Exploration of Crash Severity and Location in Work Zone-Related Crashes in Alabama

by

Bradley Michael Prichard

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Approved by

Rod E. Turochy, Chair, Associate Professor of Civil Engineering
Wesley C. Zech, Associate Professor of Construction Engineering and Management
Dheeraj Raju, Assistant Professor & Statistician, University of Alabama at Birmingham
Jeffrey LaMondia, Assistant Professor of Civil Engineering

Abstract

Work zones are necessary for maintenance and improvement of highways, but they also present opportunities for crashes that might not occur under normal driving conditions. From 2006-2011, 3,192 crashes resulted in some sort of injury, and 123 crashes resulted in a fatality in Alabama work zones. Highway safety is an issue that needs to be taken more seriously by both motorists and workers in order to reduce the frequency and severity of work zone-related crashes.

The motivation behind this project was to collect, organize, and examine available data on work zone crashes across all nine divisions in Alabama from 1998-2012. The analysis was conducted on 3,857 work zone-related crashes, and included 17 variables. Additionally, two specific, well-defined aims of the research were developed to appropriately identify the most significant factors associated with work zone-related crashes, and are as follows:

(1) "To identify the most significant factors related to crash severity for work zone-related crashes in the state of Alabama,"
(2) "To identify the most significant factors related to crash location for work zone-related crashes in the state of Alabama."

The focus of these aims was to specifically identify factors related to crash severity in work zone-related crashes, as well as determining the distribution of work zone crashes by location within the work zone.

Based on the available data, “Manner of Crash,” “Primary Contributing Factor,” “First Harmful Event” and “Highway Classification” had the greatest impact on determining the resulting crash severity of a work zone-related crash. “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes” and “Manner of Crash” had the greatest impact on determining the resulting work zone crash location. Additionally, crashes occurring within the Transition Area comprised approximately 80% of the occurrences for “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes” and “Manner of Crash.” Furthermore, 72.9% of crashes occurring within the Transition Area resulted in a fatality, making it the most severe work zone crash location.

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CHAPTER ONE

INTRODUCTION

As of June 2013, the estimated amount of travel for the year in the United States is nearly three trillion vehicle-miles, and that total will continue to grow throughout the year. According to the Bureau of Transportation Statistics, from 2005 to 2011, the average annual vehicle-miles of travel is approximately 2.983 trillion. Concurrently, the unavoidable wear and tear on the nation's highway system is getting worse, and the only way to counter this deterioration is by performing work on highways and creating more stable roadways. With the number of vehicle miles traveled annually reaching close to three trillion, roadways constantly need attention. From 1988 to 2007, the number of vehicle-miles traveled increased by approximately 58%, or an additional 1.12 trillion vehicle-miles per year (Bureau of Transportation Statistics). With the amount of travel increasing so rapidly, work zones have and will become even more frequent along highways. This increases not only the amount of exposure for both travelers and highway workers, but also the likelihood of a crash occurring within a work zone.

While work zones are necessary to the maintenance and improvements our highways need, they also create unexpected situations for motorists. Consequently, work zones present opportunities for crashes that might not occur in normal driving conditions. According to the National Work Zone Safety Information Clearinghouse (NWZSIC), 2,559 fatalities occurred in work zones across the nation from 2008 to 2011. Highway safety, especially within work zones, is an issue that needs to be taken more seriously by both motorists and workers. New and specific work zone safety measures need to be implemented to reduce the frequency and severity of crashes occurring within work zones.

1.1 Background

Work zones are unique situations, and present hazards and challenges that are uncommon to ordinary highway travel. The primary focus of a work zone is to maintain a safe and efficient flow of traffic throughout the area, while performing satisfactory work in a timely manner. While only 1.8% of the highway fatalities recorded in 2011 across the nation occurred in work zones, it is an issue that needs specific safety countermeasures so fatalities in work zones can be avoided (Alabama Traffic Crash Facts 2011). Such countermeasures include appropriate signage, a sufficient advance warning area, appropriate time to merge, and proper placement of temporary traffic control devices.

With work zones becoming more prevalent along highways, workers and motorists are at an even greater risk of being involved in a crash. According to the 2011 edition of the Alabama Traffic Crash Facts book, there were 123 crashes that resulted in a fatality and 3,192 crashes that resulted in injuries in Alabama work zones from 2006 to 2011 (Alabama Traffic Crash Facts 2011). Work zone-related crashes that resulted in property damage only occurred in approximately 80% of reported crashes.

Ranking highway work zone fatalities nationally from 2005 to 2011, Alabama is 43rd amongst all states with 158 fatalities; only seven states have had more work zone-related fatalities from 2005 to 2011 (National Work Zone Safety Information Clearinghouse). Nationally, the average amount of highway work zone fatalities in these seven years is 107; 14 states had more than 107 and 36 states had less than 107 fatalities. Breaking it down further into regions (as defined by the Census Bureau-designated areas), the southern region has the highest percentage of highway work zone fatalities at 55%. These states include Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Mississippi, Alabama, Oklahoma, Texas, Arkansas and Louisiana. The region with the smallest percentage of work zone fatalities is the Northeast region, with only 7%. With Alabama ranking in the top eight states of the nation's work zone-related fatalities, specific safety measures to Alabama highway work zones need to be identified in order to better serve the needs of the state.

While statistics regarding the amount of exposure motorists have to work zones are more difficult to develop, there is a concern that work zone fatalities and injuries are overrepresented. In 2011, nine work zone-related crashes resulted in a fatality. Considering that nine of the 895 motor vehicle fatalities recorded in Alabama in 2011 were fatal, a need arises to examine just how accurate and well represented these crashes are, and to support efforts in effectively reducing the opportunities for such crashes to occur.

1.2 Objectives

The motivation behind this project was to collect, organize, and examine available data on work zone crashes in Alabama from 1998 to 2012. More specifically, the purpose of this research is to obtain pertinent information from Alabama Uniform Traffic Crash Reports that can then be used to improve both safety in work zones and ALDOT policies and practices regarding temporary traffic control (TTC). The main objectives of this research project are:

1. Develop a database for work zone-related crashes in Alabama,
2. Identify factors that significantly influence crash severity in work zone-related crashes
3. Determine the distribution of work zone crashes by location, crash type, temporal patterns, and severity,

4. Develop recommendations for ALDOT, specifically reporting techniques with the Alabama Uniform Traffic Crash Report (AUTCR).

1.3 Scope

The analysis was conducted on 3,857 work zone-related crashes that range from the year 1998 to 2012, and represent all nine divisions across the state of Alabama. Additionally, 17 variables were chosen from a field of 165 variables, and were done so based on the significance of each variable to the crash and to the nature of the analysis. A complete description of the process of identifying the 17 variables included in the analysis can be found in Section 3.2. Of those 17 variables, "Crash Severity" and "Work Zone Crash Location" were set as the dependent variable in two separate analyses to achieve the aforementioned research goals of determining the factors that influence crash severity, as well as determining the distribution of crashes by location.

Two specific, well-defined aims of the research were developed to appropriately identify the most significant factors associated with work zone-related crashes, and are as follows:

(1) "To identify the most significant factors related to crash severity for work zone-related crashes in the state of Alabama,"

(2) "To identify the most significant factors related to crash location for work zone-related crashes in the state of Alabama."

The focus of these aims is to specifically identify factors related to crash severity in work zone-related crashes, as well as determining the distribution of work zone crashes by location within the work zone.

1.4 Outline

Chapter Two includes an in depth literature review consisting of a summary of related work. The review discusses studies that focus on crash severity and frequency, locations of crashes within work zones, and factors that influence work zone-related crashes. These factors include environmental conditions such as weather, lighting and time of day, roadway geometry and classification, driver demographics and behavior, manner of crash, and crash location within the work zone. Additionally, the methods used to test the relationships between crash severity and frequency, as well as crash location, against specific variables are addressed. These methods include chi-square tests for independence and logistic regression models.

Chapter Three outlines the project methodology that was followed to achieve the aforementioned objectives of this research project. It also provides an overview of the initial data mining process, the development of a unique, codified spreadsheet for data entry, the data entry process itself, and finally the techniques used to answer the research questions.

Chapter Four contains the results obtained from the detailed methodology covered in Chapter Three. Chapter Five presents the conclusions of this research project, as well as the recommendations given to ALDOT.

CHAPTER TWO

LITERATURE REVIEW

This chapter contains a review of scholarly literature relevant to the objectives of this thesis. This review discusses studies that focus on crash severity and frequency, locations of crashes in work zones, and factors that influence work zone-related crashes. Additionally, the methods used to test the relationships between crash severity and frequency, as well as crash location, against specific variables are addressed.

2.1 Crash Severity and Frequency

Two of the most common measures in highway safety research include crash severity and frequency. Many studies recognize the KABCO scale, but use a condensed version of the scale when analyzing crash data. Instead of the five KABCO categories ("K" represents a fatality, "A" represents an incapacitating injury, "B" represents an evident injury, "C" represents a possibly injury, and "O" represents crashes that result in property damage only), crashes are commonly grouped into the following three categories: "Fatal," "Injury" and "Property Damage Only." In a study done by Akepati and Dissanayake (2011), work zone crashes in Iowa, Kansas, Missouri, Nebraska and Wisconsin from 2002-2006 were analyzed to identify work zone crash characteristics. More specifically, the data was grouped into five different categories for analysis: environmental, vehicle related, driver related, crash related, and road characteristics. Missouri had the largest data set with 19,340 occurrences, and Nebraska had the smallest data set (2,878 occurrences). Regarding crashes resulting in fatalities, Missouri experienced the most fatalities with 100, while Nebraska had the highest percentage of fatalities at 1.4% (perhaps due to its comparatively smaller sample size). Nebraska recorded the fewest amount of injury related crashes (1,259) and property damage only crashes (1,654).

In a study done by Li and Bai (2009), only crashes resulting in a fatality or injury were analyzed, aiming to reduce crash severity and potentially prevent common human errors from contributing to the severity of crashes occurring in work zones. 655 severe crashes, including 29 fatal crashes, in Kansas from the year 2003 to 2004 were examined. 14 fatalities were attributed to inattentive or distracted driving, and 26 fatalities involved improper center/edge line traffic control devices. Lastly, the study by Daniel, Dixon and Jared (2001) focused on three different aspects regarding only fatal work zone related crashes: (1) the manner of collision, location, and construction activity associated with crashes that result in fatalities, (2) crashes occurring within active and idle work zone locations, and (3) the difference between fatal crashes occurring in a work zone and fatal crashes not related to a work zone. Results indicate that the majority of fatal crashes occur within construction work zones rather than maintenance work zones, with a large percentage of the work zones being idle. Work zone related fatalities were also more likely to be involved with another vehicle than non-work zone related fatalities.

Crash frequency is measured in the total number of crashes, fatalities, injuries, or PDOs, and can be represented in the form of graphs, tables, percentages, and other distribution techniques. They can produce trends that measure the number of crashes, fatalities, injuries, or PDOs across a range of years, in states, or specific work zone locations. They can also be used to compare the number of crashes or number of fatality, injury, or property damage only crashes with specific variables (Li and Bai 2009; Harb *et. al.* 2008; Daniel *et. al.* 2001; Garber and Zhao 2002). As in the case of crash severity, the type of frequency distribution techniques, as well as what factors are used in the distributions are appropriate to each research.

2.2 Crash Location

When analyzing work zone-related crashes, it is important to note, if possible, the specific crash location within the work zone. These locations include the Advance Warning Area, Transition Area, Activity Area and Termination Area. When known, the frequency and severity of crashes for each work zone location can determined, allowing further research on specific problem areas. Many studies have been conducted to identify the specific work zone locations with the most crashes and/or fatalities. In a study done by Akepati and Dissanayake (2011), it was found that 47.6% of work zone-related crashes in the states of Iowa, Kansas, Missouri, Nebraska and Wisconsin from the year 2002 to 2006 occurred within the Activity Area of the work zone. Crashes specific to Nebraska occurred in the Activity Area in 57.1% of the time, while crashes specific to Iowa occurred in the Activity Area 40.3% of the time. The crash location with the lowest percentage of occurrences was the Termination Area. Overall, only 4.3% of work zone related crashes happened after the work area, and before returning to normal driving conditions.

In a study conducted by Garber and Zhao (2002), work zone-related crashes in Virginia from the year 1996 to 1999 were examined, and it was determined that 70% of crashes occurred within the Activity Area, regardless of highway type. In perspective, the area with the next highest percentage of crashes was the Transition Area with 13%. Of the crashes occurring within the Activity Area, 2.5% resulted in a fatality on rural interstates, the highest fatality percentage of any highway type examined. Conversely, the area with the smallest percentage of crashes was the Termination Area, with only 2% of occurrences. Zero crashes from their dataset resulted in a fatality in the Termination Area.

Lastly, in a study done by Lindly, Noorjahan and Hill, a different approach was taken. Instead of monitoring the four main work zone locations, data was collected for five different conditions in the state of Alabama: non work zone, base work zone, work zone double fine, work zone police, and work zone police & double fine. Over 254,000 vehicles were monitored during these conditions at five different locations. As a result, it was determined that the level of service for each type was reduced by one level upon vehicles entering the work zone, the most effective measure of reducing mean speed was "police & double fine sign," with the least effective measure being "base work zone traffic control."

2.3 Contributing Factors to Work Zone-Related Crashes

Some of the most common factors analyzed with respect to crash severity and frequency for work zone-related crashes can be grouped into three categories: (1) driver behavior, (2) roadway environment, and (3) infrastructure. Factors attributed to the driver include aggressive behavior, improper lane use, and inattentive or distracted driving. In a study performed by Akepati and Dissanayake (2011), the primary contributing factors of work zone-related crashes in Iowa, Kansas, Missouri, Nebraska and Wisconsin from 2002 to 2006 that were attributed to the driver included inattentive driving, following too close for conditions, failure to yield the right of way, driving too fast for conditions, and exceeding posted speed limits within work zones. Similarly, in a study conducted by Li and Bai (2009) that examined high-severity crashes in Kansas highway work zones from 1998 to 2004, the most common factors related to driver error included disregarding traffic control, following too closely, alcohol and/or drug impairment, and driving too fast for conditions. Subsequently, the study goes on to state that: "the odds of causing fatalities in a severe crash when the disregarded-traffic-control error was present were almost three times as high as those in a severe crash that did not involve this driver error" (Li and Bai 2009). Lastly, according to a study conducted by Harb et al. that examined crash data from the state of Florida from the year 2002 to 2004, approximately 66% of work zone-related crashes were attributed to careless driving, and approximately 32% were caused by improper lane changes.

Roadway environment factors include, but are not limited to, weather, light and crash time information. In a study that compared work zone-related crashes with non-work zone-related crashes in Florida from 2002 to 2004, (Harb *et. al.* 2008), cloudy weather affected work zone-related crashes 16% more than non-work zone-related crashes. Additionally, the crash likelihood for work zone-related crashes increased by 35% compared to non-work zone-related crashes. In another study that also compared work zone-related crashes to non-work zone-related crashes in Georgia from 1995 to 1997 (Daniel *et. al.* 2001), dark conditions were found to be highly significant: 32% of non-work zone-related crashes resulted in fatalities, while 42% of work zone-related crashes resulted in fatalities.

In a study done by El-Rayes, Liu, and Elghamrawy, fatal crashes, multi-vehicle injury crashes and single-vehicle injury crashes in the state of Illinois were examined. It was determined that 44% of fatal crashes and 40.5% of single-vehicle injury crashes occurred at night (20:00 – 6:00 am). Examining these fatal crashes further, it was determined that rear-end and fixed-object collisions were the most severe manner of collision. The most frequent collision type was rear-end for both fatal crashes (22%) and multi-vehicle crashes (43%). Lastly, in a study that compared the time of day for fatal and injury work zone-related crashes (Li and Bai 2008), it was determined that the most frequent observations occurred at completely different times for crashes resulting in fatalities versus crashes resulting in injury. For fatal crashes, 37%

occurred at night and early morning (8:00 p.m. – 6:00 a.m.), whereas 42% of injury crashes occurred in the late morning and afternoon (10:00 a.m. – 4:00 p.m.).

The last group of factors commonly analyzed in work zone-related crashes involves those associated with infrastructure, such as the number of traffic way lanes, roadway classification, and roadway geometry. In a study that compared fatal and injury crash frequency for work zone-related crashes (Li and Bai 2009), 62.4% of occurrences resulting in a fatality were on two lane roads, where roads with four traffic way lanes, or roads with two lanes in each direction, resulted in a fatality in 30.6% of occurrences. Additionally, 64.7% of occurrences resulting in a fatality occurred on principal and minor arterials, compared to only 4.7% of fatal crashes occurring on major collectors, minor collectors and local roads. In a study that compared fatalities in work zone-related crashes versus non-work zone-related crashes (Daniel *et. al.* 2001), 56% of fatalities in work zone-related crashes occurred on a level roadway, while 42% occurred on a grade. Furthermore, 77% of fatalities in work zone-related crashes occurred on a straight road, and 23% occurred along a curved roadway. These percentages were fairly consistent with non-work zone-related crashes: 51% of fatal crashes occurred on a level roadway versus 45% occurring on a grade, and 69% of fatal crashes occurred on a straight road versus 31% occurring along a curved roadway.

Lastly, in the study done by El-Rayes, Liu, and Elghamrawy, the most frequent highway type for crashes resulting in a fatality was interstate (40%). The majority of fatal crashes (56%) occurred in work zones that had traffic control devices that were functioning properly, while less than 2% of fatal and injury work zone crashes occurred in work zones that had traffic control devices not functioning or functioning improperly.

2.4 Approaches in Work Zone Crash Modeling

Methods for testing the relationship between crash severity, frequency, and crash location with contributing factors range from chi-square distributions to logistic regression. These methods are ways of determining the statistical significance of the variables included in the analysis, and are specific to the type of study done. In a study that investigated characteristics of work zone crashes in Iowa, Kansas, Missouri, Nebraska and Wisconsin (Akepati and Dissanayake 2011), a chi-square test of independency was done to determine the relationship between crash severity and work zone characteristics. Of all of the independent variables included in the test, only "Surface Condition of the Road" was found to not be statistically significant to the resulting severity of a crash. Similarly, in an analysis of fatal crashes in Georgia work zones (Daniel *et al.* 2001), tests for independence were performed to determine any possible association between work zone and non-work zone-related crashes. According to the results of the study, the manner of collision, light conditions, truck involvement, and functional classification are all significant to determining the resulting severity of a crash (Daniel *et al.* 2001).

Another form of testing for statistically significant factors related to work zone crashes includes logistic regression. Regression models established in the study done by Harb *et. al.* 2008 examined the environmental, driver and vehicle risk factors for freeway work zone crashes. The results indicated that roadway geometry, weather conditions, age, gender, lighting conditions, residence code and driving under the influence of alcohol and/or drugs were statistically significant risk factors associated with work zone-related crashes. In either case, a chi-square test of independence or a logistic regression model, factors deemed statistically significant to crashes occurring in work zones were determined.

2.5 Summary

Studies examining work zone related crashes and their characteristics can do so in many different ways. Crash severity can be classified using the "KABCO" method, ranging from fatality to property damage only, or a condensed version of this, consisting of three categories: fatality, injury, and property damage only. Frequencies can be developed, measuring the total number of crashes, fatalities, injuries, or PDOs, and can be represented in the form of graphs, tables, percentages, and other distribution techniques. Trends can be identified through a range of years, across certain states, or through specific work zone locations. They can also be used to compare the number of crashes or number of fatality, injury, or property damage only crashes, involving specific variables (driver demographics, vehicle type, preliminary conditions, etc.).

Specific factors are also identified when examining work zone related crashes, specifically driver demographics such as age, gender or race, the manner of collision, the events that caused the crash, and roadway conditions, including weather, locale, time of day and the day of the week. Different techniques can be utilized in order to determine which of these factors contribute to the crash severity or location of a particular dataset, including chi square distributions, logistic regressions, and multinomial regressions. By using any combination of the aforementioned strategies and techniques, accurate and well-represented results can be determined.

CHAPTER THREE

METHODOLOGY

This chapter outlines the project methodology that was followed to accomplish the research objectives stated in Chapter One. Those objectives include developing a database for work zone-related crashes in Alabama, identifying factors that significantly influence crash severity in work zone-related crashes, determining the distribution of work zone crashes by location, and developing recommendations for ALDOT, specifically reporting techniques with the AUTCR.

The sample set of work zone-related crash reports used for analysis includes 3,857 crashes, corresponding with two specific dependent variables, and fifteen different independent variables. These reports were deemed work zone-related by either the reporting law enforcement officer or by members of the Alabama Department of Transportation (ALDOT). Initially, only 1,016 of the 3,857 crashes were deemed work zone related by the reporting officer (these crashes, making up 26.3% of the data set, were the only ones given a specific work zone crash location). The remaining crashes were later deemed work zone-related by members of ALDOT. All observations in this analysis are related to a work zone in some fashion.

This set of crash reports ranges from the year 1998 to 2012, and represents all nine ALDOT divisions across the state of Alabama. Also, it should be noted that the results generated from these crash reports are limited, for only crash reports made available to ALDOT by each division were analyzed. Divisions were not equally represented in the data set; little control existed in obtaining every work zone related crash from all nine districts. Consequently, the results are not completely indicative of all work zone-related crashes occurring in Alabama from

1998 to 2012, and should not be thought of in such manner. Rather, this report addresses a sample of work zone-related crashes that occurred in Alabama during that time period, and the results accurately reflect this.

Lastly, this chapter is further subdivided into three main sections: (1) Data Collection, (2) Data Management, and (3) Data Analysis. Data Collection describes the preliminary analysis of the raw data, and determining what exactly was made available by ALDOT. Data Management addresses the process of creating the unique, codified spreadsheet for data entry, the data entry process itself, and the steps taken to reduce, condense and prepare the data for analysis. Finally, the Data Analysis section explains the techniques used to answer the two research questions.

3.1 Data Collection

This task begins by collecting key sources of information for work zone crashes and traffic control practices in Alabama made available by ALDOT to Auburn University. Specific sources include:

1) ALDOT Crash Report Form C-25-A,
2) Alabama Uniform Traffic Crash Reports (AUTCRs) or Alabama Uniform Traffic Accident Reports (AUTARs [AUTARs were phased out starting in June, 2008 and replaced with AUTCRs]),
3) Contractor written reports, including cover letters to the Construction Engineer of ALDOT.

Each crash ranges from having only the AUTCR to having all three of the aforementioned sources, depending on the thoroughness of the crash reporting. For a crash to be considered in the eventual analysis, it must have at least the AUTCR.

Completed C-25-A forms must be filled out by the project traffic control inspectors (PTCI), and are required for any crash that occurs within the limits of a work zone on an ALDOT-maintained highway. The C-25-A form is a one page document that contains basic identifying information regarding the project, and it includes the following information:

- specific prevailing conditions,
- description of temporary traffic control (TTC) in place,
- the type of work being performed,
- injuries or fatalities,
- equipment involved,
- a general description of the crash.

A sample C-25-A form can be found in Figure 3.1.

Form C-25-A
Rev. 3/2008

Alabama Department of Transportation

CRASH REPORT

Project Information			
Date		Project /Contract ID	
Division		Contractor	
District		Project Description	
County		Location	

Crash Information			
Date of Crash		Time of Crash	
Weather Condition		Road Condition	

Location of Crash (Use Mile Post Reference if Possible)

Description of Traffic Control in place (lane closures, haul road crossing, etc.) List Typical Application (TA #) from MUTCD, Part 6 if applicable.

Phase of Sequence of Construction in Use at Time of Crash, if Applicable

Type of Work Being Performed in Crash Area, if Applicable

Injuries or Fatalities

Vehicles (Type), Equipment, etc. Involved

Description of Crash (List names of witnesses, investigating officer, and other pertinent data)

Signature of Project Traffic Control Inspector

pc: District
Division
File

Attachments: Alabama Uniform Traffic Crash Report (AUTCR)
Contractor's Written Report

Figure 3.1 – Sample C-25-A Form

The AUTCR or AUTAR describes the nature of the crash, including location and time, driver and vehicle information for each unit involved, injured and uninjured occupants, a diagram of the crash, a narrative of the crash, the roadway environment, and a property damage description. The AUTAR was initially implemented in January of 1991, and served as the primary crash report until 2008; the AUTAR was phased out and replaced with the AUTCR in June of 2008. Additionally, it should be noted that the AUTCR was adopted at different rates throughout the nine divisions, and a mixture of both reports have been in use since June, 2008. For the purpose of this study, AUTAR and AUTCR are interchangeable, but will be referred to as the AUTCR, since both serve the purpose of being a primary crash report.

The AUTCR ranges from five to seven pages, depending on how many units were involved in the crash. Additionally, for crashes involving buses, heavy trucks, and/or trailers, a Truck/Bus Supplemental Sheet is offered, giving more information about the truck/bus involved. Lastly, a legend is attached to the end of every AUTCR, giving the category, code, and description for every field found in the report itself. Figure 3.2 provides an example of an AUTAR, while Figure 3.3 displays an AUTCR, with the AUTCR including both a Truck/Bus Supplemental Sheet and legend (since these figures represent actual crashes, the names, dates of birth, addresses, telephone numbers, zip codes, driver’s license numbers, and tag numbers have been marked out).

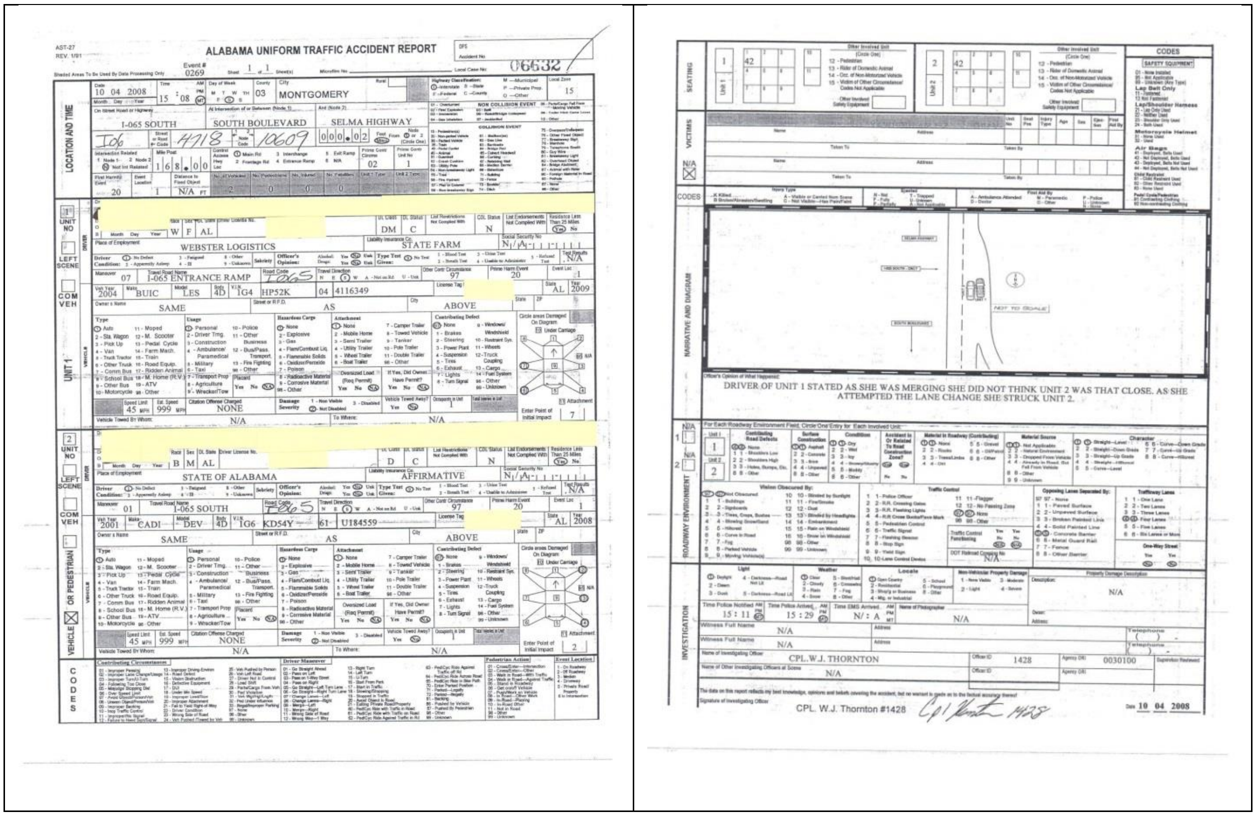
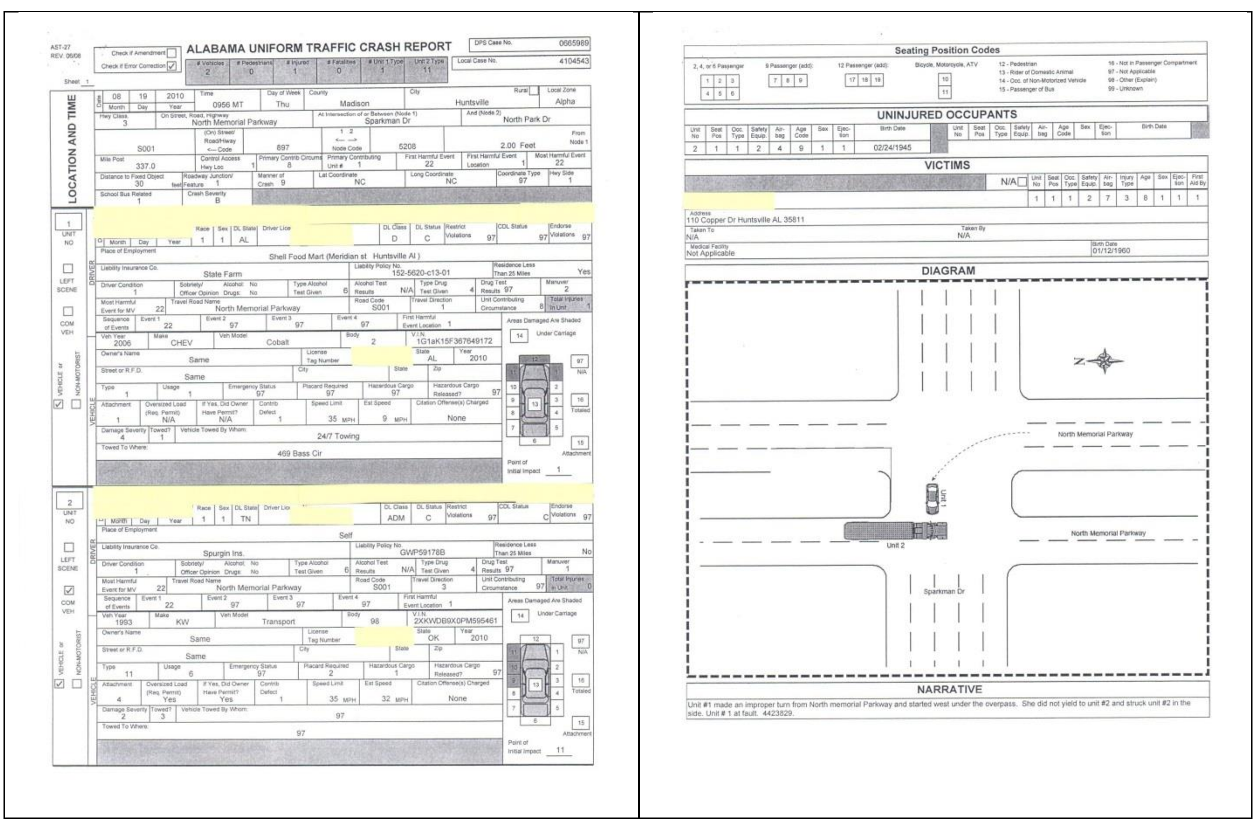


Figure 3.2 – Sample AUTAR Form



ROADWAY ENVIRONMENT

Unit No.	1	Involved Road/ Bridge	1	Road Surface Type	1	Roadway Condition	1	Workzone Related?	3	Workzone Type	1	Workers Present	Yes	Workzone Law Enforcement Present?	1	Contributing Circumstances Environment	1	Contrib Matl In Roadway	1		
Contrib Material Source	97	Rdway Curve & Grade	1	Vision Obscured By	1	Traffic Control	6	Traffic Control Functioning	1	Opposing Lane Separation	6	Trafficway Lanes	2	Turn Lanes	2	One-Way Street	No	Total # Occupant s In Unit	0	Total # Injured In Unit	1
Total Number of Units: 2		Light: 1				Weather: 2				Locale: 3				Police Present? No		DOT Railroad Crossing No. N/A					
Unit No.	2	Involved Road/ Bridge	1	Road Surface Type	1	Roadway Condition	1	Workzone Related?	3	Workzone Type	1	Workers Present	Yes	Workzone Law Enforcement Present?	1	Contributing Circumstances Environment	1	Contrib Matl In Roadway	1		
Contrib Material Source	97	Rdway Curve & Grade	1	Vision Obscured By	1	Traffic Control	6	Traffic Control Functioning	1	Opposing Lane Separation	6	Trafficway Lanes	2	Turn Lanes	2	One-Way Street	No	Total # Occupant s In Unit	1	Total # Injured In Unit	0
Total Number of Units: 2		Light: 1				Weather: 2				Locale: 3				Police Present? No		DOT Railroad Crossing No. N/A					

INVESTIGATION

Property Damage Description

Description: N/A

Address:

Owner:

Telephone:

Name of Photographer: N/A

Non-Vehicular Property Damage: 1

Time Police Notified	Time Police Arrived	Time EMS Arrived	EMS Response Run #
0957 MT	0959 MT	1001 MT	N/A

Witness Full Name: Clint n/a Scales — Address: 3574 Pryor Rd Madison, AL 35756 — Telephone:

Witness Full Name: N/A — Address: — Telephone:

Name of Investigating Officer: — Officer ID: 10016 — Agency ORI: AL0470100

Name of Investigating Officer: — Officer ID: — Agency ORI:

The data on this report reflects the best knowledge, opinion, and belief regarding the crash, but no warrant is made as to the factual accuracy thereof.

Unit No. 2
(same as on main report)

ALABAMA UNIFORM TRAFFIC CRASH REPORT
Truck/Bus Supplemental Sheet

AST-27B Rev. 06/08

General Instructions

Complete this form each qualifying vehicle ONLY if the crash meets BOTH of the Following criteria:

1. The crash involved a qualifying vehicle (a truck with a gross vehicle weight rating (GVWR) or a gross combination weight rating (GCWR) of more than 10,000 pounds, or Haz/Mat placard, or a vehicle designed to carry nine 9 or more, including driver) and;
2. The crash resulted in at least one of the following: **A.** one or more fatalities **B.** one or more persons injured and taken from the scene for immediate medical attention, or **C.** one or more involved vehicles had to be towed from the scene as a result of disabling damage or had to receive assistance to leave.

Screening Information

Number of Qualifying Vehicles:
Trucks with GVWR or GCWR of more than 10,000 pounds or Haz/Mat placard 1
Buses designed to carry 9 or more (including driver) 0

Number of Persons:
Sustaining fatal injuries 0
Transported for *immediate* medical treatment 0

Number of vehicles towed from scene due to damage or provided assistance 1

Vehicle Information

Weight Rating of Power Unit of the Truck: 3. - More than 26,000 pounds

Hazardous Material Involvement
Did vehicle have a Haz/Mat placard? ☐
If Yes, include following information from placard
A. Name or 4-digit number from Diamond or box
B. The 1-digit number from bottom of diamond
Was hazardous material released from THIS vehicle's cargo? ☐

Vehicle Configuration: 9. - Tractor with semi-trailer
Bus Usage: 1. - Not a bus
Cargo Body Type: 5. - Flatbed
Cargo Type: 98. - Other

Motor Carrier Information

NOTE: If NOT a motor carrier, enter NONE under Carrier Name, 0 for None under Carrier Identification Numbers, and go to Sequence Of Events Section

Carrier Name Conner Transport Inc.
Carrier Phone 99
Carrier Mailing Address (Street or P.O. Box) Rt 3 Box 1920 Hwy 59 North
City, State, Zip Stil Well, OK 74960
Carrier Identification Number (None = 0)
Motor Carrier Type 1. - Interstate carrier
US DOT 504984 *ICC MC* Unk *STATE NO.* Unk
STATE *OTHER COUNTRY AUTHORITY* *COUNTRY* Unk

Sequence of Events

NOTE: for THIS vehicle -- list up to four Event #1 13 Event #2 97 Event #3 97 Event #4 97

EVENT CODES

Non-Collision: 1. Ran off road 2. Jackknife 3. Overturned (rollover) 4. Downhill runaway 5. Cargo loss or shift 6. Explosion or fire 7. Separation of units 8. Cross median/centerline 9. Equipment Failure (brake failure, blown tires, etc.) 10. Other non-collision 11. Unknown

Collision with: 12. Pedestrian 13. Motor Vehicle in Transport 14. Parked Motor Vehicle 15. Train 16. Pedalcycle 17. Animal 18. Fixed object 19. Work Zone Maintenance equipment 20. Other movable object 21. Unknown movable object

Not applicable: 97. Not applicable

Definitions

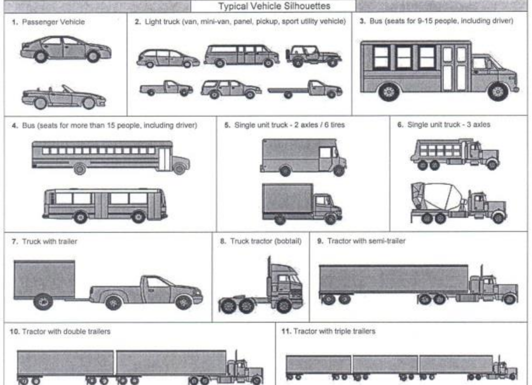
Truck
A motor vehicle designed, used or maintained primarily for the transportation of property. For the purpose of this form the vehicle must also meet one of the following criteria:
* Have a GVWR or a GCWR of more than 10,000 pounds, **or**
* Carry a Hazardous Material Placard

Bus
A motor vehicle providing seats for 9 or more persons including the driver and used primarily for the transportation of persons.

Trailer
A non-power vehicle towed by a motor vehicle.

Reportable Crash
A highway related incident normally investigated by a police officer and reported on a standard crash report form involving one or more trucks or buses (as defined here) which results in:
* One or more fatalities, **or**
* One or more non-fatal injuries requiring transportation for the purpose of obtaining immediate medical treatment, **or**
* One or more of the vehicles being removed from the scene as a result of disabling damage, **or**
* One or more of the vehicles requiring intervening assistance before proceding under its own power.

Typical Vehicle Silhouettes



Typical Hazardous Material Placards

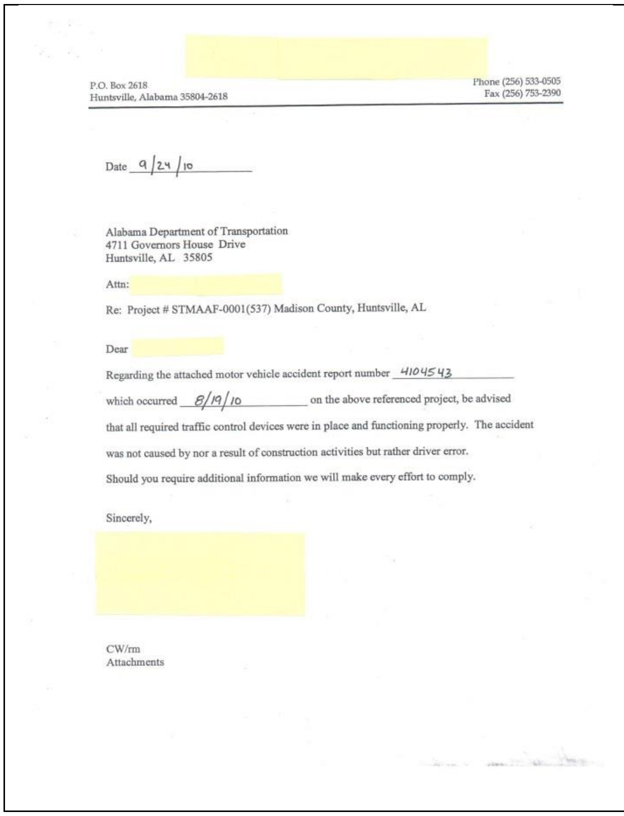
LEGEND

Location	Category	Code	Description	Location	Category	Code	Description
Report Header	Unit Type	1	Passenger car	Driver	Race	1	White / Caucasian
Report Header	Unit Type	11	Tractor / semi-trailer	Driver	Residence Within 25 Miles	No	No
Location And Time	Contributing Circumstance	8	Made improper turn	Driver	Residence Within 25 Miles	Yes	Yes
Location And Time	Contributing Unit	10	Unit1	Driver	Travel Direction	1	North
Location And Time	Controlled Access Highway Location	1	Main road	Driver	Travel Direction	3	South
Location And Time	Coordinate Status	NC	NoCapability	Vehicle	Attachment	1	None
Location And Time	Coordinate Type	97	Not applicable	Vehicle	Attachment	4	Other semi trailer
Location And Time	Crash Manner	9	Side impact (90 degree)	Vehicle	Body	2	Four door
Location And Time	Crash Severity	B	Non-incapacitating injury	Vehicle	Body	98	Other (explain in narrative)
Location And Time	Distance Node Unit	10	Feet	Vehicle	Citation Offense	99	None
Location And Time	Harmful Event	22	Collision with vehicle in traffic	Vehicle	Damage Severity	2	Minor
Location And Time	Highway Classification	3	State	Vehicle	Damage Severity	4	Major, disabled
Location And Time	Highway Side	1	Northbound	Vehicle	Defect	1	None
Location And Time	Roadway Feature	1	No special feature	Vehicle	Emergency Status	97	Not applicable
Location And Time	School Bus Related	1	No school bus involved	Vehicle	Estimated Speed Code		Not set
Location And Time	Time Display Format	20	Military	Vehicle	Hazardous Cargo	1	None
Driver	Alcohol Test Type	6	No Test Given	Vehicle	Hazardous Cargo	97	Not applicable
Driver	Commercial Driver License Status	97	Not applicable / unlicensed	Vehicle	Hazardous Cargo Release Type	97	Not applicable
Driver	Commercial Driver License Status	C	Current / valid	Vehicle	K12 Child Going To Or From School	0	Not Set
Driver	Contributing Circumstance	8	Made improper turn	Vehicle	Make	CHEV	Chevrolet
Driver	Contributing Circumstance	97	Not applicable	Vehicle	Make	KW	Kenworth Truck Co.
Driver	Driver Address Code	0	Not Set	Vehicle	Non-Motorist Action	0	Not Set
Driver	Driver Condition	1	Apparently normal	Vehicle	Non-Motorist Location	0	Not Set
Driver	Driver License Class Code	0	Not set	Vehicle	Oversized Load	N/A	NotApplicable
Driver	Driver License Endorsement	97	Not applicable	Vehicle	Oversized Load	Yes	Yes
Driver	Driver License Number	0	Not set	Vehicle	Oversized Load Permit	N/A	NotApplicable
Driver	Driver License Restriction	97	Not applicable	Vehicle	Oversized Load Permit	Yes	Yes
Driver	Driver License State Code	0	Not set	Vehicle	Owner Address Code	Same	Same
Driver	Driver License Status	C	Current / valid	Vehicle	Owner Name Code	Same	Same as driver
Driver	Driver Name Code	0	Not Set	Vehicle	Placard Requirement	2	No
Driver	Drug Test Result	97	Not applicable	Vehicle	Placard Requirement	97	Not applicable
Driver	Drug Test Type	4	No test given	Vehicle	Tag Number		Not set
Driver	Gender	1	Male	Vehicle	Tag State	0	Not set
Driver	Harmful Event	22	Collision with vehicle in traffic	Vehicle	Tag Year	0	Not set
Driver	Liability Ins. Policy Code	0	Not Set	Vehicle	Tow Status	1	Towed due to disabling damage
Driver	Maneuver	1	Movement essentially straight	Vehicle	Tow Status	3	Not towed
Driver	Maneuver	2	Turning left	Vehicle	Towed Code	0	Not Set
Driver	Phone Number Code	0	Not Set	Vehicle	Towed Code	97	Not applicable
Driver	Place of Employment		Not Set	Vehicle	Unit Type	1	Passenger car
Driver	Place of Employment	Self	Self-employed	Vehicle	Unit Type	11	Tractor / semi-trailer

LEGEND							
Location	Category	Code	Description	Location	Category	Code	Description
Vehicle	Usage	1	Personal	Roadway Environment	Workzone Relationship	3	Between workzone warning signs and work area
Vehicle	Usage	6	Transport property	Roadway Environment	Workzone Type	1	Major construction project
Vehicle	VIN	0	Not set	Investigation	Non-Vehicular Property Damage Severity	1	None visible
Vehicle	Year		Not set	Truck/Bus Supplement	Bus Usage	1	Not a bus
Uninjured Occupants	Age Code	9	65 or older	Truck/Bus Supplement	Cargo Body Type	5	Flatbed
Uninjured Occupants	Airbag	4	Not deployed, switch on	Truck/Bus Supplement	Cargo Type	98	Other
Uninjured Occupants	Birth Date Code	0	Not Set	Truck/Bus Supplement	Carrier Address Code	0	Not Set
Uninjured Occupants	Ejection Status	1	Not ejected or trapped	Truck/Bus Supplement	Carrier Name Code	0	Not Set
Uninjured Occupants	Gender	1	Male	Truck/Bus Supplement	Carrier Phone Code	99	Unknown
Uninjured Occupants	Occupant Type	1	Driver	Truck/Bus Supplement	Country Number Code	Unk	Unknown
Uninjured Occupants	Safety Equipment	2	Shoulder and lap belt used	Truck/Bus Supplement	ICCMC Number Code	Unk	Unknown
Victims	Age Code	8	26 - 64	Truck/Bus Supplement	Motor Carrier Type	1	Interstate carrier
Victims	Airbag	7	Deployed front, switch on	Truck/Bus Supplement	State Number Code	Unk	Unknown
Victims	Birth Date Code	0	Not Set	Truck/Bus Supplement	USDOT Number Code	0	Not Set
Victims	Ejection Status	1	Not ejected or trapped	Truck/Bus Supplement	Vehicle Configuration	9	Tractor with semi-trailer
Victims	First Aid Provider	1	Paramedic / EMT	Truck/Bus Supplement	Weight Rating	3	More than 26,000 pounds
Victims	Gender	1	Male				
Victims	Injury Type	3	Non-incapacitating				
Victims	Medical Facility Transport	97	Not Applicable				
Victims	Occupant Type	1	Driver				
Victims	Safety Equipment	2	Shoulder and lap belt used				
Victims	Victim Taken By	N/A	Not applicable				
Victims	Victim Taken To	N/A	Not applicable				
Roadway Environment	Environmental Contributing Circumstance	1	None apparent				
Roadway Environment	Light Condition	1	Daylight				
Roadway Environment	Locale	3	Shopping or business				
Roadway Environment	Opposing Lane Separation	6	Concrete barrier				
Roadway Environment	Road Bridge Condition	1	None apparent				
Roadway Environment	Road Surface Type	1	Asphalt				
Roadway Environment	Roadway Condition	1	Dry				
Roadway Environment	Roadway Curvature And Grade	1	Straight, level				
Roadway Environment	Roadway Material	1	None				
Roadway Environment	Roadway Material Source	97	Not applicable				
Roadway Environment	Traffic Control	6	Traffic signals				
Roadway Environment	Traffic Control Status	1	Yes				
Roadway Environment	Trafficway Lane Count	2	Two lanes				
Roadway Environment	Turn Lane Presence	2	Left turn lane(s) only				
Roadway Environment	Vision Obscuration	1	Not obscured				
Roadway Environment	Weather Condition	2	Cloudy				
Roadway Environment	Workzone Law Enforcement Presence	1	None				

Figure 3.3 – Sample AUTCR Form

The contractor's written report serves as the company's response to any crash involved within the limits of their work site. It provides a summary for the crash, as well as any responsibility, liability, or involvement the company may have in the crash (or crashes). It can include whether or not employees or equipment were involved, if traffic control was in place and/or functioning, or if any fatalities occurred. It is addressed to the corresponding ALDOT Project Engineer, and can be written by either the General Contractor or Subcontractor. Also, cover letters to the Construction Engineer of ALDOT may be included. These letters are written in accordance with the Department of Transportation's new Traffic Control Procedure, which was revised February 25, 2008. While these reports do not provide any new information pertaining to the crash, they do further confirm information provided in the C-25-A and AUTCR. Figure 3.4 gives an example of a contractor's written report to the Project Engineer on the left, as well as a cover letter written to the Construction Engineer of ALDOT on the right.



P.O. Box 2618
Huntsville, Alabama 35804-2618

Phone (256) 533-0505
Fax (256) 753-2390

Date 9/24/10

Alabama Department of Transportation
4711 Governors House Drive
Huntsville, AL 35805

Attn:

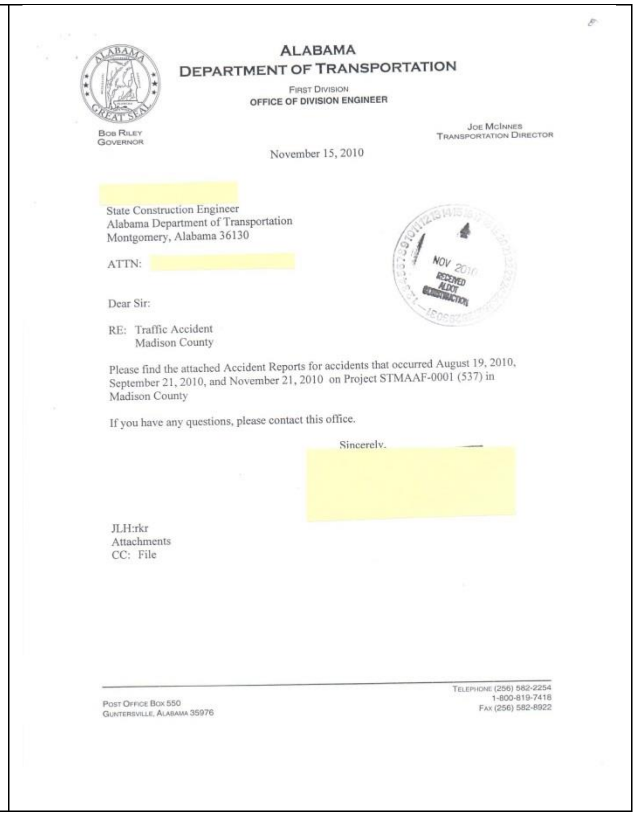
Re: Project # STMAAF-0001(537) Madison County, Huntsville, AL

Dear

Regarding the attached motor vehicle accident report number 4104543 which occurred 8/19/10 on the above referenced project, be advised that all required traffic control devices were in place and functioning properly. The accident was not caused by nor a result of construction activities but rather driver error. Should you require additional information we will make every effort to comply.

Sincerely,

CW/rm
Attachments



ALABAMA
DEPARTMENT OF TRANSPORTATION
FIRST DIVISION
OFFICE OF DIVISION ENGINEER

BOB RILEY
GOVERNOR

JOE McINNES
TRANSPORTATION DIRECTOR

November 15, 2010

State Construction Engineer
Alabama Department of Transportation
Montgomery, Alabama 36130

ATTN:

Dear Sir:

RE: Traffic Accident
Madison County

Please find the attached Accident Reports for accidents that occurred August 19, 2010, September 21, 2010, and November 21, 2010 on Project STMAAF-0001 (537) in Madison County

If you have any questions, please contact this office.

Sincerely,

JLH:rkr
Attachments
CC: File

POST OFFICE BOX 550
GUNTERSVILLE, ALABAMA 35976

TELEPHONE (256) 582-2254
1-800-819-7418
FAX (256) 582-8922

Figure 3.4 – Sample Cover Letters

3.2 Data Management

In this task, the methods and procedures used to prepare the data for analysis are explained in detail. Once the researchers had a clear understanding of the reports, specifically the information deemed useful to satisfying the research objectives, decisions were made on which fields (also referred to as variables) to include in the data entry process. Not all items within the reports were included, and only those items deemed pertinent to satisfying the research objectives were included in the unique, codified spreadsheet. A total of 165 fields were included in the codified spreadsheet for the eventual data entry.

The unique, codified spreadsheet was created using Microsoft Excel ®. First, a header was created that contained the aforementioned 165 fields (which represented all of the items deemed pertinent to satisfying the research objectives). With fields being positioned in columns, each row was designated for a specific crash report (also referred to as an observation). The spreadsheet, along with the AUTCR itself, was designed with fields for four possible units (vehicles) per crash. In the event that one crash involved more than four units, the crash information entered into the spreadsheet was carried on to the next row (Unit 1 becoming Unit 5, Unit 6 becoming Unit 2, etc.). This, however, applied to only ten crash reports, or roughly 0.26% of all crashes entered.

Next, drop-down menus were implemented for applicable fields, with the associated data used to facilitate the drop-down menu stored in a secondary sheet. This was done not only to eliminate possible typing errors, but also to increase overall consistency with the data entry. Possible categories to select for each variable ranged from one possible entry to more than 70. After the codified spreadsheet had been finalized, the data entry process itself was ready to begin. First, each crash report was unbound or unstapled when needed, so that it could be scanned and copied. Electronic copies were used to copy the diagram and narrative of the report into the spreadsheet. These were then included in the last two fields, labeled "Accident Diagram" and "Narrative."

The completion of data entry resulted in a Master spreadsheet. The Master spreadsheet consisted of 3,857 observations with 165 different variables. Since this data set was considered raw data, steps needed to be taken to condense and prepare the data before any analysis was performed. Such steps included reducing the amount of variables to be considered for analysis, and condensing the amount of categories within certain variables. While not every crash report entered had 165 inputs, the number of variables still needed to be reduced in order to create a simplified spreadsheet, with the ultimate goal of obtaining an accurate, well-fit multinomial regression in mind.

From the Master spreadsheet, a new spreadsheet was created that included the 3,857 reports, but with 48 variables. Variables were removed due to two different reasons, with the first reason being that some variables presented redundancies. For example, having both "Primary Contributing Factor" and "Unit_# Contributing Circumstance" was found to be unnecessary because both variables had the same list of categories. In other cases, having the driver's Date of Birth was unnecessary because the age code of the driver was also given. For analysis purposes, representing age by the use of a categorical variable was more appropriate. Secondly, variables that had no potential bearing on the analysis were removed. For example, "Driver's License Status" and "Unit_# Total Number of Injuries" would in no way be considered significant factors related to crash severity or work zone crash location, and were removed from the spreadsheet. The new spreadsheet proved to be much easier to work with, and ultimately provided a more robust data set to begin analysis. Table 3.2 shows the 48 variables used in the reduced spreadsheet.

Next, the categories within each variable needed to be condensed. With variables such as "Primary Contributing Factor" and "First Harmful Event" containing over 50 unique categories, the eventual multinomial regression model to be developed would not be able to properly analyze the data. With the fewest number of categories, an accurate, unbiased model would be generated. Reducing the number of categories was not challenging, as natural groupings occurred for each case. As an example, Table 3.1 outlines how categories 51-58 within "Primary Contributing Factor" were effectively reduced without endangering the integrity of the variable for the purposes of these analyses.

Table 3.1 – Reducing Categories 51-58 within “Primary Contributing Factor”

Category	New Category
51-Inattentive/Distracted by Passenger	Inattentive/Distracted
52-Inattentive/Distracted by Use of Electronic Device	Inattentive/Distracted
53-Inattentive/Distracted by Use of Other Electronic Device	Inattentive/Distracted
54-Inattentive/Distracted by Fallen Object	Inattentive/Distracted
55-Inattentive/Distracted by Fatigued/Asleep	Inattentive/Distracted
56-Inattentive/Distracted by Insect/Reptile	Inattentive/Distracted
57-Other Distraction inside Vehicle explained in Narrative	Inattentive/Distracted
58-Other Distraction outside the Vehicle explained in the Narrative	Inattentive/Distracted

In Table 3.1, categories 51-58 can be assigned a new category called “Inattentive/Distracted,” for knowing whether or not the driver was distracted by a cell phone, fallen object or reptile has no bearing on the analysis. While it is important for the police officer to accurately record the primary contributing factor related to the crash, simply knowing that the primary contributing factor to a crash was caused by inattentive or distracted driving suffices for the purpose of this study. Lastly, this process was repeated for all variables, and resulted in a simpler, condensed set of data to use for analysis.

By using all available sources of information (C-25-A forms, AUTCRs, contractor reports and cover letters), creating a unique, codified spreadsheet for data entry, and reducing and condensing the variables used in the final spreadsheet, a cohesive and comprehensive database was created. This database established the necessary framework for a detailed analysis that used the functions of two software programs: R and Rattle. R is a programming language and environment for statistical computing and graphics, and it provides a wide variety of statistical and graphical techniques (Williams). Rattle is a graphical user interface (GUI) that is used for data mining within R, and it is developed to simplify data mining projects (Williams). Two techniques that are used to analyze the data set, which are discussed at length in the following section, are accomplished through the use of R and Rattle.

3.3 Data Analysis

In the final step of the methodology, the techniques used to analyze the data are presented and explained in detail. Specific distributions and trends among the independent variables (used against the dependent variables for both research questions) are established by using two effective techniques: (1) frequency distributions and (2) multinomial regressions.

First, frequency distributions will be generated to identify patterns between all independent variables against "Crash Severity" and "Work Zone Crash Location." Frequency distributions condense and summarize large amounts of data, and are simple to interpret. The results will be presented in the form of bar charts and tables, and conclusions such as a dependent variable's representation within each independent variable, as well as each independent variable's representation within a dependent variable will be determined.

Second, multinomial regressions will be used to "predict categorical placement in or the probability of category membership on a dependent variable based on multiple independent variables" (Starkweather and Moske 2011). The multinomial regression technique was determined to be the most adequate statistical testing method for this study due to the nature of the categorical variables included in the analysis. By building multinomial regressions, the statistical significance of each independent variable, with respect to its contribution to the dependent variable, will be determined.

Multinomial regression is a classification method that is used to predict the probabilities of the many possible outcomes of a categorically distributed dependent variable that has more than two categories. One of the key properties of multinomial regression is its assumption of independence; multinomial regression inherently assumes that the choice of or membership in one category is not related to the choice or membership of another category (Starkweather and

Moske 2011). Additionally, each observation is independent of one another due to the nature of the data. With each observation representing a different crash involving different people, vehicles, and conditions, the assumption of independence is upheld.

Since all of the variables (both dependent and independent) used in the analysis are considered categorical variables, each variable can be represented by a number of possible values. For example, the variable "Crash Severity" can be represented by five, unique choices. It is reported in the "KABCO" scale, and it is used by law enforcement officers to classify the severity of injuries resulting from any particular crash. This scale ranges from the most severe injury type (Fatal Injury) to the least severe injury type (Property Damage Only). Table 3.2 explains the KABCO scale, including the description for each of the five possible values.

Table 3.2 – KABCO Severity Scale

Value	Description
K	Fatal Injury
A	Incapacitating Injury
B	Evident Injury
C	Possible Injury
O	Property Damage Only

As a result, multinomial regressions and frequency distributions can be generated to identify the factors that have the greatest impact on predicting the probability of whether the crash results in a fatal injury (K), incapacitating injury (A), evident injury (B), possible injury (C), or property damage only (O).

Multinomial regressions and frequency distributions will be constructed within Rattle, using a list of variables determined and agreed upon by the research team. From the 48 variables included in the final spreadsheet, two were the previously defined dependent variables, and the remaining 46 were considered independent variables that could potentially be a part of the analysis. Of the 46 independent variables, 16 of those were chosen to be included in the analysis. Reasons for eliminating the 30 remaining variables are as follows:

(1) Driver demographics: consisting of 12 independent variables that include race, gender and age, were ignored because they are likely to not be viewed as factors that are related to and/or contribute to crash severity or work zone crash location.

(2) Point of Impact: totaling 4 independent variables, was ignored because it is unit specific, and would yield too many inconsistencies.

(3) Coding variables: including "Date Code," "Time Code," and "Hour Slot of Crash," were ignored because they are variables that were used to produce other variables.

(4) Continuous variables: including "Date of Crash," "Number of Vehicles Involved," "Number of Fatalities Involved," and "Time," were ignored because the analysis strictly adheres to the use of categorical variables.

(5) Geographic/regional variables: including "Division" and "District," were ignored since the extent of completeness in the submittal of crash reports from the divisions to the ALDOT was not consistent. Had the data included all work zone-related crashes from all divisions from 1998 to 2012, these two independent variables would have been kept in the analysis.

(6) Inconsistent variables: including "Were Workers Involved," "Was Equipment Involved," and "Was Proper Temporary Traffic Control in Place," were ignored because they were not reported with any consistency. Also, in the case of "Were Workers Involved," only one crash report indicated yes to this variable, yielding a variable that would not be useful in the analysis.

(7) Variables with too many unique categories: including “County” and “City,” were ignored due to the large amount of unique identifiers each variable held. Combined they yielded 180 unique choices, with 90 missing fields.

The final list of independent variables used in the analysis, and used for both research questions, is presented in Table 3.3 listed below.

Table 3.3 – Independent Variables used in the Analysis of both Research Questions

	INDEPENDENT VARIABLES
1	Time of Day
2	Day of the Week
3	Highway Classification
4	Primary Contributing Factor
5	First Harmful Event
6	First Harmful Event Location
7	Manner of Crash
8	Highway Side
9	Roadway Condition
10	Work Zone Type
11	Traffic Control
12	Traffic way Lanes
13	Light
14	Weather
15	Locale

The fifteen independent variables that remained were chosen due to a number of reasons. The first of such reasons is that these variables effectively summarize the very nature of a crash, including factors such as when the crash occurs to whether or not it was raining. These variables specifically outline all important aspects for any given crash. Second, by limiting the number of variables to these fifteen, any potential redundancy was minimized. Including variables that are too similar in nature would dilute the results of the model, making it harder to decipher which variables are in fact the most statistically significant to crash severity or crash location within the work zone.

After finalizing the list of independent variables to be used for both research questions, the results of the model came into question. The original model was constructed, and 889 observations were ignored from the regression due to missing values (this equates to roughly 23% of the total crash reports). If a crash report had at least one variable that yielded a blank entry, it was not included in the regression; only completed crash reports were included. Additionally, it should be pointed out that these 889 ignored observations were missing data regardless of the dependent variable, meaning 889 observations were ignored for both research questions. These were simply crash reports that were missing data at some point in the report. As a result, it was decided that a model that included all 3,857 observations would be beneficial, and would be used to compare with the results of the original model. Thus, a model with imputed data was built.

The variables for this model were imputed, meaning that variables with missing data were substituted with the mode value for that particular variable. For example, the mode value for the independent variable “Weather” was “Clear.” For the 43 crash reports that did not indicate the weather, “Clear” was used in its place, resulting in every crash report being completed. The original number of “clear” weather crash reports was 2,412, and the imputed value increased to 2,455. This was done for every variable, ensuring that every crash report was included in the analysis. The results of the imputed model were then compared against the results of the original model, and done so for both research questions. The purpose of imputing the data was to enhance the overall quality of the multinomial regression models. However, generating frequency distributions with imputed values have no real meaning, and thus, the imputed values were only used in the multinomial regressions.

3.4 Summary

The first step in accomplishing the research objectives stated in Chapter One was to develop a database for work zone-related crashes in Alabama, and this was done by collecting and organizing data obtained from ALDOT crash reports (including any supplemental information associated with these reports, such as C-25-A forms and written reports from contractors), effectively managing the data in a codified spreadsheet, and by outlining which methods would be used to accurately analyze the data.

CHAPTER FOUR

RESULTS

This chapter presents the results of the procedures developed to address both research questions outlined in Chapter Three. More specifically, the results generated through frequency distributions and multinomial regression models for both research questions are given, including both original and imputed regression models. As mentioned in Chapter Three, the generalizability of the results generated from these crash reports are limited, for only crash reports made available to ALDOT were analyzed. The sample of crash reports used in this analysis represents crashes that occurred in Alabama from the year 1998 to 2012, with all crashes being specifically related to work zones in some fashion.

Lastly, this chapter is further subdivided into two main sections with five total parts to each. Section 4.1 pertains to factors contributing to crash severity, and Sections 4.2 pertains to the factors contributing to work zone crash location.

4.1 Analysis of Factors That Impact Crash Severity in Work Zone-Related Crashes

The first research question addresses the most significant factors related to crash severity for work zone-related crashes in the state of Alabama. Crash severity is defined on the KABCO scale, and can be represented by five different values. As a reminder, Table 4.1 displays the values and descriptions for each of the five possible values.

Table 4.1 – KABCO Severity Scale

Value	Description
K	Fatality
A	Incapacitating Injury
B	Evident Injury
C	Possible Injury
O	Property Damage Only

For the purpose of this analysis, crash severity is condensed into three categories. The "Fatality" and "Property Damage Only (PDO)" categories remain from the KABCO scale, and instead of "Incapacitating Injury," "Evident Injury" and "Possible Injury," a third category "Injury" is created in its place. Table 4.2 presents the three, condensed categories within "Crash Severity" that are used in Section 4.1.

Table 4.2 – "Crash Severity" Categories used in Section 4.1

Category	**Description**
Fatality	Crashes resulting in a fatality
Injury	Crashes resulting in some sort of injury
Property Damage Only	Crashes resulting in property damage only

Collapsing "Incapacitating Injury," "Evident Injury," and "Possible Injury" into the new category "Injury" did not compromise the integrity of the variable, as the three main possible levels of crash severity are still well-defined. By doing so, crash severity was more appropriately analyzed in both the multinomial regression models and frequency distributions; the model is able to more accurately predict the probabilities of the outcomes of crash severity when fewer categories are present.

In order to determine which factors have the most impact on determining the resulting severity of a crash, crash severity is set as the dependent variable. Basic crash information, as well as roadway geometry and conditions are set as independent variables. Lastly, the independent variables were then used generate frequency distributions and build the models. Table 4.3 displays the variables included in the analysis of Section 4.1.

Table 4.3 – Variables Used in the Analysis of Research Question 1

DEPENDENT VARIABLE	INDEPENDENT VARIABLES
Crash severity	Time of Day
	Day of the Week
	Highway Classification
	Primary Contributing Factor
	First Harmful Event
	First Harmful Event Location
	Manner of Crash
	Highway Side
	Roadway Condition
	Work Zone Crash Location
	Work Zone Type
	Traffic Control
	Traffic way Lanes
	Light
	Weather
	Locale

4.1.1 Frequency Distributions

In this section, frequency distributions of the four most statistically significant variables related to crash severity are shown (as determined by the multinomial regression models), with the remaining twelve being found in Appendix A. The four most statistically significant variables related to crash severity are “Manner of Crash,” “Primary Contributing Factor,” “First Harmful Event,” and “Highway Classification.”

As previously mentioned, there are a total of 893 observations that were ignored due to incomplete data. These observations were missing values at some point in the crash report, and were ultimately ignored due to one of two reasons: (1) either the observation was missing the value for the dependent variable, or (2) the observation had at least one independent variable that was missing a value, while the value for the dependent variable could have been present. Any combination of the aforementioned reasons as to why they were ignored could have occurred.

As a result, the total number of ignored observations *for the entire data set* equaled 893 (regardless of the dependent variable). However, when specifically examining the dependent variable against each independent variable, the number of ignored observations for each distribution varies. The highest amount of ignored observations in any distribution against "Crash Severity" is 412, which occurs in the distribution of "Highway Side."

Table 4.4 displays two distinct observation numbers for each independent variable: (1) the total number of ignored observations from the data set, and (2) the number of ignored observations when distributed against "Crash Severity."

Table 4.4 – Number of Ignored Observations in the Distribution of "Crash Severity"

Independent Variable	Total Number of Ignored Observations	Number of Ignored Observations (when distributed)
Time of Day	0	92
Day of the Week	5	96
Highway Classification	0	92
Primary Contributing Factor	103	182
First Harmful Event	6	96
First Harmful Event Location	3	93
Manner of Crash	18	98
Highway Side	412	471
Roadway Condition	48	136
Work Zone Crash Location	0	92
Work Zone Type	28	115
Traffic Control	193	237
Traffic way lanes	66	151
Light	115	193
Weather	43	129
Locale	229	309
Crash Severity	92	N/A

"Manner of Crash" was determined to be the most statistically significant factor related to crash severity; no other variable had a greater impact on predicting the probability of whether the crash resulted in a fatality, some sort of injury, or property damage only. Figure 4.1 gives the frequency distribution for "Manner of Crash" by "Crash Severity."

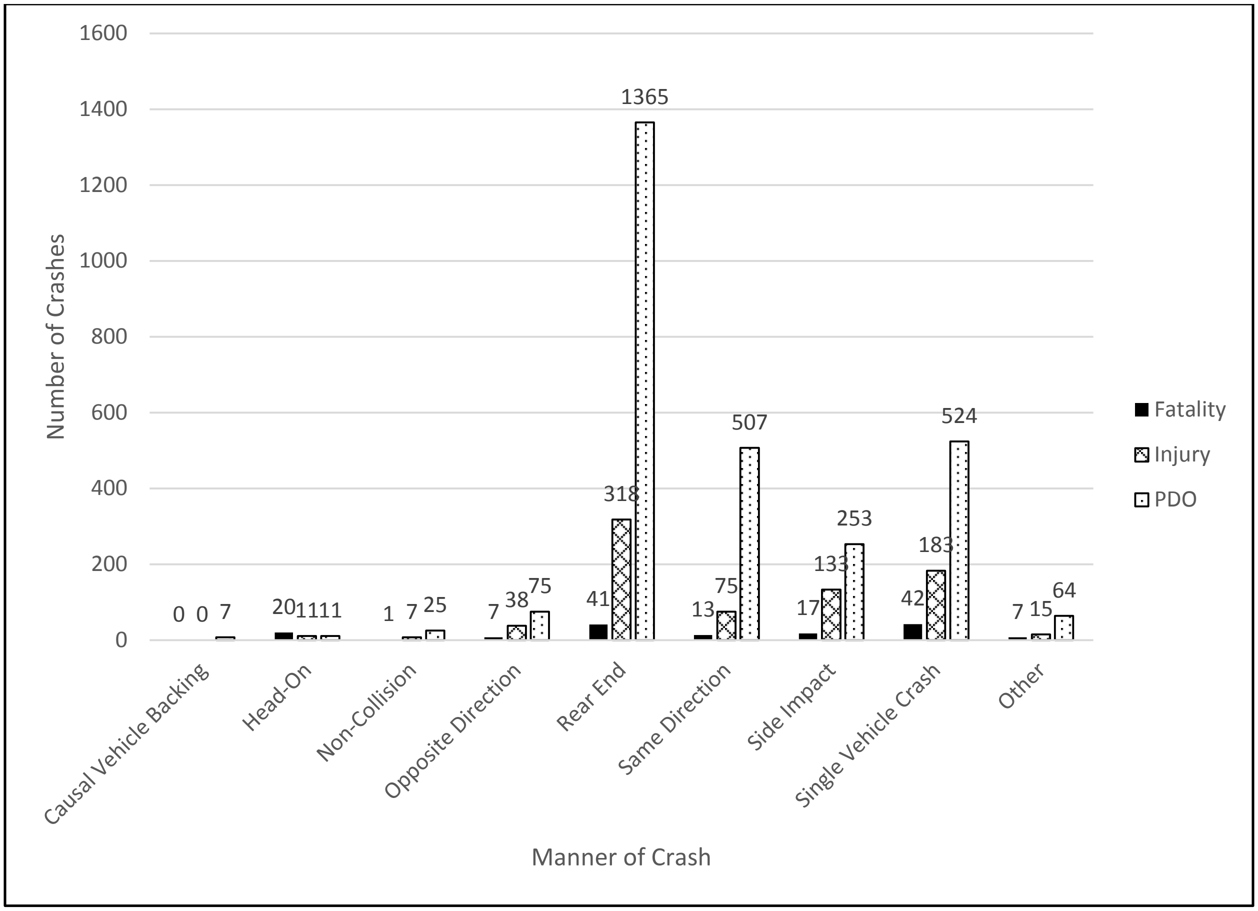


Figure 4.1 – Distribution of "Manner of Crash" by "Crash Severity"

When distributed against "Crash Severity," the most frequently occurring manner of crash is "Rear End," with 1,724 reports resulting in a rear end type crash. The manner of crash that resulted in the most fatalities was "Single Vehicle Crash," with 42 occurrences resulting in fatalities. Tables 4.5 and 4.6 summarize the results obtained from the frequency distribution of "Manner of Crash."

Table 4.5 – Distribution of “Manner of Crash” by “Crash Severity”

Manner of Crash	**Crash Severity**			
	Fatality (%)	Injury (%)	PDO (%)	**Total**
Causal Vehicle Backing	0 (0%)	0 (0%)	7 (100%)	7
Head-On	20 (47.6%)	11 (26.2%)	11 (26.2%)	42
Non-Collision	1 (3%)	7 (21.2%)	25 (75.8%)	33
Opposite Direction	7 (5.8%)	38 (31.7%)	75 (62.5%)	120
Rear End	41 (2.4%)	318 (18.4%)	1365 (79.2%)	1724
Same Direction	13 (2.2%)	75 (12.6%)	507 (85.2%)	595
Side Impact	17 (4.2%)	133 (33.0%)	253 (62.8%)	403
Single Vehicle Crash	42 (5.6%)	183 (24.4%)	524 (70.0%)	749
Other	7 (8.1%)	15 (17.4%)	64 (74.4%)	86
Total	148 (3.9%)	780 (20.8%)	2831 (75.3%)	3759

In Table 4.5, “Manner of Crash” is distributed amongst the three crash severity categories. Percentages of fatalities, injuries, and property damage only crashes are represented within each category of “Manner of Crash.” For example, “Rear End” crashes yield property damage only in 79.2% of its occurrences, while “Head-On” crashes yield a fatality in 47.6% of its occurrences. Similarly, “Non-Collision” crashes yield fatalities for 3%, injuries for 21.2%, and property damage only for 75.8% of the observations.

Table 4.6 - Distribution of "Crash Severity" by "Manner of Crash"

Crash Severity	Manner of Crash									
	Causal Vehicle Backing (%)	Head-On (%)	Non-Collison (%)	Opposite Direction (%)	Rear End (%)	Same Direction (%)	Side Impact (%)	Single Vehicle Crash (%)	Other (%)	**Total**
Fatality	0 (0%)	20 (13.5%)	1 (0.7%)	7 (4.7%)	41 (27.7%)	13 (8.8%)	17 (11.5%)	42 (28.4%)	7 (4.7%)	148
Injury	0 (0%)	11 (1.4%)	7 (0.9%)	38 (4.9%)	318 (40.8%)	75 (9.6%)	133 (17.1%)	183 (23.5%)	15 (1.9%)	780
PDO	7 (0.2%)	11 (0.4%)	25 (0.9%)	75 (2.6%)	1365 (48.2%)	507 (17.9%)	253 (8.9%)	524 (18.5%)	64 (2.3%)	2831
Total	7 (0.2%)	42 (1.1%)	33 (0.9%)	120 (3.2%)	1724 (45.9%)	595 (15.8%)	403 (10.7%)	749 (19.9%)	86 (2.3%)	3759

In Table 4.6, "Crash Severity" is distributed amongst the nine "Manner of Crash" categories. Percentages of "Causal Vehicle Backing," "Head-On," "Non-Collision," "Opposite Direction," "Rear End," "Same Direction," "Side Impact," "Single Vehicle Crash," and "Other" are represented within each category of "Crash Severity." "Single Vehicle Crash" yields the most fatalities (42), and "Rear End" yields the most injuries (318) and property damage only crashes (1,365).

"Primary Contributing Factor" was determined to be the second most statistically significant factor related to crash severity and had a high impact on predicting the probability of the resulting crash severity. Figure 4.2 gives the frequency distribution for "Primary Contributing Factor" by "Crash Severity."

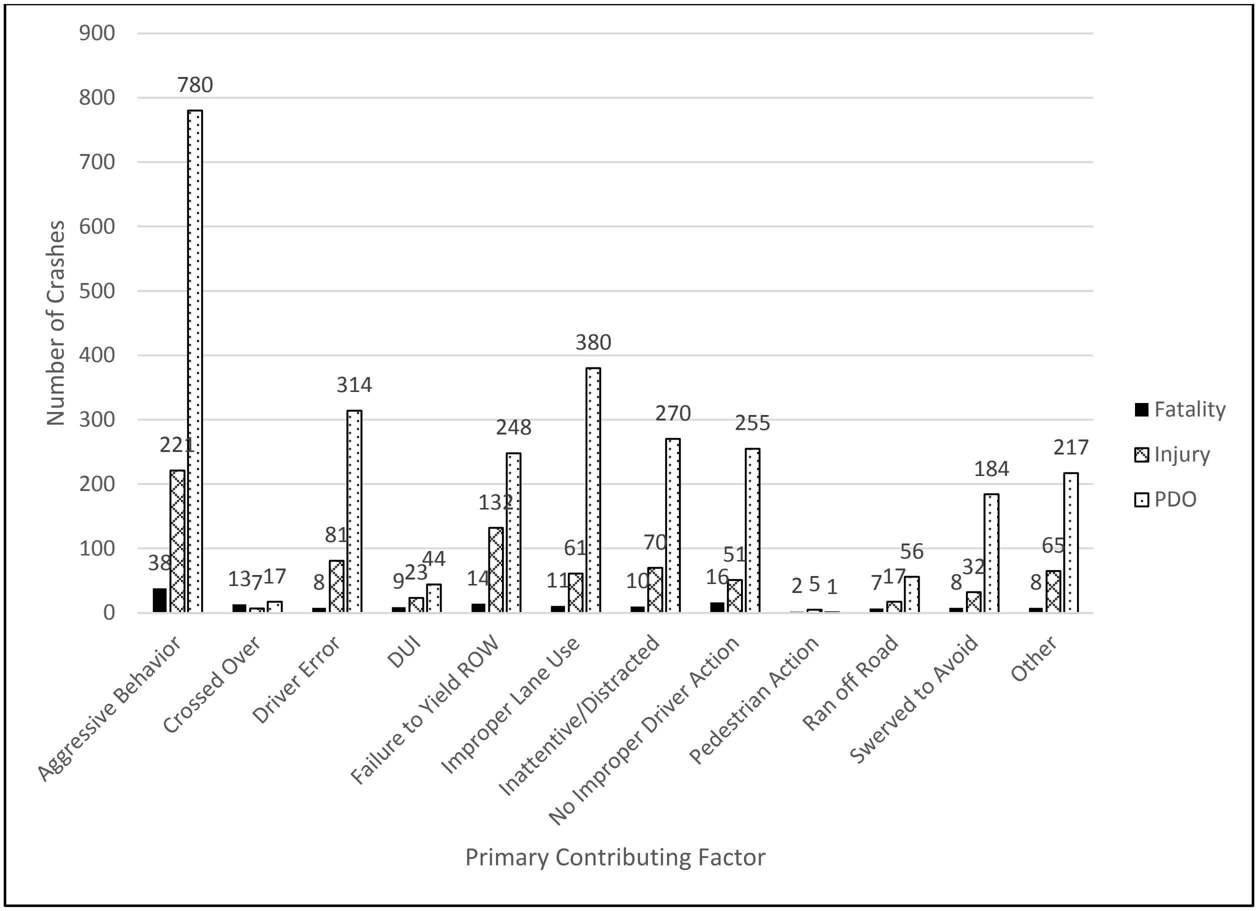


Figure 4.2 – Distribution of "Primary Contributing Factor" by "Crash Severity"

When distributed against "Crash Severity," "Aggressive Behavior" is the most frequently occurring primary contributing factor, with 1,039 reports being attributed to aggressive behavior. It is also the most severe primary contributing factor with 38 occurrences resulting in a fatality. Additionally, since this was a category that was created in order to reduce the possible number of categories, Table 4.7 summarizes the eight possible choices that make up "Aggressive Behavior."

Table 4.7 – Categories Combined to Constitute "Aggressive Behavior"

2-Aggressive Operation
3-Ran Traffic Signal
4-Ran Stop Sign
5-Disregarded Traffic Sign Other Than Stop Sign
6-Over Speed Limit
7-Driving Too Fast for Conditions
13-Disregarded Other Road Marking
15-Followed Too Close

Lastly, Tables 4.8 and 4.9 summarize the results obtained from the frequency distribution of "Primary Contributing Factor."

Table 4.8 – Distribution of "Primary Contributing Factor" by "Crash Severity"

Primary Contributing Factor	**Crash Severity**			
	Fatality (%)	Injury (%)	PDO (%)	**Total**
Aggressive Behavior	38 (3.7%)	221 (21.3%)	780 (75.1%)	1039
Crossed Over	13 (35.1%)	7 (18.9%)	17 (45.9%)	37
Driver Error	8 (2%)	81 (20.1%)	314 (77.9%)	403
DUI	9 (11.8%)	23 (30.3%)	44 (57.9%)	76
Failure to Yield ROW	14 (3.6%)	132 (33.5%)	248 (62.9%)	394
Improper Lane Use	11 (2.4%)	61 (13.5%)	380 (84.1%)	452
Inattentive/Distracted	10 (2.9%)	70 (20%)	270 (77.1%)	350
No Improper Driver Action	16 (5%)	51 (15.8%)	255 (79.2%)	322
Pedestrian Action	2 (25%)	5 (62.5%)	1 (12.5%)	8
Ran off Road	7 (8.7%)	17 (21.2%)	56 (70%)	80
Swerved to Avoid	8 (3.6%)	32 (14.3%)	184 (82.1%)	224
Other	8 (2.8%)	65 (22.4%)	217 (74.8%)	290
Total	144 (3.9%)	765 (20.8%)	2766 (75.3%)	3675

In Table 4.8, "Primary Contributing Factor" is distributed amongst the three crash severity categories, with each row tallying 100%. Percentages of fatalities, injuries, and property damage only crashes are represented within each category of "Primary Contributing Factor." For example, 84.1% of "Improper Lane Use" crash type occurrences result in property damage only, while 2.4% result in a fatality. Additionally, "Driver Error" is the least severe crash type with 2% of occurrences resulting in a fatality.

Table 4.9 – Distribution of "Crash Severity" by "Primary Contributing Factor"

Crash Severity	Primary Contributing Factor											
	Aggressive Behavior (%)	Crossed Over (%)	Driver Error (%)	DUI (%)	Failure to Yield ROW (%)	Improper Lane Use (%)	Inattentive/Distracted (%)	No Improper Driver Action (%)	Pedestrian Action (%)	Ran off Road (%)	Swerved to Avoid (%)	Other (%)	**Total**
Fatality	38 (26%)	13 (9%)	8 (6%)	9 (6%)	14 (10%)	11 (7%)	10 (7%)	16 (11%)	2 (1%)	7 (5%)	8 (6%)	8 (6%)	144
Injury	221 (29%)	7 (1%)	81 (11%)	23 (3%)	132 (17%)	61 (8%)	70 (9%)	51 (7%)	5 (1%)	17 (2%)	32 (4%)	65 (8%)	765
PDO	780 (28%)	17 (1%)	314 (11%)	44 (1%)	248 (9%)	380 (14%)	270 (10%)	255 (9%)	1 (0%)	56 (2%)	184 (7%)	217 (8%)	2766
Total	1039 (28%)	37 (1%)	403 (11%)	76 (2%)	394 (11%)	452 (12%)	350 (10%)	322 (9%)	8 (0%)	80 (2%)	224 (6%)	290 (8%)	3675

In Table 4.9, "Crash Severity" is distributed amongst the twelve "Primary Contributing Factor" categories. Percentages of "Aggressive Behavior," "Crossed Over," "Driver Error," "DUI," "Failure to Yield ROW," "Improper Lane Use," "Inattentive/Distracted," "No Improper Driver Action," "Pedestrian Action," "Ran Off Road," "Swerved to Avoid" and "Other" are represented within each category of "Crash Severity." "Aggressive Behavior" yields the most fatalities (38), injuries (221) and property damage only crashes (780).

"First Harmful Event" was determined to be the third most statistically significant factor related to crash severity, and also had a high impact on predicting the probability of the resulting crash severity. Figure 4.3 gives the frequency distribution for "First Harmful Event" by "Crash Severity."

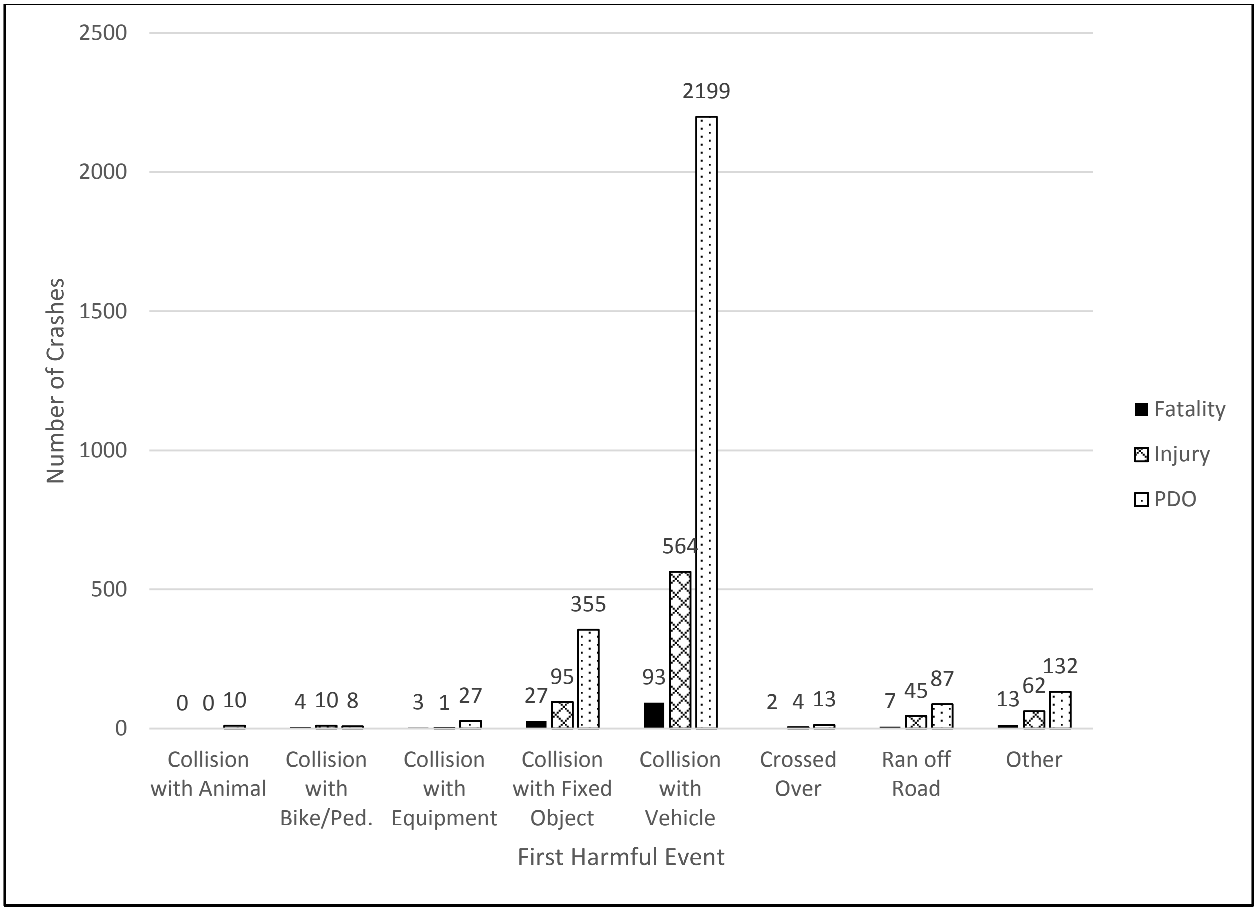


Figure 4.3 – Distribution of "First Harmful Event" by "Crash Severity"

When distributed against "Crash Severity," "Collision with Vehicle" is the most frequently occurring, with the first harmful event in 2,856 reports being attributed to a collision with a vehicle. It also accrued the highest number of fatalities, with 93 occurrences resulting in fatalities (66 more fatalities than the next category of "Collision with Fixed Object"). Lastly, Tables 4.10 and 4.11 summarize the results obtained from this frequency distribution.

Table 4.10 – Distribution of "First Harmful Event" by "Crash Severity"

First Harmful Event	Crash Severity			
	Fatality (%)	Injury (%)	PDO (%)	**Total**
Collision with Animal	0 (0%)	0 (0%)	10 (100%)	10
Collision with Bike/Ped.	4 (18.2%)	10 (45.5%)	8 (36.4%)	22
Collision with Equipment	3 (9.7%)	1 (3.2%)	27 (87.1%)	31
Collision with Fixed Object	27 (5.7%)	95 (19.9%)	355 (74.4%)	477
Collision with Vehicle	93 (3.3%)	564 (19.7%)	2199 (77%)	2856
Crossed Over	2 (10.5%)	4 (21.1%)	13 (68.4%)	19
Ran off Road	7 (5%)	45 (32.4%)	87 (62.6%)	139
Other	13 (6.3%)	62 (30%)	132 (63.8%)	207
Total	149 (4%)	781 (20.8%)	2831 (75.3%)	3761

In Table 4.10, "First Harmful Event" is distributed amongst the three crash severity categories, with each row tallying 100%. Percentages of fatalities, injuries, and property damage only crashes are represented within each category of "First Harmful Event." For example, 87.1% of "Collision with Equipment" occurrences result in property damage only, and 9.7% result in fatalities. Similarly, 36.4% of "Collision with Bike/Ped." occurrences result in property damage only, while 18.2% result in fatalities.

Table 4.11 – Distribution of "Crash Severity" by "First Harmful Event"

Crash Severity	**First Harmful Event**								
	Collision with Animal (%)	Collision with Bike/Ped. (%)	Collision with Equipment (%)	Collision with Fixed Object (%)	Collision with Vehicle (%)	Crossed Over (%)	Ran off Road (%)	Other (%)	**Total**
Fatality	0 (0%)	4 (2.7%)	3 (2.0%)	27 (18.1%)	93 (62.4%)	2 (1.3%)	7 (4.7%)	13 (8.7%)	149
Injury	0 (0%)	10 (1.3%)	1 (0.1%)	95 (12.2%)	564 (72.2%)	4 (0.5%)	45 (5.8%)	62 (7.9%)	781
PDO	10 (0.4%)	8 (0.3%)	27 (1%)	355 (12.5%)	2199 (77.7%)	13 (0.5%)	87 (3.1%)	132 (4.7%)	2831
Total	10 (0.3%)	22 (0.6%)	31 (0.8%)	477 (12.7%)	2856 (75.9%)	19 (0.5%)	139 (3.7%)	207 (5.5%)	3761

In Table 4.11, "Crash Severity" is distributed amongst the eight "First Harmful Event" categories. Percentages of "Collision with Animal," "Collision with Bike/Ped.," "Collision with Equipment," "Collision with Fixed Object," "Collision with Vehicle," "Crossed Over," "Ran off Road," and "Other" are represented within each category of "Crash Severity." "Collision with Vehicle" yields the most fatalities (93), injuries (564) and property damage only crashes (2199).

Lastly, "Highway Classification" was determined to be the fourth most statistically significant factor related to crash severity, and had a high impact on predicting the probability of whether the crash resulted in a fatality, some sort of injury, or property damage only. Figure 4.4 gives the frequency distribution for "Highway Classification" by "Crash Severity."

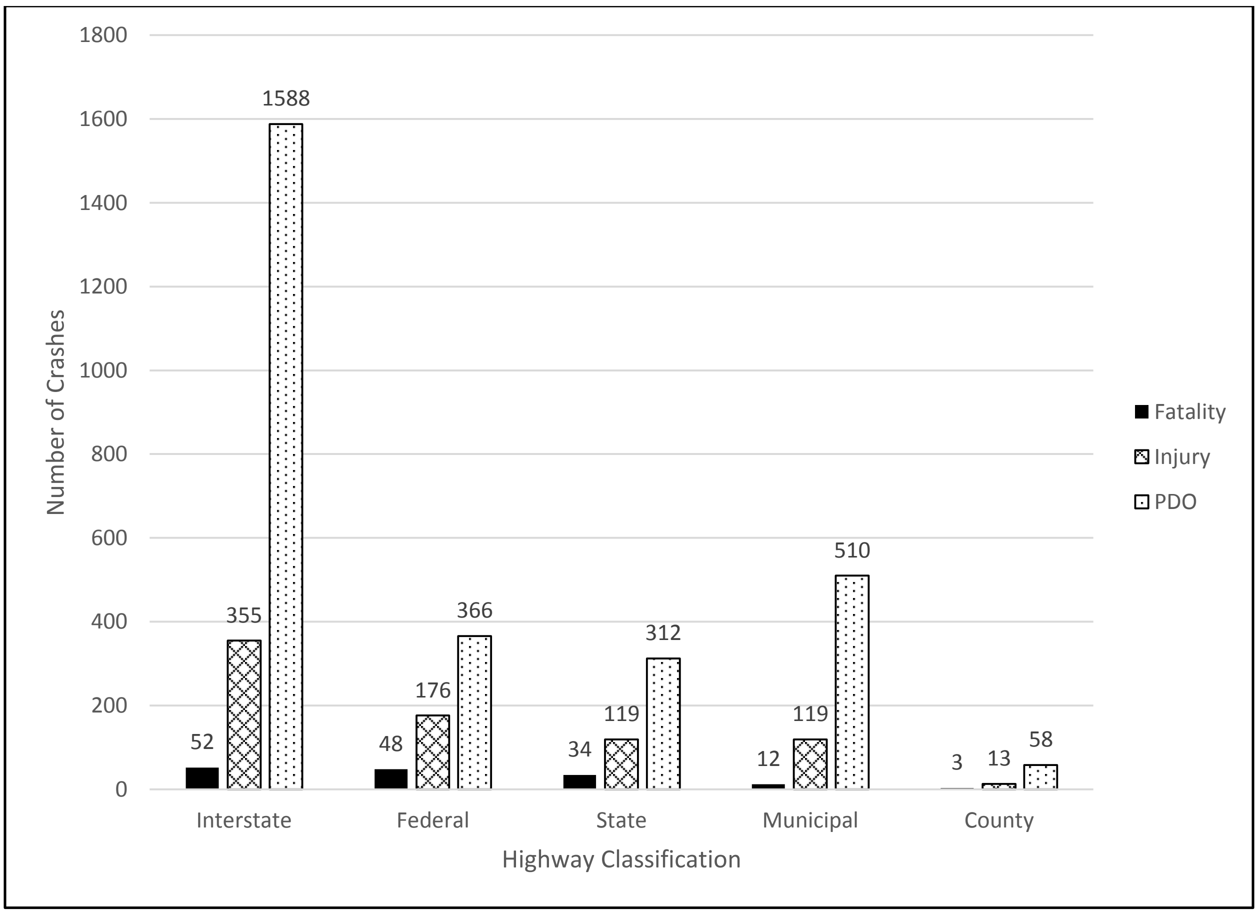


Figure 4.4 – Distribution of "Highway Classification" by "Crash Severity"

When distributed against “Crash Severity,” “Interstate” is the most frequently occurring highway classification, as well as the most severe highway classification. Crashes involving interstates occurred in 1,995 reports, with 52 occurrences resulting in fatalities. Tables 4.12 and 4.13 summarize the values obtained from this frequency distribution.

Table 4.12 – Distribution of “Highway Classification” by “Crash Severity”

Highway Classification	**Crash Severity**			
	Fatality (%)	Injury (%)	PDO (%)	**Total**
Interstate	52 (2.6%)	355 (17.8%)	1588 (79.6%)	1995
Federal	48 (8.1%)	176 (29.8%)	366 (62%)	590
State	34 (7.3%)	119 (25.6%)	312 (67.1%)	465
Municipal	12 (1.9%)	119 (18.6%)	510 (79.6%)	641
County	3 (4.1%)	13 (17.6%)	58 (78.4%)	74
Total	149 (4.0%)	782 (20.8%)	2834 (75.3%)	3765

In Table 4.12, “Highway Classification” is distributed amongst the three crash severity categories, with each row tallying 100%. Percentages of fatalities, injuries, and property damage only crashes are represented within each category of “Highway Classification.” For example, “Federal” classification crashes yield property damage only in 62% of its occurrences, and result in fatalities in 8.1% of its occurrences. When compared against the distribution of severity levels across all five highway classifications, it can be seen that the “Federal” highway classification yields the highest percentage of fatalities.

Table 4.13 – Distribution of “Crash Severity” by “Highway Classification”

Crash Severity	**Highway Classification**					
	Interstate (%)	Federal (%)	State (%)	Municipal (%)	County (%)	**Total**
Fatality	52 (34.9%)	48 (32.2%)	34 (22.8%)	12 (8.1%)	3 (2.0%)	149
Injury	355 (45.4%)	176 (22.5%)	119 (15.2%)	119 (15.2%)	13 (1.7%)	782
PDO	1588 (56%)	366 (12.9%)	312 (11%)	510 (18%)	58 (2%)	2834
Total	1995 (53%)	590 (15.7%)	465 (12.4%)	641 (18%)	74 (2%)	3765

In Table 4.13, “Crash Severity” is distributed amongst the five “Highway Classification” categories. Percentages of “Interstate,” “Federal,” “State,” “Municipal,” and “County” crashes are represented within each category of “Crash Severity.” “Interstate” crashes yield the most fatalities (52), injuries (355) and property damage only crashes (1,588).

Rear End crashes and Single Vehicle type crashes were the most severe crash types that occurred in this data set. Aggressive behavior, such as disregarding a traffic signal or sign, driving over the speed limit, or following too close, was the most severe primary contributing factor to crashes in this data set, and the most severe first harmful event was determined to be collisions with other vehicles. Lastly, over two-thirds of fatalities (67.1%) occurred on Interstate and Federal highway classifications.

4.1.2 Multinomial Regression Models

In this section, the multinomial regression models regarding factors that impact crash severity in work zone-related crashes are given. Within the model, null and alternative models were established to determine which variables were more likely to be statistically significant to crash severity. Establishing a null and alternative model accomplishes two things: (1) it measures how well the observed distribution of data differs from a theoretical distribution, and (2) it determines whether or not paired observations for two variables are independent of one another. As a result, having null and alternative hypotheses determines whether the data are significantly more likely to have an impact on crash severity if the alternative hypothesis is true than if the null hypothesis is true.

Determining observed differences between the null and alternative models is done through the use of a likelihood ratio test (LRT). A likelihood ratio test measures the goodness-of-fit between two models, and approximately follows a chi-square distribution. The LRT begins with a comparison of the likelihood scores of the two models, generated from the following equation:

$$LR = -2\ln\left(\frac{likelihood\ for\ null\ model}{likelihood\ for\ alternative\ model}\right)$$

This comparison, along with the known degrees of freedom, determines whether or not the LR statistic for each independent variable is to be considered a good approximation of the chi-square distribution. If it is indeed a good approximation of the chi-square distribution, meaning the LR statistic is equal to or greater than the critical value, the null hypothesis is rejected. By using this information, the critical value of the test statistic can be determined.

Comparisons between calculated and critical LR statistics are measured at a confidence level of 99%. Variables with LR statistics that fail to meet the criteria for their respective degrees of freedom at a confidence level of 99% are not a good approximation of the chi-square distribution. As a result, the null hypothesis is not rejected, and these variables are not statistically significant in determining the resulting crash severity.

Additionally, p-values are generated for each independent variable. The p-value represents the probability of observing the sample, assuming that the null hypothesis is true. If the p-value is small, it indicates an extremely strong presumption against the null hypothesis, and the observed data is inconsistent with the assumption that the null hypothesis is true. Therefore, the null hypothesis must be rejected, and the alternative hypothesis accepted as true. An accepted alternative hypothesis indicates that the independent variable is statistically significant in determining the resulting severity of a crash.

Lastly, this section is further subdivided into two sections. Section 4.1.2.1 addresses the multinomial regression model with the original values, and Section 4.1.2.2 addresses the multinomial regression model with imputed values.

4.1.2.1. Original Multinomial Regression Model

The first model built examined all 3,857 observations with the original values, and then disregarded 893 observations that were missing data at some point in the crash report. These observations were ignored due to incomplete data; observations with fields missing for either the dependent variable or at least one of the independent variables caused the observation to be ignored. For example, if a crash report did not have an entry for "Crash Severity," that particular observation was ignored. The same is true for an observation that did not have an entry for "Highway Side," or any other independent variable within that report. The resulting combination of missing observations totaled 893.

The results for the analysis of variance (ANOVA) for the original model are given in Table 4.14. The contents of Table 4.14 (and used for subsequent ANOVA Results tables), include:

- independent variables used in the model,
- the Likelihood Ratio (LR) statistic,
- associated degrees of freedom (df),
- the p-value generated by the LR statistic,
- the corresponding significance of each p-value.

Table 4.14 – Analysis of Variance Results of the Original Model for Research Question 1

Variable	LR	Df	p value	Significance
Time of Day	7.45	8	0.49	No
Day of the Week	17.40	12	0.14	No
Highway Classification	26.19	8	9.74E-04	Yes
Primary Contributing Factor	74.55	22	1.25E-07	Yes
First Harmful Event	54.29	14	1.15E-06	Yes
First Harmful Event Location	13.62	10	0.19	No
Manner of Crash	63.78	16	1.20E-07	Yes
Highway Side	12.17	6	0.06	No
Roadway Condition	5.47	6	0.49	No
Work Zone Crash Location	13.16	8	0.11	No
Work Zone Type	16.64	10	0.08	No
Traffic Control	36.63	14	8.4E-04	Yes
Traffic way Lanes	8.75	10	0.56	No
Light	4.65	4	0.33	No
Weather	11.17	10	0.34	No
Locale	34.69	8	3.05E-05	Yes

As previously mentioned, the LR statistic measures the difference in deviations between observed and theoretical values, and is then compared to the critical value obtained from the chi-square distribution table to determine whether or not that particular LR statistic is to be considered a good approximation. For example, the LR statistic for "Time of Day" is 7.45. With 6 six degrees of freedom measured at a confidence level of 99%, the critical value obtained from the chi-squared distribution table is 16.81. The LR statistic of 7.45 for "Time of Day" falls well beneath 16.81, and is not considered a good approximation. As a result, the null hypothesis is not rejected, indicating that "Time of Day" is not statistically significant in determining the resulting severity of a crash. Conversely, the LR statistic for "Highway Classification" is 26.19. With 8 degrees of freedom measured at a confidence level of 99%, the critical value obtained from the chi-squared distribution table is 20.09. The LR statistic of 26.19 for "Highway

Classification" exceeds 20.09, and is considered a good approximation of the chi-squared distribution table. As a result, the null hypothesis is rejected, indicating that "Highway Classification" is statistically significant in determining the resulting severity of a crash.

The significance of each p-value is determined by comparing the calculated probability against the desired probability value. If an independent variable has a highly significant impact, the corresponding p-value will be less than 0.01. Conversely, independent variables with p-values greater than 0.1 do not have a significant impact on crash severity.

For the original model, the most statistically significant variables (ones with p-values less than 0.01) are "Manner of Crash," "Primary Contributing Factor," "First Harmful Event," "Highway Classification," "Locale," and "Traffic Control." These variables have the most impact on predicting the probability of whether the crash results in a fatality, some sort of injury, or property damage only. These variables, along with their associated p-values, are listed in Table 4.15.

Table 4.15 – Most Statistically Significant Variables of the Original Model for Research Question 1

Independent Variable	**P-Value**
Manner of Crash	1.20E-07
Primary Contributing Factor	1.25E-07
First Harmful Event	1.15E-06
Highway Classification	9.74E-04
Locale	3.05E-05
Traffic Control	8.4E-04

After identifying the most statistically significant independent variables of the model, the overall goodness of fit for the model was explored. Due to the nature of multinomial regression, there is no exact way to interpret the goodness of fit for the model because there is no meaningful variance. Instead, certain measures that are used in linear regressions have been adapted to fit multinomial regressions, in order to give some idea as to whether or not the model succeeds in generating correct predictions. The R^2 value, or coefficient of determination, is used in linear regressions, and indicates how well the data points fit the model. The more the regression fits the data, or approximates the real data points, the closer the value of R^2 is to one. This is particularly useful in linear regressions, when the variables are continuous and have variation within the data. Still, even in linear regressions, there are many different methods to calculate R^2 (i.e. McFadden, Cox and Snell, etc.) and there is no general consensus on which way to calculate R^2 is best.

When dealing with multinomial regression, all of the variables included in the model are categorical. Thus, an adaption of the R^2 value is generated called the pseudo R^2. The pseudo R^2 value generated for the original model was determined to be 0.3272, meaning approximately 32.72% of the regression model fits the data.

In addition to the pseudo R^2, the log likelihood was generated for the original model. The log likelihood is another measure used to describe the goodness of fit, or strength of a model. The log likelihood is always negative, with values closer to zero indicating a better fit. The log likelihood generated for the original model was determined to be -1728.76.

While both the pseudo R^2 and log likelihood give some idea of the goodness of fit for a multinomial regression, much more can be learned from the error matrix that is generated from the model. The error matrix provides a more in depth look into how well a multinomial regression model fits the data set through the use of accuracy rates and under- and over-predictions.

The error matrix was generated to determine how accurate the model is at predicting the number of observations in each category within "Crash Severity." This is done by measuring the difference between the actual values and the predicted values for each category. This error matrix represents the 2,964 observations included in the original model, not the total number of observations of 3,857 (due to the incomplete data with missing fields). Table 4.16 shows the error matrix of the original model.

Table 4.16 – Error Matrix of the Original Model for Research Question 1

	Predicted		
Actual	Fatality	Injury	Property Damage Only
Fatality	19	20	78
Injury	6	88	537
Property Damage Only	3	53	2160

Looking at "Fatality" first, 19 fatal crashes were accurately predicted from the model, resulting in an accuracy rate of 16.24%. This rate was determined by dividing the number of accurately predicted fatalities by the total number of actual fatalities, and is represented in the following equation:

$$\frac{19}{(19+20+78)} = 0.162393 = 16.24\%$$

In summary, of the 117 observations involving a fatality that were included in the original model, only 19 were accurately predicted. The same process was applied to both "Injury" and "Property Damage Only," with resulting accuracy rates of 13.95% and 97.47%, respectively. Predicting the number of observations that result in an "Injury" was the least accurate, while predicting the number of observations that resulted in "Property Damage Only" was the most accurate.

Additionally, the error matrix provides a sense of how likely the injury types were under-predicted and over-predicted. A total of 697 observations were predicted incorrectly (observations located above and below the diagonal), as shown in Table #. By examining the predictions above the diagonal, the rate of under-predicting the severity of injuries belonging to each category can be determined, and is represented in the following equation:

$$\frac{(20 + 78 + 537)}{(20 + 78 + 537 + 6 + 3 + 53)} = \frac{635}{697} = 0.9110 = 91.1\%$$

Approximately 91% of the incorrectly predicted observations are being under-predicted, meaning these observations should be classified as a more severe crash type. Conversely, 9% of the incorrectly predicted observations are being over-predicted, meaning these observations should be classified as a less severe injury type. As a whole, the original model is under-predicting the resulting crash severity at a rate of 90%.

Ideally, the percentage of incorrectly predicted observations being under/over-predicted would be closer to a 50/50% split, with a low number of incorrectly predicted observations. For this model, if there were fewer observations above the diagonal and more observations below the diagonal, a more even split in the percentage of observations being misclassified would exist.

4.1.2.2 Imputed Multinomial Regression Model

The second model built used the imputed values for each variable, replacing fields that were initially left empty with the respective mode value. This resulted in a complete data set that included all 3,857 crash reports. Additionally, the same hypotheses, guidelines for likelihood ratios and likelihood ratio tests, and interpretation of significance of the p-values for Section 4.1.2.1 apply to the model with imputed values. Table 4.17 displays the ANOVA results for the imputed model.

Table 4.17 – Analysis of Variance Results of the Imputed Model for Research Question 1

Variable	LR	Df	p-value	Significance
IMO_Time of Day	9.43	8	0.31	No
IMO_Day of the Week	24.96	12	0.02	No
IMO_Highway Classification	40.74	8	2.34E-06	Yes
IMO_Primary Contributing Factor	76.09	22	7.05E-08	Yes
IMO_First Harmful Event	47.78	14	1.43E-05	Yes
IMO_First Harmful Event Location	15.87	10	0.10	No
IMO_Manner of Crash	84.38	16	2.67E-11	Yes
IMO_Highway Side	11.25	6	0.08	No
IMO_Roadway Condition	11.04	6	0.09	No
IMO_Workzone Crash Location	10.02	8	0.26	No
IMO_Workzone Type	14.21	10	0.16	No
IMO_Traffic Control	39.22	14	3.37E-04	Yes
IMO_Trafficway Lanes	11.09	10	0.35	No
IMO_Light	2.99	4	0.56	No
IMO_Weather	14.79	10	0.14	No
IMO_Locale	24.78	8	1.69E-03	Yes

For the imputed model, the most statistically significant variables (ones with p-values less than 0.01) are “Manner of Crash,” “Primary Contributing Factor,” “Highway Classification,” “First Harmful Event,” “Traffic Control” and “Locale.” Table 4.18 shows the most statistically significant variables, along with their p-values and associated significance levels.

Table 4.18 – Most Statistically Significant Variables of the Imputed Model for Research Questions 1

Independent Variable	P-Value
IMO_Manner of Crash	2.67E-11
IMO_Primary Contributing Factor	7.05E-08
IMO_Highway Classification	2.34E-06
IMO_First Harmful Event	1.43E-05
IMO_Traffic Control	3.37E-04
IMO_Locale	1.69E-03

The p-values of the four most statistically significant variables, "Manner of Crash," "Primary Contributing Factor," "Highway Classification," and "First Harmful Event," decreased, becoming even more significant in determining the resulting severity of a crash. Comparisons of the p-values of the most statistically significant independent variables between the original and imputed models are given in Table 4.19.

Table 4.19 – Comparison between p-values of the Original and Imputed Models

Independent Variable	Original P-Value	Imputed P-Value
Manner of Crash	1.20E-07	2.67E-11
Primary Contributing Factor	1.25E-07	7.05E-08
First Harmful Event	1.15E-06	1.43E-05
Highway Classification	9.74E-04	2.34E-06

Regarding the overall goodness of fit for the imputed model, the same approach from Section 4.1.2.1 is taken. Due to the nature of multinomial regression, there is no exact way to interpret goodness of fit for the imputed model because there is no meaningful variance. Instead, a pseudo R^2 value and a log likelihood value were generated. The imputed model yielded a pseudo R^2 value of 0.2950, and a log likelihood value of -2255.40.

To provide a more in depth look into how well the imputed model fits the data set, the error matrix was generated to determine how accurate the model is at predicting the number of observations within each category of "Crash Severity," as was done for the original model. This error matrix, however, differs from the error matrix presented in Section 4.1.2.1, in that it represents the total number of observations of 3,857. Table 4.20 shows the error matrix of the imputed model.

Table 4.20 – Error Matrix of the Imputed Model for Research Question 1

	Predicted		
Actual	Fatality	Injury	Property Damage Only
Fatality	24	15	110
Injury	7	73	702
Property Damage Only	4	44	2878

Accuracy rates of each category for "Crash Severity" were generated. Starting with "Fatality," 24 fatal crashes were accurately predicted from the model, resulting in an accuracy rate of 16.12%. Similarly, 73 "Injury" type crashes were accurately predicted, resulting in an accuracy rate of 9.34%. Lastly, 2,878 "Property Damage Only" crash types were accurately predicted, resulting in an accuracy rate of 98.36%. Comparing these rates against the rates from the original model, the accuracy rates for both "Fatality" and "Injury" decreased, while the accuracy rate for "Property Damage Only" increased. This means that after the imputation, the model was able to more accurately predict the number of observations within "Property Damage Only."

Under- and over-predictions were also generated for the imputed model. A total of 882 observations were incorrectly predicted. As a result, 93.7% of predicted injury classifications were under-predicted, meaning that these observations should be classified as a more severe crash type. Consequently, 6.3% of predicted injury classifications were over-predicted, meaning these observations should be classified as a less severe injury type. As a whole, the imputed model is under-predicting the resulting crash severity at a rate of 93.7%.

Additionally, it was stated in the previous section that if there were fewer observations above the diagonal and more observations below the diagonal, a more ideal split in the percentage of incorrectly predicted observations would exist. Comparing to the original predictions, the rate of under-prediction increased to 93.7%, and the rate of over-prediction decreased to 6.3%. For this data set, generating under- and over-predictions with imputed mode values yields an even less accurate misclassification rate, as the number of observations that should be classified as a more severe crash type increased by 2.6%.

4.2 Analysis of Factors That Impact Work Zone Location in Work Zone-Related Crashes

The second research question addresses the most significant factors related to crash location for work zone-related crashes in the state of Alabama. The work zone relationship, as reported in the AUTCR, is denoted by the following categories, and given in Table 4.21:

Table 4.21 – Work Zone Location Categories (AUTCR)

1-Not In/Related to Work Zone
2-Outside of the Work Zone Warning Signs
3-Between Work Zone Warning Signs and Work Area
4-In the Termination Area of the Work Zone
5-On Temporary Detour
6-At the Shift Transition in the Activity Area
7-Involving Workers/Equipment in the Activity Area
8-Involving Roadway Conditions in the Activity Area
9-Not Involving Workers/Conditions in the Activity Area
97-Not In/Near Work Zone
98-Other Work Zone Area Explained in Narrative
99-Unknown

Additionally, when describing crash location for work zone-related crashes, the component parts of a temporary traffic control (TTC) are vital. A temporary traffic control zone, according to the Manual on Uniform Traffic Control Devices (MUTCD), is as follows: “A TTC zone is an area of highway where road user conditions are changed because of a work zone, an incident zone, or a planned special event through the use of TTC devices, uniformed law enforcement officers, or other authorized personnel” (MUTCD, Section 6C.02). Furthermore, a temporary traffic control zone is subdivided into four main areas. These areas, described from the driver’s point of view upon entering a TTC zone, are as follows: (1) Advance Warning Area, (2) Transition Area, (3) Activity Area, and (4) Termination Area. Figure 4.5, taken from the

MUTCD, gives a visual display of a temporary traffic control zone, along with descriptions for each area.

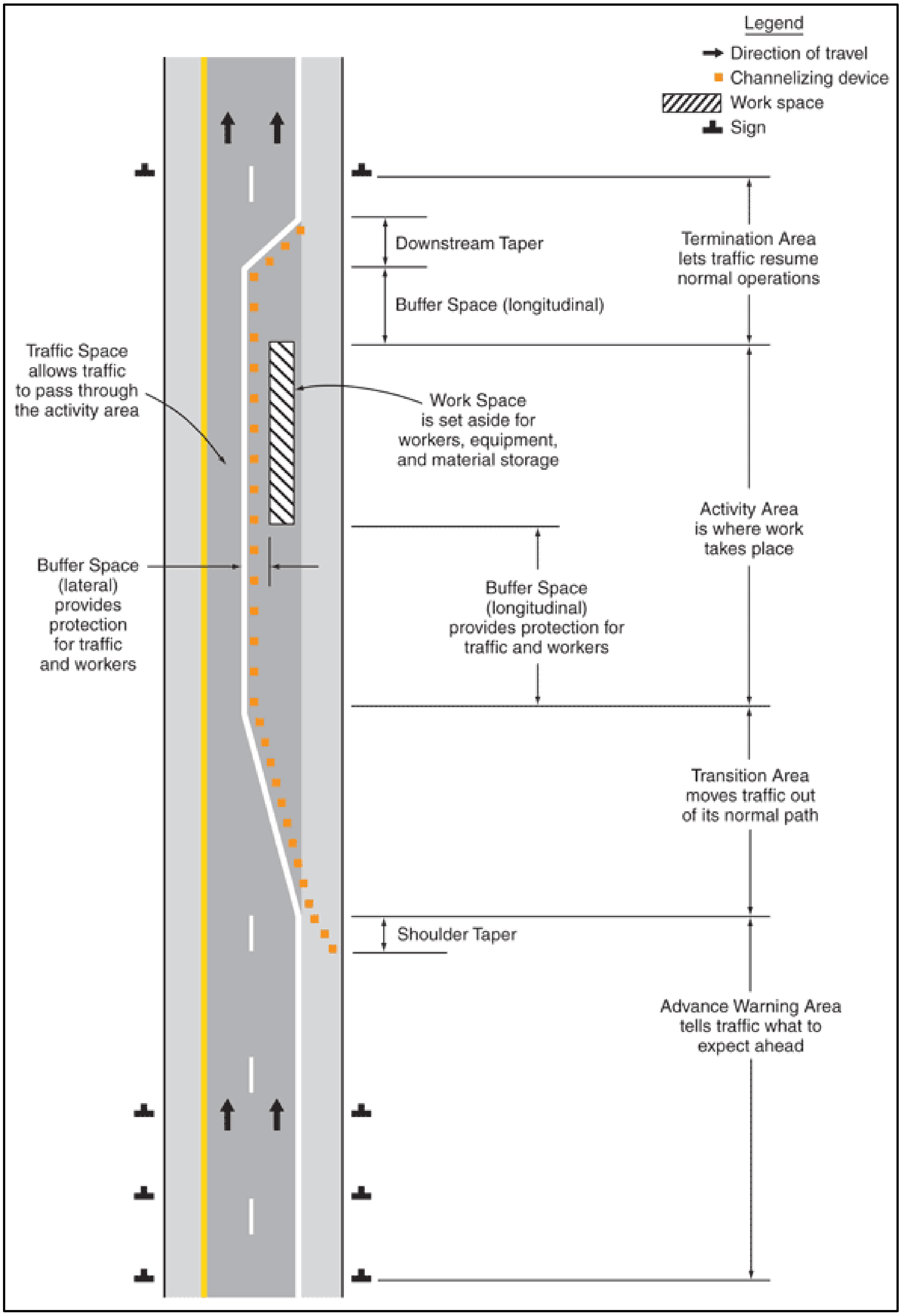


Figure 4.5 – Component Parts of a Temporary Traffic Control Zone (Source: MUTCD)

For the purpose of this analysis, the work zone location categories are condensed into five categories, taking into consideration both the work zone relationship as reported in the AUTCR, as well as the component parts of a temporary traffic control zone. Table 4.22 presents the work zone crash location categories used in the Section 4.2.

Table 4.22 – "Work Zone Crash Location" Categories used in Section 4.2

Category	Description
Advance Warning Area	Tells traffic what to expect ahead
Transition Area	Moves traffic out of its normal path
Activity Area	Where actual work takes place
Termination Area	Lets traffic resume normal operations
Other Work Zone Area	Other work zone area not clearly defined

Category "2 (Outside of the Work Zone Warning Signs)" became "Advance Warning Area," and Category "4 (In the Termination Area of the Work Zone)" became the "Termination Area." Categories "7 (Involving Workers/Equipment in the Activity Area)" and "8 (Involving Roadway Conditions in the Activity Area)" became "Activity Area," and categories "3 (Between Work Zone Warning Signs and Work Area)," "5 (On Temporary Detour)," and "6 (At the Shift Transition in the Activity Area)" became the "Transition Area." Lastly, the remaining categories indicated either "Not In/Related to Work Zone," "Other Work Zone Area," or "Unknown." All of these categories became "Other Work Zone Area" because all of these reports were deemed work zone-related by ALDOT, regardless of whether the reporting officer indicated a work zone location on the crash report or not. The category of "Other Work Zone Area" consists of categories "1 (Not In/Related to Work Zone)," "9 (Not Involving Workers/Conditions in the Activity Area)," "97 (Not In/Near Work Zone)," "98 (Other Work Zone Area Explained in Narrative)," and "99 (Unknown)."

By condensing the 12 categories listed in Table 4.23 and incorporating the component parts of a temporary traffic control zone, five appropriate categories were created. These categories accurately reflect work zone crash location by giving either the specific work zone area or denoting the location as some sort of work zone area. The last category, "Other Work Zone Area," includes the crashes that do not have a specific crash location. Observations included in this category exist because the law enforcement officer at the scene was either unaware of the specific work zone location, or did not realize that the crash actually occurred within a work zone. Although an exact location is not given, it can be safely said that a crash of this type is related to a work zone in some fashion.

Work zone crash location is set as the dependent variable, and the same 16 independent variables used in the first research question regarding basic crash information, roadway geometry and conditions, are used in this analysis. As a reminder, the independent variables used in this analysis are shown in Table 4.23.

Table 4.23 – Variables Used in the Analysis of Research Question 2

DEPENDENT VARIABLE	INDEPENDENT VARIABLE
Work Zone Crash Location	Time of Day
	Day of the Week
	Highway Classification
	Primary Contributing Factor
	First Harmful Event
	First Harmful Event Location
	Manner of Crash
	Highway Side
	Crash Severity
	Roadway Condition
	Work Zone Type
	Traffic Control
	Traffic way Lanes
	Light
	Weather
	Locale

4.2.1 Frequency Distributions

For the purpose of this section, frequency distributions of the five most statistically significant variables related work zone crash location are shown (as determined by the multinomial regression models), with the remaining eleven being found in Appendix B. The five most statistically significant variables related to work zone crash location are “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes,” and “Manner of Crash.”

As previously mentioned, there are a total of 893 observations that were ignored from the original multinomial regression due to incomplete data. These observations were missing values at some point in the crash report, and were ultimately ignored due to one of two reasons: (1) either the observation was missing the value for the dependent variable, or (2) the observation had at least one independent variable that was missing a value, while the value for the dependent variable could have been present. Any combination of the aforementioned reasons as to why they were ignored could have occurred. As a result, the total number of ignored observations *for the entire data set* equaled 893 (regardless of the dependent variable).

In the analysis of Section 4.2.2, however, the dependent variable “Work Zone Crash Location” presents a unique situation: the only reason as to why an observation was ignored is due to the fact that the observation had at least one independent variable that was missing a value, not because the value for the dependent variable was missing. All 3,857 observations in the data set have a value present for the dependent variable because all of the observations are considered to be related to a work zone in some capacity. Therefore, all of the observations have one of the five “Work Zone Crash Location” category values present. Furthermore, this indicates that when an observation is ignored in the analysis of factors impacting work zone location, it is because it is missing a value for one of the independent variables, not the value for the dependent variable.

"Work Zone Type" was determined to be the most statistically significant factor related to work zone crash location; no other variable had a greater impact on predicting the probability of whether the crash resulted in the Advance Warning Area, Transition Area, Activity Area, Termination Area, or Other Work Zone Area. Figure 4.6 gives the frequency distribution for "Work Zone Type" by "Work Zone Crash Location."

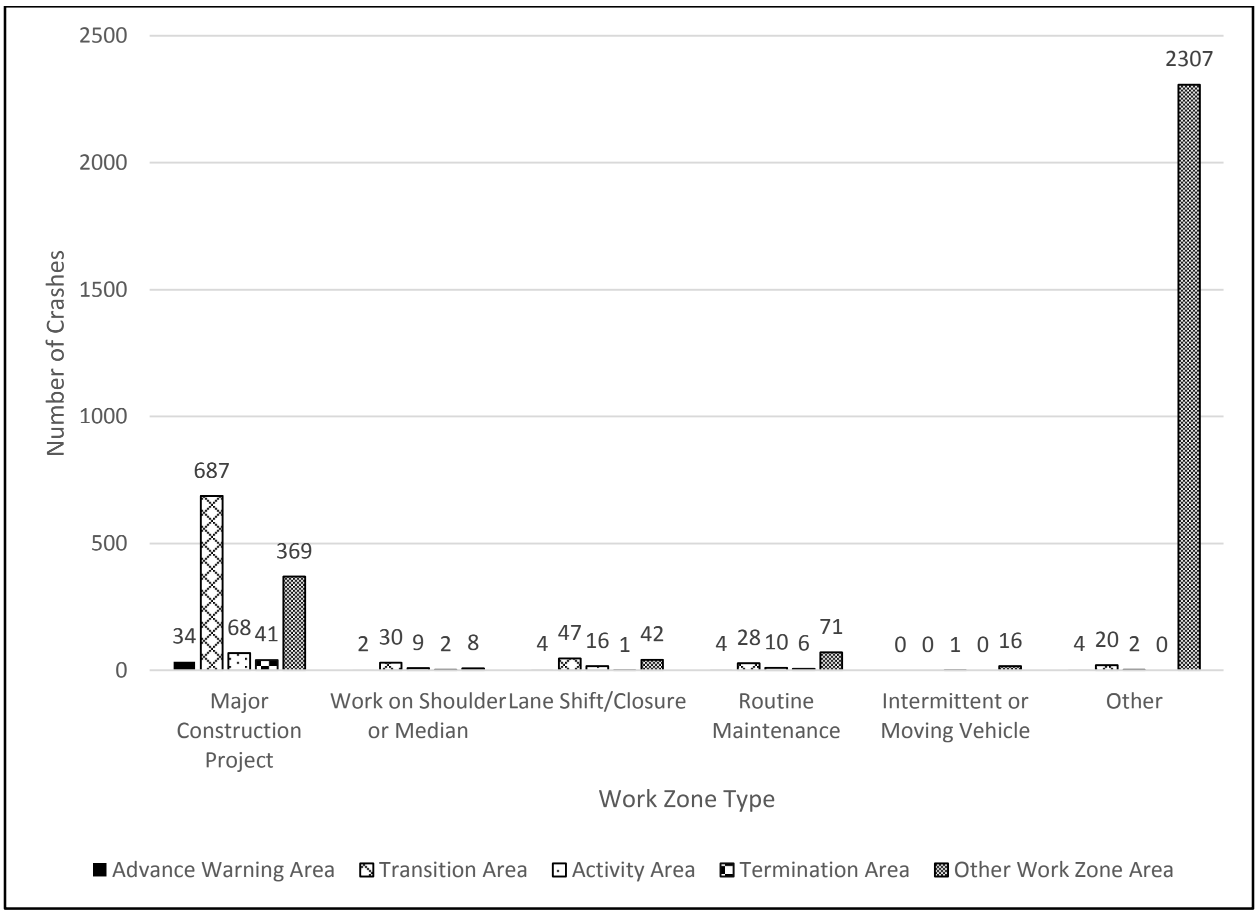


Figure 4.6 – Distribution of "Work Zone Type" by "Work Zone Crash Location"

When distributed against "Work Zone Crash Location," the most frequently occurring work zone type was "Other," with 2,333 reports having a crash location within some sort of work zone (because it is labeled "Other," there is no way to tell exactly what type of work zone the crashes occurred in). Tables 4.24 and 4.25 summarize the results obtained from this frequency distribution.

Table 4.24 – Distribution of "Work Zone Type" by "Work Zone Crash Location"

Work Zone Type	**Work Zone Crash Location**					
	Advance Warning Area (%)	Transition Area (%)	Activity Area (%)	Termination Area (%)	Other Work Zone Area (%)	**Total**
Major Construction Project	34 (2.8%)	687 (57.3%)	68 (5.7%)	41 (3.4%)	369 (30.8%)	1199
Work on Shoulder or Median	2 (3.9%)	30 (58.8%)	9 (17.6%)	2 (3.9%)	8 (15.7%)	51
Lane Shift/Closure	4 (3.6%)	47 (42.7%)	16 (14.5%)	1 (0.9%)	42 (38.2%)	110
Routine Maintenance	4 (3.4%)	28 (23.5%)	10 (8.4%)	6 (5%)	71 (59.7%)	119
Intermittent or Moving Vehicle	0 (0%)	0 (0%)	1 (5.9%)	0 (0%)	16 (94.1%)	17
Other	4 (0.2%)	20 (0.9%)	2 (0.1%)	0 (0%)	2307 (98.9%)	2333
Total	48 (1.3%)	812 (21.2%)	106 (2.8%)	50 (1.3%)	2813 (73.5%)	3829

In Table 4.24, "Work Zone Type" is distributed amongst the five work zone crash location categories, with each row tallying 100%. Percentages of "Advance Warning Area," "Transition Area," "Activity Area," "Termination Area," and "Other Work Zone Area," crashes are represented within each category of "Work Zone Type." For example, 57.4% of occurrences in the "Major Construction Project" work zone type occur in the "Transition Area," and 2.8% occur within the "Advance Warning Area." Similarly, 41.6% of occurrences in the "Lane Shift/Closure" work zone type occur within the "Transition Area," and 0.9% occur within the "Termination Area."

Unlike the total values from Section 4.1.2, the totals found in the last column of each table do accurately reflect the total number of observations for that category, because the independent variables in this analysis are being distributed against a dependent variable that has a value present for all 3,902 observations.

Table 4.25– Distribution of "Work Zone Crash Location" by "Work Zone Type"

Work Zone Crash Location	**Work Zone Type**						
	Major Construction Project (%)	Work on Shoulder or Median (%)	Lane Shift/Closure (%)	Routine Maintenance (%)	Intermittent or Moving Vehicle (%)	Other (%)	**Total**
Advance Warning Area	34 (70.8%)	2 (4.2%)	4 (8.3%)	4 (8.3%)	0 (0%)	4 (8.3%)	48
Transition Area	687 (84.6%)	30 (3.7%)	47 (5.8%)	28 (3.4%)	0 (0%)	20 (2.5%)	812
Activity Area	68 (64.2%)	9 (8.5%)	16 (15.1%)	10 (9.4%)	1 (0.9%)	2 (1.9%)	106
Termination Area	41 (82%)	2 (4%)	1 (2%)	6 (12%)	0 (0%)	0 (0%)	50
Other Work Zone Area	369 (13.1%)	8 (0.3%)	42 (1.5%)	71 (2.5%)	16 (0.6%)	2307 (82%)	2813
Total	1199 (31.3%)	51 (1.3%)	110 (2.9%)	119 (3.1%)	17 (0.4%)	2333 (60.9%)	3829

In Table 4.25, "Work Zone Crash Location" is distributed amongst the six "Work Zone Type" categories. Percentages of "Major Construction Project," "Work on Shoulder or Median," "Lane Shift/Closure," "Routine Maintenance," "Intermittent or Moving Vehicle," and "Other" are represented within each category of "Work Zone Crash Location." "Major Construction Project" yields the highest number of crashes located in the advance warning area (34), transition area (687), activity area (68) and termination area (41), while "Other" yields the highest number of crashes located in "Other Work Zone Area" with 2,307.

"Traffic Control" was determined to be the second most statistically significant factor related to work zone crash location and had a high impact on predicting the probability of the resulting crash location. Figure 4.7 gives the frequency distribution for "Traffic Control" by "Work Zone Crash Location."

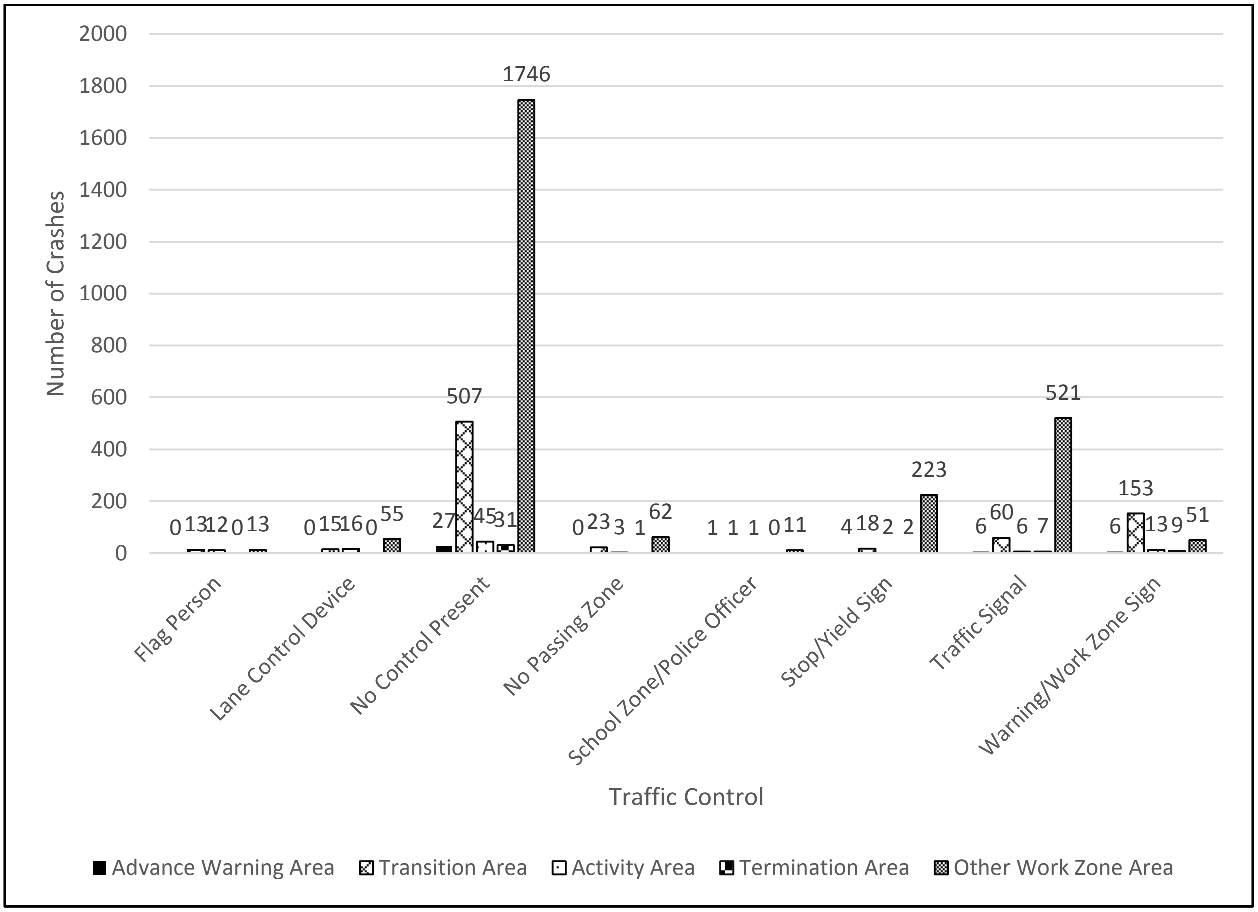


Figure 4.7 – Distribution of "Traffic Control" by "Work Zone Crash Location"

When distributed against "Work Zone Crash Location," the most frequently occurring traffic control situation is "No Control Present," with 2,356 reports not having any traffic control device present at the time of the crash. Tables 4.26 and 4.27 summarize the results obtained from this frequency distribution.

Table 4.26– Distribution of "Traffic Control" by "Work Zone Crash Location"

Traffic Control	**Work Zone Crash Location**					
	Advance Warning Area (%)	Transition Area (%)	Activity Area (%)	Termination Area (%)	Other Work Zone Area (%)	Total
Flag Person	0 (0%)	13 (34.2%)	12 (31.6%)	0 (0%)	13 (34.2%)	38
Lane Control Device	0 (0%)	15 (17.4%)	16 (18.6%)	0 (0%)	55 (64%)	86
No Control Present	27 (1.1%)	507 (21.5%)	45 (1.9%)	31 (1.3%)	1746 (74.1%)	2356
No Passing Zone	0 (0%)	23 (25.8%)	3 (3.4%)	1 (1.1%)	62 (69.7%)	89
School Zone/ Police Officer	1 (7.1%)	1 (7.1%)	1 (7.1%)	0 (0%)	11 (78.6%)	14
Stop/Yield Sign	4 (1.6%)	18 (7.2%)	2 (0.8%)	2 (0.8%)	223 (89.6%)	249
Traffic Signal	6 (1%)	60 (10%)	6 (1%)	7 (1.2%)	521 (86.8%)	600
Warning/Work Zone Sign	6 (2.6%)	153 (65.9%)	13 (5.6%)	9 (3.9%)	51 (22%)	232
Total	44 (1.2%)	790 (21.6%)	98 (2.7%)	50 (1.4%)	2682 (73.2%)	3664

In Table 4.26, "Traffic Control" is distributed amongst the five work zone crash location categories, with each row tallying 100%. Percentages of "Advance Warning Area," "Transition Area," "Activity Area," "Termination Area," and "Other Work Zone Area," crashes are represented within each category of "Traffic Control." For example, 65.9% of crashes that involve a "Warning or Work Zone Sign" traffic control device occur within the "Transition Area." Similarly, only 1.0% of all work zone crashes that involve a "Traffic Signal" device occur within the "Activity Area."

Table 4.27 – Distribution of "Work Zone Crash Location" by "Traffic Control"

Work Zone Crash Location	Traffic Control								
	Flag Person (%)	Lane Control Device (%)	No Control Present (%)	No Passing Zone (%)	School Zone/Police Officer (%)	Stop/Yield Sign (%)	Traffic Signal (%)	Warning/Work Zone Sign (%)	**Total**
Advance Warning Area	0 (0%)	0 (0%)	27 (61.4%)	0 (0%)	1 (2.3%)	4 (9.1%)	6 (13.6%)	6 (13.6%)	44
Transition Area	13 (1.6%)	15 (1.9%)	507 (64.2%)	23 (2.9%)	1 (0.1%)	18 (2.3%)	60 (7.6%)	153 (19.4%)	790
Activity Area	12 (12.2%)	16 (16.3%)	45 (45.9%)	3 (3.1%)	1 (1.0%)	2 (2%)	6 (6.1%)	13 (13.3%)	98
Termination Area	0 (0%)	0 (0%)	31 (62%)	1 (2%)	0 (0%)	2 (4%)	7 (14%)	9 (18%)	50
Other Work Zone Area	13 (0.5%)	55 (2.1%)	1746 (65.1%)	62 (2.3%)	11 (0.4%)	223 (8.3%)	521 (19.4%)	51 (1.9%)	2682
Total	38 (1.0%)	86 (2.3%)	2356 (64.3%)	89 (2.4%)	14 (0.4%)	249 (6.8%)	600 (16.4%)	232 (6.3%)	3664

In Table 4.27, "Work Zone Crash Location" is distributed amongst the eight "Traffic Control" categories. Percentages of each "Flag Person," "Lane Control Device," "No Control Present," "No Passing Zone," "School Zone/Police Officer," "Stop/Yield Sign," "Traffic Signal," and "Warning/Work Zone Sign" are represented within each category of "Work Zone Crash Location." For this distribution, "No Control Present" yields the highest number of crashes for every category within "Work Zone Crash Location."

"Highway Side" was determined to be the third most statistically significant factor related to work zone crash location and had a high impact on predicting the probability of the resulting crash location. Figure 4.8 gives the frequency distribution for "Highway Side" by "Work Zone Crash Location."

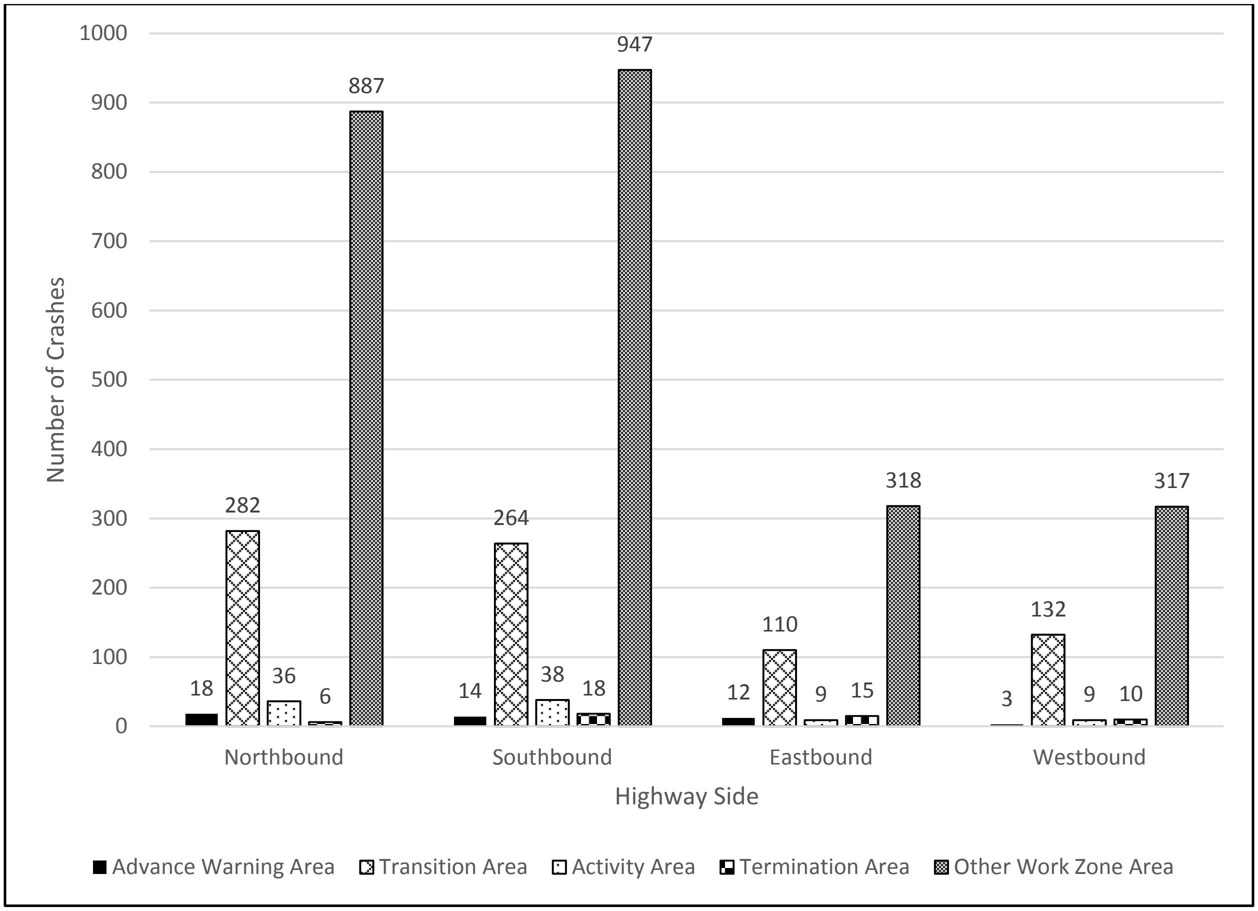


Figure 4.8 – Distribution of “Highway Side” by “Work Zone Crash Location”

When distributed against “Work Zone Crash Location,” the most frequently occurring highway side was “Southbound,” with 1,281 reports having a crash location located along the southbound side of a highway. “Northbound” was second, with 1,229 reports having a crash location located along the northbound side of a highway. Tables 4.28 and 4.29 summarize the results obtained from this frequency distribution.

Table 4.28 – Distribution of “Highway Side” by “Work Zone Crash Location”

Highway Side	**Work Zone Crash Location**					
	Advance Warning Area (%)	Transition Area (%)	Activity Area (%)	Termination Area (%)	Other Work Zone Area (%)	**Total**
Northbound	18 (1.5%)	282 (22.9%)	36 (2.9%)	6 (0.5%)	887 (72.2%)	1229
Southbound	14 (1.1%)	264 (20.6%)	38 (3.0%)	18 (1.4%)	947 (73.9%)	1281
Eastbound	12 (2.6%)	110 (23.7%)	9 (1.9%)	15 (3.2%)	318 (68.5%)	464
Westbound	3 (0.6%)	132 (28.0%)	9 (1.9%)	10 (2.1%)	317 (67.3%)	471
Total	47 (1.3%)	788 (22.9%)	92 (2.7%)	49 (1.4%)	2469 (71.7%)	3445

In Table 4.28, “Highway Side” is distributed amongst the five work zone crash location categories, with each row tallying 100%. Percentages of “Advance Warning Area,” “Transition Area,” “Activity Area,” “Termination Area,” and “Other Work Zone Area,” crashes are represented within each category of “Highway Side.” For example, 72.2% of crashes located along the northbound side of the roadway occur in a work zone in some capacity (“Other Work Zone Area”), while 0.5% of crashes located along the northbound side of the roadway occur within the “Termination Area.”

Table 4.29 – Distribution of "Work Zone Crash Location" by "Highway Side"

Work Zone Crash Location	**Highway Side**				
	Northbound (%)	Southbound (%)	Eastbound (%)	Westbound (%)	**Total**
Advance Warning Area	18 (38.3%)	14 (29.8%)	12 (25.5%)	3 (6.4%)	47
Transition Area	282 (35.8%)	264 (33.5%)	110 (14%)	132 (16.8%)	788
Activity Area	36 (39.1%)	38 (41.3%)	9 (9.8%)	9 (9.8%)	92
Termination Area	6 (12.2%)	18 (36.7%)	15 (30.6%)	10 (20.4%)	49
Other Work Zone Area	887 (35.9%)	947 (38.4%)	318 (12.9%)	317 (12.8%)	2469
Total	1229 (35.7%)	1281 (37.2%)	464 (13.5%)	471 (13.7%)	3445

In Table 4.29, "Work Zone Crash Location" is distributed amongst the four "Highway Side" categories. Percentages of "Northbound," "Southbound," "Eastbound," and "Westbound" are represented within each category of "Work Zone Crash Location." "Southbound" crash locations yield the highest number of activity area crashes (38), and termination area crashes (18) crashes, while "Northbound" yields the highest number of advance warning area (18) and transition area (282) crashes.

"Traffic way lanes" was determined to be the fourth most statistically significant factor related to work zone crash location and had a high impact on predicting the probability of the resulting crash location. Figure 4.9 gives the frequency distribution for "Traffic way lanes" by "Work Zone Crash Location."

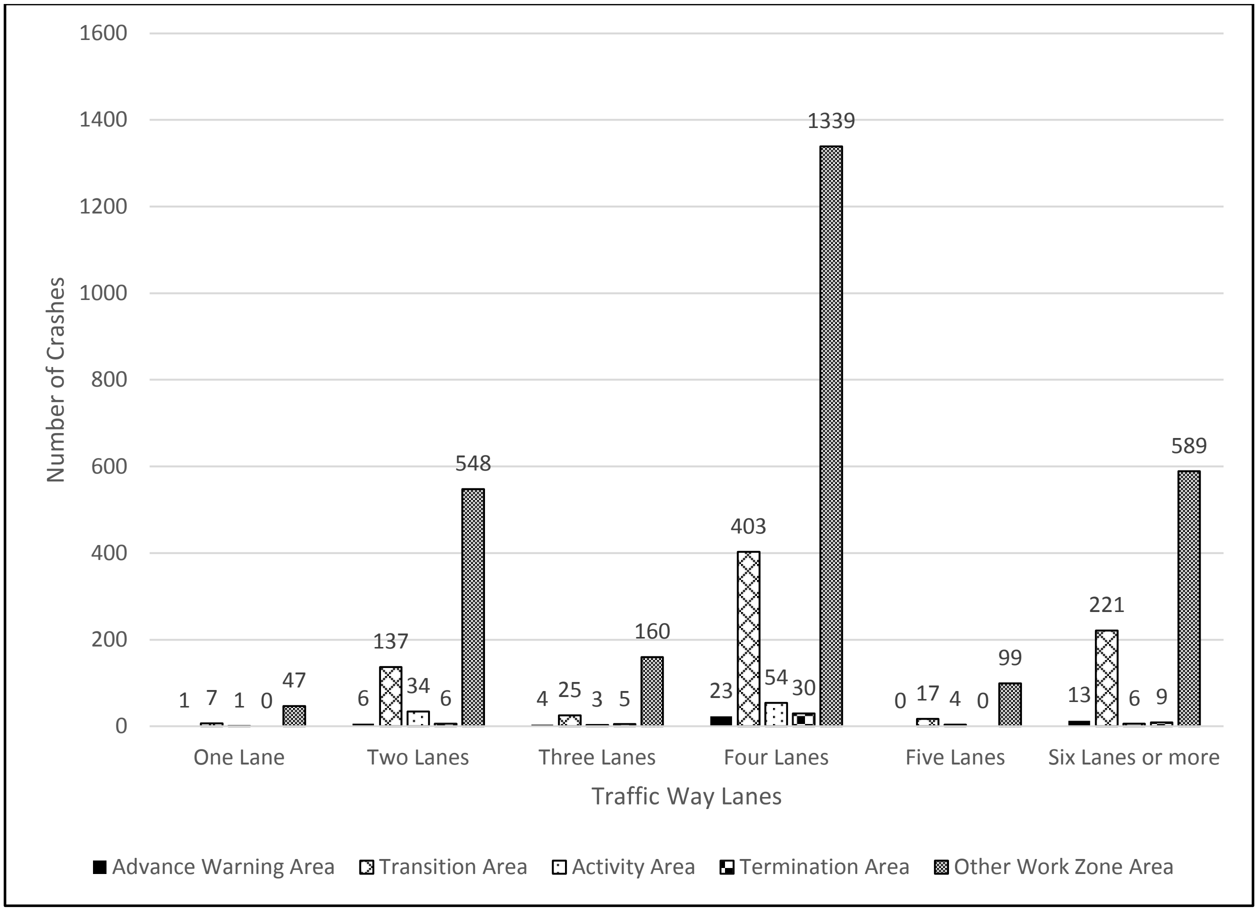


Figure 4.9 – Distribution of "Traffic way lanes" by "Work Zone Crash Location"

When distributed against "Work Zone Crash Location," the most frequently occurring number of traffic way lanes was "Four Lanes," with 1,849 reports having a crash located on a roadway with four lanes. The least frequently occurring category was "One Lane," with only 56 observations. Tables 4.30 and 4.31 summarize the results obtained from this frequency distribution.

Table 4.30 – Distribution of “Traffic way lanes” by “Work Zone Crash Location”

Traffic way lanes	**Work Zone Crash Location**					
	Advance Warning Area (%)	Transition Area (%)	Activity Area (%)	Termination Area (%)	Other Work Zone Area (%)	**Total**
One Lane	1 (1.8%)	7 (12.5%)	1 (1.8%)	0 (0%)	47 (83.9%)	56
Two Lanes	6 (0.8%)	137 (18.7%)	34 (4.7%)	6 (0.8%)	548 (75%)	731
Three Lanes	4 (2.0%)	25 (12.7%)	3 (1.5%)	5 (2.5%)	160 (81.2%)	197
Four Lanes	23 (1.2%)	403 (21.8%)	54 (2.9%)	30 (1.6%)	1339 (72.4%)	1849
Five Lanes	0 (0%)	17 (14.2%)	4 (3.3%)	0 (0%)	99 (82.5%)	120
Six Lanes or More	13 (1.6%)	221 (26.4%)	6 (0.7%)	9 (1.1%)	589 (70.3%)	838
Total	47 (1.2%)	810 (21.4%)	102 (2.7%)	50 (1.3%)	2782 (73.4%)	3791

In Table 4.30, “Traffic way lanes” is distributed amongst the five work zone crash location categories, with each row tallying 100%. Percentages of “Advance Warning Area,” “Transition Area,” “Activity Area,” “Termination Area,” and “Other Work Zone Area,” crashes are represented within each category of “Traffic way lanes.” When examining each category of “Traffic way lanes,” the majority of all categories occur within the “Other Work Zone Area” category, ranging from 70.3% for “Six Lanes or More” to 83.9% for “One Lane.”

Table 4.31 – Distribution of “Work Zone Crash Location” by “Traffic way lanes”

Work Zone Crash Location	Traffic way lanes						
	One Lane (%)	Two Lanes (%)	Three Lanes (%)	Four Lanes (%)	Five Lanes (%)	Six Lanes or More (%)	**Total**
Advance Warning Area	1 (2.1%)	6 (12.8%)	4 (8.5%)	23 (48.9%)	0 (0%)	13 (27.7%)	47
Transition Area	7 (0.9%)	137 (16.9%)	25 (3.1%)	403 (49.8%)	17 (2.1%)	221 (27.3%)	810
Activity Area	1 (1.0%)	34 (33.3%)	3 (2.9%)	54 (52.9%)	4 (3.9%)	6 (5.9%)	102
Termination Area	0 (0%)	6 (12.0%)	5 (10.0%)	30 (60.0%)	0 (0%)	9 (18.0%)	50
Other Work Zone Area	47 (1.7%)	548 (19.7%)	160 (5.8%)	1339 (48.1%)	99 (3.6%)	589 (21.2%)	2782
Total	56 (1.5%)	731 (19.3%)	197 (5.2%)	1849 (48.8%)	120 (3.2%)	838 (22.1%)	3791

In Table 4.31, “Work Zone Crash Location” is distributed amongst the six “Traffic way lanes” categories. Percentages of “One Lane,” “Two Lanes,” “Three Lanes,” “Four Lanes,” “Five Lanes,” and “Six Lanes or More” are represented within each category of “Work Zone Crash Location.” “Four Lanes” yields the highest number of every work zone crash location category: advance warning area (23), transition area (403), activity area (54), termination area (30) and other work zone area (1,339).

Lastly, “Manner of Crash” was determined to be the fifth most statistically significant factor related to work zone crash location and also had a high impact on predicting the probability of the resulting crash location. Figure 4.10 gives the frequency distribution for “Manner of Crash” by “Work Zone Crash Location.”

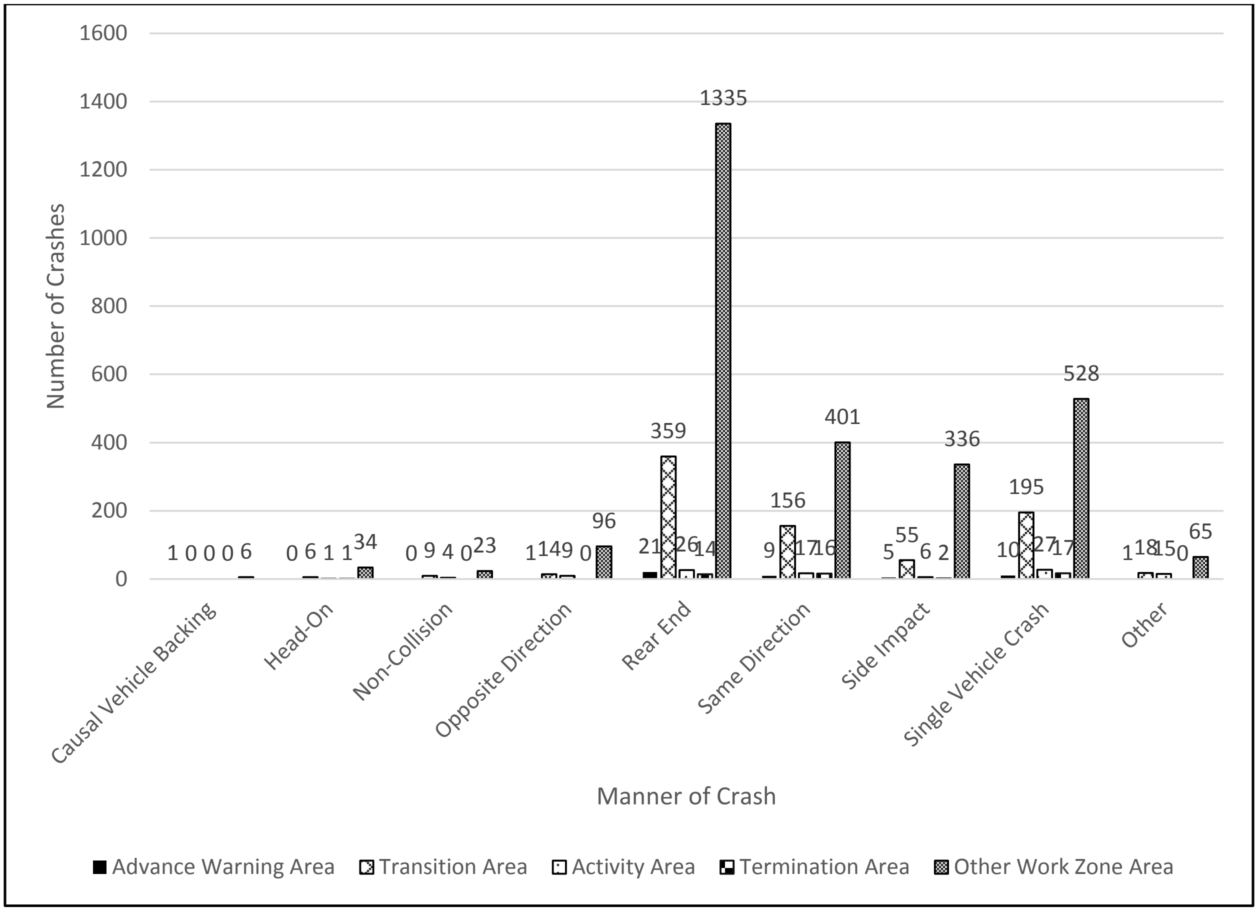


Figure 4.10 – Distribution of "Manner of Crash" by "Work Zone Crash Location"

When distributed against "Work Zone Crash Location," the most frequently occurring crash type is "Rear End," with 1,755 reports resulting in a rear end type crash. This crash type equates to 45.7% of all crash types occurring within a work zone, the largest for this variable by far. Tables 4.32 and 4.33 summarize the results obtained from this frequency distribution.

Table 4.32 – Distribution of "Manner of Crash" by "Work Zone Crash Location"

Manner of Crash	**Work Zone Crash Location**					
	Advance Warning Area (%)	Transition Area (%)	Activity Area (%)	Termination Area (%)	Other Work Zone Area (%)	**Total**
Causal Vehicle Backing	1 (14.3%)	0 (0%)	0 (0%)	0 (0%)	6 (85.7%)	7
Head-On	0 (0%)	6 (14.3%)	1 (2.4%)	1 (2.4%)	34 (81.0%)	42
Non-Collision	0 (0%)	9 (25.0%)	4 (11.1%)	0 (0%)	23 (63.9%)	36
Opposite Direction	1 (0.8%)	14 (11.7%)	9 (7.5%)	0 (0%)	96 (80.0%)	120
Rear End	21 (1.2%)	359 (20.5%)	26 (1.5%)	14 (0.8%)	1335 (76.1%)	1755
Same Direction	9 (1.5%)	156 (26.0%)	17 (2.8%)	16 (2.7%)	401 (66.9%)	599
Side Impact	5 (1.2%)	55 (13.6%)	6 (1.5%)	2 (0.5%)	336 (83.2%)	404
Single Vehicle Crash	10 (1.3%)	195 (25.1%)	27 (3.5%)	17 (2.2%)	528 (68.0%)	777
Other	1 (0.8%)	18 (18.2%)	15 (15.2%)	0 (0%)	65 (65.7%)	99
Total	48 (1.3%)	812 (21.2%)	105 (2.7%)	50 (1.3%)	2824 (73.6%)	3839

In Table 4.32, "Manner of Crash" is distributed amongst the five work zone crash location categories, with each row tallying 100%. Percentages of "Advance Warning Area," "Transition Area," "Activity Area," "Termination Area," and "Other Work Zone Area," crashes are represented within each category of "Manner of Crash." The majority of all nine "Manner of Crash" categories occur within the "Other Work Zone Area" category, ranging from 63.9% for "Non-Collision" to 85.7% for "Causal Vehicle Backing."

Table 4.33 – Distribution of "Work Zone Crash Location" by "Manner of Crash"

Work Zone Crash Location	Manner of Crash									
	Causal Vehicle Backing (%)	Head-On (%)	Non-Collision (%)	Opposite Direction (%)	Rear End (%)	Same Direction (%)	Side Impact (%)	Single Vehicle Crash (%)	Other (%)	**Total**
Advance Warning Area	1 (2.1%)	0 (0%)	0 (0%)	1 (2.1%)	21 (43.8%)	9 (18.8%)	5 (10.4%)	10 (20.8%)	1 (2.1%)	48
Transition Area	0 (0%)	6 (0.7%)	9 (1.1%)	14 (1.7%)	359 (44.2%)	156 (19.2%)	55 (6.8%)	195 (24.0%)	18 (2.2%)	812
Activity Area	0 (0%)	1 (1.0%)	4 (3.8%)	9 (8.6%)	26 (24.8%)	17 (16.2%)	6 (5.7%)	27 (25.7%)	15 (14.3%)	105
Termination Area	0 (0%)	1 (2.0%)	0 (0%)	0 (0%)	14 (28.0%)	16 (32.0%)	2 (4.0%)	17 (34.0%)	0 (0%)	50
Other Work Zone Area	6 (0.2%)	34 (1.2%)	23 (0.8%)	96 (3.4%)	1335 (47.3%)	401 (14.2%)	336 (11.9%)	528 (18.7%)	65 (2.3%)	2824
Total	7 (0.2%)	42 (1.1%)	36 (0.9%)	120 (3.1%)	1755 (45.7%)	599 (15.6%)	404 (10.5%)	777 (20.2%)	99 (2.6%)	3839

In Table 4.33, "Work Zone Crash Location" is distributed amongst the nine "Manner of Crash" categories. Percentages of "Causal Vehicle Backing," "Head-On," "Non-Collision," "Opposite Direction," "Rear End," "Same Direction," "Side Impact," "Single Vehicle Crash," and "Other" are represented within each category of "Work Zone Crash Location." "Single Vehicle Crash" yield the highest number of occurrences within the activity area with 27. "Rear End" yields the highest number of advance warning area (21) and transition area (359) crashes, while "Single Vehicle Crash" yields the highest number of termination area crashes with 17.

4.2.2 Multinomial Regression Models

In this section, the multinomial regression models regarding factors that impact crash location within work zone-related crashes are given. Within the model, null and alternative models were established to determine which variables were more likely to be statistically significant to work zone crash location. Establishing a null and alternative model accomplishes two things: (1) it measures how well the observed distribution of data differs from a theoretical distribution, and (2) it determines whether or not paired observations for two variables are independent of one another. As a result, having both the null and alternative hypotheses determines whether the data are significantly more likely to have an impact on the crash location within a work zone if the alternative hypothesis is true than if the null hypothesis is true.

These hypotheses, along with the likelihood ratio statistics, likelihood ratio tests, and p-values, are applied in the same manner as they are in Section 4.1.1. The likelihood ratio test determines whether or not the likelihood ratio statistic for each independent variable is to be considered a good approximation of the chi-square distribution. If it is indeed a good approximation, meaning the LR statistic is equal to or greater than the critical value, the null hypothesis is rejected.

Comparisons between calculated and critical LR statistics are measured at a confidence level of 99%. Variables with LR statistics that fail to meet the criteria for their respective degrees of freedom at a confidence level of 99% are not a good approximation of the chi-square distribution. As a result, the null hypothesis is not rejected, and these variables are not statistically significant to determining the crash location within a work zone.

Additionally, p-values are generated for each independent variable. The p-value represents the probability of observing the sample, assuming that the null hypothesis is true. If the p-value is small, it indicates an extremely strong presumption against the null hypothesis, and the observed data is inconsistent with the assumption that the null hypothesis is true. Therefore, the null hypothesis must be rejected, and the alternative hypothesis accepted as true. An accepted alternative hypothesis indicates that the independent variable is statistically significant to determining the crash location within a work zone.

Lastly, this section is further subdivided into two sections. Section 4.2.2.1 addresses the multinomial regression model with the original values, and Section 4.2.2.2 addresses the multinomial regression model with the imputed values.

4.2.2.1. Original Multinomial Regression Model

The first model built examined all 3,857 observations with the original values, and then disregarded 893 observations that were missing data at some point in the crash report. These observations were ignored due to incomplete data; observations with fields missing for at least one of the independent variables caused the observation to be ignored. Due to the fact that all 3,857 observations were deemed work zone-related in some fashion, every observation had a field represented for the dependent variable "Work Zone Crash Location."

The results for the analysis of variance (ANOVA) for the original model are given in Table 4.34. The contents of Table 4.34 (and used for subsequent ANOVA Results tables), include:

- independent variables used in the model,
- the Likelihood Ratio (LR) statistic,
- associated degrees of freedom (df),
- the p-value generated by the LR statistic,
- the corresponding significance of each p-value.

Table 4.34 – Analysis of Variance Results of the Original Model for Research Question 2

	LR	Df	p-value	Significance
Time of Day	39.50	16	9.21E-04	Yes
Day of the Week	49.72	24	1.54E-03	Yes
Highway Classification	42.63	16	3.18E-04	Yes
Primary Contributing Factor	59.15	44	0.06	No
First Harmful Event	67.01	28	4.81E-05	Yes
First Harmful Event Location	52.48	20	9.68E-05	Yes
Manner of Crash	73.12	32	4.65E-05	Yes
Highway Side	39.79	12	7.79E-05	Yes
Crash Severity	11.97	8	0.15	No
Roadway Condition	6.56	12	0.88	No
Work Zone Type	1582.96	20	<2.2E-016	Yes
Traffic Control	112.56	28	4.27E-12	Yes
Traffic way Lanes	58.47	20	1.22E-05	Yes
Light	15.12	8	0.06	No
Weather	24.00	20	0.24	No
Locale	19.41	16	0.25	No

As previously mentioned, the Likelihood Ratio (LR) statistic measures the difference in deviations between the observed and theoretical values, and is then compared to the critical value obtained from the chi-square distribution table to determine whether or not that particular LR statistic is to be considered a good approximation. For example, the LR statistic for "Roadway Condition" is 6.56. With 12 degrees of freedom measured at a confidence level of 99%, the critical value obtained from the chi-squared distribution table is 26.22. The LR statistic of 6.17 for "Roadway Condition" falls well beneath 26.22, and is not considered a good approximation. As a result, the null hypothesis is not rejected, indicating that "Roadway Condition" is not statistically significant to determining the crash location within a work zone. Conversely, the LR statistic for "Manner of Crash" is 73.12. With 32 degrees of freedom measured at a confidence level of 99%, the critical value obtained from the chi-squared distribution table is 53.45. The LR statistic of 73.12 for "Manner of Crash" exceeds 53.45, and is considered a good approximation of the chi-squared distribution table. As a result, the null hypothesis is rejected, indicating that “Manner of Crash” is statistically significant to determining the crash location within a work zone.

The significance of each probability is determined by comparing the calculated probability against the desired probability value. If an independent variable has a highly significant impact on determining crash location within a work zone, the corresponding p-value will be less than 0.01. Conversely, independent variables with p-values greater than 0.1 do not have a significant impact on determining crash location within a work zone.

For the original model, the most statistically significant variables (ones with p-values less than 0.01) are “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes,” and “Manner of Crash.” These variables have the most impact on predicting the probability of whether the crash results in the Advance Warning Area, Transition Area, Activity Area, Termination Area, or Other Work Zone Area. These variables, along with their associated significance levels, are listed in Table 4.35.

Table 4.35 – Most Statistically Significant Variables of the Original Model for Research Question 2

Independent Variable	**P-Value**
Work Zone Type	<2.2E-016
Traffic Control	4.27E-12
Highway Side	7.79E-05
Traffic way lanes	1.22E-05
Manner of Crash	4.65E-05

After identifying the most statistically significant independent variables of the model, the overall goodness of fit for the model was explored. When dealing with multinomial regression, all of the variables included in the model are categorical. Therefore, an adaption of a measure of goodness of fit used in linear regression is used, called the pseudo R^2 (like the one used in

Section 4.1.1.1). The pseudo R^2 value generated for the original model was determined to be 0.6185, meaning approximately 61.85% of the regression model fits the data. While this is not something that should be strictly used to measure goodness of fit, a value of 0.6185 is a high indication of fit for a multinomial regression.

In addition to the pseudo R^2, the log likelihood was generated for the original model. The log likelihood is another measure used to describe the goodness of fit. It is always negative, with values closer to zero indicating a better fit. The log likelihood for the original model was determined to be -1081.01. While both the pseudo R^2 and log likelihood give some idea of the goodness of fit for a multinomial regression, much more can be learned from the error matrix that is generated from the model. The error matrix provides a more in depth look into how well a multinomial regression model fits the data set through the use of accuracy rates.

The error matrix was generated to determine how accurate the model is at predicting the number of observations in each category within "Work Zone Crash Location." This is done by measuring the difference between the actual values and the predicted values for each category. This error matrix represents 2,964 observations, and not the total number of observations of 3,857 (due to the incomplete data with missing fields). Table 4.36 displays the error matrix of the original model.

Table 4.36 – Error Matrix of the Original Model for Research Question 2

	Predicted				
Actual	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area
Advance Warning Area	13	20	1	0	7
Transition Area	3	602	8	1	88
Activity Area	1	34	26	1	17
Termination Area	0	29	0	12	6
Other Work Zone Area	0	188	7	1	1899

Looking at "Activity Area" first, 26 crashes that occurred within the Activity Area were accurately predicted from the model, resulting in an accuracy rate of 32.9%. This rate was determined by dividing the number of accurately predicted crashes occurring in the Activity Area by the total number of actual crashes occurring in the Activity Area, and is represented in the following equation:

$$\frac{26}{(1 + 34 + 26 + 1 + 17)} = 0.32911 = 32.9\%$$

In summary, of the 79 crashes that occurred within the Activity Area included in the original model, only 26 were accurately predicted. This same process was applied to the remaining four work zone crash location categories, and their resulting accuracy rates are presented in Table 4.37.

Table 4.37 – Accuracy Rates Generated from the Error Matrix of the Original Model for Research Question 2

Advance Warning Area	31.7%
Transition Area	85.8%
Activity Area	32.9%
Termination Area	25.5%
Other Work Zone Area	90.6%

Although "Other Work Zone Area" has the highest accuracy rate, it cannot be completely relied on due to the fact that "other" is not a specific work zone location; it is simply related to a work zone in some fashion. Disregarding "Other Work Zone Area," "Transition Area" has the highest accuracy rate, or classification rate, and predicts a crash to be located within the transition area at a rate of 85.8%. "Termination Area" was the most inaccurate, yielding an accuracy rate of only 25.5%.

4.2.1.2. Imputed Multinomial Regression Model

The second model built used the imputed values for each variable, replacing cells that were initially left empty with the respective mode value. This resulted in a complete data set that included all 3,902 crash reports. Additionally, the same hypotheses, guidelines for likelihood ratios and likelihood ratio tests, and interpretation of significance of the p-values for Section 4.2.1.1 apply to the model with imputed values. Table 4.38 displays the ANOVA results for the imputed model.

Table 4.38 – Analysis of Variance Results of the Imputed Model for Research Question 2

Variable	LR	Df	p-value	Significance
IMO_Time of Day	38.13	16	1.45E-03	Yes
IMO_Day of the Week	42.07	24	0.013	No
IMO_Highway Classification	55.81	16	2.61E-06	Yes
IMO_Primary Contributing Factor	60.06	44	0.05	No
IMO_First Harmful Event	71.37	28	1.19E-05	Yes
IMO_First Harmful Event Location	34.13	20	0.03	No
IMO_Manner of Crash	77.04	32	1.39E-05	Yes
IMO_Highway Side	48.28	12	2.79E-06	Yes
IMO_Crash Severity	10.96	8	0.20	No
IMO_Roadway Condition	5.82	12	0.92	No
IMO_Workzone Type	1863.59	20	< 2.2E-16	Yes
IMO_Traffic Control	105.78	28	5.74E-11	Yes
IMO_Trafficway Lanes	49.17	20	2.9E-04	Yes
IMO_Light	16.55	8	0.04	No
IMO_Weather	14.62	20	0.79	No
IMO_Locale	25.07	16	0.07	No

For the imputed model, the most statistically significant variables are “Work Zone Type,” “Traffic Control,” “Highway Classification,” and “Highway Side.” Table 4.39 shows the most statistically significant variables, along with their p-values and associated significance levels.

Table 4.39 – Most Statistically Significant Variables of the Imputed Model for Research Question 2

Independent Variable	p-value
IMO_Workzone Type	< 2.2E-16
IMO_Traffic Control	5.74E-11
IMO_Highway Classification	2.61E-06
IMO_Highway Side	2.79E-06

Regarding the overall goodness of fit for the imputed model, the same approach from Section 4.2.2.1 is taken. Due to the nature of multinomial regression, there is no exact way to interpret goodness of fit for the imputed model because there is no meaningful variance. Instead, a pseudo R^2 value and a log likelihood value were generated. The imputed model yielded a pseudo R^2 of 0.5766 and a log likelihood value of -1417.89.

To provide a more in depth look into how well the imputed model fits the data set, the error matrix was generated to determine how accurate the model is at predicting the number of observations in each category within "Work Zone Crash Location," as was done for the original model. This error matrix, however, represents the total number of observations of 3,857 (which was not the case in Section 4.2.2.1). Table 4.40 displays the error matrix of the imputed model.

Table 4.40 – Error Matrix of the Imputed Model for Research Question 2

	Predicted				
Actual	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area
Advance Warning Area	1	28	0	0	19
Transition Area	2	676	15	1	118
Activity Area	1	45	34	1	25
Termination Area	0	30	2	9	9
Other Work Zone Area	2	234	10	0	2595

Accuracy rates for the imputed model were also generated. Starting with "Activity Area," 34 crashes that occurred within the Activity Area were accurately predicted from the model, resulting in an accuracy rate of 32.1%. In summary, of the 106 crashes that occurred within the Activity Area included in the imputed model, only 34 were accurately predicted. Table 4.41 summarizes the accuracy rates for each category of the imputed model.

Table 4.41 – Accuracy Rates Generated from the Error Matrix of the Imputed Model for Research Question 2

Advance Warning Area	2.1%
Transition Area	83.3%
Activity Area	32.1%
Termination Area	18.0%
Other Work Zone Area	91.3%

Comparing these rates against the accuracy rates from the original model, "Other Work Zone Area" was the only category with an accuracy rate that increased. Furthermore, this means that after the imputation, the model was only able to more accurately predict the number of observations within "Other Work Zone Area." Accuracy rates for the remaining four categories all decreased from the original model to the imputed model.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations made in accomplishing the research objectives of identifying patterns and correlations among crash variables, determining the distribution of work zone crashes by location, and developing recommendations for work zone related practices, including innovative countermeasures that can be implemented to reduce crash frequency and severity. The two specific research questions that were used to answer these objectives targeted crash severity and work zone crash location within the work zone, and are restated below:

(1) "What are the most significant factors related to crash severity for work zone-related crashes in the state of Alabama?"

(2) "What are the most significant factors related to crash location for work-zone related crashes in the state of Alabama?"

The focus of these questions resulted in determining the specific factors related to crash severity in work zone-related crashes, as well as the distribution of work zone crashes by location. Lastly, this chapter is subdivided into three main sections: (1) conclusions for the first research question, (2) conclusions for the second research question, and (3) recommendations made to improve the overall safety and effectiveness of work zones in Alabama.

5.1 Conclusions for the Analysis of Factors that Impact Crash Severity in Work-Zone Related Crashes

A statistical analysis utilizing multinomial regression and frequency distributions was conducted to determine the statistical significance of each of the fifteen independent variables to crash severity. The most statistically significant factors related to crash severity are "Manner of Crash," "Primary Contributing Factor," "First Harmful Event" and "Highway Classification." These variables describe aspects of a crash that have the greatest impact on crash severity.

The resulting severity of a crash is highly dependent on the manner in which the crash occurred, with higher risk crash types yielding more fatalities than lower risk crash types. When examining the nine categories of "Manner of Crash," the crash type that yields the highest percentage of fatalities is "Head-On," with 20 of the reported 42 "Head-On" crashes yielding a fatality (47.6%). The likelihood of a crash resulting in a fatality increases significantly when the vehicles involved strike each other head-on, and this increases even more when the possibility that at least one of the vehicles involved were operating under faster driving conditions is considered. The "Head-On" category, however, is highly overrepresented when compared to all crashes. Of the 3,759 crashes included in this distribution, 148 resulted in a fatality (3.9%). Additionally, the 42 "Head-On" occurrences consist of only 1.1% of all observations included in the distribution. Even though "Head-On" yields the highest percentage of fatalities amongst the nine categories, "Single Vehicle Crash" consists of the most fatalities with 42 (28.4%). These two categories, the one with the highest percentage of fatalities and the one with the highest total of fatalities, are the most severe categories in this distribution. While "Head-On" yields the highest percentage of fatalities (47.6%) per crash type, "Single Vehicle Crash" crash types yield the most fatalities (42) in all of the observations included in the distribution.

The resulting crash severity is also highly dependent on the primary contributing factor associated with each crash. When examining the twelve categories of "Primary Contributing Factor," the contributing factor that yields the highest percentage of fatalities is "Crossed Over," with 13 of the 37 reported "Crossed Over" occurrences yielding a fatality (35.1%). Additionally, this fatality percentage of 35.1% is highly overrepresented when compared to the total number of fatalities. In this distribution, 144 of the 3,675 observations result in a fatality (3.9%), which is much less than the aforementioned fatality percentage belonging to "Crossed Over" of 35.1%. The category with the highest total of fatalities, however, is "Aggressive Behavior" with 38 fatalities (approximately 26.4% of all fatalities in this distribution).

In addition to the manner of crash and primary contributing factor associated with a crash, crash severity is also highly dependent on the first harmful event that a crash experiences. When examining the eight categories of "First Harmful Event," the event that yields the highest percentage of fatalities is "Collision with Bike/Pedestrian," with 4 of the 22 reported occurrences yielding a fatality (18.2%). This percentage is highly overrepresented, as it is over four times the overall percentage of fatalities included: 149 of the reported 3,761 occurrences in this distribution resulted in a fatality (3.9%).

While "Collision with Bike/Pedestrian" represents the highest percentage of fatalities, "Collision with Vehicle" consists of the most fatalities with 93. "Collision with Vehicle" events comprise 93 of the 149 fatalities included in this distribution (62.4%), while "Collision with Bike/Pedestrian" comprise 4 of the 149 fatalities (2.7%). "Collision with Bike/Pedestrian" yield the highest percentage of fatalities, but "Collision with Vehicle" events yield the most fatalities in all of the observations included in the distribution.

Lastly, "Highway Classification" also has a significantly high impact on the resulting severity of a crash. There are five categories within "Highway Classification," and the classification that yields the highest percentage of fatalities is "Federal." In this distribution, 48 of the reported 590 occurrences result in a fatality (8.1%). Federal routes are overrepresented, as its fatality percentage is more than two times bigger than the percentage of total fatalities (4%). Of the 3,765 observations included in this distribution, 149 resulted in a fatality.

Even though "Federal" yields the highest percentage of fatalities for all five of the classifications, "Interstate" consists of the most fatalities with 52. "Interstate" classifications comprise 52 of the 149 fatalities included in the distribution (34.9%), and "Federal" classifications comprise 48 of the 149 fatalities (32.2%). Combined, these two categories account for 67.1% of fatalities, making these two categories by far the most severe highway classifications for work zone-related crashes, without being able to normalize for exposure. Without knowledge of the amount of exposure these highways experience, there is no way to make logical comparisons with these results.

In summary, each of the four independent variables described in this section have the highest impact on determining the resulting crash severity for work zone-related crashes. Additionally, each independent variable has a category that yields the highest percentage of fatalities and one that yields the highest number of fatalities. The most severe crash types are "Head-On" with fatalities resulting in 47.6% of occurrences, and "Single Vehicle Crash," which yields 42 fatalities in all. The most severe primary contributing factors are "Crossed Over," with fatalities resulting in 35.1% of occurrences, and "Aggressive Behavior," which yields 38 total fatalities. The most severe first harmful events are "Collision with Bike/Pedestrian" that result in a fatality in 18.2% of its occurrences, and "Collision with Vehicles," that yield a total of 93 fatalities. Lastly, the most severe highway classifications are "Federal" with fatalities resulting in 8.1% of its occurrences, and "Interstate" which yields 52 fatalities in all.

5.2 Conclusions for the Analysis of Factors that Impact Work Zone Location in Work Zone-Related Crashes

A statistical analysis utilizing multinomial regression and frequency distributions was conducted to determine the statistical significance of each of the fifteen independent variables to the crash location within a work zone. The most statistically significant factors related to crash location are “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes” and “Manner of Crash.” These variables describe aspects of a crash that have the greatest impact on determining crash location within a work zone. Disregarding observations with a work zone crash location of “Other Work Zone Area” and independent variables with categories containing “Other,” the strongest correlations of the remaining four work zone crash locations (“Activity Area,” “Advance Warning Area,” “Termination Area,” and “Transition Area”) are presented for each of the statistically significant independent variables.

The location of a work zone-related crash is highly dependent on the type of work being performed. When specified, the type of work being performed has the greatest impact on predicting a crash’s work zone location because the variable “Work Zone Type” is more closely related to a work zone-related crash location than any other variable. When examining the categories of “Work Zone Type,” the type of work that yields the highest percentage of Activity Area crashes is “Work on Shoulder or Median,” with 9 of the reported 51 “Work on Shoulder or Median” work zone type crashes occurring in the Activity Area (17.6%). Additionally, “Work on Shoulder or Median” work zone types yield the highest percentage of Advance Warning Area crashes (3.9%), Termination Area crashes (3.9%), and Transition Area crashes (58.8%).

Even though “Work on Shoulder or Median” yields the highest percentage of crashes for each work zone crash location, the “Major Construction Project” work zone type consists of the most crashes for each work zone location. Of the 3,829 observations included in this distribution, 1,199 occurred in or around a major construction project of some kind (31.3%), while only 51 of the 3,829 observations occurred in or around work on a shoulder or median (1.3%). The preponderance of work zone-related crashes occurring in “Major Construction Projects” may be related to the amount of exposure, in terms of vehicle-miles traveled, through that type of work zone. However, this exposure information is difficult to come by.

The resulting location of a work zone-related crash is also highly dependent on the type of traffic control present. After determining the type of work involved, the type of traffic control present or not present is the second most closely related independent variable to work zone-related crashes. When examining the categories of “Traffic Control,” the type of control that yields the highest percentage of Activity Area crashes is “Flag Person,” with 12 of the reported “Flag Person” type crashes yielding a crash location of “Activity Area” (31.6%). Similarly, the type of control that yields the highest percentage of Advance Warning Area crashes is “School Zone Signs/Police” at 7.1%. Lastly, “Warning or Work Zone Sign” yields the highest percentage of Transition Area crashes (65.9%) and Termination Area crashes (3.9%).

While the traffic control category of “Flag Person” yields the highest percentage of Activity Area crashes, the category with the highest number of crashes occurring within the Activity Area is “No Control Present,” with 45 of the reported 98 Activity Area crashes occurring when no traffic control devices are present (45.9%). This is the same for every work zone crash location, with the “No Control Present” category consisting of the highest number of crashes for each location: Advance Warning Area (27), Transition Area (507), Activity Area (45), and Termination Area (31). Whether or not a type of traffic control was actually in place, it may not have been clear to the reporting officer. Additional education on traffic control devices for law enforcement officers could potentially reduce the high number of occurrences yielding "No Control Present" for the traffic control variable.

In addition to the work zone type and traffic control device present, the resulting location of a work zone-related crash is also highly dependent on the side of the highway that the crash occurs on, as well as the number of traffic way lanes. Regarding the total number of crashes occurring within each work zone crash location, the highest amount of Activity Area crashes (38) and Termination Area crashes (18) occur along the southbound side of a roadway. Similarly, the "Northbound" category yields the highest number of Advance Warning Area crashes (18) and Transition Area crashes (282). For the number of traffic way lanes, the category with the highest number of crashes occurring within the Activity Area is "Four Lanes," with 54 of the reported 102 Activity Area crashes occurring on roadways with four lanes (52.9%). This is the same for every work zone crash location, with the category of "Four Lanes" consisting of the highest number of crashes for each location: Advance Warning Area (23), Transition Area (403), Activity Area (54) and Termination Area (30).

Lastly, "Manner of Crash" also had a high impact on determining the resulting location of a work zone-related crash. When examining the categories within "Manner of Crash," the crash type that yields the highest percentage of Activity Area crashes is "Non-Collision," with 4 of the reported 36 observations having a non-collision manner of crash (11.1%). The category of "Causal Vehicle Backing" yields the highest percentage of Advance Warning Area crashes (14.3%), and the category of "Same Direction" yields the highest percentage of Termination Area crashes (2.7%) and Transition Area crashes (26%).

While the manner of crash category of "Non-Collision" yields the highest percentage of Activity Area crashes, the category with the highest number of crashes occurring within the

Activity Area is “Single Vehicle Crash,” with 27 of the reported 105 Activity Area crashes occurring as a result of a “Single Vehicle Crash” (25.7%). This category also has the highest number of Termination Area crashes with 17. Lastly, the category of “Rear End” has the highest number of Advance Warning Area crashes (21) and Transition Area crashes (359).

In summary, for the type of work zone, “Work on Shoulder or Median” accounted for the highest percentage of crashes for each work zone location, while “Major Construction Project” yielded the highest number of crashes for each work zone location. Regarding traffic control devices, “Flag Person” accounted for the highest percentage of Activity Area crashes, “School Zone Signs/Police” accounted for the highest percentage of Advance Warning Area crashes, and “Warning or Work Zone Sign” accounted for the highest percentage of both Termination and Transition area crashes. However, the category of “No Control Present” yielded the highest number of crashes for each work zone location.

Regarding traffic way lanes, roadways consisting of four lanes accounted for the highest number of crashes for each work zone location. Lastly, regarding the manner of crash, “Non-Collision Events” accounted for the highest percentage of Activity Area crashes, “Causal Vehicle Backing” accounted for the highest percentage of Advance Warning Area crashes, and “Same Direction” accounted for the highest percentage of both Termination and Transition Area crashes. For the highest number of crashes, “Rear End” and “Single Vehicle Crash” both had the highest amount of crashes within the Activity Area; “Rear End” yielded the highest number of crashes for both the Advance Warning Area and Transition Area, while “Single Vehicle Crash” yielded the highest number of crashes within the Termination Area.

5.3 Recommendations

In this section, recommendations are made in relation to three specific areas: (1) recommendations to ALDOT in regards to improving the overall safety and efficiency of work zones in Alabama, (2) recommendations to improve crash reporting in Alabama, and (3) recommendations for future research regarding highway work zone safety.

5.3.1 Recommendations to ALDOT

Regarding the five most statistically significant independent variables of “Work Zone Type,” “Traffic Control,” “Highway Side,” “Traffic way lanes” and “Manner of Crash,” the total number of occurrences within each work zone location for each variable are further examined, in order to accurately identify specific areas of concern. As mentioned in Section 5.2, observations with a work zone crash location of “Other Work Zone Area” and independent variables with categories containing “Other” have been disregarded. Table 5.1 shows the combined distribution of all five independent variables by the four remaining categories of “Work Zone Crash Location,” and gives additional insight into the total number of occurrences within each work zone location.

Table 5.1 – Distribution of Most Statistically Significant Variables by “Work Zone Crash Location”

Independent Variable	Work Zone Crash Location				
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Total
Work Zone Type	48 (4.7%)	812 (79.9%)	106 (10.4%)	50 (4.9%)	1016
Traffic Control	44 (4.5%)	790 (80.4%)	98 (9.9%)	50 (5.1%)	982
Highway Side	47 (4.8%)	788 (80.7%)	92 (9.4%)	49 (5.0%)	976
Traffic way lanes	47 (4.7%)	810 (80.3%)	102 (10.1%)	50 (4.9%)	1009
Manner of Crash	48 (4.7%)	812 (80.0%)	105 (10.3%)	50 (4.9%)	1015

In Table 5.1, the total occurrences for the five most statistically significant independent variables are distributed amongst the work zone locations, with each row tallying 100%. Percentages of "Advance Warning Area," "Transition Area," "Activity Area," and "Termination Area" location crashes are represented for each independent variable. Approximately the same percentage of crashes exist for each independent variable, with crashes occurring within the Transition Area having the most potential to be reduced.

Furthermore, determining the resulting crash severity for Transition Area crashes will shed light onto exactly how severe these occurrences are, and how much importance should be placed on this specific work zone location. Table 5.2 shows the distribution of "Crash Severity" by "Work Zone Crash Location" (disregarding the "Other Work Zone Area" category).

Table 5.2 – Condensed Distribution of "Crash Severity" by "Work Zone Crash Location"

Crash Severity	Work Zone Crash Location				
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Total
Fatality	2 (5.4%)	27 (72.9%)	5 (13.5%)	3 (8.1%)	37
Injury	14 (7.3%)	151 (79.1%)	21 (11.0%)	5 (2.6%)	191
PDO	30 (3.9%)	624 (80.8%)	76 (9.8%)	42 (5.4%)	772
Total	46 (4.6%)	802 (80.2%)	102 (10.2%)	50 (5.0%)	1000

In Table 5.2, 27 of the reported 37 fatalities included in this distribution occurred within the Transition Area (72.9%), making it the most severe work zone crash location. While this does not reflect the total amount of occurrences within the Transition Area, it is enough reason to determine the causing factors of crashes occurring within the Transition Area, as well as potential ways to reduce the severity of these crashes.

There are three distinct groups of factors contributing to the high percentage of fatalities occurring within the Transition Area: (1) driver behavior, (2) roadway environment, and (3) infrastructure. From the driver's perspective, aggressive behavior, improper lane use, and inattentive or distracted driving consist of more than half of Transition Area crashes (55.0%) when distributed against "Primary Contributing Factor." Furthermore, 44.2% of crashes result in a rear end type crash, and the first harmful event is located on the roadway in 79.7% of occurrences.

Roadway environment factors include the time and day of crashes, as well as light, weather, locale, and roadway conditions. For the time of day, 30.7% of crashes within the Transition Area occurred during the evening (3:00 p.m. – 6:59 p.m.), and 29.4% of crashes occurred in the middle of the day (10:00 a.m. – 2:59 p.m.). The day of the week that consisted of the most Transition Area crashes was Friday with 141 of the 812 reported occurrences (17.4%). Regarding highway side, Northbound Transition Area crashes consisted of 35.8% of occurrences, while Southbound consisted of 33.5%. Together, both Northbound and Southbound Transition Area crashes accounted for 69.3% of all occurrences. The locale with the most Transition Area crashes was "Open Country," accounting for 71.6% of all occurrences. Crashes taking place in daylight consisted of 74.8% of occurrences, those in clear weather accounting for 63.8% of occurrences, and those taking place in dry roadway conditions accounted for 82.6% of Transition Area occurrences.

Driver behavior and roadway environment aspects are important, and need to be made apparent to help reduce the frequency and severity of crashes occurring in all work zone locations. Specifically for Transition Area crashes, the work zone location with the highest and most severe occurrences, the biggest impact in reducing the frequency and severity of these crashes is in regards to infrastructure: the type of work being performed, the placement of traffic control devices, the number of traffic way lanes, and the classification of the roadway.

Regarding issues with the roadway and roadway activity, the category "Major Construction Project" consists of 687 of the reported 812 Transition Area crashes (84.6%) when distributed against "Work Zone Type." For traffic control devices, 64.2% of Transition Area crashes occur when no control devices are present. Concerning the roadway itself, 49.6% of occurrences are located on roads with four traffic way lanes, and 74.4% of occurrences are located on roadways classified as "Interstate."

5.3.2 Recommendations to Crash Reporting for the AUTCR

The crash reporting itself, in the forms of ALDOT Crash Report Form C-25-A, Alabama Uniform Traffic Crash Reports (AUTCRs), and contractor written reports stands to be improved in three distinct areas: (1) condensing unnecessary or redundant categories, (2) improving consistency from law enforcement officers in reporting work zone-related fields, and (3) eliminating hand written reports of all kinds.

In the Data Management process, steps were taken to condense the number of categories for the variables included in the analysis, ultimately to create a simplified spreadsheet and obtain accurate, well-fit multinomial regressions. Natural groupings existed for many of the categories, and these groupings should be applied to AUTCRs for a simplified, reduced crash report. For example, condensing categories 71-78 for the variable "Primary Contributing Factor" to create one category of "No Improper Action" can be found in Table 5.3.

Table 5.3 – Reducing Categories 71-78 within "Primary Contributing Factor"

71-No Improper Driver Action Vision Obstruction	No Improper Action
72-No Improper Driver Action Unseen Object/Person/Vehicle	No Improper Action
73-No Improper Driver Action Roadway, Sign, or Signal Defect	No Improper Action
74-No Improper Driver Action Defective Equipment	No Improper Action
75-No Improper Driver Action Improper Load/Size	No Improper Action
76-No Improper Driver Action Cargo Fell or Load Shift	No Improper Action
77-No Improper Driver Action Improper Attachment	No Improper Action
78-No Improper Driver Action Other- Described in Narrative	No Improper Action

In Table 5.3, categories 71-78 can be assigned a new category called "No Improper Action." In the event that "No Improper Action" was the primary contributing factor for a crash, this new category can be selected and additional information can be supplied in the narrative section. By doing so, the selection process becomes much easier, as the reporting officer can simply select "No Improper Action." If further information exists regarding an obstruction, signal defect or improper attachment, it can be noted in the narrative section. Reducing the number of categories for variables would not endanger the integrity of the variable, information would not be lost, and it would provide an easier method of selection for the reporting law enforcement officer.

As previously stated, only 26.3% of observations were initially assigned a specific work zone crash location by the reporting officer (Advance Warning Area, Transition Area, Activity Area or Termination Area), with the remaining observations later being deemed work zone-related by ALDOT. With less than a third of the reports initially receiving a work zone crash location, additional education on work zones and work zone safety for law enforcement officers is needed. Instituting and requiring law enforcement officers to attend seminars on work zone safety, work zone crash reporting, and general work zone practices would not only be beneficial to the law enforcement officers, but would likely result in more accurately filled out crash reports.

Lastly, regarding the actual observations themselves, it would be beneficial if all forms of crash reports (ALDOT Crash Report Form C-25-A, AUTCRs and contractor written reports) were typed and in electronic form. Although an exact number is not available, there were enough C-25-A forms and AUTCRs hand written for this type of recommendation to be made. Additionally, crash reporting can be done electronically through the use of computers or tablets at the scene of the crash. Law enforcement officers would be able to record every aspect of the crash, and allow for accurate, real time crash reporting. This would also eliminate the possibility of leaving out any information of a crash.

5.3.3. Recommendations for Future Research

For future highway work zone safety research (particularly in Alabama), the area in most need of attention is the Transition Area, specifically to reduce the frequency and severity of crashes located within the Transition Area. Potential countermeasures include additional signage in the Advance Warning Area that's even farther from the work zone, and adopting static and/or dynamic lane merging techniques. By adopting either technique, in addition to a more robust form of the research presented in this study, the likelihood of the frequency and severity of crashes occurring within the Transition Area would be expected to decrease. To accomplish this, several measures need to be taken:

- Have simpler, condensed crash reporting regarding the C-25-A forms and AUTCRs,
- Improved consistency from reporting officers in regards to accurately recording the location of a crash within a work zone,
- Institute the use of electronic, real-time crash reporting,
- Introduce an adaption of Dynamic Late Merge in highway work zones in Alabama.

Future research could be centered on an adaption of dynamic late merging techniques in work zones in Alabama, using a more complete data set that included condensed C-25-A forms and AUTCRs and improved consistency among work zone crash locations. From there, the impacts of these recommendations could be measured against the results of this research to determine if the frequency and severity of crashes within the Transition Area are reduced.

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APPENDIX A

FREQUENCY DISTRIBUTIONS FOR SECTION 4.1: ANALYSIS OF FACTORS THAT IMPACT CRASH SEVERITY IN WORK ZONE-RELATED CRASHES

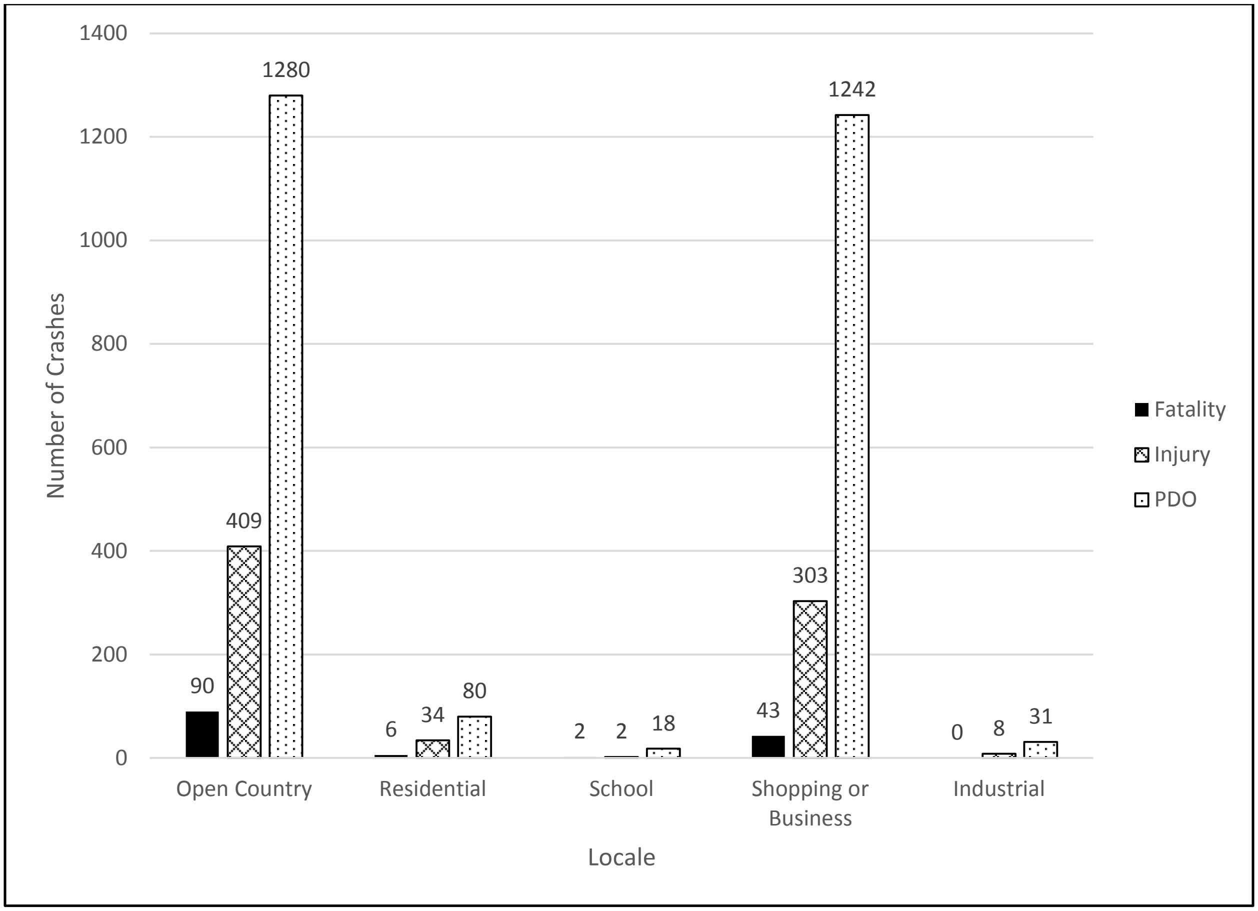

Figure A-1 – Distribution of “Locale” by “Crash Severity”

Table A-1 – Distribution of “Locale” by “Crash Severity”

Locale	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Open Country	90 (5.0%)	409 (23.0%)	1280 (72.0%)	1779
Residential	6 (5.0%)	34 (28.3%)	80 (66.7%)	120
School	2 (9.1%)	2 (9.1%)	18 (81.8%)	22
Shopping or Business	43 (2.7%)	303 (19.1%)	1242 (78.2%)	1588
Industrial	0 (0%)	8 (20.5%)	31 (79.5%)	39
Total	141 (4.0%)	756 (21.3%)	2651 (74.7%)	3548

Table A-2 – Distribution of “Crash Severity” by “Locale”

Crash Severity	**Locale**					
	Open Country	Residential	School	Shopping or Business	Industrial	**Total**
Fatality	90 (63.8%)	6 (4.3%)	2 (1.4%)	43 (30.5%)	0 (0%)	141
Injury	409 (54.1%)	34 (4.5%)	2 (0.3%)	303 (40.1%)	8 (1.1%)	756
PDO	1280 (48.3%)	80 (3.0%)	18 (0.7%)	1242 (46.9%)	31 (1.2%)	2651
Total	1779 (50.1%)	120 (3.4%)	22 (0.6%)	1588 (44.8%)	39 (1.1%)	3548

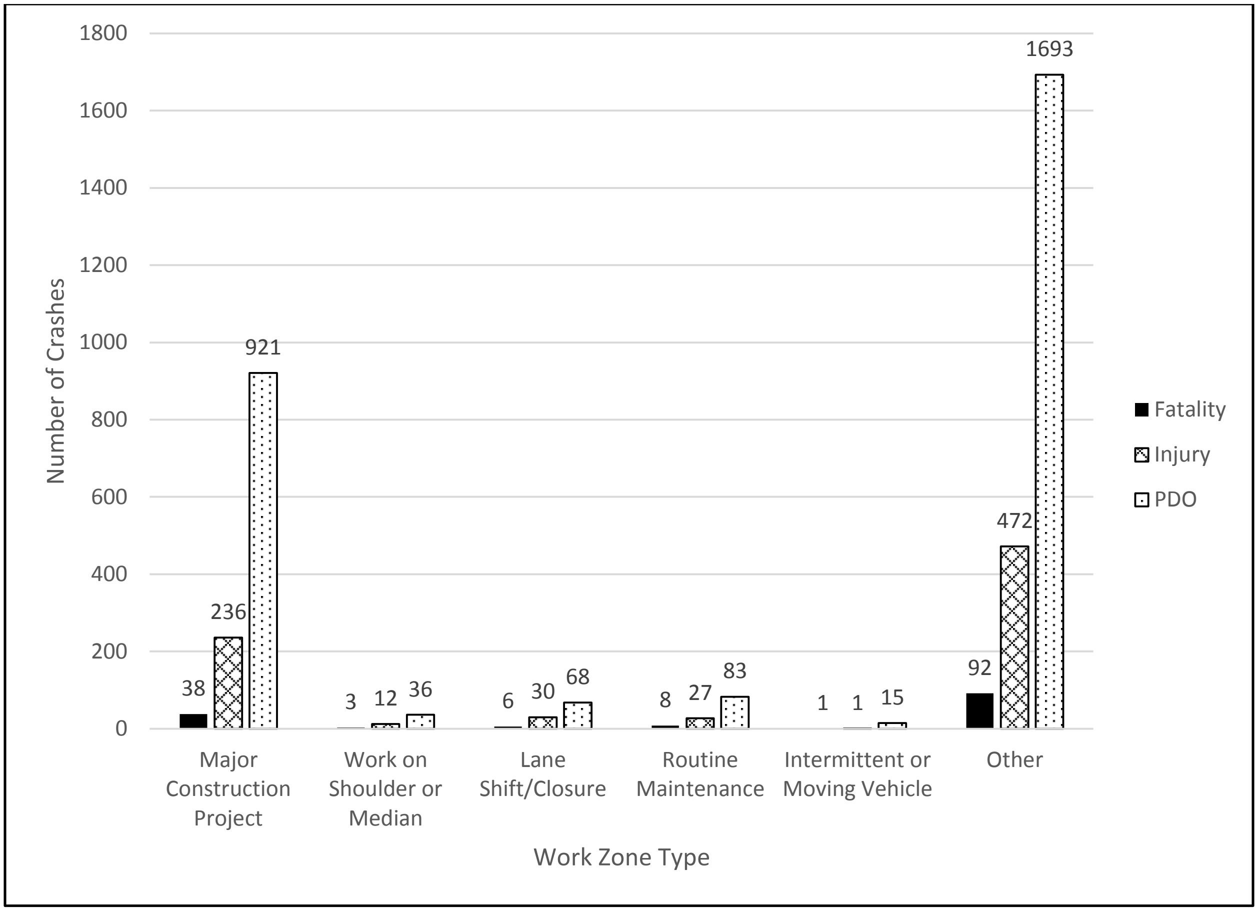

Figure A-2 – Distribution of “Work Zone Type” by “Crash Severity”

Table A-3 – Distribution of "Work Zone Type" by "Crash Severity"

Work Zone Type	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Major Construction Project	38 (3.2%)	236 (19.7%)	921 (77.1%)	1195
Work on Shoulder or Median	3 (5.9%)	12 (23.5%)	36 (70.6%)	51
Lane Shift/Closure	6 (5.8%)	30 (28.8%)	68 (65.4%)	104
Routine Maintenance	8 (6.8%)	27 (22.9%)	83 (70.3%)	118
Intermittent or Moving Vehicle	1 (5.9%)	1 (5.9%)	15 (88.2%)	17
Other	92 (4.1%)	472 (20.9%)	1693 (75.0%)	2257
Total	148 (4.0%)	778 (20.8%)	2816 (75.3%)	3742

Table A-4 – Distribution of "Crash Severity" by "Work Zone Type"

Crash Severity	**Work Zone Type**						
	Major Construction Project	Work on Shoulder or Median	Lane Shift/Closure	Routine Maintenance	Intermittent or Moving Vehicle	Other	**Total**
Fatality	38 (25.7%)	3 (2.0%)	6 (4.1%)	8 (5.4%)	1 (0.7%)	92 (62.2%)	148
Injury	236 (30.3%)	12 (1.5%)	30 (3.9%)	27 (3.5%)	1 (0.1%)	472 (60.7%)	778
PDO	921 (32.7%)	36 (1.3%)	68 (2.4%)	83 (2.9%)	15 (0.5%)	1693 (60.1%)	2816
Total	1195 (31.9%)	51 (1.4%)	104 (2.8%)	118 (3.2%)	17 (0.5%)	2257 (60.3%)	3742

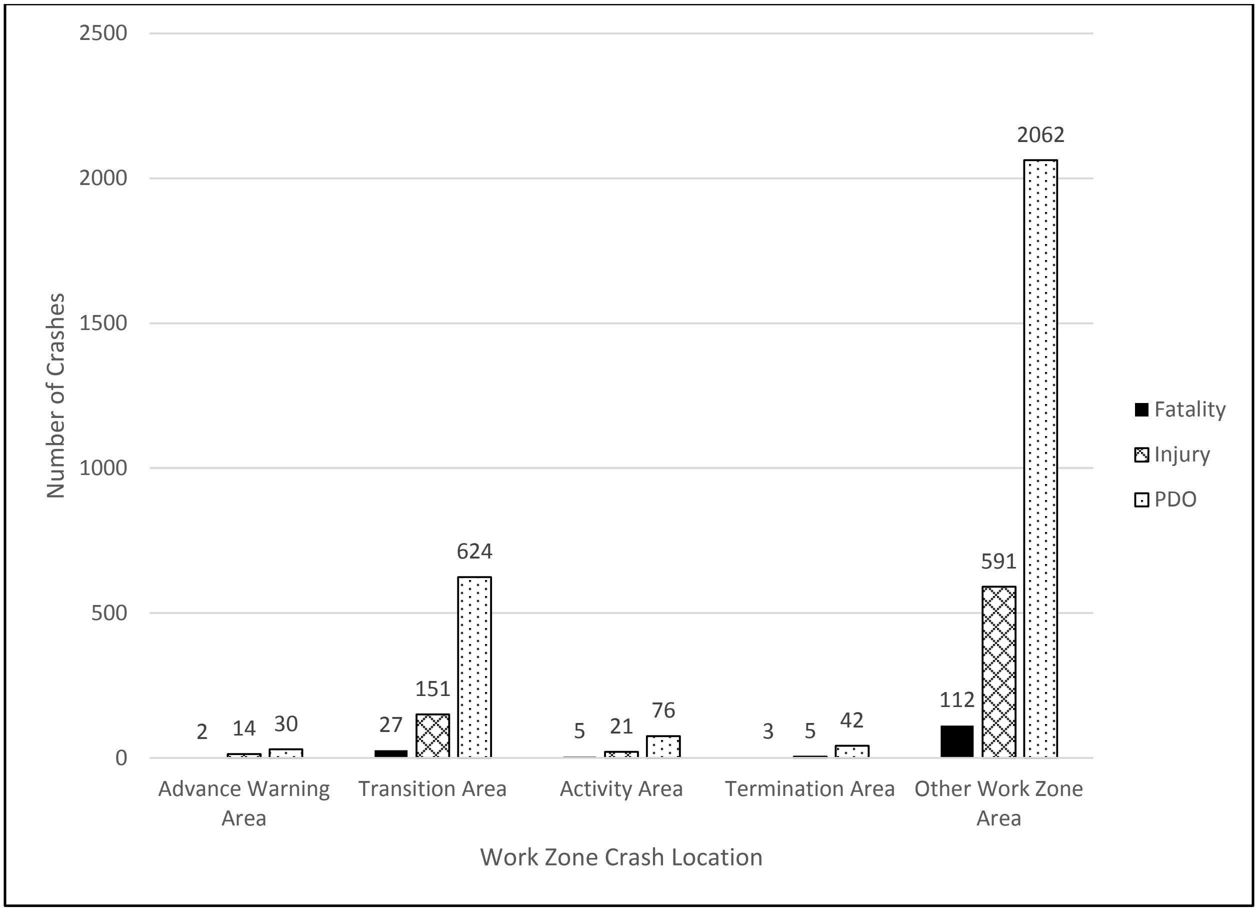

Figure A-3 – Distribution of “Work Zone Crash Location” by “Crash Severity”

Table A-5 – Distribution of "Work Zone Crash Location" by "Crash Severity"

Work Zone Crash Location	Crash Severity			
	Fatality	Injury	PDO	**Total**
Advance Warning Area	2 (4.3%)	14 (30.4%)	30 (65.2%)	46
Transition Area	27 (3.4%)	151 (18.8%)	624 (77.8%)	802
Activity Area	5 (4.9%)	21 (20.6%)	76 (74.5%)	102
Termination Area	3 (6.0%)	5 (10.0%)	42 (84.0%)	50
Other Work Zone Area	112 (4.1%)	591 (21.4%)	2062 (74.6%)	2765
Total	149 (4.0%)	782 (20.8%)	2834 (75.3%)	3765

Table A-6 – Distribution of "Crash Severity" by "Work Zone Crash Location"

Crash Severity	Work Zone Crash Location					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Fatality	2 (1.3%)	27 (18.1%)	5 (3.4%)	3 (2.0%)	112 (75.2%)	149
Injury	14 (1.8%)	151 (19.3%)	21 (2.7%)	5 (0.6%)	591 (75.6%)	782
PDO	30 (1.1%)	624 (22.0%)	76 (2.7%)	42 (1.5%)	2062 (72.8%)	2834
Total	46 (1.2%)	802 (21.3%)	102 (2.7%)	50 (1.3%)	2765 (73.4%)	3765

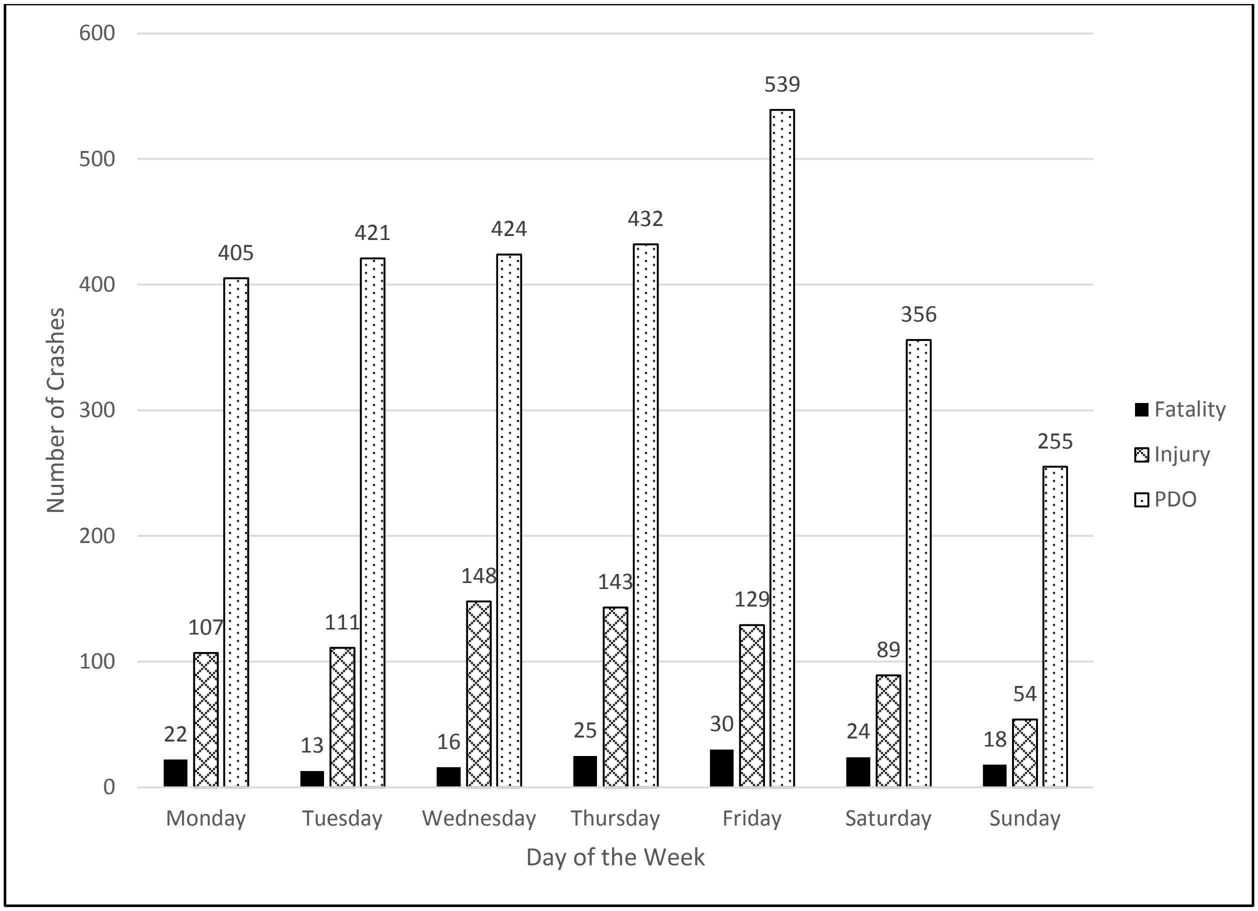

Figure A-4 – Distribution of "Day of the Week" by "Crash Severity"

Table A-7 – Distribution of "Day of the Week" by "Crash Severity"

Day of the Week	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Monday	22 (4.1%)	107 (20.0%)	405 (75.8%)	534
Tuesday	13 (2.4%)	111 (20.4%)	421 (77.2%)	545
Wednesday	16 (2.7%)	148 (25.2%)	424 (72.1%)	588
Thursday	25 (4.2%)	143 (23.8%)	432 (72.0%)	600
Friday	30 (4.3%)	129 (18.5%)	539 (77.2%)	698
Saturday	24 (5.1%)	89 (19.0%)	356 (75.9%)	469
Sunday	18 (5.5%)	54 (16.5%)	255 (78.0%)	327
Total	148 (3.9%)	781 (20.8%)	2832 (75.3%)	3761

Table A-8 – Distribution of "Crash Severity" by "Day of the Week"

Crash Severity	**Day of the Week**							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	**Total**
Fatality	22 (14.9%)	13 (8.8%)	16 (10.8%)	25 (16.9%)	30 (20.3%)	24 (16.2%)	18 (12.2%)	148
Injury	107 (13.7%)	111 (14.2%)	148 (19.0%)	143 (18.3%)	129 (16.5%)	89 (11.4%)	54 (6.9%)	781
PDO	405 (14.3%)	421 (14.9%)	424 (15.0%)	432 (15.3%)	539 (19.0%)	356 (12.6%)	255 (9.0%)	2832
Total	534 (14.2%)	545 (14.5%)	588 (15.6%)	600 (16.0%)	698 (18.6%)	469 (12.5%)	327 (8.7%)	3761

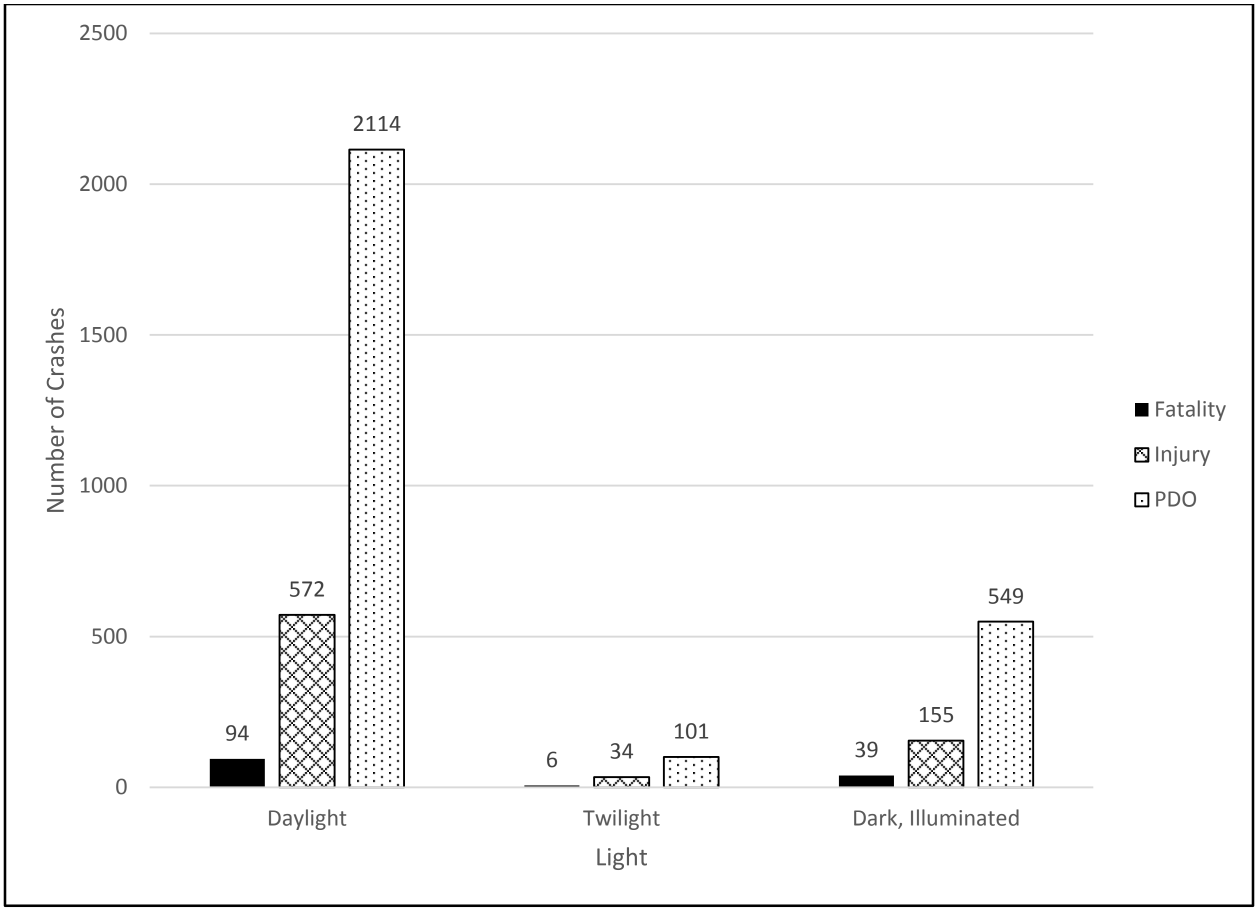

Figure A-5 – Distribution of “Light” by “Crash Severity”

Table A-9 – Distribution of “Light” by “Crash Severity”

Light	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Daylight	94 (3.4%)	572 (20.6%)	2114 (76.0%)	2780
Twilight	6 (4.3%)	34 (24.1%)	101 (71.6%)	141
Dark, Illuminated	39 (5.2%)	155 (20.9%)	549 (73.9%)	743
Total	139 (3.8%)	761 (20.8%)	2764 (75.4%)	3664

Table A-10 – Distribution of “Crash Severity” by “Light”

Crash Severity	**Light**			
	Daylight	Twilight	Dark, Illuminated	**Total**
Fatality	94 (67.6%)	6 (4.3%)	39 (28.1%)	139
Injury	572 (75.2%)	34 (4.5%)	155 (20.4%)	761
PDO	2114 (76.5%)	101 (3.7%)	549 (19.9%)	2764
Total	2780 (75.9%)	141 (3.8%)	743 (20.3%)	3664

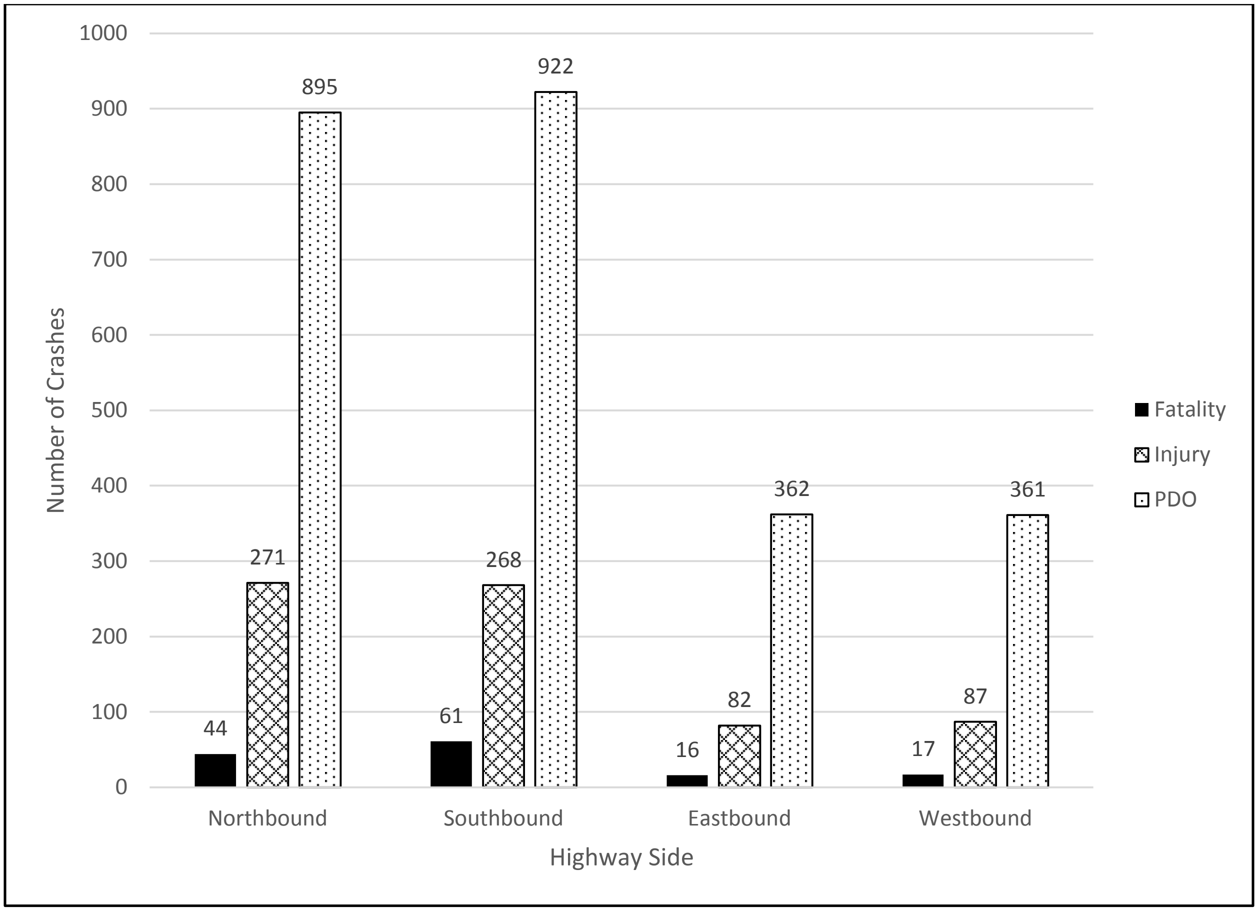

Figure A-6 – Distribution of “Highway Side” by “Crash Severity”

Table A-11 – Distribution of “Highway Side” by “Crash Severity”

Highway Side	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Northbound	44 (3.6%)	271 (22.4%)	895 (74.0%)	1210
Southbound	61 (4.9%)	268 (21.4%)	922 (73.7%)	1251
Eastbound	16 (3.5%)	82 (17.8%)	362 (78.7%)	460
Westbound	17 (3.7%)	87 (18.7%)	361 (77.6%)	465
Total	138 (4.1%)	708 (20.9%)	2540 (75.0%)	3386

Table A-12 – Distribution of “Crash Severity” by “Highway Side”

Crash Severity	**Highway Side**				
	Northbound	Southbound	Eastbound	Westbound	**Total**
Fatality	44 (31.9%)	61 (44.2%)	16 (11.6%)	17 (12.3%)	138
Injury	271 (38.3%)	268 (37.9%)	82 (11.6%)	87 (12.3%)	708
PDO	895 (35.2%)	922 (36.3%)	362 (14.3%)	361 (14.2%)	2540
Total	1210 (35.7%)	1251 (36.9%)	460 (13.6%)	465 (13.7%)	3386

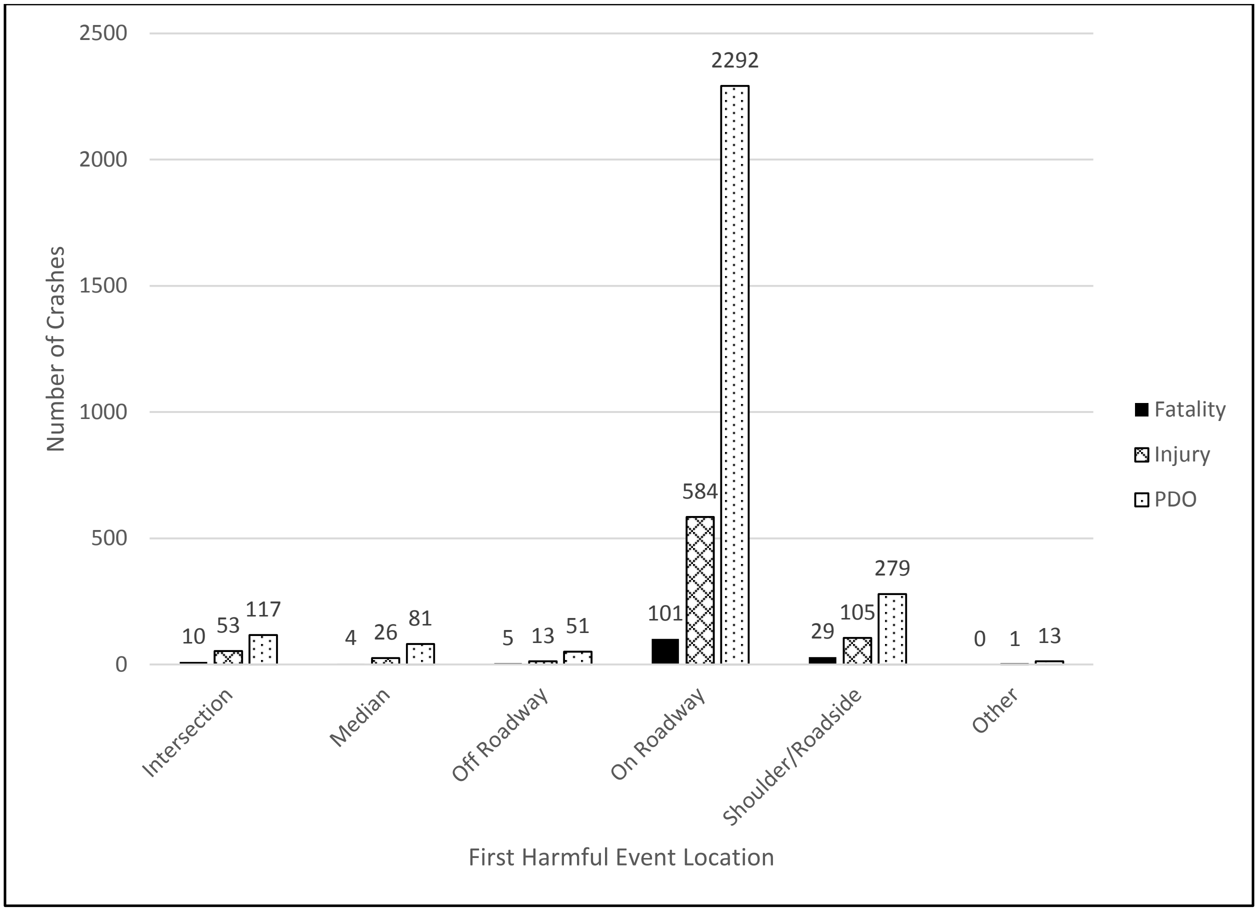

Figure A-7 – Distribution of “First Harmful Event Location” by “Crash Severity”

Table A-13 – Distribution of “First Harmful Event Location” by “Crash Severity”

First Harmful Event Location	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Intersection	10 (5.6%)	53 (29.4%)	117 (65.0%)	180
Median	4 (3.6%)	26 (23.4%)	81 (73.0%)	111
Off Roadway	5 (7.2%)	13 (18.8%)	51 (73.9%)	69
On Roadway	101 (3.4%)	584 (19.6%)	2292 (77.0%)	2977
Shoulder/Roadside	29 (19.5%)	105 (25.4%)	279 (67.6%)	413
Other	0 (0%)	1 (7.1%)	13 (92.9%)	14
Total	149 (4.0%)	782 (20.8%)	2833 (75.3%)	3764

Table A-14 – Distribution of “Crash Severity” by “First Harmful Event Location”

Crash Severity	**First Harmful Event Location**						
	Intersection	Median	Off Roadway	On Roadway	Shoulder/ Roadside	Other	**Total**
Fatality	10 (6.7%)	4 (2.7%)	5 (3.4%)	101 (67.8%)	29 (19.5%)	0 (0%)	149
Injury	53 (6.8%)	26 (3.3%)	13 (1.7%)	584 (74.7%)	105 (13.4%)	1 (0.1%)	782
PDO	117 (4.1%)	81 (2.9%)	51 (1.8%)	2292 (80.9%)	279 (9.8%)	13 (0.5%)	2833
Total	180 (4.8%)	111 (2.9%)	69 (1.8%)	2977 (79.1%)	413 (11.0%)	14 (0.4%)	3764

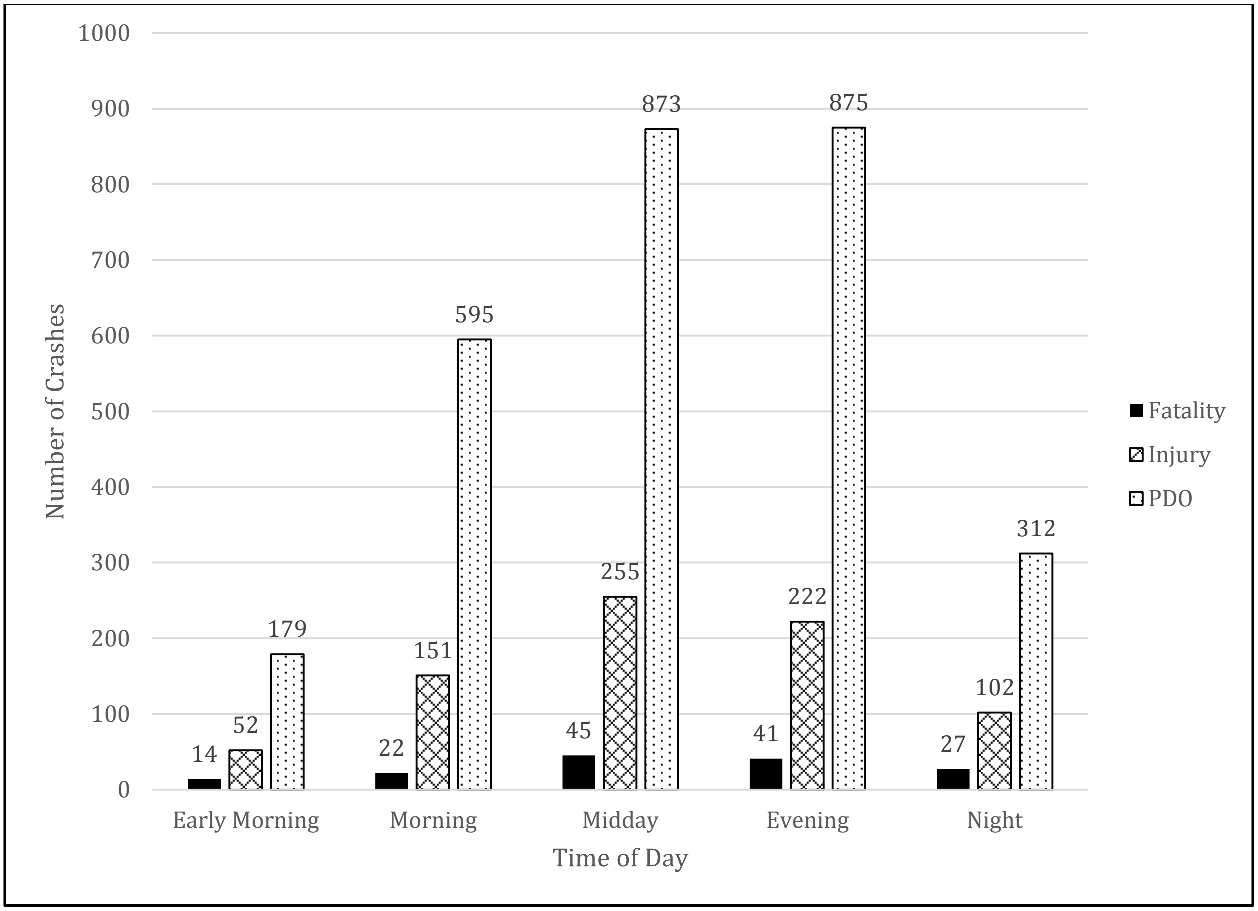

Figure A-8 – Distribution of “Time of Day” by “Crash Severity”

Table A-15 – Distribution of “Time of Day” by “Crash Severity”

Time of Day	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Early Morning	14 (5.7%)	52 (21.2%)	179 (73.1%)	245
Morning	22 (2.9%)	151 (19.7%)	595 (77.5%)	768
Midday	45 (3.8%)	255 (21.7%)	873 (74.4%)	1173
Evening	41 (3.6%)	222 (19.5%)	875 (76.9%)	1138
Night	27 (6.1%)	102 (23.1%)	312 (70.7%)	441
Total	149 (4.0%)	782 (20.8%)	2834 (75.3%)	3765

Table A-16 – Distribution of “Crash Severity” by “Time of Day”

Crash Severity	**Time of Day**					
	Early Morning	Morning	Midday	Evening	Night	**Total**
Fatality	14 (9.4%)	22 (14.8%)	45 (30.2%)	41 (27.5%)	27 (18.1%)	149
Injury	52 (6.6%)	151 (19.3%)	255 (32.6%)	222 (28.4%)	102 (13.0%)	782
PDO	179 (6.3%)	595 (21.0%)	873 (30.8%)	875 (30.9%)	312 (11.0%)	2834
Total	245 (6.5%)	768 (20.4%)	1173 (31.2%)	1138 (30.2%)	441 (11.7%)	3765

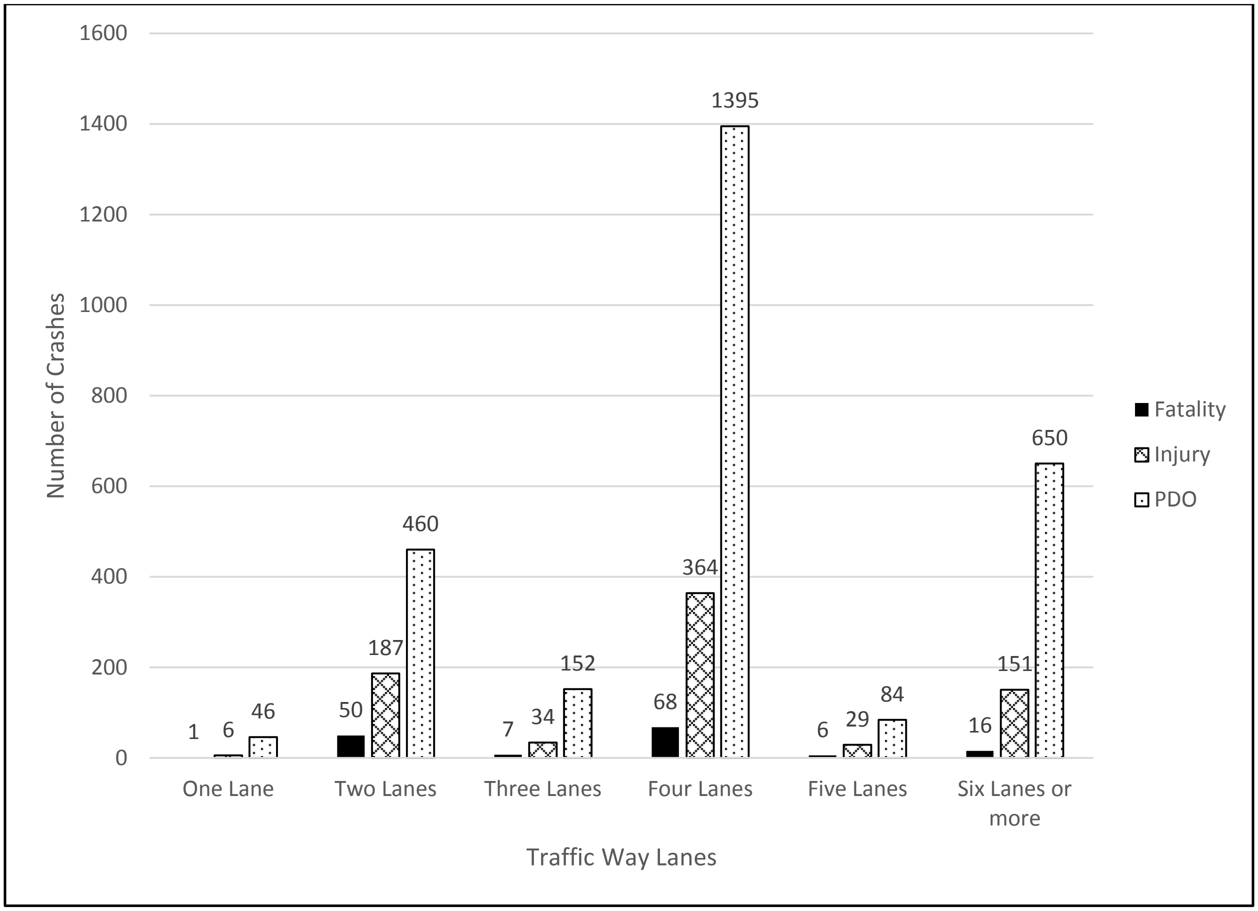

Figure A-9 – Distribution of “Traffic way lanes” by “Crash Severity”

Table A-17 - Distribution of “Traffic way lanes” by “Crash Severity”

Traffic way lanes	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
One Lane	1 (1.9%)	6 (11.3%)	46 (86.8%)	53
Two Lanes	50 (7.2%)	187 (26.8%)	460 (66.0%)	697
Three Lanes	7 (3.6%)	34 (17.6%)	152 (78.8%)	193
Four Lanes	68 (3.7%)	364 (19.9%)	1395 (76.4%)	1827
Five Lanes	6 (5.0%)	29 (24.4%)	84 (70.6%)	119
Six Lanes or More	16 (2.0%)	151 (18.5%)	650 (79.6%)	817
Total	148 (4.0%)	771 (20.8%)	2787 (75.2%)	3706

Table A-18 – Distribution of “Crash Severity” by “Traffic way lanes”

Crash Severity	**Traffic way lanes**						
	One Lane	Two Lanes	Three Lanes	Four Lanes	Five Lanes	Six Lanes or More	**Total**
Fatality	1 (0.7%)	50 (33.8%)	7 (4.7%)	68 (45.9%)	6 (4.1%)	16 (10.8%)	148
Injury	6 (0.8%)	187 (24.3%)	34 (4.4%)	364 (47.2%)	29 (3.8%)	151 (19.6%)	771
PDO	46 (1.7%)	460 (16.5%)	152 (5.5%)	1395 (50.1%)	84 (3.0%)	650 (23.3%)	2787
Total	53 (1.4%)	697 (18.8%)	193 (5.2%)	1827 (49.3%)	119 (3.2%)	817 (22.0%)	3706

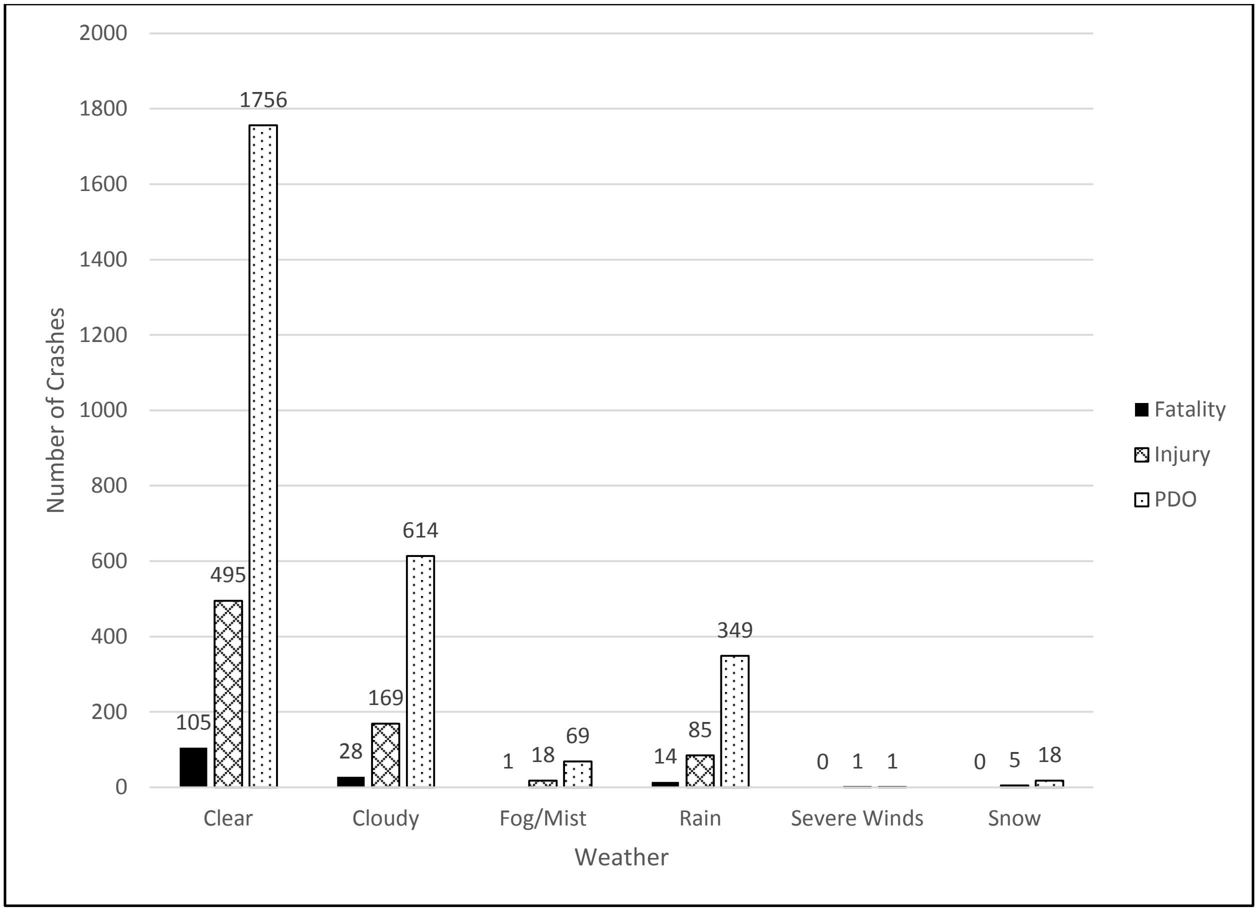

Figure A-10 – Distribution of “Weather” by “Crash Severity”

Table A-19 – Distribution of “Weather” by “Crash Severity”

Weather	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Clear	105 (4.5%)	495 (21.0%)	1756 (74.5%)	2356
Cloudy	28 (3.5%)	169 (20.8%)	614 (75.7%)	811
Fog/Mist	1 (1.1%)	18 (20.5%)	69 (78.4%)	88
Rain	14 (3.1%)	85 (19.0%)	349 (77.9%)	448
Severe Winds	0 (0%)	1 (50%)	1 (50%)	2
Snow	0 (0%)	5 (21.7%)	18 (78.3%)	23
Total	148 (4.0%)	773 (20.7%)	2807 (75.3%)	3728

Table A-20 – Distribution of “Crash Severity” by “Weather”

Crash Severity	**Weather**						
	Clear	Cloudy	Fog/Mist	Rain	Severe Winds	Snow	**Total**
Fatality	105 (70.9%)	28 (18.9%)	1 (0.7%)	14 (9.5%)	0 (0%)	0 (0%)	148
Injury	495 (64.0%)	169 (21.9%)	18 (2.3%)	85 (11.0%)	1 (0.1%)	5 (0.6%)	773
PDO	1756 (62.6%)	614 (21.9%)	69 (2.5%)	349 (12.4%)	1 (0.1%)	18 (0.6%)	2807
Total	2356 (63.2%)	811 (21.8%)	88 (2.4%)	448 (12.0%)	2 (0.1%)	23 (0.6%)	3728

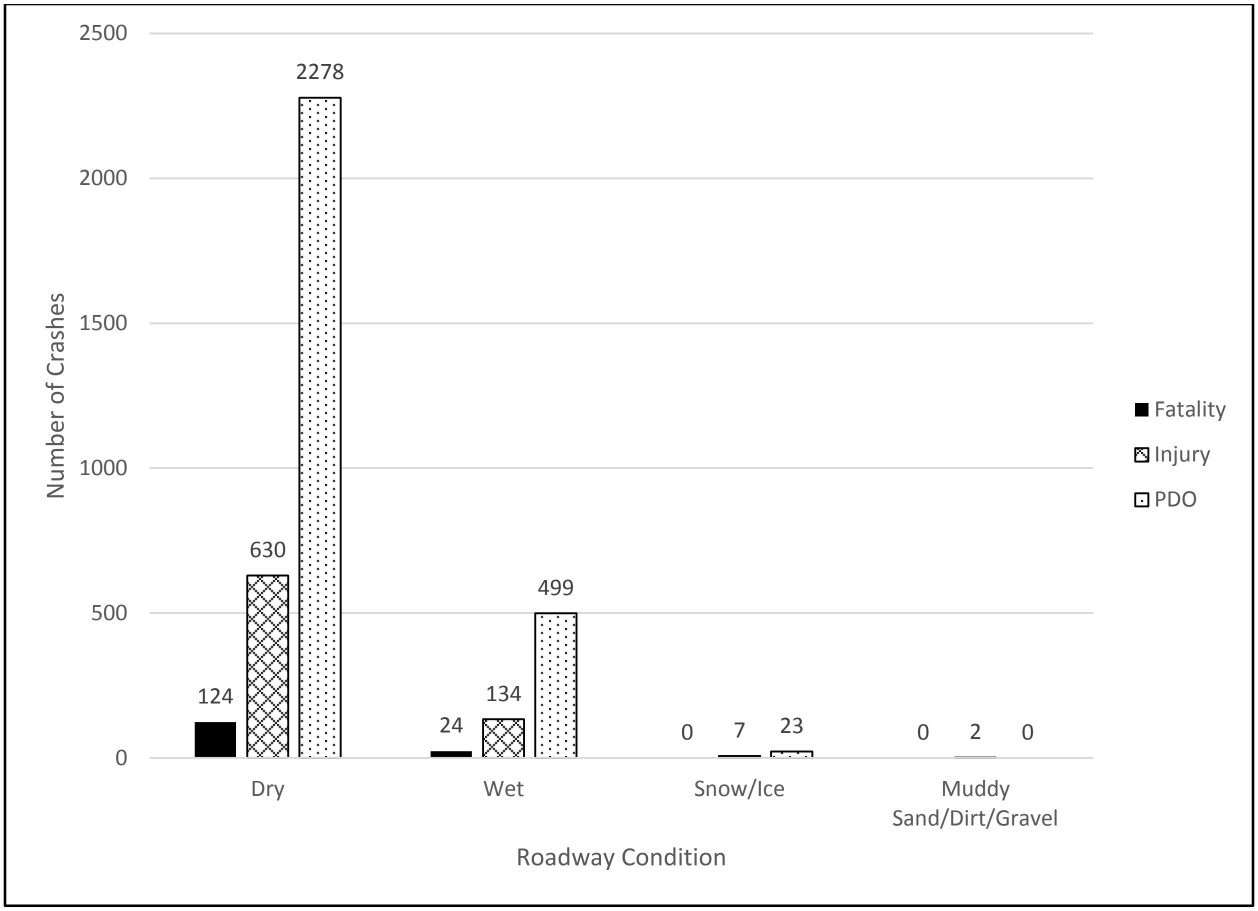

Figure A-11 – Distribution of “Roadway Condition” by “Crash Severity”

Table A-21 – Distribution of "Roadway Condition" by "Crash Severity"

Roadway Condition	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Dry	124 (4.1%)	630 (20.8%)	2278 (75.1%)	3032
Wet	24 (3.6%)	134 (20.4%)	499 (76.0%)	657
Snow/Ice	0 (0%)	7 (23.3%)	23 (76.7%)	30
Muddy Sand/Dirt/Gravel	0 (0%)	2 (100%)	0 (0%)	2
Total	148 (4.0%)	773 (20.8%)	2800 (75.2%)	3721

Table A-22 – Distribution of "Crash Severity" by "Roadway Condition"

Crash Severity	**Roadway Condition**				
	Dry	Wet	Snow/Ice	Muddy Sand/ Dirt/Gravel	**Total**
Fatality	124 (83.8%)	24 (16.2%)	0 (0%)	0 (0%)	148
Injury	630 (81.5%)	134 (17.3%)	7 (0.9%)	2 (0.3%)	773
PDO	2278 (81.4%)	499 (17.8%)	23 (0.8%)	0 (0%)	2800
Total	3032 (81.5%)	657 (17.7%)	30 (0.8%)	2 (0.1%)	3721

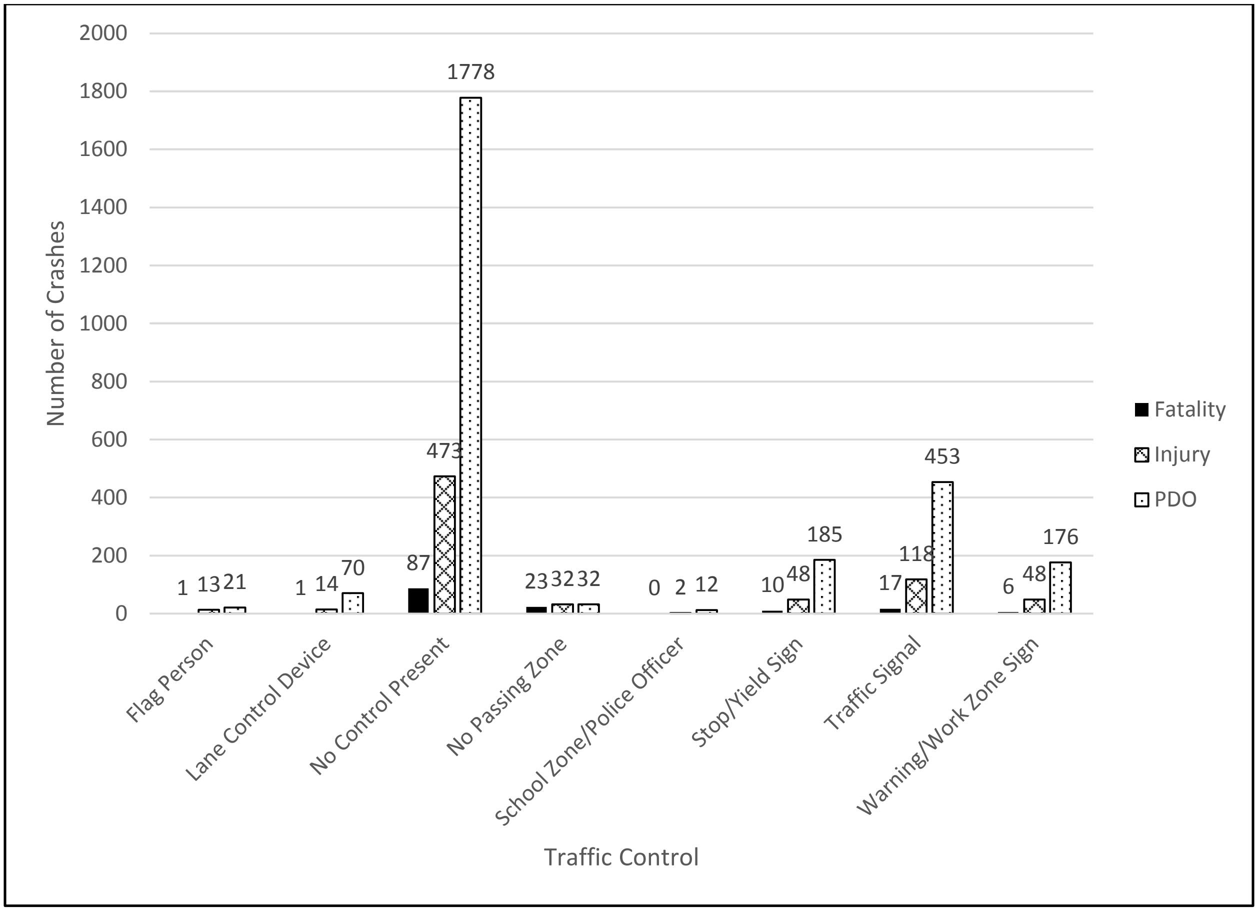

Figure A-12 – Distribution of “Traffic Control” by “Crash Severity”

Table A-23 – Distribution of “Traffic Control” by “Crash Severity”

Traffic Control	Crash Severity			
	Fatality	Injury	PDO	**Total**
Flag Person	1 (2.9%)	13 (37.1%)	21 (60.0%)	35
Lane Control Device	1 (1.2%)	14 (16.5%)	70 (82.4%)	85
No Control Present	87 (3.7%)	473 (20.2%)	1778 (76.0%)	2338
No Passing Zone	23 (26.4%)	32 (36.8%)	32 (36.8%)	87
School Zone/Police Officer	0 (0%)	2 (14.3%)	12 (85.7%)	14
Stop/Yield Sign	10 (4.1%)	48 (19.8%)	185 (76.1%)	243
Traffic Signal	17 (2.9%)	118 (20.1%)	453 (77.0%)	588
Warning/Work Zone Sign	6 (2.6%)	48 (20.9%)	176 (76.5%)	230
Total	145 (4.0%)	748 (20.7%)	2727 (75.3%)	3620

Table A-24 – Distribution of “Crash Severity” by “Traffic Control”

Crash Severity	Traffic Control								
	Flag Person	Lane Control Device	No Control Present	No Passing zone	School Zone/Police Officer	Stop/Yield Sign	Traffic Signal	Warning/Work Zone Sign	**Total**
Fatality	1 (0.7%)	1 (0.7%)	87 (60.0%)	23 (15.9%)	0 (0%)	10 (6.9%)	17 (11.7%)	6 (4.1%)	145
Injury	13 (1.7%)	14 (1.9%)	473 (63.2%)	32 (4.3%)	2 (0.3%)	48 (6.4%)	118 (15.8%)	48 (6.4%)	748
PDO	21 (0.8%)	70 (2.6%)	1778 (65.2%)	32 (1.2%)	12 (0.4%)	185 (6.8%)	453 (16.6%)	176 (6.5%)	2727
Total	35 (1.0%)	85 (2.3%)	2338 (64.6%)	87 (2.4%)	14 (0.4%)	243 (6.7%)	588 (16.2%)	230 (6.4%)	3620

APPENDIX B

FREQUENCY DISTRIBUTIONS FOR SECTION 4.2: ANALYSIS OF FACTORS THAT IMPACT WORK ZONE LOCATION IN WORK ZONE-RELATED CRASHES

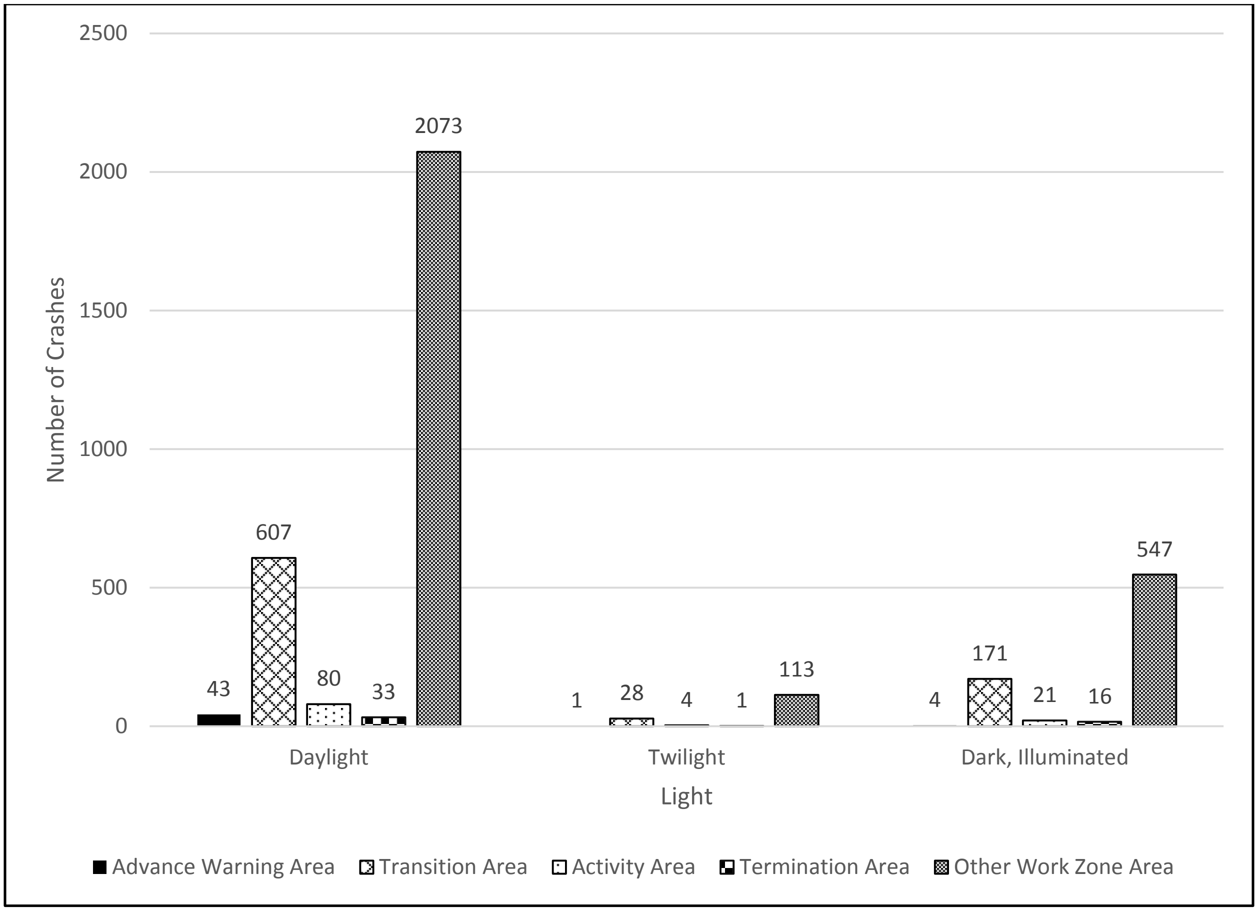

Figure B-1 – Distribution of “Light” by “Work Zone Crash Location”

Table B-1 – Distribution of “Light” by “Work Zone Crash Location”

Light	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Daylight	43 (1.5%)	607 (21.4%)	80 (2.8%)	33 (1.2%)	2073 (73.1%)	2836
Twilight	1 (0.7%)	28 (19.0%)	4 (2.7%)	1 (0.7%)	113 (76.9%)	147
Dark, Illuminated	4 (0.5%)	171 (22.5%)	21 (2.8%)	16 (2.1%)	547 (72.1%)	759
Total	48 (1.3%)	806 (21.5%)	105 (2.8%)	50 (1.3%)	2733 (73.0%)	3742

Table B-2 – Distribution of “Work Zone Crash Location” by “Light”

Work Zone Crash Location	**Light**			
	Daylight	Twilight	Dark, Illuminated	**Total**
Advance Warning Area	43 (89.6%)	1 (2.0%)	4 (8.3%)	48
Transition Area	607 (75.3%)	28 (3.5%)	171 (21.2%)	806
Activity Area	80 (76.2%)	4 (3.8%)	21 (20.0%)	105
Termination Area	33 (66.0%)	1 (2.1%)	16 (32.0%)	50
Other Work Zone Area	2073 (75.9%)	113 (4.1%)	547 (20.0%)	2733
Total	2836 (75.8%)	147 (3.9%)	759 (20.3%)	3742

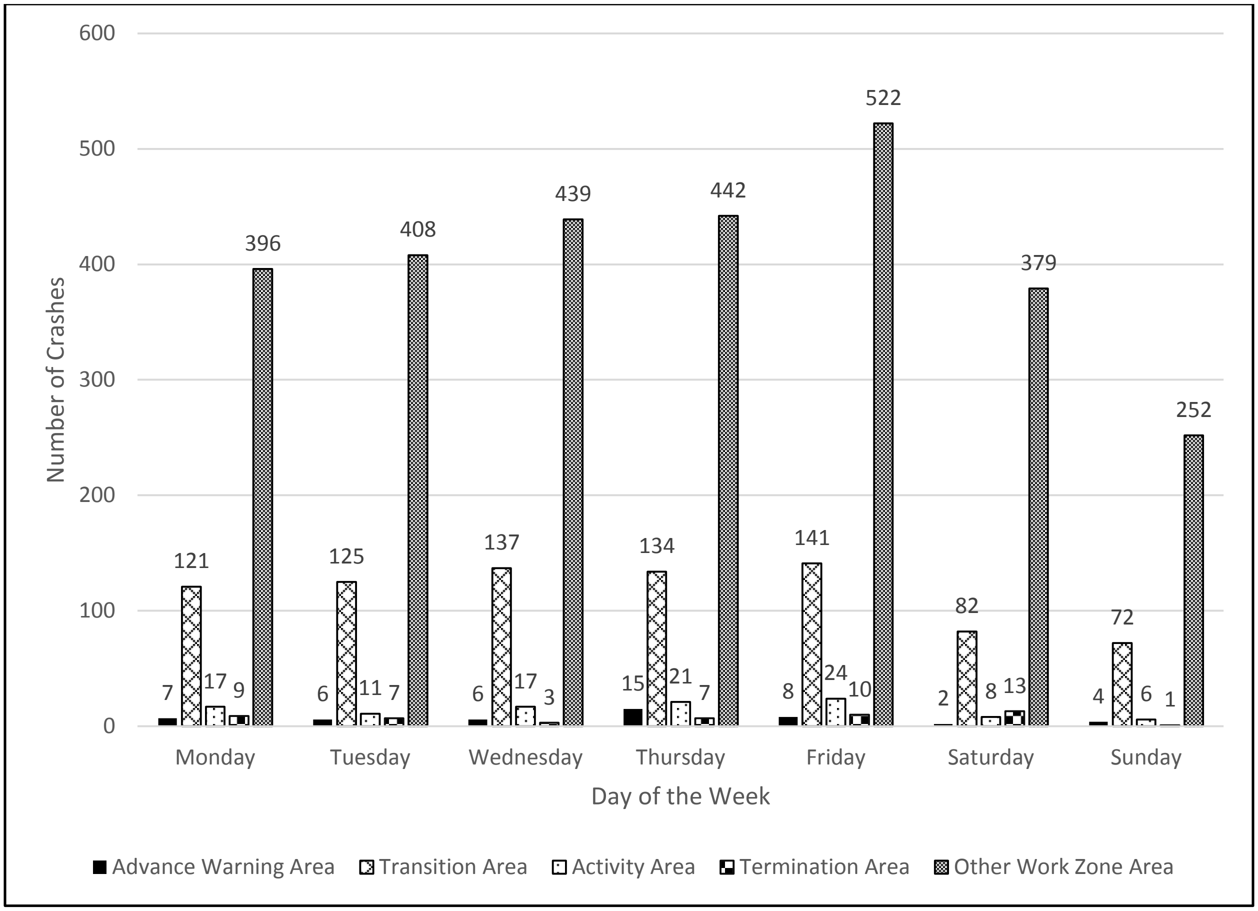

Figure B-2 – Distribution of “Day of the Week” by “Work Zone Crash Location”

Table B-3 – Distribution of “Day of the Week” by “Work Zone Crash Location”

Day of the Week	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Monday	7 (1.3%)	121 (22.0%)	17 (3.1%)	9 (1.6%)	396 (72.0%)	550
Tuesday	6 (1.1%)	125 (22.4%)	11 (2.0%)	7 (1.3%)	408 (73.2%)	557
Wednesday	6 (1.0%)	137 (22.8%)	17 (2.8%)	3 (0.5%)	439 (72.9%)	602
Thursday	15 (2.4%)	134 (21.6%)	21 (3.4%)	7 (1.1%)	442 (71.4%)	619
Friday	8 (1.1%)	141 (20.0%)	24 (3.4%)	10 (1.4%)	522 (74.0%)	705
Saturday	2 (0.4%)	82 (16.9%)	8 (1.7%)	13 (2.7%)	379 (78.3%)	484
Sunday	4 (1.2%)	72 (21.5%)	6 (1.8%)	1 (0.3%)	252 (75.2%)	335
Total	48 (1.2%)	812 (21.1%)	104 (2.7%)	50 (1.3%)	2838 (73.7%)	3852

Table B-4 – Distribution of “Work Zone Crash Location” by “Day of the Week”

Work Zone Crash Location	**Day of the Week**							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	**Total**
Advance Warning Area	7 (14.6%)	6 (12.5%)	6 (12.5%)	15 (31.2%)	8 (16.7%)	2 (4.2%)	4 (8.3%)	48
Transition Area	121 (14.9%)	125 (15.4%)	137 (16.9%)	134 (16.5%)	141 (17.4%)	82 (10.1%)	72 (8.9%)	812
Activity Area	17 (16.3%)	11 (10.6%)	17 (16.3%)	21 (20.2%)	24 (23.1%)	8 (7.7%)	6 (5.8%)	104
Termination Area	9 (18.0%)	7 (14.0%)	3 (6.0%)	7 (14.0%)	10 (20.0%)	13 (26.0%)	1 (2.0%)	50
Other Work Zone Area	396 (14.0%)	408 (14.4%)	439 (15.5%)	442 (15.6%)	522 (18.4%)	379 (13.4%)	252 (8.9%)	2838
Total	550 (14.3%)	557 (14.5%)	602 (15.6%)	619 (16.1%)	705 (18.3%)	484 (12.6%)	335 (8.7%)	3852

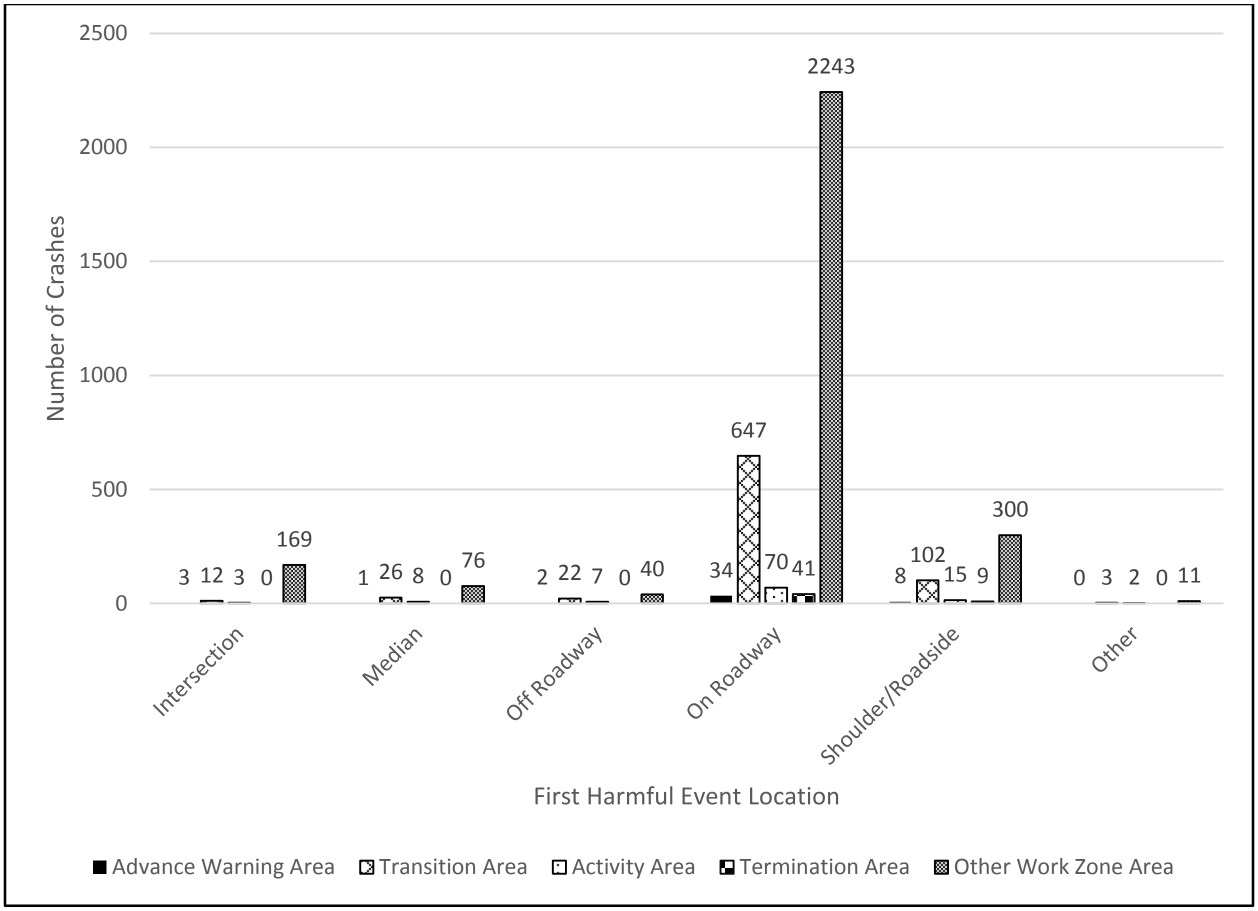

Figure B-3 – Distribution of “First Harmful Event Location” by “Work Zone Crash Location”

Table B-5 – Distribution of "First Harmful Event Location" by "Work Zone Crash Location"

First Harmful Event Location	Work Zone Crash Location					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Intersection	3 (1.6%)	12 (6.4%)	3 (1.6%)	0 (0%)	169 (90.4%)	187
Median	1 (0.9%)	26 (23.4%)	8 (7.2%)	0 (0%)	76 (68.5%)	111
Off Roadway	2 (2.8%)	22 (31.0%)	7 (9.9%)	0 (0%)	40 (56.3%)	71
On Roadway	34 (1.1%)	647 (21.3%)	70 (2.3%)	41 (1.4%)	2243 (73.9%)	3035
Shoulder/Roadside	8 (1.8%)	102 (23.5%)	15 (3.5%)	9 (2.1%)	300 (69.1%)	434
Other	0 (0%)	3 (18.8%)	2 (12.5%)	0 (0%)	11 (68.8%)	16
Total	48 (1.2%)	812 (21.1%)	105 (2.7%)	50 (1.3%)	2839 (73.7%)	3854

Table B-6 – Distribution of "Work Zone Crash Location" by "First Harmful Event Location"

Work Zone Crash Location	First Harmful Event Location						
	Intersection	Median	Off Roadway	On Roadway	Shoulder/ Roadside	Other	**Total**
Advance Warning Area	3 (6.2%)	1 (2.1%)	2 (4.2%)	34 (70.8%)	8 (16.7%)	0 (0%)	48
Transition Area	12 (1.5%)	26 (3.2%)	22 (2.7%)	647 (79.7%)	102 (12.6%)	3 (0.4%)	812
Activity Area	3 (2.9%)	8 (7.6%)	7 (6.7%)	70 (66.7%)	15 (14.3%)	2 (1.9%)	105
Termination Area	0 (0%)	0 (0%)	0 (0%)	41 (82.0%)	9 (18.0%)	0 (0%)	50
Other Work Zone Area	169 (6.0%)	76 (2.7%)	40 (1.4%)	2243 (79.0%)	300 (10.6%)	11 (0.4%)	2839
Total	187 (4.9%)	111 (2.9%)	71 (1.8%)	3035 (78.7%)	434 (11.3%)	16 (0.4%)	3854

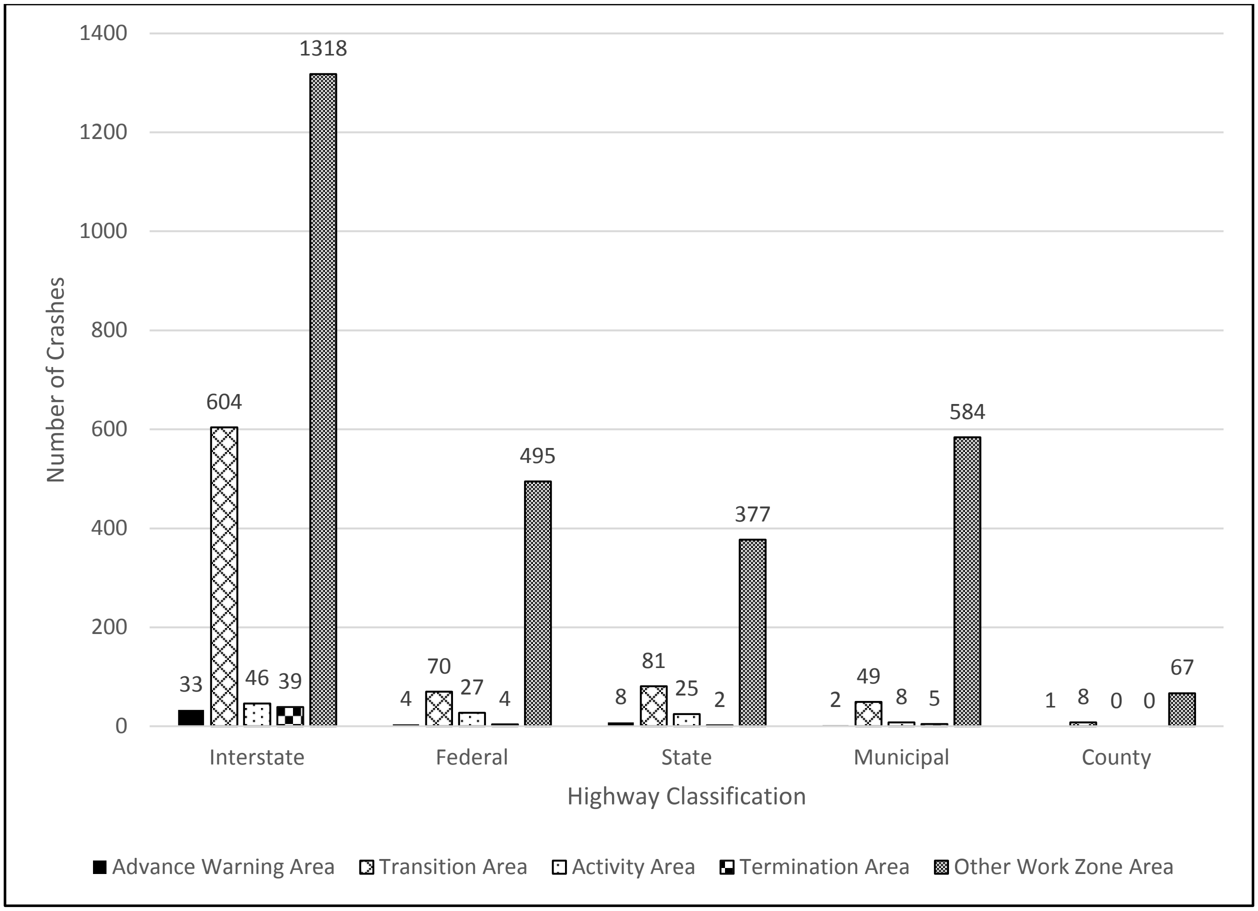

Figure B-4 – Distribution of "Highway Classification" by "Work Zone Crash Location"

Table B-7 – Distribution of "Highway Classification" by "Work Zone Crash Location"

Highway Classification	Work Zone Crash Location					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Interstate	33 (1.6%)	604 (29.6%)	46 (2.3%)	39 (1.9%)	1318 (64.6%)	2040
Federal	4 (0.7%)	70 (11.7%)	27 (4.5%)	4 (0.7%)	495 (82.5%)	600
State	8 (1.6%)	81 (16.4%)	25 (5.1%)	2 (0.4%)	377 (76.5%)	493
Municipal	2 (0.3%)	49 (7.6%)	8 (1.2%)	5 (0.8%)	584 (90.1%)	648
County	1 (1.3%)	8 (10.5%)	0 (0%)	0 (0%)	67 (88.2%)	76
Total	48 (1.2%)	812 (21.1%)	106 (2.7%)	50 (1.3%)	2841 (73.7%)	3857

Table B-8 – Distribution of "Work Zone Crash Location" by "Highway Classification"

Work Zone Crash Location	Highway Classification					
	Interstate	Federal	State	Municipal	County	**Total**
Advance Warning Area	33 (68.8%)	4 (8.3%)	8 (16.7%)	2 (4.2%)	1 (2.1%)	48
Transition Area	604 (74.4%)	70 (8.6%)	81 (10.0%)	49 (6.0%)	8 (1.0%)	812
Activity Area	46 (43.4%)	27 (25.5%)	25 (23.6%)	8 (7.5%)	0 (0%)	106
Termination Area	39 (78.0%)	4 (8.3%)	2 (4.0%)	5 (10.0%)	0 (0%)	50
Other Work Zone Area	1318 (46.4%)	495 (17.4%)	377 (13.3%)	584 (20.6%)	67 (2.4%)	2841
Total	2040 (52.9%)	600 (15.6%)	493 (12.8%)	648 (16.8%)	76 (2.0%)	3857

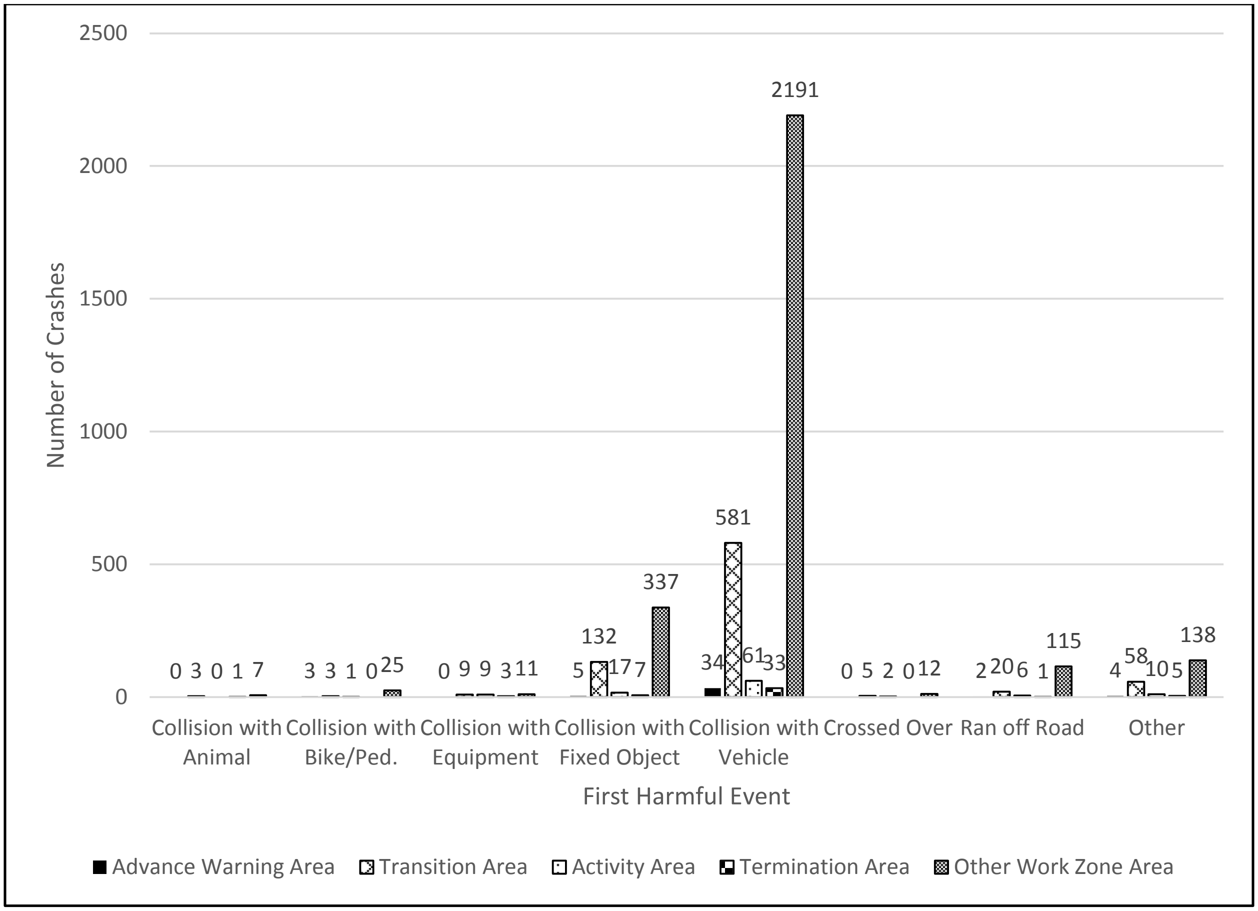

Figure B-5 – Distribution of “First Harmful Event” by “Work Zone Crash Location”

Table B-9 – Distribution of “First Harmful Event” by “Work Zone Crash Location”

First Harmful Event	Work Zone Crash Location					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Coll. with Animal	0 (0%)	3 (27.3%)	0 (0%)	1 (9.1%)	7 (63.6%)	11
Coll. with Bike/Ped.	3 (9.4%)	3 (9.4%)	1 (3.1%)	0 (0%)	25 (78.1%)	32
Coll. with Equipment	0 (0%)	9 (28.1%)	9 (28.1%)	3 (9.4%)	11 (34.4%)	32
Coll. with Fixed Object	5 (1.0%)	132 (26.5%)	17 (3.4%)	7 (1.4%)	337 (67.7%)	498
Coll. with Vehicle	34 (1.2%)	581 (20.0%)	61 (2.1%)	33 (1.1%)	2191 (75.6%)	2900
Crossed Over	0 (0%)	5 (26.3%)	2 (10.5%)	0 (0%)	12 (63.2%)	19
Ran off Road	2 (1.4%)	20 (13.9%)	6 (4.2%)	1 (0.7%)	115 (79.9%)	144
Other	4 (1.9%)	58 (27.0%)	10 (4.7%)	5 (2.3%)	138 (64.2%)	215
Total	48 (1.2%)	811 (21.1%)	106 (2.8%)	50 (1.3%)	2836 (73.6%)	3851

Table B-10 – Distribution of “Work Zone Crash Location” by “First Harmful Event”

Work Zone Crash Location	First Harmful Event								
	Coll. with Animal	Coll. with Bike/Ped.	Coll. with Equipment	Coll. with Fixed Object	Coll. with Vehicle	Crossed Over	Ran off Road	Other	**Total**
Advance Warning Area	0 (0%)	3 (6.2%)	0 (0%)	5 (10.4%)	34 (70.8%)	0 (0%)	2 (4.2%)	4 (8.3%)	48
Transition Area	3 (0.4%)	3 (0.4%)	9 (1.1%)	132 (16.3%)	581 (71.6%)	5 (0.6%)	20 (2.5%)	58 (7.2%)	811
Activity Area	0 (0%)	1 (0.9%)	9 (8.5%)	17 (16.0%)	61 (57.5%)	2 (1.9%)	6 (5.7%)	10 (9.4%)	106
Termination Area	1 (2.0%)	0 (0%)	3 (6.0%)	7 (14.0%)	33 (66.0%)	0 (0%)	1 (2.0%)	5 (10.0%)	50
Other Work Zone Area	7 (0.2%)	25 (0.9%)	11 (0.4%)	337 (11.9%)	2191 (77.3%)	12 (0.4%)	115 (4.1%)	138 (4.9%)	2836
Total	11 (0.3%)	32 (0.8%)	32 (0.8%)	498 (12.9%)	2900 (75.3%)	19 (0.5%)	144 (3.7%)	215 (5.6%)	3851

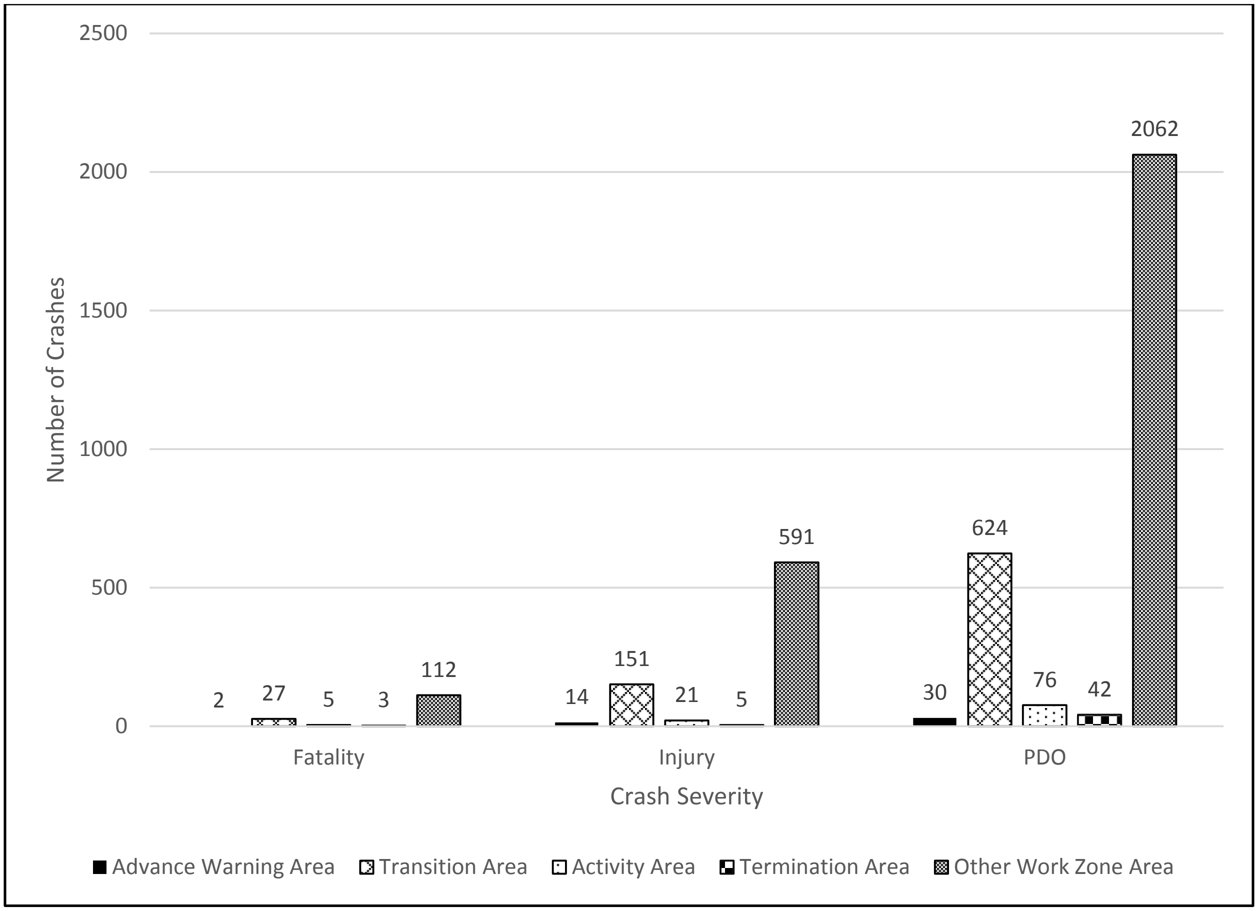

Figure B-6 – Distribution of “Crash Severity” by “Work Zone Crash Location”

Table B-11 – Distribution of "Crash Severity" by "Work Zone Crash Location"

Crash Severity	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Fatality	2 (1.3%)	27 (18.1%)	5 (3.4%)	3 (2.0%)	112 (75.2%)	149
Injury	14 (1.8%)	151 (19.3%)	21 (2.7%)	5 (0.6%)	591 (75.6%)	782
PDO	30 (1.1%)	624 (22.0%)	76 (2.7%)	42 (1.5%)	2062 (72.8%)	2834
Total	46 (1.2%)	802 (21.3%)	102 (2.7%)	50 (1.3%)	2765 (73.4%)	3765

Table B-12 – Distribution of "Work Zone Crash Location" by "Crash Severity"

Work Zone Crash Location	**Crash Severity**			
	Fatality	Injury	PDO	**Total**
Advance Warning Area	2 (4.3%)	14 (30.4%)	30 (65.2%)	46
Transition Area	27 (3.4%)	151 (18.8%)	624 (77.8%)	802
Activity Area	5 (4.9%)	21 (20.6%)	76 (74.5%)	102
Termination Area	3 (6.0%)	5 (10.0%)	42 (84.0%)	50
Other Work Zone Area	112 (4.1%)	591 (21.4%)	2062 (74.6%)	2765
Total	149 (4.0%)	782 (20.8%)	2834 (75.3%)	3765

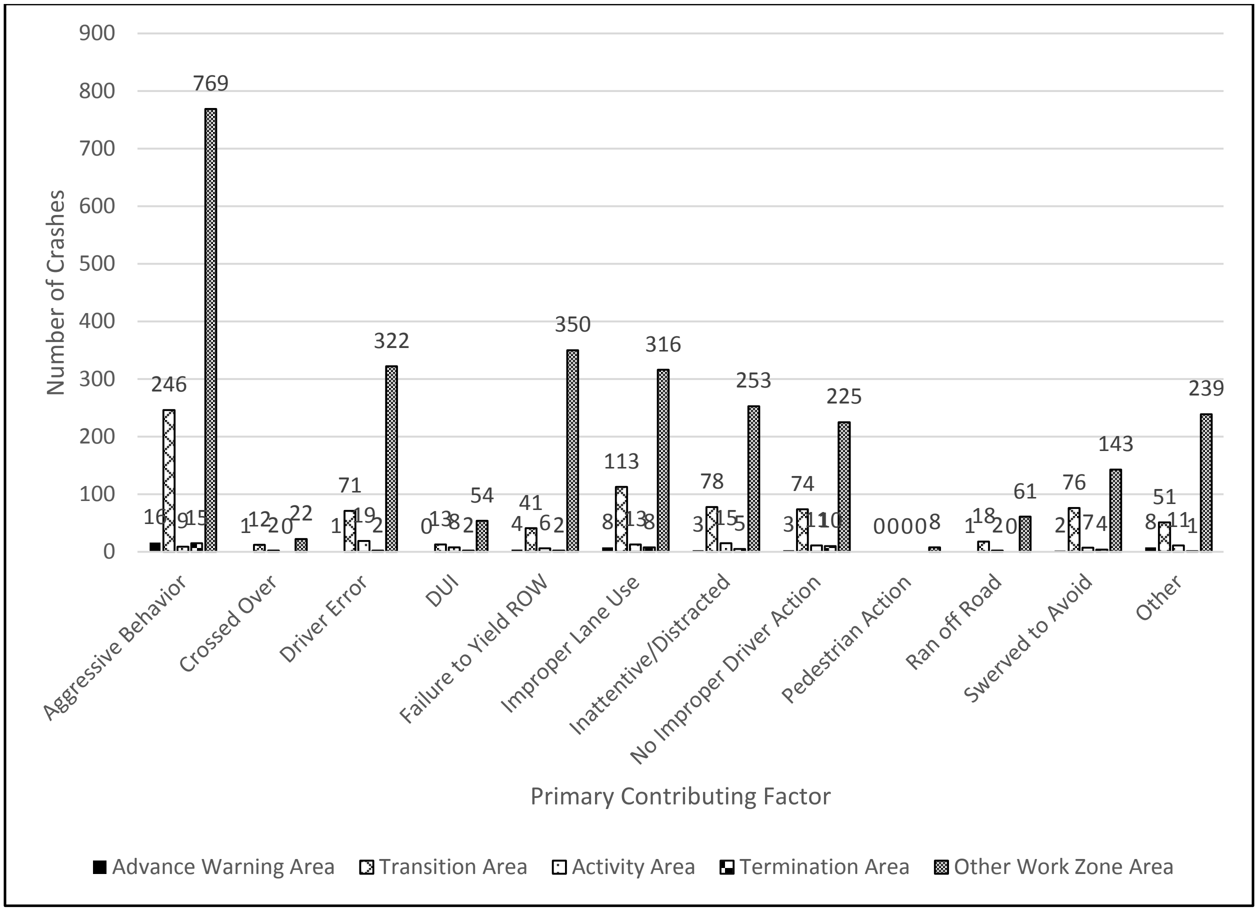

Figure B-7 – Distribution of “Primary Contributing Factor” by “Work Zone Crash Location”

Table B-13 – Distribution of "Primary Contributing Factor" by "Work Zone Crash Location"

Primary Contributing Factor	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Aggressive Behavior	16 (1.5%)	246 (23.3%)	9 (0.9%)	15 (1.4%)	769 (72.9%)	1055
Crossed Over	1 (2.7%)	12 (32.4%)	2 (5.4%)	0 (0%)	22 (59.5%)	37
Driver Error	1 (0.2%)	71 (17.1%)	19 (4.6%)	2 (0.5%)	322 (77.6%)	415
DUI	0 (0%)	13 (16.9%)	8 (10.4%)	2 (2.6%)	54 (70.1%)	77
Failure to Yield ROW	4 (1.0%)	41 (10.2%)	6 (1.5%)	2 (0.5%)	350 (86.8%)	403
Improper Lane Use	8 (1.7%)	113 (24.7%)	13 (2.8%)	8 (1.7%)	316 (69.0%)	458
Inattentive/Distracted	3 (0.8%)	78 (22.0%)	15 (4.2%)	5 (1.4%)	253 (71.5%)	354
No Improper Driver Action	3 (0.9%)	74 (22.9%)	11 (3.4%)	10 (3.1%)	225 (69.7%)	323
Pedestrian Action	0 (0%)	0 (0%)	0 (0%)	0 (0%)	8 (100%)	8
Ran off Road	1 (1.2%)	18 (22.0%)	2 (2.4%)	0 (0%)	61 (74.4%)	82
Swerved to Avoid	2 (0.9%)	76 (32.8%)	7 (3.0%)	4 (1.7%)	143 (61.6%)	232
Other	8 (2.6%)	51 (16.5%)	11 (3.5%)	1 (0.3%)	239 (77.1%)	310
Total	47 (1.3%)	793 (21.1%)	103 (2.7%)	49 (1.3%)	2762 (73.6%)	3754

Table B-14 – Distribution of "Work Zone Crash Location" by "Primary Contributing Factor"

Work Zone Crash Location	**Primary Contributing Factor**												
	Aggressive Behavior	Crossed Over	Driver Error	DUI	Failure to Yield ROW	Improper Lane Use	Inattentive/Distracted	No Improper Driver Action	Pedestrian Action	Ran off Road	Swerved to Avoid	Other	**Total**
Advance Warning Area	16 (34.0%)	1 (2.1%)	1 (2.1%)	0 (0%)	4 (8.5%)	8 (17.0%)	3 (6.4%)	3 (6.4%)	0 (0%)	1 (2.1%)	2 (4.3%)	8 (17.0%)	47
Transition Area	246 (31.0%)	12 (1.5%)	71 (9.0%)	13 (1.6%)	41 (5.2%)	113 (14.2%)	78 (9.8%)	74 (9.3%)	0 (0%)	18 (2.3%)	76 (9.6%)	51 (6.4%)	793
Activity Area	9 (8.7%)	2 (1.9%)	19 (18.4%)	8 (7.8%)	6 (5.8%)	13 (12.6%)	15 (14.6%)	11 (10.7%)	0 (0%)	2 (1.9%)	7 (6.8%)	11 (10.7%)	103
Termination Area	15 (30.6%)	0 (0%)	2 (4.1%)	2 (4.1%)	2 (4.1%)	8 (17.0%)	5 (10.2%)	10 (20.4%)	0 (0%)	0 (0%)	4 (8.2%)	1 (2.0%)	49
Other Work Zone Area	769 (27.8%)	22 (0.8%)	322 (11.7%)	54 (2.0%)	350 (12.7%)	316 (11.4%)	253 (9.2%)	225 (8.1%)	8 (0.3%)	61 (2.2%)	143 (5.2%)	239 (8.7%)	2762
Total	1055 (28.1%)	37 (1.0%)	415 (11.1%)	77 (2.1%)	403 (10.7%)	458 (12.2%)	354 (9.4%)	323 (8.6%)	8 (0.2%)	82 (2.2%)	232 (6.2%)	310 (8.3%)	3754

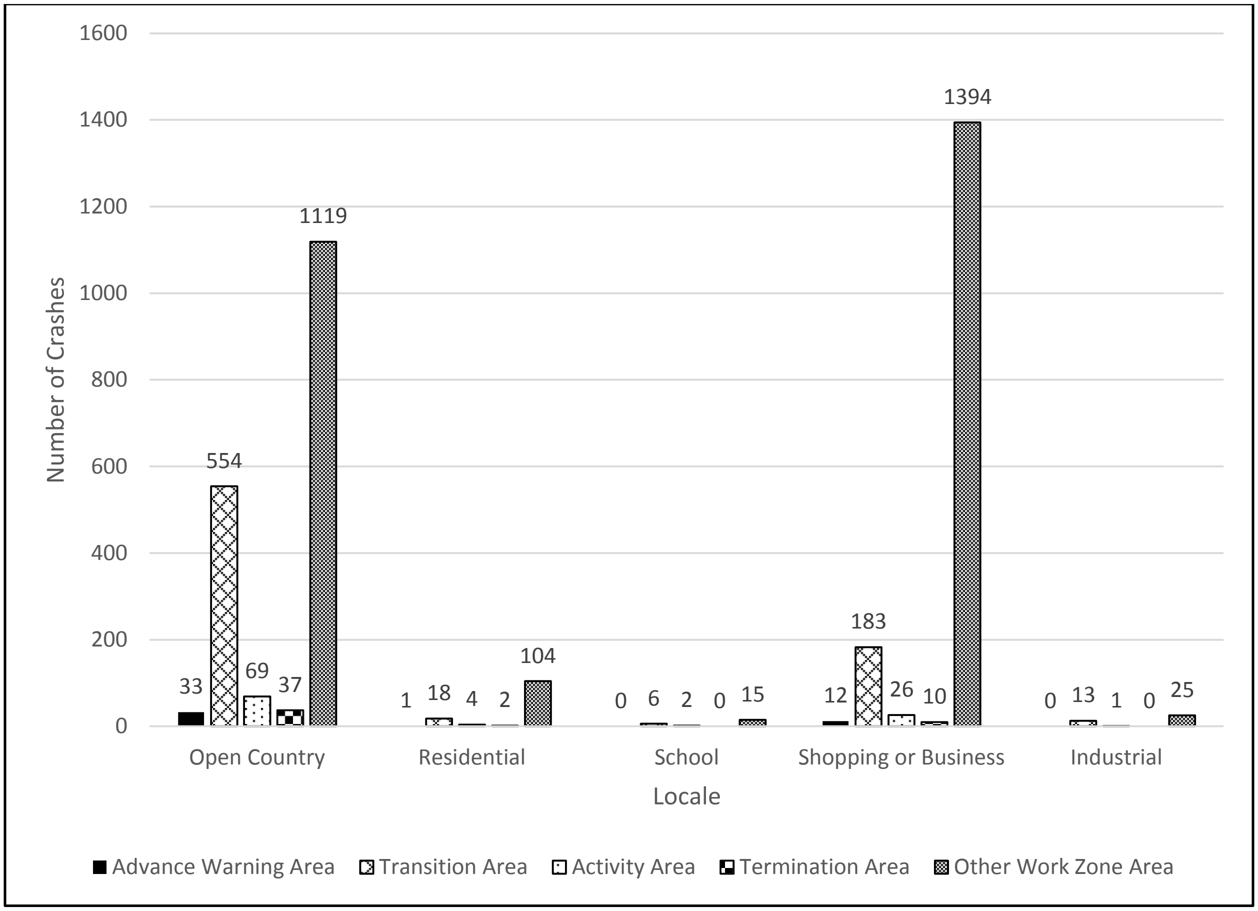

Figure B-8 – Distribution of “Locale” by “Work Zone Crash Location”

Table B-15 – Distribution of "Locale" by "Work Zone Crash Location"

Locale	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Open Country	33 (1.8%)	554 (30.6%)	69 (3.8%)	37 (2.0%)	1119 (61.8%)	1812
Residential	1 (0.8%)	18 (14.0%)	4 (3.1%)	2 (1.6%)	104 (80.6%)	129
School	0 (0%)	6 (26.1%)	2 (8.7%)	0 (0%)	15 (65.2%)	23
Shopping or Business	12 (0.7%)	183 (11.3%)	26 (1.6%)	10 (0.6%)	1394 (85.8%)	1625
Industrial	0 (0%)	13 (33.3%)	1 (2.6%)	0 (0%)	25 (64.1%)	39
Total	46 (1.3%)	774 (21.3%)	102 (2.8%)	49 (1.4%)	2657 (73.2%)	3628

Table B-16 – Distribution of "Work Zone Crash Location" by "Locale"

Work Zone Crash Location	**Locale**					
	Open Country	Residential	School	Shopping or Business	Industrial	**Total**
Advance Warning Area	33 (71.7%)	1 (2.2%)	0 (0%)	12 (26.1%)	0 (0%)	46
Transition Area	554 (71.6%)	18 (2.3%)	6 (0.8%)	183 (23.6%)	13 (1.7%)	774
Activity Area	69 (67.6%)	4 (3.9%)	2 (2.0%)	26 (25.5%)	1 (1.0%)	102
Termination Area	37 (75.5%)	2 (4.1%)	0 (0%)	10 (20.4%)	0 (0%)	49
Other Work Zone Area	1119 (42.1%)	104 (3.9%)	15 (0.6%)	1394 (52.5%)	25 (0.9%)	2657
Total	1812 (49.9%)	129 (3.6%)	23 (0.6%)	1625 (44.8%)	39 (1.1%)	3628

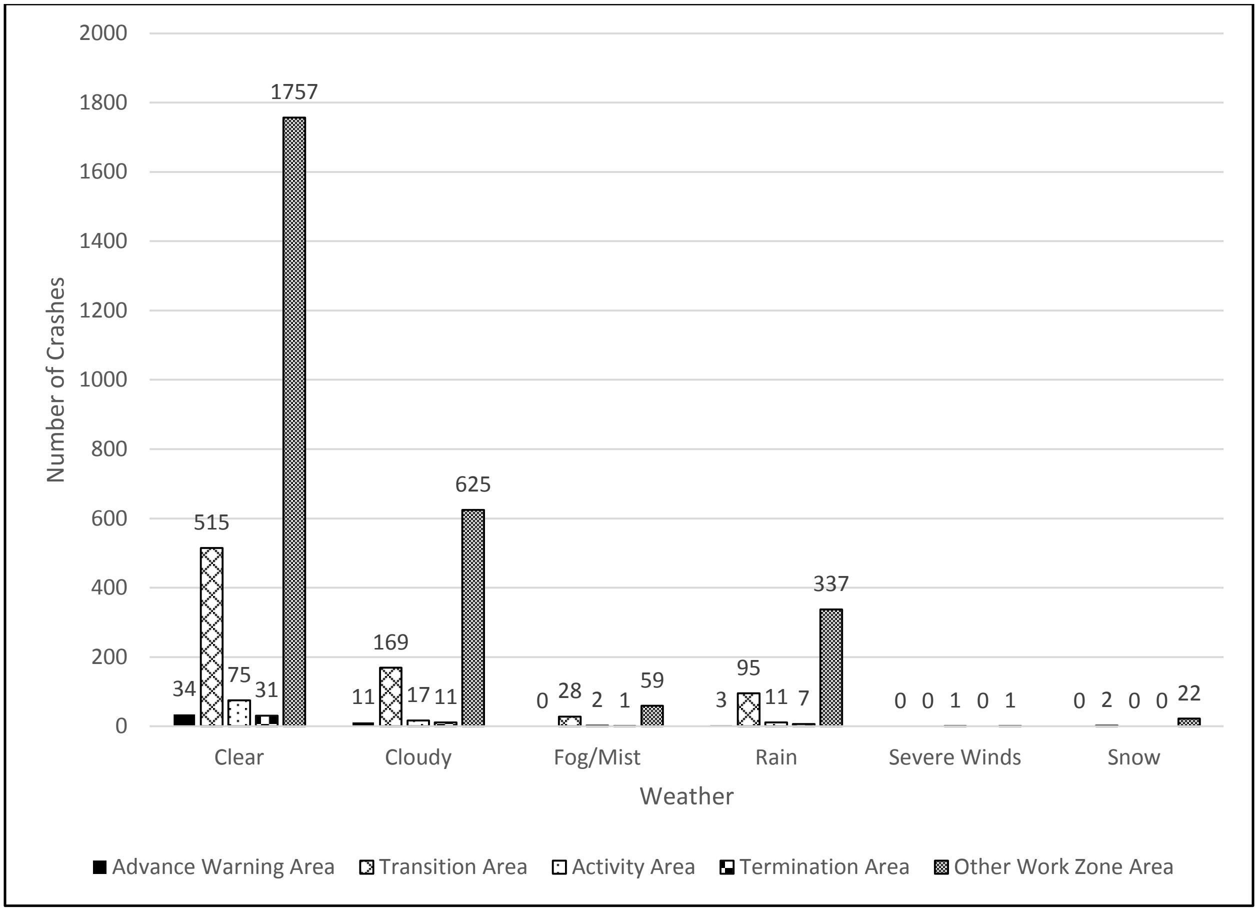

Figure B-9 – Distribution of “Weather” by “Work Zone Crash Location”

Table B-17 – Distribution of "Weather" by "Work Zone Crash Location"

Weather	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Clear	34 (1.4%)	515 (21.4%)	75 (3.1%)	31 (1.3%)	1757 (72.8%)	2412
Cloudy	11 (1.3%)	169 (20.3%)	17 (2.0%)	11 (1.3%)	625 (75.0%)	833
Fog/Mist	0 (0%)	28 (31.1%)	2 (2.2%)	1 (1.1%)	59 (65.6%)	90
Rain	3 (0.7%)	95 (21.0%)	11 (2.4%)	7 (1.5%)	337 (74.4%)	453
Severe Winds	0 (0%)	0 (0%)	1 (50%)	0 (0%)	1 (50%)	2
Snow	0 (0%)	2 (8.3%)	0 (0%)	0 (0%)	22 (91.7%)	24
Total	48 (1.3%)	809 (21.2%)	106 (2.8%)	50 (1.3%)	2801 (73.4%)	3814

Table B-18 – Distribution of "Work Zone Crash Location" by "Weather"

Work Zone Crash Location	**Locale**						
	Clear	Cloudy	Fog/Mist	Rain	Severe Winds	Snow	**Total**
Advance Warning Area	34 (70.8%)	11 (22.9%)	0 (0%)	3 (6.2%)	0 (0%)	0 (0%)	48
Transition Area	515 (63.7%)	169 (20.9%)	28 (3.5%)	95 (11.7%)	0 (0%)	2 (0.2%)	809
Activity Area	75 (70.8%)	17 (16.0%)	2 (1.9%)	11 (10.4%)	1 (0.9%)	0 (0%)	106
Termination Area	31 (62.0%)	11 (22.0%)	1 (2.0%)	7 (14.0%)	0 (0%)	0 (0%)	50
Other Work Zone Area	1757 (62.7%)	625 (22.3%)	59 (2.1%)	337 (12.0%)	1 (0%)	22 (0.8%)	2801
Total	2412 (63.2%)	833 (21.8%)	90 (2.4%)	453 (11.9%)	2 (0.1%)	24 (0.6%)	3814

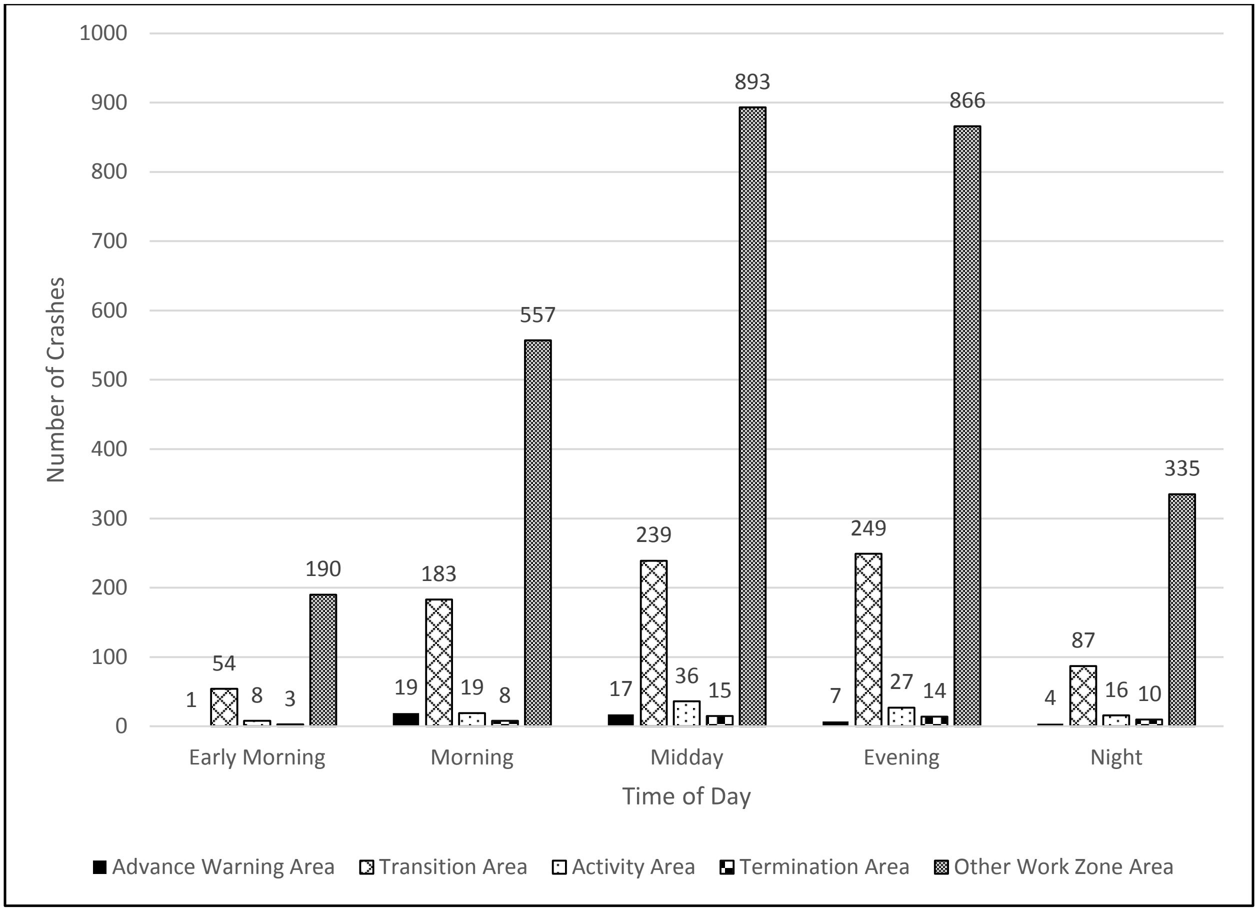

Figure B-10 – Distribution of “Time of Day” by “Work Zone Crash Location”

Table B-19 – Distribution of "Time of Day" by "Work Zone Crash Location"

Time of Day	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Early Morning	1 (0.4%)	54 (21.1%)	8 (3.1%)	3 (1.2%)	190 (74.2%)	256
Morning	19 (2.4%)	183 (23.3%)	19 (2.4%)	8 (1.0%)	557 (70.9%)	786
Midday	17 (1.4%)	239 (19.9%)	36 (3.0%)	15 (1.2%)	893 (74.4%)	1200
Evening	7 (0.6%)	249 (21.4%)	27 (2.3%)	14 (1.2%)	866 (74.5%)	1163
Night	4 (0.9%)	87 (19.2%)	16 (3.5%)	10 (2.2%)	335 (74.1%)	452
Total	48 (1.2%)	812 (21.1%)	106 (2.7%)	50 (1.3%)	2841 (73.7%)	3857

Table B-20 – Distribution of "Work Zone Crash Location" by "Time of Day"

Work Zone Crash Location	**Time of Day**					
	Early Morning	Morning	Midday	Evening	Night	**Total**
Advance Warning Area	1 (2.1%)	19 (2.4%)	17 (35.4%)	7 (14.6%)	4 (8.3%)	48
Transition Area	54 (6.7%)	183 (22.5%)	239 (29.4%)	249 (30.7%)	87 (10.7%)	812
Activity Area	8 (7.5%)	19 (17.9%)	36 (34.0%)	27 (25.5%)	16 (15.1%)	106
Termination Area	3 (6.0%)	8 (16.0%)	15 (30.0%)	14 (28.0%)	10 (20.0%)	50
Other Work Zone Area	190 (6.7%)	557 (19.6%)	893 (31.4%)	866 (30.5%)	335 (11.8%)	2841
Total	256 (6.6%)	786 (20.4%)	1200 (31.1%)	1163 (30.2%)	452 (11.7%)	3857

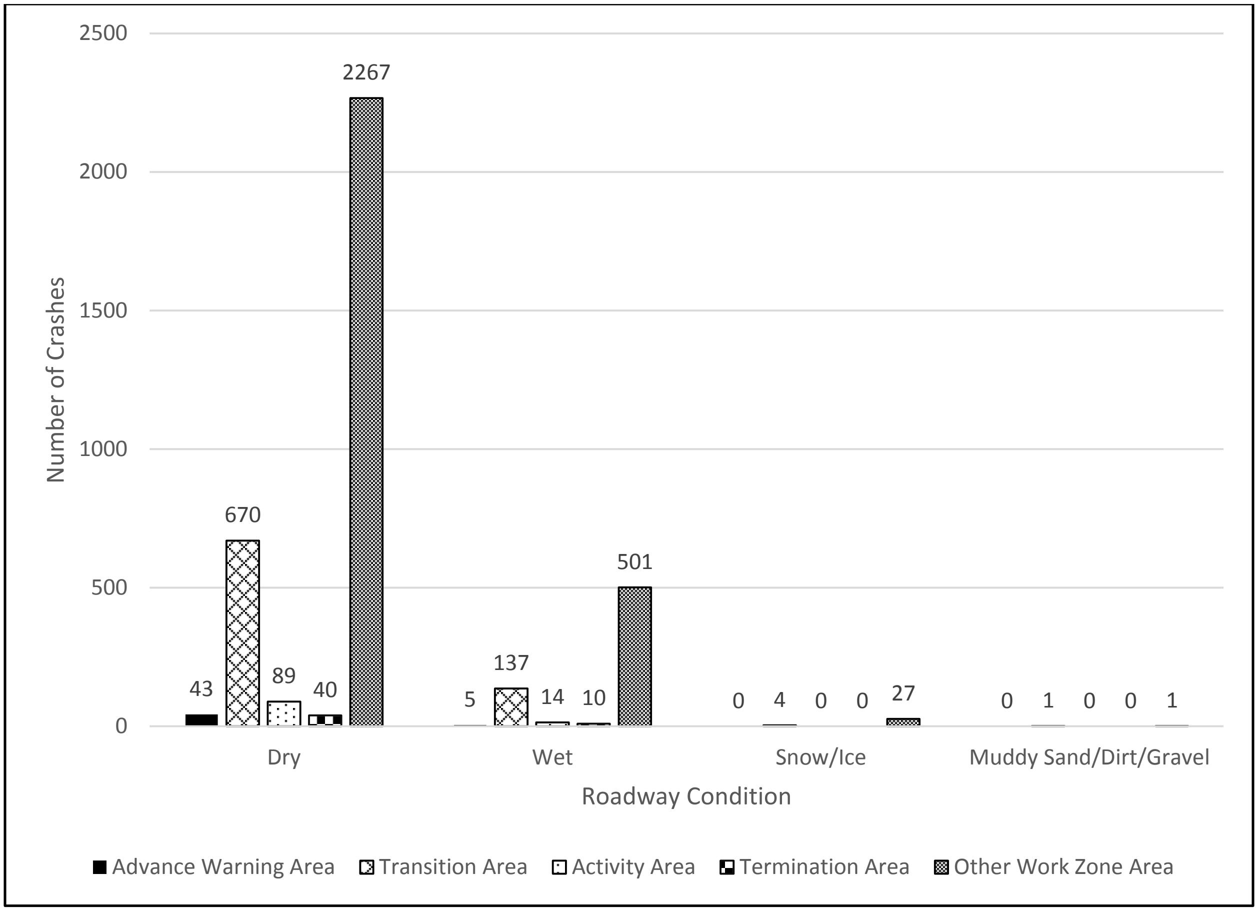

Figure B-11 – Distribution of “Roadway Condition” by “Work Zone Crash Location”

Table B-21 – Distribution of "Roadway Condition" by "Work Zone Crash Location"

Roadway Condition	**Work Zone Crash Location**					
	Advance Warning Area	Transition Area	Activity Area	Termination Area	Other Work Zone Area	**Total**
Dry	43 (1.4%)	670 (21.6%)	89 (2.9%)	40 (1.3%)	2267 (72.9%)	3109
Wet	5 (0.7%)	137 (20.5%)	14 (2.1%)	10 (1.5%)	501 (75.1%)	667
Snow/Ice	0 (0%)	4 (12.9%)	0 (0%)	0 (0%)	27 (87.1%)	31
Muddy Sand/ Dirt/Gravel	0 (0%)	1 (50%)	0 (0%)	0 (0%)	1 (50%)	2
Total	48 (1.3%)	812 (21.3%)	103 (2.7%)	50 (1.3%)	2796 (73.4%)	3809

Table B-22 – Distribution of "Work Zone Crash Location" by "Roadway Condition"

Work Zone Crash Location	**Roadway Condition**				
	Dry	Wet	Snow/Ice	Muddy Sand/ Dirt/Gravel	**Total**
Advance Warning Area	43 (89.6%)	5 (10.4%)	0 (0%)	0 (0%)	48
Transition Area	670 (82.5%)	137 (16.9%)	4 (0.5%)	1 (0.1%)	812
Activity Area	89 (86.4%)	14 (13.6%)	0 (0%)	0 (0%)	103
Termination Area	40 (80.0%)	10 (20.0%)	0 (0%)	0 (0%)	50
Other Work Zone Area	2267 (81.1%)	501 (17.9%)	27 (1.0%)	1 (<0%)	2796
Total	3109 (81.6%)	667 (17.5%)	31 (0.8%)	2 (0.1%)	3809

APPENDIX C

CATEGORY REDUCTIONS FOR APPLICABLE VARIABLES

Table C-1 – Reducing Categories within "Time of Day"

Category	New Category
12:00 am – 5:59 am	Early Morning
6:00 am – 9:59 am	Morning
10:00 am – 2:59 pm	Midday
3:00 pm – 6:59 pm	Evening
7:00 pm – 11:59 pm	Night

Table C-2 – Reducing Categories within "Primary Contributing Factor"

Category	New Category
1-DUI	DUI
2-Agressive Operation	Aggressive Behavior
3-Ran Traffic Signal	Failure to Yield ROW
4-Ran Stop Sign	Failure to Yield ROW
5-Disregarged Traffic Sign Other Than Stop Sign	Failure to Yield ROW
6-Over Speed Limit	Aggressive Behavior
7-Driving Too Fast for Conditions	Aggressive Behavior
8-Made Improper Turn	Improper Lane Use
9-Improper or No Signal	Improper Lane Use
10-Traveling Wrong Way/Wrong Side	Crossed Over
11-Crossed Centerline	Crossed Over
12-Crossed Median	Crossed Over
13-Disregarded Other Road Marking	Aggressive Behavior
14-Ran off Road	Ran Off Road
15-Followed Too Close	Aggressive Behavior
16-Swerved to Avoid Vehicle	Swerved to Avoid
17-Swerved to Avoid Object	Swerved to Avoid
18-Swerved to Avoid Non-Motorists	Swerved to Avoid
19-Swerved to Avoid Animal	Swerved to Avoid
20-Over Correcting/Over Steering	Driver Error
21-Improper Passing	Improper Lane Use
22-Improper Lane Change/Use	Improper Lane Use
23-Improper Backing	Driver Error
24-Misjudging Stopping Distance	Driver Error
25-Under Minimum Speed Limit	Improper Lane Use
26-Improper Parking/Stopped in Road	Improper Lane Use
31-Failure to Yield Right-of-Way from Traffic Signal	Failure to Yield ROW
32-Failure to Yield Right-of-Way from Stop Sign	Failure to Yield ROW
33-Failure to Yield Right-of-Way from Yield Sign	Failure to Yield ROW
34-Failure to Yield Right-of-Way Making left or U-turn	Failure to Yield ROW
35-Failure to Yield Right-of-Way Making Right Turn	Failure to Yield ROW
36-Failure to Yield Right-of-Way Making Right Turn on Red Signal	Failure to Yield ROW
37-Failure to Yield Right-of-Way from Driveway	Failure to Yield ROW
38-Failure to Yield Right-of-Way from Parked Position	Failure to Yield ROW
39-Failure to Yield Right-of-Way at Uncontrolled Intersection	Failure to Yield ROW
40-Failure to Yield Right-of-Way to Pedestrian in Crosswalk	Failure to Yield ROW

41-Other Failed to Yield explained in Narrative	Failure to Yield ROW
51-Inattentive/Distracted by Passenger	Inattentive/Distracted
52-Inattentive/Distracted by Use of Electronic Communication Device	Inattentive/Distracted
53-Inattentive/Distracted by Use of Other Electronic Device	Inattentive/Distracted
54-Inattentive/Distracted by Fallen Object	Inattentive/Distracted
55-Inattentive/Distracted by Fatigued/Asleep	Inattentive/Distracted
56-Inattentive/Distracted by Insect/Reptile	Inattentive/Distracted
57-Other Distraction inside Vehicle explained in Narrative	Inattentive/Distracted
58-Other Distraction outside the Vehicle explained in Narrative	Inattentive/Distracted
59-Other Improper Action Explained in Narrative	Inattentive/Distracted
71-No Improper Driver Action Vision Obstruction	No Improper Action
72-No Improper Driver Action Unseen Object/Person/Vehicle	No Improper Action
73-No Improper Driver Action Roadway, Sign, or Signal Defect	No Improper Action
74-No Improper Driver Action Defective Equipment	No Improper Action
75-No Improper Driver Action Improper Load/Size	No Improper Action
76-No Improper Driver Action Cargo Fell or Load Shift	No Improper Action
77-No Improper Driver Action Improper Attachment	No Improper Action
78-No Improper Driver Action Other- Described in Narrative	No Improper Action
81-Pedestrian Actions Improper Crossing	Pedestrian Actions
82-Pedestrian Actions Lying or Sitting in Roadway	Pedestrian Actions
83-Pedestrian Actions Failure to Yield the Right-of-Way	Pedestrian Actions
84-Pedestrian Actions Not Visible Explained in Narrative	Pedestrian Actions
85-Pedestrian Actions Pedestrian under the Influence	Pedestrian Actions
86-Pedestrian Actions Failure to Obey Signs, Signals, or Officer	Pedestrian Actions
87-Pedestrian Actions Wrong Side of Road	Pedestrian Actions
88-Not Applicable unit is Railroad Train	Other
97-Not Applicable	Other
98-Other Explained in Narrative	Other
99-Unknown	Other

Table C-3 – Reducing Categories within "First Harmful Event"

Category	New Category
1-Non-Collision Event: Ran off Road, Right	Ran Off Road
2-Non-Collision Event: Ran off Road, Straight	Ran Off Road
3-Non-Collision Event: Ran off Road, Left	Ran Off Road
4-Non-Collision Event: Crossed Centerline	Crossed Over
5-Non-Collision Event: Crossed Median	Crossed Over
6-Non-Collision Event: Evasive Action	Other
7-Non-Collision Event: Downhill Runaway	Other
8-Non-Collision Event: Cargo/Equipment Loss or Shift	Other
9-Non-Collision Event: Vehicle defect/Component Failure	Other
10-Non-Collision Event: Separation of Units	Other
11-Non-Collision Event: Overturn/Rollover	Other
12-Non-Collision Event: Jackknife	Other
13-Non-Collision Event: Fire/Explosion	Other
14-Non-Collision Event: Immersion	Other
15-Non-Collision Event: Non-Contact Vehicle	Other
16-Non-Collision Event: Fell/Jumped from Motor Vehicle	Other
17-Non-Collision Event: Thrown or Fallen Object	Other
18-Non-Collision Event: Re-Entering Roadway	Other
19-Other Non-Collision Event explained in Narrative	Other
20-Collision with Non-Fixed Object: Non-Motorist- Pedestrian	Collision with Bike/Ped.
21-Collision with Non-Fixed Object: Non-Motorist- Pedal cycle	Collision with Bike/Ped.
22-Collision with Non-Fixed Object: Vehicle in Traffic	Collision with Vehicle
23-Collision with Non-Fixed Object: Vehicle in/from Other Roadway	Collision with Vehicle
24-Collision with Non-Fixed Object: Parked Motor Vehicle	Collision with Vehicle
25-Collision with Non-Fixed Object: Railway Vehicle/Train	Collision with Vehicle
26-Collision with Non-Fixed Object: Animal-Deer	Collision with Animal
27-Collision with Non-Fixed Object: Animal- Farm/Ranch	Collision with Animal
28-Collision with Non-Fixed Object: Animal-Other	Collision with Animal
29-Collision with Non-Fixed Object: Struck by Falling Object	Collision with Equipment
30-Collision with Non-Fixed Object: Equipment/Maintenance	Collision with Equipment
31-Collision with Non-Fixed Object: Other explained in Narrative	Other
32- Collision with Fixed Object: Bridge Abutment/Bridge Rail	Collision with Fixed Object
33- Collision with Fixed Object: Bridge Support/Column	Collision with Fixed Object
34- Collision with Fixed Object: Overhead Object	Collision with Fixed Object
35- Collision with Fixed Object: Culvert Headwall	Collision with Fixed Object
36- Collision with Fixed Object: Ditch	Collision with Fixed Object
37- Collision with Fixed Object: Embankment	Collision with Fixed Object
38- Collision with Fixed Object: Curb/Island/Raised Median	Collision with Fixed Object
39- Collision with Fixed Object: Guardrail Face	Collision with Fixed Object
40- Collision with Fixed Object: Guardrail End	Collision with Fixed Object
41- Collision with Fixed Object: Concrete Barrier	Collision with Fixed Object
42- Collision with Fixed Object: Cable Barrier	Collision with Fixed Object
43- Collision with Fixed Object: Other Traffic Barrier	Collision with Fixed Object
44- Collision with Fixed Object: Tree	Collision with Fixed Object
45- Collision with Fixed Object: Utility Pole	Collision with Fixed Object

46- Collision with Fixed Object: Light Pole (Breakaway)	Collision with Fixed Object
47- Collision with Fixed Object: Light Pole (Non-Breakaway)	Collision with Fixed Object
48- Collision with Fixed Object: Traffic Sign Pole	Collision with Fixed Object
49- Collision with Fixed Object: Sign Post	Collision with Fixed Object
50- Collision with Fixed Object: Other Post, Pole, or Support	Collision with Fixed Object
51- Collision with Fixed Object: Fence	Collision with Fixed Object
52- Collision with Fixed Object: Mailbox	Collision with Fixed Object
53-Collision with Fixed Object: Impact Attenuator	Collision with Fixed Object
54- Collision with Fixed Object: Other explained in Narrative	Collision with Fixed Object
99-Unknown	Other

Table C-4 – Reducing Categories within "First Harmful Event Location"

Category	New Category
1-On Roadway	On Roadway
2-Shoulder	Shoulder or Roadside
3-Median	Median
4-Roadside	Shoulder or Roadside
5-Outside of Right-of-Way	Off Roadway
6-Off Roadway-Location Unknown	Off Roadway
7-In Parking Lane	Other
8-Gore	Other
9-Separator	Off Roadway
21-Intersection with Crosswalk and Pedestrian Signal	Intersection
22-Intersection with Crosswalk and No Pedestrian Signal	Intersection
23-At Intersection, No Crosswalk	Intersection
24-Non-Intersection Crosswalk	Other
25-Other Non-Intersection Explained in Narrative	Other
26-Driveway Access Crosswalk	Other
27-Sidewalk	Other
28-Off Roadway	Off Roadway
29-Not Applicable Because Unit is a Railroad Train	Other
98-Other Explain in Narrative	Other
99-Unknown	Other

Table C-5 – Reducing Categories within "Manner of Crash"

Category	New Category
1- Non-Collision	Non-Collision
2- Single Vehicle Crash	Single Vehicle Crash
3- Head-On	Head-On
4- Angle Oncoming	Opposite Direction
5- Angle Same Direction	Same Direction
6- Angle Opposite Direction	Opposite Direction
7- Rear End	Rear End
8- Side Impact Angled	Side Impact
9- Side Impact 90 degrees	Side Impact
10- Sideswipe Same Direction	Same Direction
11- Sideswipe Opposite Direction	Opposite Direction
12- Casual Vehicle Backing: Rear to Side	Causal Vehicle Backing
13- Casual Vehicle Backing: Rear to Rear	Causal Vehicle Backing
98- Other Explained in Narrative	Other
99- Unknown	Other

Table C-6 – Reducing Categories within "Roadway Condition"

Category	New Category
1- Dry	Dry
2- Wet	Wet
3- Ice	Snow/Ice
4- Snow	Snow/Ice
5- Slush	Snow/Ice
6- Muddy Sand/Dirt/Gravel	Muddy Sand/Dirt/Gravel
7- Water Buildup	Wet
97- Not Applicable	N/A
98- Other Explained in Narrative	N/A
99- Unknown	N/A

Table C-7 – Reducing Categories within "Work Zone Type"

Category	New Category
1-Major Construction Project	Major Construction Project
2-Routine Maintenance	Routine Maintenance
3-Lane Closure	Lane Shift/Closure
4-Lane Shift/Closure	Lane Shift/Closure
5-Work on Shoulder or Median	Work on Shoulder or Median
6-Intermittent or Moving Vehicle	Intermittent or Moving Vehicle
97-Not Applicable	Other
98-Other Explained in Narrative	Other

Table C-8 – Reducing Categories within "Traffic Control"

Category	New Category
1- No Control Present	No Control Present
2- Police Officer	School Zone Signs/Police Officer
3- Crossing Guard	School Zone Signs/Police Officer
4- Flag Person	Flag Person
5- School Zone Signs	School Zone Signs/Police Officer
6- Traffic Signals	Traffic Signal
7- Flashing Traffic Control Signal	Traffic Signal
8- Stop Sign	Stop or Yield Sign
9- Yield Sign	Stop or Yield Sign
10- No Passing Zone	No Passing Zone
11- Warning Sign	Warning or Work Zone Sign
12- Work zone Sign	Warning or Work Zone Sign
13- RR Gates	N/A
14- RR Signals	N/A
15- RR Stop Sign	N/A
16- RR Advanced Sign	N/A
17- RR Pavement Markings	N/A
18- RR Cross bucks	N/A
19- Pedestrian Control	School Zone Signs/Police Officer
20- Lane Control Device	Lane Control Device
97- Not Applicable	Other
98- Other	Other
99- Unknown	Other

Table C-9 – Reducing Categories within “Light”

Category	New Category
1-Daylight	Daylight
2-Dusk	Twilight
3-Dawn	Twilight
4-Dark, Roadway Lighted	Dark, Illuminated
5-Dark, Spot Illumination one side of Roadway	Dark, Illuminated
6-Dark, Spot Illumination both side of Roadway	Dark, Illuminated
7-Dark, Continuous Illumination one side of Roadway	Dark, Illuminated
8-Dark, Continuous Illumination both sides of Roadway	Dark, Illuminated
9-Dark, Unknown Roadway Lighting	N/A
97-Not Applicable	N/A
98-Other	N/A
99-Unknown	N/A

Table C-10 – Reducing Categories within “Weather”

Category	New Category
1-Clear	Clear
2-Cloudy	Cloudy
3-Fog	Fog/Mist
4-Mist	Fog/Mist
5-Rain	Rain
6- Sleet, Hail, Freezing Rain	Snow
7-Snow	Snow
8-Blowing Snow	Snow
9-Severe Winds	Severe Winds
10-Blowing Sand, Soil, Dirt	Severe Winds
98-Other Explained in Narrative	N/A
99-Unknown	N/A