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A Study of Wrong-Way Driving Crashes in Alabama

Volume 2: Divided Highways

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A STUDY OF WRONG-WAY DRIVING CRASHES IN ALABAMA

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Final Report
Volume 2: Divided Highways

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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, 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 typically 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. The final report on freeway WWD crashes was published in 2015 (Zhou, 2015). This report summarizes the research activities and findings on part 2: WWD crashes on multilane divided highways, and it includes six chapters. Chapter 2 is a review of the current and past studies conducted in different states in the U.S.. 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, correlation analysis, and a logistic regression method. Using these methods, contributing factors regarding WWD crashes on Alabama divided highways are identified. As the next step and using the crash data, several locations (intersections of side streets and divided highways) 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, the 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

This section summarizes existing literature about WWD movements on divided highways, provides a perspective of the problem, looks at the latest knowledge, and illustrates prevention methods of WWD on divided highways. Only the following few studies have evaluated the subject and the number of studies on this topic is scarce. However, for the existing literature on WWD crashes on controlled-access highways, readers are encouraged to refer to the previous report Volume 1: Freeways (Zhou, 2015) of the project.

In 1973, the Virginia Highway Department and the Department of State Police conducted an investigation to determine means for alleviating WWD on four-lane divided highways. The data were obtained from (1) a 25-month survey of incidents of WWD on 2,000 miles of Virginia's divided highways, (2) investigations of the physical aspects of interchanges where WWD incidents occurred within the past 3 years. However, results were only given on incident details and recommendations for preventing WWD entries at interchanges.

In 1974, the Indiana State Highway Commission participated in a study of the problem of WWD movements on divided, rural highways in Indiana. The research was in two parts: a general review of the characteristics of WWD crashes that had occurred in Indiana, and an investigation of various alternatives that could be used to reduce WWD movements. Field investigations were made at each crash site to supplement data shown on the crash records and to determine the physical characteristics of access points where WWD movements originated. WWD crashes were exceptionally severe with 39 deaths resulting from 96 crashes over a three year period. Studies of wrong-way (WW) drivers indicated that only 31 of them were not drunk, were not old (over 65) and/or were not fatigued (driving between 12:00 a.m. and 6:00 a.m.). An analysis of WWD crashes in the state of Indiana during the 1970 to 1972 time period showed that approximately 55 percent (42 out of 77) of drivers were impaired. Conditions at typical WWD movement origin sites included darkness, low land use and low traffic volumes. Possible countermeasures included night lighting, raising the elevation of crossroads, making medians more distinct and the use of simple, understandable configurations. At certain locations, the use of additional channelization and barrier curbs can direct traffic in the right direction and could block WWD movements.

A report by the Arizona Department of Transportation (ADOT) (2015), studied the feasibility of a pilot deployment of a WWD detection and warning system on divided highways. The study was aimed at researching ways to detect a WW driver and instantly inform them of their mistake. A total of 91 people died and others were injured in 245 WWD crashes in Arizona from 2004 through 2014. On average, the crash data analysis revealed 25 percent of all WWD crashes were fatal compared to 1 percent of overall crashes that occur on divided highways. Impaired drivers are the cause of 65 percent of all WWD crashes. The crash analysis also showed that WWD crashes occur most often after dark and predominately in the morning hours from 12 a.m. to 2 a.m. Fifty-three percent of WWD crashes were on urban divided highways and 47 percent occurred on rural divided highways. WWD crashes were more common on weekends. Sixty-five percent of WW drivers were male, 25 percent were female and 10 percent were documented as unknown gender. This research developed a conceptual system to detect a WW driver upon entry, inform the errant driver of their mistake, notify the Traffic Operations Center and law enforcement instantly, track the WWD vehicle on the highway system, and warn right-way (RW) drivers in the vicinity of the oncoming vehicle. The proposed design would integrate readily available technologies with the existing infrastructure.

3. CRASH DATA COLLECTION

Similar to what was done in the first volume of this project about WWD on freeways, 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 main difference between data collection process between freeways and divided highways, however, is in the definition of filters in step 1. The following sections elaborate upon the WWD crash identification and verification process.

3.1 Crash Database

Five years worth of crash data from 2009 to 2013 on Alabama divided highways were collected for analysis. CARE (CAPS, 2014), as the main software to access Alabama crash records, was used. This software enables to create user-defined filters and extract specific crashes with attributes of interest. This feature was used to nominate possible WWD crashes on divided highways for further investigation using extra steps (crash narrative, diagram, and location). The following sub-sections elaborate more on the process of WWD identification and verification.

3.2 WWD Crash Identification

The process of identifying WWD crashes on divided highways comprises two parts, identifying those crashes that happened on divided highways and nominating possible WWD crashes on those facilities. To identify crashes on divided highways, a filter was created in CARE that extracts crashes on non-controlled-access Federal and State highways in which the Opposing Lane Separation variable takes one of the following values: Paved Surface, Unpaved Surface, Concrete Barrier, and Metal Guardrail. Following this attempt, another filter was defined on the extracted crashes to identify possible WWD crashes on these facilities. 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

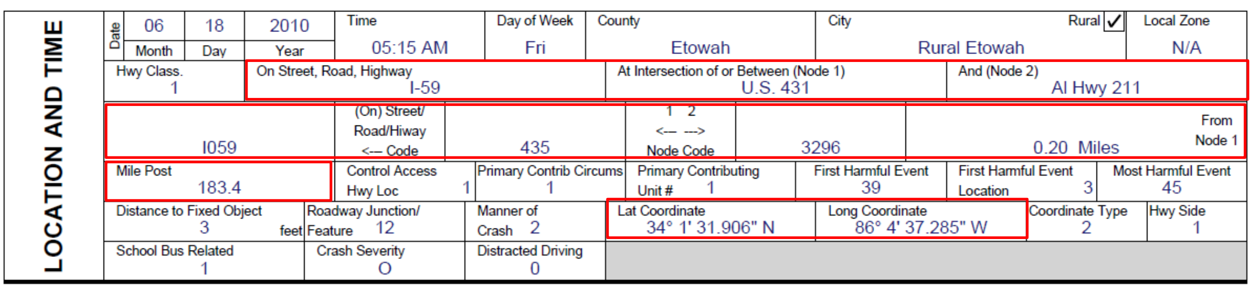
	- Wrong Way on One Way
V2 Vehicle Maneuvers	- Wrong Side of Road - Wrong Way on One Way
CU Citation Issued	- Wrong Side of Road
V2 Citation Issued	- Wrong Side of Road

Applying these filters identified 1,321 possible WWD crashes on divided highways in five years. The next step was to look through all the crashes to further verify if the crashes were truly caused by WWD.

3.3 WWD Crash Verification

To verify the actual WWD crashes on divided highways, hardcopy reports for those 1,321 possible WWD crashes were requested from ALDOT. The first step was to confirm if the crashes had occurred on divided highways by checking crash diagrams or locating these crashes on 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 divided highway. 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 “traveling on the wrong side of roadway.” Altogether, 112 crashes were verified as true WWD crashes on divided highways. Table 3.2 lists the number of total crashes, divided highway 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
Divided Highway Crashes	7,401	10,368	10,643	10,692	10,607	49,711
Possible WWD crashes	465	246	207	209	197	1,321
Actual WWD crashes	28	33	18	18	15	112

Table 3.3 presents the percentage of total and fatal crashes on divided highways that were caused by WWD in Alabama from 2009 to 2013. Approximately 5% of all fatal divided highway crashes were due to WWD even though WWD crashes comprised around 0.23% of all divided highway crashes (indicating a rare event).

Table 3.3 Percentage of WWD Crashes on Divided Highways

Year	2009	2010	2011	2012	2013	Total
Divided Highway Crashes	7,401	10,368	10,643	10,692	10,607	49,711
WWD Crashes	28	33	18	18	15	112
Percent	0.38%	0.32%	0.17%	0.17%	0.14%	0.23%
Divided Highway Fatal Crashes	44	68	63	64	52	291
WWD Fatal Crashes	4	3	1	6	0	14
Percent	9.1%	4.4%	1.6%	9.4%	0.0%	4.8%

3.4 Additional Information from Crash Reports

A spreadsheet of the 112 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, airbag deployment, seatbelt use, type of crash and Causal Unit (CU) model year;
2. 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” or “Other/ Unknown” when the narratives indicated that the driver had positive alcohol/drug test results above the allowed levels.
3. 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 from entry at median opening. For 18 WWD crashes, the entry points were already documented in the narrative description of the crash reports. Seven of them were recorded entered at median opening. Four of them entered at signalized intersection. Five of them entered from parking of gas station or business area. The remaining two entered by undeliberate or improper lane change. However, for the remaining 94 WWD crashes, no information about the entry points was available in the crash reports. Ninety three of them can be estimated by checking the latest possible entry points at median openings, and the entry point of the only remaining one was interchange related.

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 divided highway 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 economic loss and WWD entry point analysis.

4.1 Spatiotemporal Distributions

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. 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 divided highways each year from 2009 to 2013. The severity used throughout this document is on the 5-level KABCO scale in which fatal injury is 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	
Fatal Crash	14	12.5%	4	14.3%	3	9.1%	1	5.6%	6	33.3%	0	0.0%
A Injury Crash	20	17.9%	8	28.6%	7	21.2%	2	11.1%	0	0.0%	3	20.0%
B Injury Crash	17	15.2%	2	7.1%	5	15.2%	3	16.7%	3	16.7%	4	26.7%
C Injury Crash	7	6.3%	1	3.6%	4	12.1%	1	5.6%	1	5.6%	0	0.0%
No Injuries	52	46.4%	13	46.4%	14	42.4%	10	55.6%	7	38.9%	8	53.3%
Unknown	2	1.8%	0	0.0%	0	0.0%	1	5.6%	1	5.6%	0	0.0%

Table 4.2 gives a general scheme of the WWD crashes compared to non-WWD crashes on divided highways 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 divided highways in Alabama within the same time period is only 7%. The variables in red in this table and the following tables show those that are over-represented and/or statistically significant.

Table 4.2 General Characteristics of WWD and other Divided Highway Crashes

Variable	Category	WWD Crashes (n=112)		Other Crashes (n=49,599)	
		Frequency	Percentage	Frequency	Percentage
Crash Severity	Fatal Crash	14	12.5	291	0.6
	Incapacitating	20	17.9	3,174	6.4
	Non-Incapacitating	17	15.2	4,020	8.1
	Possible Injury	7	6.3	4,235	8.5
	PDO	52	46.4	37,315	75.2
	Unknown	2	1.8	564	1.1

Number of Persons	One	6	5.4	6,657	13.4
	Two	57	50.9	20,608	41.5
	Three and More	49	43.8	22,334	45.0
Number of Vehicles	One	7	6.3	9,112	18.4
	Two	98	87.5	36,786	74.2
	Three and More	7	6.3	3,701	7.5

In addition, WWD crashes resulted in 18 fatalities in 14 fatal crashes (1.29 fatalities per fatal crashes), while this number for all divided highway fatal crashes was 1.13 (328 fatalities in 291 fatal crashes), which translates to 16 more fatalities per 100 fatal crashes. The statistics also show that 95% of WWD crashes involve two or more vehicles, which is higher than the average 82% of overall divided highway 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 defines if the driver's dwelling place was within 25 miles of the crash location. After comparing the WW driver characteristics with other divided highway crash drivers, the key findings are as follows:

- Drivers older than 65 years are over-represented in WWD crashes.
- About 23% of WW drivers were driving under the influence (DUI), whereas less than 3% of drivers in non-WWD crashes were intoxicated.

Table 4.3 Responsible Driver Characteristics of WWD and other Divided Highway Crashes

Variable	Category	WWD Crashes (n=112)		Other Crashes (n=49,599)	
		Frequency	Percentage	Frequency	Percentage
Driver Age	Less than 24	18	16.1	13,973	28.2
	25 to 34 years	18	16.1	9,896	20.0
	35 to 44 years	16	14.3	7,360	14.8
	45 to 54 years	10	8.9	6,698	13.5
	55 to 64 years	14	12.5	4,973	10.0
	65 years or over	30	26.8	5,350	10.8
	Other/Unknown	6	5.4	1,349	2.7
Driver Gender	Male	63	56.2	26,634	53.7
	Female	39	34.8	21,892	44.1
	Other/Unknown	10	8.9	1,073	2.2
Driver Race	White/Caucasian	75	67.0	36,960	74.5
	African American	15	13.4	9,655	19.5

	Hispanic	6	5.4	1,344	2.7
	Asian/Pacific Islander	4	3.6	346	0.7
	American Indian	0	0.0	40	0.1
	Other/Unknown	12	10.7	1,254	2.5
Driver Condition	Apparently Normal	51	45.5	44,718	90.2
	DUI	26	23.2	1,508	3.0
	Asleep/Fainted/Fatigued	1	0.9	757	1.5
	Illness	2	1.8	228	0.5
	Emotional	2	1.8	0	0.0
	Other/Unknown	30	26.8	2,388	4.8
Driver Residency Distance	Less than 25 Miles	71	63.3	35,747	72.1
	Greater than 25 Miles	31	27.7	12,239	24.7
	Other/Unknown	10	8.9	1614	3.3

4.1.3 *Crash Time*

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

- The percentage of WWD crashes happened on weekends is nearly twice higher than other divided highway crashes that happened on weekends.
- The hourly distribution also varied within the entire day but with the evening encompassing the highest frequency of WWD crashes. Accordingly, the hours of 6:00 PM to 12:00 AM has the highest frequency of the WWD crashes, about 45.5% of WWD crashes happened during this time period. Figure 4.1 shows the detailed hourly distribution of WWD crashes during the day.
- The number of WWD crashes ranges between 5 and 14 per month. January, February, August and December can be 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 15 to 28, with the year of 2010 having the highest number of WWD crashes and an average frequency of about 22 crashes per year (Table 3.3).

Table 4.4 Temporal Information of WWD and other Divided Highway Crashes

Variable	Category	WWD Crashes (n=112)		Other Crashes (n=49,599)	
		Frequency	Percentage	Frequency	Percentage
Month	January	13	11.61	3,732	7.52
	February	14	12.50	3,742	7.54
	March	11	9.82	3,951	7.97

	April	8	7.14	3,967	8.00
	May	5	4.46	4,078	8.22
	June	5	4.46	4,014	8.09
	July	8	7.14	4,235	8.54
	August	12	10.71	4,175	8.42
	September	6	5.36	4,018	8.10
	October	10	8.93	4,320	8.71
	November	7	6.25	4,518	9.11
	December	13	11.61	4,849	9.78
Day	Monday	16	14.3	7,480	15.1
	Tuesday	12	10.7	7,608	15.3
	Wednesday	15	13.4	7,523	15.2
	Thursday	9	8.0	7,778	15.7
	Friday	20	17.9	9,219	18.6
	Saturday	23	20.5	5,918	11.9
	Sunday	17	15.2	4,073	8.2
Time	Morning (6-12)	11	9.8	13,657	27.5
	Afternoon (12-18)	27	24.1	24,656	49.7
	Evening (18-24)	51	45.5	8,678	17.5
	Night (0-6)	22	19.6	2,599	5.2
	Other/Unknown	1	0.9	9	0.0

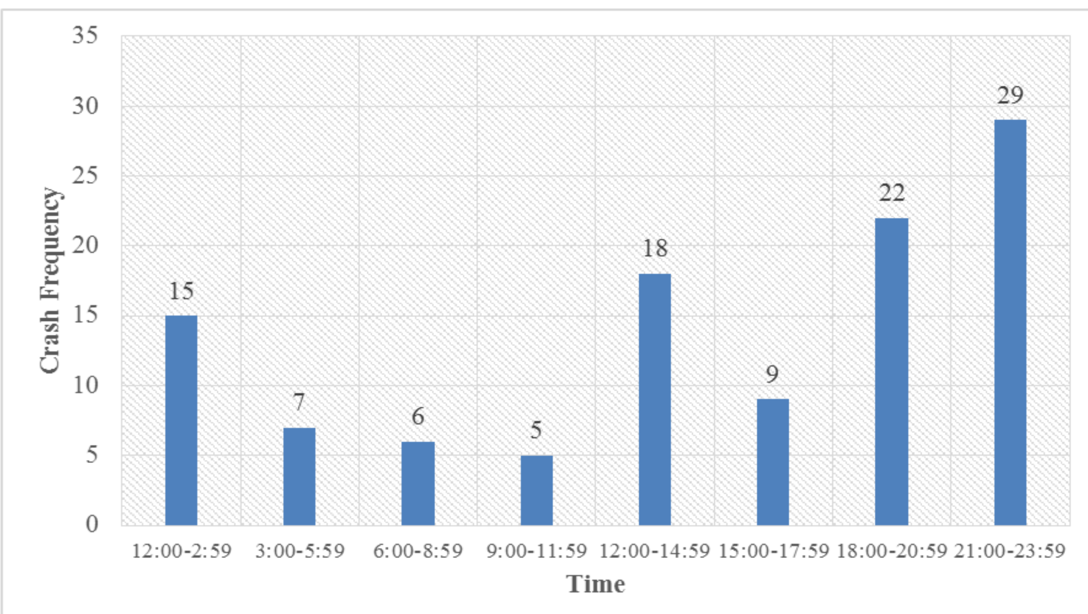


Figure 4.1 Hourly Distribution of WWD Crashes on Alabama Divided Highways

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 divided highway crashes during the same time period. The results indicate that:

- Most of WWD vehicles are passenger cars, and they take up about 60.7%.
- Approximately 68.8% of the WWD vehicles become disabled after the crash, while this percentage for other divided highway crashes is only 37%, resulting in more vehicles being towed after WWD crashes (73.2% of WWD vehicles vs. 57.5% of other vehicles).
- Approximately 70.5% of WW drivers used their seat belts, which is lower than the 92.8% of other divided highway drivers that were belted.
- Airbag deployment is also more prevalent among WWD crashes (45.5%) than other non-WWD crashes (13.4%).

Table 4.5 Vehicle Information of WWD and other Divided Highway Crashes

Variable	Category	WWD Crashes (n=112)		Other Crashes (n=49,599)	
		Frequency	Percentage	Frequency	Percentage
Causal Unit (CU) Type	Passenger Car	68	60.7	26,212	52.8
	Truck	21	18.8	10,201	20.6
	SUV	19	17.0	8487	17.1
	Van	3	2.7	2158	4.4
	Other/Unknown	1	0.9	2,541	5.1
Vehicle Age	Less than 5 years	21	18.8	10,759	21.7
	5 to 15 years	73	65.2	31,945	64.4
	More than 15 years	11	9.8	5,834	11.8
	Unknown	7	6.3	1,061	2.1
CU Vehicle Damage	Minor/None Visible	16	14.3	20,711	41.8
	Major Not Disabled	12	10.7	9,408	19.0
	Major and Disabled	77	68.8	18,334	37.0
	Other/Unknown	7	6.3	1,146	2.3
Vehicle Towed?	No	29	25.6	28,510	57.5
	Yes	82	73.2	20,240	40.8
	Other/Unknown	1	0.9	849	1.7
CU Driver Seatbelt Use	Belt Used	79	70.5	46,024	92.8
	Belt Not Used	14	12.5	1,310	2.6
	Other/Unknown	19	17.0	2,265	4.6
CU Driver Airbag Status	Not Deployed	42	37.5	37,290	75.2
	Deployed	51	45.5	6,646	13.4
	Other/Unknown	19	17.0	5,663	11.4

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 divided highway crashes. The results show that:

- WWD crashes had a similar percentage distribution between rural and urban areas as other divided highway crashes.
- The percentage of WWD crashes during dark conditions (whether roadway is lit or not) is much higher than other divided highway crashes (71.1% vs. 21.3%).
- Most of WWD crashes occurred under clear weather conditions and on dry roadway surfaces.

Table 4.6 Environmental Condition of WWD and other Divided Highway Crashes

Variable	Category	WWD Crashes (n=112)		Other Crashes (n=49,599)	
		Frequency	Percentage	Frequency	Percentage
Setting	Rural	37	33.3	15,674	31.6
	Urban	75	66.7	33,925	68.4
Lighting Condition	Daylight	33	29.7	37,152	74.9
	Dark, Road Lit	30	27.0	5,577	11.2
	Dark, Road Not Lit	49	44.1	5,033	10.1
	Dawn/Dusk	0	0.0	1,742	3.5
	Other/Unknown	0	0.0	95	0.2
Weather Condition	Clear/Cloudy	94	84.7	42,088	84.9
	Fog/Mist	0	0	6,031	12.2
	Precipitation	18	16.2	1,480	3.0
	Other/Unknown	94	84.7	42,088	84.9
Roadway Condition	Dry	91	81.2	40,176	81.0
	Wet	21	18.8	8,870	17.9
	Other/Unknown	0	0.0	553	1.1

4.2 Haddon Matrices

The Haddon matrix, developed by Dr. William Haddon Jr. in the 1960s, is commonly used to approach safety analysis at a site in a systematic fashion. It is a two-dimensional model showing different factors involved, set against the time sequence of a crash. The first dimension is the phase of a crash divided into pre-crash, crash, and post-crash. The second dimension is the factors of a crash: human, vehicle/equipment, and environment. Each cell of the matrix illustrates the range of risk or protective factors involved in which crash contributing factors, circumstances, and countermeasures can be identified in a causal sequence to reduce the likelihood of a crash.

In this study, one Haddon matrix was developed for each injury WWD crash, one-by-one, in three different severity categories, i.e. fatal crash, A-injury crash, and B-injury, based on the information from each WWD crash report. Thus, these Haddon matrices cover all factors categorized as human, vehicle, and environment in all phases of a crash, i.e. the pre-crash, crash, and post-crash. Accordingly, cumulative frequencies for each category were summarized in 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. When completed, it provides insight into the range of possible safety issues and concerns as well as where and when to implement traffic safety countermeasures. Twenty five cumulative frequencies tables are developed and analyzed for "Fatal," "A-injury," "B-injury," "Fatal and A-injury," and "Fatal, A, and B-Injury."

Regarding the human factor, for the pre-crash human category, the largest frequencies of fatal WWD crash were drivers aged above 65, with a percentage of 38%. The prevalent age group for A-injury was 25-34 and 35-44, each with a percentage of 23%. For B-injury WWD crashes, it was older drivers (65 years old and above), accounting for 24% among all. In terms of gender, male drivers were over-represented for all three crash types, 69% of fatal and 59% of A-injury and B-injury crashes. Without considering 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. Traveling wrong way/wrong side was the most prevalent driver contributing circumstance for all severity levels.

In terms of the vehicle factor, for the pre-crash vehicle category, Passenger Car accounted for the largest percentage of all crashes, 62% for fatal, 50% for A-injury, and 71% for B-injury crashes, respectively. The prevalent maneuver type for both the at-fault vehicle and second vehicle was essentially straight, which led to the fact that the largest amount of crashes are head-on crashes, as in the crash phase, 93% of fatal crashes, 72% of A-injury crashes, and 55% of B-injury crashes were the head-on. For the majority of crashes in all severity levels, the air bags had been deployed as a result of the crash. Seatbelt use for causing vehicles shows a decreasing trend with increasing severity type, as 62% for fatal crashes, 64% for A-injury, and 82% for B-injury crashes. This parameter shows the active role of seatbelt use in providing safety for the vehicle occupants during crash.

As for the environmental factor, most of the crashes in all severity levels happened on dry pavement surfaces, i.e. 92% for fatal crashes, 86% for A-injury, and 71% for B-injury crashes. Darkness was the contributing factor for 69%, 55%, and 71% of all fatal, A-injury, and B-injury crashes, respectively. Additionally, the majority of WWD crashes were not related with Work Zone, while the weather condition was clear. The more detailed frequencies can be found in Appendix C: Contributing Factor Frequency.

4.3 Correlation Analysis

Furthermore, a correlation analysis was conducted based on the time and severity of each crash and the age and physical condition of each driver. The analysis assists investigators in connecting contributing factors to the time, the driver age, and the physical condition of the crashes.

In order to assign each of these factors to an age group, correlation analysis was conducted. The closer the results are to a value of one, the more relation the two factors share and the stronger the correlation. If the results indicate a negative relation, one factor increases as the other decreases. The correlation analyses results are presented in Table 4.7. For example, the correlation between “DUI Drivers” and “Night Crashes” is a significant positive number, which means that once a WWD crash happened during nighttime, it is very likely to involve DUI drivers. There is a negative correlation between “Older Drivers” and “Night Crashes”, and it indicates older drivers are relatively unlikely to lead to a WWD crash at night. Significant correlations have been found between “Young Drivers” and “Weekend Crashes”, “Older Drivers” and “Night Crashes”, “Older Drivers” and “Male Drivers”, “Older Drivers” and “Fatal/Injury Crashes”, “DUI Drivers” and “Night Crashes”, “DUI Drivers” and “Male Drivers”, “Night Crashes” and “Male Drivers”, and “Weekend Crashes” and “Fatal/Injury Crashes.”

Table 4.7 Correlation Analysis between Contributing Factors

	% Young Drivers	% Older Drivers	% DUI Drivers	% Night Crashes	% Male Drivers	% Weekend Crashes	% Fatal/Injury Crashes
% Young Drivers	1.00						
% Older Drivers	-0.277	1.00					
% Night Crashes	0.072	**-0.272**	**0.240**	1.00			
% Male Drivers	0.051	**-0.307**	**0.234**	**0.119**	1.00		
% Weekend Crashes	**0.130**	-0.059	0.082	-0.028	0.032	1.00	
% Fatal/Injury Crashes	-0.023	**0.215**	**-0.143**	0.028	-0.064	**-0.147**	1.00

Note: there is no physical meaning between older drivers and young drivers.

4.4 Logistic Regression 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 divided highways 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. This method was first successfully used to study WWD freeway crashes in the first part of this project (Zhou, 2015).

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 STATA software package "firthlogit" was used as a comprehensive tool to estimate the effect of various contributing factors on the probability of WWD crashes. 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 4.8 summarizes the results of the backward elimination procedure of Firth's model.

Table 4.8 Final Firth's Penalized-Likelihood Regression Model for WWD Crashes

Variable	Category	Est. Coef.	Est. S.E. of Coef.	OR
Intercept	–	-8.48	0.33	–
Driver Age	Less than 25 years	–	–	Reference
	25 to 35 years	0.01	0.31	1.01
	35 to 45 years	0.37	0.32	1.44
	45 to 55 years	0.03	0.37	1.03
	55 to 64 years	0.90	0.34	2.46
	65 years or over	1.86	0.28	6.43
Driver Condition	Apparently Normal	–	–	Reference
	DUI	1.38	0.26	3.98
	Asleep/Faint/Fatigue	-0.60	0.83	0.55
	Illness	1.22	0.67	3.40
CU Driver Seatbelt Use	Use	–	–	Reference
	Not Use	0.74	0.31	2.10
Setting	Rural	–	–	Reference
	Urban	0.67	0.23	1.95
CU Driver Airbag Status	Not Deployed	–	–	Reference
	Deployed	1.31	0.20	3.74
Lighting Condition	Daylight	–	–	Reference
	Dawn/Dusk	-1.17	1.43	0.31
	Dark, roadway light	1.60	0.26	4.96
	Dark, roadway not light	2.50	0.25	12.15
Penalized Likelihood Ratio Test: χ^2=-641.79715 on 14 d.f., *p*-value<0.05				

Wald Test = 282.83 on 14 d.f., *p*-value<0.005 **AIC= 1313.594**

Looking at the obtained model (as shown in Table 4.8), it can be inferred that all of the included parameters have been previously found to explain WWD crashes. The penalized-likelihood ratio test statistic of -641.80 with corresponding significant p-value of less than 0.05 (with 14 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 (in red), 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 55 to 64 years old (OR=2.46) or 65 and older (OR=6.43), to be under the influence of alcohol and drugs (OR=3.98) or due to illness (OR=3.38), to be driving in urban area (OR=1.95), to be not using seatbelt (OR=2.10), to be driving in dark with lighting condition (OR=4.96) or dark without lighting condition (OR=12.15), which is higher among other categories under the variable. Moreover, WWD crashes can be characterized by airbag deployment (OR=3.74).

4.5 Additional Data Analysis

4.5.1 *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 $1.6 million to $28.3 million, averaging at $17.1 million per year for the studied period. When considering the costs by severity, it can be found that fatalities account for 84.8% of total costs imposed by WWD crashes. Consequently, reducing the number and severity 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	5	4	1	6	0	16
A-Injury	16	17	5	3	5	46
B-Injury	6	7	4	4	6	27
C-Injury	2	7	1	2	0	12
PDO	46	53	34	31	39	203
Total	75	88	45	46	50	304

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

Type	2009	2010	2011	2012	2013	Sum by Severity	% of Total
Killed	22,690,000	18,152,000	4,538,000	27,228,000	0	72,608,000	84.81%
A-Injury	3,680,000	3,910,000	1,150,000	690,000	1,150,000	10,580,000	12.36%
B-Injury	352,200	410,900	234,800	234,800	352,200	1,584,900	1.85%
C-Injury	56,000	196,000	28,000	56,000	0	336,000	0.39%
PDO	115,000	132,500	85,000	77,500	97,500	507,500	0.59%
Sum by Year	26,893,200	22,801,400	6,035,800	28,286,300	1,599,700	85,616,400	100.00%

4.5.2 *WW Entry Points*

One of the most challenging aspects of studying WWD crashes is to identify where the driver first turned into the wrong direction on the roadway. Based on previous studies, the most common WWD scenarios on divided highways occur when drivers (1) miss an intended exit, (2) turn left on the nearby directional roadway instead of the far or second directional roadway when joining from a crossroad (See Figure 4.2 for an example), (3) enter a roadway going the wrong direction at the median opening, (4) make a U-turn and misunderstand that the next lane will be in the opposite direction, and (5) attempt to get back on the main road after stopping at a service or parking area (Scifres 1975; Vaswani 1977).

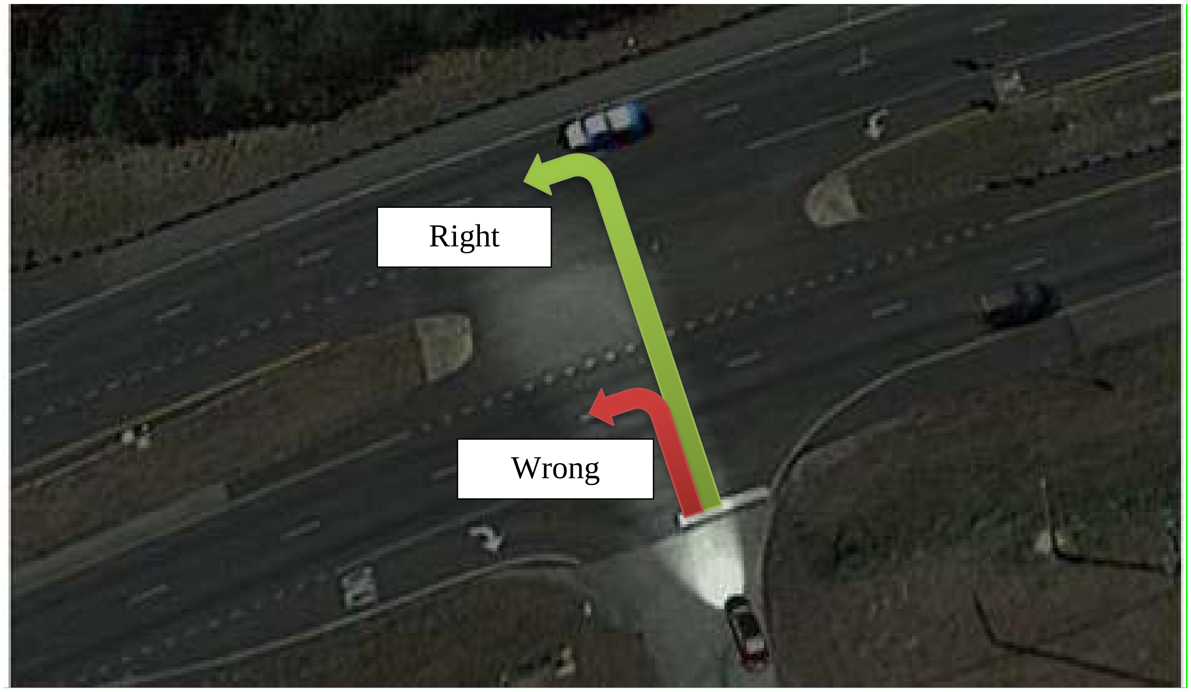


Figure 4.2 Left-turning Movements from Crossroads on Divided Highways (Wang et al. 2016)

Several previous studies used information sources such as police crash reports, surveys, and images from camera surveillance systems to determine where a WWD movement originated. Most entry points for two-thirds of the crashes were unknown because the WW driver usually could not provide information due to his/her intoxicated condition or because he/she died in the crash (Scifres 1975; Vaswani 1977).

Scifres et al.' (1975) study showed that on non-interstate four-lane divided highways, about 40 percent of drivers making WWD entries emerged from intersections with crossroads, about 25 percent originated from business establishments such as gas stations and motels, and about 20 percent originated from residential areas, crossovers, beginnings of divided sections, and construction sites, or were associated with U-turns and median openings. The origins of the remaining 15 percent were unknown.

In this study, the coordinates of the 112 WWD crash locations were extracted. Corresponding median widths were measured using existing online maps. The possible WWD entry point for each crash was estimated by checking the closest possible entry point on the Google Map, and cross checked with the hard-copy police reports. Special attention was paid to crash narratives, collision diagrams, and crash circumstances. Hence, 18 confirmed and 94 possible WWD entry points on multilane divided highways were identified (See Table 4.12).

Table 4.12 Wrong-Way Entry Points

	Category	Number
WWD Crashes with Known Entry Points	Recorded Entry at Median Opening	7
	Recorded Entry at Signalized Intersection	4
	Entry from Parking of Gas Station/ Business Area	5
	Entry by Undeliberate Lane Change *(Distracted and DUI)*	1
	Entry by Improper Lane Use *(Travelling/Speeding Through A Median Opening On The Two-Way Turn Lane)*	1
WWD Crashes with Unknown Entry Points	Interchange Related (3 Interchanges but No Median Opening Nearby)	1
	Estimated Entry at Median Opening or Intersection	93

4.6 Comparison of WWD Crashes between Divided Highways and Freeways

This section provides a comparison of spatiotemporal distribution results and the final Firth's logistic regression model of WWD crashes between divided highways and freeways. The spatiotemporal distribution comparisons include general characteristics, responsible driver characteristics, temporal information, vehicle information, and environmental condition. The distribution of variables showing no conspicuous difference (a difference of more than 10% is considered conspicuous) between the two types of facilities are not presented in the following tables. None of the variables of environmental condition have conspicuous differences, so a comparison of environmental conditions between divided highways and freeways are not presented below.

4.6.1 *Spatiotemporal Distribution Comparison*

Table 4.13 shows general characteristics of WWD crashes on divided highways and freeways. The number of persons and vehicles involved in WWD crashes is different between these two facility types, and more persons and vehicles are involved in WWD on divided highways. It can be seen in Table 4.13 that the frequency of WWD crashes involving one person on divided highways is smaller than that on freeways (5.4% vs. 16.1%). The frequency of two vehicles being involved in WWD crashes on divided highways is much higher than on freeways (87.5% vs 71.0%).

Table 4.13 General Characteristics of WWD Crashes on Divided Highways and Freeways

Variable	Category	Divided Highways (n=112)		Freeways (n=93)	
		Frequency	Percentage	Frequency	Percentage
Number of Persons	One	6	5.4	15	16.1
	Two	57	50.9	43	46.2
	Three and More	49	43.8	35	37.6
Number of Vehicles	One	7	6.3	12	12.9
	Two	98	87.5	66	71

	Three and More	7	6.3	15	16.1

Responsible driver characteristics including driver's age, race, and condition are compared in Table 4.14. There is a higher percentage of WW drivers aged 55 to 64 years on divided highways than on freeways (12.5% vs 4.3%), while the percentage of WW drivers who are African-American is higher on freeways (13.4% vs 36.6%). A higher percentage of WW drivers on freeways are DUI (46.2%), while a higher percentage of WW drivers on divided highways are apparently normal (45.5%).

Table 4.14 Responsible Driver Characteristics of WWD Crashes on Divided Highways and Freeways

Variable	Category	Divided Highways (n=112)		Freeways (n=93)	
		Frequency	Percentage	Frequency	Percentage
Driver Age	Less than 24	18	16.1	17	18.3
	25 to 34 years	18	16.1	21	22.6
	35 to 44 years	16	14.3	14	15.1
	45 to 54 years	10	8.9	8	8.6
	55 to 64 years	14	12.5	4	4.3
	65 years or over	30	26.8	24	25.8
	Other/Unknown	6	5.4	5	5.4
Driver Race	White/Caucasian	75	67.0	44	47.3
	African American	15	13.4	34	36.6
	Hispanic	6	5.4	5	5.4
	Asian/Pacific Islander	4	3.6	0	0
	American Indian	0	0.0	0	0
	Other/Unknown	12	10.7	10	10.8
Driver Condition	Apparently Normal	51	45.5	23	24.7
	DUI	26	23.2	43	46.2
	Physical Impairment	0	0.0	4	4.3
	Asleep/Fainted/Fatigued	1	0.9	1	1.1
	Illness	2	1.8	1	1.1
	Emotional	2	1.8	0	0
	Other/Unknown	30	26.8	21	22.6

Table 4.15 presents WWD temporal information including month, day and time between divided highways and freeways. The difference in time distributions is conspicuous. WWD crashes on divided highways happened in the afternoon (12 p.m. – 6 p.m.) are three times more than on freeways (24.1% vs 7.5%), while the percentage of WWD crashes on freeways that happened during midnight to early morning (12 a.m. - 6 a.m.) is more than double on divided highways (19.6% vs 40.2%).

Table 4.15 Temporal Information of WWD Crashes on Divided Highways and Freeways

Variable	Category	Divided Highways (n=112)		Freeways (n=93)	
		Frequency	Percentage	Frequency	Percentage
Month	January	13	11.6	4	4.3
	February	14	12.5	8	8.6
	March	11	9.8	13	14
	April	8	7.1	3	3.2
	May	5	4.5	15	16.1
	June	5	4.5	6	6.5
	July	8	7.1	6	6.5
	August	12	10.7	4	4.3
	September	6	5.4	6	6.5
	October	10	8.9	6	6.5
	November	7	6.3	13	14
	December	13	11.6	9	9.7
Day	Monday	16	14.3	15	16.1
	Tuesday	12	10.7	6	6.5
	Wednesday	15	13.4	7	7.5
	Thursday	9	8.0	5	5.4
	Friday	20	17.9	16	17.2
	Saturday	23	20.5	20	21.5
	Sunday	17	15.2	24	25.8
Time	Morning (6-12)	11	9.8	12	12.9
	Afternoon (12-18)	27	24.1	7	7.5
	Evening (18-24)	51	45.5	31	33.3
	Night (0-6)	22	19.6	43	46.2
	Other/Unknown	1	0.9	4	4.3

Table 4.16 compares the vehicle information of WWD crashes on the two types of roadways; two variables (causal unit type and if the vehicle were towed) show conspicuous differences. More CU are trucks on divided highways, while only few CU are trucks on freeways (18.8% vs 1.1%). More vehicles are towed away after crashes on freeways than on divided highways (25.6% vs 15.1%). Additionally, there are more severe crashes (fatal crash and A injury crash) happened on freeways (39.4%) than on divided highways (30.4%), so the higher severity would likely lead to more towing.

Table 4.16 Vehicle Information of WWD Crashes on Divided Highway and Freeways

Variable	Category	Divided Highways (n=112)		Freeways (n=93)	
		Frequency	Percentage	Frequency	Percentage
Causal Unit (CU) Type	Passenger Car	68	60.7	89	95.7
	Truck	21	18.8	1	1.1
	Bus	0	0.0	0	0
	SUV	19	17.0	0	0.0

	Van	3	2.7	0	0.0
	Motorcycle	0	0.0	0	0
	Other/Unknown	1	0.9	3	3.2
Vehicle Towed?	No	29	25.6	14	15.1
	Yes	82	73.2	76	81.7
	Other/Unknown	1	0.9	3	3.2

4.6.2 *Logistic Regression Analysis Comparison*

Table 4.17 compares the final Firth's penalized likelihood regression models together with ORs results between WWD crashes on divided highways and freeways. Both models contain the variables like driver age, driver condition, as well as driver airbag status. Most of them have similar ORs, except for the ORs of DUI (3.98 vs 16.09). Additionally, lighting condition, CU driver seatbelt use condition and roadway setting are specific variables of the model on divided highways. Time of the day, driver residency distance, roadway condition and vehicle age are all specially developed for the Firth's model on freeways. It can be seen in the table that the OR of dark roadway, not light condition of divided highway model is large (OR= 12.15), and the OR of the similar variable, crash happened in the night time of freeways is also large (OR=4.45).

Table 4.17 Firth's Model for WWD Crashes on Divided Highways and Freeways

Divided Highway (n=112)			Freeways (n=93)		
Variable	**Category**	**OR**	**Variable**	**Category**	**OR**
Driver Age	Less than 25 years	Reference	**Driver Age**	Less than 25 years	Reference
	25 to 35 years	1.01		25 to 35 years	1.01
	35 to 45 years	1.44		35 to 45 years	1.23
	45 to 55 years	1.03		45 to 55 years	1.05
	55 to 64 years	2.46		55 to 64 years	1.12
	65 years or over	6.43		65 years or over	8.71
Driver Condition	Apparently Normal	Reference	**Driver Condition**	Apparently Normal	Reference
	DUI	3.98		DUI	16.09
	Asleep/Faint/Fatigue	0.55		Asleep/Faint/Fatigue	0.75
	Illness	3.40		Physical Impairment	74.29
CU Driver Airbag Status	Not Deployed	Reference	**CU Driver Airbag Status**	Not Deployed	Reference
	Deployed	3.74		Deployed	3.12
Lighting Condition	Daylight	Reference	**Time of the Day**	Morning (6-12)	Reference
	Dawn/Dusk	0.31		Afternoon (12-18)	0.44
	Dark, roadway light	4.96		Evening (18-24)	2.51
	Dark, roadway not light	12.15		Night (0-6)	4.45
CU Driver Seatbelt Use	Use	Reference	**Driver Residency Distance**	Less than 25 Miles	Reference
	Not Use	2.10		Greater than 25 Miles	0.60
Setting	Rural	Reference	**Roadway Condition**	Dry	Reference
	Urban	1.95		Wet	0.41
–			**Vehicle Age**	Less than 5 years	Reference
				5 to 15 years	1.50

			More than 15 years	1.90

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.

Field reviews were made at each study site to supplement data collected from crash records and to determine the physical characteristics of access point where WW movements originated. Field experiments were conducted to determine drivers' sight distances from side streets at nighttime. The sight distance in this study was the distance that drivers can see with the vehicle's headlight illumination at nighttime, not stopping sight distance, passing sight distance, or decision sight distance defined in the American Association of State Highway and Transportation Officials (AASHTO) Green Book (AASHTO 2011). When a driver is completing a crossing maneuver, there must be sufficient sight distance in both directions available to cross the intersecting roadway and avoid approaching traffic. If the sight distance is shorter than the entire cross section width of the median opening, the segment should be treated as two separate intersections.

Thirty-four sites in total, with median widths distributed between 7ft. and 119 ft., were selected from the 110 WWD entry points to conduct comprehensive field experiments. 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 Sites

Geographic Location	No. of Locations Visited	Date
U.S. Highway 280, AL	10	April 2015
Montgomery, AL	5	May 2015
Birmingham, AL	13	May 2015
Phenix City, AL	6	May 2015

5.1 Geometric Data Collection

Detailed data of the roadway geometric features were collected in the fields and cross checked using GIS capabilities of Google Earth Professional. For a study location, the measure parameters include: available sight distance (ft.), change in grade percent (%), median width measured according to the definition in the *Manual On Uniform Traffic Control Devices* (MUTCD) (ft.), width of lanes in one direction on the adjacent side to the stop bar (ft.), distance from stop bar to the adjacent lane (ft.), width of the opposite side roadways (ft.), and width of the entire cross section of the median opening (ft.), which is the distance from stop bar to the opposite roadside. See Figure 5.1 for a diagram of the measured parameters.

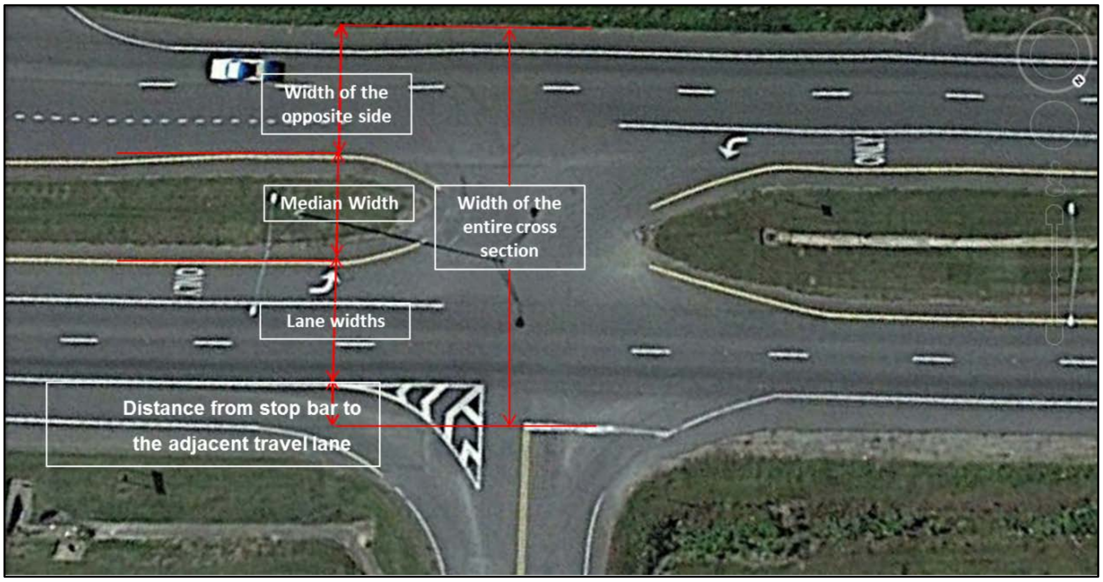


Figure 5.1 Diagram of the Measured Parameters

The roadway elevations were determined based on the profile view of the vertical alignment of each median opening. The roadway grade was calculated by the equation (1):

$$Grade\ (\%) = \frac{E_2 - E_1}{L} * 100 \qquad (1)$$

Where:
Grade: grade of the roadway cross section in percent
E_2: elevation of the ending point of the roadway cross section
E_1: elevation of the starting point of the roadway cross section
L: total length of the roadway cross section

Furthermore, the actual sight distance at drivers' eye height in a passenger car was checked in the field. Relevant data such as intersection controls, advanced signage, vertical curvature, and intersection conspicuity, which could not be clearly identified from online maps, were collected during field reviews. For each intersection approach, several more attributes were collected: 1) The presence, type, and amount of traffic control devices (TCDs), which were grouped into five types: conventional guide signage, freeway-style (larger) guide signage, overhead signage, route number signage, and warning signage; 2) The distance for intersection recognizability: the distance to the intersection at which there are obvious indications of the intersection presence, and if it is shorter than drivers' sight distance; 3) Median type and width; and 4) Grades and vertical curvature (e.g. upgrade or downgrade, crest or sag vertical curve, etc.).

These data were documented by photos taken in the field. Figure 5.2 gives examples of the driver front view, left side view, and right side view with vehicle headlight illumination only at one of the study sites. From the front view in Figure 5.2 (a), observed TCDs in the roadway environment consisted of a STOP sign, One-Way signs mounted on STOP sign and on the opposite side of the cross section, and different pavement markings. From the side views in Figures 5.2 (b) and (c), other types of TCDs can be perceived, such as the Do Not Enter (DNE) sign, WW sign, Yield sign, etc.

(a)

(b) (c)

Figure 5.2 Examples of the Driver Front View (3a), Left Side View (3b), and Right Side View (3c) on the Divided Highway

Recommended by the AASHTO Green Book (2011), vehicles' average headlight span is 160~180 feet and drivers' eye height in a passenger's car is 3.5 feet above the roadway. Field experiments were also conducted to verify the two specifications of the vehicle used in the experiment. The experimental vehicle was passenger car, a 2010 Chrysler Sebring. The vehicle manual indicated that the headlights can reach approximately 160 feet during nighttime.

Measurements were performed multiple times with a measurement wheel. The measured headlight span and driver's eye height were approximately 164 feet and 3.5 feet on average.

5.2 Sight Distance Determination

As the current sight distance determination methods in the AASHTO Green Book are not applicable to this problem, profiles of the entire cross section with drivers' sight in a passenger car were drawn for the 110 possible WWD entry median openings. Figure 5.3 illustrates an example of the profile for a median opening cross section. Denotations of the letters are: S = Available sight distance (ft.), G1 and G2 = Grades in percent, G = Algebraic grade change in percent (%), M = Median width measured per the MUTCD definition (ft.), W = Width of the lanes in one direction on the adjacent side of the stop bar (ft.), D = Distance from stop bar to the adjacent lane (ft.), O = Width of the opposite side roadways (ft.), L = Width of the entire cross section of the median opening (ft.), and Ø = Upswept angle of headlight beam from horizontal (typically 1 degree). In each profile, the driver's available sight distance at the median opening was calculated based on the projection of drivers' sight on the profile of the entire cross section. The results were compared with the entire cross section width to determine if the available sight distance for drivers at this median opening was enough.

The worst-case scenario for drivers' sight distance requirement was selected for the sight distance determination, which is the left-turn or through movement from the side streets. The basic rationale behind this method is that if drivers making left turns or going through from side streets cannot see the far side main roadways, then it is necessary to treat the median opening as two intersections for WW-related TCD requirements. Given that most WWD crashes occurred at nighttime, the sight distance was only checked for nighttime conditions.

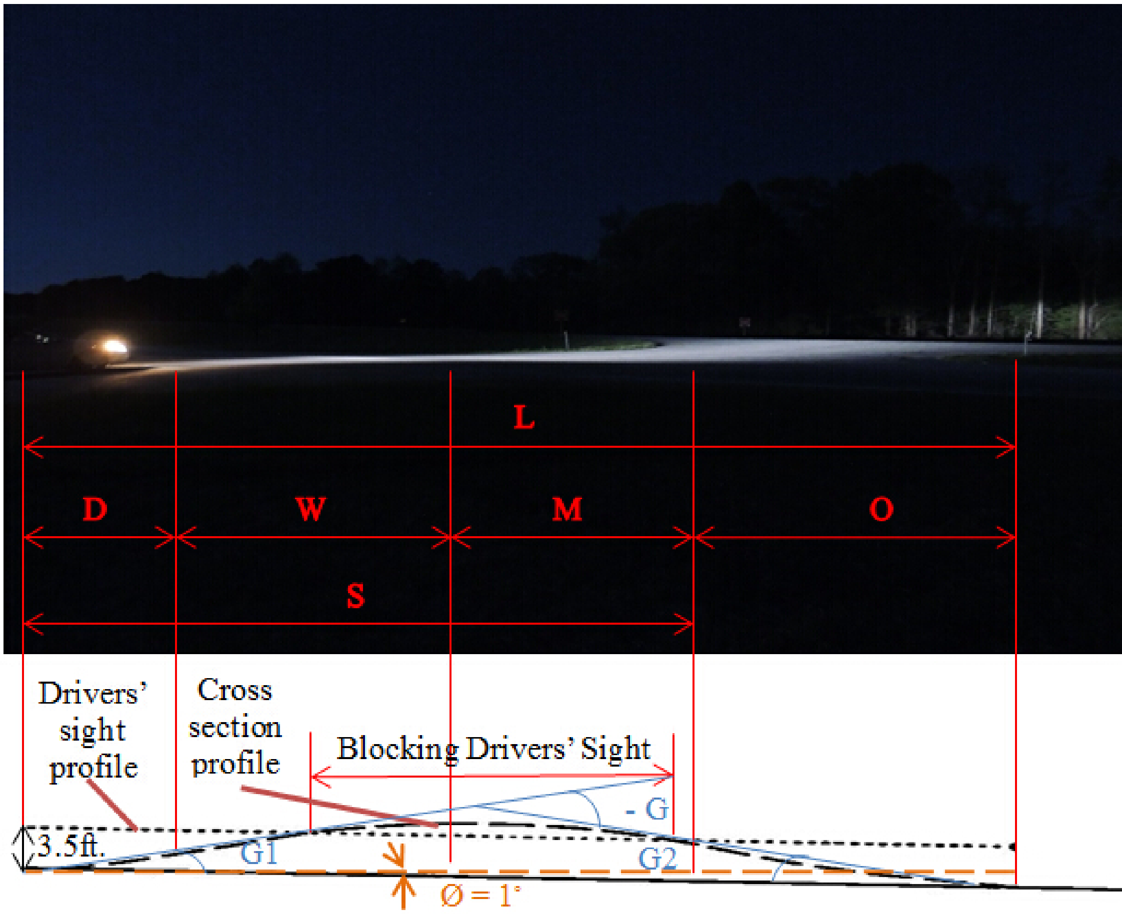


Figure 5.3 Example of a Profile Drawn For the Entire Cross Section of a Median Opening

5.3 Field Inspections

In addition to the geometric features of median openings, conditions of WW-related TCDs are also significant contributing factors for WWD crashes. There are multiple elements to consider for this review. Therefore, a checklist (see Appendix E) was designed to examine the existing TCDs were adequate to deter WWD at each study location, which include the visibility, number, and condition for all possible types of TCDs. This checklist serves as a tool to assess possible problematic locations identified for WWD prevention based on general issues in terms of sight distance, signage, pavement marking, and geometric design on multilane divided highways.

5.4 General Issues

For all 34 study locations with median width ranging from 7.6 to 118.8 feet, 6 of them were treated as two separate intersections, while 20 (including three that has been treated as two intersections) of them should be based on current MUTCD criteria (when median width ≥ 30 feet), and 6 (including one that has been treated as two intersections and five that are not) should be based on the method developed in the study. Furthermore, 14 have no TCDs (8 narrow medians and 6 wide medians); 5 have only parts of MUTCD required one-way signing (such as Keep Right, Keep Left, and ONE WAY) (2 narrow medians and 3 wide medians); 9 wide medians have either the WW or the DNE signs, 6 have MUTCD required WW and DNE signs.

General issues regarding signing (including DNE, WW, ONE WAY, No Left/Right Turn, and Keep Right), pavement marking (including double yellow lines, white edge line, stop line on crossroads, stop line on median roads, Left/Right Turn Only Arrow, and Lane-line Extensions), and geometric designs are detailed in Table 5.2. Selected examples of issues in different categories are given below.

Table 5.2 Summary of General Issues

Category	Issues
Signing	Visibility can be improved for nighttime and low visibility conditions
	Angle of signs needs to be adjusted: some DNE signs do not face the potential WW drivers
	Absence of required and optional signs at some locations
	Some DNE signs are placed so far from the nose of the median that they can be observed only after drivers enter the wrong way
	The heights of some DNE and WW signs are above the reach of crossroad drivers' headlights illumination
Pavement Marking	Visibility can be improved
	Absence of required and optional pavement markings such as double yellow line, white edge line, and stop line on crossroads and median roads
	Faded pavement markings
	Confusing pavement markings
	Markings of adjacent crossroads were extended too far
	Lack of directional pavement markings to guide the large-turning radii drivers at wide median opening locations
Geometric Design	The elevation of crossroads should be equal to or great than that of the divided highway
	Access control at gas station or service areas, e.g. channelized driveway, roadway information signage, closing the driveway, etc.
	Sight obstructions at median openings
	Unconventional intersection layouts

a) Traffic sign

Figure 5.4 gives an example of absence of required and optional signs at a median opening. It can be seen no signage presence for both directions of the divided highway. Figure 5.5 shows an example of an improperly oriented sign. The DNE sign is parallel to the divided highways, not facing the potential right-turn WW drivers. Figure 5.6 shows an example of DNE signs placed so far away and can be observed only after drivers enter the wrong way.

(a) Front View

(b) Left-Side View (c) Right-Side View

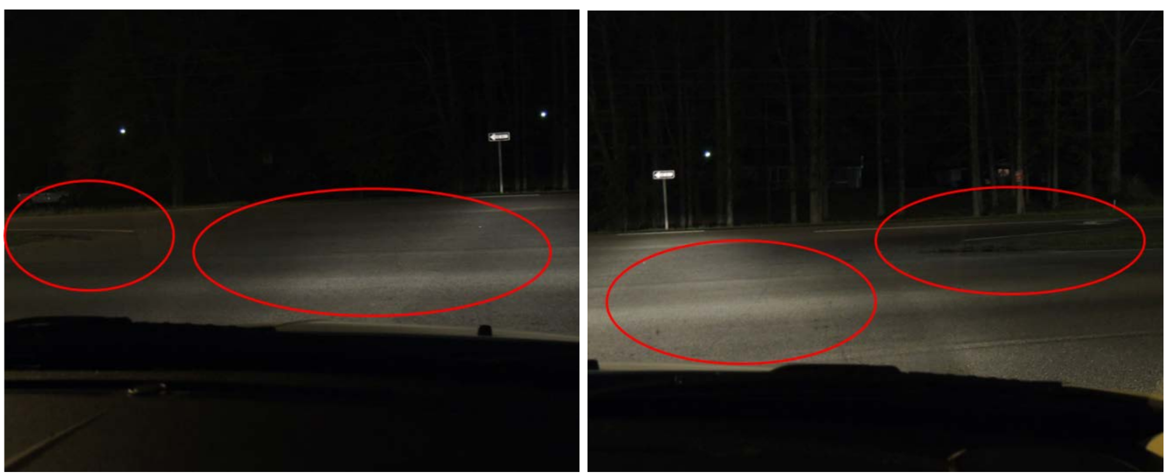
Figure 5.4 Example of Sign Absence at a Median Opening in AL

Figure 5.5 Example of an Improperly Oriented Sign in AL

Figure 5.6 Example of DNE Signs Placed Too Far From the Nose of the Median in AL

b) Pavement Marking

Figure 5.7 shows an example that pavement marking of the lanes and median edges are faded at a median opening, which makes the roadway layout less recognizable for the drivers on crossroads.



(a) Left-Side View (b) Right-Side View

Figure 5.7 Example of Faded Pavement Markings at a Median Opening in AL

c) Geometric Design

Figure 5.8 shows a raised island presence at the median opening, which could block driver sight of the far side of the divided highway at nighttime. Figure 5.9 shows an example of big elevation changes at a median opening. The elevation of the divided highway is higher than that of the crossroad, which makes it hard for drivers to perceive the presence of the far side divided highways, especially at nighttime. Figure 5.10 shows an example of a skewed intersection at a divided highway-crossroad intersection. Such layouts are frequently confusing and may encourage WWD based on the past studies.

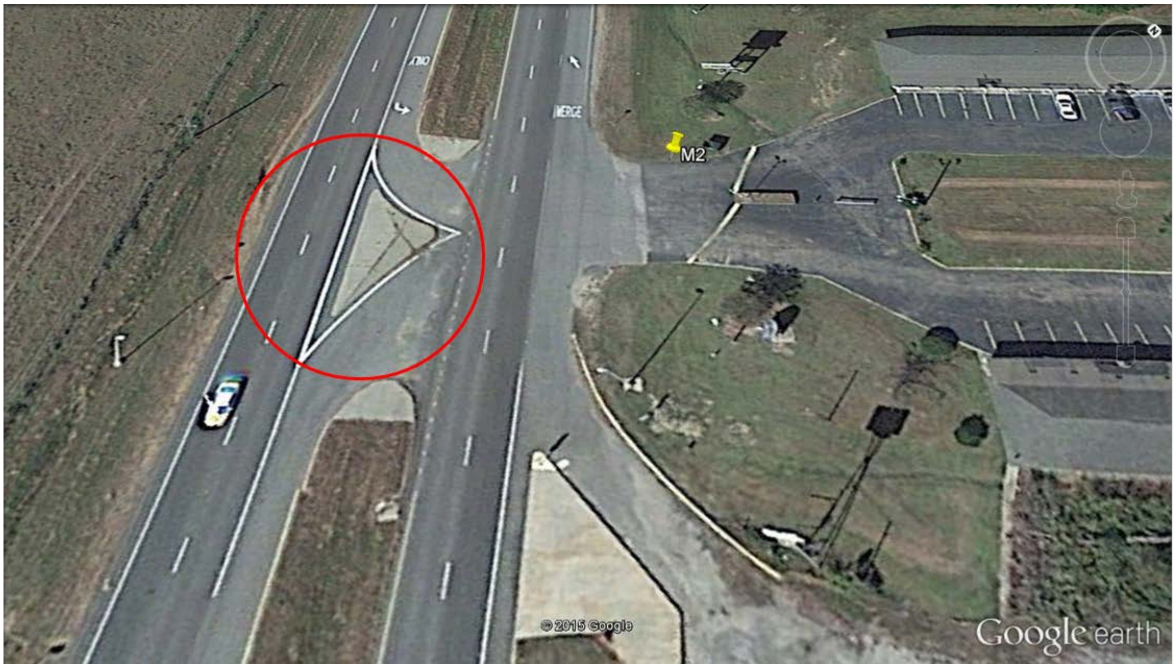


Figure 5.8 Example of a Raised Island at A Median Opening in AL


Figure 5.9 Example of Big Elevation Changes at a Median Opening in AL

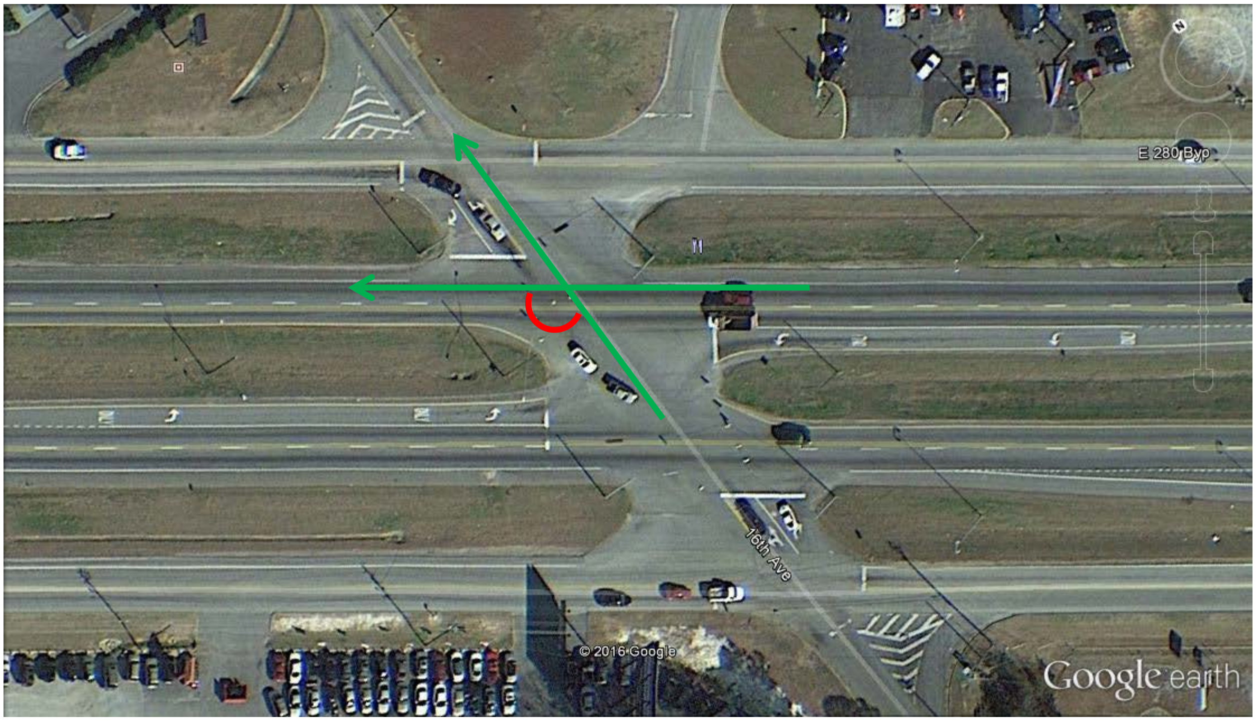


Figure 5.10 Example of a Skewed Intersection in AL

5.5 General Countermeasures

In order to reduce the frequency and severity of WWD crashes on multilane divided highways, in addition to regular installation and maintenance of existing TCDs to ensure that they are working properly, enhanced TCDs should be considered at high crash locations to reduce the probability of WWD entries. Detailed general countermeasures for signing, pavement markings, median modifications, access management techniques, and geometric design are listed in Table 5.3. Most of methods are standard in the MUTCD (2009) or AASHTO Green Book (2011) or proven to be effective based on literature review.

Table 5.3 Summary of General Countermeasures

Category	Issues
Signing	Supplement the MUTCD guideline on TCDs at median openings with the new method developed in this study. If drivers' sight distance is not sufficient, WW-related TCDs should follow the guidelines for two separate intersections.
	Increasing the visibility of signs by using following techniques: o Internally illuminated signposts using flashing, internally illuminated signs. o Adding small LED units along the sign's borders to attract drivers' attention.

	o Affixing red retro-reflective tape to the signposts to enhance nighttime visibility, particularly for those who are impaired, disoriented, or confused. o Orient the existing signs towards potential WWD drivers. o Lower the heights of DNE and WW signs. o Place at least one pair of DNE and WW sign to fall within the area covered by vehicles' headlights.
Supplemental/Optional Sign	Provide signage to help drivers on the crossroad approach recognize that left turns into the near roadway of the divided highway are not permitted. This may include One-Way signs, No Left Turn sign, WW signs, and Divided Highway plaques.
	Supplemental items such as placards, flashing beacons, or flags can be added to DNE and/or WW signs as an enhancement to the traditional approach.
	Use the optional Keep Right sign and/or ONE WAY sign at median openings.
	Use No Right Turn sign at median openings.
	Use Divided Highway signs (R6-3 or R6-3a in the MUTCD) to provide intersection geometry information to the drivers entering a multilane divided highway.
	Install another set of "WW, DNE" signs farther down the wrong way at problem median-crossroad intersections to give drivers a second chance to realize their mistake.
Pavement Marking	Install markings such as yellow line, white edge line, and stop line on crossroads and median openings, based on the MUTCD for intersection treatments.
	Increase the visibility of pavement markings by adding retroreflective raised pavement markers.
	Avoid confusing pavement markings such as too-far extended two-way turn lanes, painted median between lanes in the same direction.
	Use lane-use arrow on each lane of the divided highway upstream of the crossroad intersection.
Supplemental/Optional Pavement Marking	Add optional WW arrows and Stop Line equipped with Raised Pavement Markers.
	Delineate of the nose of the median by curb and paint (Yellow). The median should be distinct to aid the driver in understanding the intersection layout and function. Distinctiveness can be achieved by raising and coloring the median. Medians do not have curbs or pavement edge markings around the nose of the median could be very inconspicuous at nighttime for old drivers and slightly impaired drivers.
Geometric Design	Clear sight obstructions at the median opening that limit the view of the far-side roadway.
	Design the elevation of crossroads equal to or great than that of the divided highway to give drivers on crossroads a clear view of both directions of highways.
	Avoid skew angles of intersection as well as unconventional intersection layouts.
	Use channelization and barrier curbs on crossroads/business area driveways to direct traffic in the right direction and block WW movements.
Median Type, Design, and Modification	Replacing painted median with raised median to better direct traffic movements.
Access Management	Use access management techniques such as channelized islands, and provide exclusive U-turn bays for in direct left turns from driveways at service areas.

Others	Provide spotlighting to make roadways conspicuous to assist old or impaired drivers.
	Whenever possible, divided highway intersections with wider medians and/or big grade changes should be lighted to assist drivers in seeing both sides of the major road and recognizing it as a divided highway.
	Adding data-driven DUI checkpoints.
	Use Radio, Autonomous Vehicle, Connected Vehicle, Vehicle to Vehicle (V2V), and Vehicle to Infrastructure (V2I) to warn right-way drivers of oncoming WW drivers.
	Coordinate with the primary 911 public safety answering points to share information on reports of WW movements on highway facilities.
	Use Prototype WWD Detection System/Video Surveillance and Detection System.

The definition of intersection in Section 1A.13 of the 2009 MUTCD indicates that crossings of two roadways 30 feet or more apart shall be considered two separate intersections. Figure 5.11 (a) shows the recommended WW signing for divided highways with median widths of 30 feet or wider. When median width is 30 feet or greater, the DNE sign and WW sign should be placed directly in view of a road user at the point where a road user could wrongly enter a divided highway. The WW sign is used as a supplement to physically discourage or prevent WW entry at intersections of divided highways. If used, it should be placed farther downstream than the DNE sign on the divided highway. In Figure 5.11 (a), the DNE signs are placed at a 45-degree angle facing the potential WW drivers (*FHWA, 2009*).

Figure 5.11 (b) and (c) replicate Figures 2B-16 and 2B-15 in the MUTCD illustrating the recommended One Way signing at divided highway intersections with narrow and wide (30 feet or wider) medians, respectively (*FHWA, 2009*).

The MUTCD states "*At an intersection with a divided highway that has a median width at the intersection itself of less than 30 feet, Keep Right signs and/or ONE WAY signs shall be installed. If Keep Right signs are installed, they shall be placed as close as practical to the approach ends of the medians and shall be visible to traffic on the divided highway and each crossroad approach. If ONE WAY signs are installed, they shall be placed on the near right and far left corners of the intersection and shall be visible to each crossroad approach*." (*FHWA, 2009*) As shown in Figure 5.11, no control (yield, stop, or signal) is provided for the interior approaches when the junction functions as a single intersection when the median is narrower than 30 feet. Similar to intersections of undivided highways, the basic assumption is left-turning vehicles from opposing directions do not cross paths (i.e., turn in front of each other).

Meanwhile, "*At an intersection with a divided highway that has a median width at the intersection itself of 30 feet or more, ONE WAY signs shall be placed, visible to each crossroad approach, on the near right and far left corners of each intersection with the directional roadways*." (*FHWA, 2009*) As shown in Figure 5.11 (c), interior control in the median is provided when the median is 30 feet or wider and the location functions as two separate intersections. In this case, opposing left turns from the divided highway cross paths (i.e., turn behind one another) and the interior of the divided highway is treated as a roadway rather than as part of the intersection. This leads to the need for additional signing at each separate intersection.

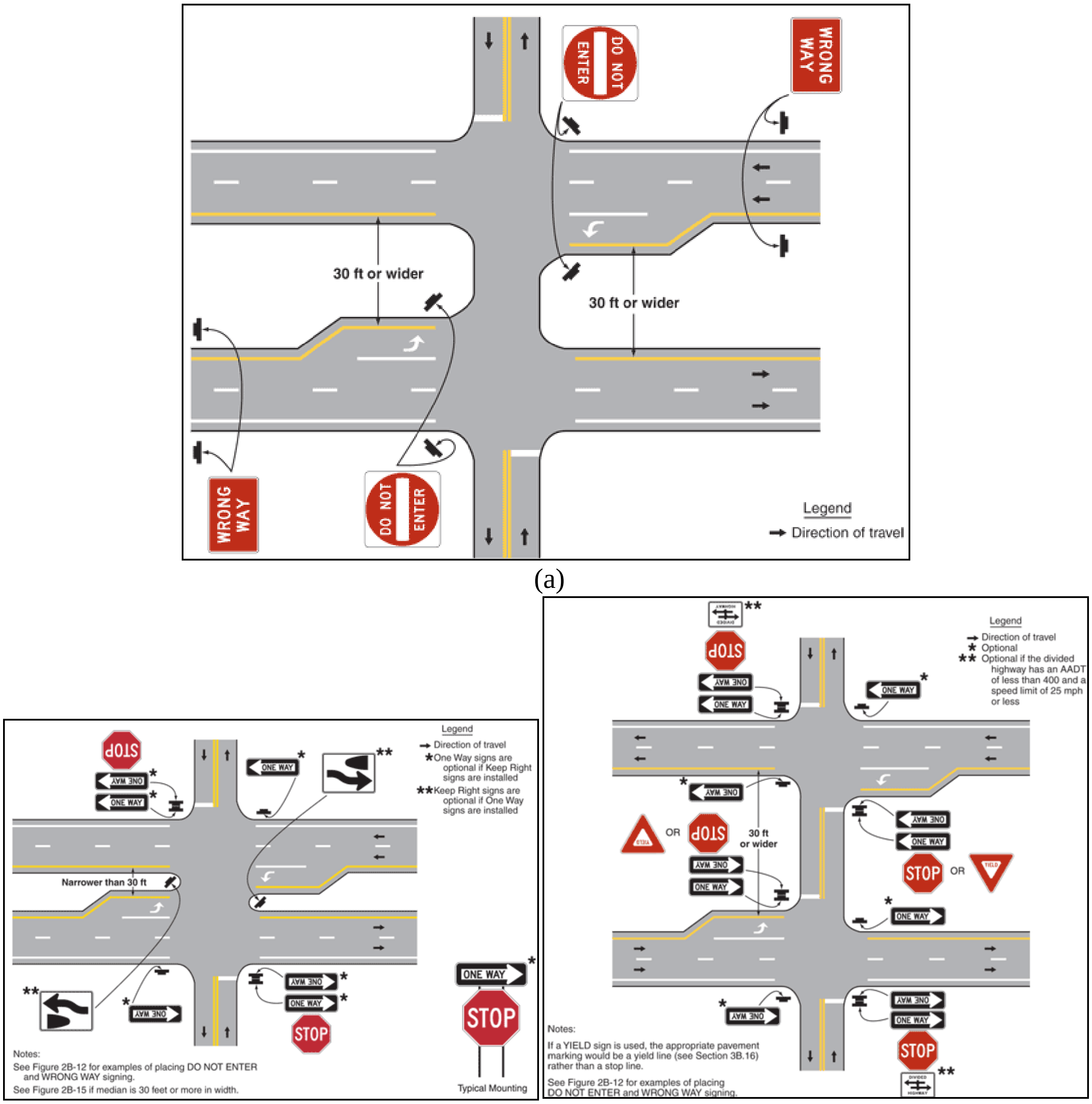


Figure 5.11 WW Signing for Divided Highways with Median Widths of 30 feet or Wider (a) and One Way Signing at Divided Highway Intersections with Narrow (b) and Wide Median (c) (Image: MUTCD 2009)

For Alabama divided roadways, ALDOT has found that it is impractical to sign and mark as depicted in Figure 5.11 (c). When the median is less than about 70-ft. wide, but greater than 30-ft., there is no practical location to install a stop or yield sign so that it is visible to approaching vehicles. ALDOT recently implemented some alternative marking/signing plans at various locations that anecdotally appear to function more effectively than Figure 5.11 (c); however, additional study needs to be undertaken to measure the safety effectiveness of the modification. The most recent was at US-80 at SR-25 in Marengo County, as shown in Figure 5.12. This modified marking/signing has become a typical approach at these narrower (less than 70-ft.) medians when there is a crash history related to failure to yield at the second crossing. Figure 5.13 shows another example of application of a channelization island and additional signs to prevent WW left turn movements from a driveway in AL.

Figure 5.12 Example of Alternative Marking/Signing at US-80 at SR-25

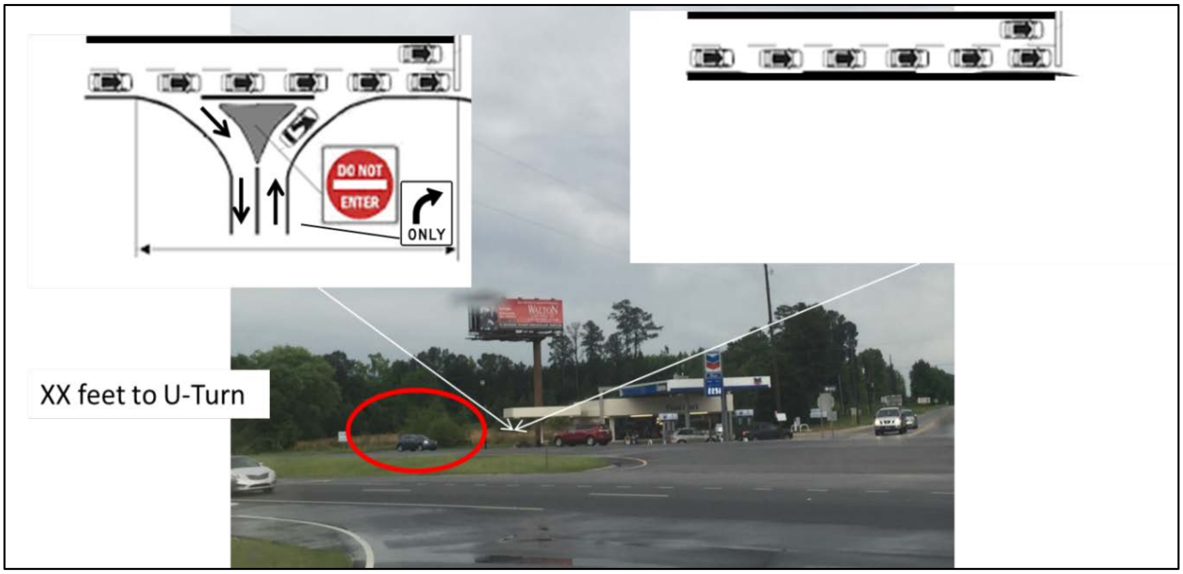


Figure 5.13 Example of Countermeasures for Preventing WW Left Turns from a Gas Station in AL

5.6 Case Study

Of the sites inspected in this study, the following six divided highway-crossroad intersections, with known entry points of WWD crashes in the study period, were used for case studies. The first five resulted from WWD entries from left-turns on crossroads. All happened at nighttime. Three occurred on weekends and two occurred on weekdays. Four WWD entries were made by unimpaired drivers and 1 were by a drunk driver. All five drivers are male, 4 old drivers (>65 years old). The sixth WWD case was caused by undeliberate lane change of a driver under distracted and DUI condition at daytime on weekday.

5.6.1 *Case 1*

Signalized Intersection of US Highway 84 E (Multilane Divided Highway) and AL Highway 85 (Crossroad) (Figure 5.14): the median width is 34 ft. At this intersection, one WWD entry by an unimpaired driver was recorded. The following possible contributing factors were noted:

a. Large turning radius for left turning vehicles
b. Lack of pavement marking to guide large left turning movements
c. Painted median was used to separate through and left turn lanes.

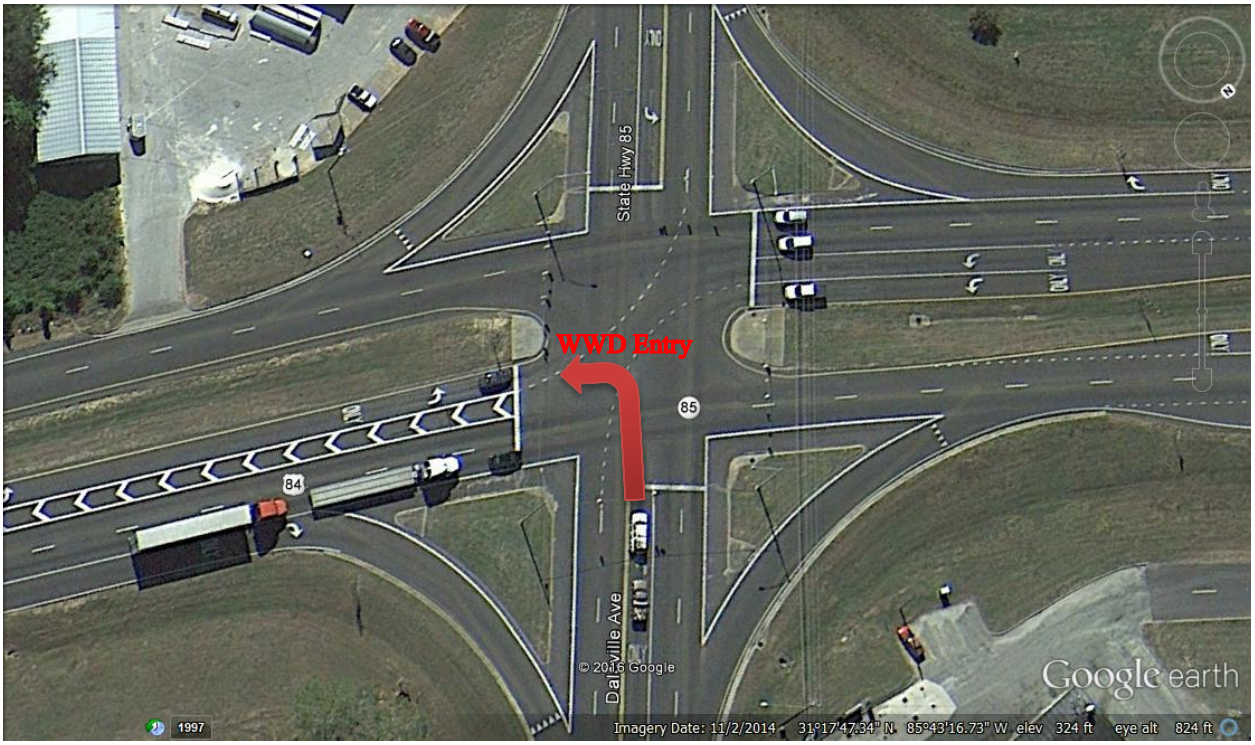


Figure 5.14 Signalized Intersection of US Highway 84 E (Multilane Divided Highway) and AL Highway 85 (Crossroad) in AL

Recommended countermeasures:

a. Add the elephant pavement marking to guide left turns
b. Reduce the width to median nose to increase the width of receiving lanes

5.6.2 *Case 2*

Unsignalized Intersection of US Highway 31 (Multilane Divided Highway) and IGA store parking lot driveway (Crossroad) (Figure 5.15): the median width is 20 ft. At this intersection, one WW entry by an unimpaired driver was recorded. The following possible contributing factors were noted:

a. Both sides of the divided highways have no DNE or WW signs
b. No supplemental signs, i.e. Keep Right, ONE WAY, or Divided Highway signs in the median or at crossroad stop line
c. No STOP sign at the crossroad stop bar

Figure 5.15 Unsignalized Intersection of US Highway 31 (Multilane Divided Highway) and IGA store parking lot driveway (Crossroad) in AL

Recommended countermeasures:

a. Add lane use arrow on both directions of major highways
b. Add STOP sign at the driveway
c. Add KEPT RIGHT sign at the median

5.6.3 *Case 3*

Unsignalized Intersection of AL Highway 75 (Multilane Divided Highway) and AL Highway 68 (Crossroad) (Figure 5.16): the median width is 77 ft. At this intersection, one WWD entry by an unimpaired driver was recorded. The following possible contributing factors were noted:

a. Both sides of the divided highways have no WW signs
b. DNE signs are not visible, too far away from the intersection
c. No supplemental signs, i.e. Keep Right, ONE WAY, or Divided Highway signs at the median opening
d. Faded pavement markings
e. Darkness/no lighting exists

Figure 5.16 Unsignalized Intersection of AL Highway 75 (Multilane Divided Highway) and AL Highway 68 (Crossroad) in AL

Recommended countermeasures:

a. The intersection should be treated as two separate intersections for WW-related signs per MUTCD.
b. Add lane use arrow on both sides of major roads

5.6.4 *Case 4*

Unsignalized Intersection of US 231 (Multilane Divided Highway) and Private Property Driveway (Crossroad) (Figure 5.17): the median width is 30 ft. At this intersection, one WW entry by a drunk driver was made. The following possible contributing factors were noted:

a. No DNE or WW signs
b. No supplemental signs, i.e. Keep Right, ONE WAY, or Divided Highway signs at the median opening
c. No STOP sign at the crossroad stop bar
d. Darkness/no lighting

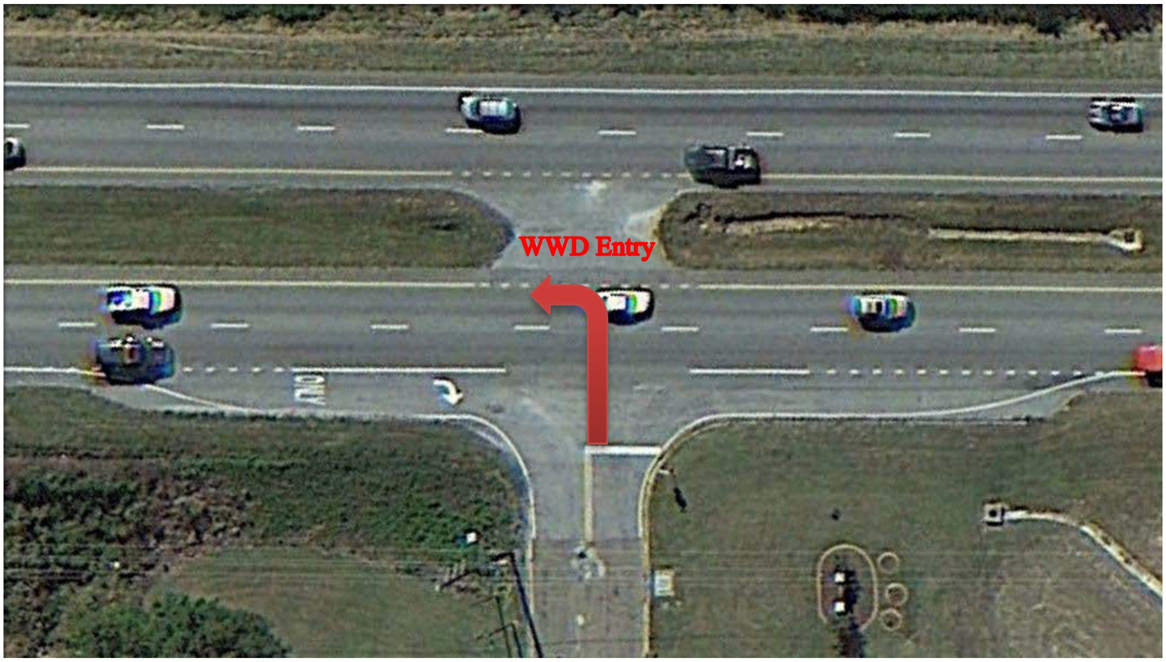


Figure 5.17 Unsignalized Intersection of US 231 (Multilane Divided Highway) and Private Property Driveway (Crossroad) in AL

Recommended countermeasures:

a. Add STOP sign at the crossroad
c. Improve WW-related signs
d. Add lane use through arrow on both directions of major highways

5.6.5 *Case 5*

Unsignalized Intersection of US HWY 431 S (Multilane Divided Highway) and Byron Ave. (Crossroad) (Figure 5.18): The median width is 18 ft. At this intersection, one wrong-way entry by an unimpaired driver has been made. The following possible contributing factors were noted:

a. No DNE or WW signs
b. No roadway information signs, i.e. Keep Right, ONE WAY, or Divided Highway signs in the median or at the crossroad stop line
c. No STOP sign at the crossroad stop bar
d. Darkness/no lighting exists at nighttime

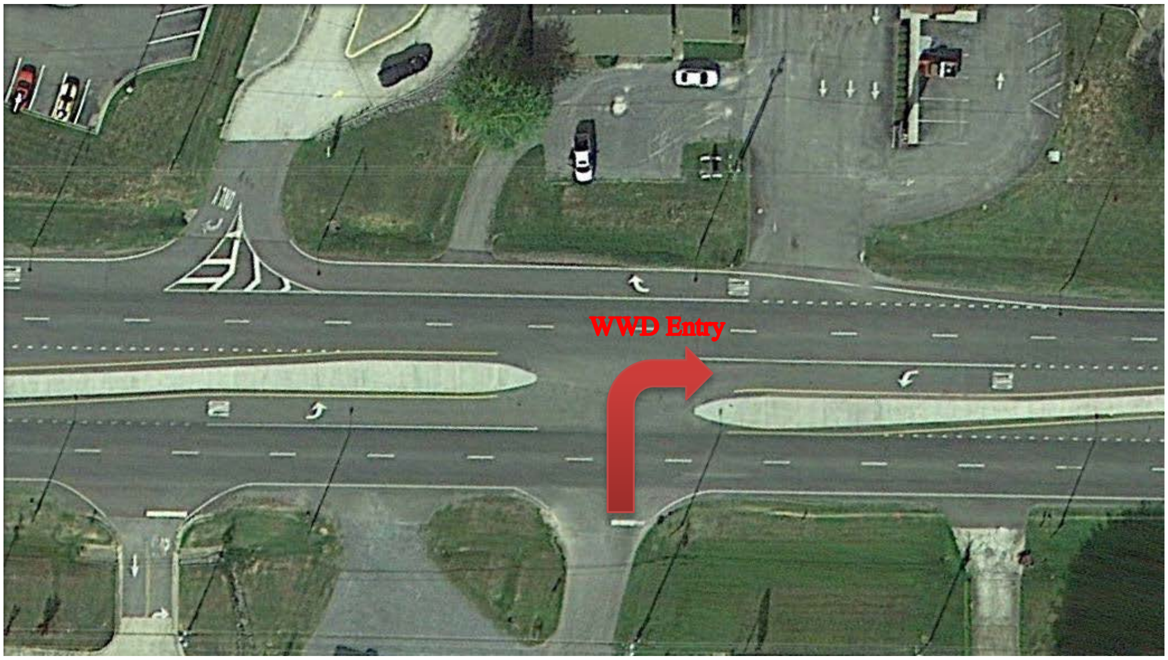


Figure 5.18 Unsignalized Intersection of US HWY 431 S (Multilane Divided Highway) and Byron Ave. (Crossroad) in AL

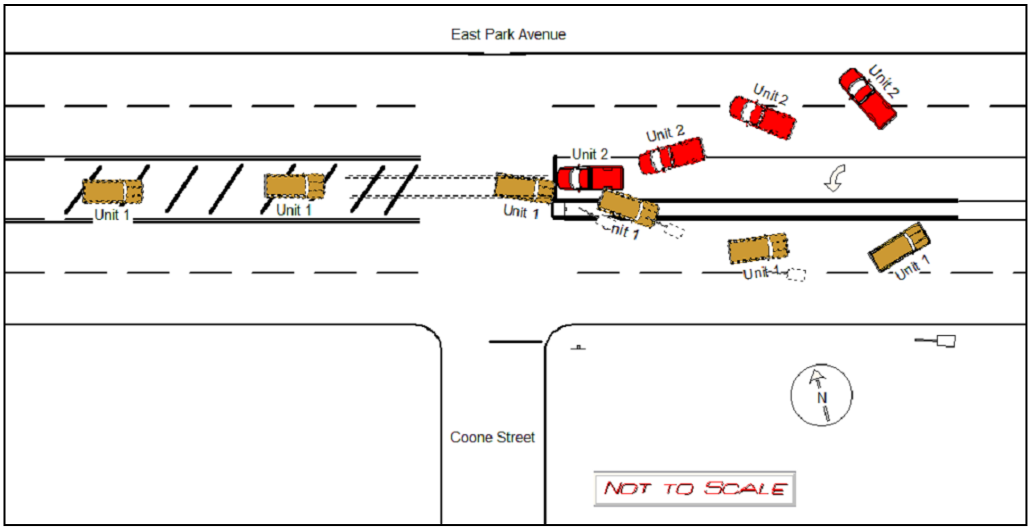
Recommended countermeasures:

a. Add STOP sign at the crossroad
b. Improve WW-related signs
c. Add lane use through arrow on both directions of major highways

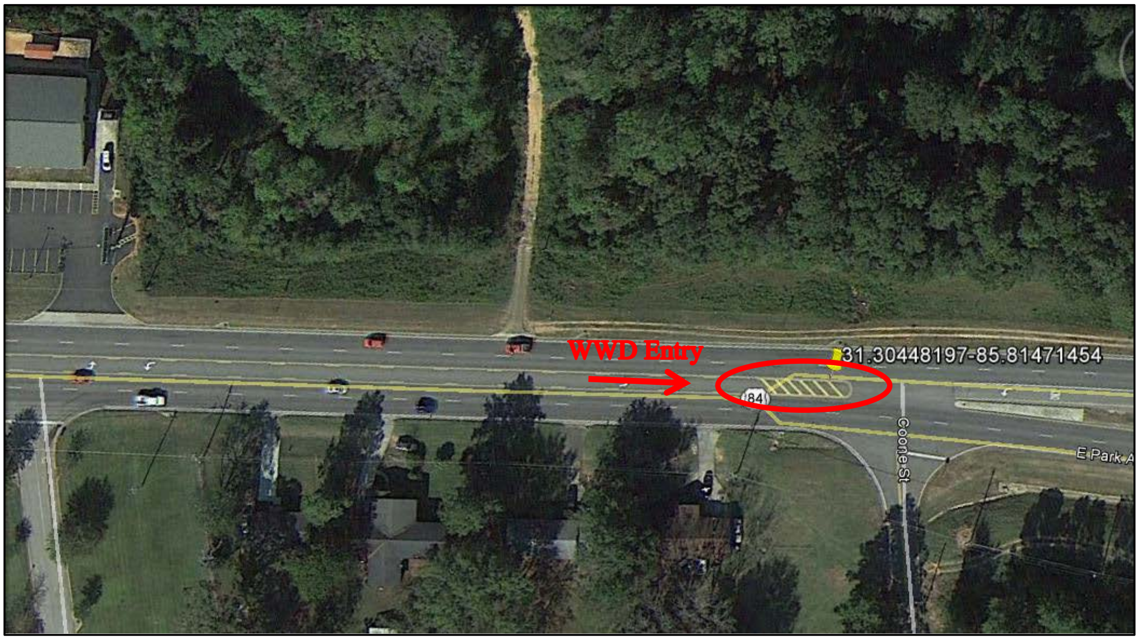
5.6.6 *Case 6*

Unsignalized Intersection of East Park Avenue (Multilane Divided Highway) and Coone Street (Crossroad) (Figure 5.19): at this intersection, one WWD entry by a drunk driver has been made at the end of a two-way left turn lane. The following deficiencies were noted:

a. The two-way left turn lane extended too far into the median road
b. Painted median is not effective enough to stop WWD
c. No signs to discourage WWD



(a) Crash diagram by ALDOT



(b) Full view

Figure 5.19 Unsignalized Intersection of East Park Avenue (Multilane Divided Highway) and Coone Street (Crossroad) in AL.

Recommended countermeasures:

a. Install raised curb median at the end of two-way left turn lane

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study developed and refined knowledge of the contributing factors and corresponding countermeasures on WWD on multilane divided highways in Alabama. This was done through a review of the current literature on the subject, and the data collected and analyzed in the execution of the project. The ALDOT crash database, along with the hardcopy reports of possible WWD crashes, were used to identify the crashes that were truly caused by WW drivers on divided highways. 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 obtain a better understanding of the WWD crashes on divided highways, these distributions were compared with other crashes on divided highways. Haddon matrix analyses were conducted to identify the contributing factors according to human, vehicle, and environmental characteristics for pre-crash, during-crash, and post-crash time periods. Consequently, older drivers, male drivers, being under the influence of alcohol/drugs, driving passenger cars, and darkness were found as notable factors with higher frequency in fatal, A-injury, and B-injury crashes. The active roles of seatbelt and airbag use are shown in providing safety for the vehicle occupants during crash.

A correlation analysis concluded that the correlation between "DUI Drivers" and "Night Crashes" is a significant positive number, which means that a WWD crash occurring during nighttime is likely to involve DUI drivers. Based on the results of the crash data analysis using logistic regression models, factors including driver age, driver condition, seatbelt use, type of setting, airbag status, and lighting conditions were found to distinguish between WWD crashes and other divided highway crashes. Odds ratios (OR) as a measure of relative effectiveness were estimated to quantify the effect of these variables. Accordingly, drivers who cause WWD crashes are more likely to be 55 to 64 years old (OR=2.46) or 65 and older (OR=6.43), to be under the influence of alcohol and drugs (OR=3.98) or to be ill (OR=3.38), to be driving in an urban area (OR=1.95), not using a seatbelt (OR=2.10), to be driving in the dark with lighting provided (OR=4.96) or dark without any kind of lighting (OR=12.15), which is the highest among other categories under the variable. Moreover, WWD crashes can be characterized by airbag deployment (OR=3.74).

Datasets of median widths, grade changes, and relevant vertical curvatures for all 110 possible WW entry medians were further collected and processed for sight distance calculations and determination. Field inspections were conducted at 34 selected possible WWD entry median openings with median widths between 7 and 119 ft. The rationale behind this method is that if left-turn or through drivers from side streets cannot see the far side of the main roadways at nighttime, then it is necessary to treat the median opening as two intersections for WW-related TCDs. If the determined sight distance is not enough based on the cross section profile, median width and grade change, TCDs should follow the treatments for two separate intersections. Conditions of TCDs were also examined at the 34 selected fields for the purpose of deterring WWD.

Countermeasures for WWD crash reduction were recommended to improve traffic safety on multilane divided highways. Two sets of data analyses were conducted to analyze the correlation between median widths and WWD crashes, to re-evaluate the current breakpoint for median width, to determine sight distance requirements, and to examine if the existing TCDs are sufficient to deter WW movements on divided highways. Any measure that improves the driver's visibility and perception of access points to divided highways would potentially decrease WW movements. Possible measures included night lighting, properly design the elevation of crossroads, making medians more distinct and the use of simple, understandable configurations. At service areas, the use of additional channelization will direct traffic in the right direction and could deter WW movements.

6.2 Recommendations

The study identified the significant contributing factors to WWD crashes on divided highways based on crash data analysis and general issues through extensive field inspection and review. The countermeasures developed can be implemented in two phases. Phase one focuses on short-term, low-cost countermeasures, such as regular maintenance and inspection of the existing signing, pavement markings, median modifications, and simple access management techniques. Phase two is a long-term, systematic approach on improving geometric design elements, education, enforcement, and the application of ITS technologies.

6.2.1 Short-term, Low-cost Countermeasures

It was found from field review that besides the geometric features of median openings, a lack of required TCDs makes a WWD event more likely. These types of countermeasures are mainly related to traditional signing and pavement marking. Additionally, as darkness was the common condition for the majority of the WWD crashes on divided highways, visibility of TCDs may be improved using several methods such as adding small LED units along the sign’s borders to catch a WW driver’s attention, affixing red retro-reflective strips to the sign supports to enhance nighttime visibility, and adding retro-reflective raised pavement markers. Furthermore, using illuminated signs will be practical countermeasures. Older drivers and DUI drivers are the main contributors to WWD crashes, so enlarging the size of traffic signs, adding a second identical sign and using augmenting warning signs at high frequency WWD crashes locations could draw more attention from drivers. According to the Traffic Manual of Californian Transportation and Housing Department of Transportation, WW arrows (type V arrows) accompanied by warning signs can also be installed on divided highways. It can help WW drivers realize that they are running the risk of WWD and can prevent WWD crashes effectively. This countermeasure is now extensively used on California divided highways. Figure 6.1 shows this type of WWD treatment on divided highways in California.

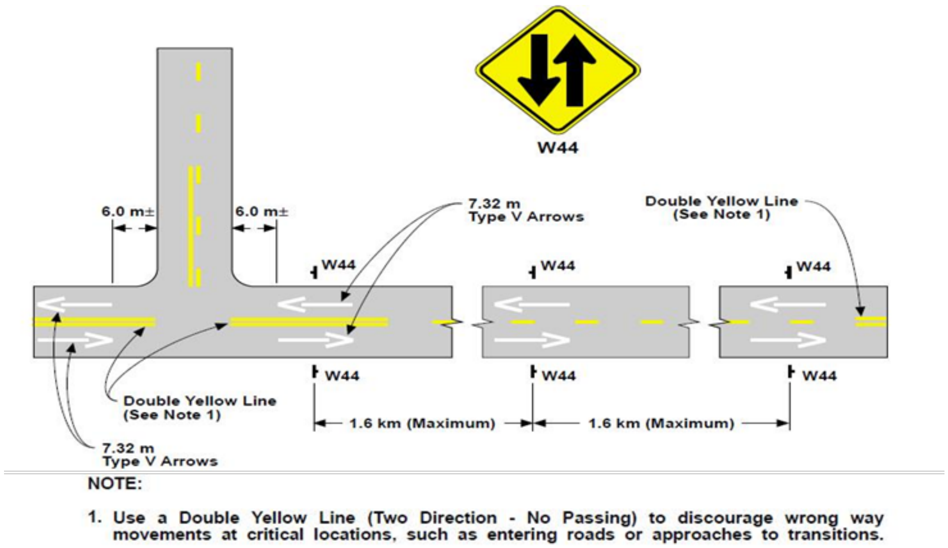


Figure 6.1 WWD Treatment on Divided Highway in California

More general issues and corresponding low-cost countermeasures to deter WWD are summarized in a report of *Guidelines for Reducing Wrong-way Crashes on Freeways* by the Illinois Department of Transportation (Zhou and Pour-Rouholamin, 2014), regarding the use of traffic signs, pavement markings, traffic signals and geometric design elements.

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). These proposed countermeasures and strategies can help prevent WWD incidents and reduce the severity of the WWD crashes on multilane divided highways. Engineering: it is recommended that a WWD inspection team conduct field reviews of high crash divided highways sections or median openings. Also, it is recommended that guidelines for WW-related signage, pavement marking, and geometric designs be developed. Education strategies can be implemented to improve public awareness and understanding of (1) the basics of road designs and median 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 focus especially on old drivers and DUI drivers. Enforcement strategies that could be implemented include adding data-driven DUI checkpoints, ways to stop WW drivers, and using radio, dynamic message signs (DMS), ITS, Connected Vehicle, Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) to warn right-way drivers of oncoming WW drivers. However, countermeasures alone cannot eliminate WWD incidents by impaired driving. Thus, in addition to engineering, enforcement and education, emergency response should also be incorporated into any WWD mitigation program.

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APPENDIX A
FIGURES FOR WWD CRASH DATA ANALYSIS

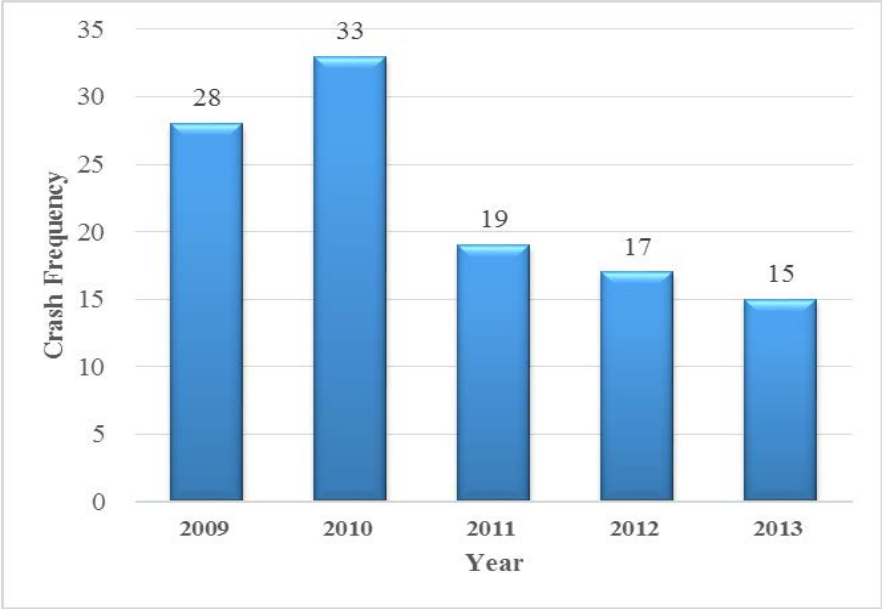


Figure A.1. Annual distribution of wrong-way crashes.

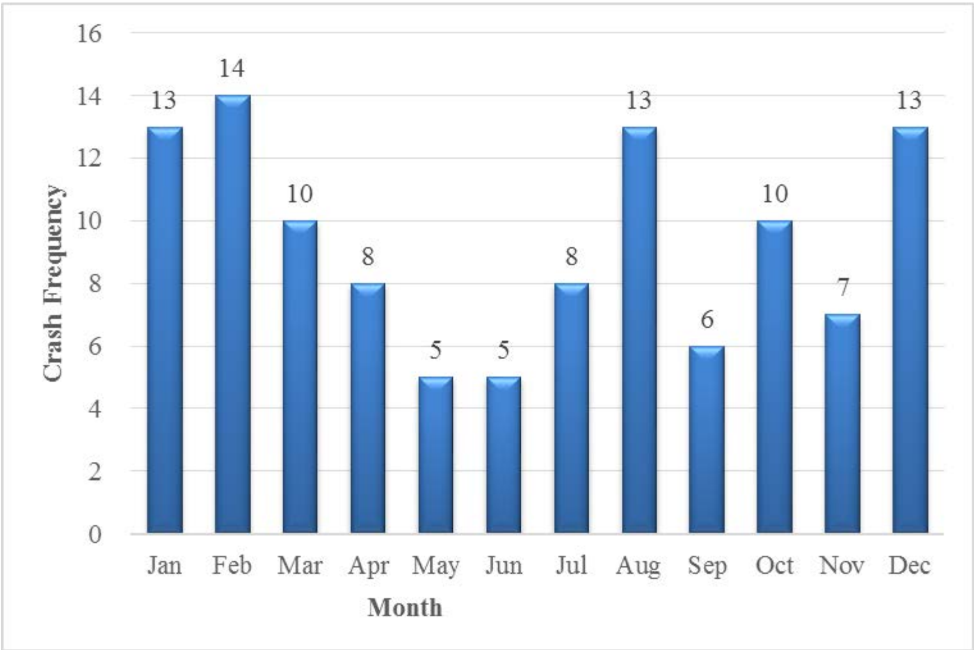


Figure A.2. Monthly distribution of wrong-way crashes.

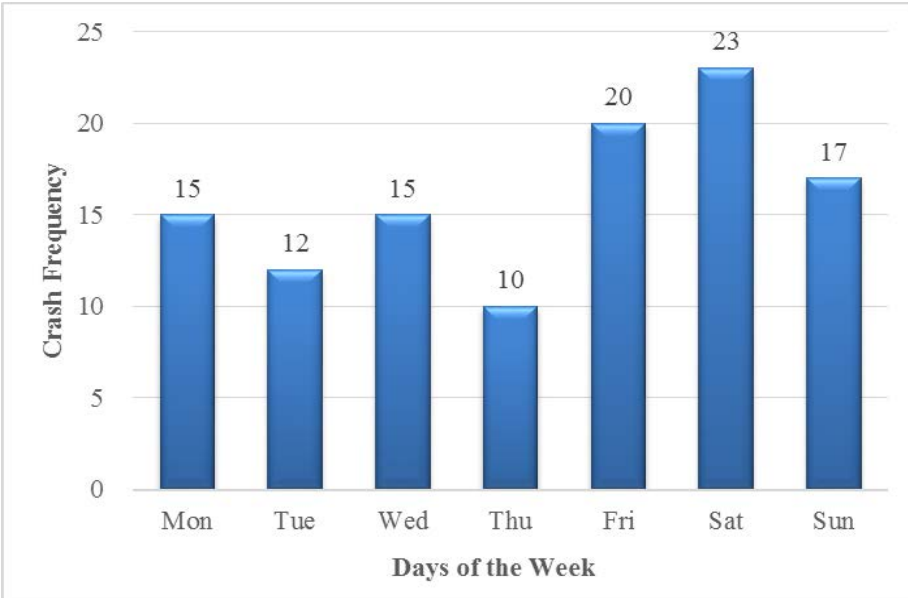


Figure A.3. Weekly distribution of wrong-way crashes.

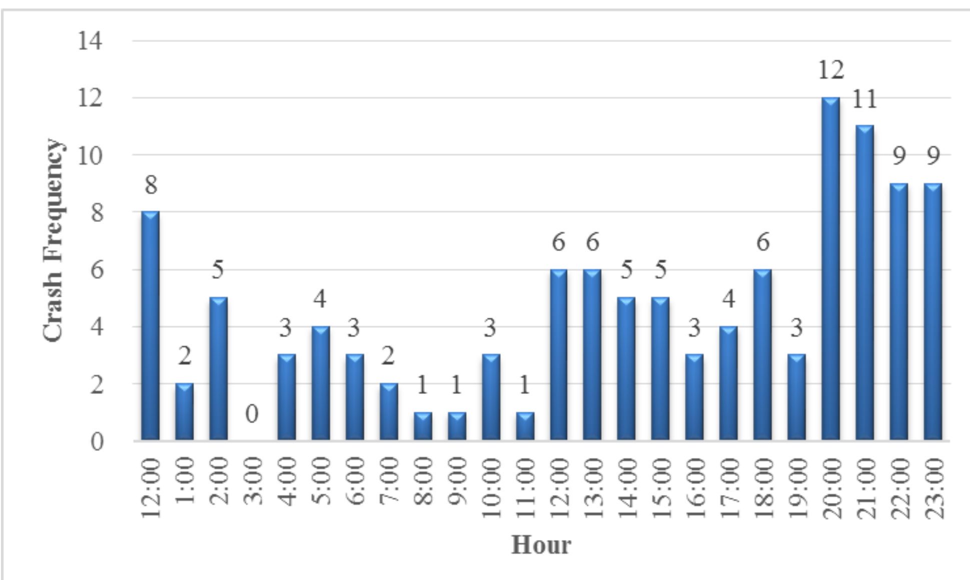


Figure A.4. Hourly distribution of wrong-way crashes.

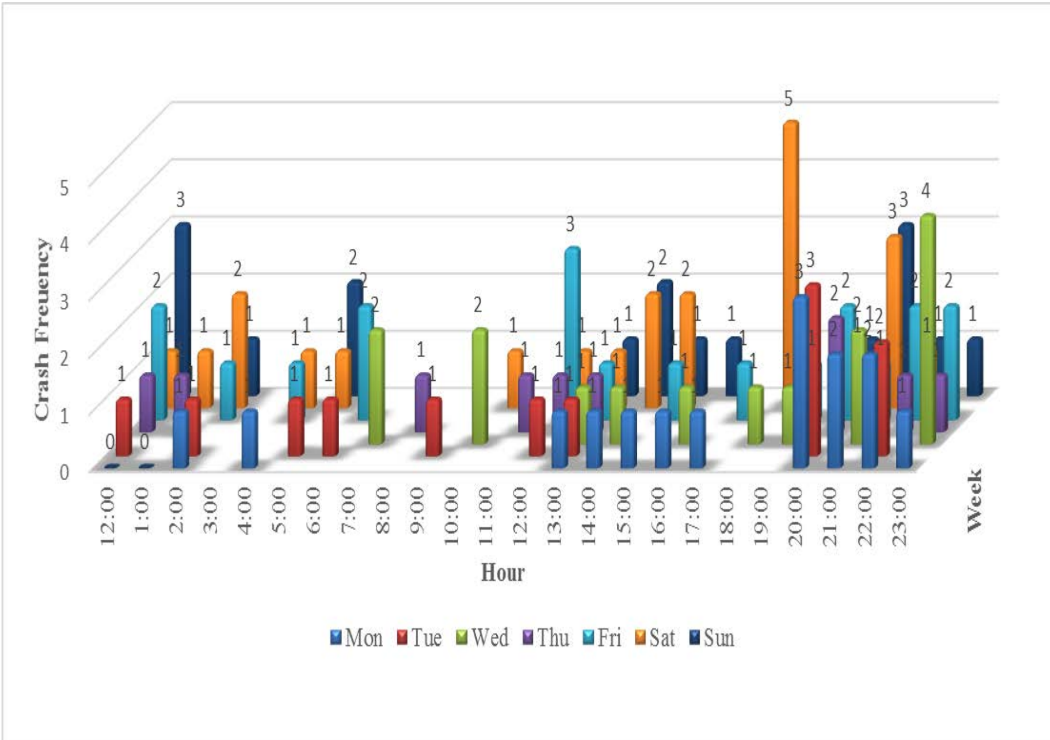


Figure A.5. Temporal distribution of wrong-way crashes.

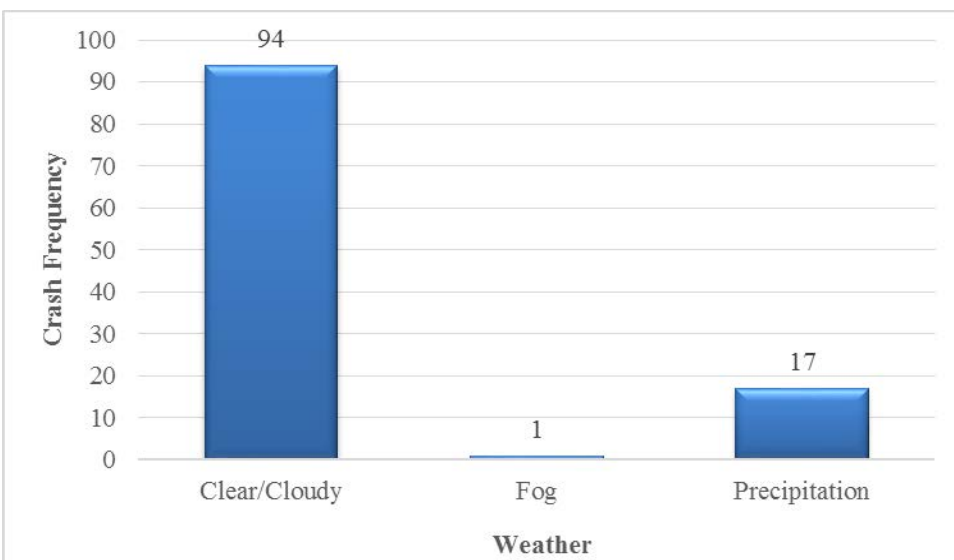


Figure A.6. Weather condition for wrong-way crashes.

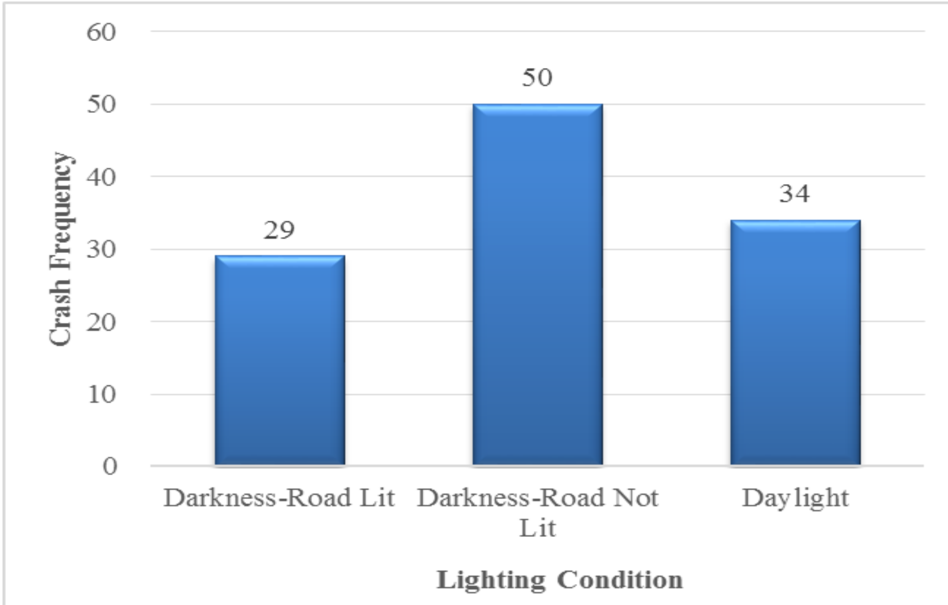


Figure A.7. Lighting condition for wrong-way crashes.

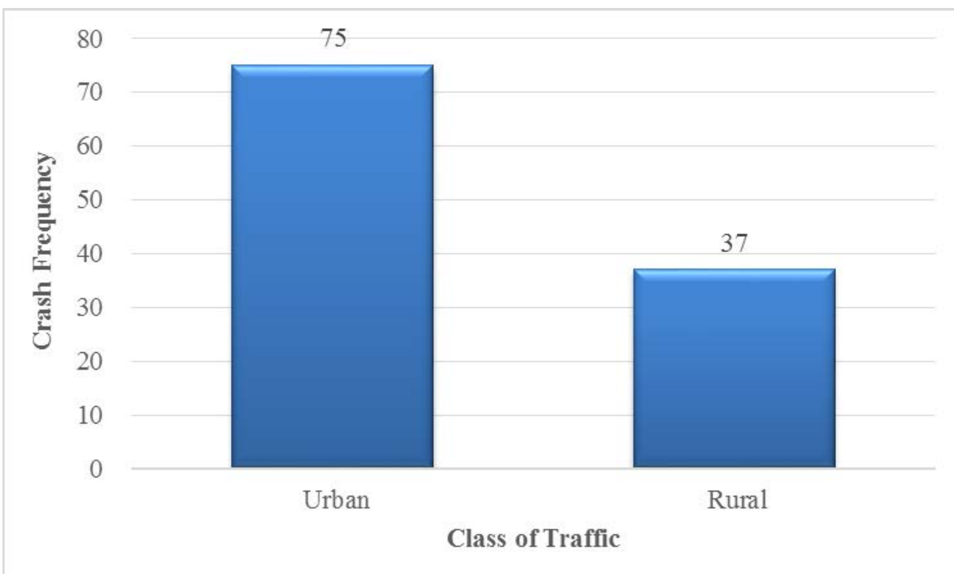


Figure A.8. Class of traffic way for wrong-way crashes.

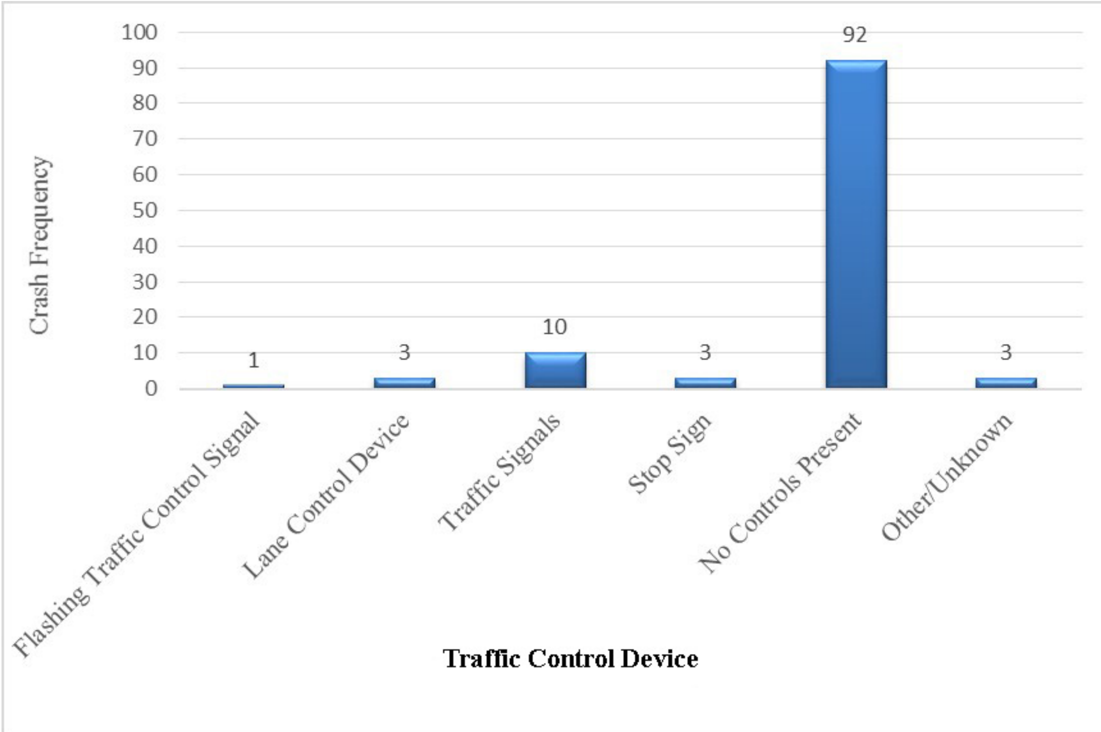


Figure A.9. Traffic control device presence for wrong-way crashes.

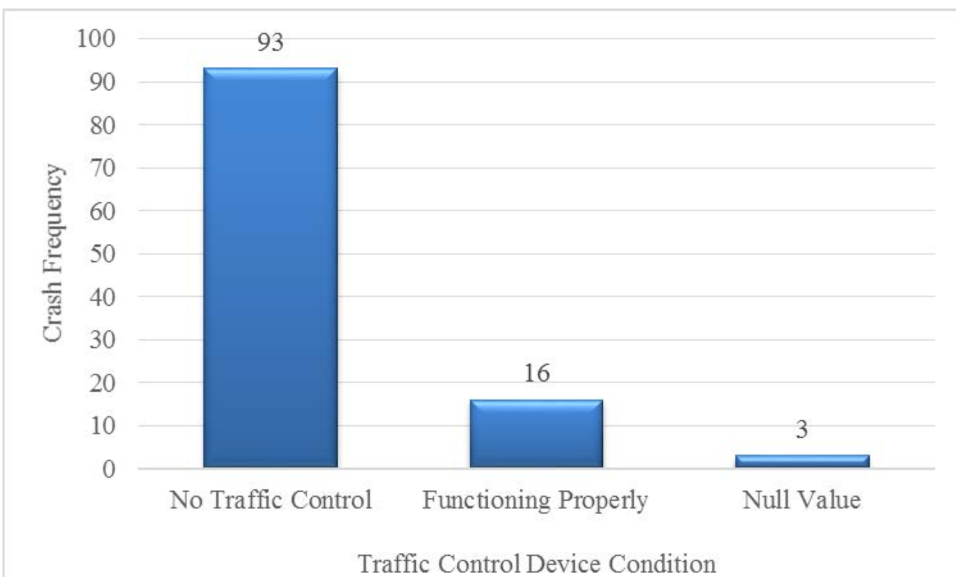


Figure A.10. Traffic control device operating condition for wrong-way crashes.

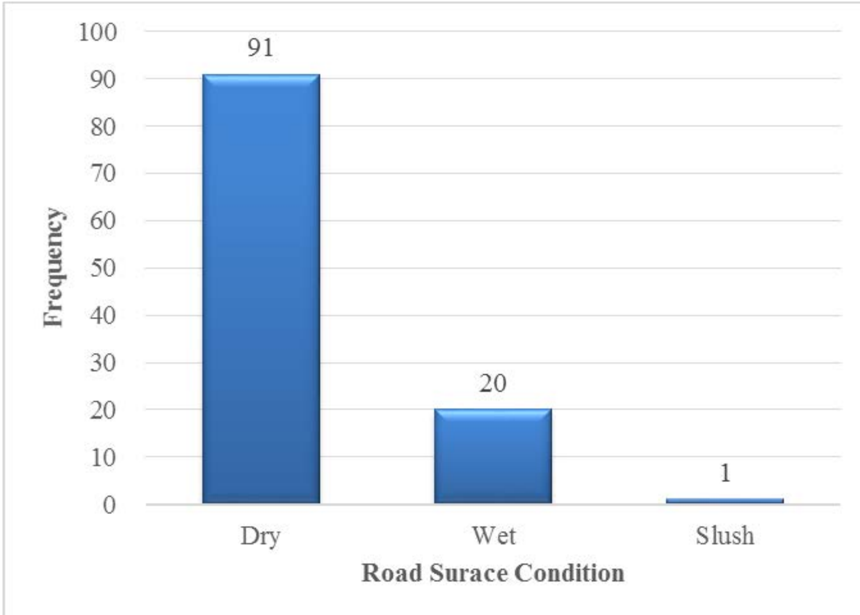


Figure A.11. Road surface condition for wrong-way crashes.

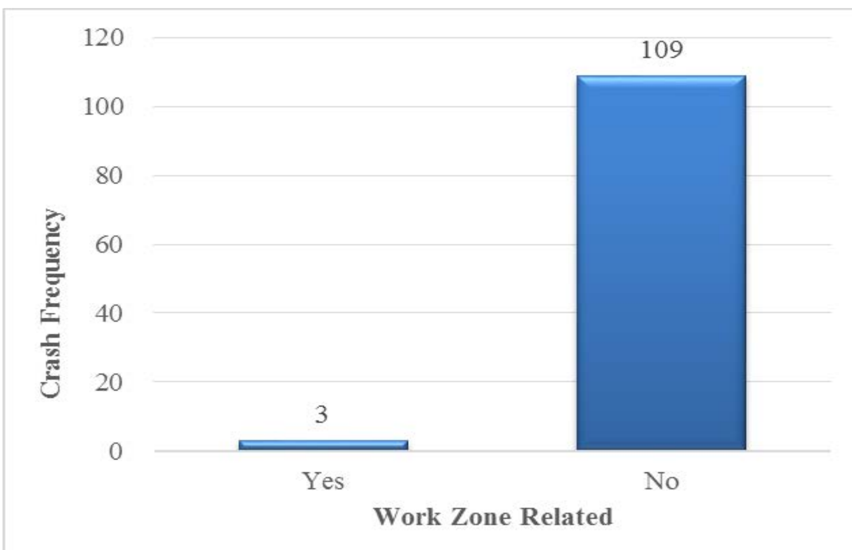


Figure A.12. Work zone–related wrong-way crashes.

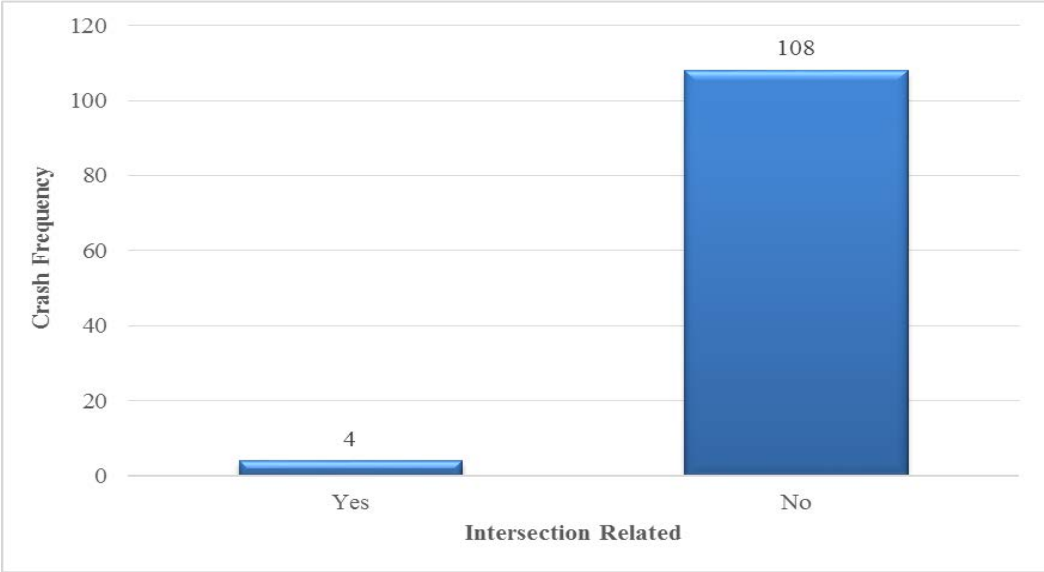


Figure A.13. Relationship between intersections and wrong-way crashes.

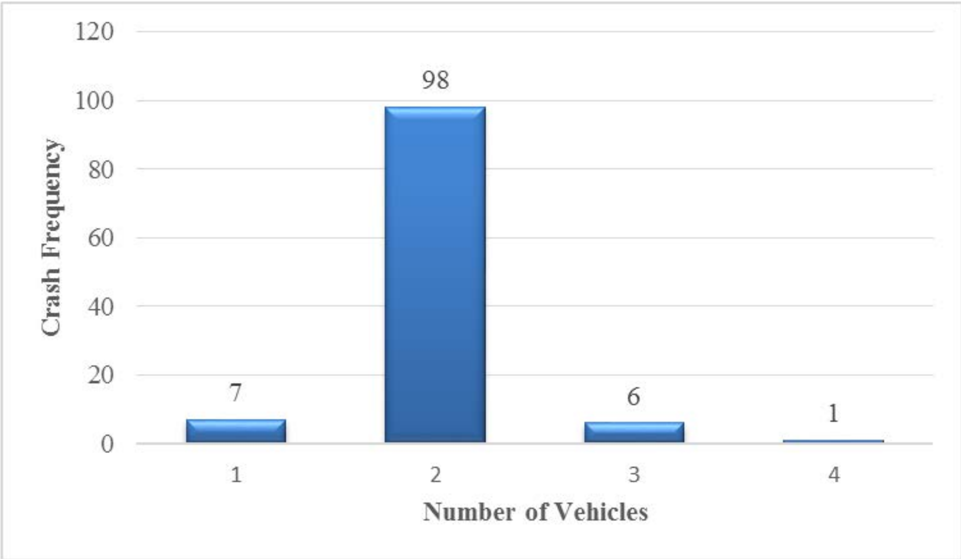


Figure A.14. Number of vehicles involved in wrong-way crashes.

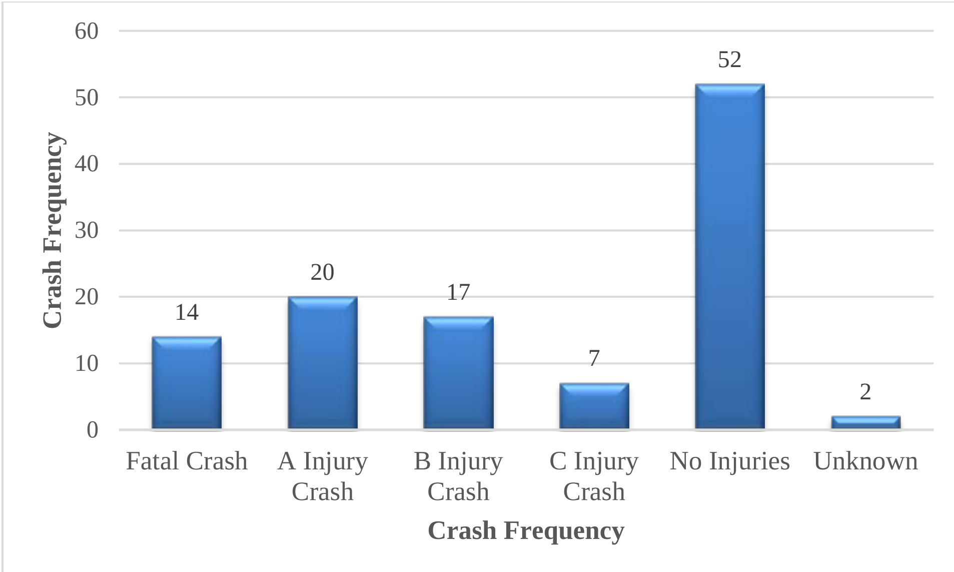


Figure A.15. Wrong-way crash severity.

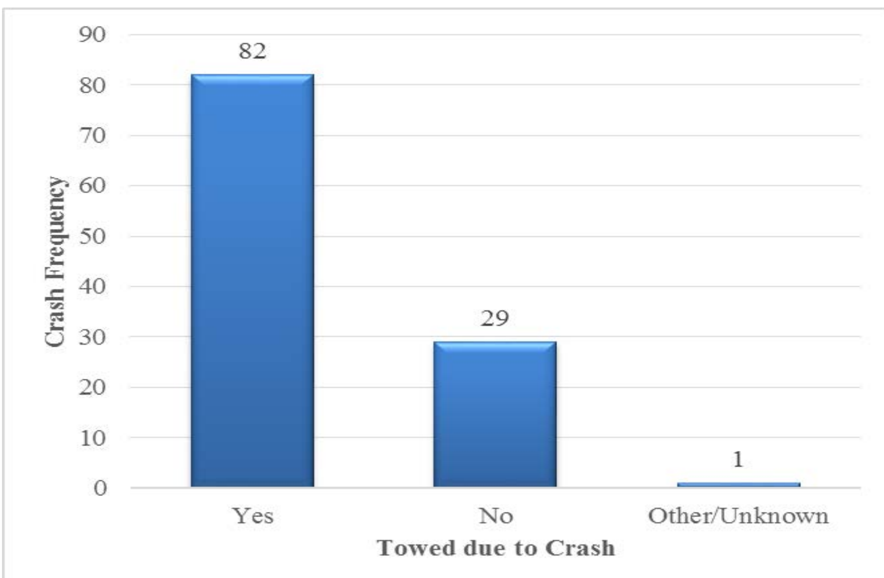


Figure A.16. Towed due to crash for wrong-way crashes.

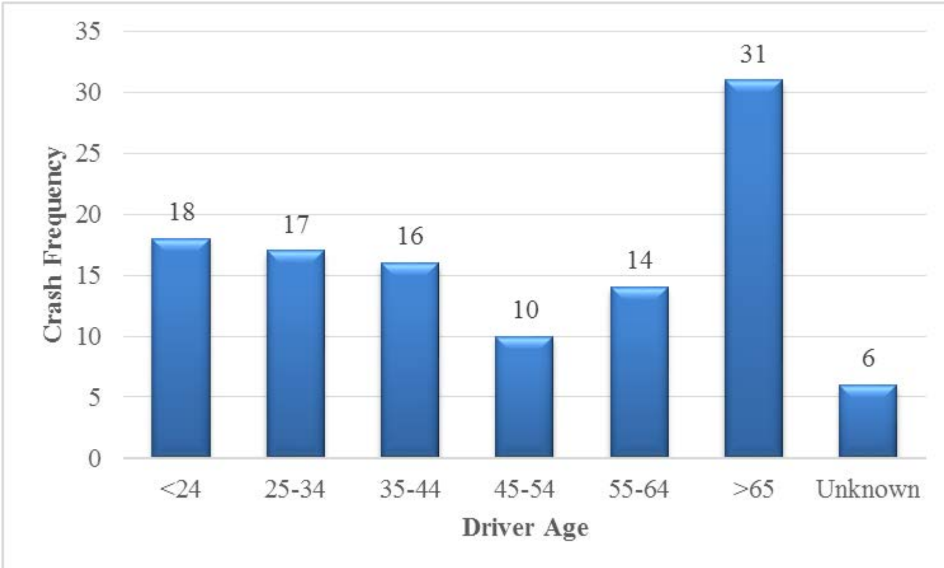


Figure A.17. Wrong-way driver age group.

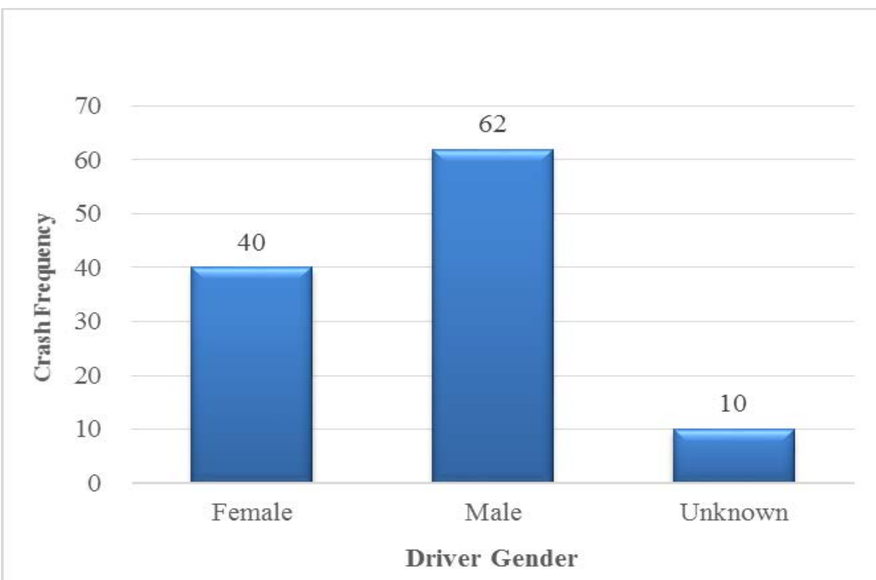


Figure A.18. Wrong-way driver gender distribution.

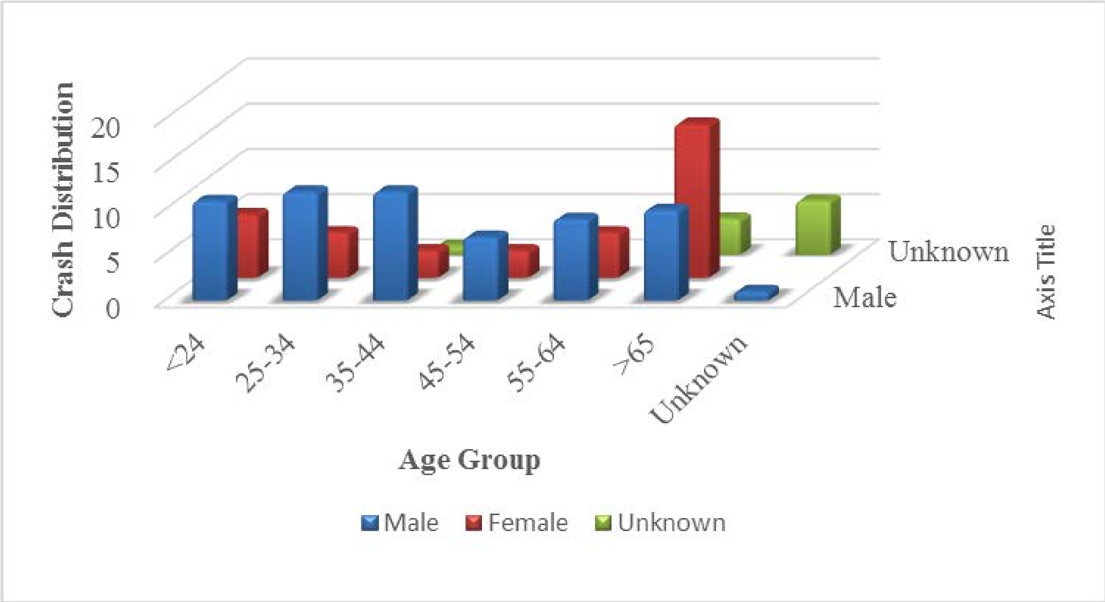


Figure A.19. Relationship between wrong-way driver age group and gender.

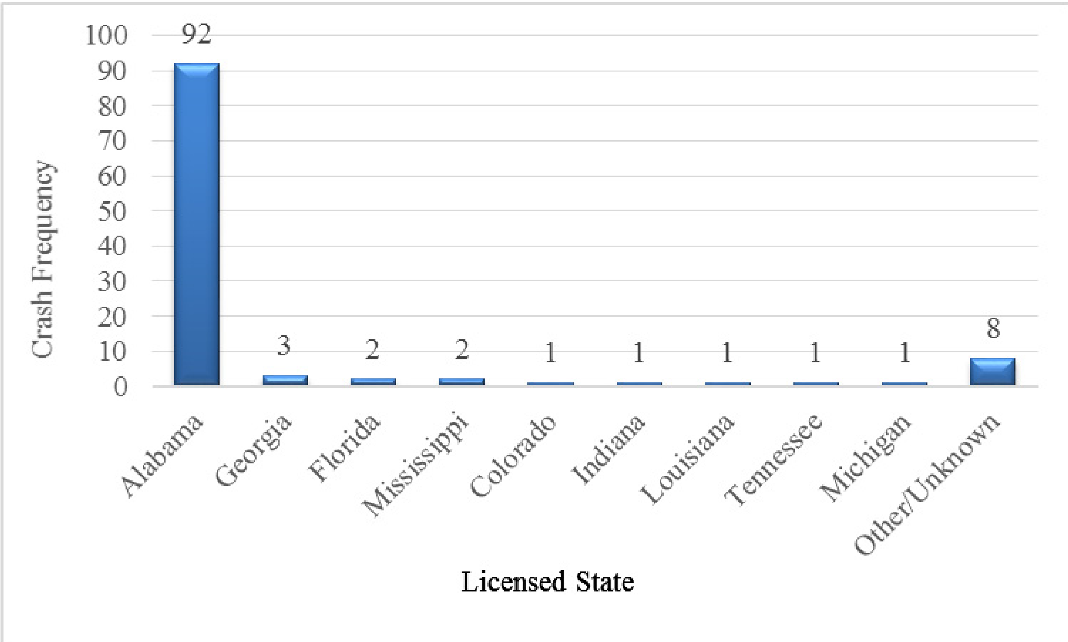


Figure A.20. Licensed state for wrong-way drivers.

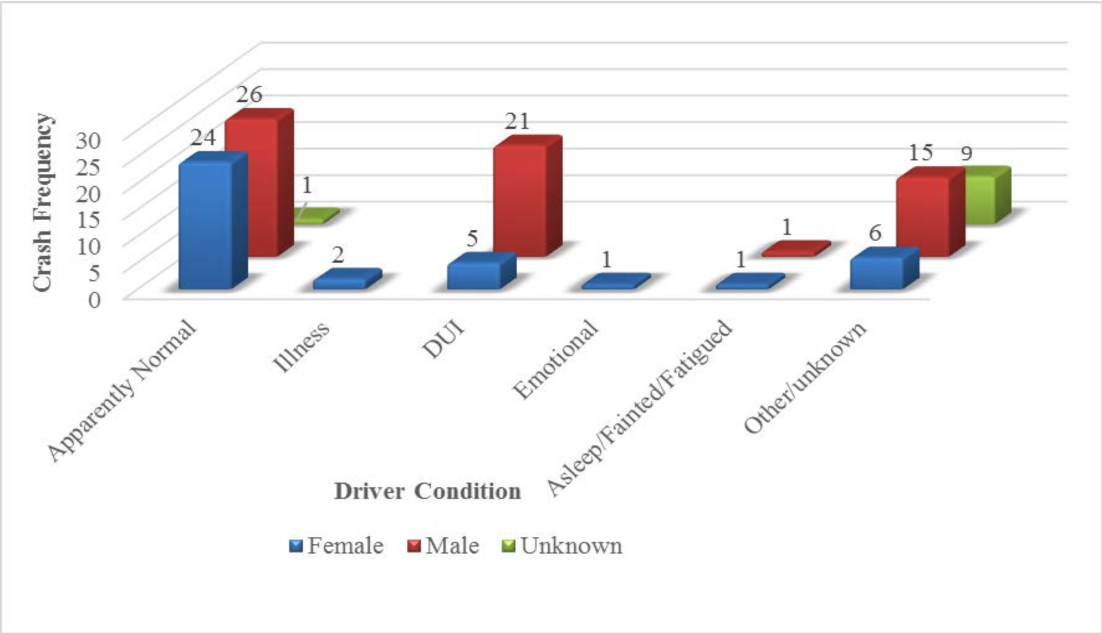


Figure A.21. Relationship between driver gender and condition.

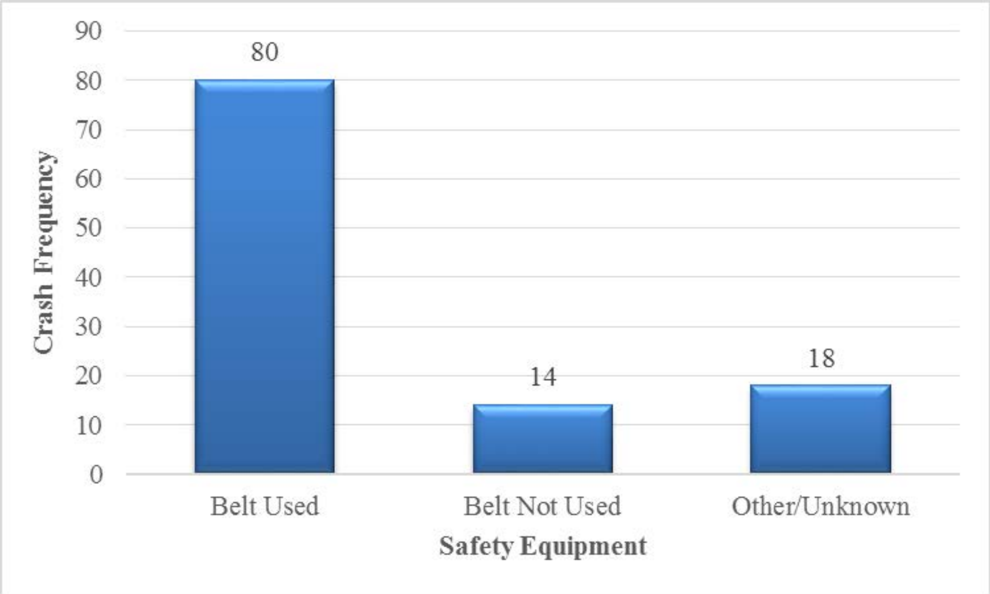


Figure A.22. Safety equipment used by wrong-way drivers.

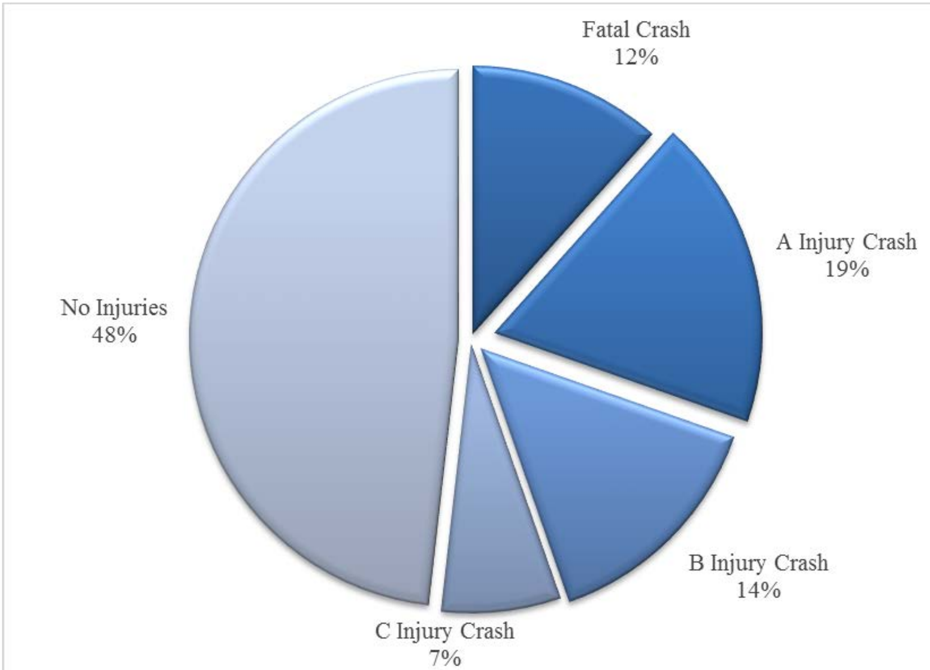


Figure A.23. Injury severity level for wrong-way drivers.

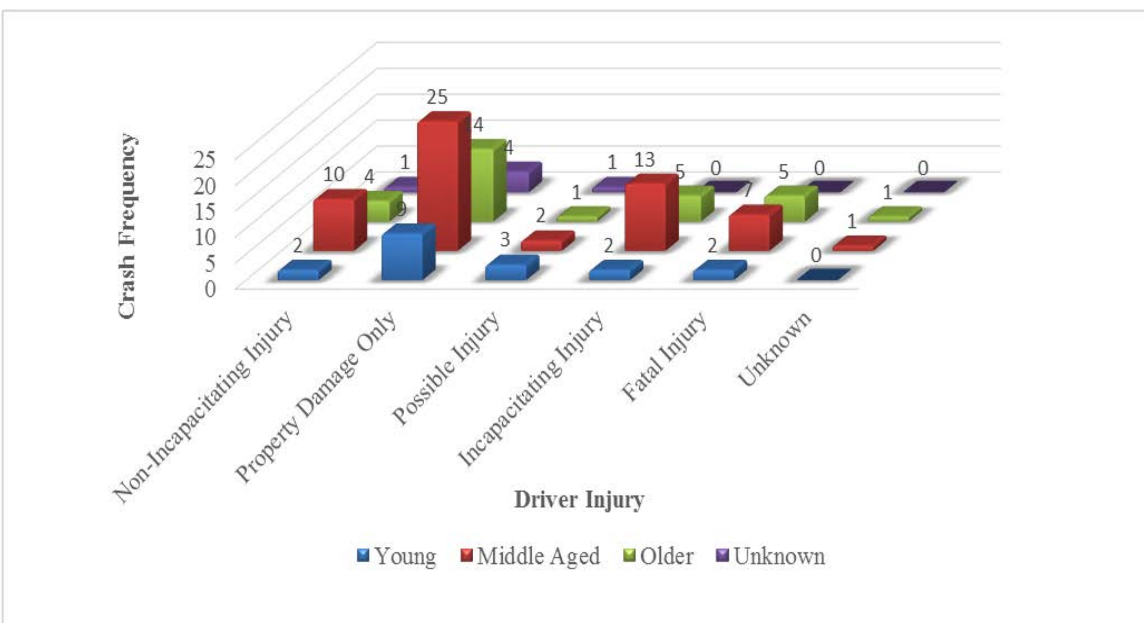


Figure A.24. Relationship between driver injury severity level and driver age group

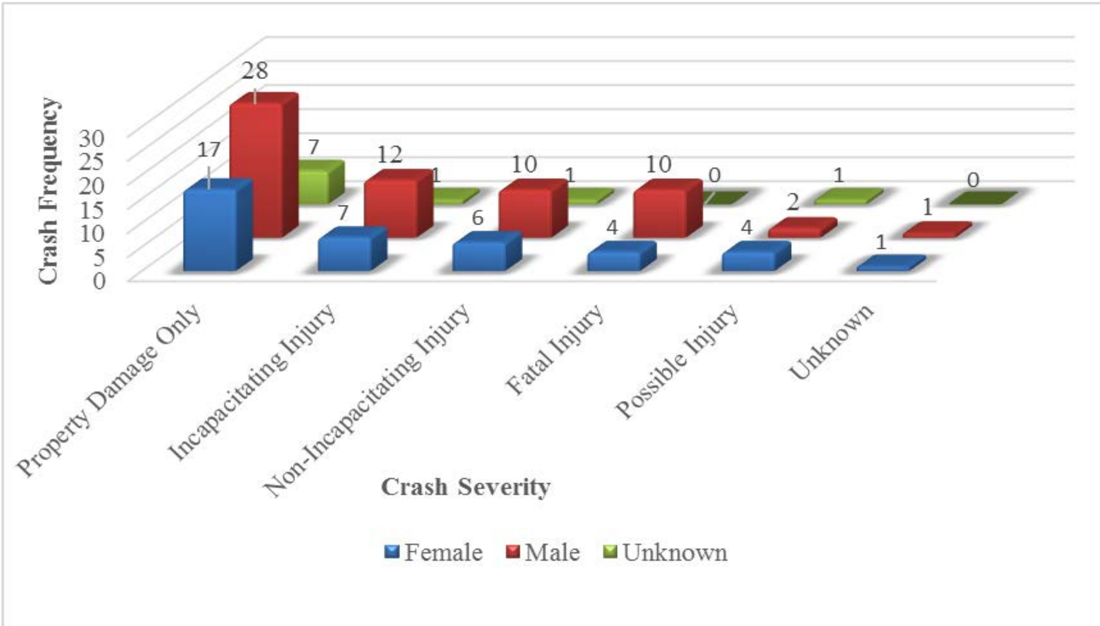


Figure A.25. Relationship between driver injury severity level and driver gender

APPENDIX B
TABLES FOR WWD CRASH DATA ANALYSIS

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

Route	Frequency	Percent
AL-1	24	21%
AL-2	10	9%
AL-3	11	10%
AL-4	1	1%
AL-5	5	4%
AL-6	4	4%
AL-7	1	1%
AL-8	2	2%
AL-9	1	1%
AL-12	11	10%
AL-13	4	4%
AL-14	1	1%
AL-16	2	2%
AL-21	5	4%
AL-38	11	10%
AL-39	1	1%
AL-53	3	3%
AL-67	1	1%
AL-69	1	1%
AL-75	2	2%
AL-79	1	1%
AL-149	1	1%
AL-157	1	1%
AL-158	2	2%
AL-192	1	1%
AL-193	1	1%
AL-210	3	3%
Unknown	1	1%

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

Ranking	County	No. of WWD Crashes	Percent
1	Jafferson	12	11%
2	Madison	11	10%
3	Houston	10	9%
4	Russell	7	6%
5	Lee	6	5%
6	Cullman	5	4%
7	Mobile	5	4%
8	Morgan	5	4%
9	Tuscaloosa	5	4%
10	Marshall	4	4%
11	Shelby	4	4%
12	Barbour	3	3%
13	Coffee	3	3%
14	Dale	3	3%
15	Franklin	3	3%
16	Walker	3	3%
17	Tallapoosa	3	3%
18	Calhoun	2	2%
19	Elmore	2	2%
20	Etowah	2	2%
21	Jackson	2	2%
22	Talladega	2	2%
23	Russell	1	1%
24	Autauga	1	1%
25	Baldwin	1	1%
26	Chambers	1	1%
27	Colbert	1	1%
28	Covington	1	1%
29	Dallas	1	1%
30	Escambia	1	1%
31	Lauderdale	1	1%
32	Limestone	1	1%
33	Montgomery	1	1%
Total		112	100%

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

Ranking	City Name	Frequency	Percentage	Ranking	City Name	Frequency	Percentage
1	Phenix City	6	5%	**35**	Rural Colbert	1	1%
2	Rural Madison	5	5%	**36**	Rural Russell	1	1%
3	Rural Lee	5	5%	**37**	Attalla	1	1%
4	Rural Houston	4	5%	**38**	Rural Walker	1	1%
5	Dothan	4	5%	**39**	Rural Tuscaloosa	1	1%
6	Rural Cullman	4	5%	**40**	Vestavia Hills	1	1%
7	Birmingham	4	5%	**41**	Rural Franklin	1	1%
8	Enterprise	3	5%	**42**	Alexander City	1	1%
9	Huntsville	3	5%	**43**	Killen	1	1%
10	Tuscaloosa	3	5%	**44**	Kimberly	1	1%
11	Rural Shelby	3	5%	**45**	Waverly	1	1%
12	Eufaula	3	5%	**46**	Ashford	1	1%
13	Daleville	2	5%	**47**	Rural Mobile	1	1%
14	Rural Elmore	2	5%	**48**	Smiths Station	1	1%
15	Rural Marshall	2	5%	**49**	Rural Morgan	1	1%
16	Russellville	2	5%	**50**	Sardis City	1	1%
17	Decatur	2	5%	**51**	New Hope	1	1%
18	Rural Talladega	2	5%	**52**	Cullman	1	1%
19	Jasper	2	5%	**53**	Creola	1	1%
20	Scottsboro	2	5%	**54**	Homewood	1	1%
21	Hartselle	2	5%	**55**	Spanish Fort	1	1%
22	Anniston	2	5%	**56**	Sanford	1	1%
23	Mobile	2	5%	**57**	Northport	1	1%
24	Albertville	1	5%	**58**	Ozark	1	1%
25	Rural Dale	1	5%	**59**	Madison	1	1%
26	Saraland	1	5%	**60**	Montgomery	1	1%
27	Pelham	1	5%	**61**	Cowarts	1	1%
28	Prattville	1	5%	**62**	Morris	1	1%
29	Selma	1	5%	**63**	Leeds	1	1%
30	Tarrant City	1	5%	**64**	Kimberly	1	1%
31	Rural Tallapoosa	1	5%	**65**	Boaz	1	1%
32	Rural Jefferson	1	5%	**66**	Owens Crossroads	1	1%
33	Athens	1	5%	**67**	Brewton	1	1%
34	Bessemer	1	5%	**68**			

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

Collision Type	Frequency
Angle Oncoming (frontal)	8
Angle Opposite Direction	9
Angle Same Direction	1
Causal Vehicle Backing: Rear to Rear	1
Head-on	48
Non-collision	2
Rear End (front to rear)	2
Side Impact	6
Sideswipe - Opposite direction	20
Sideswipe - Same Direction	2
Single Vehicle Crash	9
Other	4
Total	112

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

Crash Severity	Total	2009	2010	2011	2012	2013
Fatal Crash	14	4	3	1	6	0
A Injury Crash	20	8	7	2	0	3
B Injury Crash	17	2	5	3	3	3
C Injury Crash	7	1	4	1	1	1
No Injuries	52	13	14	11	7	8
Other	2	0	0	0	1	0
Total	112	28	33	18	18	15

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

Collision Type	Crash Severity Level						
	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Head-on	9	9	11	4	13	0	47
Angle Oncoming (Frontal)	1	2	0	1	3	1	8
Angle Opposite Direction	0	2	2	0	5	0	9
Angle Same Direction	0	0	0	0	1	0	1
Non-collision	0	1	0	0	1	0	2
Other	0	0	1	0	4	0	5
Rear End (front to rear)	1	1	0	0	1	0	2
Side Impact (Angled)	1	2	1	0	2	0	6
Sideswipe, opposite direction	1	2	1	0	15	0	20
Single Vehicle Crash	1	0	1	2	4	1	9
Sideswipe, same direction	0	0	0	0	2	0	2
Causal Veh Backing: Rear to Rear	0	1	0	0	1	0	1
Total	14	20	17	7	52	2	112

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

	# of Vehicles			
Collision Type	1	2	3	4
Angle Oncoming (frontal)	0	8	0	0
Angle Opposite Direction	0	9	0	0
Angle Same Direction	0	1	0	0
Causal Vehicle Backing: Rear to Rear	0	1	0	0
Head-on	3	42	3	0
Non-collision	0	1	1	0
Rear End (front to rear)	0	2	0	0
Side Impact	1	5	0	0
Sideswipe - Opposite direction	1	19	0	0
Sideswipe - Same Direction	1	1	0	0
Single Vehicle Crash	1	7	0	1
Other	0	5	0	0

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

Contributory Cause	Frequency
Avoid Vehicle/Object/Non-Motorist	1
DUI	29
Failed to Yield the Right-of-Way	1
Traveling Wrong Way/Wrong Side	56
Distracted by Use of Other Electronic Device/ Passenger	2
Ran off Road	1
Driver Not in Control	2
Over Speed Limit	1
Other/ Unknown	19
Total	112

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

Number of Vehicles					
Crash Severity	1	2	3	4	Total
Fatal Injury	0	13	1	0	14
Incapacitating Injury	1	17	1	1	20
Non-Incapacitating Injury	0	16	1	0	17
Possible Injury	1	5	1	0	7
Property Damage Only	4	46	2	0	52
Unknown	1	1	0	0	2
Total	7	98	6	1	112

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

Vehicle Type	Crash Frequency	Percent（%）
Passenger Car	68	61
Pick-up	21	19
SUV	19	17
Van	3	3
Other	1	1
Total	112	100

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

CU Commercial Motor Vehicle Indicator	Crash Frequency	Frequency （%）
CU is CMV	1	0.9
CU is Not CMV	111	99.1
Total	112	100.0

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

Number of Occupants	Crash Frequency	Total Occupants
1	6	6
2	57	114
3	25	75
4	14	56
5	4	20
6	5	30
7	1	7
Total	112	308

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

CU Driver Condition	Frequency	Percent (%)
Apparently Normal	51	45.5
Asleep/Fainted/Fatigued	1	0.9
Under the Influence of Alcohol/Drugs	29	25.9
Illness	2	1.8
Other/Unknown	29	25.9
Total	112	100

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

Driver BAC Test	Crash Frequency	Percent (%)
0-1	20	17.9
1-5	0	0.0
6-10	0	0.0
11-15	0	0.0
16-20	0	0.0
21-25	0	0.0
Above25	0	0.0
NA	91	81.3
Refused	1	0.9
Total	112	100

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

Air Bag Deployment	Crash Frequency	Percent (%)
Deployed	51	46
Other/Unknown	19	17
Not Deployed	42	38
Total	112	100

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

	Crash Severity Level						
Safety Equipment	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Belt Used	7	13	14	4	41	0	79
Belt Not Used	5	5	2	1	1	0	14
Other/Unknown	2	2	1	2	10	2	19
Total	14	20	17	7	52	2	112

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

	Crash Severity Level						
Driver Condition	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Apparently Normal	4	7	7	3	30	0	51
Asleep/Fainted/Fatigued	0	0	0	0	1	0	1
Illness	0	1	0	1	0	0	2
Other/Unknown	8	3	3	1	14	1	30
Under the Influence of Alcohol/Drugs	2	9	7	2	7	1	28
Total	14	20	17	7	52	2	112

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

Airbag Status	Crash Severity Level						
Airbag Deployment	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Deployed	13	15	10	3	9	1	51
Not Deployed	0	2	4	3	32	1	42
Other/Unknown	1	3	3	1	11	0	19
Total	14	20	17	7	52	2	112

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

	Driver Severity						
Driver BAC Test	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
0-1	3	2	2	0	13	0	20
1-5	0	0	0	0	0	0	0
6-10	0	0	0	0	0	0	0
11-15	0	0	0	0	0	0	0
16-20	0	0	0	0	0	0	0
21-25	0	0	0	0	0	0	0
Above25	0	0	0	0	0	0	0
NA	9	15	8	1	57	1	91
Refused	0	0	0	0	0	1	1
Total	12	17	10	1	70	2	112

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

Crash Severity							
	Fatal	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Young	2	2	2	3	9	0	18
Middle Aged	7	13	10	2	25	1	58
Older	5	5	4	1	14	1	30
Unknown	0	0	1	1	4	0	6
Total	14	20	17	7	52	2	112

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	10	12	10	2	28	1	63
Female	4	7	6	4	17	1	39
Other/Unknown	0	1	1	1	7	0	10
Total	14	20	17	7	52	2	112

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

	Driver Severity Level						
Driver Condition	Fatality	A Injury	B Injury	C Injury	No Injury	Unknown	Total
Apparently Normal	4	7	7	3	30	0	51
Asleep/Fainted/Fatigued	0	0	0	0	1	0	1
Illness	0	1	0	1	0	0	2
Other/Unknown	8	3	3	1	14	1	30
Under the Influence of Alcohol/Drugs	2	8	7	2	8	1	28
Total	14	20	17	7	52	2	112

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	3	8	2	3	13	1	30
Darkness-Road Not Lit	9	8	12	3	17	0	49
Daylight	2	4	3	1	22	1	33
Total	14	20	17	7	52	2	112

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	14	17	14	7	40	2	94
Fog/Mist	0	0	0	0	1	0	1
Precipitation	0	3	3	0	11	0	17
Total	14	20	17	7	52	2	112

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	10	12	4	32	1	68
Pick-up	1	9	2	0	8	1	21
SUV	2	1	3	2	11	0	19
Van	2	0	0	1	0	0	3
Unknown	0	0	0	0	1	0	1
Total	14	20	17	7	52	2	112

APPENDIX C
CONTRIBUTING FACTORS FREQUENCY

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

Pre-Crash: Human			
Age of Driver	16-24	2	15.38%
	25-34	0	0.00%
	35-44	3	23.08%
	45-54	0	0.00%
	55-64	3	23.08%
	Above 65	5	38.46%
Gender of Driver	Male	9	69.23%
	Female	4	30.77%
Driver Condition	Under the Influence of Alcohol/Drugs	1	7.69%
	Other/Unknown	12	92.31%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	11	84.62%
	Other/Unknown	1	7.69%
	DUI	1	7.69%

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

Pre-Crash: Human			
Age of Driver	16-24	2	9.09%
	25-34	5	22.73%
	35-44	5	22.73%
	45-54	2	9.09%
	55-64	1	4.55%
	Above 65	7	31.82%
Gender of Driver	Male	13	59.09%
	Female	8	36.36%
	NA	1	4.55%
Driver Condition	Under the Influence of Alcohol/Drugs	9	40.91%
	Apparently Normal	8	36.36%
	Asleep, fainted, fatigued, etc.	0	0.00%
	Emotional (Depressed/Angry/Disturbed)	1	4.55%
	Illness	1	4.55%
	Other/Unknown	3	13.64%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	18	81.82%
	Other/Unknown	2	9.09%
	Driver Condition	1	4.55%
	DUI	1	4.55%

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

Pre-Crash: Human			
Age of Driver	16-24	2	11.76%
	25-34	3	17.65%
	35-44	2	11.76%
	45-54	3	17.65%
	55-64	2	11.76%
	Above 65	4	23.53%
	Unknown	1	5.88%
Gender of Driver	Male	10	58.82%
	Female	6	35.29%
	NA	1	5.88%
Driver Condition	Under the Influence of Alcohol/Drugs	7	41.18%
	Apparently Normal	7	41.18%
	Other/Unknown	3	17.65%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	12	70.59%
	Driver Condition	1	5.88%
	DUI	1	5.88%
	NA or Other	3	17.65%

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

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	12	92.31%
	Wrong Way on One Way	1	7.69%
Vehicle 1 Type	Passenger Car	8	61.54%
	Pick-up	1	7.69%
	SUV	2	15.38%
	Van	2	15.38%
Vehicle 2 Maneuver	Movement Essentially Straight	13	100.00%
Vehicle 2 Type	Passenger Car	8	61.54%
	SUV	1	7.69%
	Pick-up	2	15.38%
	Single Unit Truck/Other Light Truck	2	15.38%

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

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	18	81.82%
	Wrong Side of Road	3	13.64%
	Making U-Turn	1	4.55%
Vehicle 1 Type	Passenger Car	11	50.00%
	Pick-up	10	45.45%
	SUV	1	4.55%
Vehicle 2 Maneuver	Movement Essentially Straight	18	81.82%
	Stopped for Sign/Signal	1	4.55%
	Slowing/Stopping	1	4.55%
	No Second Vehicle	1	4.55%
	Other	1	4.55%
Vehicle 2 Type	Passenger Car	8	36.36%
	Pick-up	8	36.36%
	SUV	4	18.18%
	Tractor/semi-trailer	1	4.55%
	Single-Unit Truck	1	4.55%

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

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	15	88.24%
	Turning Left	1	5.88%
	Other	1	5.88%
Vehicle 1 Type	Passenger Car	12	70.59%
	Pick-up	2	11.76%
	SUV	3	17.65%
Vehicle 2 Maneuver	Movement Essentially Straight	13	76.47%
	Stopped in Traffic	1	5.88%
	Turning Left	2	11.76%
	Other	1	5.88%
Vehicle 2 Type	Passenger Car	12	70.59%
	Pick-up	2	11.76%
	Tractor/semi-trailer	1	5.88%
	SUV	1	5.88%
	Motorcycle	1	5.88%

Table C.7 Crash/Human – Fatal Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	13	100.00%

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

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	13	59.09%
	DUI	9	40.91%

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

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	12	70.59%
	Improper Lane Change/Use	1	5.88%
	DUI	4	23.53%

Table C.10 Crash/Vehicle – Fatal Crashes

Crash: Vehicle			
Type of Crash	Head-on	9	69.23%
	Angle Opposite Direction	1	7.69%
	Angle Oncoming (Frontal)	1	7.69%
	Single Vehicle Crash	1	7.69%
	Sideswipe - Opposite Direction	1	7.69%
Air Bag	Deployed Front	9	69.23%
	Deployed Multiple Combinations	2	15.38%
	Deployed	1	7.69%
	Not Installed	1	7.69%
Safety Equipment	Seat Belts Used	8	61.54%
	Seat Belts Not Used	5	38.46%

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

Crash: Vehicle			
Type of Crash	Head-on	11	50.00%
	Non-collision	1	4.55%
	Side Impact (Angled)	2	9.09%
	Angle Oncoming (Frontal)	4	18.18%
	Sideswipe, Opposite Direction	2	9.09%
	Angle Opposite Direction	2	9.09%
Air Bag	Deployed Front	14	63.64%
	Not Deployed	3	13.64%
	Deployed	2	9.09%
	Unknown	3	13.64%
Safety Equipment	Seat Belts Used	14	63.64%
	Seat Belts Not Used	5	22.73%
	Unknown	3	13.64%

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

Crash: Vehicle			
Type of Crash	Head-on	11	64.71%
	Angle Opposite Direction	2	11.76%
	Side Impact (Angled)	1	5.88%
	Single Vehicle Crash	1	5.88%
	Sideswipe, opposite direction	1	5.88%
	Other	1	5.88%
Air Bag	Deployed Front	9	52.94%
	Not Deployed	4	23.53%
	Deployed	1	5.88%
	Not Installed	1	5.88%
	Unknown	2	11.76%
Safety Equipment	Seat Belts Used	14	82.35%
	Seat Belts Not Used	2	11.76%
	NA	1	5.88%

Table C.13 Crash/Environment – Fatal Crashes

Crash: Environment			
Roadway Surface	Dry	12	92.31%
	Wet	1	7.69%
Light Condition	Darkness-Road Not Lit	9	69.23%
	Darkness-Road Lit	2	15.38%
	Daylight	2	15.38%
Weather	Clear	10	76.92%
	Cloudy	3	23.08%
Work Zone	Not In/Related	12	92.31%
	Yes	1	7.69%

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

Crash: Environment			
Roadway Surface	Dry	19	86.36%
	Wet	3	13.64%
Light Condition	Darkness-Road Not Lit	12	54.55%
	Darkness-Road Lit	4	18.18%
	Daylight	6	27.27%
Weather	Clear	18	81.82%
	Cloudy	1	4.55%
	Rain	3	13.64%
Work Zone	Not In/Related	19	86.36%
	NA	1	4.55%
	Between Warning Signs and Work Area	2	9.09%

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

Crash: Environment			
Roadway Surface	Dry	12	70.59%
	Wet	5	29.41%
Light Condition	Darkness-Road Not Lit	12	70.59%
	Darkness-Road Lit	2	11.76%
	Daylight	3	17.65%
Weather	Clear	8	47.06%
	Cloudy	6	35.29%
	Rain	3	17.65%
Work Zone	Not In/Related	16	94.12%
	NA	1	5.88%

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

Pre-Crash: Human			
Age of Driver	16-24	4	11.43%
	25-34	5	14.29%
	35-44	8	22.86%
	45-54	2	5.71%
	55-64	4	11.43%
	Above 65	12	34.29%
Gender of Driver	Male	22	62.86%
	Female	12	34.29%
	NA	1	2.86%
Driver Condition	Under the Influence of Alcohol/Drugs	10	28.57%
	Apparently Normal	8	22.86%
	Asleep, fainted, fatigued, etc.	0	0.00%
	Emotional (Depressed/Angry/Disturbed)	1	2.86%
	Illness	1	2.86%
	Other/Unknown	15	42.86%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	29	82.86%
	Other/Unknown	3	8.57%
	Driver Condition	1	2.86%
	DUI	2	5.71%

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

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	30	85.71%
	Wrong Side of Road	3	8.57%
	Wrong Way on One Way	1	2.86%
	Making U-Turn	1	2.86%
Vehicle 1 Type	Passenger Car	19	54.29%
	Pick-up	11	31.43%
	SUV	3	8.57%
	Van	2	5.71%
Vehicle 2 Maneuver	Movement Essentially Straight	31	88.57%
	Stopped for Sign/Signal	1	2.86%
	Slowing/Stopping	1	2.86%
	Other	1	2.86%
	No Second Vehicle	1	2.86%
Vehicle 2 Type	Passenger Car	16	45.71%
	Pick-up	10	28.57%
	SUV	5	14.29%
	Tractor/semi-trailer	1	2.86%
	Single-Unit Truck	3	8.57%

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

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	26	74.29%
	DUI	9	25.71%

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

Crash: Vehicle			
Type of Crash	Head-on	20	57.14%
	Angle Oppisite Direction	3	8.57%
	Angle Oncoming (Frontal)	5	14.29%
	Single Vehicle Crash	1	2.86%
	Sideswipe - Opposite Direction	3	8.57%
	Side Impact (Angled)	2	5.71%
	Non-collision	1	2.86%
Air Bag	Deployed Front	23	65.71%
	Not Deployed	3	8.57%
	Deployed Multiple Combinations	2	5.71%
	Deployed	3	8.57%
	Not Installed	1	2.86%
	Unknown	3	8.57%
Safety Equipment	Seat Belts Used	22	62.86%
	Seat Belts Not Used	10	28.57%
	NA	3	8.57%

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

Crash: Environment			
Roadway Surface	Dry	31	88.57%
	Wet	4	11.43%
Light Condition	Darkness-Road Not Lit	21	60.00%
	Darkness-Road Lit	6	17.14%
	Daylight	8	22.86%
Weather	Clear	28	80.00%
	Cloudy	4	11.43%
	Rain	3	8.57%
Construction Zone	Not In/Related	31	88.57%
	Yes	1	2.86%
	NA	1	2.86%
	Between Warning Signs and Work Area	2	5.71%

Table C.21 Pre-Crash/Human – Fatal, A-, and B-Injury Crashes

Pre-Crash: Human			
Age of Driver	16-24	6	11.54%
	25-34	8	15.38%
	35-44	10	19.23%
	45-54	5	9.62%
	55-64	6	11.54%
	Above 65	16	30.77%
	Unknown	1	1.92%
Gender of Driver	Male	32	61.54%
	Female	18	34.62%
	NA	2	3.85%
Driver Condition	Under the Influence of Alcohol/Drugs	17	32.69%
	Apparently Normal	15	28.85%
	Emotional (Depressed/Angry/Disturbed)	1	1.92%
	Illness	1	1.92%
	Other/Unknown	18	34.62%
Driver Contributing Circumstance	Traveling Wrong Way/Wrong Side	41	78.85%
	Driver Condition	2	3.85%
	DUI	3	5.77%
	Other/Unknown	6	11.54%

Table C.22 Pre-Crash/Vehicle – Fatal, A-, and B-Injury Crashes

Pre-Crash: Vehicle			
Vehicle 1 Maneuver	Movement Essentially Straight	45	86.54%
	Wrong Side of Road	3	5.77%
	Wrong Way on One Way	1	1.92%
	Making U-Turn	1	1.92%
	Turning Left	1	1.92%
	Other	1	1.92%
Vehicle 1 Type	Passenger Car	31	59.62%
	Pick-up	13	25.00%
	SUV	6	11.54%
	Van	2	3.85%
Vehicle 2 Maneuver	Movement Essentially Straight	44	84.62%
	Stopped for Sign/Signal	2	3.85%
	Slowing/Stopping	1	1.92%
	Turning Left	2	3.85%
	Other	2	3.85%
	No Second Vehicle	1	1.92%
Vehicle 2 Type	Passenger Car	28	53.85%
	Pick-up	12	23.08%
	SUV	6	11.54%
	Tractor/semi-trailer	2	3.85%
	Motorcycle	1	1.92%
	Single-Unit Truck	3	5.77%

Table C.23 Crash/Human – Fatal, A, and B-Injury Crashes

Crash: Human			
Contributing Circumstance	Traveling Wrong Way/Wrong Side	38	73.08%
	Improper Lane Change/Use	1	1.92%
	DUI	13	25.00%

Table C.24 Crash/Vehicle – Fatal, A, and B-Injury Crashes

Crash: Vehicle			
Type of Crash	Head-on	31	59.62%
	Angle Opposite Direction	5	9.62%
	Angle Oncoming (Frontal)	5	9.62%
	Single Vehicle Crash	2	3.85%
	Sideswipe - Opposite Direction	4	7.69%
	Side Impact (Angled)	3	5.77%
	Other	1	1.92%
	Non-collision	1	1.92%
Air Bag	Deployed Front	32	61.54%
	Not Deployed	7	13.46%
	Deployed Multiple Combinations	2	3.85%
	Deployed	4	7.69%
	Not Installed	2	3.85%
	Unknown	5	9.62%
Safety Equipment	Seat Belts Used	36	69.23%
	Seat Belts Not Used	12	23.08%
	NA	4	7.69%

Table C.25 Crash/Environment – Fatal, A, and B-Injury Crashes

Crash: Environment			
Roadway Surface	Dry	43	82.69%
	Wet	9	17.31%
Light Condition	Darkness-Road Not Lit	33	63.46%
	Darkness-Road Lit	8	15.38%
	Daylight	11	21.15%
Weather	Clear	36	69.23%
	Cloudy	10	19.23%
	Rain	6	11.54%
Work Zone	Not In/Related	47	90.38%
	Yes	1	1.92%
	NA	2	3.85%
	Between Warning Signs and Work Area	2	3.85%

APPENDIX D
FIELD OBSERVATION LOCATIONS

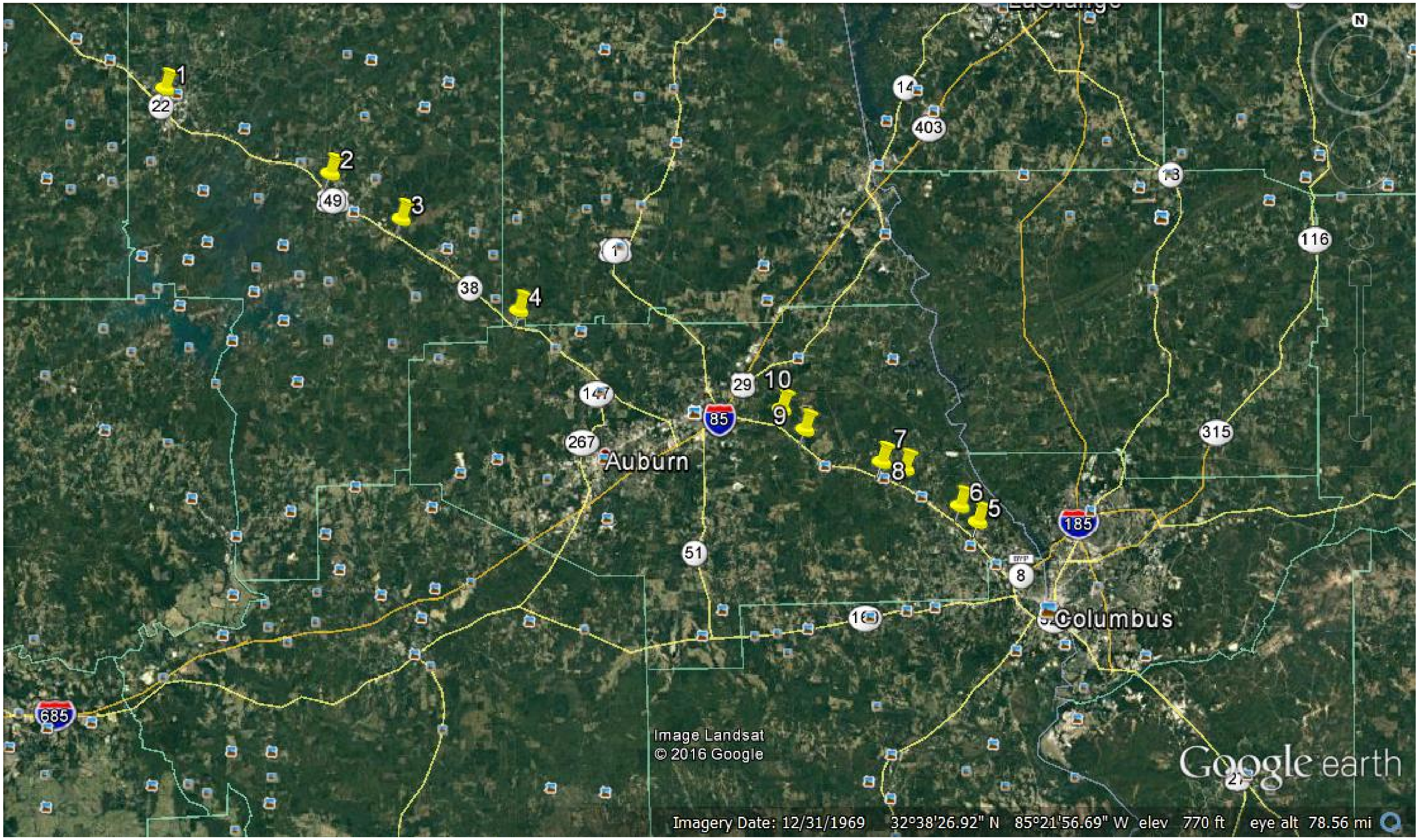


Figure D.1 Field Observation Locations near Auburn AL, along a 63.9 mile segment from Milepost 0001 120.249 to Milepost 0001 135.605 on U.S. Highway 280– April 2015 (10 Locations)

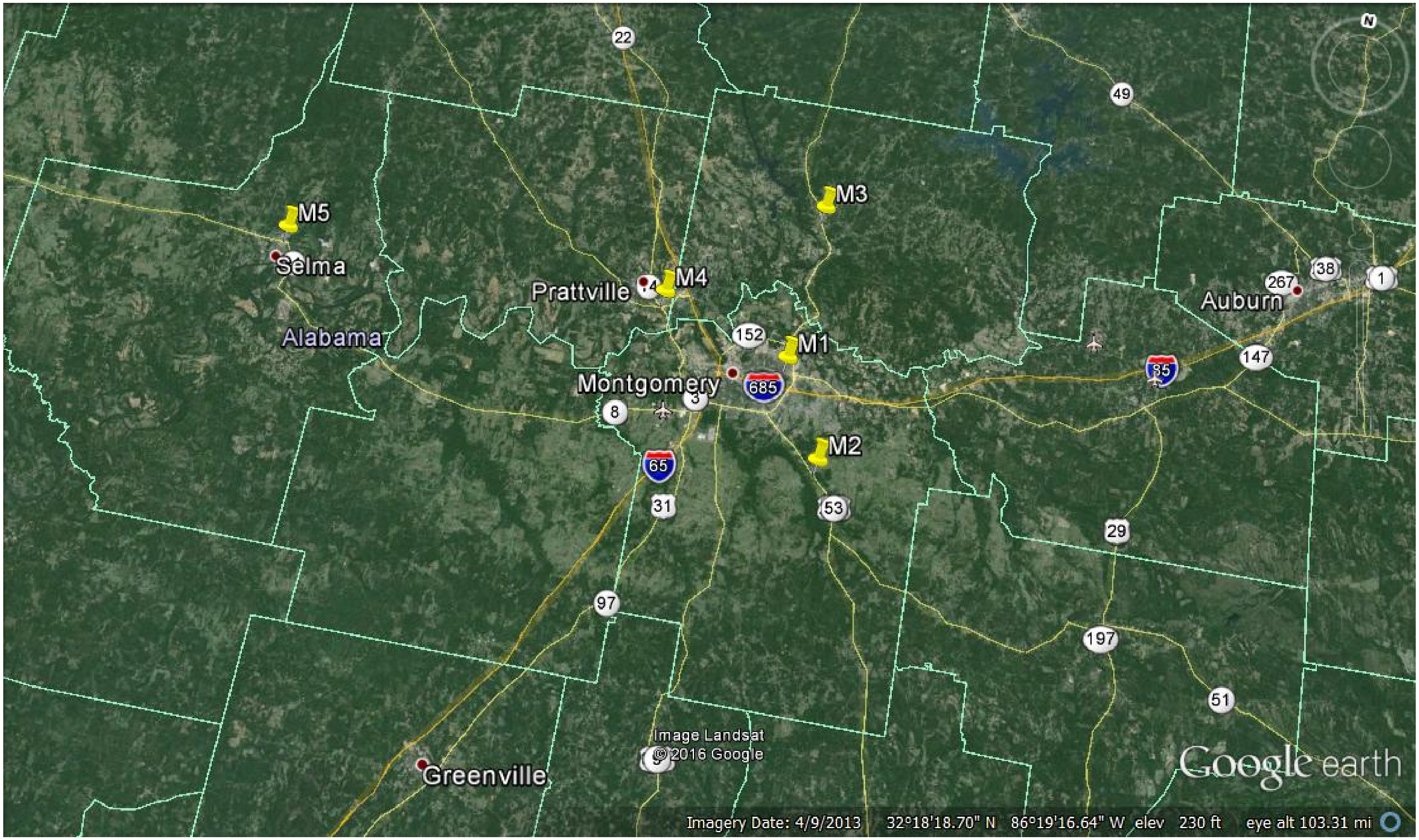


Figure D.2 Field Observation Locations in Montgomery, AL – May 2015 (5 Locations)

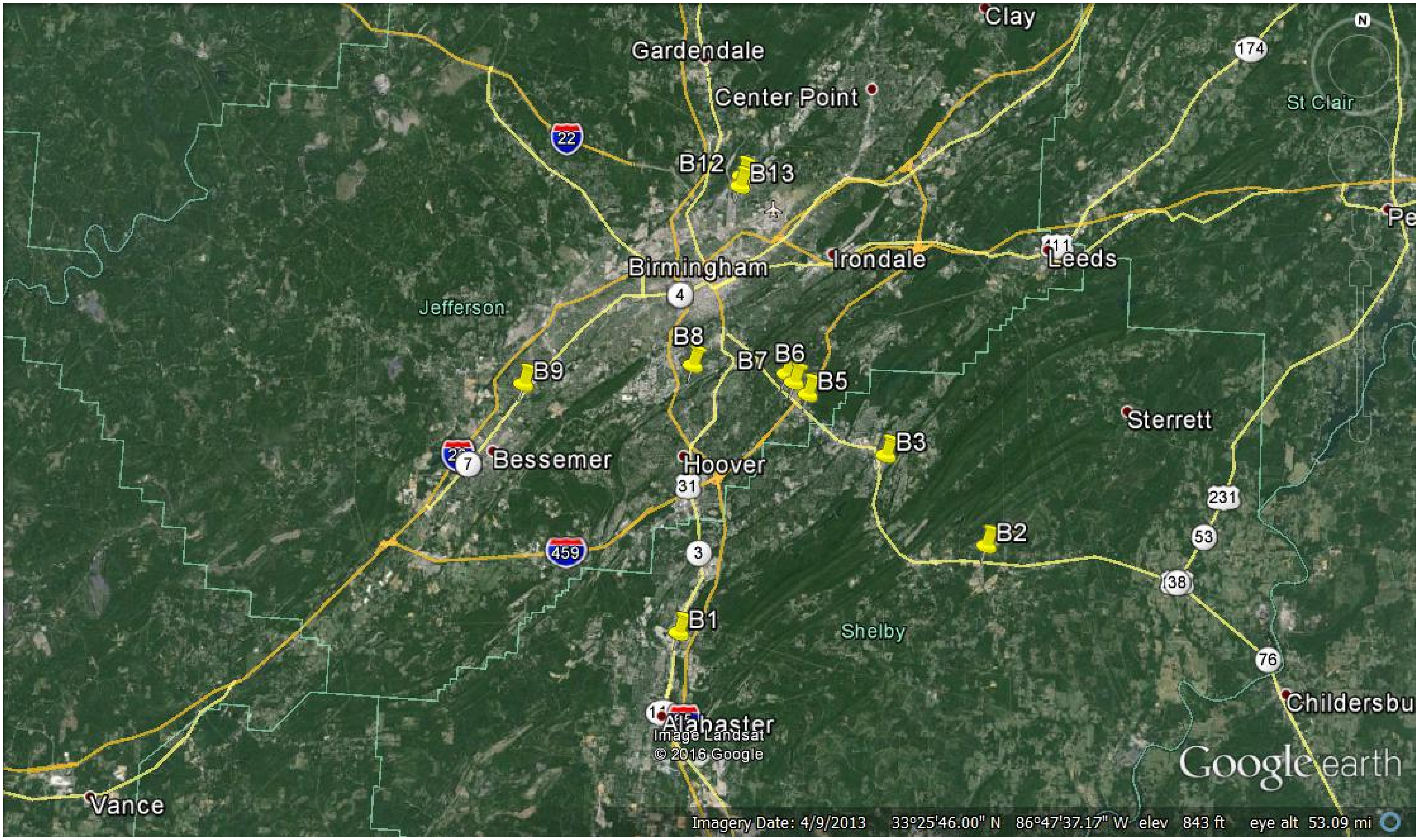


Figure D.3 Field Observation Locations in Birmingham, AL – May 2015 (13 Locations)

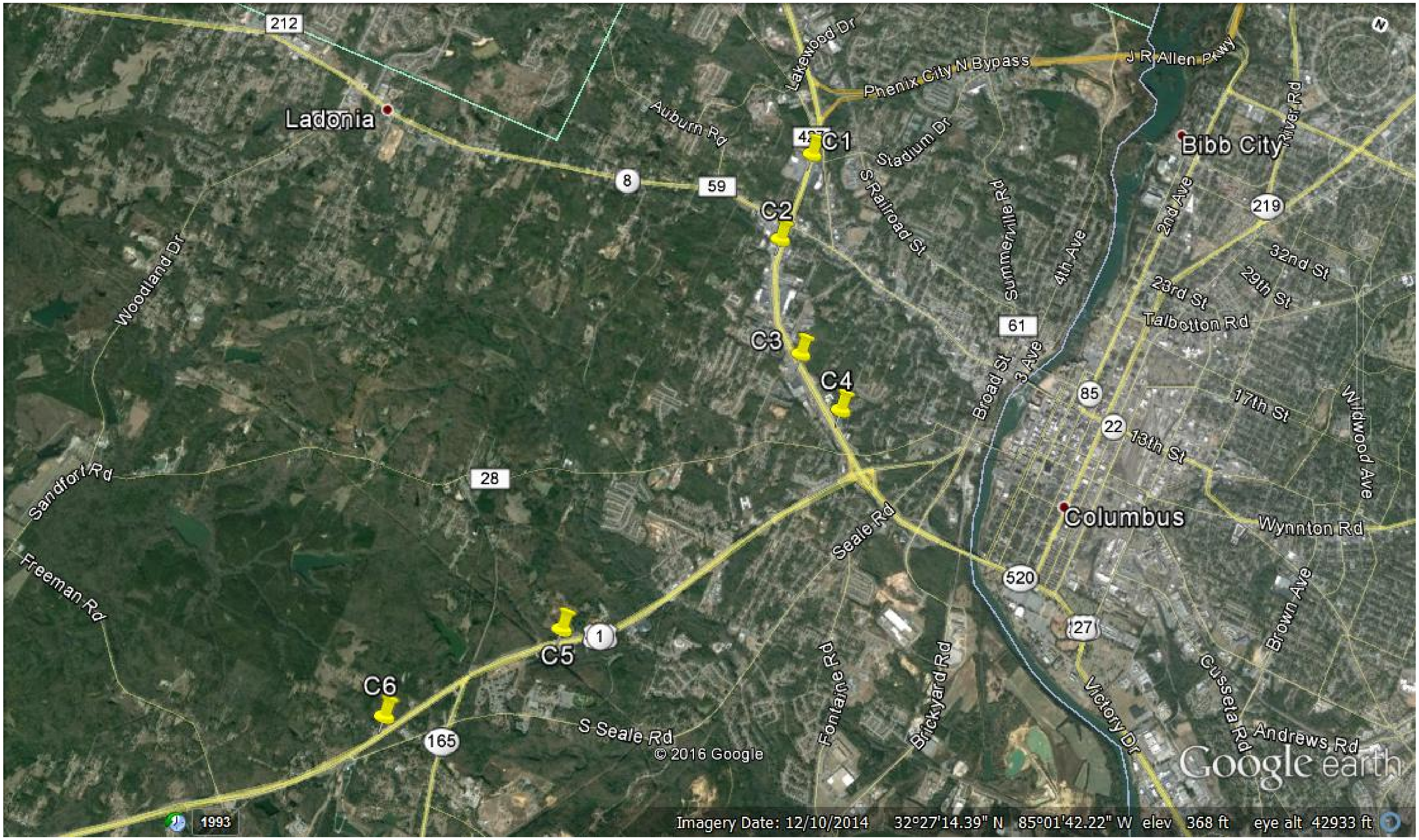


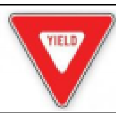
Figure D.4 Field Observation Locations in Phenix City, AL – May 2015 (6 Locations)

APPENDIX E
FIELD OBSERVATION CHECKLIST

Inspector:		
Route Information:		Date
Median Width:		Time

SIGN	CHECK IF	YES	Number	CONDITION & COMMENTS
	Present			
	Can be seen by driver			
	Present			
	Can be seen by driver			
	Present at adjacent side			
	Present at opposed side/in median opening			
	Present at side road			
	Present at opposed side/in median opening			

PAVEMENT MARKNG	CHECK IF	YES	Number	CONDITION & COMMENTS
Stopping bars at side road	Present			
Stopping bars in median opening	Present			
Yellow lines in median opening	Present			

GEOMETRC DESIGN FEATURES	CHECK IF	YES	Number	CONDITION & COMMENTS
Raised curb/other special median	Present			
	Present			
	Present			
Farthest pavement marking seen by driver	Median edge line Pavement edge line Centerline Farther pavement edge line		N/A	