A Study of Differences in Severity among Crash Types in Work Zones and between Work Zone and Non-Work Zone Crashes in Alabama

by

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ABSTRACT

Highway work zones have become a hazardous place for both construction workers and roadway users due to the increasing risk caused by maintaining and reconstructing roadways. Both the number of crashes and fatalities in the work zones in the United States have grown between years 2013 to 2016. It is necessary for transportation agencies to understand the characteristics of work zones that are related to crashes with severe injuries and figure out countermeasures to improve work zone safety. In this study, the significant differences in crash severity among different crash types in the work zones, as well as between work zone and non-work zone conditions in Alabama were investigated by using two-sample Kolmogorov-Smirnov tests (K-S test). The work zone crash data used in this study were obtained from the hardcopy crash reports by Alabama Department of Transportation (ALDOT), and the crash data in non-work zones were retrieved from the online version of the Critical Analysis Reporting Environment (CARE). The results found that single vehicle, head-on, angle oncoming, and side impact 90-degree crashes that occurred within work zones in Alabama were significantly more severe than these crash types that occurred in non-work zones; single vehicle, head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes were significantly more severe than other crash types in Alabama work zones. From the results of the comparisons, conclusions were drawn and recommendations were provided for ALDOT to identify countermeasures and devote resources to reduce severity of the crash types that should be of greatest concern.

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LIST OF ABBREVIATIONS

ALDOT	Alabama Department of Transportation
CAPS	Center for Advanced Public Safety
CARE	Critical Analysis Reporting Environment
DUI	Driver under the Influence
FHWA	Federal Highway Administration
K-S	Kolmogorov-Smirnov
MNL	Multinomial Logit
MUTCD	Manual on Uniform Traffic Control Devices
NB	Negative Binomial Regression
NIST	National Institute of Standards and Technology
OR	Odds Ratio
PDO	Property Damage Only
TTC	Temporary Traffic Control
Wald x^2	Wald Chi-Squared Value

CHAPTER ONE:
INTRODUCTION

1.1 Background

As the highway system ages, rebuilding roadway pavement and improving infrastructure have become major concerns for federal, state, and local transportation agencies. This situation means that more roadway construction as well as maintenance will be conducted, and highway capacity will decrease in work zones where the road work is taking place. As a result, construction workers and road users are being exposed to increasing volumes of traffic. Although traffic control devices such as work zone warning signs and speed reduction signs are often applied in highway work zones, there are still increasing safety considerations for the workers who are working on high-speed interstate highways.

A highway work zone is not only a hazardous place for the workers, but also for travelers. According to the statistics from Federal Highway Administration (FHWA), 96,626 crashes occurred in work zones in the nation in 2015, which is an increase of 7.8% over 2014, and 42% since 2013 (67,887 work zone crashes) (FHWA, 2017). The number of work zone fatalities in the country in 2013 was 593, which reduced from 830 in 2007 (National Work Zone Safety Information Clearinghouse, 2018). However, the trend of fatality numbers has increased since 2013. In Alabama, the number of fatalities varies more widely. It decreases dramatically from 35 in 2007 to 8 in 2009, but there is a spike in fatalities in 2015, and it is relatively consistent before and after 2015. Figure 1-1 is based on data obtained from the National Work Zone Safety Information Clearinghouse, which shows the trend of work zone fatalities in Alabama and in the U.S. from 2007 to 2016.

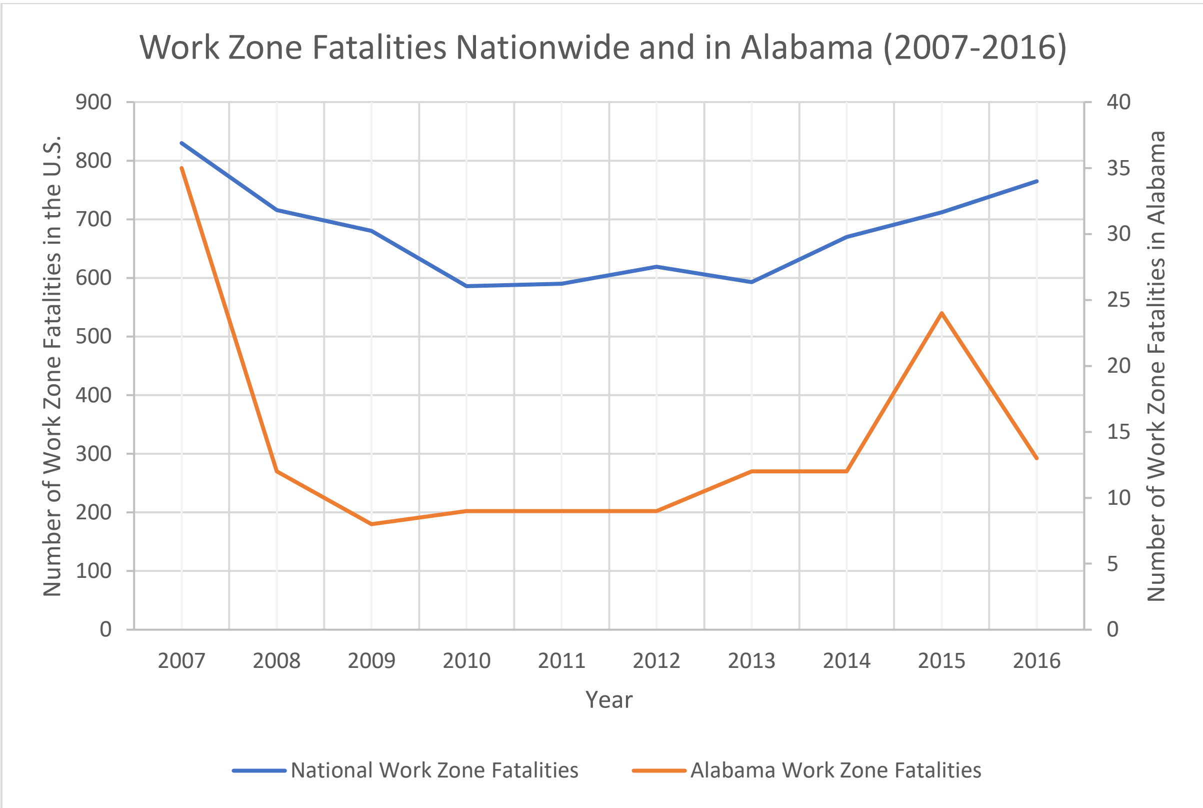

Figure 1-1: Work Zone Fatality Trend in the U.S. and in Alabama from 2007 to 2016.

According to the Alabama Department of Transportation (ALDOT), during the ten-year period from 2006 to 2015, the number of work zone injury crashes reduced slightly from 518 to 492, but the number of fatal crashes increased slightly from 29 to 31 (ALDOT, 2015). The number of work zone crashes in the state was 2,346 in 2013 (ALDOT, 2013), 2,377 in 2014 (ALDOT, 2014), and 2,435 in 2015 (ALDOT, 2015), which include 23%, 21%, and 20% of injury crashes, respectively. The proportion of fatal crashes remain the same, approximately 1% of all work zone crashes in each year. The extremely slight decrease of injury crash proportion and the stagnant number of fatal crashes indicate that no real countermeasures were efficient to improve work zone safety. This thesis will investigate the relationship between crash severity and crash types to figure out the significantly more severe crash types to be of greater concern for safety improvement.

1.2 Temporary Traffic Control (TTC) Zone

The temporary traffic control zone is one of the factors examined by reporting law enforcement officers to provide crash details when completing crash reports. The Manual on Uniform Traffic Control Devices (MUTCD) identifies a temporary traffic control zone as composed of four areas, which are the advance warning area, transition area, activity area, and termination area (Figure 1-2) (FHWA, 2009). In the advance warning area, drivers are informed of the forthcoming roadway conditions and what to expect ahead. A single sign, vehicles with flashing lights, or a series of signs are commonly used in this area. The transition area is where traffic is redirected from its normal travel path to a new path. Traffic drums and vehicle-mounted arrow boards are examples of the traffic control devices used to channelize traffic and convey relevant information. The activity area in the work zone is where road work is happening. It includes a buffer space, traffic space, and work space. The buffer space consists of longitudinal buffer space and lateral buffer space, both of which are used for protecting the traffic and workers through providing additional space to separate them. The traffic space is the roadway section that vehicles use to travel through the working area. The work space is a roadway segment that is reserved for workers, equipment, and material stockpiles. In termination area, the work zone is ended, and traffic returns to normal traveling paths.

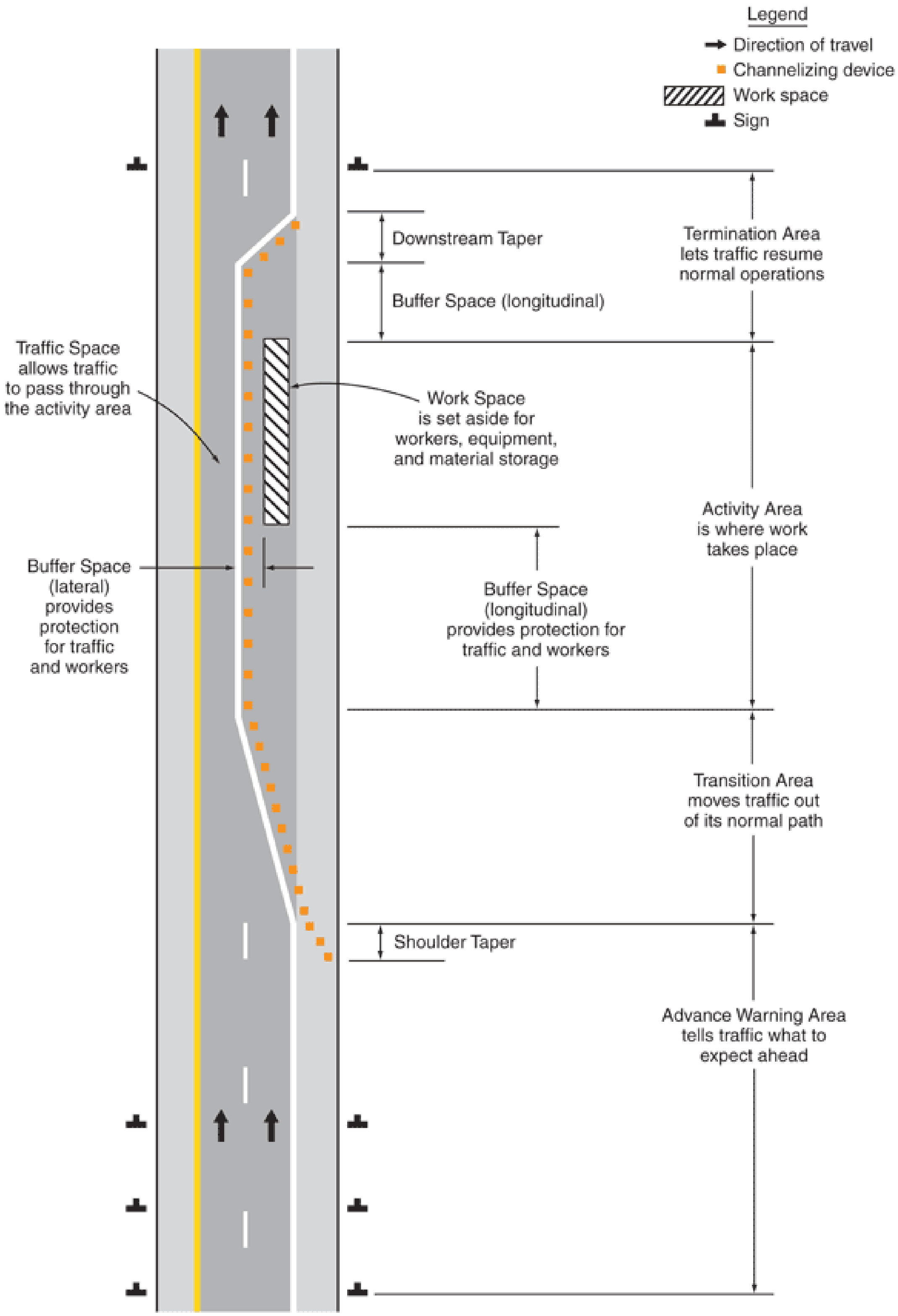

Figure 1-2: MUTCD Temporary Traffic Control Zone.

(Source: FHWA, 2009)

1.3 Crash Database

The data used in this research is the electronic database of crash reports that are identified as occurring within work zone by ALDOT, and it has 5,424 records, which include the work zone crashes in Alabama from 2007 to 2014. Some crashes were noted on crash reports that they did not occur within work zone. This is due to different judgement standards by ALDOT and the reporting law enforcement officer completing the crash report. In the judgement of the ALDOT project engineer, a crash was considered as occurring within work zone as long as there was a project ongoing managed by ALDOT. The reporting law enforcement officer may identify a work zone based on other factors, for example, if there is a construction sign that can be noticed. Because of this difference between law enforcement officers and ALDOT engineers, some work zone crashes identified by ALDOT were not considered as occurring within work zone by the reporting officers due to them not seeing any construction signs at the scene. Therefore, two datasets were created – one was the crashes deemed work zone-related by ALDOT (5,424 records), and the other was the subset that was deemed directly related to work zone by the reporting officer (2,111 records).

The data were manually entered into Excel spreadsheets and the database containing 5,424 crash records was assembled by 14 students through reviewing hardcopy crash reports completed by the reporting law enforcement officers. The database is comprised of 172 variables, including crash related information, demographic characteristics, environmental conditions, work zone information and narratives. The crash related information includes crash location, date, time, number of vehicles, contributing factors, manner of crash, crash severity, etc. The demographic characteristics are the gender, age, and race of each driver involved into the crash. Environmental conditions include weather, roadway condition, light, locale, etc. The work zone information illustrates the workers present or not, construction phase, work zone related, work zone type, etc. The narratives describe how the crashes occurred and consequence of the crash. From those variables, manner of crash (crash type) and crash severity are applied for this research.

In addition, the crash data in non-work zone are required for the proposed analysis, and the online version of the Critical Analysis Reporting Environment (CARE) is used to obtain the crash data in the entire state. CARE is a data analysis software designed by the Center for Advanced Public Safety (CAPS) at the University of Alabama for identifying problems and developing statistical analysis to deal with traffic safety-related issues (CAPS, 2018). It provides descriptive analysis, information mining, geographic information system access, roadway engineering support, and dashboard support. The statewide non-work zone number of crashes for each severity level by each type of crash from 2007 to 2014 can be found in the CARE dashboard support using the "filter variables" command.

1.4 Work Zones Crash Type and Severity

The crash types utilized in the research include non-collision, single vehicle crash, head-on, angle oncoming, angle same direction, angle opposite direction, rear-end, side impact angled, side impact 90-degree, sideswipe same direction, sideswipe opposite direction, causal vehicle backing: rear to side, causal vehicle backing: rear to rear, other types, and unknown types. These categories were the options shown on the hardcopy crash report and they were selected by the reporting law enforcement officer. Of all collision types, rear-end crashes are the most frequent type of crash occurred within work zone, caused by speeding or inattentive driving behavior (ALDOT, 2015). Figure 1-3 illustrates the geometry of crash types involving more than one vehicle.

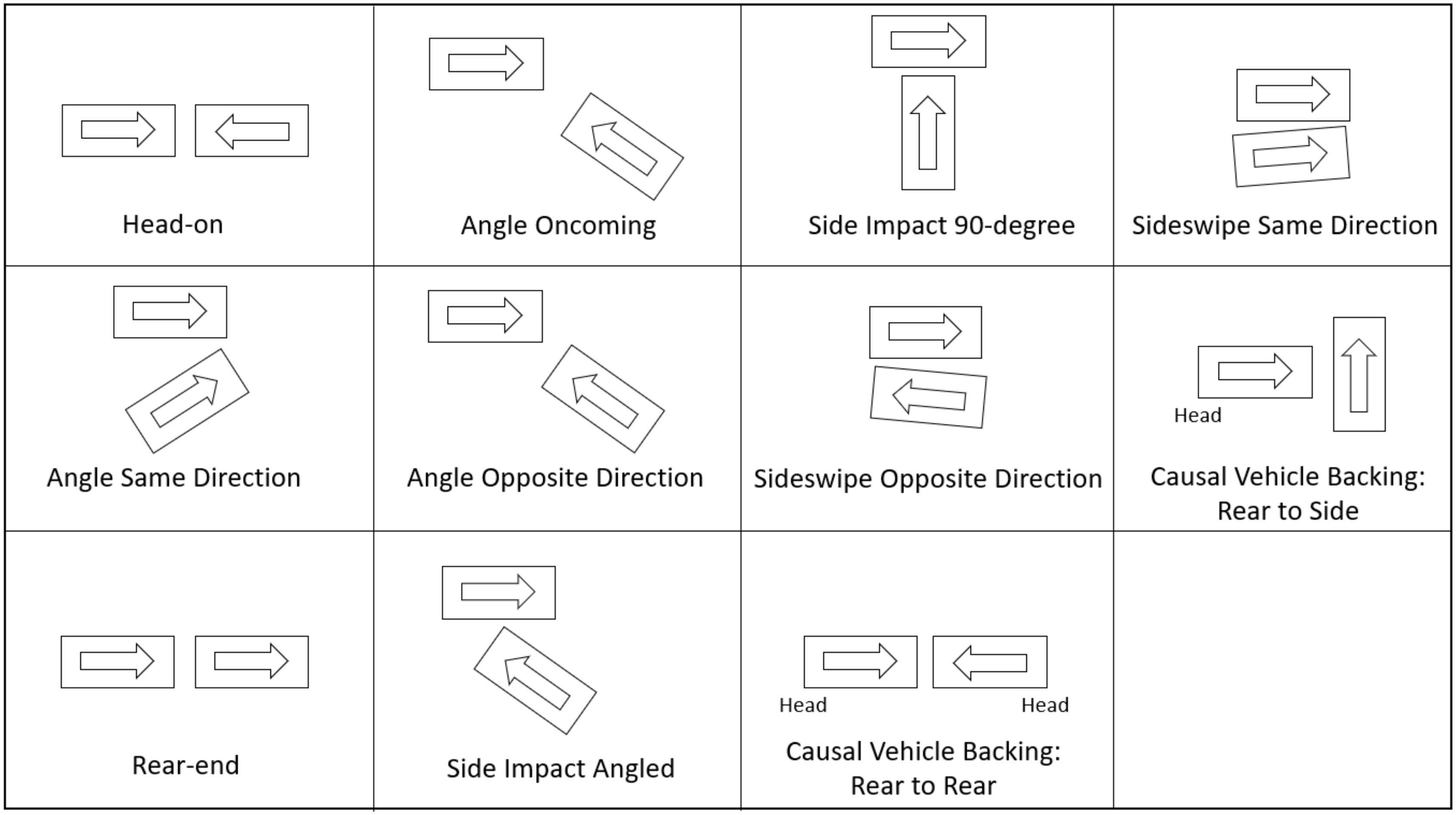

Figure 1-3: Diagrams of Crash Types.

Crash severity is a key focus in this study, which is based on an injury scale: K, A, B, C, and O to identify level of injury severities (Institute for Traffic Safety Management and Research, 2016). Fatal injuries that resulted in deaths within 30 days of the crash are classified as category K. Incapacitating injuries include severe injuries, such as skull fractures, unconsciousness, severe lacerations, burns, and other type of severe injuries that cause the victim not able to leave the scene are classified as category A. Non-incapacitating injury is moderate injury that includes abrasions, minor lacerations, lumps, etc., which are classified as category B. Possible injury includes minor injury like complaints of pain, nausea, and temporary unconsciousness but no visible signs of injury, which are classified as category C. Finally, crashes with property damage only and without any fatality or injury are classified as category O, which are commonly called property damage only (PDO) crashes.

1.5 Research Objectives

To determine work zone crash types that are significantly more severe than others, and to determine crash types that are significantly more severe in work zones than outside of work zones, this study aims to investigate the significant differences in crash severity between crash types in work zones, as well as examine the severity difference between work zone and non-work zone crashes for each type of crash. With a deeper understanding of the statistical significance in crash severity, results, conclusions and recommendations focusing on which crash types should be of greater concern will be provided to ALDOT so that traffic control improvements could be performed and significant resources could be devoted to improving work zone safety. The main objectives of this research are:

1. Determine the severity distribution by crash types in work zone and in Alabama using the data from 2007 to 2014.

2. Develop the severity comparison for crash types among work zone-related database (2,111 records), work zone crashes entire database (5,424 records), and non-work zone crashes in Alabama.
3. Study the significance of differences for severity distribution among crash types in both work zone-related database and work zone crashes entire database.
4. Provide recommendations based on this research and goals for future study.

1.6 Thesis Outline

This thesis includes five chapters and is organized as following: Chapter 1 discusses the introduction of highway work zone safety, including why work zone safety has become a major concern for transportation agencies, the statistic facts of work zone crashes and fatalities in the country and the stagnant trend of fatality in Alabama in recent years. In addition, work zone crash type and severity, which are the primary focus in this research are introduced. Research objectives, why the research is worth doing, what to accomplish, and where the data come from are also introduced. Chapter 2 is the literature review which includes the information and knowledge obtained from published papers and documents. Work zone crashes and characteristics, influence on work zone crash severity by factors and characteristics, in-depth analysis of crash severity for specific crash types are shown in this chapter. Chapter 3 talks about the methodology utilized in the study, focusing on the description of the Kolmogorov-Smirnov test and equations. Chapter 4 shows the results from applying the analytical method in Chapter 3, including severity distributions, statistical results, and statement of statistically significant differences. Chapter 5 provides conclusions to summarize this thesis and develops suggestions and recommendations to improve work zone safety according to the findings of this study.

CHAPTER TWO:
LITERATURE REVIEW

2.1 Introduction

Significant past research has been carried out to study work zone crashes. This chapter is divided into multiple sections to describe past research efforts associated with the topic of this thesis. Characteristics of work zone crashes are primarily introduced, followed by the crash type versus crash severity studies. This chapter also includes work zone versus non-work zone studies. In the last section, a summary is provided for what was found through the literature.

2.2 Characteristics of Work Zone Crashes

A work zone is a hazardous location for both road users and construction workers because it generates conflicts between work activities and the traffic. A past study analyzed the characteristics of work zone crashes occurred in Virginia between 1996 and 1999 and figured out countermeasures to mitigate the impacts of the work zone (Garber and Zhao, 2002). The crash characteristics include crash locations, severity, collision types, and time of crash. The study conducted distribution analysis for each crash characteristic and used the proportionality test to examine significant differences among factors at 5% confidence level. In addition, number of involved vehicles and number of fatal crashes were compared between work zone crashes and non-work zone crashes. The study found that the activity area was the predominant work zone location for all crashes as well as fatal crashes, whereas the termination area was the safest area having the least number of crashes. With total 1,484 work zone crashes studied, the activity area had 70% of total crashes and 76% of fatal crashes; at the other extreme, only 2% of all crashes occurred within termination area. Rear-end crashes were the predominant collision type regardless of crash location and type of roadway, except for work zone termination area, where only angle crashes occurred. PDO crashes were the most common severity type, followed by injury crashes and fatal crashes. Nighttime crashes most likely occurred in the activity area, but there was no significant difference between daytime crash severity and nighttime crash severity. Based on the comparison between work zone crashes and non-work zone crashes, the proportion of multiple-vehicle crashes in work zones was 89.4%, which was much higher than that in non-work zones (78.1%).

Another study focused on investigating work zone crash characteristics in Iowa, Kansas, Missouri, Nebraska and Wisconsin, to help transportation agencies develop traffic control plans on improving work zone safety (Akepati and Dissanayake, 2011). The research found that most crashes occurred under daylight condition and clear weather condition, corresponding to 75.3% and 68.9% of total work zone crashes, respectively. PDO crashes were the most common type of severity within work zone, contributing 72.2% of the total. Crashes resulting in injuries and fatalities were 27.2% and 0.7% of total work zone crashes, respectively. When considering collisions between vehicles, 42.7% of work zone crashes were rear-end, followed by 14.4% of angle collisions. For the information about work zone crash locations, only Iowa and Nebraska had records, and it was found that activity area was the predominant location, where 47.6% of crashes took place. Other results related to demographic characteristics show that 21% of work zone crashes was due to inattentive driving, followed by 16.6% of crashes caused by following too close.

A study of work zone crashes in Alabama between 2008 and 2012 was carried out to identify crash factors and figure out potential countermeasures to improve work zone safety (Sisiopiku et al., 2015). The study found that key characteristics for crashes in Alabama work zones include posted speed limit, lighting in dark conditions, traffic control devices in work zone, and human factors. PDO crashes (77.8%) were identified as dominant type of severity. Rear-end crashes (32%) were identified as dominant type of crash, followed by single-vehicle crashes (15%) and sideswipe crashes (8%). Majority of crashes (89%) occurred when the posted speed limit was over 35 miles per hour. When there were poor lightings under dark conditions, 1,411 work zone crashes occurred, which was much higher than the 472 crashes when the roadway was lighted. Driver errors were also concerned as work zone crash factors, including inattentive driving and misjudgment/disregarded traffic controls, which emphasized the necessity of improving traffic control devices.

2.3 Crash Type and Severity Studies

Modeling type of crash and level of severity simultaneously for two-vehicle crashes was done in a previous study using a joint unordered-ordered discrete model in which crash type was treated as an unordered discrete outcome variable and severity level was treated as an ordered discrete response variable (Ye et al., 2008). Crash severity was represented according to the KABCO scale, and crash type had five categories including rear-end, head on, angle, sideswipe, and other. This study found that positive coefficients for variables obtained from the unordered multinomial logit model of crash type indicate increase of likelihood to affect the crash type, while negative coefficients from the output of the model indicate decrease of chance to influence crash type. Additionally, for the ordered probit model of crash severity, positive and negative coefficients were used to examine the impact on injury level by different variables, including the five crash types. The error correlations between crash types and severity with absolute values greater than 0.1 were used to determine their statistical significance at the 95% confidence level. Thus, rear-end crash and head-on crash were found to significantly impact on crash severity.

A study of characteristics for fatal and injury work zone crashes in Kansas between 1992 and 2004 was investigated, additionally the significant difference between fatal and injury crashes were figured out (Li and Bai, 2008). This study concludes that 24% of fatal crashes were head-on crashes, which was the dominant type, closely followed by 20% of angle-side impact crashes. Rear-end crashes accounted for 46% of all injury crashes, followed by 18% of angle-side impact crashes. It was also found that complicated roadway geometry, poor light conditions, involvement of heavy vehicles, high speed limits, and head-on collisions significantly increased the crash severity within work zones. Recommendations suggested by the researchers focused on improvement of work zone traffic control, such as installation of reducing speed signs, highly retroreflective signs, and median separators to mitigate work zone collisions.

Another research effort analyzed the significant differences between type of crash and severity at signalized intersections in Brevard, Hillsborough and Seminole Counties, as well as the city of Orlando in Florida (Keller, 2004). It was found that left turn, angle and head-on crashes significantly caused the highest level of injuries in motor-vehicle crashes, while right turn and sideswipe crashes were found to significantly decrease the level of severity.

A study of traffic-related work zone crashes in Illinois investigated the frequency analysis of crash type caused by fatal and injury crashes (El-Rayes et al., 2013). Results shown that 22% of fatal work zone crashes in Illinois were rear-end crashes, followed by 19% of fixed-object crashes. Rear-end crashes were also the predominant collision type for injury crashes involving multiple vehicles, accounting for 43%, followed by turning (13%), angle (10%) and fixed-object crashes (9%). The correlation analysis identified the statistically significant correlations between crash severity and crash types. Thus, different crash types contributed to different level of injuries. Rear-end crashes accounted for 43% of all crashes, and 25.4% out of 43% was no visible injury but complaint of pain (category C on the KABCO scale). For other crash types such as angle, turning and fixed object, the most frequent level of injury was injury evident to others (category B on the KABCO scale).

Akepati and Dissanayake (2011) carried out an analysis of relationship between risk factors and injury severity for the crashes occurred in Iowa work zones from years 2002 to 2006. They found that sideswipe collisions in the same direction resulted in higher severity level than overturn, fixed object, head-on, broadside and sideswipe in the opposite direction crashes.

2.4 Work Zone Crash and Non-Work Zone Crash Studies

To better understand the work zone safety and select effective countermeasures to improve, a work zone safety study was carried out in which they examined the crash rate when work zones were present compared with the same road segment when it was non-work zone (Ozturk et al., 2013). Descriptive analysis was also conducted to provide number of crashes for injury levels and occurring time, based on 50,766 crash records in 60 studied sites in New Jersey from years 2001 to 2011. Results indicated that 26.4% of non-work zone crashes was injury crashes and 24.2% of work zone crashes resulted in injury. For fatal crashes, they accounted for 0.2% of total work zone crashes, reducing by 0.1% from that of non-work zone crashes, which was 0.3%. Nighttime crashes occurring in non-work zones were 30.5% and in work zone were 30.0%. However, crashes involved in pre-work zone conditions were excluded from the work zone versus non-work zone comparison and the studied work zone sites reduced to 45. The before-during comparison indicated that the monthly average crash number significantly increased by 18.7% for the presence of work zone compared with non-work zone conditions. Moreover, the number of daytime injury crashes in work zone increased by 15.5%, nighttime injury crashes in work zone increased by 18.1%. Work zone daytime PDO crashes increased by 22.6% and nighttime PDO crashes had 12.2% of increased than non-work zone. Furthermore, the descriptive comparisons of crash type, severity, weather condition, speed and other characteristics between work zone and non-work zone conditions were also implemented. Results shown that rear-end crash was the major crash type and it accounted for 57.3% of work zone crashes, which increased by 8.6% than that in non-work zones. The fatality rate reduced by 0.1% for work zone crashes, while injury rate reduced by 2.2%, and PDO crashes increased by 2.2%. Other factors that had significant growth for work zone condition compared with non-work zone condition included clear weather with a 6.6% increase, vehicle speed between 45 and 54 miles per hour with a 3.1% increase, and two-vehicle involved crashes, which had a 6.9% increase. Five negative binomial models were used to estimate the relationship between crash counts and multiple variables at 95% confidence level. The models were created for total crash count, number of crashes during daytime, number of crashes during nighttime, PDO crash count, and injury crash count, respectively. The indicator of work zone presence was one of the variables. Results indicated that the total crash count would increase by 15.5% at the presence of work zone. The number of daytime crashes increased by 18.5% when the work zone was present, whereas nighttime crash count increased by only 7.5% at the presence of work zone. It was also found that work zone presence resulted in 19.4% of increase for PDO crashes, but there was no significant relation between work zone indicator and injury crashes due to the p-value greater than the confidence level.

A study of fatal crashes in Georgia work zones was carried out to examine the significant difference of fatal crash activity between work zones and non-work zones (Daniel et al., 2000).

Based on 181 fatal crashes within work zones from years 1995 to 1997, the analysis shown that single-vehicle crashes accounted for 48.6%, followed by 17.7% of head-on crashes and 17.7% of angle crashes. Rear-end crashes only accounted for 12.1% of all fatal work zone crashes. In non-work zones, single-vehicle crashes were the dominant collision type as well, accounted for 56.3%, followed by 20.7% of angle crashes, 16.1% of head-on crashes, and 5% of rear-end crashes. The proportions of crash under different conditions including manner of collision, light conditions, truck involvement, and roadway classification were also determined, and the comparison was conducted by investigating their differences between work zone and non-work zone using chi-square test at a significance level of α = 0.05. The results found that the null hypothesis, showing the conditions were significantly independent to the presence of work zone, was rejected. This paper concluded that the examined conditions under which fatal crashes took place in Georgia were significantly affected by the presence of work zone.

Silverstein et al. (2016) studied the significant influence of factors on fatal crashes occurred in work zones and non-work zones in the U.S. from years 2010 to 2011 by collision types. Moreover, significant differences between work zone and non-work zone scenarios for rear-end and sideswipe fatal crashes were investigated. A preliminary analysis of the fatal crash frequency found that the 23.09% of fatal work zone crashes was rear-end crashes, whereas rear-end crashes in non-work zones accounted for only 6.72% (almost four times differential). The percentage of sideswipe collisions increased from 2.41% in non-work zones to 4.37% in work zones (almost doubled). Other types of collision such as no impact, single vehicle, frontal impact and head-on had close proportions in the two scenarios. Negative binomial regression (NB) model and multinomial logit (MNL) model were used to estimate the influence of various factors on each type of collision. The results showing significant correlations indicated that in both scenarios, the presence of precipitation or curve decreased the likelihood of rear-end/side swipe crashes, whereas higher speed limit or more lanes increased the likelihood of those two types of crashes. As comparing the estimated coefficients for each factor, it was found that higher speed limit had more effect on rear-end/side swipe crashes in work zones, while increasing number of lanes resulted in more rear-end/sideswipe collisions in non-work zones. In the frequency analysis, rear-end and sideswipe crashes were found to be significantly 18.33% higher in work zones compared with those in non-work zones. Thus, a comparison of coefficients for each factor obtained from previous models was conducted for only rear-end/sideswipe crashes using binary probit model. Results shown that presence of precipitation, number of lanes and speed limit were statistically significant to the occurrence of rear-end/sideswipe crashes in work zones and non-work zones, which were consistent to the results of NB and MNL models.

Another study investigated two years of work zone crashes in Virginia from 2011 to 2012 and developed the percentage distribution of crash types by roadway classification between work zones and non-work zones (Clark and Fontaine, 2015). In this study, crashes reported as occurring close to work zone (coded crashes) in Virginia were further explored and a subset was created containing crashes that were directly affected by a work zone (directly related crashes). It was found that the directly related crashes only accounted for 23% of the coded crashes. Table 2-1 shows the comparison by roadway type and crash type among total (work zone and non-work zone) crashes, coded crashes and directly related crashes. It is found that percentage of rear-end crashes for each roadway type in coded-crash dataset is higher compared with the percentage in total crashes. The percentage of sideswipe-same direction crashes also increases in coded crash dataset. Contrarily, the percentage of fixed object-off road crashes decreases on all types of roadways. The comparison between coded crash dataset and directly related crash dataset indicates that the percentage of rear-end crashes decreases on interstate and primary roads but increases on secondary roads. The proportion of angle crashes decreases on all roadway facilities, whereas fixed object-off road proportions increase dramatically in work zone directly related crashes.

Table 2-1: Summary of Crashes by Roadway and Crash Type, 2011–2012 (Source: Clark and Fontaine, 2015)

Crash Type	Percentage of Total Crashes (count)	Percentage of Coded Work Zone Crashes (count)	Percentage of Directly Related Work Zone Crashes (count)
Interstate			
Rear end	51.1 (14,570)	60.5 (2,195)	41.0 (344)
Angle	8.0 (2,272)	8.8 (319)	5.0 (42)
Sideswipe–same direction	13.4 (3,815)	17.0 (618)	9.4 (79)
Fixed object–off road	27.6 (7,883)	13.6 (495)	44.6 (374)
Primary			
Rear end	45.0 (22,529)	60.4 (1,163)	54.7 (244)
Angle	26.9 (13,450)	22.6 (435)	15.9 (71)
Sideswipe–same direction	7.1 (3,570)	10.5 (202)	16.1 (72)
Fixed object–off road	20.9 (10,478)	6.6 (127)	13.2 (59)
Secondary			
Rear end	26.1 (11,384)	41.8 (287)	48.8 (78)
Angle	31.4 (13,698)	38.3 (263)	22.5 (36)
Sideswipe–same direction	4.5 (1,952)	9.9 (68)	10.0 (16)
Fixed object–off road	38.0 (16,603)	10.0 (69)	18.8 (30)
All Facility Types			
Rear end	39.7 (48,483)	58.3 (3,745)	45.9 (679)
Angle	24.1 (29,420)	16.5 (1,062)	10.8 (160)
Sideswipe–same direction	7.6 (9,337)	14.1 (906)	11.5 (170)
Fixed object–off road	28.6 (34,964)	11.1 (711)	31.8 (471)

NOTE: Each facility's crash type proportions sum vertically to 100%. For example, 41.0% of directly related Interstate crashes were rear-end crashes. Percentages are based on the summation of rear-end, angle, sideswipe–same direction, and fixed object–off road crashes. Other crash types are excluded for consistency.

Ozturk et al. (2015) carried out a study of modeling severity for crashes occurred in New Jersey work zones and non-work zones from years 2006 to 2010 as well as a comparison of the modeling parameters between the two conditions. Binary logistic regression was used to model crash severity for both work zone and non-work zone database, and the modeling results for each variable were displayed in tables which contained the estimated coefficient, standard error, the Wald chi-squared value (Wald x^2), and the odds ratio (OR). The Wald x^2 was obtained from the Wald chi-squared test, which examined the statistical significance of each variable in the model. The OR values were used to estimate the influence of each variable on crash severity and interpret the results for both conditions: the higher the OR value, the more impact on crash severity by the variable. In the results of work zone crashes, variables with OR values significantly greater than others include driver under the influence (DUI), light vehicle involved into the crash, angle collision, opposite direction collision, overturned collision, fixed object collision, and driving at unsafe speed. The highest OR value is 13.71 for overturned collision, indicating that the overturned crash is 13.71 times as risky as rear-end crash, which was treated as base type of collision in the analysis. In the results of non-work zone crashes, variables that have significantly high OR values are also included in work zone crashes, except that posted speed limit under human control more likely resulted in injuries-the injury risk is 85.3% higher than no human-controlled speed limit. Then, the odds ratios for significant variables were compared between work zone and non-work zone, and Table 2-2 displays the comparison. It is found that human-controlled facility is 38.0% less likely to cause injury within work zone. For each additional vehicle involved into the crash, it is 50.2% more likely for an injury crash occurred in work zone. The differential of odds ratio for the variable "light vehicle involved in crash' is also dramatic. It indicates that it is 97.2% less likely to result in an injured crash in work zone with light vehicle involved. The 779% differential for overturned crash indicates that it is 779% more likely to cause injured crash within work zone compared with non-work zone. Fixed-object crash is 40.4% more likely to result in injury in work zone condition. Driving at unsafe speed, inattention driving and following close are contributing factors that lead to higher likelihood of injury crashes in work zone.

Table 2-2: Comparison of OR Values between Work Zone and Non-Work Zone (Source: Ozturk et al., 2015)

Variable	Symbol	Odds Ratio		Difference of Unique Impact
		Work Zone	Non-Work Zone	
Driver gender	Drv_gender	1.209	1.151	5.8%
Driver license state	License	0.924	0.890	3.4%
Driver under the influence	DUI	2.198	2.127	7.1%
Vehicle type	Light_veh	1.627	1.551	7.6%
Vehicle age	Veh_age	1.012	1.011	0.1%
Road class	Rd_classmedium	1.221	1.129	9.2%
Posted speed limit	Speedmedium	1.069	1.141	-7.2%
Traffic control type	Humancontrol	1.473	1.853	-38.0%
	Signalsign	1.396	1.517	-12.1%
	Lanemark	1.172	1.255	-8.3%
Number of vehicles involved	Veh_num	1.562	1.060	50.2%
Number of persons involved	Person_num	1.169	1.203	-3.4%
Truck involved in crash	Truck_involved	0.672	0.770	-9.8%
Light vehicle involved in crash	Lightvehinvolved	1.688	2.660	-97.2%
Crash type	C_angle	1.859	1.618	24.1%
	C_opposite	2.196	1.961	23.5%
	C_overturn	13.716	5.926	779.0%
	C_fixedobj	1.892	1.488	40.4%
Contributing circumstances	Unsafespeed	1.616	1.194	42.2%
	Inattention	1.231	0.890	34.1%
	Close	1.22	0.901	31.9%
Vehicle precrash action	Maketurn	0.611	0.779	-16.8%
	Slowmove	0.898	0.601	29.7%
	Interaction	0.586	0.604	-1.8%

2.5 Summary

This chapter presents previous research efforts regarding characteristics of work zone crashes. It is found that activity area was the predominant location for the occurrence of work zone crashes. PDO crashes were the predominant severity category, followed by injury crashes and fatal crashes.

Rear-end crashes were the most common crash type within work zones. Some characteristics related to human factors also contributed to work zone crashes, including inattentive driving, misjudging/disregarded traffic controls and following too close.

Studies associated with crash type and severity found that rear-end crashes and head-on crashes significantly influence the level of severity in nationwide crashes. Head-on crashes accounted for 24% of fatal work zone crashes in state of Kansas between 1992 and 2004, with being determined that it significantly influenced the crash severity of work zone crashes. Left turn, angle, and head-on crashes were found to significantly influence high level of severity for crashes occurred at signalized intersections in Florida. The study of Illinois work zone crashes found that 25.4% out of 43% of rear-end crashes resulted in no visible injury but complaint of pain, and the study in Iowa work zones found that sideswipe collisions in the same direction caused the highest level of injury.

The significant correlations between work zone crashes and non-work zone crashes were studied to figure out countermeasures to improve work zone safety. During years 2001 to 2011, the presence of work zone in New Jersey was found to significantly result in increasing of total crashes, daytime crashes, nighttime crashes, and number of PDO crashes. The study of fatal crashes in Georgia found that the evaluated conditions under which fatal crashes occurred were significantly influenced by the presence of work zone. In both work zone and non-work zone conditions in the U.S., the occurrence of rear-end and sideswipe crashes were found to be significantly affected by precipitation, number of lanes as well as speed limit. The study of work zone crashes in Virginia found that rear-end crashes and sideswipe-same direction crashes in coded work zone dataset accounted for higher percentage than those in total of work zone and non-work zone crashes, whereas percentage of fixed object-off road crashes decreased in total crashes. The study of crash severity in New Jersey from years 2006 to 2010 carried out the modeling for crash severity for both work zone and non-work zone conditions and a comparison between modeling parameters. Results found that human-controlled facility and involving light vehicles reduced the likelihood of injury in work zone, but additional involved vehicle, overturned crashes, fixed-object crashes, driving at unsafe speed, inattentive driving and following closely caused higher likelihood of injury crashes in work zone compared with non-work zone.

CHAPTER THREE:
METHODOLOGY

3.1 Introduction

This chapter explains the methods to proceed through data cleaning and statistical analysis that lead to the findings of differences of crash severity distribution and potential countermeasures to improve work zone safety. The methods to tidy the data and develop datasets for statistical analysis are primarily discussed in data cleaning and analysis section, followed by the mathematical theory and hypothesis of the two-sample K-S test. The next section introduces the employed software. Finally, a summary of this chapter is provided.

3.2 Data Cleaning and Analysis

As noted in Section 1.3, the ALDOT project engineer and reporting law enforcement officer used different judgement to identify work zone-related crashes. ALDOT project engineers' categorizations were based on the presence of ongoing construction project managed by ALDOT, while law enforcement officers completing the crash reports decisions were based on the presence of construction signs. The work zone-related assessment was made using the "Work Zone Related" field in the work zone crashes entire database containing 5,424 crash records from years 2007 to 2014. This variable includes 12 categories, which are shown in the bulleted list below:

- Not in/related to work zone

- Outside of the work zone warning signs
- Between work zone warning signs and work area
- In the termination area of the work zone
- On temporary detour
- At the shift transition in the activity area
- Involving workers/equipment in the activity area
- Involving roadway conditions in the activity area
- Not involving workers/conditions in the activity area
- Not in/near work zone
- Other work zone area explained in narrative
- Unknown

By examining the categories in the “Work Zone Related” variable, crashes marked with categories shown in the following bulleted list were deemed directly related to work zone by the reporting officers, and a subset including 2,111 crashes was created.

- Outside of the Work Zone Warning Signs
- Between Work Zone Warning Signs and Work Area
- In the Termination Area of the Work Zone
- At the Shift Transition in the Activity Area
- Involving Workers/Equipment in the Activity Area
- Involving Roadway Conditions in the Activity Area
- Not Involving Workers/Conditions in the Activity Area
- Other Work Zone Area Explained in Narrative

Also, “Crash Severity” and “Manner of Crash” fields in the crash reports were examined. Crash severity includes the five injury levels discussed in Section 1.4 as well as unknown category. Manner of crash refers to crash type and it includes the fifteen categories introduced in Section 1.4. The number of crashes for each crash type was then obtained by KABCO injury scale using the filter function in Excel for both work zone crashes entire database and work zone-related database. Additionally, statewide crash number for each severity level of each type of crash during the same years was retrieved from the online version of CARE. These numbers indicating crash count by injury severity constituted three datasets: WZ-Related Dataset, WZ Database, and All Crashes, which stand for work zone-related database, work zone crashes entire database, and statewide crashes, respectively. Thus, three comparisons are to be made in the examination of the statistical significance of differences in crash severity between work zone and non-work zone conditions using the K-S test, which are the comparison of crash severity for each type of crash between WZ-Related Dataset and WZ Database, between WZ Database and All Crashes, and between WZ-Related Dataset and All Crashes. For the second objective, which is the study of significant differences for severity distribution among crash types in the two work zone conditions, the comparison of severity distribution will work between each two different crash types in each dataset.

3.3 Statistical Method

To understand if there is a statistically significant difference in crash severity among different crash types as well as between work zone and non-work zone crashes, a two-sample Kolmogorov-Smirnov test (K-S test) will be employed to determine if two samples of data come from the same distribution at 95% confidence level, in other words, the statistical significance of differences between two empirical distribution functions.

The two-sample K-S test is a widely-used nonparametric method to compare two samples based on no assumption for the distribution of data, which means that the distribution of data is not required to know before running the test (NIST, 2016). It quantifies the maximum distance between the plotted curves shown on the empirical cumulative distribution diagram to indicate the difference between distributions, and the maximum vertical deviation is expressed as D-statistic.

Assume X_i stands for n observations, and each random observation has the same probability distribution and is independent to each other, the empirical distribution function F_n for X_i is stated in Equation 3-1, in which $I_{[-\infty,x]}(X_i)$ is an indicator function of X_i, being equal to 1 if $X_i \leq x$, otherwise it is equal to 0 (van der Vaart, 1998).

$$F_n(x) = \frac{1}{n}\sum_{i=1}^{n} I_{[-\infty,x]}(X_i) \qquad \text{(Eq. 3-1)}$$

As illustrated above, the D-statistic of the two-sample K-S test is the maximum vertical distance between two empirical distribution functions. This is expressed as the maximum absolute value for the differential between two distribution functions that are $F_n(x)$ and $G_p(x)$ at the same x as shown in Equation 3-2, where n and p represent each sample size, $D_{n,p}$ is the D-statistic, and sup_x stands for the supremum of the multiple vertical distances (the largest distance) (NIST, 2016).

$$D_{n,p} = sup_x\left|F_n(x) - G_p(x)\right| \qquad \text{(Eq. 3-2)}$$

To better interpret the D-statistic, the Glivenko–Cantelli theorem is shown in Equation 3-3, where limiting function $F(x)$ is uniformly converged by a sequence of functions $F_n(x)$, indicating that as n tends to infinity, the length of the vector $\|F_n - F\|$, or the supremum of distances between two distributions, almost surely converges to 0 (van der Vaart, 1998). Back to the D-statistic in two-sample K-S test, if the distributions of both $F_n(x)$ and $G_p(x)$ are the same, the D-statistic almost surely converges to 0 within the limit of n tending to infinity (Crualaoich, 2018).

$$\|F_n - F\|_\infty = sup_{x \in R}|F_n(x) - F(x)| \rightarrow 0 \text{ almost surely} \qquad \text{(Eq. 3-3)}$$

Following the illustration of methodology for the two-sample K-S test, the null hypothesis identified as H_0 and the alternative hypothesis identified as H_1 are shown in Equation 3-4 and Equation 3-5, respectively. The null hypothesis is that both empirical distribution functions come from the same distribution, and they have no significant difference. The alternative hypothesis indicates that the empirical distribution function $F_n(x)$ is statistically significant different than the empirical distribution function $G_p(x)$. Additionally, the correlation between D-statistic and D-critical when null hypothesis is rejected is shown in Equation 3-6, where D-critical is expressed as $C(\alpha)\sqrt{\frac{n+p}{np}}$, in which $C(\alpha)$ is calculated by the confidence level as shown in Equation 3-7 (Angers, 2018).

$$H_0: F_n(x) = G_p(x) \qquad \text{(Eq. 3-4)}$$

$$H_1: F_n(x) \neq G_p(x) \qquad \text{(Eq. 3-5)}$$

$$D_{n,p} > C(\alpha)\sqrt{\frac{n+p}{np}} \qquad \text{(Eq. 3-6)}$$

$$C(\alpha) = \sqrt{-\frac{1}{2}\ln\left(\frac{\alpha}{2}\right)} \qquad \text{(Eq. 3-7)}$$

3.4 Software

Microsoft Excel and an add-in called Real Statistics Using Excel were employed in the study. Microsoft Excel was used to tidy the data and retrieve necessary information from the original dataset. It was also used to calculate cumulative proportions for the K-S test and create pie charts as well as histograms to clearly display the findings. Real Statistics Using Excel is an add-in for Microsoft Excel to do statistical analysis and it extends the built-in statistical capabilities to carry out more varied statistical analysis (Zaiontz, 2018).

Real Statistics Using Excel was applied to conduct the Kolmogorov-Smirnov test in this research, and specific functions provided by the resource pack of the add-in featuring the difference between two cumulative proportions, D-statistic, D-critical and p-value were used. These functions are shown in Equation 3-8 through Equation 3-11 below. In Equation 3-8, x and y stand for the cumulative proportion of each crash severity category for the two datasets that are comparing to each other. The difference is the absolute value of differential between x and y. In Equation 3-9, the D-statistic is the maximum value of differences among comparisons of five severity categories. Equation 3-10 is a specific function provided by the add-in to calculate D-critical, where α is the confidence level, n is the first sample size, and p is the second sample size. Equation 3-11 is also provided by the add-in, which is specifically used to calculate p-value based on the obtained D-critical and the two sample sizes. To determine the significant difference between severity distributions, any D-statistic greater than D-critical or p-value greater than the significance level of α = 0.05 can be used to conclude that null hypothesis is rejected.

$$Difference = abs(x - y) \quad \text{(Eq. 3-8)}$$

$$D\text{-}statistic = max(Differences) \quad \text{(Eq. 3-9)}$$

$$D\text{-}critical = KSINV(\alpha, n, p) \quad \text{(Eq. 3-10)}$$

$$p\text{-}value = KSDIST(D\text{-}statistic, n, p) \quad \text{(Eq. 3-11)}$$

3.5 Summary

This chapter is divided into multiple sections illustrating how the “Work Zone Related” assessment was made, which fields in the crash reports were examined, the three levels of comparisons between severity distributions, the 72 comparisons totally of severity distributions between crash types for the two different scales of work zone conditions, the methodology for the two-sample K-S test, and the employed software.

Due to the different judgement on identifying work zone-related crashes by ALDOT and reporting law enforcement officers, two work zone datasets were created: one is the dataset containing 5,424 crash records by identifying the ongoing construction project managed by ALDOT, the other is the dataset including 2,111 crashes identified by the reporting officers with seeing the construction signs at the scene. The dataset containing 2,111 crashes was created by examining the “Work Zone Related” field in the work zone crashes entire database, and this variable includes 12 categories, nine of which was identified as occurring directly related to work zone. To conduct severity distribution comparisons, the proportion of each severity category was needed. Therefore, the number of crashes for each severity category of each type of crash was obtained through examining “Crash Severity” and “Manner of Crash” fields in both datasets. For statewide crashes, the filter command was used in the online version of CARE to obtain the number of crashes for different crash types by severity category. These crash numbers were then entered into three spreadsheets named WZ-Related Dataset, WZ Database, and All Crashes, respectively.

Using the crash numbers by severity category for crash types, cumulative proportions were computed and comparisons were carried out through the two-sample K-S test, which includes three levels of severity distribution comparisons for each crash type among WZ-Related Dataset, WZ

Database, and All Crashes, as well as 72 severity distribution comparisons between each two crash types in both work zone datasets.

The two-sample K-S test is a powerful nonparametric test to compare distributions of data, without any assumptions of distribution before running the test. The empirical distribution function $F_n(x)$ is the number of observations that are less than or equal to x divided by the sample size. The D-statistic is the largest absolute distance between two distribution functions. The D-statistic converges to 0 when both distributions are the same, which is consistent with the followed correlation equations to reject null hypothesis: the null hypothesis which is both distribution functions come from the same distribution is rejected if D-statistic is greater than a specific value at 95% confidence level.

Microsoft Excel was used to clean the data, retrieve information, do calculations and plot graphs. The Real Statistics Using Excel was used to conduct two sample K-S test through running specific functions provided by the resource pack of the add-in to determine absolute differences, D-statistic, D-critical, and p-value. These functions were repeated for each comparison to complete the two objectives of comparison in this study.

CHAPTER FOUR:
RESULTS

4.1 Introduction

This chapter breaks into six sections to show the results from data cleaning and analysis. Firstly, the number of crashes for each crash type and severity level in each of the three datasets: WZ-Related Dataset, WZ Database, and All Crashes is displayed in tables. Moreover, pie charts are used to show the distribution of number of crashes by injury severity. To investigate the similarity and difference between the work zone crashes in Alabama being studied and the findings in previous research efforts, comparisons are shown in the third section. Comparisons and examination of results of Kolmogorov-Smirnov test are presented with tables and histograms in Section 4.4 and Section 4.5. Also, significance of differences in crash severity distributions for each crash type between the three datasets, as well as between crash types within work zone datasets were determined. The results of these comparisons are used to interpret which collision types should be of greater concern in work zone crashes and help transportation agencies devote resources on improving work zone safety for those crash types whose severity distribution is significantly different than others. Finally, a summary of analysis is shown in the Section 4.6.

4.2 Data Cleaning and Analysis

Descriptive analysis was primarily carried out to identify the severity distribution within different crash datasets. The number of crashes for each severity level of each crash type was obtained from the three different sources: work zone-related database, work zone crashes entire database, and statewide crashes provided by the online version of CARE. In addition to the five severity levels, there were crashes with unknown severity, which might be due to drivers leaving the scene. Although the unknown crashes were considered in the descriptive analysis, they were not included in the statistical analysis since the distribution of injury severity is being studied. The total number of crashes was calculated using the "Sum" function in Excel based on the number of each category: K, A, B, C, O and Unknown. Then, a percentage was computed for each severity category of each crash type. Additionally, the proportion of the total number of crashes for each crash type in each database is calculated and shown in the last column of the tables. The tables including descriptive analysis for three different work zone and non-work zone conditions are shown in Table 4-1, Table 4-2, and Table 4-3, respectively.

Table 4-1: Severity Distribution within WZ-Related Dataset

Crash Types	K	A	B	C	O	Unknown	Total	Proportion of Total Crashes
Non-collision	0	0	2	1	16	0	19	0.90%
	0.00%	0.00%	10.53%	5.26%	84.21%	0%	100.00%	
Single Vehicle Crash	14	47	47	35	355	5	503	23.83%
	2.78%	9.34%	9.34%	6.96%	70.58%	1%	100.00%	
Head-on	8	5	3	0	5	0	21	0.99%
	38.10%	23.81%	14.29%	0.00%	23.81%	0%	100.00%	
Angle Oncoming	0	6	2	4	12	0	24	1.14%
	0.00%	25.00%	8.33%	16.67%	50.00%	0%	100.00%	
Angle Same Direction	0	0	4	5	30	0	39	1.85%
	0.00%	0.00%	10.26%	12.82%	76.92%	0%	100.00%	
Angle Opposite Direction	3	2	4	2	11	0	22	1.04%
	13.64%	9.09%	18.18%	9.09%	50.00%	0%	100.00%	
Rear-end	1	41	49	90	789	2	972	46.04%
	0.10%	4.22%	5.04%	9.26%	81.17%	0.21%	100.00%	
Side Impact Angled	2	8	4	6	57	0	77	3.65%
	2.60%	10.39%	5.19%	7.79%	74.03%	0%	100.00%	
Side Impact 90-degree	5	8	10	9	38	0	70	3.32%
	7.14%	11.43%	14.29%	12.86%	54.29%	0%	100.00%	
Sideswipe Same Direction	2	12	6	12	276	0	308	14.59%
	0.65%	3.90%	1.95%	3.90%	89.61%	0.00%	100.00%	
Sideswipe Opposite Direction	0	0	0	0	5	0	5	0.24%
	0.00%	0.00%	0.00%	0.00%	100.00%	0%	100.00%	
Causal Vehicle Backing: Rear to Side	0	0	0	0	4	0	4	0.19%
	0.00%	0.00%	0.00%	0.00%	100.00%	0%	100.00%	
Causal Vehicle Backing: Rear to Rear	0	0	0	0	0	0	0	0.00%
	-	-	-	-	-	-	-	
Other Explained in Narrative	1	4	3	4	34	1	47	2.23%
	2.13%	8.51%	6.38%	8.51%	72.34%	2%	100.00%	
Blank	0	0	0	0	0	0	0	0.00%
	-	-	-	-	-	-	-	
All Types	36	133	134	168	1632	8	**2111**	100.00%
	1.71%	6.30%	6.35%	7.96%	77.31%	0.38%	100.00%	

Table 4-2: Severity Distribution within WZ Database

Crash Types	K	A	B	C	O	Unknown	Total	Proportion of Total Crashes
Non-Collision	1	1	5	2	34	0	43	0.79%
	2.33%	2.33%	11.63%	4.65%	79.07%	0%	100.00%	
Single Vehicle Crash	36	94	90	74	701	10	1005	18.53%
	3.58%	9.35%	8.96%	7.36%	69.75%	1%	100.00%	
Head-on	17	12	11	3	16	0	59	1.09%
	28.81%	20.34%	18.64%	5.08%	27.12%	0%	100.00%	
Angle Oncoming	2	17	8	12	26	0	65	1.20%
	3.08%	26.15%	12.31%	18.46%	40.00%	0%	100.00%	
Angle Same Direction	0	2	5	9	83	0	99	1.83%
	0.00%	2.02%	5.05%	9.09%	83.84%	0%	100.00%	
Angle Opposite Direction	6	4	8	9	51	0	78	1.44%
	7.69%	5.13%	10.26%	11.54%	65.38%	0%	100.00%	
Rear-end	4	102	93	282	2166	8	2655	48.95%
	0.15%	3.84%	3.50%	10.62%	81.58%	0.30%	100.00%	
Side Impact Angled	3	24	27	39	218	3	314	5.79%
	0.96%	7.64%	8.60%	12.42%	69.43%	1%	100.00%	
Side Impact 90-degree	10	43	38	44	166	0	301	5.55%
	3.32%	14.29%	12.62%	14.62%	55.15%	0%	100.00%	
Sideswipe Same Direction	2	23	10	36	608	1	680	12.54%
	0.29%	3.38%	1.47%	5.29%	89.41%	0.15%	100.00%	
Sideswipe Opposite Direction	1	0	0	2	14	0	17	0.31%
	5.88%	0.00%	0.00%	11.76%	82.35%	0%	100.00%	
Causal Vehicle Backing: Rear to Side	0	0	0	0	9	0	9	0.17%
	0.00%	0.00%	0.00%	0.00%	100.00%	0%	100.00%	
Causal Vehicle Backing: Rear to Rear	0	0	0	1	1	0	2	0.04%
	0.00%	0.00%	0.00%	50.00%	50.00%	0%	100.00%	
Other Explained in Narrative	5	8	5	5	70	2	95	1.75%
	5.26%	8.42%	5.26%	5.26%	73.68%	2%	100.00%	
Blank	0	0	0	0	0	2	2	0.04%
	0.00%	0.00%	0.00%	0.00%	0.00%	100%	100.00%	
All Types	87	330	300	518	4163	26	**5424**	100.00%
	1.60%	6.08%	5.53%	9.55%	76.75%	0.48%	100.00%	

Table 4-3: Severity Distribution within All Crashes

Crash Types	K	A	B	C	O	Unknown	Total	Proportion of Total Crashes
Non-collision	28	252	488	341	4135	350	5594	0.89%
	0.50%	4.50%	8.72%	6.10%	73.92%	6%	100.00%	
Single Vehicle Crash	2148	14697	22065	9096	93752	3758	145516	23.15%
	1.48%	10.10%	15.16%	6.25%	64.43%	3%	100.00%	
Head-on	411	1630	1972	1329	6794	468	12604	2.01%
	3.26%	12.93%	15.65%	10.54%	53.90%	4%	100.00%	
Angle Oncoming	136	1128	1912	1630	8945	468	14219	2.26%
	0.96%	7.93%	13.45%	11.46%	62.91%	3%	100.00%	
Angle Same Direction	23	490	1031	1090	13837	637	17108	2.72%
	0.13%	2.86%	6.03%	6.37%	80.88%	4%	100.00%	
Angle Opposite Direction	130	1071	2117	2288	13760	884	20250	3.22%
	0.64%	5.29%	10.45%	11.30%	67.95%	4%	100.00%	
Rear-end	257	5173	12759	20832	177850	5844	222715	35.44%
	0.12%	2.32%	5.73%	9.35%	79.86%	3%	100.00%	
Side Impact Angled	191	2152	4105	4620	37337	1438	49843	7.93%
	0.38%	4.32%	8.24%	9.27%	74.91%	3%	100.00%	
Side Impact 90-degree	430	4344	7388	7204	36792	1200	57358	9.13%
	0.75%	7.57%	12.88%	12.56%	64.14%	2%	100.00%	
Sideswipe Same Direction	50	611	1539	1559	39252	979	43990	7.00%
	0.11%	1.39%	3.50%	3.54%	89.23%	2%	100.00%	
Sideswipe Opposite Direction	25	305	621	407	8519	313	10190	1.62%
	0.25%	2.99%	6.09%	3.99%	83.60%	3%	100.00%	
Causal Vehicle Backing: Rear to Side	1	14	133	119	10021	319	10607	1.69%
	0.01%	0.13%	1.25%	1.12%	94.48%	3%	100.00%	
Causal Vehicle Backing: Rear to Rear	0	4	35	24	2679	84	2826	0.45%
	0.00%	0.14%	1.24%	0.85%	94.80%	3%	100.00%	
Other Explained in Narrative	167	638	1140	694	10323	630	13592	2.16%
	1.23%	4.69%	8.39%	5.11%	75.95%	5%	100.00%	
Unknown	8	23	57	68	1646	303	2105	0.33%
	0.38%	1.09%	2.71%	3.23%	78.19%	14%	100.00%	
All Types	4005	32532	57362	51301	465642	17675	**628517**	100.00%
	0.64%	5.18%	9.13%	8.16%	74.09%	2.81%	100.00%	

From the tables shown above, a total of 2,111 crashes were considered as directly related to the work zone because the reporting law enforcement officer selected the 9 categories within "Work Zone Related" field as illustrated in Section 3.2 through identifying specific construction signs at the scene, while 5,424 crashes were identified by ALDOT project engineers as occurring within work zone according to an ongoing project managed by them. During the years from 2007 to 2014, overall there were 628,517 crashes in the state of Alabama. It should be noted that the sample size for some crash types in WZ-Related Dataset is too small to make the severity distribution reliable, and those crash types are excluded from the analysis, which are non-collision, sideswipe opposite direction, causal vehicle backing: rear to side, causal vehicle backing: rear to rear, and unknown types. Other types explained in narrative are also excluded because the type of collision is not specified. Thus, a total of nine crash types were considered into the analysis including single vehicle crash, head-on, angle oncoming, angle same direction, angle opposite direction, rear-end, side impact angled, side impact 90-degree, and sideswipe same direction.

According to Table 4-1, it can be found that within WZ-Related Dataset, the sample size of head-on crashes is 21 and it only accounts for 0.99% of all types of crashes, but 38.10% of them are fatal crashes, which is much higher than the proportion of fatal crashes of other crash types. It is followed by angle opposite direction crashes, which resulted in 13.64% of fatal crashes. For incapacitating injury crashes, 25% of angle oncoming crashes resulted in such severe injuries. In addition to the 38.10% of head-on crashes causing fatality, 23.81% of this crash type caused incapacitating injury. Therefore, a sum of 61.91% of head-on crashes resulted in incapacitating injury and fatal injury, which is a high proportion and warrants more attention to the results in statistical analysis. For non-incapacitating injuries, angle opposite direction crashes caused the highest percentage which is 18.18%, followed by 14.29% of head-on crashes and 14.29% of side impact 90-degree crashes. For possible injury crashes, angle oncoming crashes resulted in the highest percentage which is 16.67%, followed by 12.86% of side impact 90-degree and 12.82% of angle same direction. PDO crashes of each type of collision accounted for a significantly high percentage, represented by 89.61% of sideswipe same direction crashes, 81.17% of rear-end crashes, and 76.92% of angle same direction crashes.

Investigating the distribution table of WZ Database (Table 4-2), the highest percentage of fatal crashes among all types is also caused by head-on crashes, which is 28.81%, while the second-highest proportion the 7.69% of angle opposite direction crashes and 3.58% of single vehicle crashes. The highest percentage of incapacitating injury, non-incapacitating injury and possible injury is 26.15% of angle oncoming crashes, 18.64% of head-on crashes, and 18.46% of angle oncoming crashes, respectively. In addition to these crash types that lead to the highest proportion in each severity category, other types such as single vehicle, angle opposite direction, rear-end, side impact angled, and side impact 90-degree crashes also resulted in injuries. For PDO crashes, sideswipe same direction crashes have the highest proportion which is 89.41%, followed by 83.84% of angle same direction crashes and 81.58% of rear-end crashes.

For all crashes occurring within the state during the same period, head-on crashes are still the type of collision that resulted in the highest percentage of fatality, which is 3.26%. Furthermore, head-on crashes also caused the highest percentage of incapacitating injury and non-incapacitating injury across all crash types, which is 12.93% and 15.65%, respectively. The crash type that resulted in the highest percentage of possible injury crashes is side impact 90-degree crashes. For PDO crashes, side swipe same direction crashes are the dominant type, and it can be interpreted that 89.23% of sideswipe same direction crashes resulted in PDO. The descriptive of statewide crash severity distribution found that head-on collision is a major type of crash causing higher level of injury than other crash types.

Although the crash types with small sample size could not provide much crash records for each severity category, pie charts are still used for visually identifying the severity distribution of all crash types listed in the tables. Figure 4-1, Figure 4-2, and Figure 4-3 show distributions of single vehicle crashes in WZ-Related Dataset, WZ Database and All Crashes, respectively, and pie charts for other crash types are shown in the appendix.

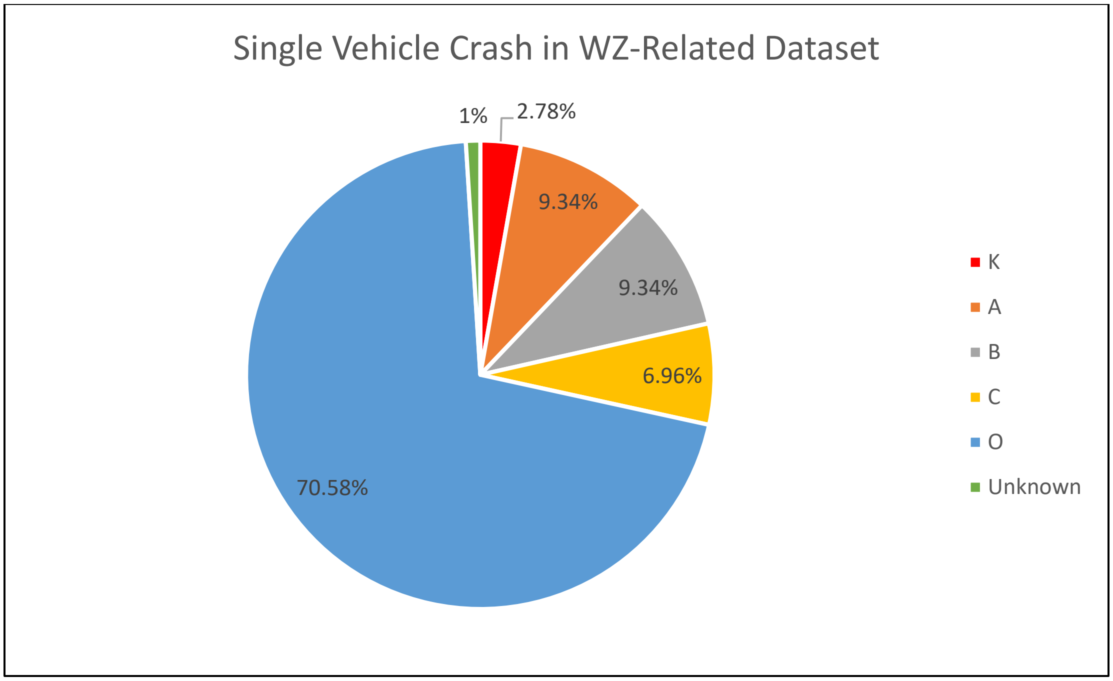

Figure 4-1: Severity Distribution of Single Vehicle Crash in WZ-Related Dataset.

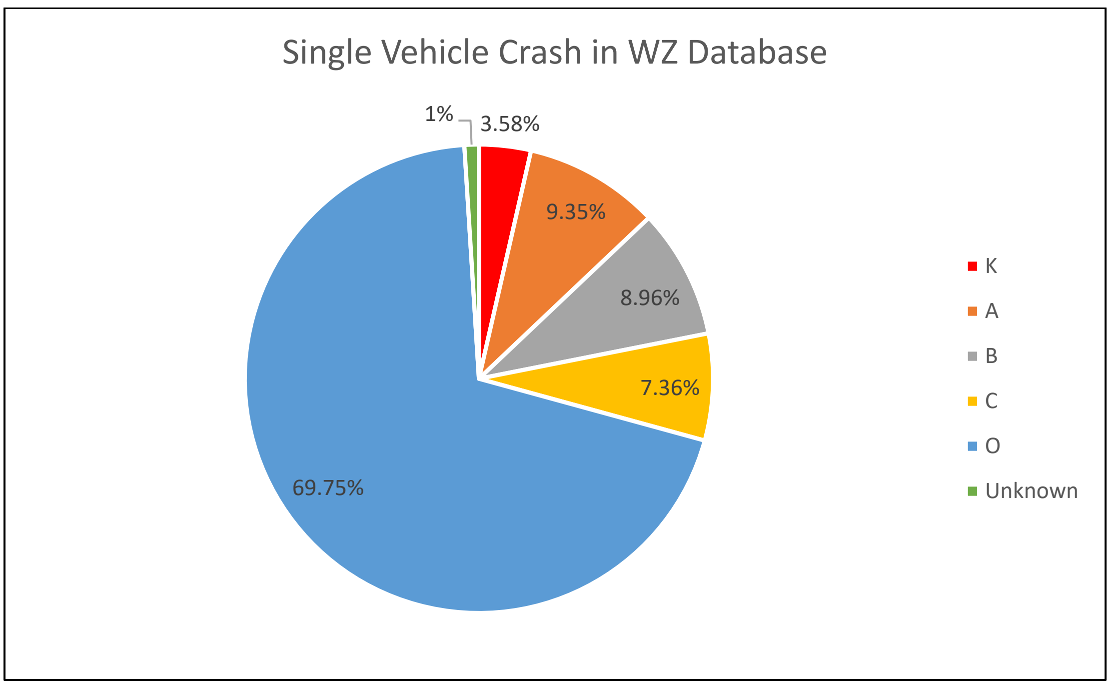

Figure 4-2: Severity Distribution of Single Vehicle Crash in WZ Database.

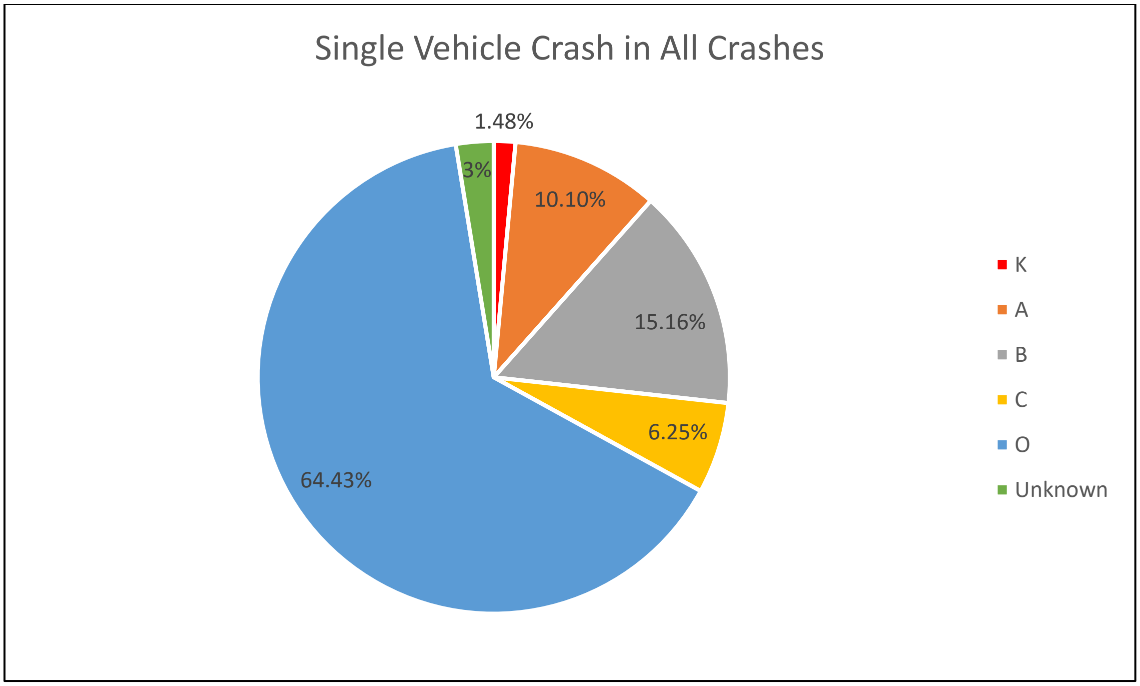

Figure 4-3: Severity Distribution of Single Vehicle Crash in All Crashes.

As mentioned above, unknown severity was not included in the comparisons of differences between crash severity distributions. Thus, the total number of crashes for each of the nine crash types was computed based on five severity categories after excluding crashes with unknown severity. Below the number of crashes for each severity category of the crash types, cumulative proportions are calculated for each crash type within each dataset and shown in Table 4-4, Table 4-5, and Table 4-6, respectively. These proportions are further processed from Table 4-1, Table 4-2, and Table 4-3, because Section 3.3 and Section 3.4 indicate that cumulative proportions are used to conduct the distribution comparisons with the two-sample K-S test.

Table 4-4: Cumulative Proportions for WZ-Related Dataset

Crash Types	K	A	B	C	O	Total
Single Vehicle Crash	14	47	47	35	355	498
	2.81%	12.25%	21.69%	28.71%	100.00%	
Head-on	8	5	3	0	5	21
	38.10%	61.90%	76.19%	76.19%	100.00%	
Angle Oncoming	0	6	2	4	12	24
	0.00%	25.00%	33.33%	50.00%	100.00%	
Angle Same Direction	0	0	4	5	30	39
	0.00%	0.00%	10.26%	23.08%	100.00%	
Angle Opposite Direction	3	2	4	2	11	22
	13.64%	22.73%	40.91%	50.00%	100.00%	
Rear-end	1	41	49	90	789	970
	0.10%	4.33%	9.38%	18.66%	100.00%	
Side Impact Angled	2	8	4	6	57	77
	2.60%	12.99%	18.18%	25.97%	100.00%	
Side Impact 90-degree	5	8	10	9	38	70
	7.14%	18.57%	32.86%	45.71%	100.00%	
Sideswipe Same Direction	2	12	6	12	276	308
	0.65%	4.55%	6.49%	10.39%	100.00%	
Total						**2029**

Table 4-5: Cumulative Proportions for WZ Database

Crash Types	K	A	B	C	O	Total
Single Vehicle Crash	36	94	90	74	701	995
	3.62%	13.07%	22.11%	29.55%	100.00%	
Head-on	17	12	11	3	16	59
	28.81%	49.15%	67.80%	72.88%	100.00%	
Angle Oncoming	2	17	8	12	26	65
	3.08%	29.23%	41.54%	60.00%	100.00%	
Angle Same Direction	0	2	5	9	83	99
	0.00%	2.02%	7.07%	16.16%	100.00%	
Angle Opposite Direction	6	4	8	9	51	78
	7.69%	12.82%	23.08%	34.62%	100.00%	
Rear-end	4	102	93	282	2166	2647
	0.15%	4.00%	7.52%	18.17%	100.00%	
Side Impact Angled	3	24	27	39	218	311
	0.96%	8.68%	17.36%	29.90%	100.00%	
Side Impact 90-degree	10	43	38	44	166	301
	3.32%	17.61%	30.23%	44.85%	100.00%	
Sideswipe Same Direction	2	23	10	36	608	679
	0.29%	3.68%	5.15%	10.46%	100.00%	
Total						**5234**

Table 4-6: Cumulative Proportions for All Crashes

Crash Types	K	A	B	C	O	Total
Single Vehicle Crash	2148	14697	22065	9096	93752	141758
	1.52%	11.88%	27.45%	33.86%	100.00%	
Head-on	411	1630	1972	1329	6794	12136
	3.39%	16.82%	33.07%	44.02%	100.00%	
Angle Oncoming	136	1128	1912	1630	8945	13751
	0.99%	9.19%	23.10%	34.95%	100.00%	
Angle Same Direction	23	490	1031	1090	13837	16471
	0.14%	3.11%	9.37%	15.99%	100.00%	
Angle Opposite Direction	130	1071	2117	2288	13760	19366
	0.67%	6.20%	17.13%	28.95%	100.00%	
Rear-end	257	5173	12759	20832	177850	216871
	0.12%	2.50%	8.39%	17.99%	100.00%	
Side Impact Angled	191	2152	4105	4620	37337	48405
	0.39%	4.84%	13.32%	22.87%	100.00%	
Side Impact 90-degree	430	4344	7388	7204	36792	56158
	0.77%	8.50%	21.66%	34.48%	100.00%	
Sideswipe Same Direction	50	611	1539	1559	39252	43011
	0.12%	1.54%	5.11%	8.74%	100.00%	
Total						**567927**

4.3 Comparison of Alabama Work Zone Crashes with Work Zone Crashes Outside Alabama

In this section, the results of descriptive analysis are compared with findings in previous studies to estimate the similarity of work zone crash characteristics between Alabama and other states in the U.S. Akepati and Dissanayake (2011) found that in Iowa, Kansas, Missouri, Nebraska and Wisconsin, 72.2% of work zone crashes was PDO, 27.2% was injury, and 0.7% was fatal. They also found that 42.7% of the crashes were rear-end crashes, which was the dominant type of crash. In WZ Database of this study, the PDO crashes account for 76.8%, injury crashes account for 21.2%, and fatal crashes account for 1.6%. The most frequent crash type is rear-end crash, accounting for 49.0% of total crashes. These numbers estimate that the work zone crash characteristics in Alabama resulted in similar distribution of severity levels and type of crashes compared with other states. Besides, Li and Bai (2008) found that 24% of fatal crashes was head-on crashes in Kansas work zones between years 1992 and 2004, which was the dominant crash type. However, the percentage of fatal head-on crashes in this study is approximately 20%, less than the percentage of fatal single vehicle crashes, which accounts for 41% of total fatal crashes in the database. In Illinois, El-Rayes et al. (2013) found that the most frequent crash type of fatal crashes was rear-end, accounting for 22%, and it accounted for 43% of all crashes, while only 5% of fatal crashes are rear-end crashes in Alabama work zones. Rear-end crashes in Illinois work zones resulted in more fatal crashes. The study in New Jersey by Ozturk et al. (2013) found that rear-end crash was the dominant crash type and accounted for 57.3% of work zone crashes. This percentage is greater than the percentage of work zone crashes in Alabama (49.0%) that are rear-end crashes. The study in Georgia work zones by Daniel et al. (2000) discovered that 48.6% of fatal crashes were single vehicle crashes, followed by 17.7% of head-on crashes. In Alabama, the proportion for each of these crash types is 41.4% and 19.5%, respectively. The predominant fatal crash types in Georgia are similar to those in Alabama. The study of fatal rear-end and sideswipe work zone crashes in the U.S. conducted by Silverstein et al. (2016) found that the percentage of rear-end crashes in work zones was 23.09%, which is much higher than the proportion of fatal crashes in Alabama work zones that are rear-end collisions (4.60%). Also, they found that the total proportion of rear-end and sideswipe work zone crashes were significantly 18.33% higher than in non-work zones. In Alabama, the combined proportion of these two crash types is 8.05% in WZ Database, and 8.29% in All Crashes, which only have a 0.24% differential. Another study in Virginia from years 2011 to 2012 by Clark and Fontaine (2015) investigated coded crashes, directly related crashes, and total crashes (work zone and non-work zone). They found that 23% of the coded crashes was directly work zone related crashes; rear-end and sideswipe same direction crashes accounted for 58.3% and 14.1% of coded work zone crashes, respectively, and these two crash types accounted for 45.9% and 11.5% of directly work zone related crashes, respectively. For the datasets used to study Alabama work zones in this thesis, 39% of crashes in WZ Database is identified as work zone-related crashes. In WZ Database, 49.0% of crashes are rear-end crashes, and 12.5% of crashes are sideswipe same direction crashes. In WZ-Related Dataset, rear-end crashes account for 46.0%, and sideswipe same direction crashes account for 14.6%. Overall, the percentage distribution of rear-end and sideswipe crashes in Virginia and Alabama is similar, except that crashes directly related to work zones account for higher proportion of work zone crashes identified by reporting law enforcement officers in Alabama.

4.4 Comparison of Severity Distributions between Work Zone and Non-Work Zone Crashes

As shown in Table 4-4, Table 4-5, and Table 4-6, the cumulative proportions for each severity category of each crash type were obtained, and these proportions were used in the K-S test functions to determine the statistical significance of differences, as explained in Section 3.3. Results including the D-statistic, the critical D-statistic, and p-value for each comparison between WZ-Related Dataset and WZ Database, WZ Database and All Crashes, as well as WZ-Related Dataset and All Crashes for the nine crash types are shown in Tables 4-7 through 4-15. The cells marked with yellow indicate that the null hypothesis is rejected based on p-value smaller than the significance level of α = 0.05, and the two distributions are significantly different than each other. Additionally, the severity distribution histograms based on the proportions of injury levels of each crash type in the three different conditions are shown in Figures 4-5 through 4-13. The purpose in creating these histograms is to clearly display the proportion of each severity level and facilitate interpretation of the statistical results. Within the tables, the D-statistic is the maximum difference between the cumulative distribution functions. For example, for the cumulative distribution comparison between single vehicle crash within WZ-Related Dataset and All Crashes in Figure 4-4, the D-statistic is the maximum difference of the bars' height, which is 5.76%. The D-critical is the critical value at 95% confidence level of the two sample K-S test for the two samples' sizes, and the p-value is to compare with the significance level of α = 0.05 to indicate the significant difference between distributions. The smaller the p-value, the more significant the difference is between the two distribution functions.

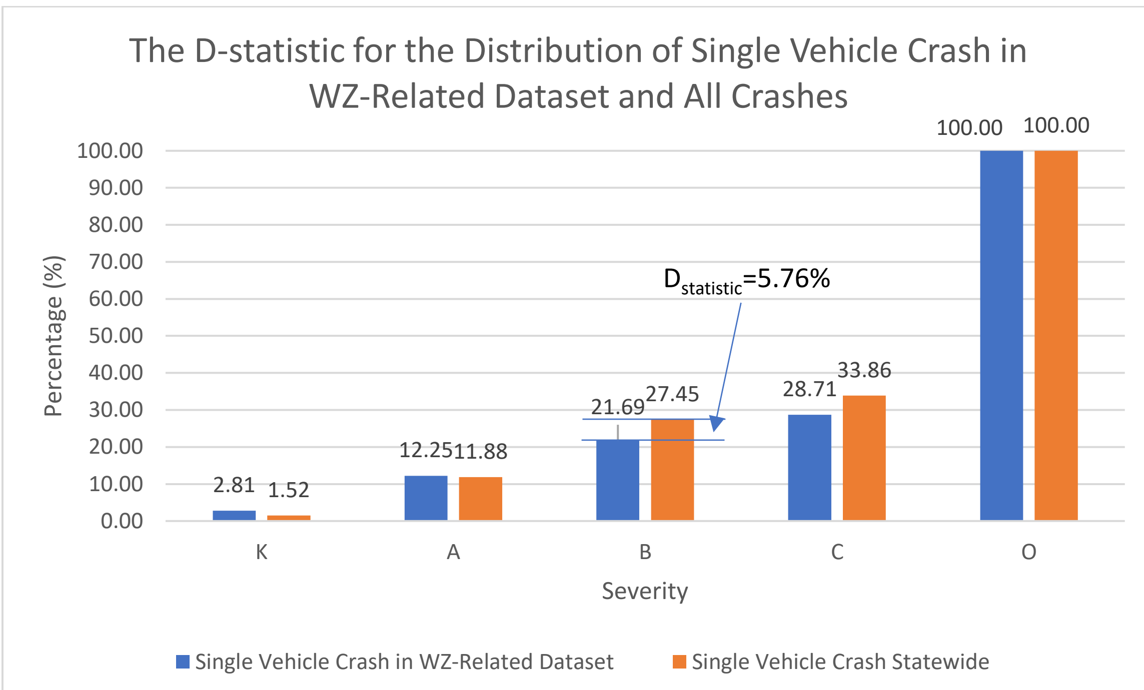

Figure 4-4: The D-statistic for the Distribution of Single Vehicle Crash in WZ-Related Dataset and All Crashes.

As shown in Figure 4-5 for the analysis of single vehicle crashes, it is found that the height of the bars at each severity level appears to be similar; however, through the K-S test results shown in Table 4-7, the D-statistic is found to be greater than D-critical for the comparison between WZ Database and All Crashes, and the p-value is smaller than α = 0.05. This indicates that the null hypothesis is rejected at 95% confidence level, and the distribution of single vehicle crash in WZ

Database is statistically significantly different from its distribution in All Crashes. The results of the other two comparisons have D-statistic smaller than D-critical, and p-value greater than α = 0.05, which means that the severity distribution for single vehicle crash in WZ-Related Dataset is not significantly different from its distribution in both WZ Database and All Crashes.

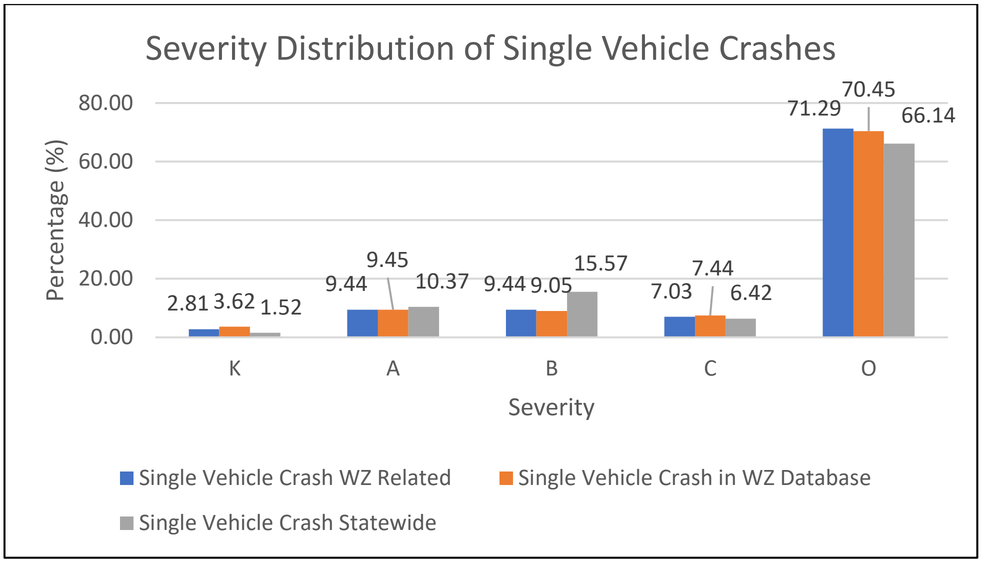

Figure 4-5: Severity Distribution of Single Vehicle Crashes.

Table 4-7: K-S Test Results of Single Vehicle Crashes

	Single Vehicle Crash in WZ-Related Dataset	Single Vehicle Crash in WZ Database	Single Vehicle Crash in All Crashes
Single Vehicle Crash in WZ Database	D-statistic: 0.0083 D-critical: **0.0740** p-value: ≈1.0000 Not Significantly Different		
Single Vehicle Crash in All Crashes	D-statistic: 0.0576 D-critical: **0.0606** p-value: 0.0715 Not Significantly Different	D-statistic: **0.0534** D-critical: 0.0430 p-value: 0.0069 Significantly Different	

The distribution comparisons for head-on crashes are shown in Figure 4-6, in which the height of the bars is visibly uneven, especially for the proportions of "K" category and "O" category. So, the distribution of statewide crashes seems to be statistically different than the others. From the results obtained from K-S test in Table 4-8, two of the comparisons have p-value smaller than α = 0.05, which are the head-on crashes between WZ-Related Dataset and All Crashes, as well as between WZ Database and All Crashes. This indicates that the distribution of statewide crashes is significantly different than the distribution of work zone crashes either identified by reporting law enforcement officers or ALDOT. Also, the p-value for the comparison between WZ Database and All Crashes is smaller than the p-value of 0.0002, which means the two distributions are significantly more different than the distributions between WZ-Related Dataset and All Crashes.

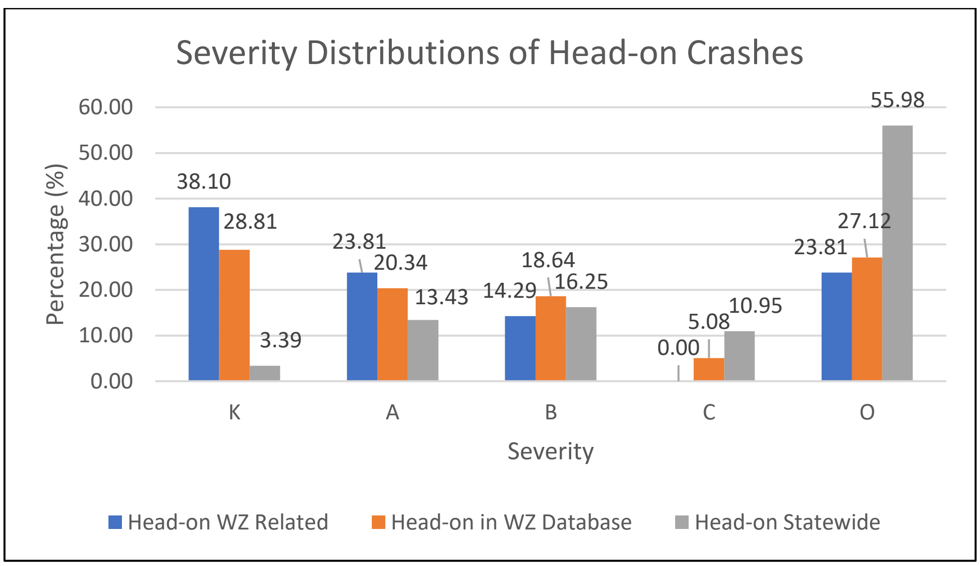

Figure 4-6: Severity Distribution of Head-on Crashes.

Table 4-8: K-S Test Results of Head-on Crashes

	Head-on Crash in WZ-Related Dataset	Head-on Crash in WZ Database	Head-on Crash in All Crashes
Head-on Crash in WZ Database	D-statistic: 0.1275 D-critical: **0.3326** p-value: 0.9490 Not Significantly Different		
Head-on Crash in All Crashes	D-statistic: **0.4509** D-critical: 0.2876 p-value: 0.0002 Significantly Different	D-statistic: **0.3472** D-critical: 0.1742 p-value: < 0.0001 Significantly Different	

Figure 4-7 presents the distributions for angle oncoming crashes. It can be seen that incapacitating injury crashes (injury level "A") constitute a higher percentage in work zones than in non-work zones, while the percentage of PDO crashes is much greater in the All Crashes. The K-S test results shown in Table 4-9 indicate there is a significant difference between WZ Database and All Crashes due to p-value smaller than α = 0.05, as well as D-statistic greater than D-critical. This conclusion is reasonable because there is a 17.95% differential for incapacitating injury crashes and 25.05% differential for PDO crashes between work zones identified by the reporting law enforcement officers and statewide non-work zone crashes.

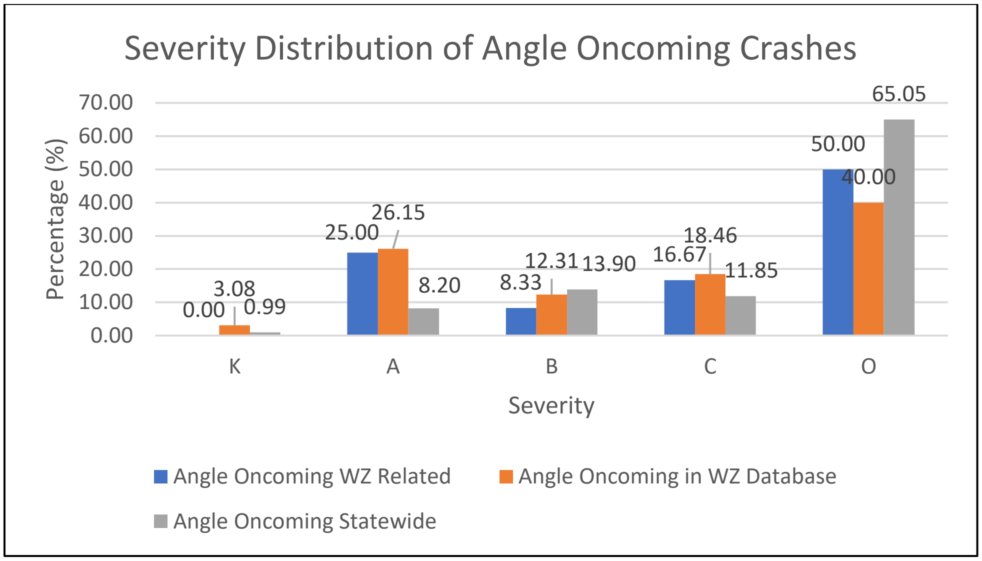

Figure 4-7: Severity Distribution of Angle Oncoming Crashes.

Table 4-9: K-S Test Results of Angle Oncoming Crashes

	Angle Oncoming Crash in WZ-Related Dataset	Angle Oncoming Crash in WZ Database	Angle Oncoming Crash in All Crashes
Angle Oncoming Crash in WZ Database	D-statistic: 0.1000		
	D-critical: **0.3134**		
	p-value: 0.9919		
	Not Significantly Different		
Angle Oncoming Crash in All Crashes	D-statistic: 0.1581	D-statistic: **0.2505**	
	D-critical: **0.2696**	D-critical: 0.1661	
	p-value: 0.5502	p-value: 0.0005	
	Not Significantly Different	Significantly Different	

As shown in Table 4-10 through Table 4-13, for angle same direction, angle opposite direction, rear-end, and side impact angled crashes, the D-statistic values are all smaller than D-critical values, and all p-values are greater than $\alpha = 0.05$. Therefore, none of the null hypotheses are rejected, and there is no significant difference among these comparisons.

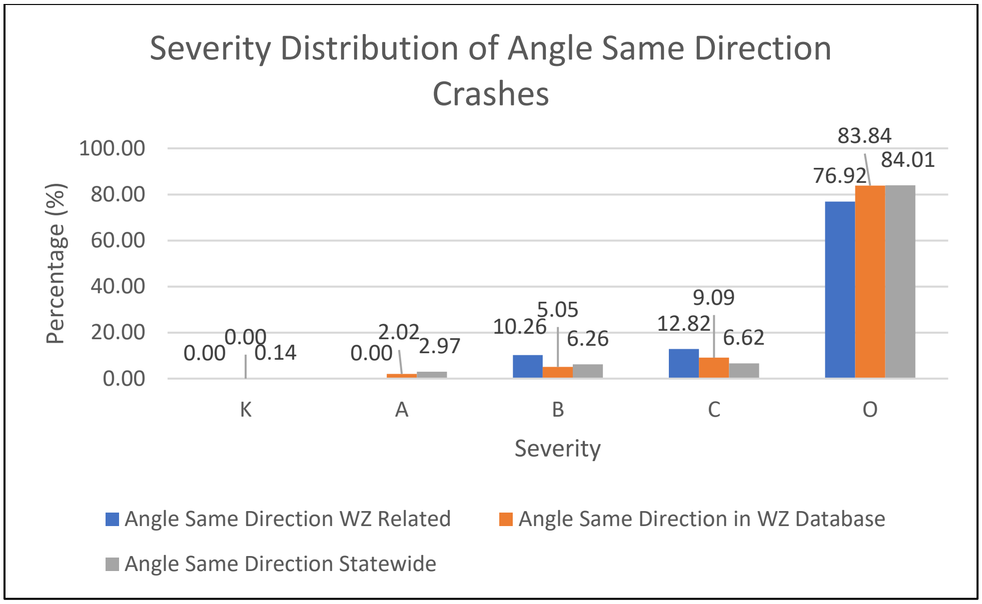

Figure 4-8: Severity Distribution of Angle Same Direction Crashes.

Table 4-10: K-S Test Results of Angle Same Direction Crashes

	Angle Same Direction Crash in WZ-Related Dataset	Angle Same Direction Crash in WZ Database	Angle Same Direction Crash in All Crashes
Angle Same Direction Crash in WZ Database	D-statistic: 0.0692 D-critical: **0.2501** p-value: 0.9989 Not Significantly Different		
Angle Same Direction Crash in All Crashes	D-statistic: 0.0709 D-critical: **0.2130** p-value: 0.9869 Not Significantly Different	D-statistic: 0.0230 D-critical: **0.1351** p-value: ≈1.0000 Not Significantly Different	

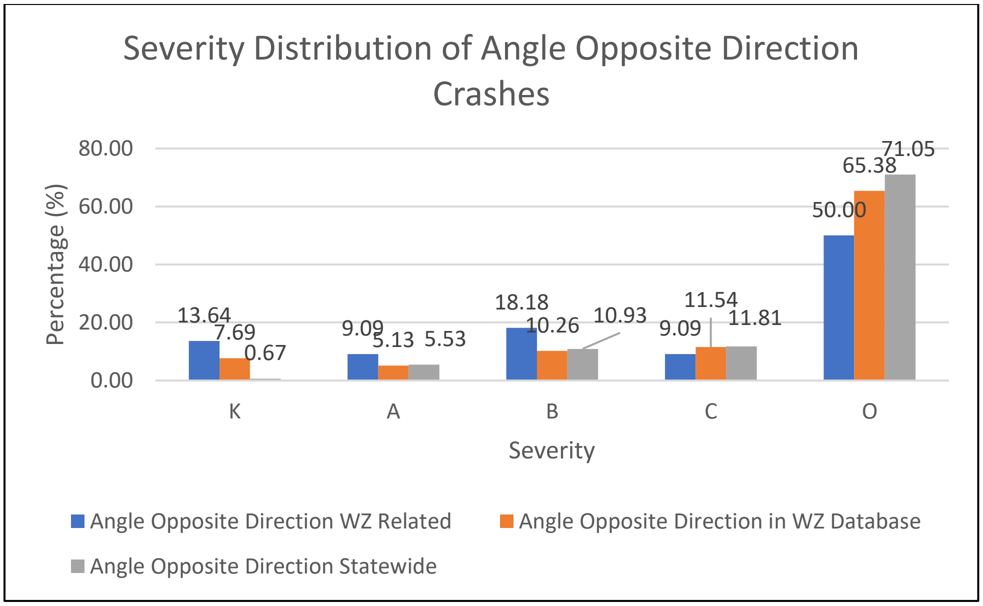

Figure 4-9: Severity Distribution of Angle Opposite Direction Crashes.

Table 4-11: K-S Test Results of Angle Opposite Direction Crashes

	Angle Opposite Direction Crash in WZ-Related Dataset	Angle Opposite Direction Crash in WZ Database	Angle Opposite Direction Crash in All Crashes
Angle Opposite Direction Crash in WZ Database	D-statistic: 0.1783 D-critical: **0.3166** p-value: 0.6023 Not Significantly Different		
Angle Opposite Direction Crash in All Crashes	D-statistic: 0.2378 D-critical: **0.2811** p-value: 0.1428 Not Significantly Different	D-statistic: 0.0702 D-critical: **0.1518** p-value: 0.8250 Not Significantly Different	

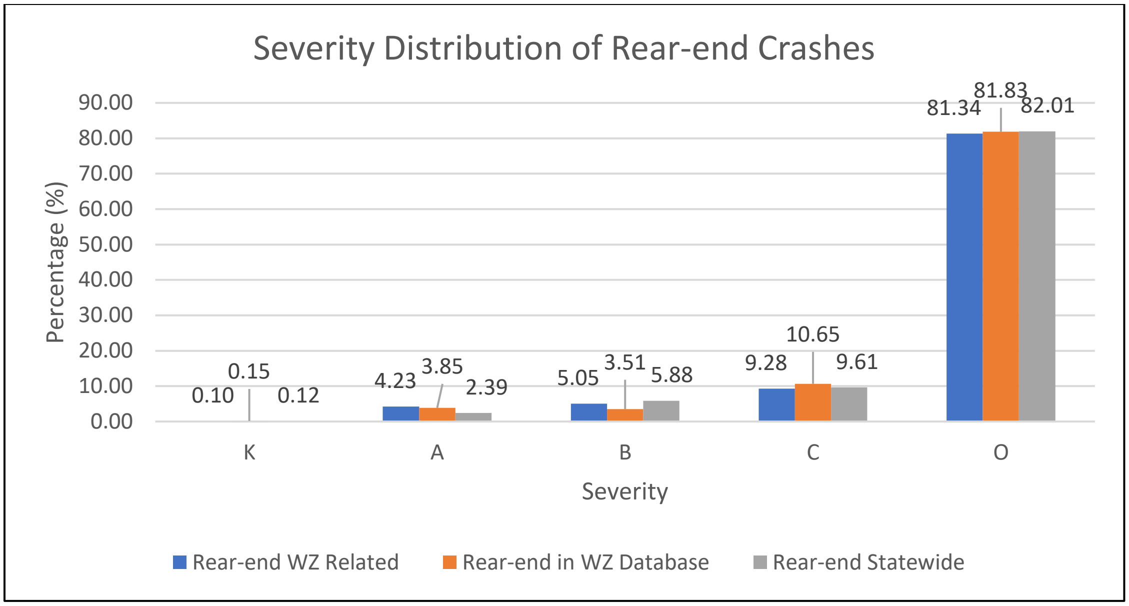

Figure 4-10: Severity Distribution of Rear-end Crashes.

Table 4-12: K-S Test Results of Rear-end Crashes

	Rear-end Crash in WZ-Related Dataset	Rear-end Crash in WZ Database	Rear-end Crash in All Crashes
Rear-end Crash in WZ Database	D-statistic: 0.0186 D-critical: **0.0507** p-value: 0.9647 Not Significantly Different		
Rear-end Crash in All Crashes	D-statistic: 0.0183 D-critical: **0.0435** p-value: 0.9017 Not Significantly Different	D-statistic: 0.0150 D-critical: **0.0265** p-value: 0.5948 Not Significantly Different	

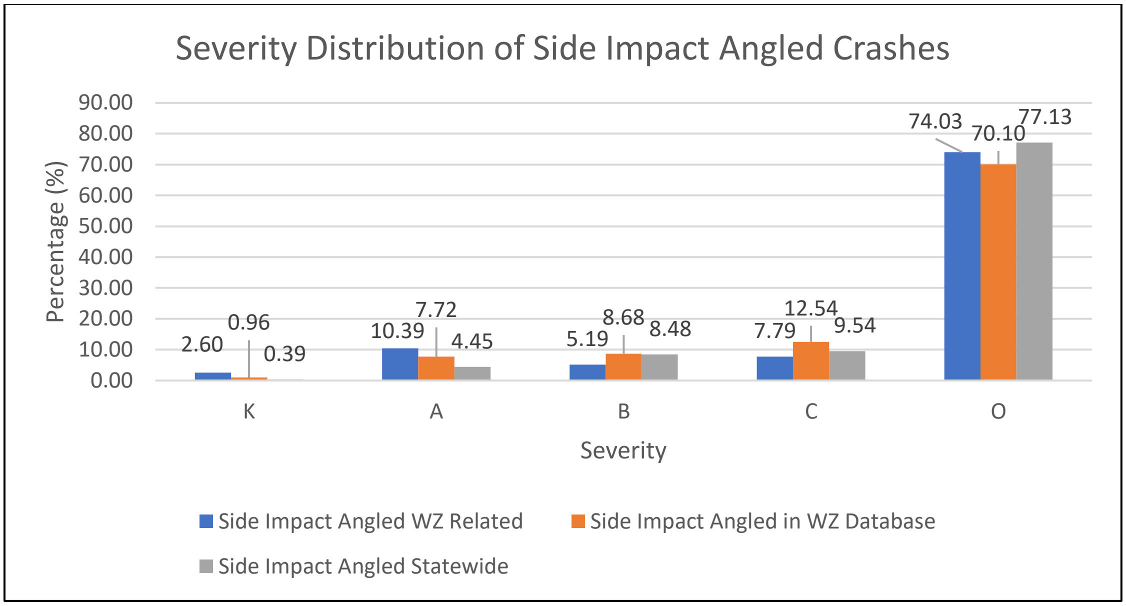

Figure 4-11: Severity Distribution of Side Impact Angled Crashes.

Table 4-13: K-S Test Results of Side Impact Angled Crashes

	Side Impact Angled Crash in WZ-Related Dataset	Side Impact Angled Crash in WZ Database	Side Impact Angled Crash in All Crashes
Side Impact Angled Crash in WZ Database	D-statistic: 0.0431 D-critical: **0.1700** p-value: 0.9998 Not Significantly Different		
Side Impact Angled Crash in All Crashes	D-statistic: 0.0815 D-critical: **0.1526** p-value: 0.6687 Not Significantly Different	D-statistic: 0.0703 D-critical: **0.0767** p-value: 0.0902 Not Significantly Different	

Table 4-14 shows the K-S test results for side impact 90-degree crashes, and it is found that the distribution of this type of crash in WZ Database is significantly different than in All Crashes. According to Figure 4-12, the proportion of fatal crashes and incapacitating injury crashes in work zones identified by reporting law enforcement officers is greater than statewide fatal and incapacitating injury crashes.

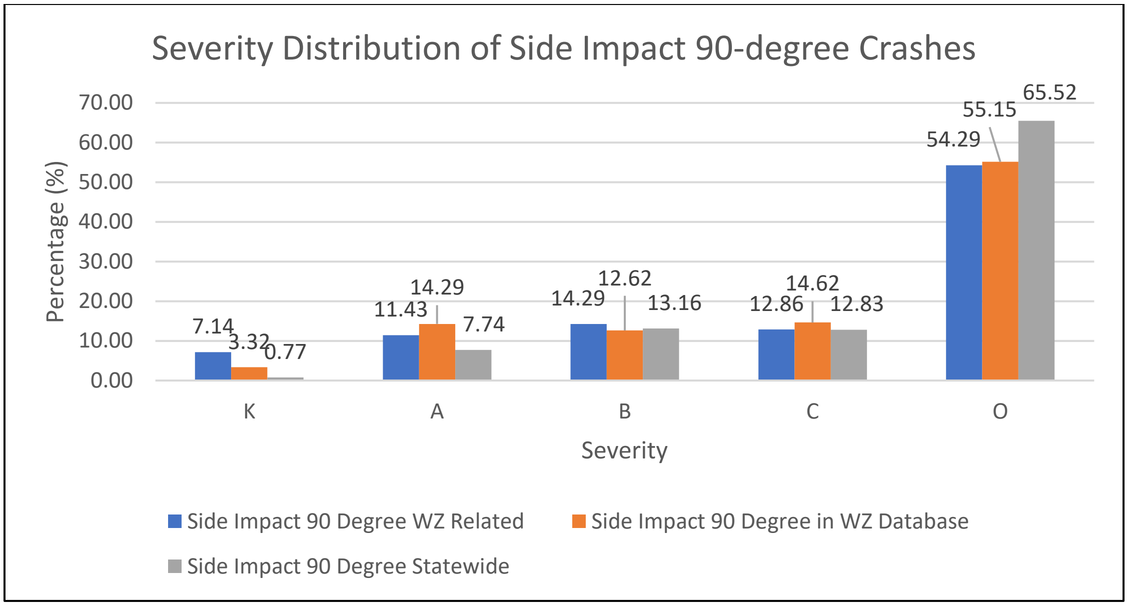

Figure 4-12: Severity Distribution of Side Impact 90-degree Crashes.

Table 4-14: K-S Test Results of Side Impact 90-degree Crashes

	Side Impact 90-degree Crash in WZ-Related Dataset	Side Impact 90-degree Crash in WZ Database	Side Impact 90-degree Crash in All Crashes
Side Impact 90-degree Crash in WZ Database	D-statistic: 0.0382 D-critical: **0.1771** p-value: 1.0000 Not Significantly Different		
Side Impact 90-degree Crash in All Crashes	D-statistic: 0.1123 D-critical: **0.1599** p-value: 0.3227 Not Significantly Different	D-statistic: **0.1037** D-critical: 0.0779 p-value: 0.0029 Significantly Different	

For side swipe same direction crashes, the percentage of injury and fatal crashes in both work zones and non-work zones are extremely low as shown in Figure 4-13, with very high and close proportions for PDO crashes. Also, the statistical results shown in Table 4-15 determine that none of the null hypothesis is rejected, and the distributions are not significantly different.

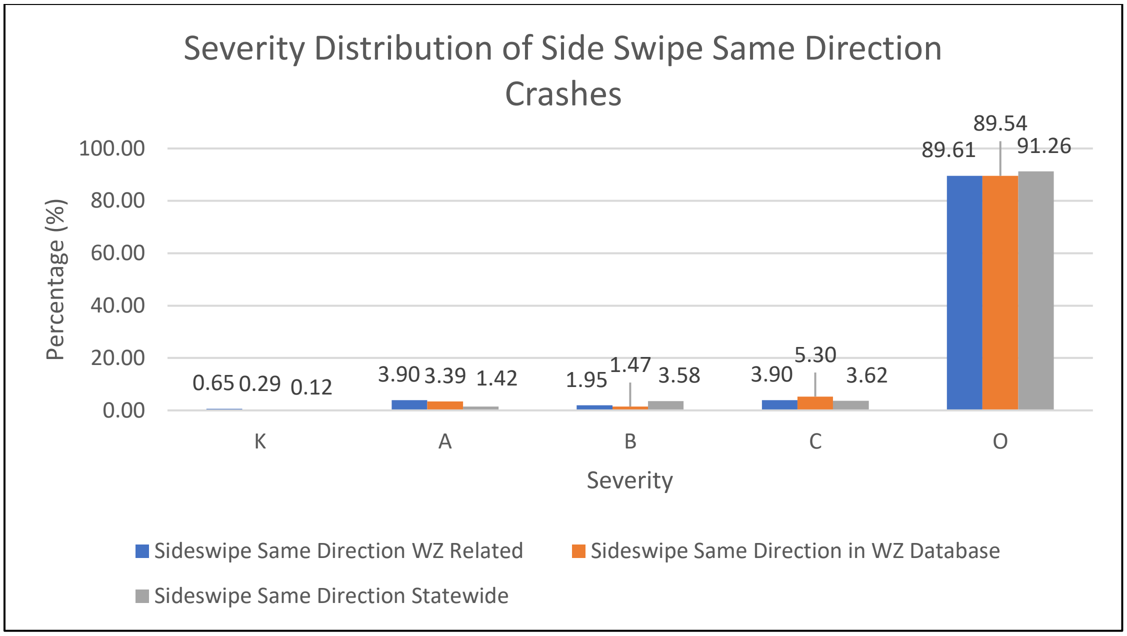

Figure 4-13: Severity Distribution of Side Swipe Same Direction Crashes.

Table 4-15: K-S Test Results of Side Swipe Same Direction Crashes

	Side Swipe Same Direction Crash in WZ-Related Dataset	Side Swipe Same Direction Crash in WZ Database	Side Swipe Same Direction Crash in All Crashes
Side Swipe Same Direction Crash in WZ Database	D-statistic: 0.0134		
	D-critical: **0.0925**		
	p-value: ≈1.0000		
	Not Significantly Different		
Side Swipe Same Direction Crash in All Crashes	D-statistic: 0.0301	D-statistic: 0.0215	
	D-critical: **0.0771**	D-critical: **0.0523**	
	p-value: 0.9415	p-value: 0.9153	
	Not Significantly Different	Not Significantly Different	

4.5 Comparison of Severity Distributions between Crash Types in Work Zones

To study the significant differences between crash types in work zone, comparisons were implemented for each two crash types in both WZ-Related Dataset and WZ Database. Since nine crash types were being studied, total 36 comparisons were done for each dataset.

Figure 4-14 shows the severity distribution for each crash type within WZ-Related Dataset. It can be found that the proportion of head-on crashes that are fatal is significantly greater than other crash types, and the proportion of incapacitating injury for head-on and angle oncoming crashes is greater than others. Also, the percentage of PDO crashes for angle opposite direction and side impact 90-degree crashes is much lower, which means the total proportion of injury and fatal crashes of them is greater. These lead to a speculation that the distributions of head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes are statistically different than others.

Table 4-16 displays the results of 36 comparisons for WZ-Related Dataset. For the results of each comparison, the first value is the D-statistic, followed by the D-critical in the parenthesis. The p-value is shown below the D-statistic and D-critical, which is marked with yellow when there is significant difference of the comparison, indicating that D-statistic is greater than D-critical, and the p-value is smaller than $\alpha = 0.05$. It should be noted that the smaller the p-value, the more significant difference between the two severity distributions. These comparisons include single vehicle crash versus head-on, rear-end, and sideswipe same direction crashes, respectively; head-on crashes versus angle oncoming, angle same direction, rear-end, side impact angled, side impact 90-degree, and sideswipe same direction crashes, respectively; angle oncoming crashes versus rear-end and sideswipe same direction crashes, respectively; angle opposite direction crashes versus rear-end and sideswipe same direction crashes, respectively; rear-end crashes versus side impact 90-degree crashes; and side impact 90-degree crashes versus sideswipe same direction crashes. From these comparisons, it is discovered that rear-end and sideswipe same direction crashes are frequently involved into comparisons which have significantly different distributions. Furthermore, rear-end and sideswipe same direction crashes have higher proportion of PDO crashes than other crash types as shown in Figure 4-14. This is concluded that crashes that are significantly different than rear-end and sideswipe same direction crashes statistically involved higher proportion of injury and fatal crashes, and those crash types are single vehicle, head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes.

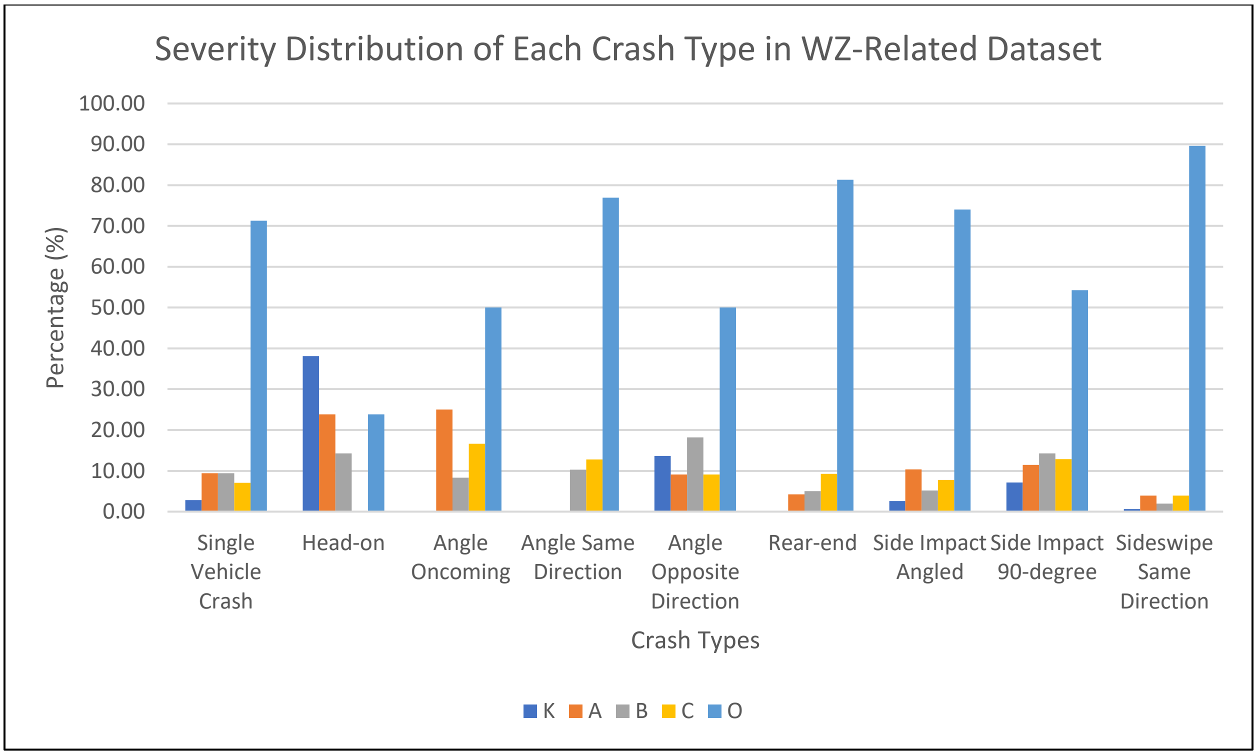

Figure 4-14: Severity Distribution of Crash Types within WZ-Related Dataset.

Table 4-16: Comparison Results between Each Two Crash Types within WZ-Related Dataset

	Single Vehicle Crash	Head-on	Angle Oncoming	Angle Same Direction	Angle Opposite Direction	Rear-end	Side Impact Angled	Side Impact 90-degree
Head-on	0.5450 (0.2931)							
	< 0.0001							
Angle Oncoming	0.2129 (0.2756)	0.4286 (0.3881)						
	0.2212	0.0222						
Angle Same Direction	0.1225 (0.2207)	0.6593 (0.3533)	0.2692 (0.3393)					
	0.6211	< 0.0001	0.1958					
Angle Opposite Direction	0.2129 (0.2869)	0.3918 (0.3958)	0.1364 (0.3836)	0.3065 (0.3483)				
	0.2619	0.0539	0.9739	0.1148				
Rear-end	0.1231 (0.0744)	0.6681 (0.2903)	0.3134 (0.2726)	0.0442 (0.2169)	0.3153 (0.2840)			
	< 0.0001	< 0.0001	0.0153	1.0000	0.0212			
Side Impact Angled	0.0350 (0.1636)	0.5801 (0.3227)	0.2403 (0.3070)	0.1299 (0.2597)	0.2403 (0.3171)	0.0880 (0.1583)		
	1.0000	< 0.0001	0.2087	0.7456	0.2401	0.6188		
Side Impact 90-degree	0.1700 (0.1704)	0.4333 (0.3260)	0.0714 (0.3105)	0.2264 (0.2639)	0.0805 (0.3204)	0.2705 (0.1653)	0.1974 (0.2193)	
	0.0510	0.0029	1.0000	0.1324	0.9998	0.0001	0.1006	
Sideswipe Same Direction	0.1833 (0.0975)	0.6970 (0.2966)	0.3961 (0.2793)	0.1269 (0.2255)	0.3961 (0.2905)	0.0827 (0.0881)	0.1558 (0.1701)	0.3532 (0.1767)
	< 0.0001	< 0.0001	0.0012	0.6035	0.0021	0.0774	0.0905	< 0.0001

Figure 4-15 includes the crash severity distribution for each crash type in WZ Database. Head-on and angle oncoming crashes are also found to have higher proportion of fatal and incapacitating injury crashes, while angle same direction, rear-end, and sideswipe same direction crashes have higher proportion of PDO crashes. The K-S test results are shown in Table 4-17, which has 27 comparisons (75% of the total comparisons) with null hypothesis being rejected. This means that each crash type is significantly different than most of the crash types (more than 4 out of 8) that it is compared with, except for angle same direction and angle opposite direction crashes-these two “only” have four crash types that are significantly different from them, respectively. The distributions of single vehicle, head-on, angle oncoming, and side impact 90-degree crashes are significantly different than 6, 8, 7, and 6 crash types, respectively. Referring to the severity distributions in Figure 4-15, it is seen that the percentage of PDO crashes for these crash types is relatively low, and the percentage of injury and fatal crashes is higher. So, these four crash types are of greater concern than other crash types in work zones as identified by the ALDOT project engineers. Also, the distributions of rear-end and sideswipe same direction crashes are significantly different than 7 other crash types, respectively. However, these two crash types are of lesser concern than others since the proportion of PDO crashes of them is higher than most of others and they are considered as low-severity crash types.

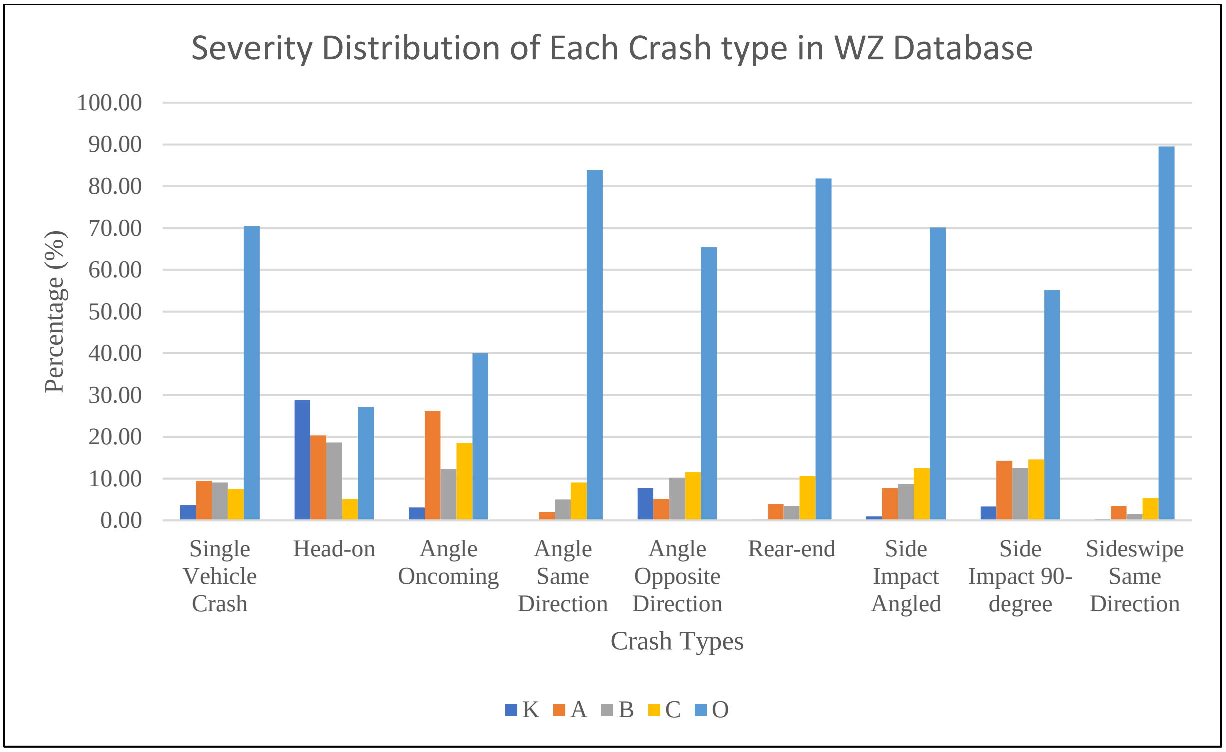

Figure 4-15: Severity Distribution of Crash Types within WZ Database.

Table 4-17: Comparison Results between Each Two Crash Types within WZ Database

	Single Vehicle Crash	Head-on	Angle Oncoming	Angle Same Direction	Angle Opposite Direction	Rear-end	Side Impact Angled	Side Impact 90-degree
Head-on	0.4569 (0.1787)							
	< 0.0001							
Angle Oncoming	0.3045 (0.1709)	0.2626 (0.2382)						
	< 0.0001	0.0226						
Angle Same Direction	0.1504 (0.1412)	0.6073 (0.2184)	0.4384 (0.2122)					
	0.0304	< 0.0001	< 0.0001					
Angle Opposite Direction	0.0507 (0.1572)	0.4472 (0.2288)	0.2538 (0.2229)	0.1845 (0.2014)				
	0.9908	< 0.0001	0.0167	0.0905				
Rear-end	0.1459 (0.0503)	0.6028 (0.1757)	0.4183 (0.1677)	0.0201 (0.1372)	0.1644 (0.1537)			
	< 0.0001	≈ 0	< 0.0001	≈ 1	0.0293			
Side Impact Angled	0.0475 (0.0875)	0.5043 (0.1892)	0.3010 (0.1819)	0.1374 (0.1544)	0.0673 (0.1691)	0.1173 (0.0808)		
	0.6495	< 0.0001	< 0.0001	0.1075	0.9322	0.0008		
Side Impact 90-degree	0.1530 (0.0886)	0.3756 (0.1897)	0.1515 (0.1824)	0.2869 (0.1550)	0.1024 (0.1697)	0.2668 (0.0820)	0.1495 (0.1087)	
	< 0.0001	< 0.0001	0.1568	< 0.0001	0.5131	≈ 0	0.0019	
Sideswipe Same Direction	0.1909 (0.0672)	0.6264 (0.1810)	0.4954 (0.1733)	0.0571 (0.1441)	0.2416 (0.1598)	0.0772 (0.0581)	0.1945 (0.0922)	0.3439 (0.0932)
	< 0.0001	≈ 0	< 0.0001	0.9345	0.0004	0.0030	< 0.0001	≈ 0

4.6 Summary of Analysis

In the descriptive analysis, tables and pie charts were developed to display the severity distribution of each crash type in three different databases: WZ-Related Dataset, WZ Database, and All Crashes, in which nine crash types were considered for analysis. In WZ-Related Dataset, head-on and angle oncoming crashes were found to be the dominant crash types for fatal crashes and incapacitating injury crashes, respectively. For non-incapacitating injury, angle opposite direction crashes resulted in the highest percentage among all crash types, and for crashes involving possible injuries, it is angle oncoming. For PDO crashes, sideswipe same direction crashes have the largest percentage in that severity category. In WZ Database, the most frequent crash type for each severity category following the KABCO order is head-on, angle oncoming, head-on, angle oncoming, and sideswipe same direction, respectively. In All Crashes, head-on crashes have the highest percentage of fatal, incapacitating injury, and non-incapacitating injury, while side impact 90-degree crashes resulted in the highest percentage of possible injury crashes, and the percentage of sideswipe same direction PDO crashes is the highest among all crash types.

After excluding crashes with unknown severity from the K-S test analysis, cumulative proportions of five severity categories for each crash type in three different conditions were computed. Through the analysis of comparison between each two conditions for every crash type, the null hypothesis is rejected and two distributions are significantly different if p-value is smaller than the significance level of α = 0.05. Table 4-18 summarizes significant differences found in Tables 4-7 through 4-15.

Table 4-18: Summary Table of Statistically Significant Differences at α = 0.05

	WZ-Related Dataset vs. WZ Database	WZ Database vs. All Crashes	WZ-Related Dataset vs. All Crashes
Single Vehicle Crash	No	**Yes**	No
Head-on	No	**Yes**	**Yes**
Angle Oncoming	No	**Yes**	No
Angle Same Direction	No	No	No
Angle Opposite Direction	No	No	No
Rear-end	No	No	No
Side Impact Angled	No	No	No
Side Impact 90-degree	No	**Yes**	No
Sideswipe Same Direction	No	No	No

It can be found that 5 out of 27 comparisons have significant differences, which are shown in the following bulleted list. The p-value for each of the five comparisons is 0.0069, < 0.0001, 0.0002, 0.0005, and 0.0029, respectively. Therefore, crash type that is significantly more severe is head-on crashes in WZ Database, followed by head-on crashes in WZ-Related Dataset, angle oncoming crashes in WZ Database, side impact 90-degree crashes in WZ Database, and single vehicle crashes in WZ Database. One potential reason that more crash types in WZ Database have statistically significant differences when compared with all crashes than WZ-Related Dataset is that there are differences in sample size between these two databases due to broader criteria for identifying a crash as work zone related by ALDOT than by reporting law enforcement officers.

- Single vehicle crash in WZ Database versus All Crashes.
- Head-on crash in WZ Database versus All Crashes.
- Head-on crash in WZ-Related Dataset versus All Crashes.
- Angle oncoming crash in WZ Database versus All Crashes.
- Side impact 90-degree crash in WZ Database versus All Crashes.

The second analysis was carried out for the comparison between two different crash types in WZ-Related Dataset and WZ Database, which includes 36 comparisons, respectively. For the crashes that occurred within work zones as identified by reporting law enforcement officers as shown in Table 4-16, 15 comparisons have the result of significant difference, in which rear-end and sideswipe same direction crashes are frequently involved. Based on the severity distribution shown in Figure 4-14, crash types significantly different than rear-end and sideswipe same direction crashes were estimated to involve higher level of injuries, which are single vehicle, head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes. For the crashes that occurred within work zones on projects ongoing managed by ALDOT as shown in Table 4-17, 27 comparisons have null hypothesis rejected. In these cases, each crash type is significantly different than several other crash types being compared with. The histogram of severity distribution in Figure 4-15 shows that single vehicle, head-on, angle oncoming, and side impact 90-degree crashes have higher proportion of fatal and injury crashes. In addition, based on the number of crash types that are significantly different, these crash types were estimated to be of greatest concern, followed by side impact angled, angle same direction, and angle opposite direction crashes. Although rear-end and sideswipe same direction crashes are significantly different than most of other crash types, they were treated as crash types with low severity due to much higher percentage of PDO crashes.

CHAPTER FIVE:
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The purpose of this research was to determine the significance of differences in crash severity distribution between various work zone and non-work zone conditions, and between different crash types in work zones, to figure out which crash types should be of greater concern and help transportation agencies in Alabama devote resources on those crash types that are significantly different than others. Previous research efforts were reviewed to understand work zone crash studies as well as support the comparisons of work zone crash characteristics between Alabama and other states. Moreover, the methods to tidy and analyze the dataset, the mathematical theory of the two-sample K-S test, and the employed software for the study were discussed. In the end, the descriptive analysis of the datasets, and the comparisons of significant differences in crash severity distribution were developed.

5.2 Conclusions

This study revolves around three variables: crash type, crash severity, and extent to which a crash may be work zone related. Also, two research questions based on these variables were examined: the study of significant differences in crash severity between work zone and non-work zone conditions for each crash type, as well as between crash types in the work zones. The analysis was implemented using Microsoft Excel and an add-in called Real Statistics Using Excel. Since the reporting law enforcement officers and ALDOT used different criteria to identify work zones, the "Work Zone Related" field in the electronic work zone crash database was examined according to the different judgement by them to create two datasets: work zone-related database and work zone crashes entire database, in which "Crash Severity" and "Manner of Crash" fields were investigated to determine the number of crashes by KABCO injury scale for each crash type. For crashes occurring in non-work zones, the number of crashes for different crash types by severity category was retrieved from the online version of CARE. The proportions of the obtained values constituted three datasets that were compared with each other using the K-S test functions in Real Statistics Using Excel. The major findings of the comparisons are shown in the bulleted list below:

- The severity distribution of single vehicle crashes in WZ Database is significantly different than that in All Crashes (p-value = 0.0069).
- The severity distribution of head-on crashes in WZ-Related Dataset is significantly different than that in All Crashes (p-value = 0.0002).
- The severity distribution of head-on crashes in WZ Database is significantly different than that in All Crashes (p-value < 0.0001).
- The severity distribution of angle oncoming crashes in WZ Database is significantly different than that in All Crashes (p-value = 0.0005).
- The severity distribution of side impact 90-degree crashes in WZ Database is significantly different than that in All Crashes (p-value = 0.0029).
- In WZ-Related Dataset, the severity distribution of single vehicle crashes is significantly different than the severity distribution of head-on crashes, rear-end crashes, and sideswipe same direction crashes, respectively.

- In WZ-Related Dataset, the severity distribution of head-on crashes is significantly different than the severity distribution of angle oncoming crashes, angle same direction crashes, rear-end crashes, side impact angled crashes, side impact 90-degree crashes, and sideswipe same direction crashes, respectively.
- In WZ-Related Dataset, the severity distribution of angle oncoming crashes is significantly different than the severity distribution of rear-end crashes and sideswipe same direction crashes, respectively.
- In WZ-Related Dataset, the severity distribution of angle opposite direction crashes is significantly different than the severity distribution of rear-end crashes and sideswipe same direction crashes, respectively.
- In WZ-Related Dataset, the severity distribution of rear-end crashes is significantly different than the severity distribution of side impact 90-degree crashes.
- In WZ-Related Dataset, the severity distribution of side impact 90-degree crashes is significantly different than the severity distribution of sideswipe same direction crashes.
- In WZ Database, the severity distribution of single vehicle crashes is significantly different than the severity distribution of head-on crashes, angle oncoming crashes, angle same direction crashes, rear-end crashes, side impact 90-degree crashes, and sideswipe same direction crashes, respectively.
- In WZ Database, the severity distribution of head-on crashes is significantly different than the severity distribution of angle oncoming crashes, angle same direction crashes, angle opposite direction crashes, rear-end crashes, side impact angled crashes, side impact 90-degree crashes, and sideswipe same direction crashes, respectively.

- In WZ Database, the severity distribution of angle oncoming crashes is significantly different than the severity distribution of angle same direction crashes, angle opposite direction crashes, rear-end crashes, side impact angled crashes, and sideswipe same direction crashes, respectively.
- In WZ Database, the severity distribution of angle same direction crashes is significantly different than the severity distribution of side impact 90-degree crashes.
- In WZ Database, the severity distribution of angle opposite direction crashes is significantly different than the severity distribution of rear-end crashes and sideswipe same direction crashes, respectively.
- In WZ Database, the severity distribution of rear-end crashes is significantly different than the severity distribution of side impact angled crashes, side impact 90-degree crashes, and sideswipe same direction crashes.
- In WZ Database, the severity distribution of side impact angled crashes is significantly different than the severity distribution of side impact 90-degree crashes and sideswipe same direction crashes.
- In WZ Database, the severity distribution of side impact 90-degree crashes is significantly different than the severity distribution of sideswipe same direction crashes.

In conclusion, crash types that are significantly more severe include single vehicle, head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes.

5.3 Recommendations and Future Research Goals

This research investigated the significant differences in severity distributions between work zone and non-work zone crashes as well as among different crash types within the work zone. The results of the findings can be used by state transportation agencies to devote resources on the crash types that are significantly different, to assist in addressing the issue of stagnant number of fatal crashes in the state in recent years through developing effective methods to reduce the occurrence of severe crashes. The following recommendations are provided for the state transportation agencies based on the findings of this research:

- Single vehicle, head-on, angle oncoming, and side impact 90-degree crashes in Alabama work zones are significantly more severe than each of those occurring in non-work zones in Alabama; single vehicle, head-on, angle oncoming, angle opposite direction, and side impact 90-degree crashes are significantly more severe than other crash types in Alabama work zones. ALDOT should focus on identifying countermeasures to reduce the severity of these crash types.

Future research goals can be developed from this project. Beyond the scope of the 5,424 crash records used in this study, more data will be collected to evaluate the accuracy of the crash types found to be significantly severer in this study and the effectiveness of the countermeasures figured out by ALDOT in the future, through determining the significance of differences between the severe crash types found in this study and other crash types in the work zones, as well as between work zone and non-work zone conditions in Alabama.

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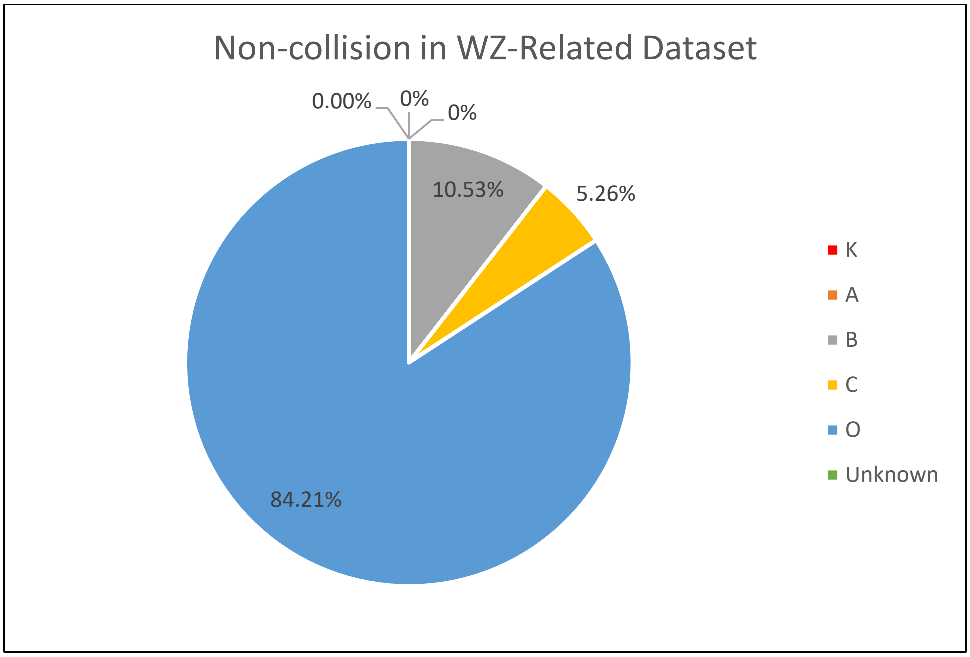
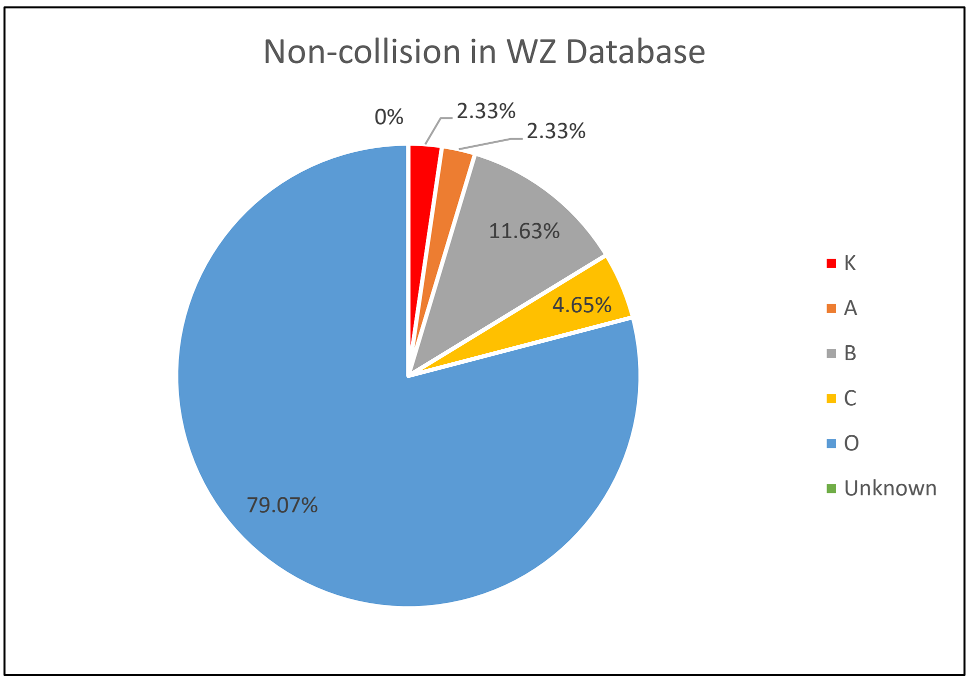
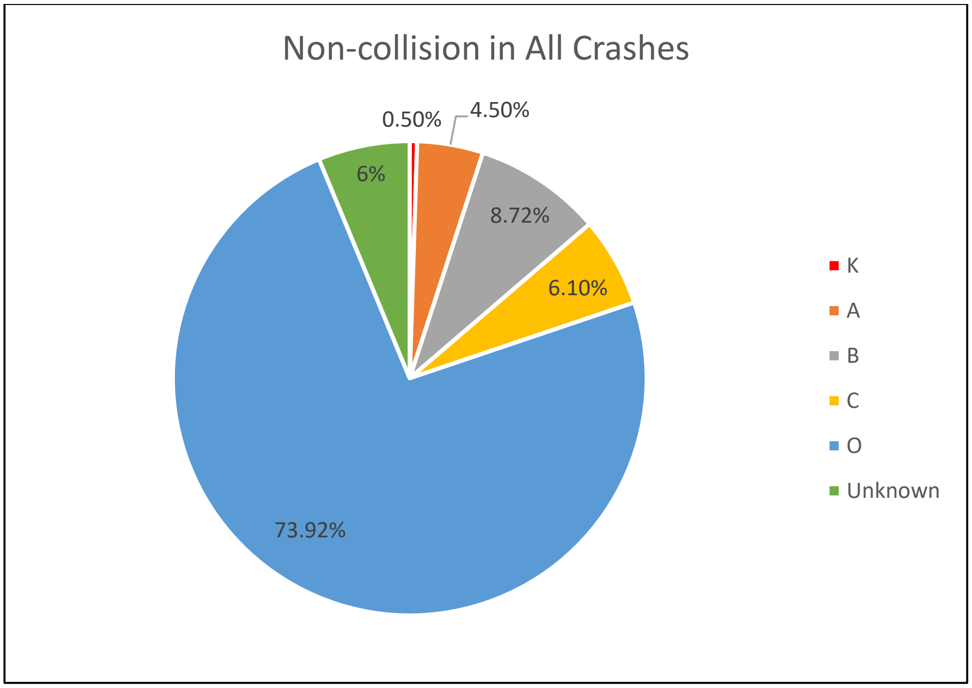
APPENDIX:

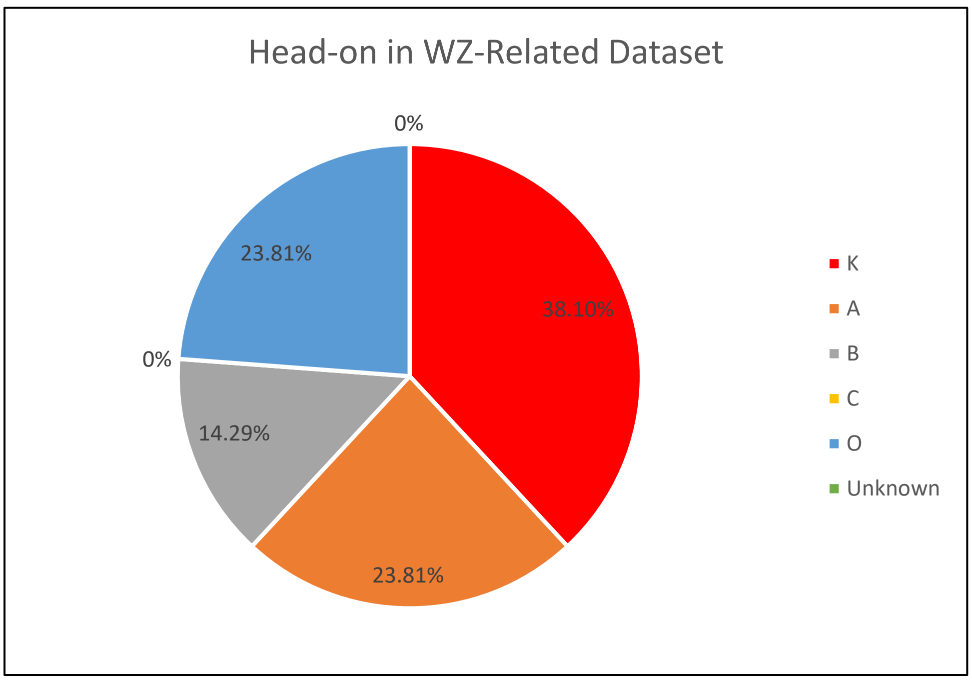
SEVERITY DISTRIBUTION OF CRASH TYPES IN WZ-RELATED DATASET, WZ DATABASE, AND ALL CRASHES


Non-collision in WZ-Related Dataset
0.00%
0%
0%
10.53%
5.26%
84.21%
K
A
B
C
O
Unknown

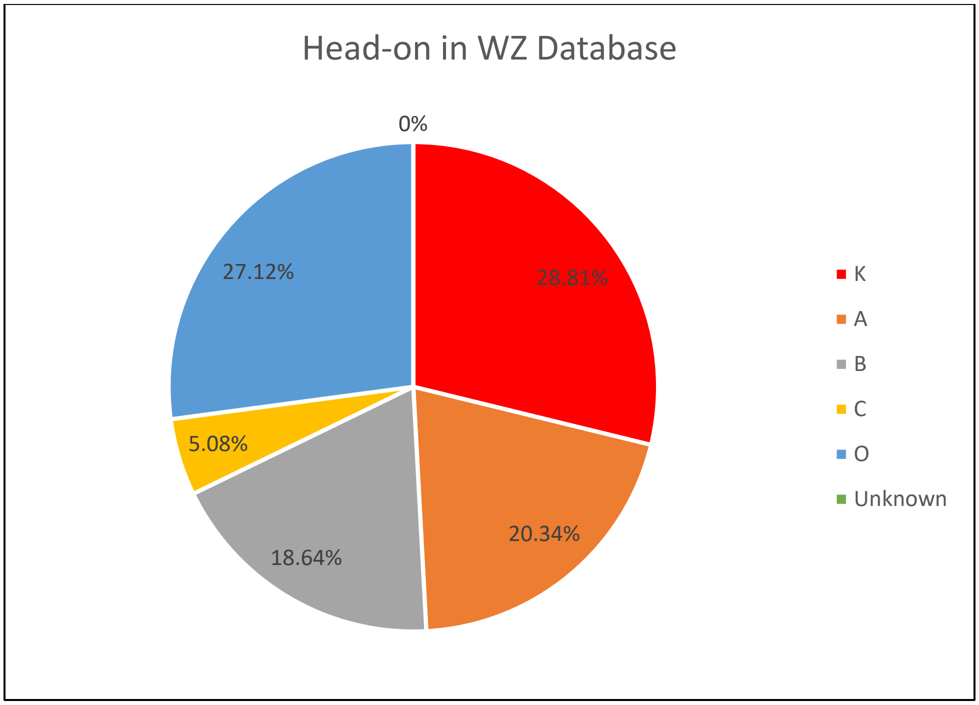

Non-collision in WZ Database
0%
2.33%
2.33%
11.63%
4.65%
79.07%
K
A
B
C
O
Unknown

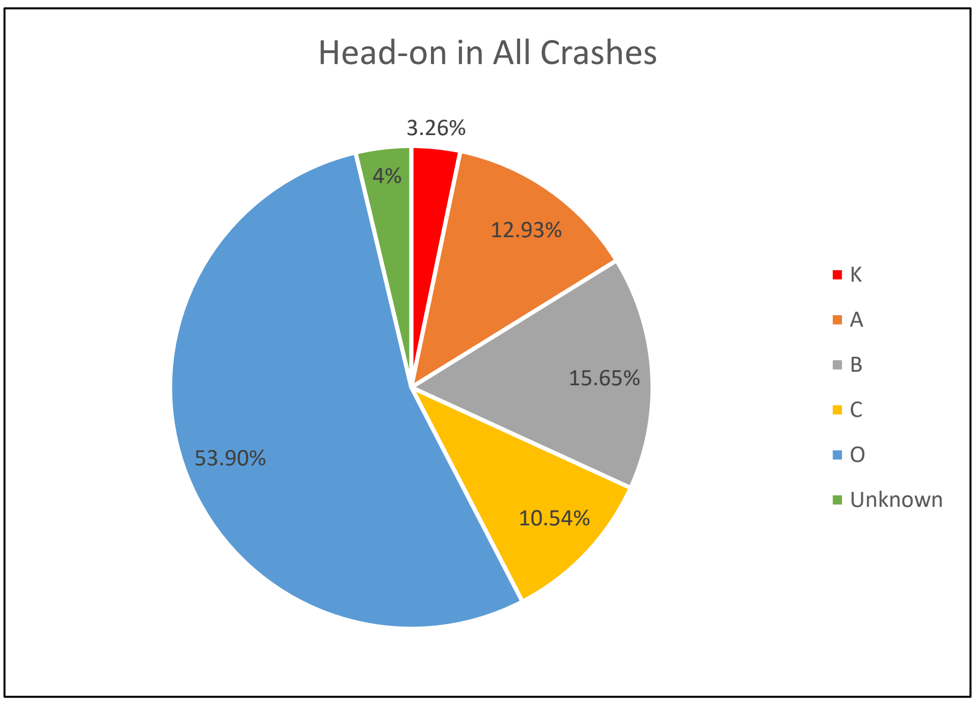


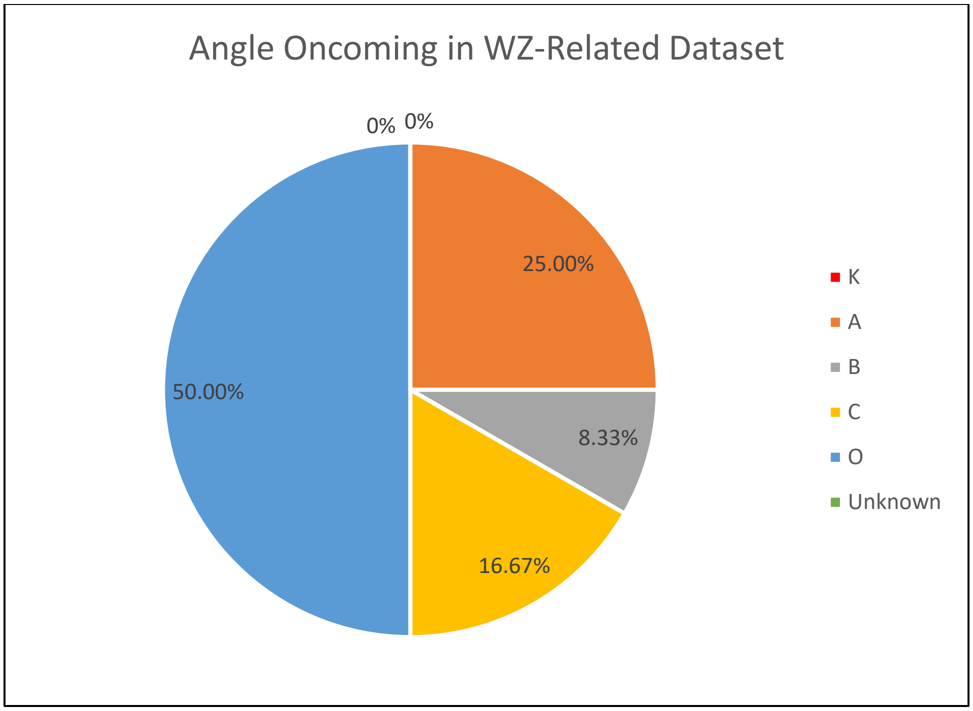
Non-collision in All Crashes
0.50%
4.50%
8.72%
6.10%
73.92%
6%
K
A
B
C
O
Unknown

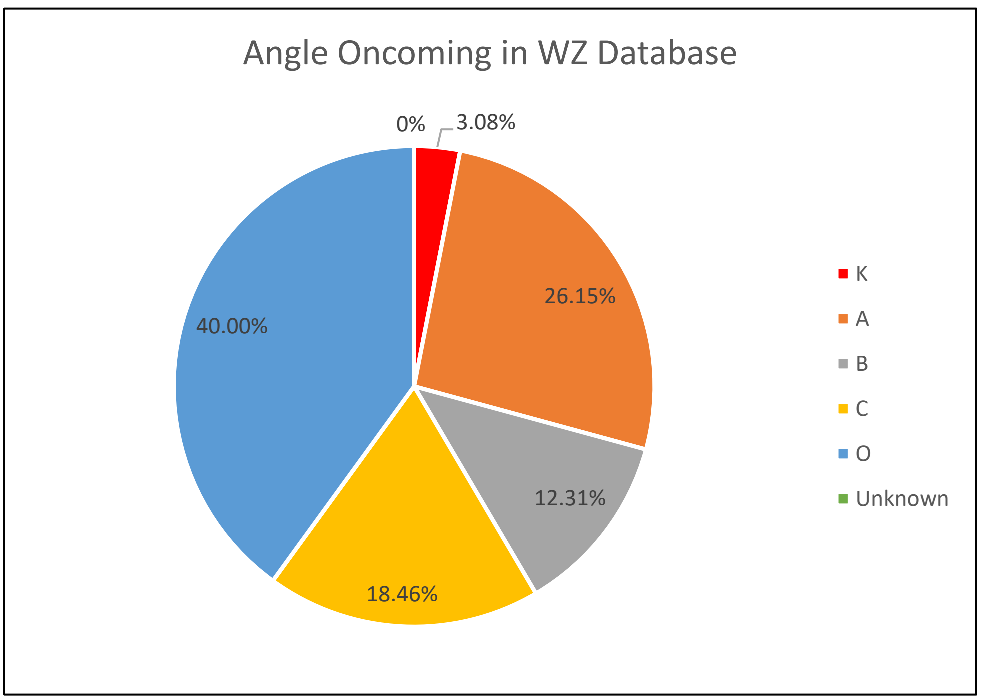


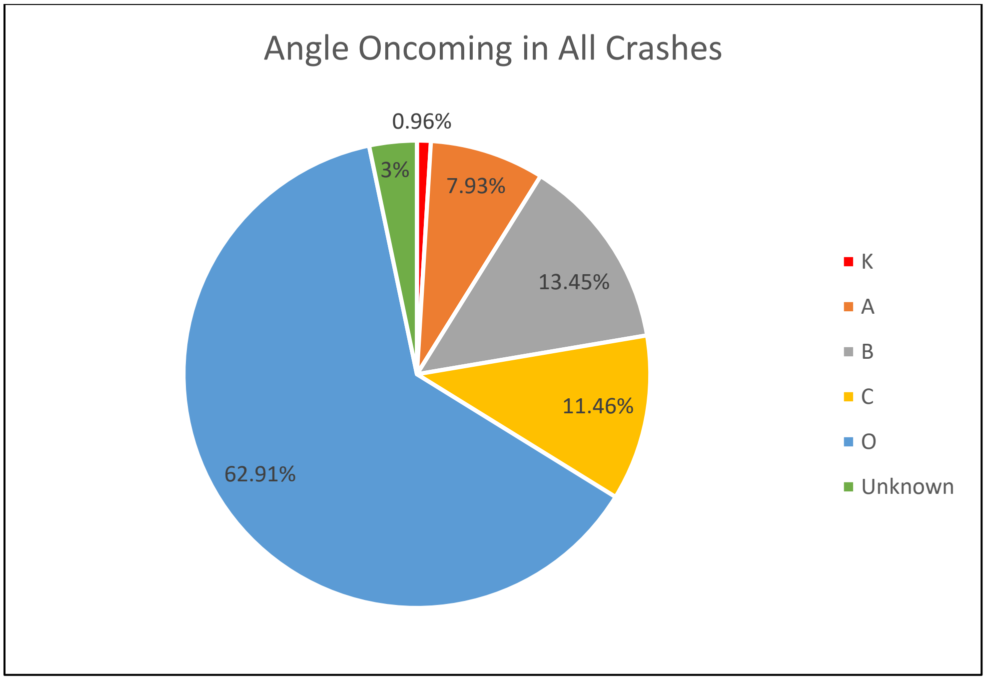
Head-on in WZ-Related Dataset
0%
38.10%
23.81%
14.29%
0%
23.81%
K
A
B
C
O
Unknown

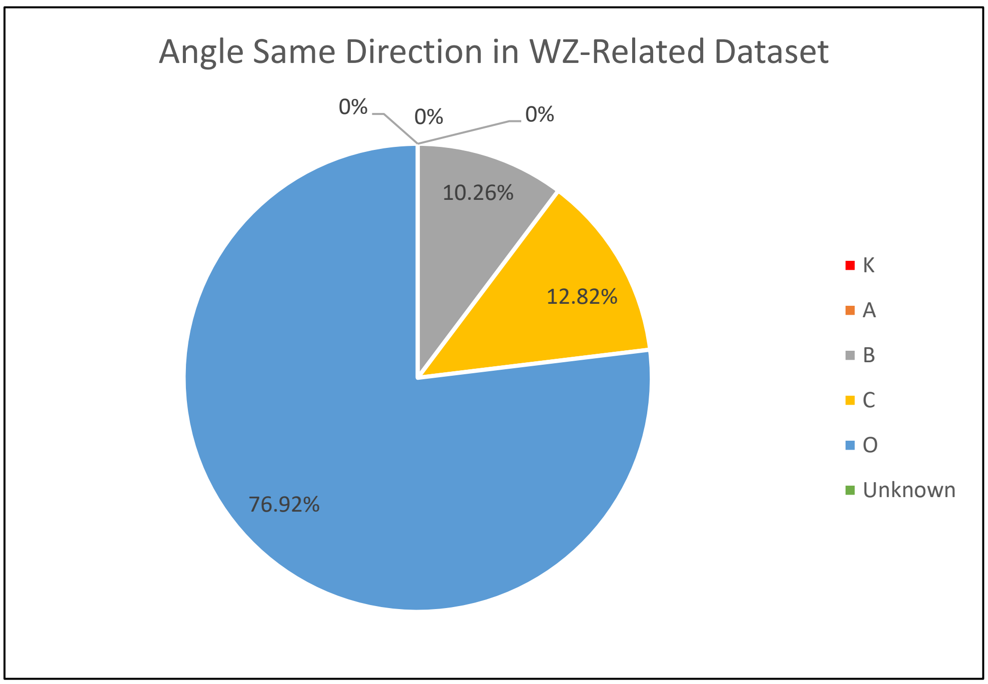

Head-on in WZ Database
0%
28.81%
27.12%
5.08%
18.64%
20.34%
K
A
B
C
O
Unknown

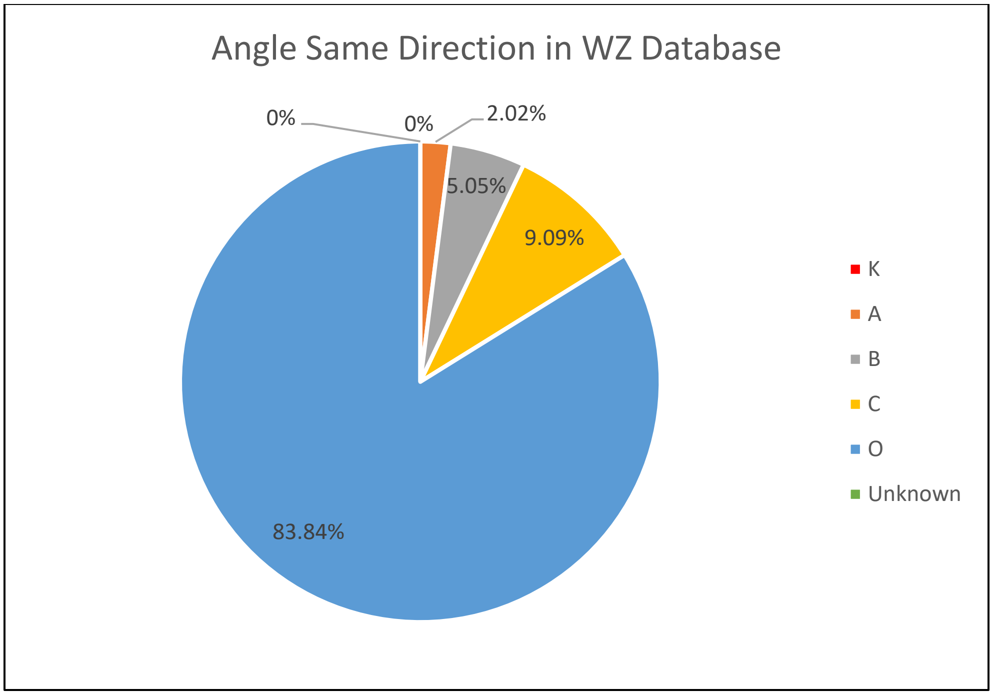

Head-on in All Crashes
3.26%
4%
12.93%
15.65%
53.90%
10.54%
K
A
B
C
O
Unknown

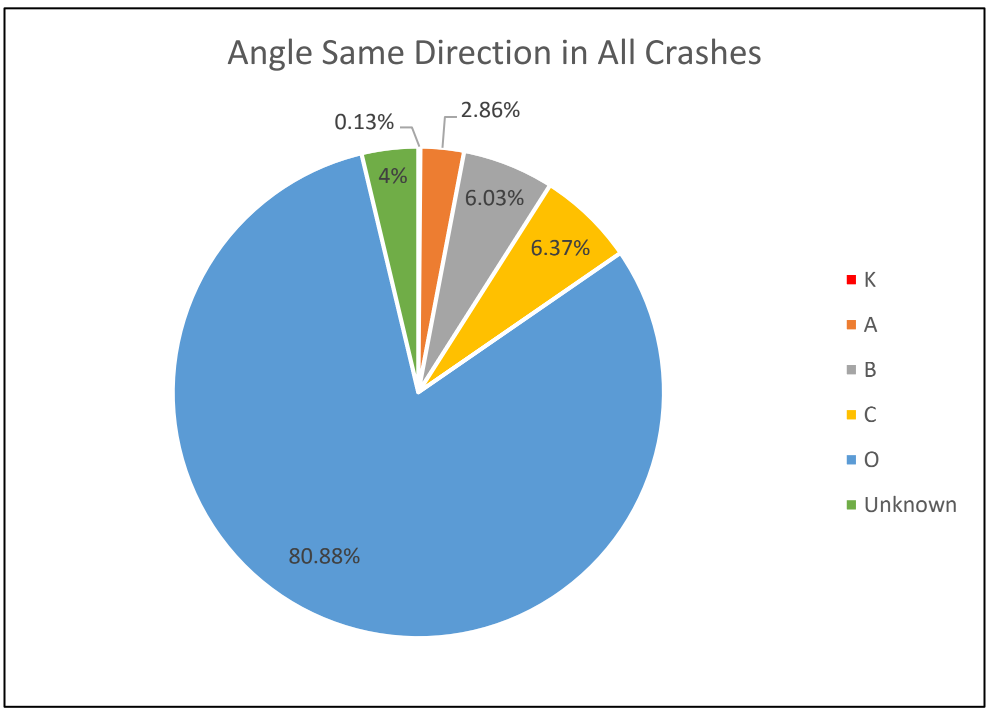

Angle Oncoming in WZ-Related Dataset
0%
0%
25.00%
8.33%
16.67%
50.00%
K
A
B
C
O
Unknown

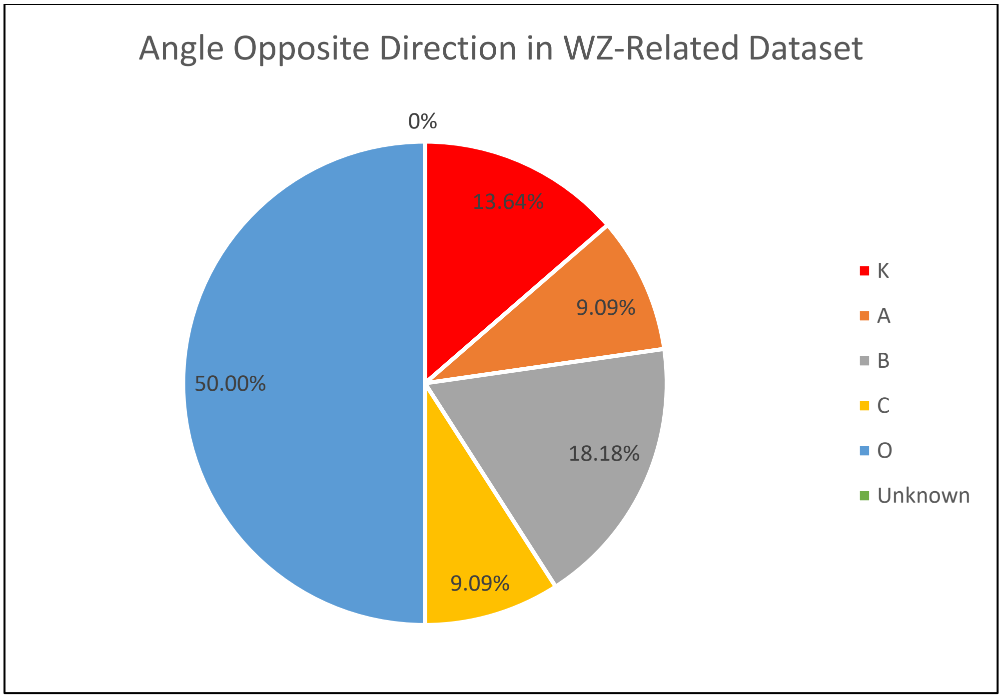

Angle Oncoming in WZ Database
0%
3.08%
26.15%
12.31%
18.46%
40.00%
K
A
B
C
O
Unknown

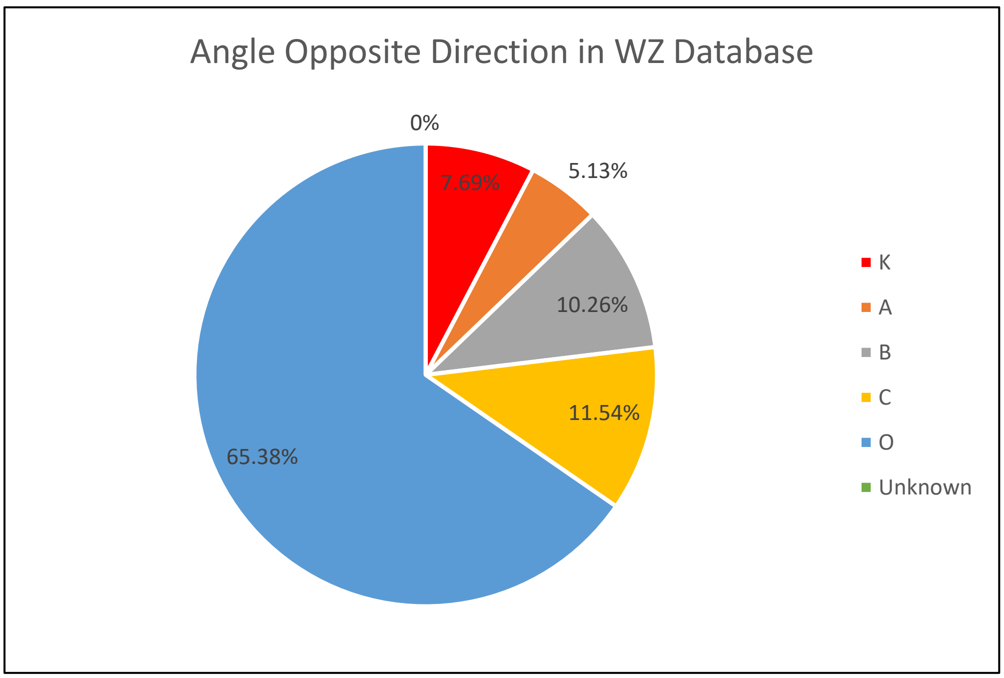

Angle Oncoming in All Crashes
0.96%
3%
7.93%
13.45%
11.46%
62.91%
K
A
B
C
O
Unknown

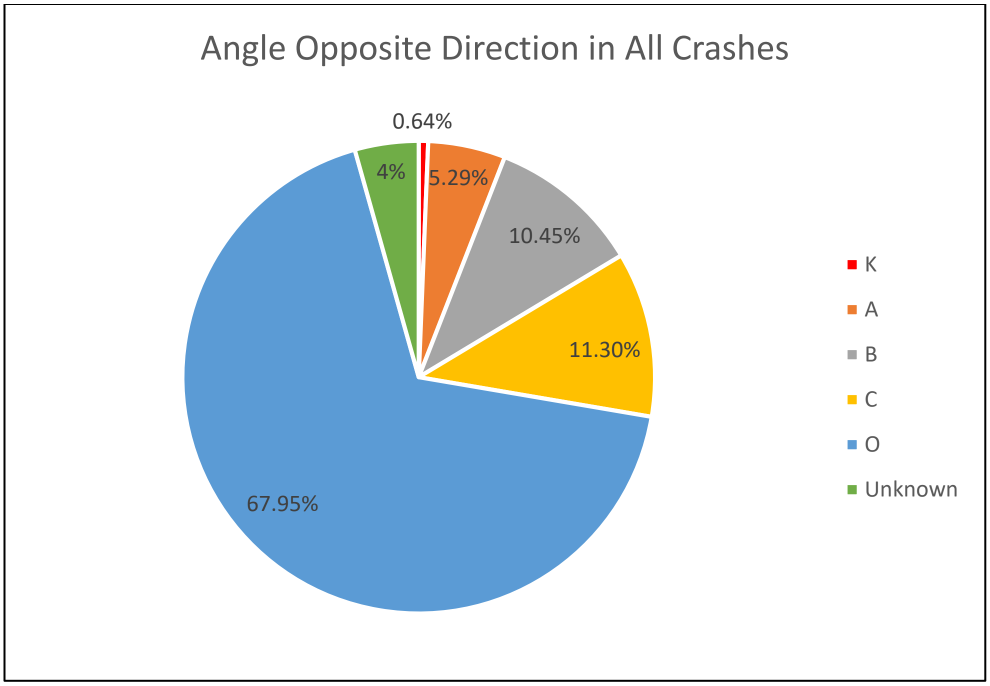

Angle Same Direction in WZ-Related Dataset
0%
0%
0%
10.26%
12.82%
76.92%
K
A
B
C
O
Unknown


Angle Same Direction in WZ Database
0%
0%
2.02%
5.05%
9.09%
83.84%
K
A
B
C
O
Unknown

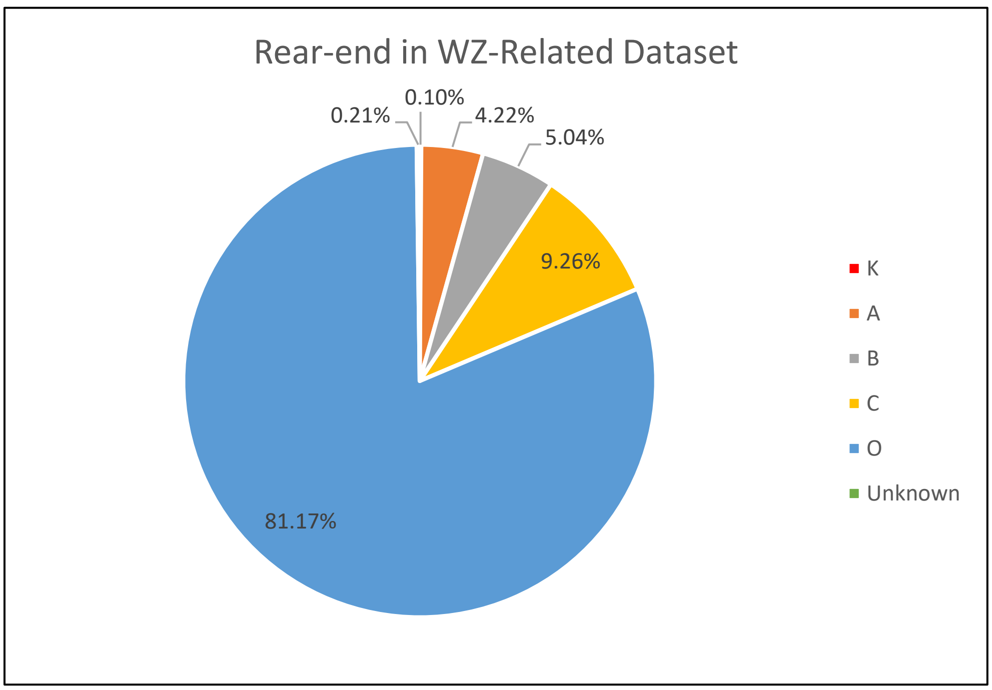

Angle Same Direction in All Crashes
0.13%
2.86%
4%
6.03%
6.37%
80.88%
K
A
B
C
O
Unknown


Angle Opposite Direction in WZ-Related Dataset
0%
13.64%
9.09%
18.18%
9.09%
50.00%
K
A
B
C
O
Unknown

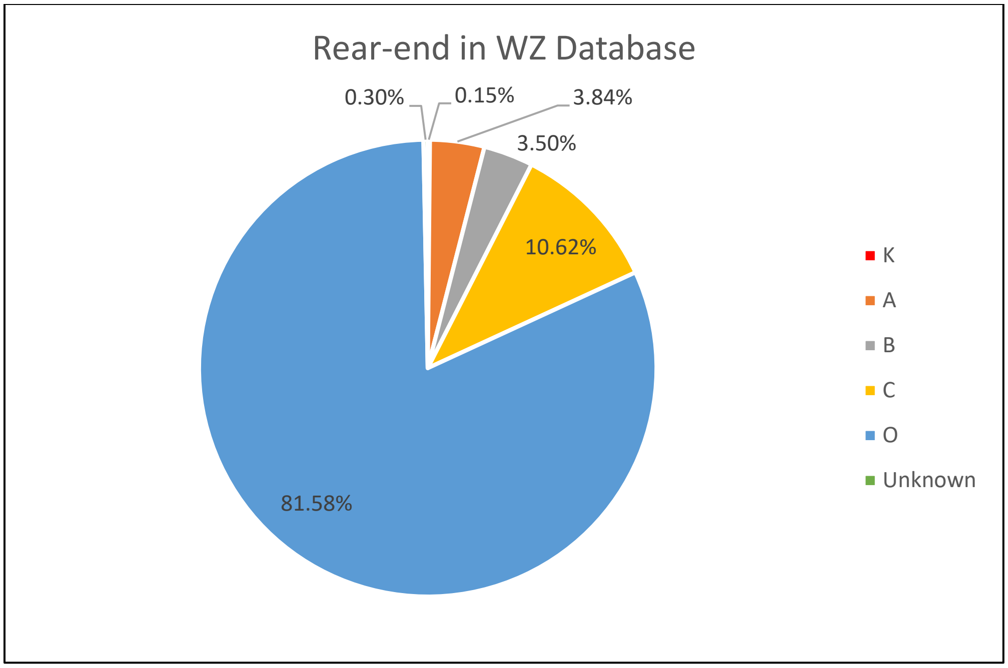

Angle Opposite Direction in WZ Database
0%
7.69%
5.13%
10.26%
11.54%
65.38%
K
A
B
C
O
Unknown

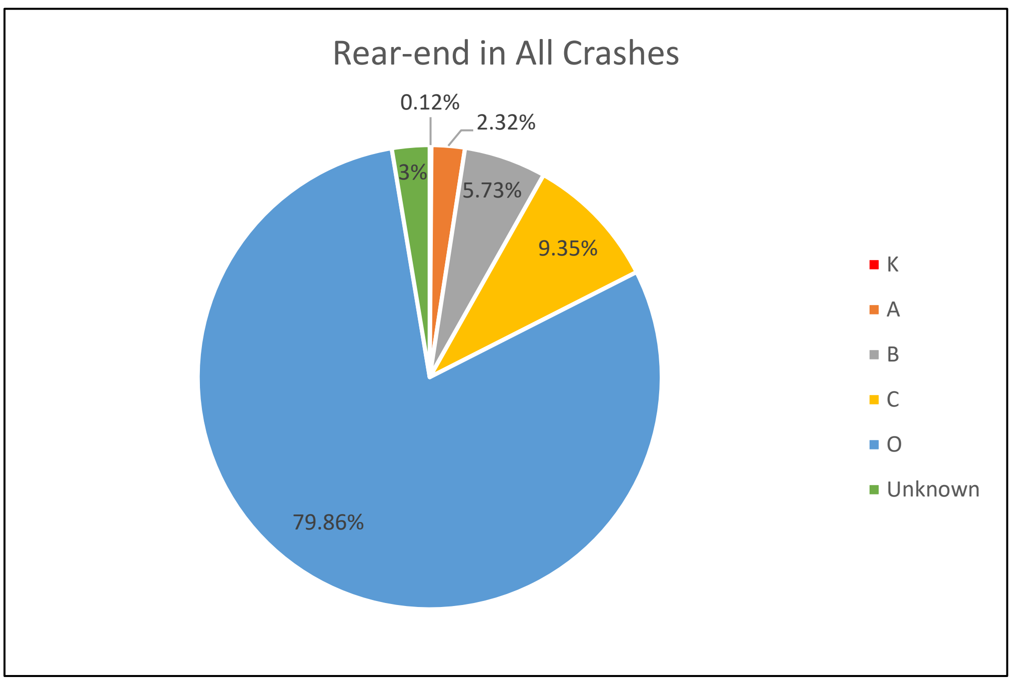


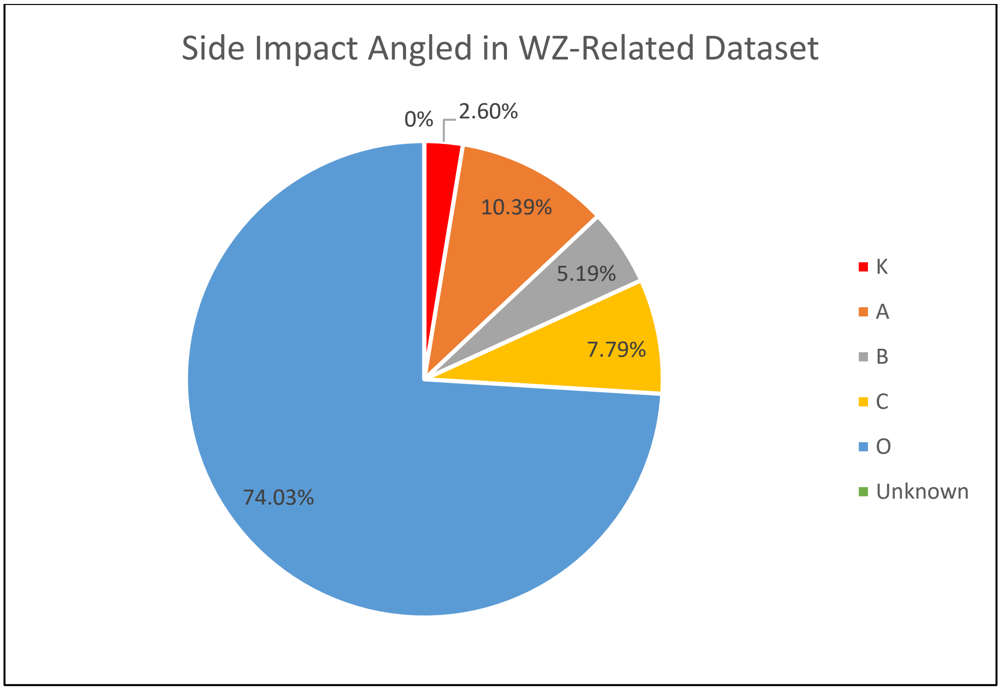
Angle Opposite Direction in All Crashes
0.64%
4%
5.29%
10.45%
11.30%
67.95%
K
A
B
C
O
Unknown



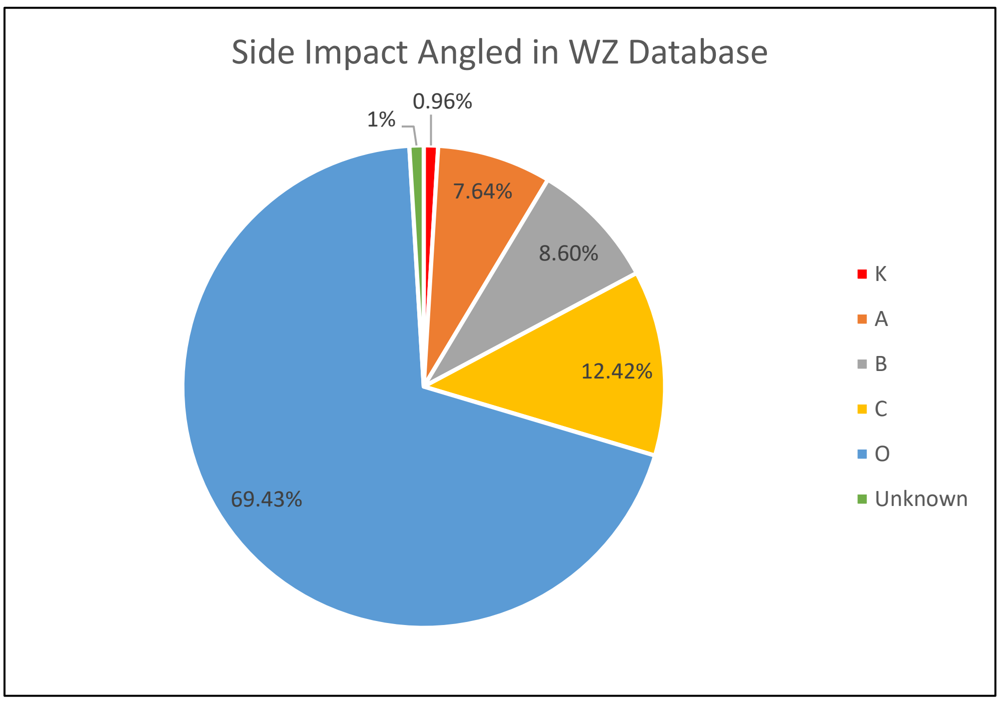
Rear-end in WZ-Related Dataset
0.21%
0.10%
4.22%
5.04%
9.26%
81.17%
K
A
B
C
O
Unknown


Rear-end in WZ Database
0.30%
0.15%
3.84%
3.50%
10.62%
81.58%
K
A
B
C
O
Unknown

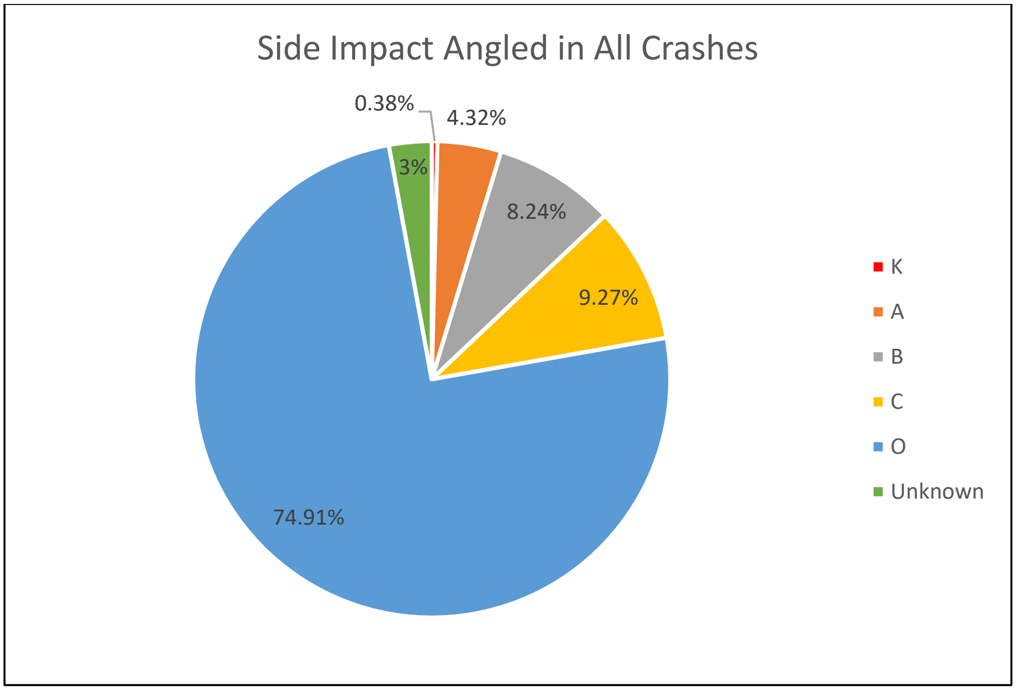

Rear-end in All Crashes
0.12%
2.32%
3%
5.73%
9.35%
79.86%
K
A
B
C
O
Unknown

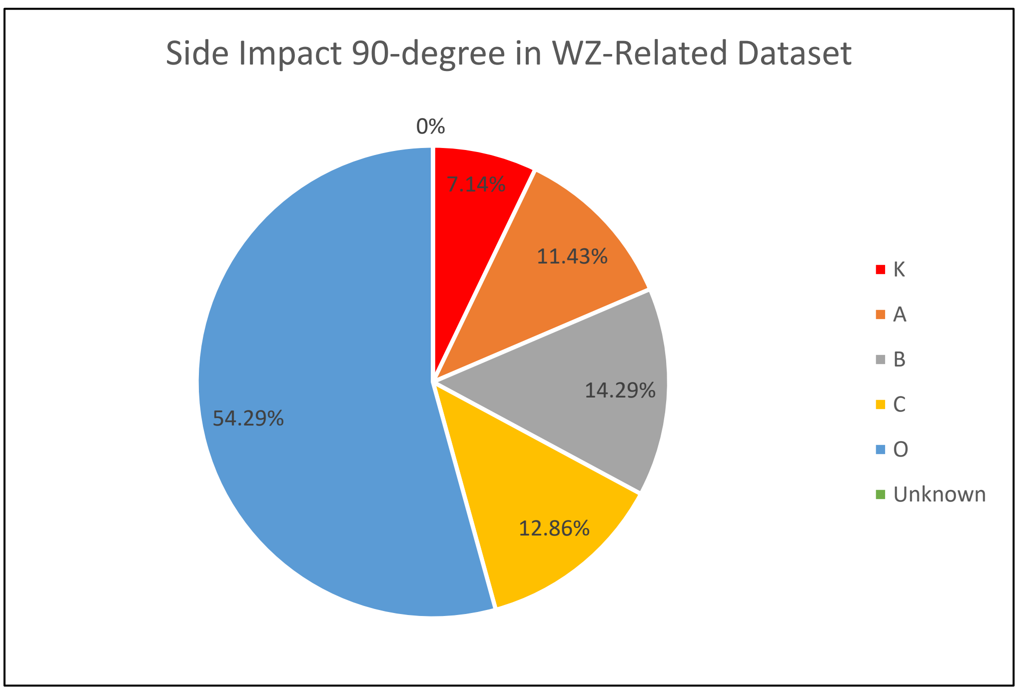


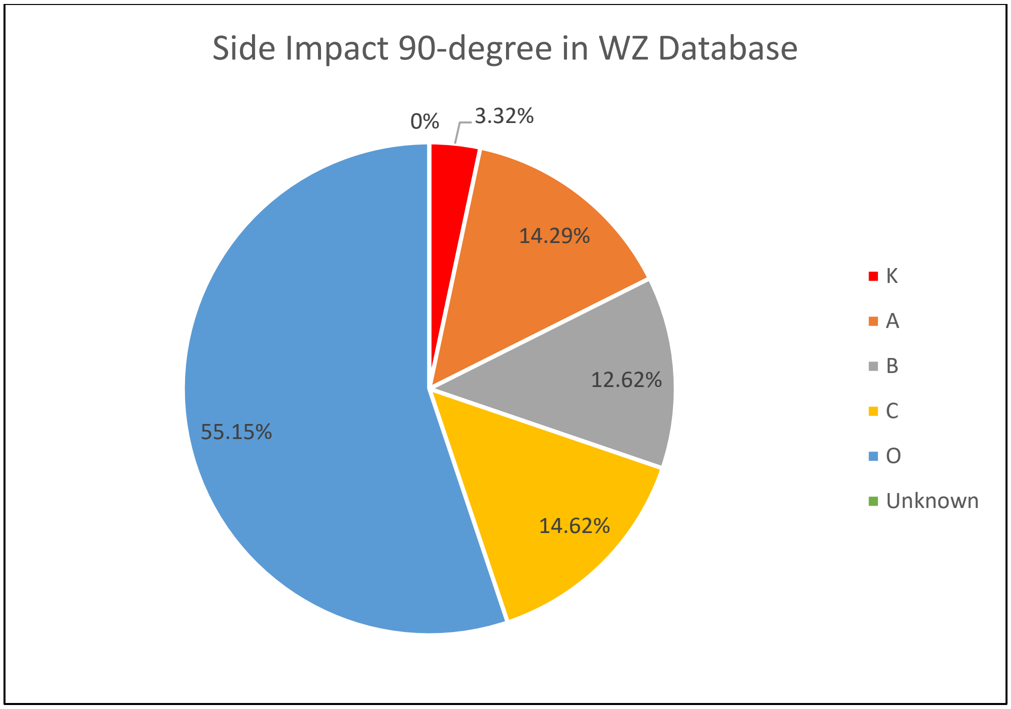
Side Impact Angled in WZ-Related Dataset
0%
2.60%
10.39%
5.19%
7.79%
74.03%
K
A
B
C
O
Unknown

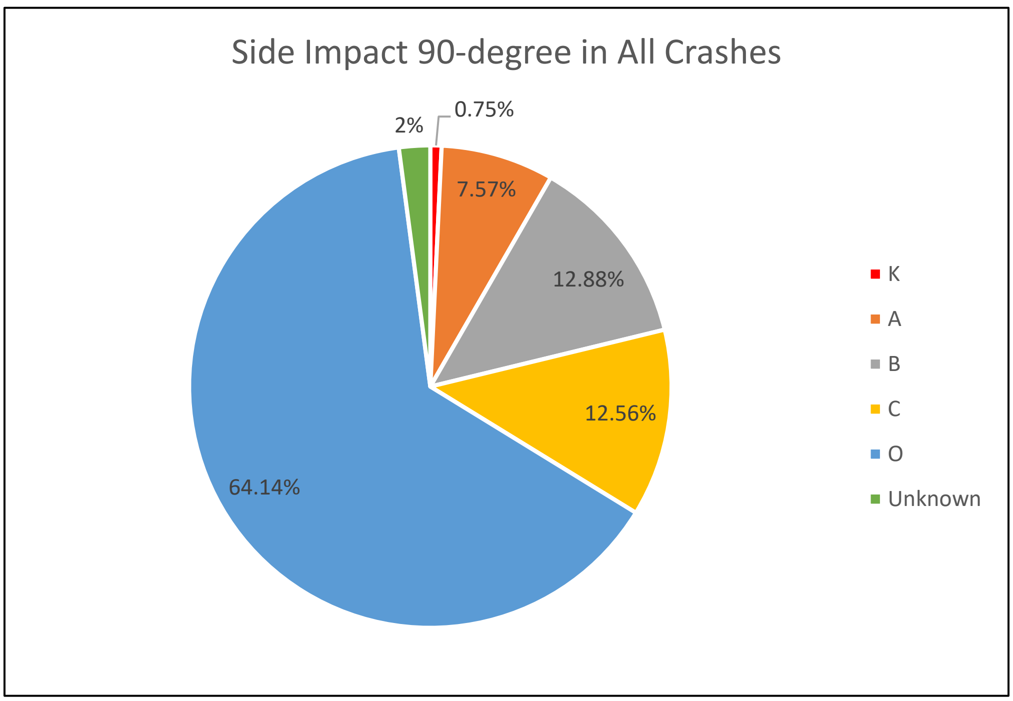


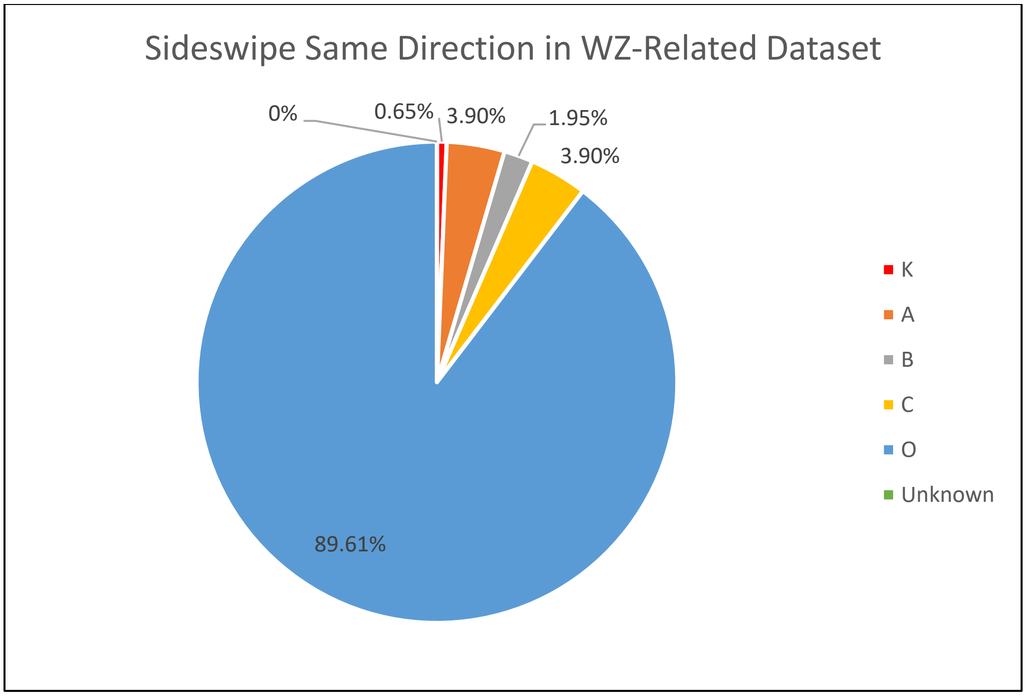
Side Impact Angled in WZ Database
1%
0.96%
7.64%
8.60%
12.42%
69.43%
K
A
B
C
O
Unknown

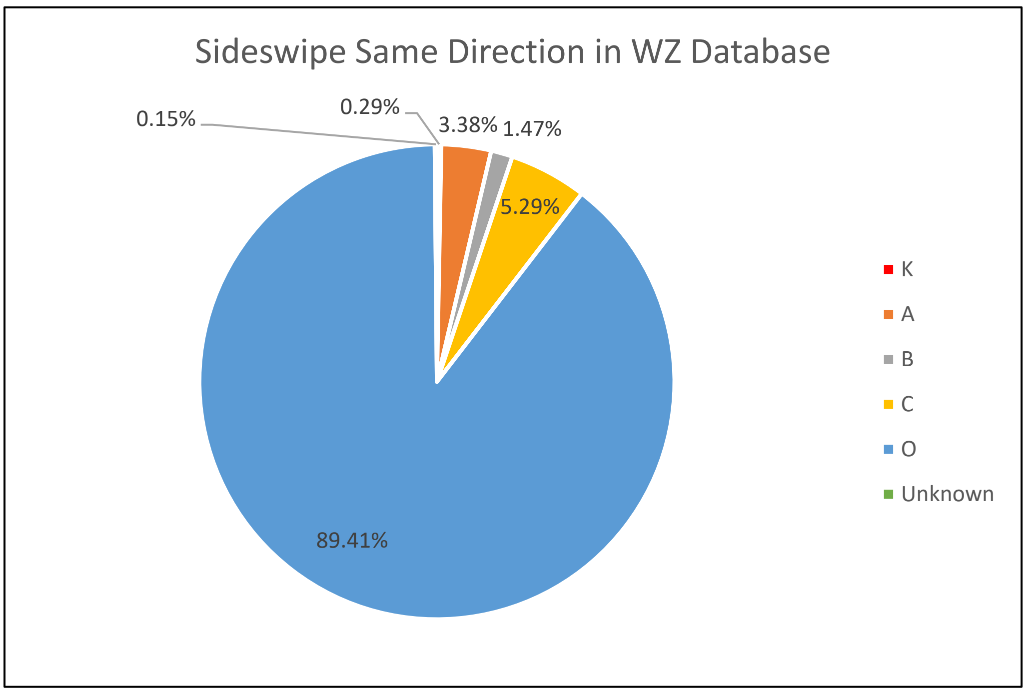

Side Impact Angled in All Crashes
0.38%
4.32%
3%
8.24%
9.27%
74.91%
K
A
B
C
O
Unknown

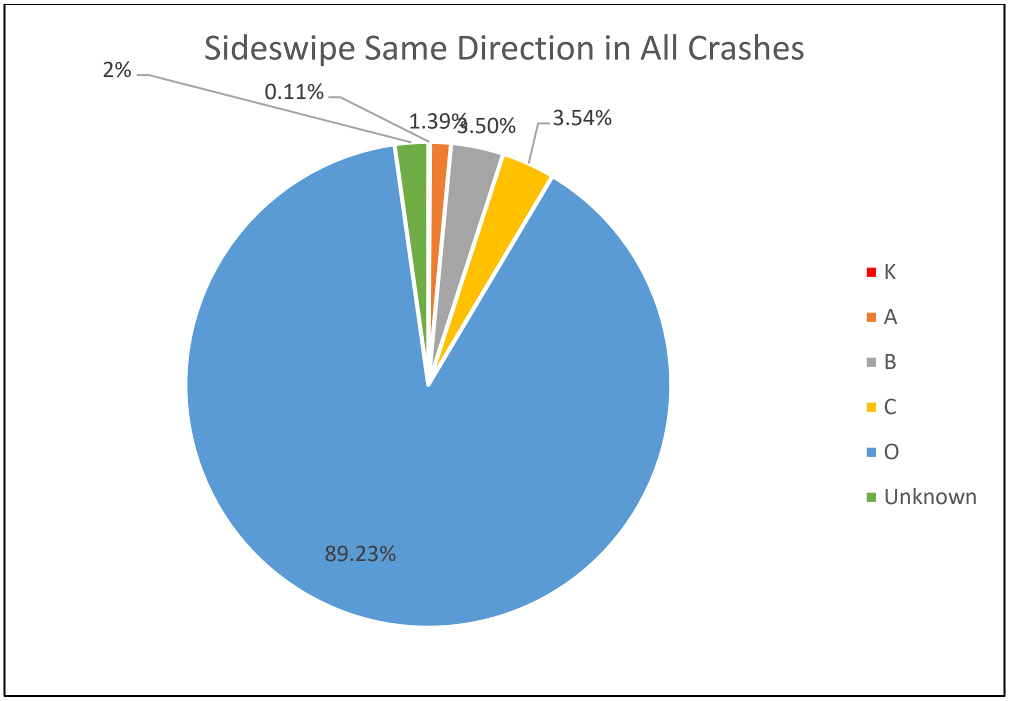

Side Impact 90-degree in WZ-Related Dataset
0%
7.14%
11.43%
14.29%
12.86%
54.29%
K
A
B
C
O
Unknown


Side Impact 90-degree in WZ Database
0%
3.32%
14.29%
12.62%
14.62%
55.15%
K
A
B
C
O
Unknown

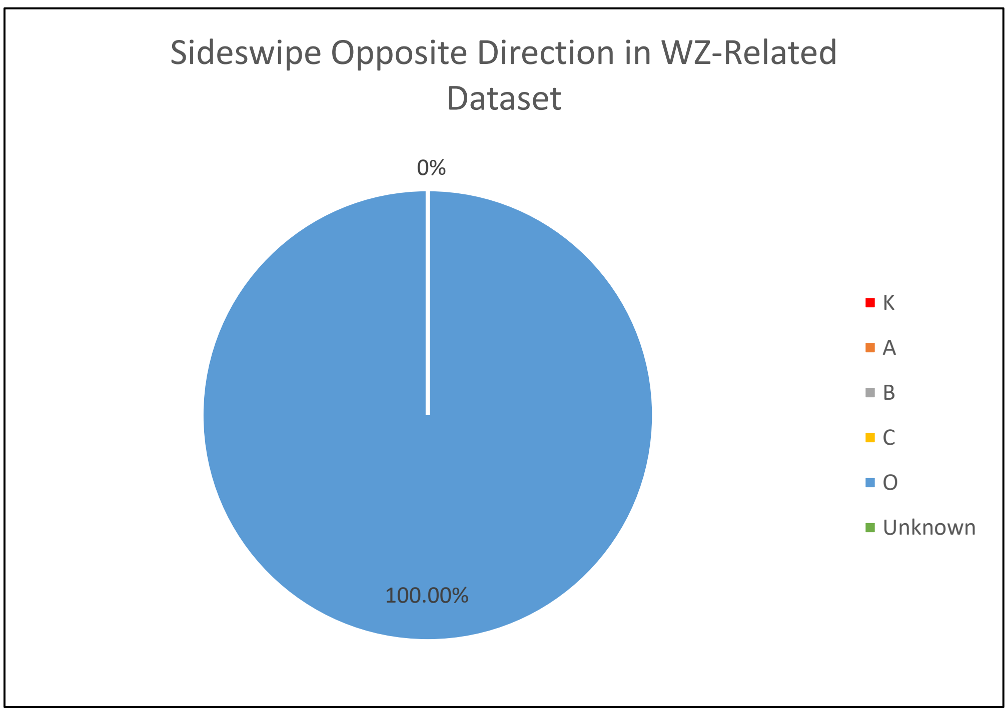

Side Impact 90-degree in All Crashes
2%
0.75%
7.57%
12.88%
12.56%
64.14%
K
A
B
C
O
Unknown


Sideswipe Same Direction in WZ-Related Dataset
0%
0.65%
3.90%
1.95%
3.90%
89.61%
K
A
B
C
O
Unknown

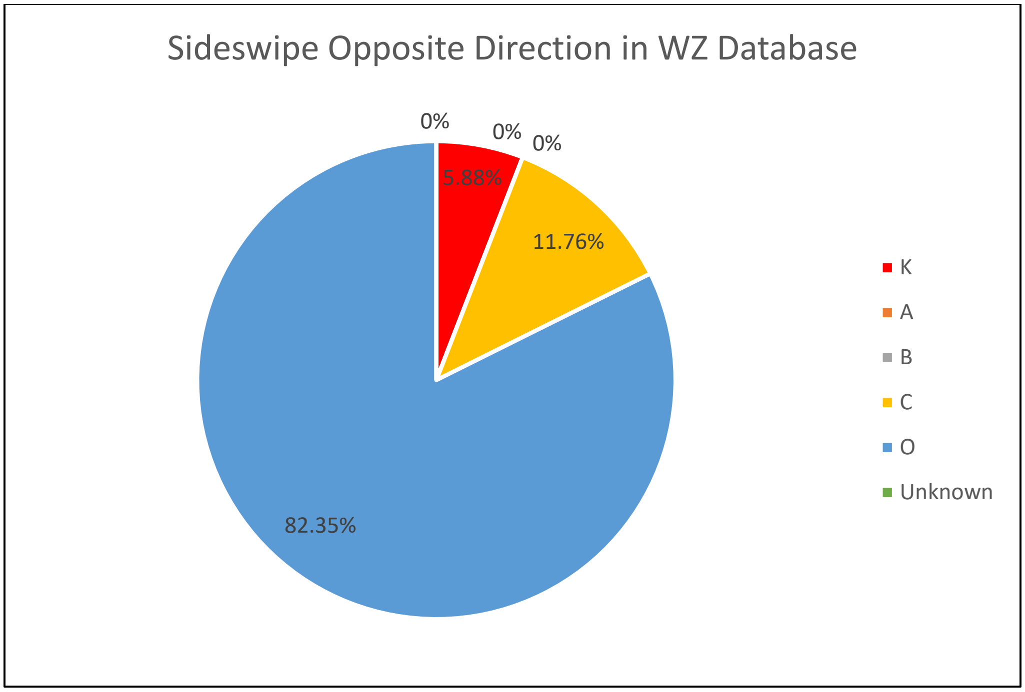

Sideswipe Same Direction in WZ Database
0.15%
0.29%
3.38%
1.47%
5.29%
89.41%
K
A
B
C
O
Unknown

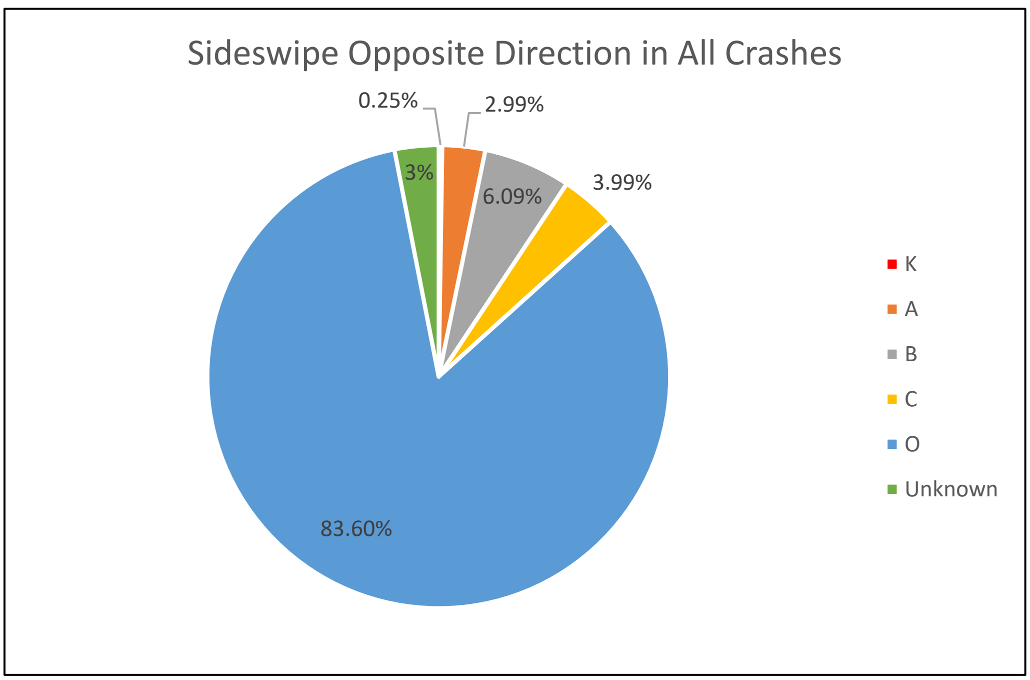


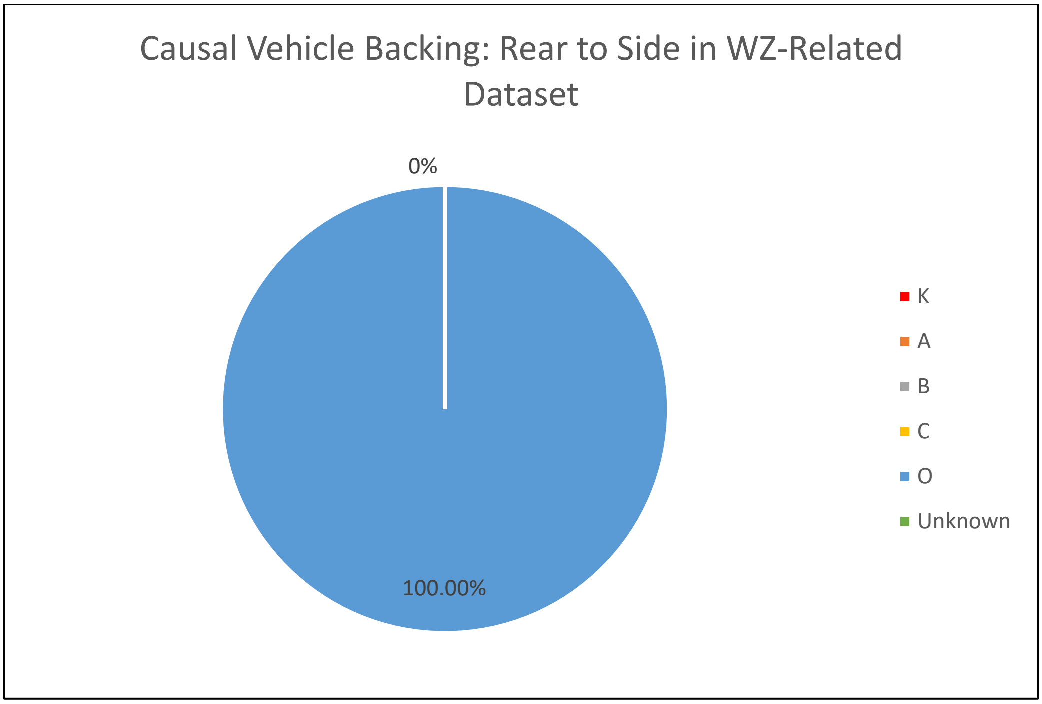
Sideswipe Same Direction in All Crashes
2%
0.11%
1.39%
3.50%
3.54%
89.23%
K
A
B
C
O
Unknown



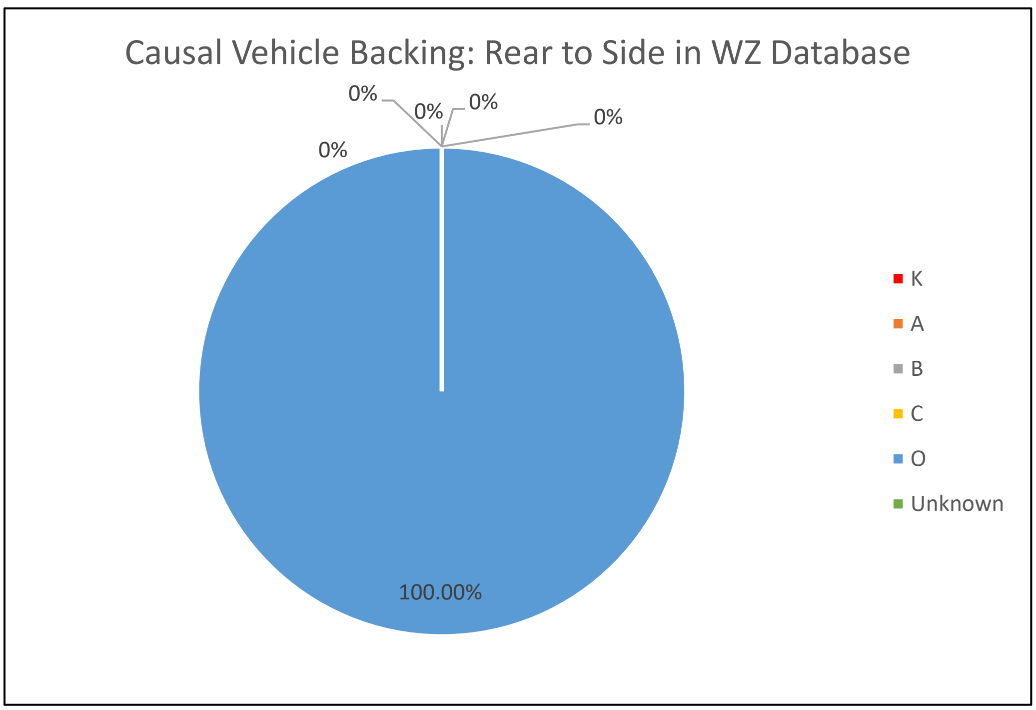
Sideswipe Opposite Direction in WZ-Related Dataset
0%
100.00%
K
A
B
C
O
Unknown


Sideswipe Opposite Direction in WZ Database
0%
0%
0%
5.88%
11.76%
82.35%
K
A
B
C
O
Unknown

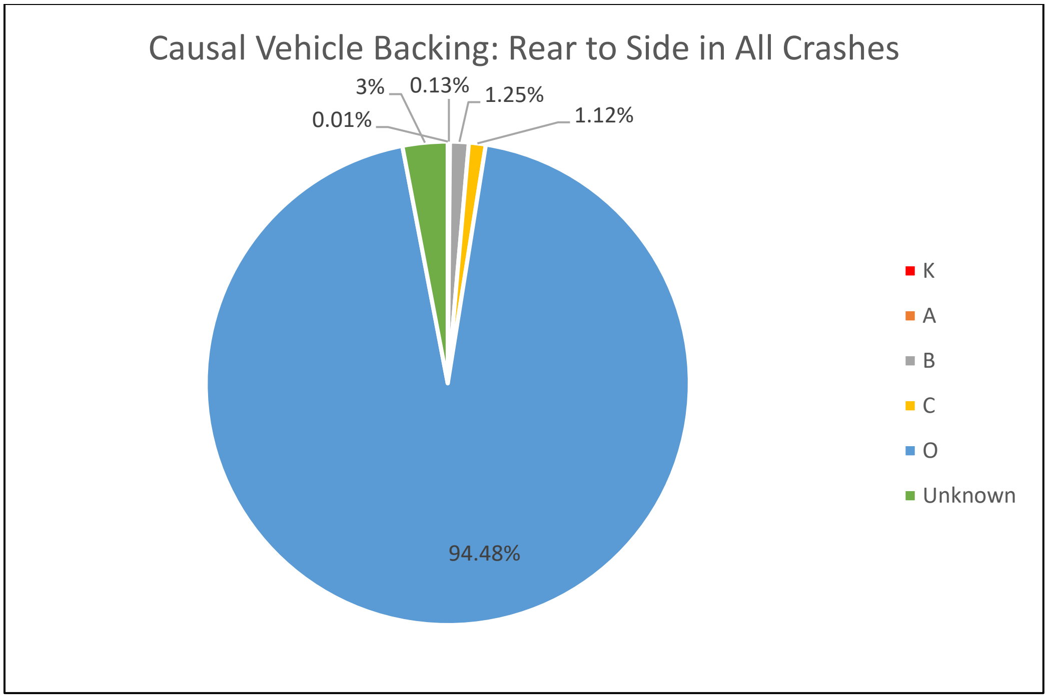

Sideswipe Opposite Direction in All Crashes
0.25%
2.99%
3%
6.09%
3.99%
83.60%
K
A
B
C
O
Unknown

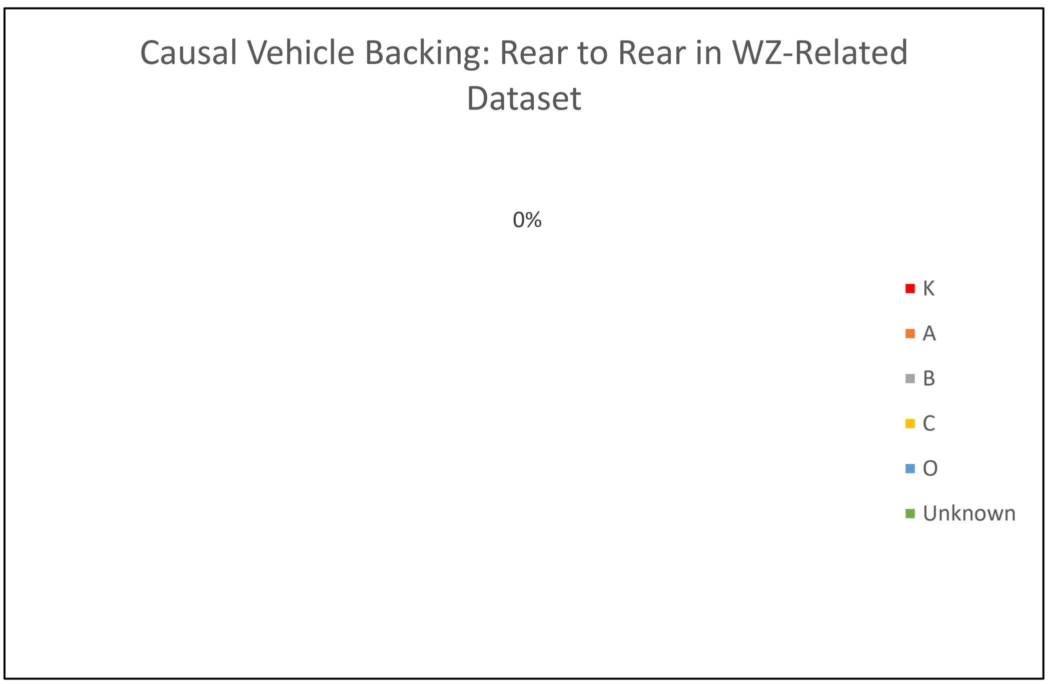


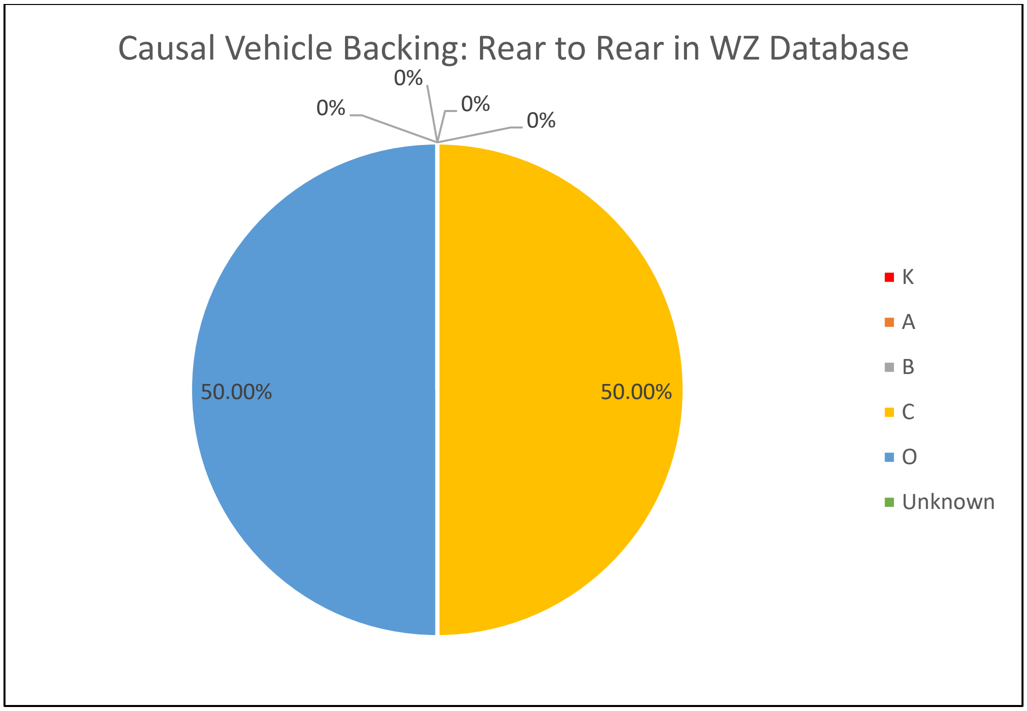
Causal Vehicle Backing: Rear to Side in WZ-Related Dataset
0%
100.00%
K
A
B
C
O
Unknown

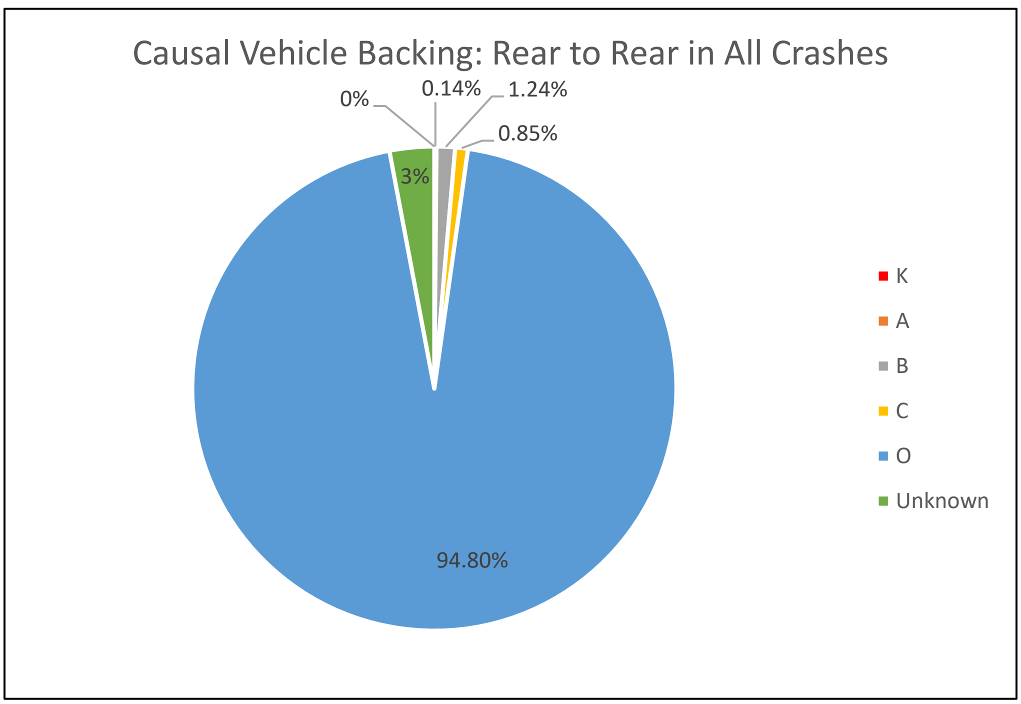


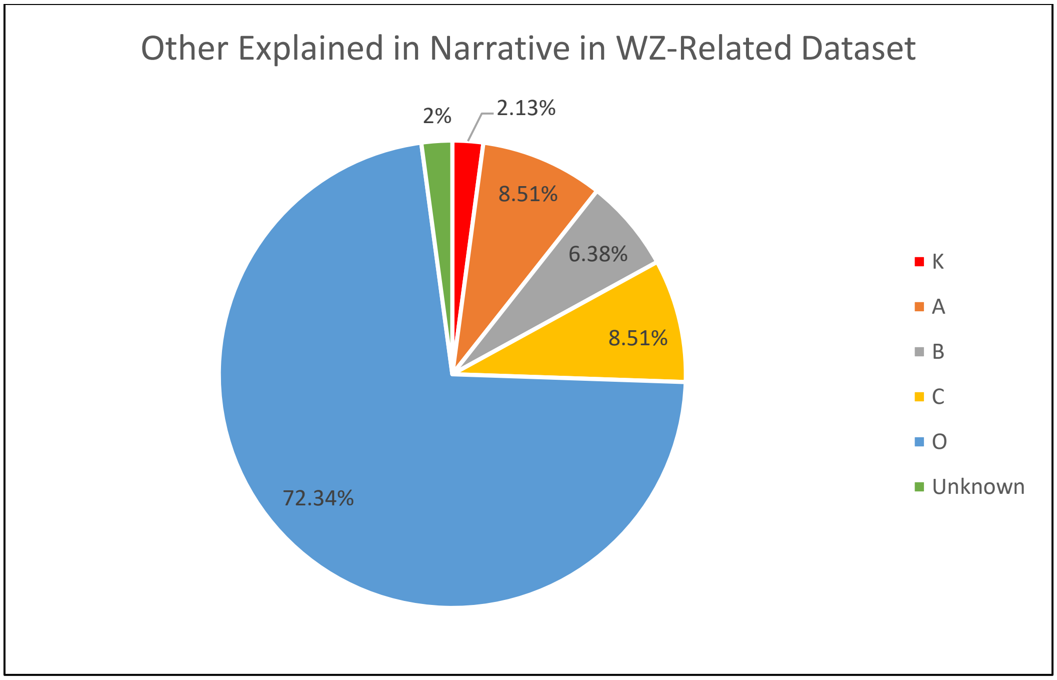
Causal Vehicle Backing: Rear to Side in WZ Database
0%
0%
0%
0%
0%
100.00%
K
A
B
C
O
Unknown

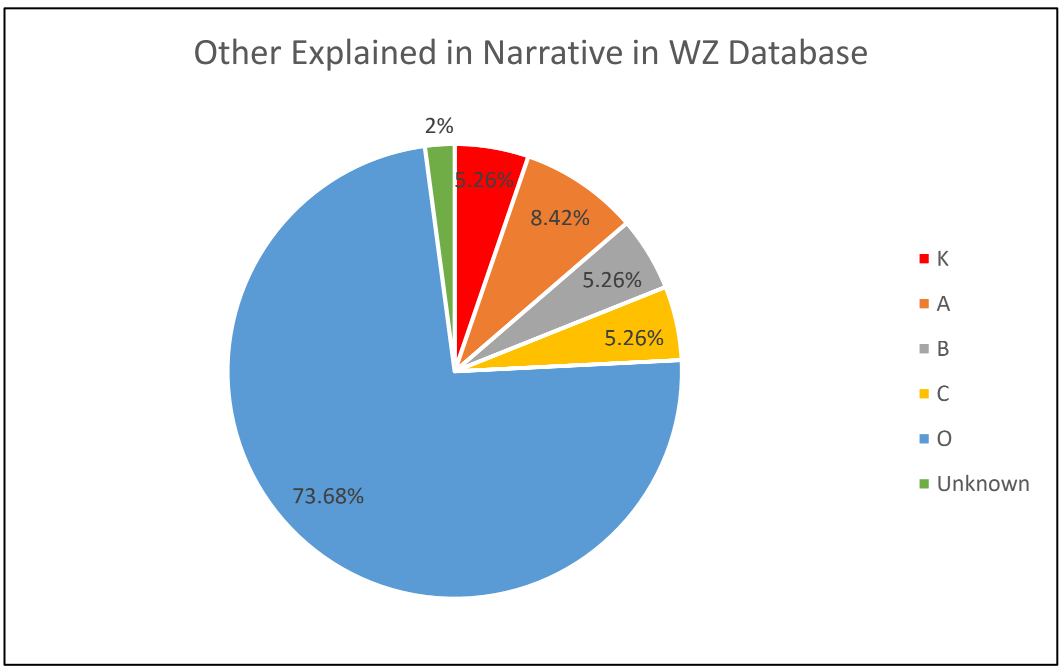

Causal Vehicle Backing: Rear to Side in All Crashes
3%
0.13%
1.25%
0.01%
1.12%
K
A
B
C
O
Unknown
94.48%

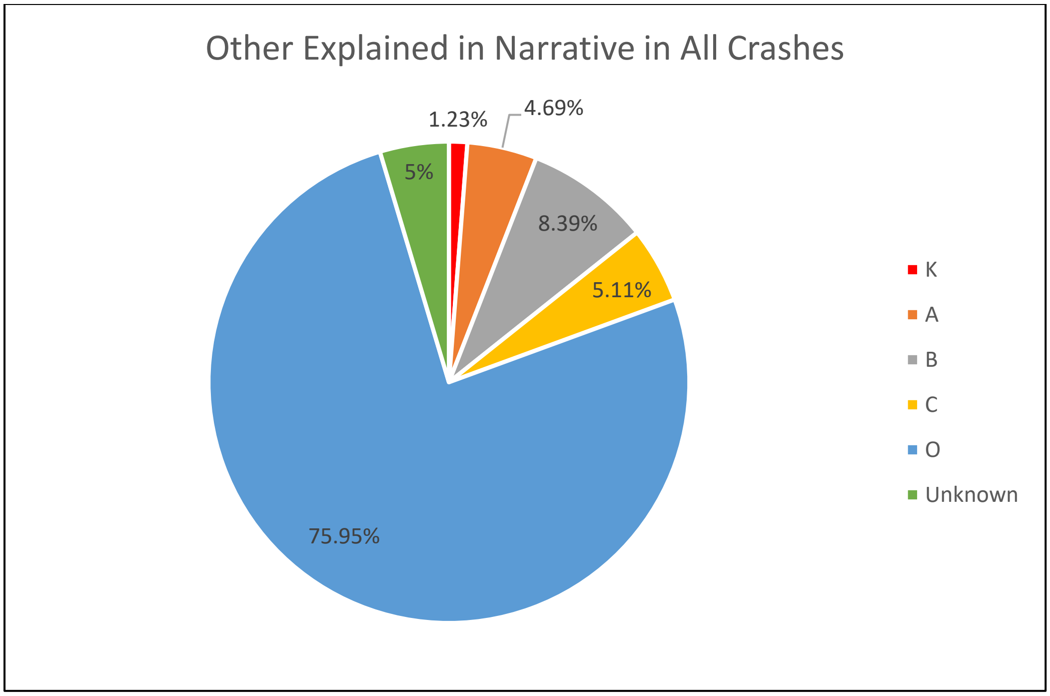

Causal Vehicle Backing: Rear to Rear in WZ-Related Dataset
0%
K
A
B
C
O
Unknown

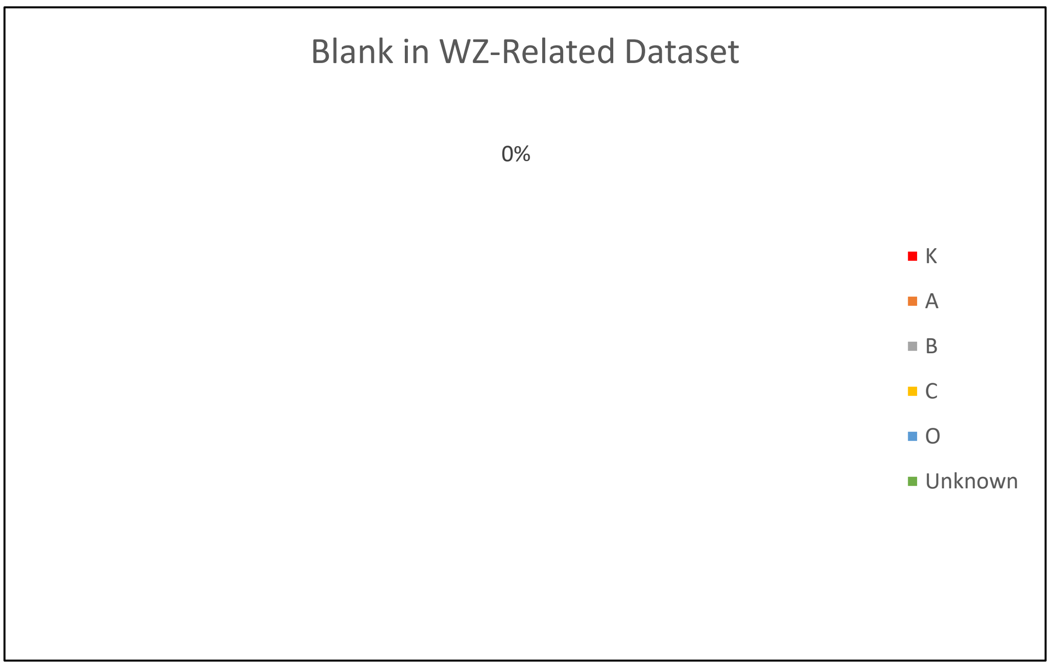

Causal Vehicle Backing: Rear to Rear in WZ Database
0%
0%
0%
0%
50.00%
50.00%
K
A
B
C
O
Unknown

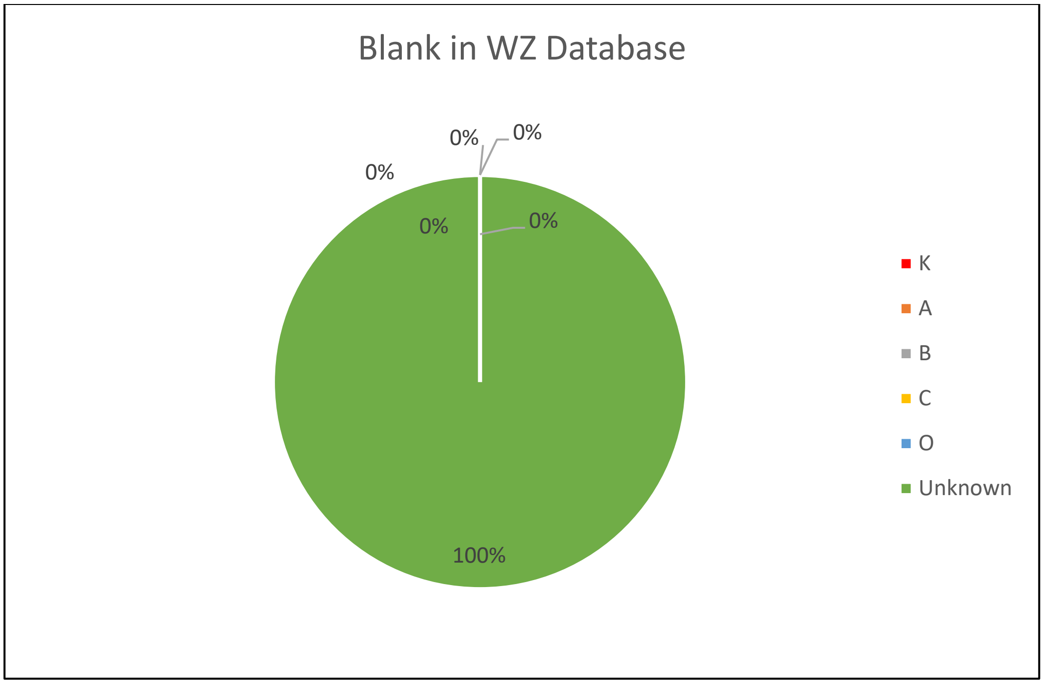

Causal Vehicle Backing: Rear to Rear in All Crashes
0%
0.14%
1.24%
0.85%
3%
94.80%
K
A
B
C
O
Unknown

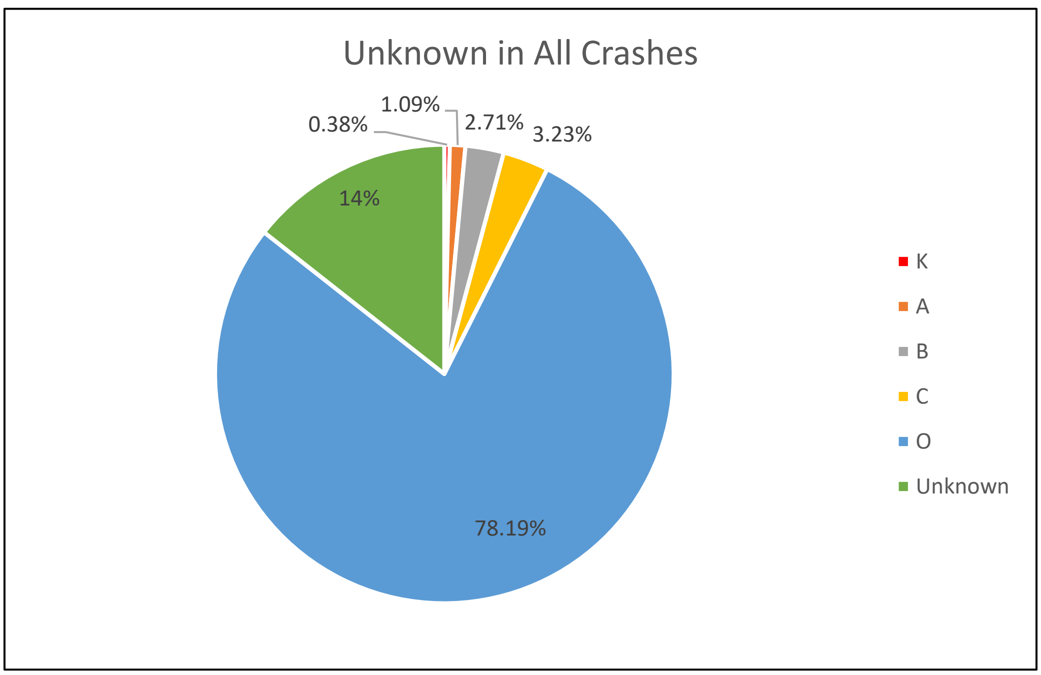

Other Explained in Narrative in WZ-Related Dataset
2%
2.13%
8.51%
6.38%
8.51%
72.34%
K
A
B
C
O
Unknown


Other Explained in Narrative in WZ Database
2%
5.26%
8.42%
5.26%
5.26%
73.68%
K
A
B
C
O
Unknown


Other Explained in Narrative in All Crashes
1.23%
4.69%
5%
8.39%
5.11%
75.95%
K
A
B
C
O
Unknown


Blank in WZ-Related Dataset
0%
K
A
B
C
O
Unknown


Blank in WZ Database
0%
0%
0%
0%
0%
100%
K
A
B
C
O
Unknown


Unknown in All Crashes
1.09%
0.38%
2.71%
3.23%
14%
78.19%
K
A
B
C
O
Unknown