sideswipe, opposite direction	1	4.0%
	Angle Opposite Direction	1	4.0%
Air Bag	Deployed Airbag Front	20	80.0%
	Not Deployed	2	8.0%
	Deployed Multiple Combinations	1	4.0%
	NA	2	8.0%
Safety Equipment	Seat Belts Used	18	72.0%
	Seat Belts Not Used	4	16.0%
	NA	3	12.0%

Table C.12 Crash/Vehicle – B-Injury Crashes

Crash: Vehicle			
Type of Crash	Head-on	6	54.6%
	Single Vehicle Crash	1	9.1%
	Side Impact (Angled)	1	9.1%
	Sideswipe, opposite direction	3	27.3%
Air Bag	Deployed Airbag Front	6	54.6%
	Not Deployed	4	36.4%
	Deployed Multiple Combinations	1	9.1%
Safety Equipment	Seat Belts Used	9	81.8%
	Seat Belts Not Used	1	9.1%
	NA	1	9.1%

Table C.13 Crash/Environment – Fatal Crashes

Crash: Roadway			
Roadway Surface	Dry	13	92.9%
	Wet	1	7.1%
Light Condition	Darkness-Road Not Lit	8	57.1%
	Darkness-Road Lit	5	35.7%
	Daylight	1	7.1%
Weather	Clear	10	71.4%
	Cloudy	3	21.4%
	Rain	1	7.1%
Construction Zone	No	14	100.0%
	Yes	0	0.0%

Table C.14 Crash/Environment – A-Injury Crashes

Crash: Roadway			
Roadway Surface	Dry	24	96.0%
	Wet	1	4.0%
Light Condition	Darkness-Road Not Lit	9	36.0%
	Darkness-Road Lit	9	36.0%
	Daylight	5	20.0%
	Dusk	1	4.0%
	Dawn	1	4.0%
Weather	Clear	16	64.0%
	Cloudy	7	28.0%
	Rain	1	4.0%
	Fog	1	4.0%
Construction Zone	No	23	92.0%
	Yes	1	4.0%
	Unknown	1	4.0%

Table C.15 Crash/Environment – B-Injury Crashes

Crash: Roadway			
Roadway Surface	Dry	11	100.0%
	Wet	0	0.0%
Light Condition	Darkness-Road Not Lit	7	63.6%
	Darkness-Road Lit	2	18.2%
	Daylight	2	18.2%
Weather	Clear	10	90.9%
	Cloudy	1	9.1%
Construction Zone	No	11	100.0%
	Yes	0	0.0%

Table C.16 Pre-Crash/Human – Fatal, A, and B-Injury Crashes

Pre-Crash: Human			
Age of Driver	16-24	8	16.0%
	25-34	15	30.0%
	35-44	7	14.0%
	45-54	3	6.0%
	55-64	3	6.0%
	Above 65	11	22.0%
	NA	3	6.0%
Gender of Driver	Male	36	72.0%
	Female	11	22.0%
	NA	3	6.0%
Driver Condition	Under the Influence of Alcohol/Drugs	16	32.0%
	Apparently Normal	7	14.0%
	Asleep, fainted, fatigued, etc.	1	2.0%
	Physical Impairment	3	6.0%
	Illness	2	4.0%
	Other/Unknown	21	42.0%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	31	62.0%
	Unseen Object/Person/Vehicle	1	2.0%
	Wrong Side of Road	3	6.0%
	Other/Unknown	8	16.0%
	Disregarded Traffic Sign other than Stop Sign	1	2.0%
	Vehicle Left in Road	1	2.0%
	Improper Lane Change/Use	1	2.0%
	DUI	4	8.0%

Table C.17 Pre-Crash/Vehicle – Fatal, A, and B-Injury Crashes

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	30	76.9%
	Wrong Side of Road	12	30.8%
	Negotiating a Curve	2	5.1%
	Entering Main Road	3	7.7%
	Other/Unknown	3	7.7%
Vehicle 1 Type	Passenger Car	29	74.4%
	Tractor/semi-trailer	1	2.6%
	Pick-up	16	41.0%
	SUV	4	10.3%
Vehicle 2 Maneuver	Movement Essentially Straight	41	105.1%
	Negotiating a Curve	2	5.1%
	Slowing/Stopping	2	5.1%
	Changing Lanes	1	2.6%
	No Second Vehicle	4	10.3%
Vehicle 2 Type	Passenger Car	22	56.4%
	SUV	2	5.1%
	Pick-up	7	18.0%
	Van	2	5.1%
	No Second Vehicle	4	10.3%
	Tractor/semi-trailer	8	20.5%
	Truck Tractor	5	12.8%

Table C.18 Crash/Human – Fatal, A, and B-Injury Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	32	82.1%
	DUI	18	46.2%

Table C.19 Crash/Vehicle – Fatal, A, and B-Injury Crashes

Crash: Vehicle			
Type of Crash	Head-on	37	94.9%
	Single Vehicle Crash	4	10.3%
	Side Impact (Angled)	2	5.1%
	Angle Oncoming (Frontal)	1	2.6%
	Sideswipe, opposite direction	4	10.3%
	Angle Opposite Direction	2	5.1%
Air Bag	Deployed Airbag Front	34	87.2%
	Not Deployed	9	23.1%
	Deployed Multiple Combinations	2	5.1%
	Not Applicable (vehicle did not contain airbags)	1	2.6%
	NA	4	10.3%
Safety Equipment	Seat Belts Used	35	89.7%
	Seat Belts Not Used	9	23.1%
	NA	6	15.4%

Table C.20 Crash/Environment – Fatal, A, and B-Injury Crashes

Crash: Roadway			
Roadway Surface	Dry	48	96.0%
	Wet	2	4.0%
Light Condition	Darkness-Road Not Lit	24	48.0%
	Darkness-Road Lit	16	32.0%
	Daylight	8	16.0%
	Dusk	1	2.0%
	Dawn	1	2.0%
Weather	Clear	36	72.0%
	Cloudy	11	22.0%
	Fog	1	2.0%
	Rain	2	4.0%
Construction Zone	No	48	96.0%
	Yes	1	2.0%
	Unknown	1	2.0%

APPENDIX D
FIELD OBSERVATION LOCATIONS

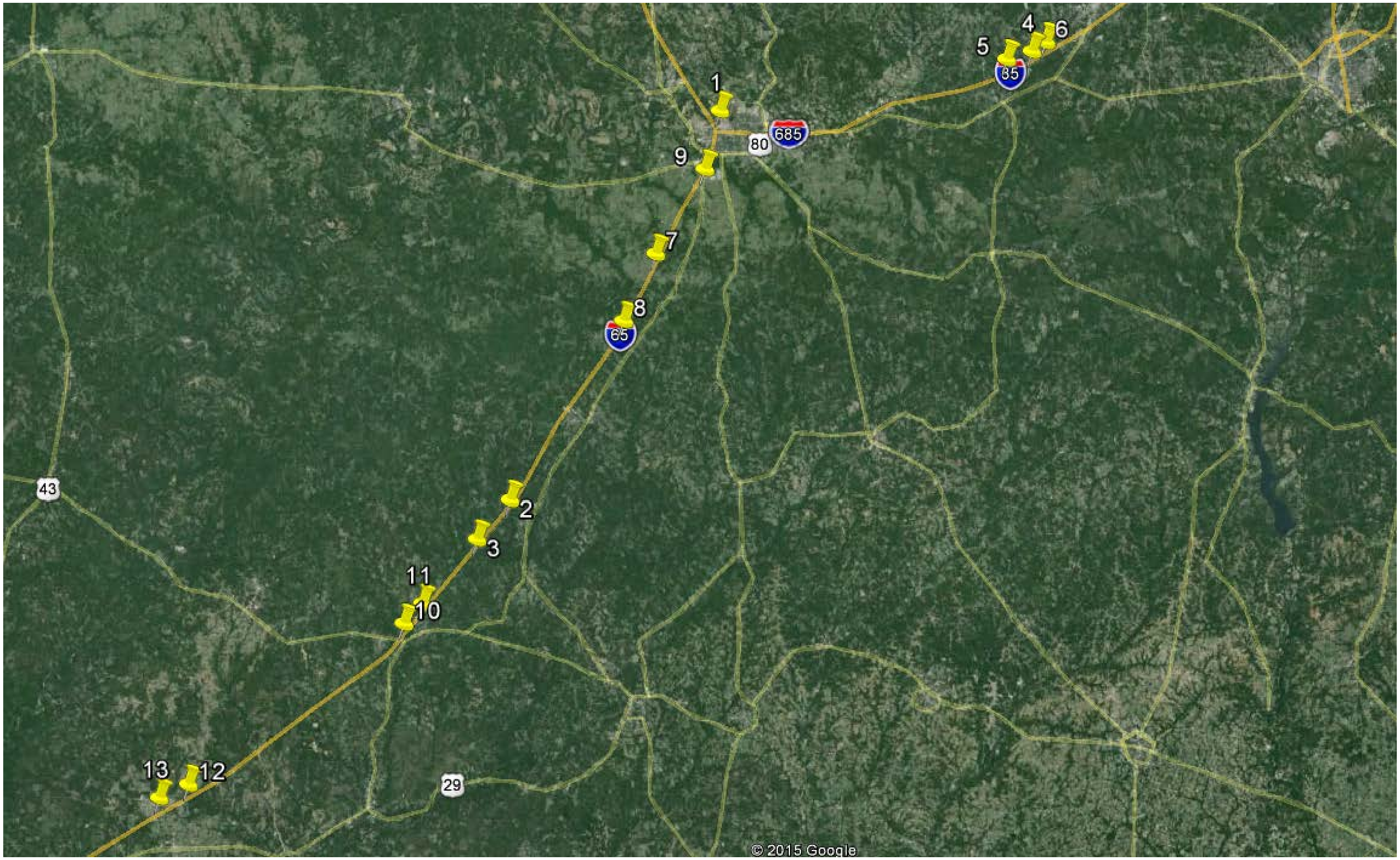

Figure D.1 Field Observation Locations along I-85 and I-65 – June 2014 (13 Locations)

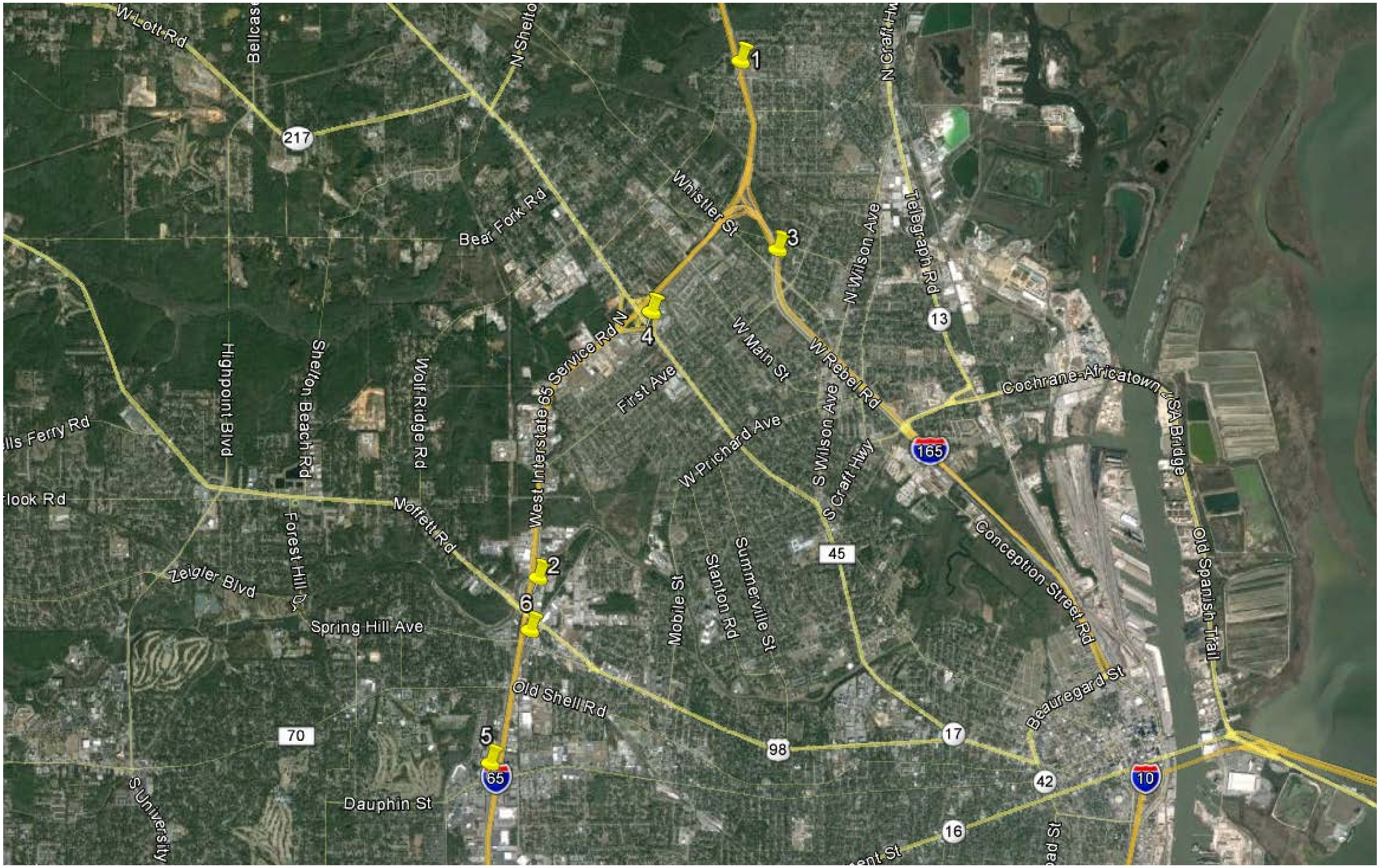

Figure D.2 Field Observation Locations in Mobile, AL – September 2014 (6 Locations)

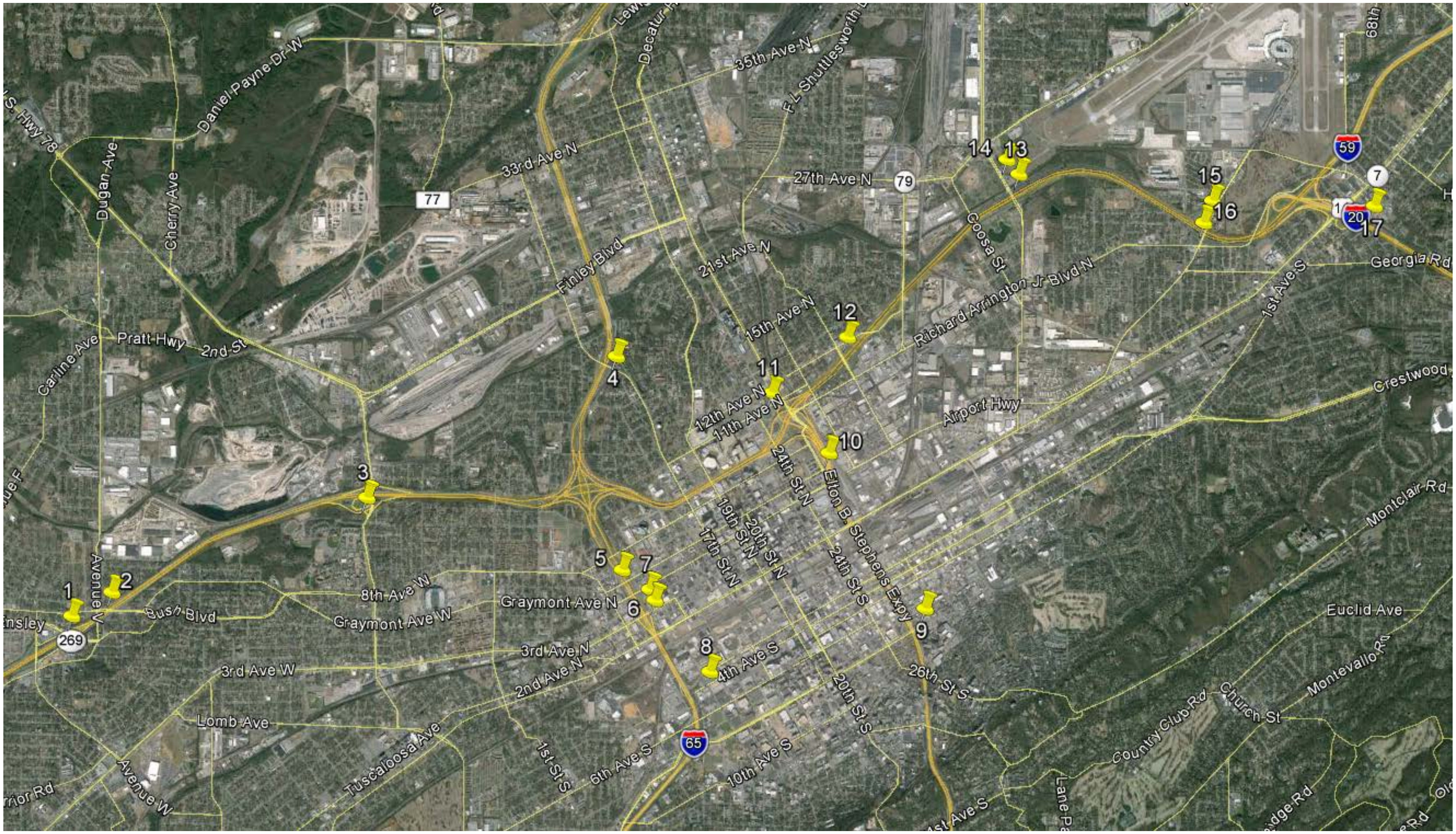

Figure D.3 Field Observation Locations in Birmingham, AL – December 2014 (17 Locations)

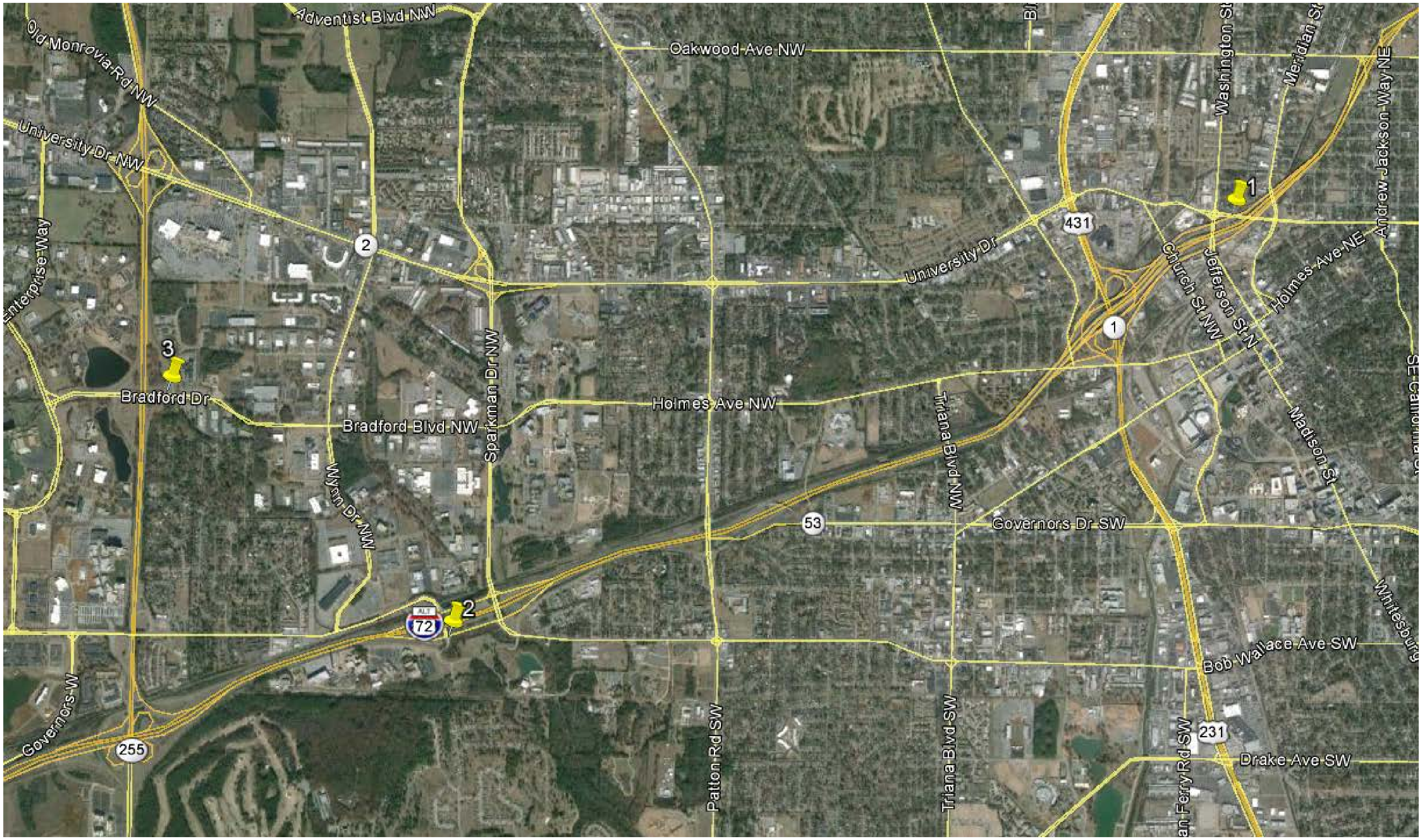

Figure D.4 Field Observation Locations in Huntsville, AL – December 2014 (3 Locations)

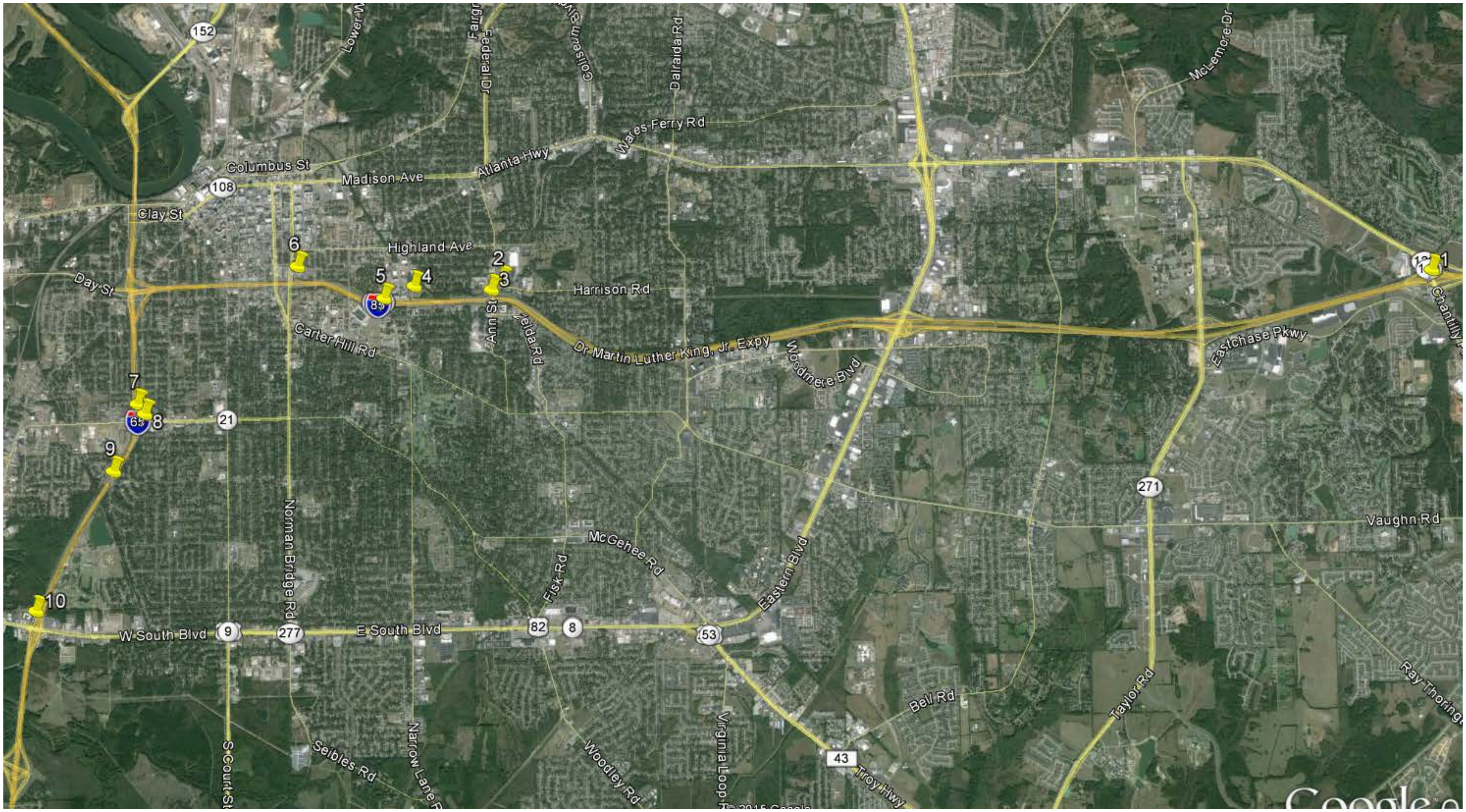

Figure D.5 Field Observation Locations in Montgomery, AL – March 2015 (10 Locations)

APPENDIX E
FIELD OBSERVATION CHECKLIST

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

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

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

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

APPENDIX F
EXAMPLES OF THE GEOMETRIC DESIGN FEATURES AT PARTIAL CLOVERLEAF INTERCHANGES

Figure F.1 A good example of the application of geometric design features at parclo interchanges

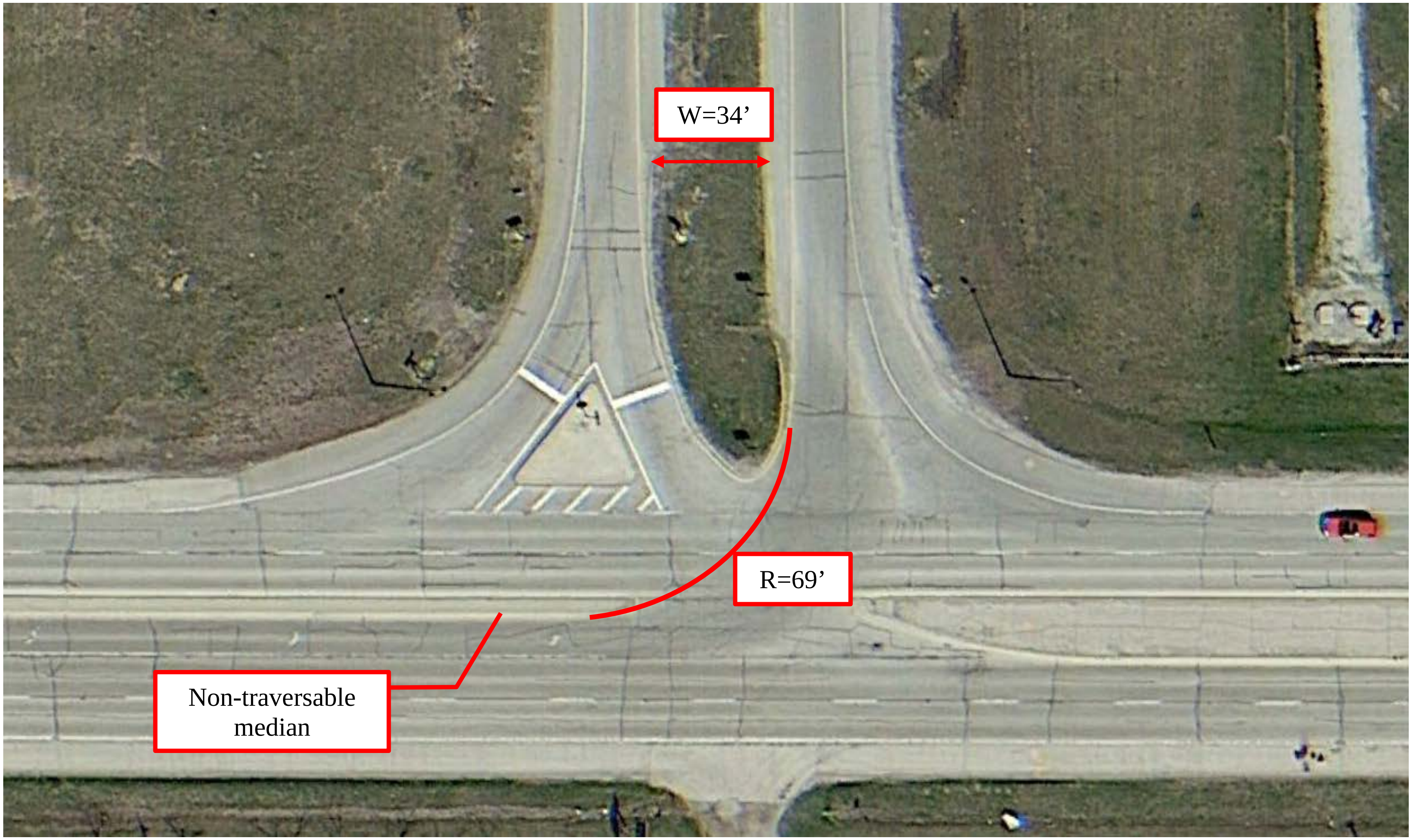

Figure F.2 A good example of the application of geometric design features at parclo interchanges