MODELING THE CRASH INJURY SEVERITY IN WORK ZONE AREAS ON FREEWAYS

by

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ABSTRACT

ALAIN SENGA MIATUDILA, SR. Modeling the crash injury severity in work zone areas on freeways (Under the direction of DR. MARTIN R. KANE)

The rising frequency of crashes in work zones on American freeways is a growing issue inherently linked to the degrading state of our transportation infrastructure. As travel demand increases and our infrastructure continues to age and wear out, work zones will need to be implemented to add capacity or repair and replace those components that pose elevated risk for public safety. Despite the fact that work zones have received national attention for more than two decades due to elevated risk for crash and injury, very little decrease in work zone crash or injury has occurred as a result of this national awareness. Decreasing work zone crashes and injury is an issue that still needs to be addressed. With work zone definitions still being largely determined at the state level, identifying work zone characteristics and modeling risk or crash injury severity is important in assisting those state Departments of Transportation (DOTs) with the design of safer work zones. More specifically, highlighting aspects of design that contribute to the most severe injuries in road crashes have recently become the focus as economic policies have dictated more conservative fiscal budget allocations.

The purpose of this research is to develop and evaluate models that can help not only identify, but also quantify the different contributing factors and their role in the severity of work zone crashes. The data used in this research is obtained from the North Carolina Department of Transportation (NCDOT) maintained Traffic Engineering Accident Analysis System (TEAAS) for the years 2007-2014. TEAAS utilizes DMV-349 reports filed by law enforcement officials at the scene of every reported crash. The dataset was organized into three different categories: human factors, roadway environmental factors, and vehicle factors. Multinomial Logit models were developed for the overall work zone, as well as the different work zone types and areas.

The results obtained indicated that alcohol was associated with more fatal & A injury severity type crashes, whilst speed was prevalent across all areas of work zones. The construction work zone contained the vast majority of the crashes, as well as the highest severity crashes. The high severity crashes most often occurred during the morning and evening peak traffic hours of 9:00-11:59 AM and 3:00-5:59 PM. The most dangerous and high risk area in the work zone was within the construction work zone transition/activity area. This area was found to have a higher risk in comparison to the advance warning and termination area.

Overall, the results obtained from this research provide details on specific risk factors for work zone crashes, which have aided in developing a better understanding of these high risk work zone traffic environments. These results will be helpful to both government and highway industries, as well as safety engineers and researchers when determining potential countermeasures to help eliminate those risks.

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DEDICATION

This work is dedicated firstly to my Lord and Savior Jesus Christ, the Son of the living God, who, through faith in Him, has made this achievement possible. At times, thick clouds of obstacles and challenges have obscured hope to prevent me from achieving this doctoral program. However, through it all, God made what appeared impossible to men possible to me (Luke 18:27). When I felt tired He gave me strength; for it is recorded in Holy Scriptures that “they that wait upon the LORD shall renew their strength; they shall mount up with wings as eagles; they shall run and not be weary; and they shall walk, and not faint” (Isaiah 40:31).

Secondly, I dedicate this work to my wife, Ma-Ikay K. Miatudila, I must express my heartfelt gratitude for her immeasurable sacrifices. Also to my daughters, Grace J. Miatudila and Leeya L. Miatudila, and my son, Alain S. Miatudila, Jr., they have all been a constant reminder of love and generosity through understanding and support. I hope that this will inspire them all to achieve more than I.

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CHAPTER 1: INTRODUCTION

Safety is a critical factor in any engineering or construction project. The project must meet design requirements, use available resources efficiently, and maintain or improve the level of safety for the contractor, client, and the public for successful implementation. The safety of transportation related projects is especially important due to the high risk nature of the environment that both workers and the public experience during the construction project. Freeway construction and repair rarely closes the entire roadway; rather, work zones are established to allow for continued traffic flow. Temporary traffic control planning is often essential to maintain safety and minimize impact to traffic flow and work schedules.

Work zones are the established means through which transportation personnel are able to conduct their construction or repair work. According to the Manual on Uniform Traffic Control Devices (MUTCD), there are three types of work zones: utility, maintenance, and construction (Federal Highway Administration, 2009: Weng & Meng, 2011). These three zones are defined as follows:

1. Utility work zones: the shortest in duration and smallest in project scope. The MUTCD defines these work zones as taking 1 hour or less with a very small crew.
2. Maintenance work zones: defined as lasting more than 1 hour, but no more than three days.
3. Construction work zones: work zones lasting more than 3 days.

Both maintenance and utility work zones are shorter in duration and project scope than construction work zones. With less workers and a shorter duration, these work zones do not typically carry the inherent risk that more long-term and intensive construction work zones carry. A recent study comparing driver casualties across the different work zone types found that construction work zones have the highest driver casualty risks. Most research in this area appears to be focused on working with construction work zones (Weng & Meng, 2011).

The definition of a work zone varies from state to state at the time of this writing. In the late 1990s, the Federal Highway Administration (FHWA) attempted to derive a consensus national definition of a work zone. It was unable to complete this task due to various technical and legal constraints. Although there is no current federally recognized definition of work zone, the FHWA has the following working definition:

"A work zone is an area of a trafficway with construction, maintenance, or utility-work activities. A work zone is typically marked by signs, channeling devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the "End of Road Work" sign or the last traffic control device. A work zone may be for short or long durations and may include stationary or moving activities (FHWA, 1999)."

The full definition has the following inclusions:

1. Long-term stationary highway construction such as building a new bridge, adding travel lanes to the roadway, and extending an existing trafficway.
2. Mobile highway maintenance such as striping the roadway, median, and roadside grass mowing/landscaping, and pothole repair.

3. Short-term stationary utility work such as repairing electric, gas, or water lines within the trafficway.

Though the FHWA definition of a work zone is a good general definition of a work zone, its lack of nationwide acceptance makes it problematic for the purposes of research operational definitions, in particular, state specific research. Previous research efforts have noted that even crash reporting procedures and training for police officers generating such reports can vary widely from state to state. For example, work zone crashes in Wisconsin include any crashes resulting from work zone activities, even if they occur outside of the work zone (Coburn et. al., 2013). Other states, like Michigan, consider work zone crashes to occur only within the physical limits of the work zone (Coburn et. al., 2013). This high variability across state Departments of Transportation (DOTs) has the potential to limit the extent to which research can be generalized across state lines. Thus, many states are pursuing individualized efforts to mitigate work zone risk and to find out more about where, when, and why work zone crashes are occurring.

An area of work zone research that has received considerable attention is where crashes are occurring within the physical parameters of the work zone itself. It has typically utilized the specification set forth in the MUTCD. The MUTCD divides the work zone into the following four areas: Advance Warning, Transition, Activity, and Termination Area (Figure 1). The Advance Warning Area is the first part of the work zone one encounters while traveling. It is the initial section of the work zone where road users are informed about the upcoming work zone. The signals indicating the upcoming work zone can vary from incremental warning signs to various flashing and/or oscillating lights. The Advance Warning Area is followed by the Transition Area, which is where roadway users are redirected out of the normal flow of traffic. This is typically done through various tapering procedures, which help to gradually redirect the flow of traffic (FHWA, 2009). Previous research on tapering methodology has found that reducing the taper length increases risk for both drivers and work zone personnel (Morgan et. al., 2010).

The Activity Area of a work zone is the place where the construction and work is actually taking place. This area consists of 3 component areas: the work space, traffic space, and buffer space. The values of the buffer space length are typically calculated based upon stopping sight distance and vary according to the design speed. The final area of the work zone is called the Termination Area. It is defined as the section of the work zone that returns road users to the normal flow of traffic. The Termination Area extends from the downstream end of the work zone to the final Temporary Traffic Control Device (FHWA, 2009: Elghamrawy, 2011). Previous research on this sub-section of the work zone has identified this area to have the least number of crashes of any section of the work zone (Bai & Li, 2006).

Some of the earliest freeway work zone focused research began to appear in the mid-1960s. The Highway Safety Research Institute was both conducting and publishing research at this time, and concerns over work zone crashes were being addressed by the Department of Public Works (Munro & Huang, 1968; Department of Public Works, 1965). However, freeway work zone research really began to gain some momentum in the 1990s, as collected data from the 1980s began to indicate a growing increase in work zone injuries and fatalities. Work zone fatalities rose from 500 per year in 1982 to 700 per year in 1987 (Khattack & Council, 2002).

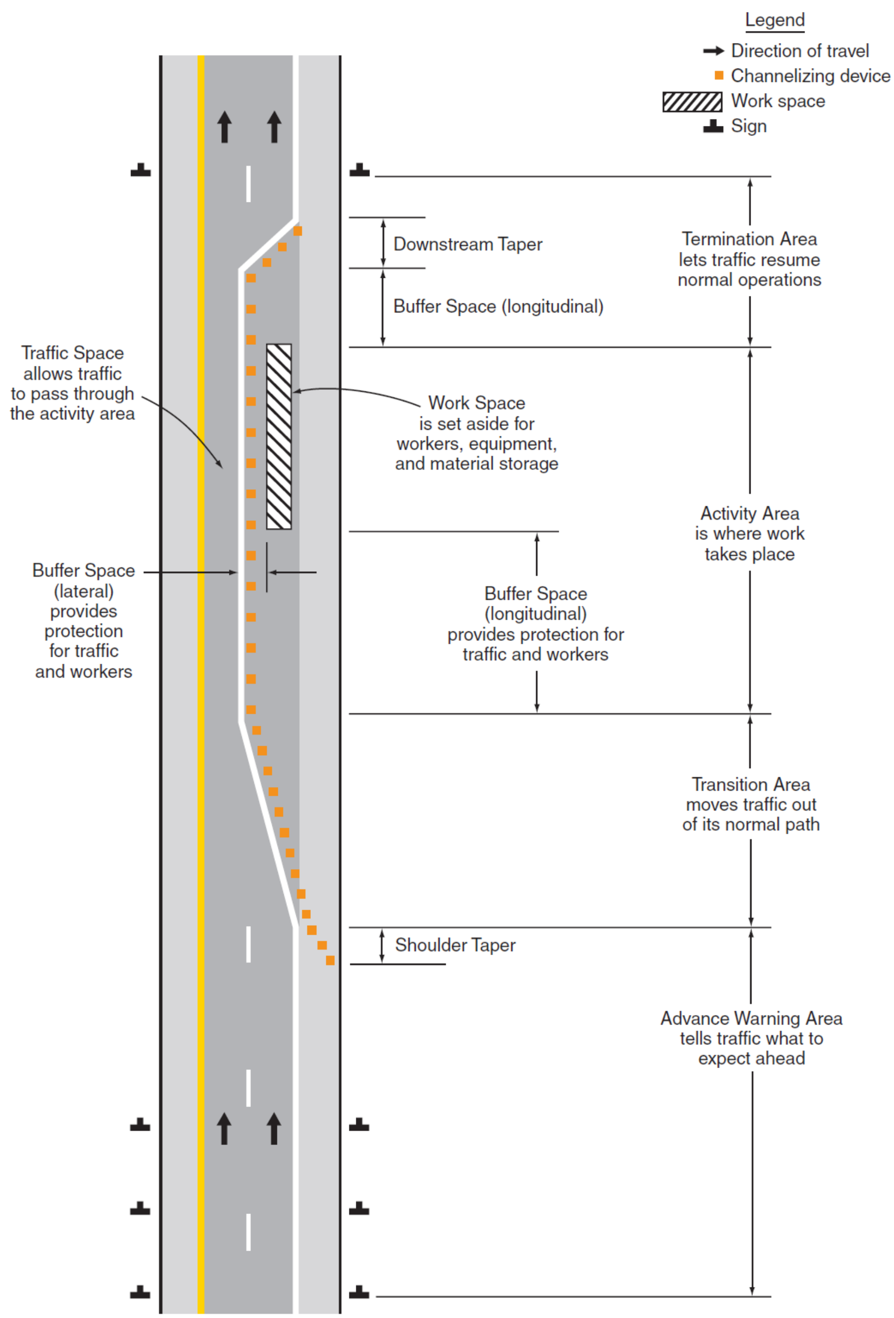

FIGURE 1: Physical sub-boundaries of the work zone

(Source: Figure 6C-1 Component parts of a temporary traffic control zone)

(MUTCD, 2009)

An early American Association of State Highway and Transportation Officials (AASHTO) study found that work zones have higher fatal crash frequencies and average fatalities than non-work zone comparable sections of freeway (AASHTO, 1987). This high incidence of work zone injuries and fatalities in the 1990s began to draw attention to the need for increasing work zone safety and standardizing research for the various organizations involved in regulating the highway system.

Congress addressed work zone safety with the Intermodal Surface Transportation Efficiency Act of 1991 and the National Highway System Designation Act of 1995. The National Transportation Safety Board (NTSB) in 1992 further recommended that the FHWA revise the work zone reporting system and "standardize the work zone data elements for all states" (FHWA, 1999). Another organization that has been working on this endeavor is the AASHTO. Even with these efforts to improve work zone safety, there has been little to no progress nationwide in overall work zone safety.

The national awareness of degrading infrastructure, increasing numbers of work zones, and persevering threat of injury and fatality, along with congressional attention have helped to bring visibility and priority to the need for research on improving work zone design and safety standards. Work zones are likely to increase in frequency and with little to no improvement in mitigating risk of injury and/or fatality, those injuries and fatalities are likely to increase as well. Continued research into the aspects of the work zone that contribute to crash causation and injury appears to be an essential task necessary to decreasing the risk that environment poses on life and limb of personnel and public alike.

This research on work zones utilizes available data for the purpose of mitigating the increased risk that those work zones pose on human life and injury. The data and work zone definitions vary from one state to another state. Since this study utilizes data collected in the state of North Carolina, it will need to rely upon the North Carolina Department of Transportation (NCDOT) definition of a work zone. The NCDOT defines a work zone as a designated area on a street or highway where construction is taking place (NCDOT Work Zone FAQ’s, 2014). Construction is defined as any type of new or repair work done to any part of a roadway structure. The NCDOT also differentiates types of work zones between construction, maintenance, and utility. Utility work zones tend to be on the sides of roadways and typically require mobile traffic control devices.

At any given time, there are over 200 major work zones occurring in North Carolina. There were over 2,125 work zone crashes during the year of 2009. There were 11 fatalities and 80% of the individuals killed were motorists. 1,208 people were reported as injured due to crashes in work zones. Speeding and distracted driving were reported to account for more than 50% of all work zone crashes. While 71% of work zone crashes occurred on clear days, 82% occurred on dry road conditions. Likewise, 75% of all work zone crashes occurred during day light hours (NCDOT Fact Sheet, 2009).

These facts merit the necessity for further research into the risk factors for injury that occur as a result of freeway work zone environments. Though the human factors that contribute to crash causation have been explored rather thoroughly, less attention has been given to the design of work zones themselves or environmental factors of crash causation. The persistence of work zone injury and fatality despite years of awareness of the issue further highlight the importance of this research. More specifically, focusing on identifying and quantifying the risk factors most pertinent to causing severe injury or fatality may be the most efficient means for addressing injury risk intervention.

1.1 Background

The history of American freeways and the automobile are intricately connected, as industrialization and the mass production of the automobile created a significantly larger demand for better paved roads and faster means of travel. The bulk, however, of the expansion of the modern interstate system did not occur until President Dwight Eisenhower signed the Federal Aid Highway Act of 1956. This marked the beginning of heavy federal investment in a national network of interstates and their supporting infrastructure (Karnes, 2009). The initial construction of the freeway system may have been considerably easier to manage at the time of origination as there were fewer vehicles on the roadways and no regular users dependent upon them for corridors of transportation. The freeway system in many ways became a symbol of American expansion and luxury as it provided the world an example of a national cooperative effort to make high speed travel and the transportation of goods across the continent a reality for American small businesses (Karnes, 2009).

The establishment of federal institutions in the 1950s and 60s was the beginning of a more centralized and systemic approach to highway design and funding (Karnes, 2009). Revolutions in safety research and the establishment of the National Highway and Traffic Safety Administration (NHTSA) helped to establish modern automobile safety research and lead to standardized safety equipment designed to prevent and/or decrease the likelihood of injury and/or fatality from crashes. In addition to standardizing safety, there was a growing awareness of the need to make the design of the roads safer as well

(Goetsch, 2010). A beginning effort to address freeway safety was begun when the FHWA was created on Oct. 15th, 1966 within the DOT "to support state and local governments in the design, construction, and maintenance of the Nation's Highway System and various federally and tribally owned lands" (FHWA, 2013).

The establishment of these organizations and initiatives marked the beginning of the rapid expansion of the American freeway system. This continued growth in infrastructure went on unabated for decades and it has only been recently that construction of additional capacity has decreased (Karnes, 2009). Modern focus on the freeway systems is now turned towards resolving the issues that come from an aging infrastructure already in use, bogged down by an ever growing rate of highway travel (Karnes, 2009). Many of the major segments of highway and bridges that were developed during the system expansion era of freeway construction have already exceeded their recommended lifetime. The construction work zones that are now necessary to improve the infrastructure are becoming an impediment to mobility and a disruption to the already strained flow of travel on our freeway systems. These freeway work zone sites then tend to become an area of significant safety concern as they have an elevated crash and injury risk associated with them (Garber & Zhao, 2002).

Though isolated studies on transportation and freeway research did appear in the literature in the 60s, the bulk of the research literature did not really develop until the 1970s and 80s. Even at this time, transportation research seemed to be focused on Human Error Theory (Sivak, 1981) and traditional Domino Theory models of linear causality (Sabet et al., 2013). A 1977 study of freeway crash investigations was found to cite human factors as responsible for 93% of crashes (Treat et al, 1977). This paradigm of thought tended to see crashes as the result of human error and emphasized the chronological sequences of crash causation, focusing on preceding events and their resultant consequences.

It wasn’t until the early 1990s that transportation and highway research began to be influenced by systemic theories of crash causation. These theories acknowledged the role that the environment can play in crash causation. The importance of this emerging scientific paradigm of crash causation was that causality was seen as a systemic problem with interactional potential beyond that of simple chain-of-events causality (Goetsch, 2010). Current crash and safety research tends to be dominated by the Systems Theory Model. This model posits that crash potential arises from the interaction of the following components: person, machine, and environment. Thus, “Changes in the patterns of interactions can increase or reduce the probability of an accident” (Goetsch, 2010).

These more complex models of crash causation allowed for investigation of environmental and design related contributions to crash occurrence. This shift in acknowledging the role non-human environmental factors play in crash causation facilitated more intensive research efforts into designing systems more tolerant of the human performance within them (Johnston, 2006).

Sophisticated computer modeling has more recently become a preferred methodology for analyzing work zone risks and factors of crash causation due to the complexity of information and number of variables typically being examined when analyzing crash causation data. Previous research has successfully utilized various models and methodologies to determine significant contributions towards crash causation and injury in other states (Li & Bai, 2008: Garber & Zhao, 2002). With national public awareness of work zone safety and a well-documented case for the need for work zone safety research, further research into work zone injury severity utilizing modeling technology and analysis promises both fruitfulness and positive public perception.

1.2 Problem Statement

The frequency of work zones on the freeway system is on the rise as the aging American infrastructure is in desperate need of repair and replacement. The high incidence of work zone crash, injury, and fatality that was observed through the 1980s was met with some federal initiatives to increase the safety of work zone environments. Despite various attempts to address this ongoing risk, little headway has been made in decreasing work zone injuries and/or fatalities.

Though a considerable body of research has been accumulated on crash characteristics at work zones and the human factors that contribute to crash causation, there has been less research to specifically address the prevention of severe injury and/or fatalities through the identification of the risk factors that contribute to their occurrences within work zones.

With the number of work zones increasing, fatality and/or severe injury is likely to also increase without proper intervention. Since the operational definition of work zones is left at a state level and varies according to different state DOTs, research on risk factors affecting work zones must be done at the state level. The proposed target of study for this research is severe injury crashes in work zones in North Carolina and the risk factors contributing to those crashes.

1.3 Research Objectives

The primary research goal of this dissertation is to identify and quantify work zone risk factors that contribute to injury severity in work zones so as to mitigate those risks through preventative measures. The key research objectives of this dissertation necessary for this include:

1. Identification and description of work zone crash characteristics
2. Identification and quantification of risk factors for those crashes
3. Development of work zone crash causation model in an effort to help alleviate risk and proactively apply countermeasures

Crash data from 2007 – 2014 for North Carolina, obtained from the NCDOT was used to process, analyze and achieve the research goal and objectives.

1.4 Research Organization

The organization of this dissertation consists of four more chapters. Chapter 2 presents a comprehensive literature review of peer reviewed research on work zone crash characteristics and injury or crash severity. Chapter 2 also identifies many limitations that have occurred with other studies on work zone crashes.

Chapter 3 provides an explanation and review of the methodology used to conduct the research. It includes the data collection process used to identify the where, when and why work zone crashes occur, methods to extract and analyze data from North Carolina Crash Database and Traffic Engineering Accident Analysis System (TEAAS). The chapter also includes the development and validation process for the multinomial logit model used in the modeling process in this study.

Chapter 4 describes several of the remaining steps taken in the study, starting with the crash data itself and an explanation of the variables utilized, crash trends that became apparent when analyzing the data, and the research hypothesis. Variable significance and evaluation of the goodness of fit of the model used in the study is also discussed. The results obtained and summary of findings, and potential countermeasures from this research is also presented in Chapter 4. Conclusions and potential for future research is presented in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

The current paradigm of crash causation is dominated by systems theory models. These theories maintain that crashes occur as a result of the interaction of person, machine, and environment (Goetsch, 2010). Early crash causation research was governed by Human Error Theory (Sivak, 1981) and Domino Theory Models of linear causality (Sabet et. al., 2013). Much of this early research was devoted entirely to understanding the human aspects that contribute to crashes and was relatively unconcerned with the other contributory factors. As systemic theories of crash causation began to become more widely developed and utilized, and national attention to work zone injuries began to increase, more research began to appear that examined both the mechanical and environmental aspects of crash causation accommodated by systems theories (Goetsch, 2010).

Current work zone safety research seeks to better understand the circumstances that lead to severe crashes so as to either prevent them from occurring or to ease the impact of those crashes on injury severity or likelihood of fatality. Identification of the risks posed to public and personnel safety in the work zone is essential in the current political and economic climate to ensure that the greatest gains are achieved with limited funding availability. The research and resulting data on this topic seem to be focused on the identification and description of work zone crash characteristics and the identification of risk factors for those crashes in an effort to decrease crash or injury severity (Li & Bai, 2008; Garber & Zhao, 2002).

2.1 Work Zone Crash Characteristics

The rise of fatalities in work zones in the 1990s sparked federal and political interest in improving the safety of work zones so as to decrease injuries and fatalities (Khattack & Council, 2002). Despite various efforts, fatalities have remained at a fairly constant level per year of around 700. Of those fatalities, 85% are car occupants and 15% are work zone personnel (Yang et. al., 2013). This along with the 40,000 injuries per year resulting from work zone crashes, has served as the basis for continuing research seeking to better understand the complexity of variables at work in crash causation and the risk factors that can lead to crashes and injuries within it (Yang et. al., 2013).

The sheer complexity of work zone circumstances may make definitive causal attributions ever elusive, but the growing fund of knowledge stemming from this research is essential to facilitating countermeasures to elevated work zone risk (Yang et. al., 2013). A number of studies have found inconsistent results as to whether the average work zone crash itself is more severe than non-work zone crashes (Garber & Zhao, 2002), but the majority consensus is that “crash rates increase in the presence of work zones compared to normal conditions” (Yang et. al., 2013, p.192). Some of the inconsistency may come from differences in operational definitions, methodology, and data collection between the various studies conducted in differing states (Garber & Zhao, 2002; Li & Bai, 2008), as well as the complexity of the variables being analyzed or modeled, and the nuances of disparate statistical analyses.

Some of the more comprehensive reviews of research summarizing crash characteristics and crash risk factors have been conducted through collaborative efforts between state DOTs and academic researchers working through universities (Li & Bai, 2008: Garber & Zhao, 2002). The literature does reflect considerable variation in crash characteristics at different parts of the work zone and in crash reporting characteristics (Garber & Zhao, 2002).

The majority of previous work zone studies on crash characteristics can be categorized with the following factors: crash rate, crash type, time, location, traffic control devices, contributory factors, and severity (Garber & Zhao, 2002; Li & Bai, 2008).

2.1.1 Crash Rate

The research topic of how work zones affect crash rates has been fairly well addressed with largely consistent results across studies. The introduction of a work zone to a freeway system seems to inherently bring with it an increased rate of crash occurrence related to the disruption of regular traffic flow (Cheng et. al., 2012: Li &Bai, 2008). This has been a fairly consistent research finding across studies and over time (AASHTO, 1987; Garber & Zhao, 2002(B); Hall & Lorenz, 1989; Pal & Sinha, 1996; Pigman & Agent, 1990). The estimation of that increase has varied across studies to be anywhere from 7 to 21.5% higher than comparable sections of highway without work zones (Khattack, & Council, 2002; Ullman & Krammes, 1990; Rouphail et al., 1988). In fact, a constant rate of 0.8 crashes per mile per day in work zones was observed, regardless of their length and duration (Rouphail et. al, 1988).

2.1.2 Crash Type

The predominant type of crash in work zones can vary widely with other crash risk factors such as time of day and location, but the general consensus across literature is that "rear-end" type collisions are the most frequent crash type in work zones (Li & Bai, 2008; Khattack & Council, 2002; Coburn et. al., 2013; Garber & Zhao, 2002; Pigman & Agent, 1990; Hall & Lorenz, 1989). Sideswipe collisions were also found to be a secondary crash modality and these tended to happen as traffic moved from the advance warning area to the transition area (Garber & Zhao, 2002; Garber & Woo, 1990; Khattack & Council, 2002). Some studies have also found "fixed-object" type crashes to be fairly significant (Mohan & Guatum, 2002), and crashes involving heavy trucks to be more frequent as well (Khattack & Targa, 2004). Finally, work zone crashes have been found to have a larger percentage of "multiple-vehicle" crashes than non-work zone crashes (Garber & Zhao, 2002).

2.1.3 Crash Time

The majority of work zone crashes naturally distribute around the temporal and seasonal parameters that govern construction activity. Consequently, crashes are more likely to occur during the height of construction season in the Northern hemisphere (from June to October) and during the daytime when most construction activity occurs (Li & Bai, 2008; Mohan & Gautam, 2002; Pigman & Agent, 1990). A few researchers in the past have found nighttime crashes to be significantly more severe (Pigman & Agent, 1990), but others have found contradictory results (Garber & Zhao, 2002). Further, research on nighttime crashes in work zones suggests that crashes occurring at nighttime have a greater likelihood of being fixed object and single-vehicle crashes (Ha & Nemeth, 1995).

2.1.4 Crash Location

Both the location where crashes tend to occur on the freeway system and where they tend to occur within the work zone itself have been addressed consistently in the past. With regard to the geographic location of the crashes themselves, an early AASHTO study found that work zones on rural freeway systems accounted for 69% of all fatalities (AASHTO, 1987). Other studies have consistently found higher work zone crash rates in rural freeway systems and two-lane roads (Pigman & Agent, 1990; Rouphail et al., 1988). More recent research completed in cooperation with the Virginia DOT further corroborates that the majority of work zone crashes take place on rural freeways, interstates or other principal arteries, and in non-intersection areas without remarkable features (Li & Bai, 2008).

There has also been a significant amount of research on where the crashes are occurring within the work zone itself. With regard to the physical sub-boundaries of the work zone, the activity area of the work zone has repeatedly been demonstrated to have a higher number of crashes than the other areas of the work zone (Garber & Zhao, 2002; Pigman & Agent, 1990). These numbers vary to be 45 to 69% higher than other parts of the work zone (Garber & Zhao, 2002). Some research has indicated an increased risk of getting involved in a crash within the transition area that contains the longitudinal traffic buffer. In fact, shortening the length of this buffer zone has been found to pose both an increased crash risk to drivers and work zone personnel (Morgan et. al., 2010).

2.1.5 Other Causal or Contributory Factors

A considerable amount of work zone research has been concerned with identifying the causes of crashes and delineating the risk factors for those crashes. Though environmental variables such as rain, snow, poor visibility, or road surface conditions due to weather undoubtedly pose some risk to crash causation within the work zone, previous research has not demonstrated that risk to be significantly different from the surrounding area (Li & Bai, 2008; Garber & Woo, 1990). There have been fairly extensive efforts to investigate the significance of human errors in crash causation within the work zone. Numerous studies have identified the significance of their role in crash causation and some studies suggest that inattentive driving, following too closely, and other misjudgments may be a primary cause of crashes (Li & Bai, 2008; Mohan & Guatam, 2002; Pigman & Agent, 1990).

Another area that has been identified as a significant contributory factor to work zone crash causation is speed or more specifically, “speed differential” (Garber & Zhao, 2002). Speed differential is the difference between vehicle speeds as they are transitioning to the work zone speed from the regular freeway posted speed. Garber & Woo (1990) refer to this as “speed variance” and find that the introduction of work zones increases the speed variance of vehicles traveling on the freeway. This increase is directly related to the increase in crash rates. Some research has indicated that this increase in speed variance in work zones comes from a large proportion of drivers who make no significant effort to reduce their speeds until necessary, despite appropriate signage (Garber & Gadiraju, 1981).

The reduction in speed limit in work zones is important because it does help to make the zones safer for the workers. However, it can significantly increase vehicular delays based on several factors. Work zones cause disruption to the traffic flows and reduce capacity resulting in delays for vehicles (Imran & Pulugurtha, 2014). The ability to predict traffic delays is crucial in order to minimize effects on vehicular traffic. However, reducing the posted speed limit can lead to congestion which can lead to crashes such as rear-end collisions (Imran & Pulugurtha, 2014).

Khattack, & Council (2002) conducted a fairly comprehensive study using The Highway Safety Information System (HSIS) data developed by the FHWA and crash data files from the California DOT. A negative binomial model was used to investigate how frequencies of crashes were affected by manipulating work zone traffic, length, and duration. Their results indicated that increasing the length of the work zone increases both crash and injury risk and frequency. Non-injury crash rates were reported at 23.5% higher and injury rates at 17% higher (Khatttack & Council, 2002).

Harb et al. (2008) examined freeway work zone crash traits through a combination of conditional and multiple logistic regression models using the Florida crash database for the years 2002-2004. They found that roadway geometry, age, gender, alcohol/drug influence, weather condition, lighting condition, and residence code increase risk in work zones (Harb et. al., 2008).

A rather large study was conducted by Garber & Zhao (2002) in conjunction with The Virginia Transportation Research Council, United States DOT, and the FHWA to identify the crash characteristics at work zones. They investigated crashes occurring in Virginia between 1996 and 1999 to analyze where within the work zone the crashes were occurring and what type of crashes were occurring. They sub-divided the boundaries of the work zone into the following five areas: advance warning area, transition area, longitudinal buffer area, activity area, and termination area. They found that the activity area had the largest number of crashes and fatalities, while the termination area had the least amount of crashes. They also found that rear-end crashes were the most common type across road types and work zone areas, except for the termination area. Crashes in the termination area tended to be angular based crashes. The advance warning area was significantly characterized by rear-end crashes (83%). Most nighttime crashes occurred in the activity area and had significantly more fixed object crash types (Garber & Zhao, 2002).

Garber & Zhao (2002) were able to reach a number of conclusions with applicable strategies for mitigating crash risk in state work zones. Activity areas have the most crashes and therefore pose the most danger in a work zone. Therefore, countermeasures aimed at the activity area will have the largest impact on increasing safety. The over-representation of rear-end crashes in work zones is suggestive of speed, or more specifically speed variance, as a major contributing factor to work zone crashes, particularly in the advance warning area as vehicle slowing occurs. They also suggest that the increase in fixed object crashes that occurs at nighttime might be addressed through better lighting techniques (Garber & Zhao, 2002).

Other research has begun to focus on specific characteristics of crashes in work zones, such as issues of injury or fatality. Li & Bai (2008) utilized data from Kansas's DOT crash database to investigate the characteristics of crashes causing injury or fatality. From the data they were also able to ascertain some important crash characteristics of these types of crashes. Crashes causing fatalities were most likely head-on collisions, and rear-end crashes were the most common type of crash reported with injury. Fatal crashes were more likely to involve trucks, while injury crashes were most commonly reported in lighter duty vehicles. Fatal crashes were also more likely to involve unfavorable light conditions and complex road geometries, and injury crashes were more likely to come from following too closely (Li & Bai, 2008).

2.2 Crash & Injury Severity

While a large amount of research has begun to develop on the characteristics of crashes in work zones, it has only been recently that a specific focus on the nature of injury severity in work zones has begun to be addressed. Crash and injury severity research within the work zone is primarily concerned with identifying the factors of the work zone that contribute to more severe crashes and/or injuries. The limited funds available to state DOTs, along with the increasing costs of crashes and treating their injuries, demand that increasing research efforts be made to identify the most severe crash and injury risks. Current research both complements and reflects a nationwide emphasis on reducing fatalities and severe injuries. The development of effective countermeasures to mitigate severe crashes and injuries is imperative both from economic and humanitarian points of view (Coburn et. al., 2013).

Crash and injury severity are often researched or discussed interchangeably as they are both a measure of crash severity using different preferential criterion. Though they may be strongly correlated through the crash severity commonality, a severe crash can occur without injury. As noted by Coburn et al. (2013) crash severity will be the same for all participants in a crash, whereas injury severity will vary for each individual involved.

It has only been in the past decade that research has begun to explore how work zone risk factors affect injury and/or crash severity. Khattack & Targa (2004) explored the role of work zone characteristics on injury severity and total harm in truck-involved work zone crashes in North Carolina. Data was taken from the HSIS for the year 2000. Injury severity was modeled using three probit models for injury severity and three Ordinary Least Squares (OLS) log transformed models for total harm. In addition to finding truck involved crashes to be more injurious than non-truck involved crashes, they were able to identify multiple aspects of the physical form of the work zone as contributory risk factors to injury severity.

Li & Bai (2009) investigated highway work zone risk factors and their impact on crash severity. They used available Kansas crash data from the years 1998 to 2004 to examine fatalities and data from the years 2003 and 2004 for injury crashes. After identifying the risk factors using various Chi-Square procedures, the factors were further analyzed using logistic regression and frequency analysis techniques. They identified the following risk factors for crash severity: age and gender (of at fault driver), poor lighting conditions, vehicle type (truck vs. non-truck), arterial roads and other poor road conditions, and driver error.

Akepati and Dissanayake (2011) also investigated risk factors associated with injury severity in work zone crashes. They utilized work zone crash data from the Iowa DOT from the years 2002-2006. They used an ordered probit model for the analysis of the data, as probit models can take into account the indexed nature of various ordinal response variables. Injury severity in this study, as an ordinal response, had variables of the following categories from least to most severe: Non-injury, possible injury, non-incapacitating, incapacitating/disabling, and fatal injury. A total of 35 independent variables were modeled with injury severity as the dependent variable. They found that the following variables showed a greater likelihood for severe injury: truck-involved collisions, following too closely, airbag malfunctions, sideswipe same way collisions, and crashes involving left or right turns.

2.3 Modeling Injury Severity

Sophisticated computer modeling has more recently become a preferred methodology for analyzing work zone risks and factors of crash causation due to the complexity of information and number of variables typically being examined when analyzing crash causation data. This research has used a broad array of different statistical analyses and modeling techniques with rationale for choice typically being made based upon the nature or form of the available data. Injury severity is typically compiled in crash databases as an ordinal discrete variable utilizing such categories as: no injury, minor injury, major or debilitating injury, and fatality (Yasmin & Eluru, 2013).

A recent review of the literature conducted by Yasmin & Eluru (2013) found that the most prevalent means for modeling injury severity were logistic regression and ordered response models at 77% of 31 articles reviewed. They further noted that logistic regression modeling has been increasing in the past decade, and this is largely due to the nature of how traffic crash data is being reported and coded into databases. The discrete ordinal nature of injury severity data lends itself well to these statistical modeling techniques. They further found that the most prevalent unordered response models were utilizing multinomial logit models (Yasmin & Eluru, 2013).

Savolainen et al. (2011) note that the appropriate methodological approach to model injury severity “can often depend heavily on the available dataset, including the number of observations, quantity and quality of explanatory variables, and other data-specific characteristics” (p.1673). Their review of the literature found 27 different types of statistical analyses used with injury severity data. Some of the more commonly utilized models include multinomial logit, binary logit & binary probit, ordered logit and ordered probit, and mixed logit models (Savolainen et. al., 2011; Yasmin & Eluru, 2013).

The majority of the research specifically reviewed in this paper utilized either logistic regression modeling techniques or ordered probit modeling. Harb et al (2008) used logistic regression working with the Florida crash database for crash analysis and risk factor identification. Li & Bai (2008, 2008b, 2009) have repeatedly utilized logistic regression in their work identifying risk factors for injury and/or fatality. Logistic regression was also utilized by Weng & Meng (2011) in analyzing driver casualty risk for different work zone types.

2.4 Limitations

The push for increased transportation safety in the past two decades has helped to facilitate better research methods and create an interest in more complete datasets. Despite the variety of methodologies for modeling the data and their individual strengths and weaknesses, there are also some general concerns and limitations when working with crash data.

Of utmost concern is the persistence of increased risk for injury and/or fatality that occurs in freeway work zones. Fatalities and injuries seem to remain at a fairly constant level despite years of research and intervention (Yang et. al., 2013). Failure to make clear headway in mitigating work zone risks suggests either insufficient identification of causal factors for crashes or a failure in applying research findings to procedural and/or design strategies utilized by state DOTs. Either way, the need for continued research into this matter is a necessity to decreasing the continued risk.

Another major limitation of work zone research is the inconsistency in results across studies. Several major studies and significant literature reviews have repeatedly found contradictory results as to whether the average work zone crash is any more severe than its non-work zone counterpart (Garber & Zhao, 2002). Though there are contradictory results in the literature, the common consensus has been that “crash rates increase in the presence of work zones compared to normal conditions (Yang et. al., 2013, p.192). Various inconsistencies across the literature can come from differences in operational definitions, methodology, and data collection, as well as the sheer complexity of the variables being analyzed or modeled and the various nuances of disparate statistical analyses (Garber & Zhao, 2002; Li & Bai, 2008).

Another major limitation of previous research has been the focus of the research itself. Science, as a social institution, is governed by paradigms of thought or theory. Previous research on human factors in the late 1970s and early 1980s focused almost exclusively on the human related variables that lead to crash causation. Consequently, the majority of human factors affecting crash causation have been extensively identified. As a consequence of the theoretical emphasis on human caused crash etiology, not as much attention has been given to environmental and mechanical (human-road complex machine) design related issues. Initial research into environmental conditions such as rain, snow, poor visibility, or road surface conditions has often found their risk to be equally independent of work zone presence (Li &Bai, 2008; Garber & Woo, 1990).

Still another limitation of current crash and/or injury severity research within the work zone has been the relatively recent emergence of this study area. This research focus has only just begun to be elaborated upon, stemming from a national effort to decrease work zone injuries and fatalities that began in the 1990s. The majority of the research on injury and/or crash severity within the work zone is less than a decade old (Khattack & Targa, 2004). Contributing to this knowledge base is vital for improved understanding of risk and preservation of human life.

A final limitation to the previous research is the crash/injury correlation. Some research may use the terms interchangeably as they are both simple measures of the severity of a crash using different criterion. Though crash severity and injury severity are strongly correlated, it should be noted that a severe crash could occur without injury. Further, crash severity will be the same for all individuals in a crash, but injury severity will vary at the individual level (Coburn et. al., 2013).

Though there have been some major limitations to the scope of previous research, the research has continued in an effort to decrease risk of injury in work zones. Further, previous research has made considerable progress in identifying crash characteristics in work zones and the human factors contributing to those crashes. However, not as much targeted attention has been given to modeling injury severity. It should be also noted that injury and fatality rates in work zones have remained relatively consistent over the past decade. The current purpose of this research is to provide more information on how work zone risk factors contribute to crash causation and severe injury so as to design successful interventions that help to mitigate those injuries and crashes.

CHAPTER 3: METHODOLOGY

This dissertation research aims to identify the risk factors that contribute to injury severity as well as develop a model of injury severity utilizing data from the NCDOT maintained TEAAS. Modeling and analysis is selected based upon the appropriate structure and distribution of the data samples as substantiated by prior peer reviewed research. The development of a model for injury severity in work zone crashes is an endeavor with the potential to guide revising safety standards, operational guidelines, and crash prevention equipment that will mitigate the increased risk for injury associated with work zone activities. Results from this research should help to identify the largest contributors towards work zone injury risk, so that these risks can be most efficiently mitigated with limited available funding and resources.

The proposed methodology for conducting the research necessary to achieve the goals and objectives identified in Section 1.3 involves the following steps.

1. Defining Study Area and Data Collection Process
2. Locating Work Zone Crashes
3. Analyzing and Extracting Data from TEAAS
4. Developing Research Database
5. Developing Statistical Model
6. Validating Statistical Model

3.1 Defining Study Area and Data Collection Process

This study is particularly focused on freeway crashes occurring in North Carolina work zones. Data utilized in this study comes from DMV-349 reports that have been entered into the North Carolina crash database for the years 2007 – 2014.

DMV-349 reports are filed when a crash occurs on the roadway. It is the current version of the North Carolina Division of Motor Vehicle's (DMV) standard crash report (TEAAS, 2014). After a crash occurs on the roadway, a local police officer will respond to the scene and submit a standard form containing all the information about the crash. The DMV-349 report must be filed if the crash resulted in a fatality or injury, in property damage of $1,000 or more, or the vehicle was seized or is subject to forfeiture. If the crash meets these criteria and it occurred on a trafficway or after running off the trafficway, then there must be a DMV-349 report (DMV-349, 2012).

3.2 Locating Work Zone Crashes

After properly identifying and delineating the parameters of the study area, it is important to identify the physical location of the work zone crashes. To ensure that all available crash data are located geospatially, techniques such as linear referencing have been developed.

Linear referencing is a method for storing geographic locations using relative positioning along a line. It is an alternative to standard (x,y) coordinate data that expresses geospatial location through relaying relative positions measured from a linear known feature. Linear referencing is commonly utilized in traffic and transportation related datasets as an alternative means for locating a traffic crash, not dependent upon utilizing Geographic Information Systems (GIS) data. For example, a traffic crash might be recorded as having occurred 1,060 feet east of reference mile marker 42 along Highway 19.

Linear referencing in this study utilizes milepost data and route coding. The route coding is a numerical representation of both the inventoried route number plus the North Carolina county code called “Route 10.” The formula for “Route 10” is as follows:

$$\mathrm{INVD_{CD}} * 100 + \text{North Carolina county code} \qquad \text{(Eq. 1)}$$

where,

$\mathrm{INVD_{CD}}$ = inventoried route 8 digit code, and,

100 = is the conversion factor for leading zero when 8 digit code is less than 10.

The state of North Carolina is divided into 100 counties (Figure 2). Table 1 shows county names and their respective code numbers. For example, the code is 9 for Brunswick County. If the inventoried route for US 17 is 20000017, the “Route 10” is calculated as 20000017 * 100 + 9 = 2000001709.

The route coding “Route 10” and the calculated mileposts data (presented in section 3.3.2) were imported into GIS environment. The work zone crash locations were then geocoded on to the North Carolina network map (Figure 3).

3.3 Analyzing and Extracting Data from TEAAS

The TEAAS is used to link data from the North Carolina crash database with other information including roadway information, calculated milepost information, and ordinance information in a separate database for modeling and analysis purposes.

TABLE 1: North Carolina county numbers

(Source: NCDOT TEAAS, 2014)

County Numbers

County	Code	County	Code	County	Code	County	Code
Alamance	0	Cumberland	25	Johnston	50	Randolph	75
Alexander	1	Currituck	26	Jones	51	Richmond	76
Alleghany	2	Dare	27	Lee	52	Robeson	77
Anson	3	Davidson	28	Lenoir	53	Rockingham	78
Ashe	4	Davie	29	Lincoln	54	Rowan	79
Avery	5	Duplin	30	Macon	55	Rutherford	80
Beaufort	6	Durham	31	Madison	56	Sampson	81
Bertie	7	Edgecombe	32	Martin	57	Scotland	82
Bladen	8	Forsyth	33	McDowell	58	Stanly	83
Brunswick	9	Franklin	34	Mecklenburg	59	Stokes	84
Buncombe	10	Gaston	35	Mitchell	60	Surry	85
Burke	11	Gates	36	Montgomery	61	Swain	86
Cabarrus	12	Graham	37	Moore	62	Transylvania	87
Caldwell	13	Granville	38	Nash	63	Tyrrell	88
Camden	14	Greene	39	New Hanover	64	Union	89
Carteret	15	Guilford	40	Northampton	65	Vance	90
Caswell	16	Halifax	41	Onslow	66	Wake	91
Catawba	17	Harnett	42	Orange	67	Warren	92
Chatham	18	Haywood	43	Pamlico	68	Washington	93
Cherokee	19	Henderson	44	Pasquotank	69	Watauga	94
Chowan	20	Hertford	45	Pender	70	Wayne	95
Clay	21	Hoke	46	Perquimans	71	Wilkes	96
Cleveland	22	Hyde	47	Person	72	Wilson	97
Columbus	23	Iredell	48	Pitt	73	Yadkin	98
Craven	24	Jackson	49	Polk	74	Yancey	99

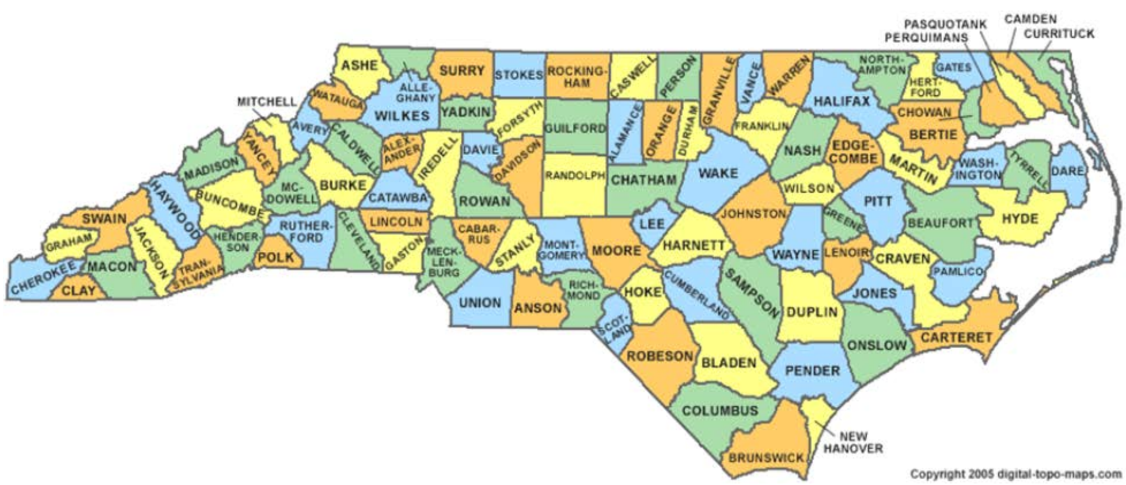

FIGURE 2: North Carolina county map

(Source: NCDOT TEAAS, 2014)

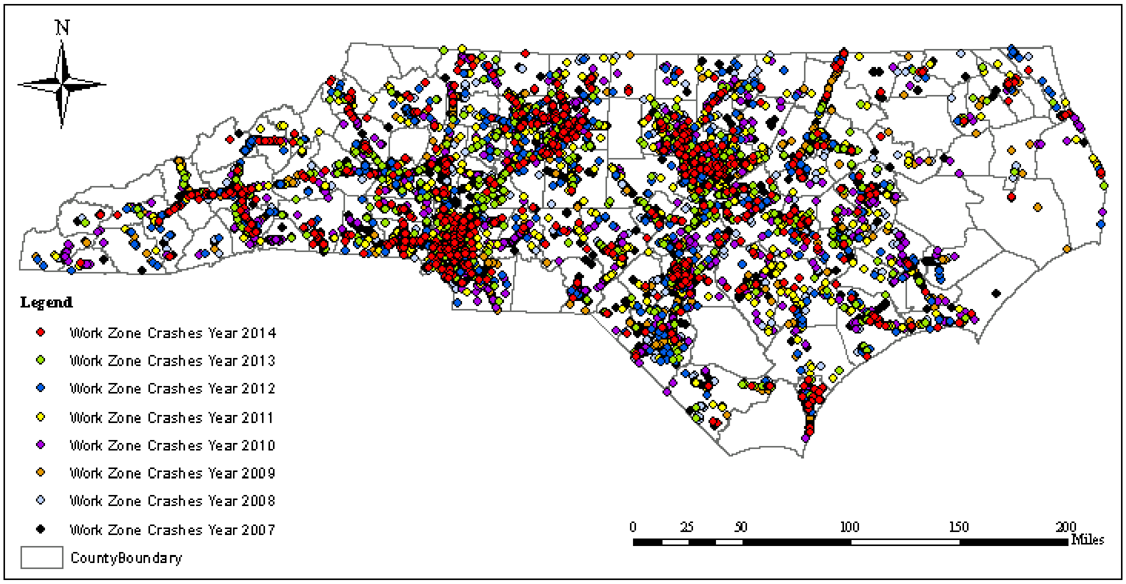

FIGURE 3: North Carolina work zone crash locations years 2007 – 2014

The data utilized in this study were from crashes reported in North Carolina freeway work zones for the years 2007 – 2014. The TEAAS database, however, contains information on all reported crashes in North Carolina since January 1st, 1990. TEAAS mainly consists of crash level information. However, for this research, the data database was limited according to three different levels: crash, unit, and person.

1. Crash level data: this data is applicable to the entirety of the crash regardless of units or people involved. Examples of crash level data might include time, location, and road surface condition.
2. Unit level data: this data is specific to the unit or vehicle only. Examples of unit level data might include speed or type of the vehicle involved in the crash.
3. Person level data: this data is specific only to the individual. Examples of person level data might include gender, age, or injury of the person(s) involved in the crash.

3.3.1 Routes Information

The State Highway System (SHS) of North Carolina has three types of roads: interstate routes (I), primary routes (US and NC), and secondary routes (SR). The interstate and primary routes generally do not coincide with the secondary routes. Where appropriate, routes are identified with both a state route number and a local name. Roads with coinciding routes have one route that is considered the highest order route (TEAAS, 2014). Crashes in the TEAAS system are given an 8 digit code to represent the type of road on which the crash occurred. Each eight digit code provides four categories of information. The first digit represents the route/boundary type, the second digit represents the special route type, and the third digit represents the couplet direction. The last five digits represent the route/boundary number left padded with zeros to fill five spaces (Figure 4). The lower the 8-digit code in most cases, with some exceptions where routes have been changed, the higher its order. Inventoried routes are those that are recorded in TEAAS (TEAAS, 2014).

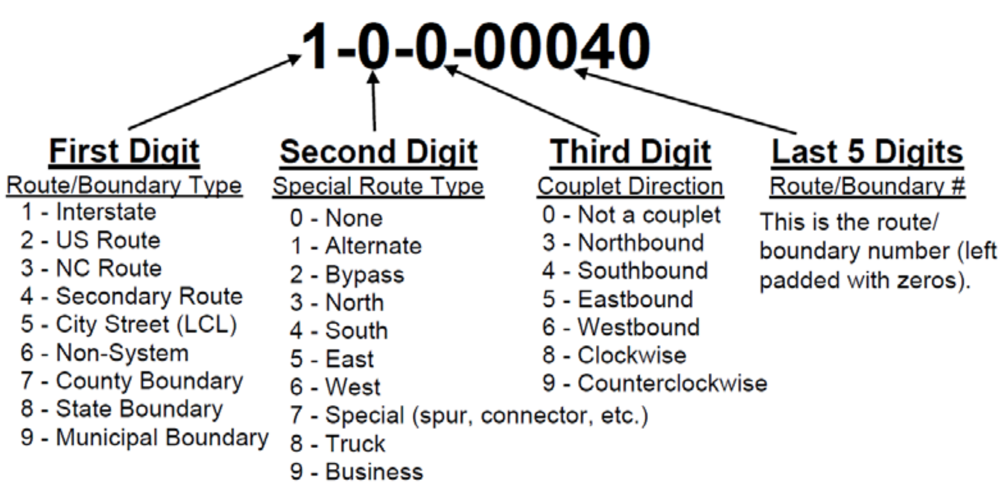

FIGURE 4: 8-Digit code

(Source: NCDOT TEAAS, 2014)

3.3.2 Milepost Information

Mileposts are a means for describing a location along a freeway or roadway, typically expressed in miles in the United States. These mileposts are pragmatic distance approximations along a freeway that are specific to each county and have defined beginning and ending points. Features along a roadway that might typically get assigned a milepost value are intersections, political boundaries, and route mileage values that are non-county specific (TEAAS, 2014). The standard for mileposting typically begins with milepost 0.000 and ends with a milepost number equal to the entire length of the road.

Since geospatial coordinates are not available for all the crash records in the database, mileposts were used to represent approximate locations. Crashes were georeferenced using milepost information on North Carolina DMW-349 reports. Mileposts were calculated from crash reports utilizing the road or route name on which the crash occurred, the name of the road or route at the closest intersection, and the distance between the crash and the closest intersecting road, as well as the direction. This information is typically denoted as:

1. Road On: road or route name on which the crash occurred
2. From Road: road name of an intersecting road near the crash
3. Distance From: distance between crash and “from road”
4. Direction From: direction of crash from the “from road”
5. Towards Road: next intersecting road in direction “from road”

The importance of this step is that it allows the TEAAS a means of locating crashes and ordinances along the length of a roadway in relation to other known features of the roadway. The formula for mileposts is based on the North Carolina DOT's Linear Referencing System (LRS) and is as follows:

$$\text{MP}_{n+1} = \text{MP}_n + (\text{Distance between feature}_n \text{ and feature}_{n+1}) \qquad \text{(Eq. 2)}$$

where,

MP = milepost, and,

n = milepost number.

Data collected from the North Carolina crash database and utilized by TEAAS with missing or incorrect milepost information was excluded from the study and marked within the database with milepost number 999.999.

3.3.3 Ordinances

Ordinances refer to posted traffic regulations governing mandatory traffic behavior and motor vehicle operation. An example of an ordinance relevant to crash data is posted speed limit.

3.4 Develop Research Database

The database utilized in this research comes from the North Carolina crash database. The North Carolina crash database consists of data from completed crash reports, DMV-349 forms that are submitted to the DMV for processing and submission to the North Carolina crash database. A copy of that crash data is then submitted to the TEAAS system, which then incorporates the data with roadway information, calculated milepost information, and ordinance information for the user of the system (Figure 5).

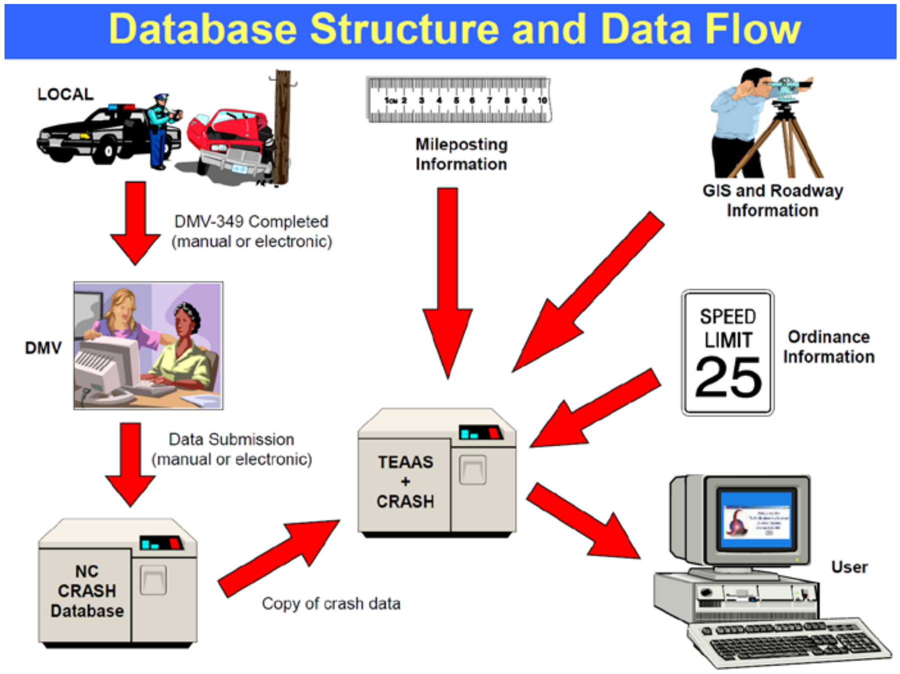

FIGURE 5: Database structure and data flow

(Source: NCDOT TEAAS, 2014)

3.5 Developing Statistical Model

3.5.1 Modeling

In order to ensure an increase in the safety of work zones on freeways, a crash severity model was developed and analyzed using resulting data from multiple existing traffic safety and work zone studies. Due to the numerous different variables that can or may impose threats on traffic safety in work zones, there were many factors considered for and analyzed in the modeling process. Some of the variables that were analyzed and used in the development of the crash severity model include the severity of work zone crashes, work zone types and locations, road conditions, the changing speed limits and the type of traffic control devices used. The ultimate objective of traffic safety modeling is to strive for safer work zone practices through analyzing the comparison of the number of recorded crashes in relation to its crash severity and the set work zone parameters.

The dependent variable that is being tested for is the severity or amount of fatalities that occur in a work zone. By comparing each independent variable to the dependent variable in multiple modeling forms, it is very easy to show which independent variables mostly affects the severity of crashes or amount of fatalities in a work zone. The modeling procedure efficiently displays all of the effects that each individual variable has made on the overall crash severity, typically by observing the amount of injuries or casualties that have taken place in the observed work zone (Caulfield, 2008).

Due to the large number of different factors that could have an influence on the injuries occurring in a work zone, the most accurate way to tell which variable is having the greatest effect on the work zone is to test each independent variable individually against the severity of crash injuries occurring in that work zone. The dependent variable for model testing is the severity of vehicular crashes taking place in a work zone.

Through the process of modeling, all of the effects taking place on injury severity due to each independent variable can easily be observed and used for analysis. When performing these model analyses, it must be noted that different model methodology forms should be used depending on the independent variable being tested for (Caulfield, 2008).

The results of different model methodology forms vary from each other, making it important for the engineer and researcher to select the proper methodology model when testing for a specific factor or variable. For instance, a discrete choice model can be used to analyze the dependent variable of crash severity against independent variables of work zone type or location, whereas the testing of independent variables such as the traffic control devices used in the work zone may be modeled by developing a regression model or using an Artificial Neural Network or a Back Propagation Neural Network.

There are various types of work zones on roadways that are defined by multiple characteristics of the construction project at hand, such as the project's location, size and duration (Hardy and Wunderlich, 2006). Due to the various scenarios each work zone type presents, different model methodologies are to be used to perform the analyses because each work zone type will have a different effect on the overall severity occurring in that zone. The location of the work zone is another factor that plays a significant role in the crash severity. The reason for this is because the work zone's location can relate directly to traffic congestion in the area as well as the amount of cars passing through the work zone. Each of the different work zone types typically relate to a different type of construction project taking place, and due to such a variance of factors between the different work-zone types, separate models must be analyzed for each zone. This is done in order to determine what independent variables are producing the largest impact on crash severity in those zones.

Traffic control devices also affect crash rates in work zones on freeways. Similar to the work zone types, there are multiple different traffic control devices that are to be tested and analyzed in separate models as well. It can be difficult to accurately model for traffic control devices because they all affect traffic patterns in different ways. The placement, size and category that the traffic control device may fall under will always have a different effect on the overall crash severity occurring in that work zone (Federal Highway Administration, 2014). There are some instances where it is not possible to model for these devices because it can sometimes not be determined if the crash was caused by the traffic control device present or simply due to a driver's error. It also can be difficult to obtain information regarding traffic crashes due to control devices because many of them are placed outside of the roadway or on the shoulder, so they may not have a direct impact on the traffic passing through that zone. There are instances where work zones on freeways do not have any traffic control devices as well, which makes it impossible to model or perform an analysis for them. (Bligh, 2006).

3.5.2 Modeling Methodology

3.5.2.1 Discrete Choice

A discrete choice model is generally used for the analysis and prediction of a choice of alternative from a finite set. A discrete choice model is extremely helpful when it comes to scenarios that are influenced by multiple different variables that affect a non-continuous dependent variable. It can interpret and analyze each variable individually to determine its overall effect on the outcome. This allows the analyst to not only determine how each individual variable influences the decision maker's choice, but also observe the characteristics of individuals when they make choice decisions (Koppelman and Bhat, 2006).

There are a number of different discrete choice model types that can be used for analysis purposes. However, the best model that applied ultimately depends on the subject matter being interpreted or tested for. Nested Logit models are typically the most popular form used for extreme value models but are not seen as flexible enough to approximate arbitrary discrete choice models. Many studies show that Nested Logit models are not effective in analyzing most traffic behavior patterns, and that Multinomial

Logit and Mixed Logit models are more much suitable due to their flexibility (Brownstone, 2001).

A discrete choice type model would usually be the best representation of a model form to use when modeling the crash severity occurring on freeways. One of the more popular and widely used discrete choice model types is the Multinomial Logit (MNL) Model which is commonly used in statistical scenarios (Caulfield, 2008). Koppelman and Bhat (2006) state that there are three assumptions leading to the MNL. They are:

1. Error components are extreme-value or Gumbel distributed,
2. Error components are identically and independently distributed across the alternatives, and,
3. Error components are identically and independently distributed across observation/individual.

Figures 6 and 7 display how a normally distributed dataset compares to that of a Gumbel distribution. The Gumbel distribution is commonly used in probabilistic choice models and it is a close approximation of the normal distribution model.

The formula shown in Equation 7 is a basic equation used for modeling severity based on a normally distributed dataset. It is derived by a combination of all of the preceding equations listed in Equations 3 through 6 (Koppelman and Bhat, 2006). Equations 3 and 4 represent the cumulative distribution and probability density functions, respectively, and relate to the Gumbel distribution model as well. Equations 5 and 6 were formulas used to determine the corresponding mean and the variance of the overall distribution.

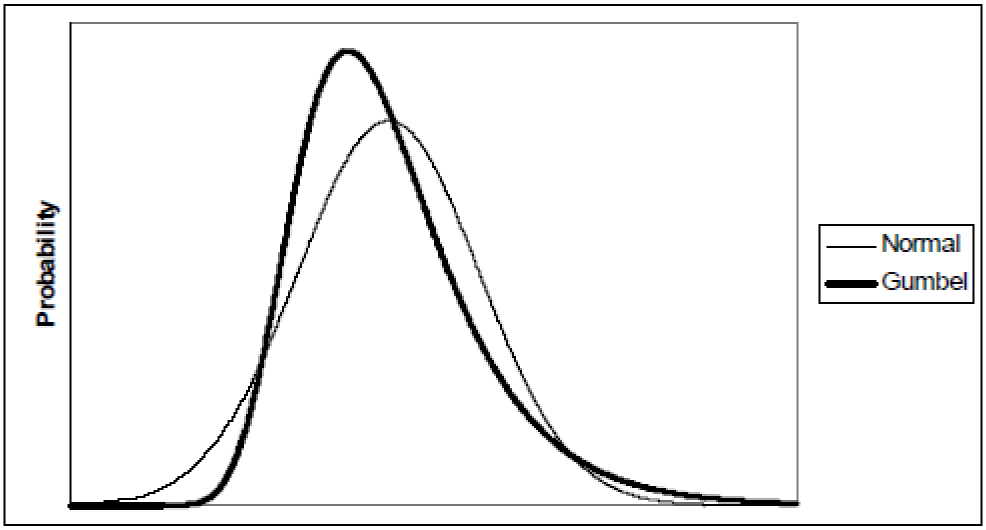

FIGURE 6: Probability density function for Gumbel and normal distributions

(Source: A self instructing course in mode choice modeling:

Multinomial and Nested logit models, 2006)

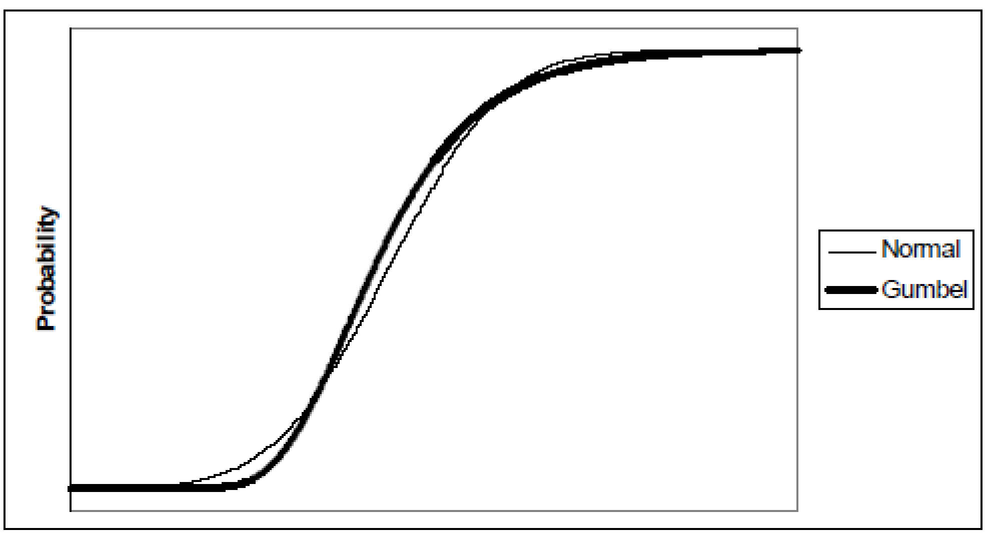

FIGURE 7: Cumulative distribution function for Gumbel and normal distributions

with the same mean and variance

(Source: A self instructing course in mode choice modeling:

Multinomial and Nested logit models, 2006)

$$F(\in) = \exp\{-\exp\{-\mu(\in - \eta)\}\} \quad \text{(Eq. 3)}$$

$$f(\in) = \mu \times \{\exp\{-\mu(\in - \eta)\}\} \times \exp\{-\exp\{-\mu(\in - \eta)\}\} \quad \text{(Eq. 4)}$$

where,

μ = is the scale parameter which determines the variance of the distribution, and,

η = is the location (mode) parameter.

$$\text{Mean} = \eta + \frac{0.577}{\mu} \quad \text{(Eq. 5)}$$

$$\text{Variance} = \frac{\pi^2}{6\mu^2} \quad \text{(Eq. 6)}$$

Using these 4 equations above, Equation 7 could then be derived, and the variable being solved for Pr(*i*) represents the probability that alternative "*i*" is chosen.

$$\Pr(i) = \frac{\exp(V_i)}{\sum_{j=1}^{j} \exp(V_j)} \quad \text{(Eq. 7)}$$

where,

V_j = is the systematic component of the utility of alternative *j*, and,

Pr(*i*) = is the probability of the severity choosing alternative *i* (different levels of severity: F & A, B & C, and PDO), where, Pr(*i*) is the probability of the occurrence of alternative *i*, and *Vi* is the systematic component of the utility of alternative *j*. In other words, the probability of fatal and disabling type of injury (F & A), evident and possible types of injury (B & C), and Property Damage Only (PDO) occurring on a roadway segment can be computed such as:

$$\Pr(F\ \&\ A) = \frac{\exp(V_{F\&A})}{\exp(V_{F\&A}) + \exp(V_{B\&C}) + \exp(V_{PDO})} \tag{Eq. 8}$$

$$\Pr(B\ \&\ C) = \frac{\exp(V_{B\&C})}{\exp(V_{B\&C}) + \exp(V_{F\&A}) + \exp(V_{PDO})} \tag{Eq. 9}$$

$$\Pr(PDO) = \frac{\exp(V_{PDO})}{\exp(V_{PDO}) + \exp(V_{F\&A}) + \exp(V_{B\&C})} \tag{Eq. 10}$$

where,

$\Pr(F\ \&\ A)$ = is the probability of the F & A severity,

$\Pr(B\ \&\ C)$ = is the probability of the B & C severity,

$\Pr(PDO)$ = is the probability of the PDO severity,

$\exp(V_{F\&A})$ = is the systematic component of the utility of alternative F & A,

$\exp(V_{B\&C})$ = is the systematic component of the utility of alternative B & C,

$\exp(V_{PDO})$ = is the systematic component of the utility of alternative PDO,

F & A = is the fatal and disabling type of injury,

B & C = is the evident and possible types of injury, and,

PDO = Property Damage Only.

The systematic component of the utilities (utility function) of severity ($V_{F\ \&\ A}, V_{B\ \&\ C}, V_{PDO}$) are random and based on rational theory such that:

$$V_{F\ \&\ A} = (\beta_1 \text{ x variable}_1) + (\beta_2 \text{ x variable}_2) + \cdots \tag{Eq. 11}$$

$$V_{B\,\&\,C} = (\beta_1 \text{ x variable}_1) + (\beta_2 \text{ x variable}_2) + \cdots \quad \text{(Eq. 12)}$$

$$V_{PDO} = (\beta_1 \text{ x variable}_1) + (\beta_2 \text{ x variable}_2) + \cdots \quad \text{(Eq. 13)}$$

where,

$V_{F\,\&\,A}$ = is the component of the utility of F & A,

$V_{B\,\&\,C}$ = is the component of the utility of B & C, and,

V_{PDO} = is the component of the utility of PDO.

The term V_i is referred to as the systematic component of utility for alternative "*i*," while the expression "*exp*" represents the exponential in the equation. Variable *J* in the formula stands for the number of alternatives being tested for in the dataset and term *j* represents other alternatives that may vary the outcome. The last variable in the equation of V_j is referred to as the systematic component of utility for alternative "*j*." It is generally up to the analyst to decide what variables or alternatives to use for tests, but if the probability of crash severity is what is being tested for, then the severity would most likely be represented by variable "*i*." By plugging these associated variables into the given MNL formula, a resulting severity probability can finally be derived. Figure 8 is a graph used to display the relationship between terms V_i and exp(V_i). It is very easy to see that term exp(V_i) always has a positive value and it increases with a monotonical relation to variable V_i as it also increases (Koppelman and Bhat, 2006).

As discussed earlier, there are numerous different model types that can be used for the analysis of traffic behavior studies. The MNL model is the best choice for our study because it is a measure of severity. There are a number of different model types that can be used to model crash frequency such as Poisson or Negative Binomial, but they are not considered effective in severity studies because they tend to exploit potential human factors in the study. The MNL model is excellent in analyzing studies of crash severity because the model takes all of the factors into consideration instead of focusing only on the crash occurrence at certain locations (Zhang, 2010).

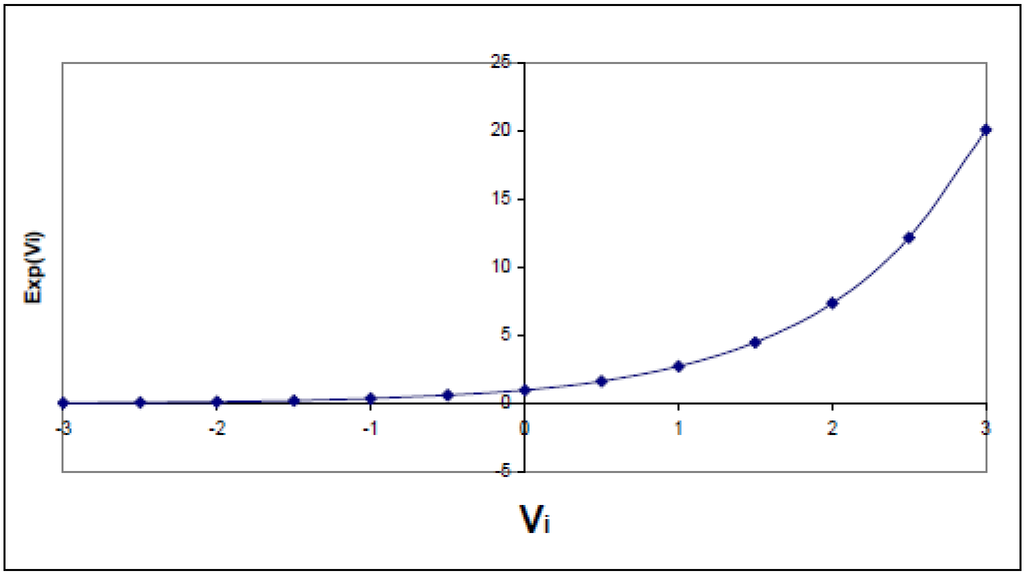

FIGURE 8: Relationship between V_i and Exp(V_i)

(Source: A self instructing course in mode choice modeling:

Multinomial and Nested logit models, 2006)

Due to the MNL model's closed-form formula and its ease of interpretation, the MNL is considered to be the easiest and most widely used form of discrete choice model when testing for choice probabilities. The MNL model takes all of the potential factors into consideration when calculating an outcome, which is why it is generally a much more accurate prediction when it comes to severity models. Factors that are taken into consideration for analysis when using the MNL model include the environment, roadway, vehicle and even the human driver (Zhang, 2010).

3.6 Validating Statistical Model

Validation of the test data was performed at the end of the modeling process by computing various error values, depending on which error metric fit the dataset the best. Twenty percent (20%) of the dataset was randomly sampled by the error metric methods in order to determine the effectiveness of the model in evaluating work zone crash severity. A few of the most common error metrics used to evaluate model performance are the Mean Forecast Error (MFE) and the Mean Absolute Deviation (MAD). Each form of error metric has its own equation for calculations. Since each error metric gives different results depending on the type of model used and dataset, the analyzer must decide which error value gives the best interpretation for validation of that data (Twomey and Smith, 1995).

To summarize the proposed methodology, after the area of study is defined, crash data is then collected and work zone crashes are located using linear referencing. North Carolina crash data and information regarding roadways, mileposts and ordinances can all be extracted and analyzed by use of TEAAS. All of this information is useful in developing a research database as well as a statistical model to be used for the analysis of this study. The model methodology that is being proposed for the analysis of work zone crashes is a discrete choice model. The modeling data is calibrated based on severity, work zone types and areas, and other contributing factors. The statistical model used for the analysis of work zone crash severity is then put through the validation process.

CHAPTER 4: DATA PROCESSING AND ANALYSIS

4.1 Crash Data

The data used in this research was obtained from the NCDOT maintained TEAAS for the years 2007 – 2014. TEAAS utilizes DMV-349 reports filed by police officers at the scene of a crash. The DMV-349 reports contain several important characteristics about the crash, such as severity, location, potential driver impairment, and road conditions. TEAAS and the DMV-349 reports were explained in further detail in Chapter 3. In the case of this research, the data that is being used is coming from crashes that occurred in designated work zones.

For every crash recorded in the database, there are numerous factors and characteristics that are taken into consideration. These different characteristics are organized into three different categories. They are: human factors, roadway environment factors, as well as vehicle factors. Human factors are the factors that were influencing the driver responsible for the crash, such as the condition of the driver, decisions made by the driver, actions such as speeding, or violation of traffic laws. Characteristics such as age, presence of alcohol or other impairments, and gender are also found within this category. Roadway environment factors relate to several different aspects of the physical roadway itself and its condition at the time of the crash. This includes the weather conditions at the time of the crash or various roadside hazards such as trees or poles blocking lines of sight or obstructions on the roadway itself. The design of the roadway and work zone itself is also considered in this category by looking at different factors such as narrow lanes, medians, curves, and access points. Lastly, vehicle factors take into consideration any mechanical failures or design issues on the part of the vehicle.

A total of 26 independent variables were considered in the development of work zone crash prediction models. The three dependent variables that were considered for the model were based off of different levels of crash severity. In the case of this model, the crash severity is determined by the most severe injury of the persons involved in the crash. F (Fatal) and A (Disabling) type injuries were combined, B (Evident) and C (Possible) type injuries were also combined, and Property Damage Only (PDO). Table 2 summarizes the dependent and independent variables used to develop all MNL models, and Table 3 provides more details about these variables.

4.2 Crash Trend

The numbers of work zone crashes for the years 2007 – 2014, organized via severity level is displayed in Table 4. This table shows how many crashes of each severity occurred within a given year, while also displaying what percentage of crashes fell into each severity level category compared to the total number of work zone crashes for the year. Figures 9, 10, and 11 summarize percent of F & A, B & C, and PDO crashes by year, respectively.

Overall, there was a considerable increase in the number of work zone crashes that occurred between the years of 2007 and 2014, the total increasing from 1,895 crashes in 2007 to 2,680 crashes in 2014. However, the percentage of F & A type injury crashes decreased by nearly half from 2007 to 2014. There is also a decrease in the overall percentage of B & C type injury crashes between 2007 and 2014. The number of PDO crashes increased during this period. Nevertheless, despite the increase in crashes from 2007 to 2014, it appears that fewer severe crashes occurred during that time.

TABLE 2: Description of variables used in this research

Variables	Description
Dependent Variables	
F & A	Fatal and disabling type of injury
B & C	Evident and possible types of injury
PDO	Property Damage Only
Independent Variables	
RD	Road classification (Crash roadway location)
RDCONF	Road configuration
RDCHAR	Road character (Horizontal and vertical alignment)
TIME	Crash time
SEASON	Crash date (Month, day, and year)
DAY	Crash week day
CRASHTYPE	Crash type
WORKZONE	Work zone type which a crash occurred
WZACTIV	Work zone activity at the time of crash
WZMARKED	Work zone area marked with warning signs
B4&AFTER	Location of crash within temporary traffic control zone
WEATHER	Weather condition
RDFEATURE	Road features
RDSURFACE	Road surface condition
LIGHT	Ambient light
SPDLMT	Vehicle authorized speed limit
WZSPDLMT	Vehicle authorized speed limit within work zone construction area
VEHICLE	Vehicle style
GENDER	Driver's gender involved in crash
ALCOHOL	Alcohol or other drugs suspected
BELT	Occupant/non-motorist protection system use
AGE	Driver's date of birth
OCPNTTOT	Total number of occupants in all vehicles involved in crash
OCPNTS	Number of occupants in a single vehicle involved in crash
UNITS	Number of vehicle involved in crash
SPDIMPACT	Estimated speed of each vehicle at moment of impact

TABLE 3: Explanation of variables used in this research

Variables	Explanation
Dependent Variables	
F & A	Severity = 1
B & C	Severity = 2
PDO	Severity = 3
Independent Variables	
RD	Interstate = 1; State highway = 2; Secondary highway = 3; US highway = 4
RDCONF	1-way, not divided = 1; 2-way, divided, positive median barrier = 2; 2-way, divided, unprotected median barrier = 3; 2-way, not divided = 4; Other = 5
RDCHAR	Curve-bottom & hillcrest = 1; Curve-grade = 2; Curve-level = 3; Straight-bottom & hillcrest = 4; Straight-grade = 5; Straight-level = 6; Other = 7
TIME	12:00-2:59am = 1; 3:00-5:59am = 2; 6:00-8:59am = 3; 9:00-11:59 am = 4; 12:00-2:59 pm = 5; 3:00-5:59pm = 6; 6:00-8:59pm = 7; 9:00-11:59pm = 8
SEASON	Spring (March, April, and May) = 1; Summer (June, July, and August) = 2; Fall (September, October, and November) = 3; Winter (December, January, and February) = 4
DAY	Monday = 1; Tuesday = 2; Wednesday = 3; Thursday = 4; Friday = 5; Saturday = 6; Sunday = 7
CRASHTYPE	Angle = 1; Animal = 2; Backing up = 3; Fixed object = 4; Head on = 5; Jackknife = 6; Left turn = 7; Movable object = 8; Overturn/rollover = 9; Parked motor vehicle = 10; Pedalcyclist = 11; Pedestrian = 12; Ran off road = 13; Rear end = 14; Right turn = 15; Railroad engine = 16; Sideswipe = 17; Other = 18
WORKZONE	Construction work area = 1; Maintenance work area = 2; Utility work area = 3
WZACTIV	Ongoing = 1; No apparent activity = 0
WZMARKED	Work zone marked (Yes = 1; No = 0)
B4&AFTER	Termination area = 1; Transition/Activity area = 2 Advance warning area = 3
WEATHER	Clear = 1; Cloudy = 2; Rain = 3; Snow = 4; Fog, smog, and smoke = 5; Sleet, hail, freezing rain/drizzle = 6; Other = 7
RDFEATURE	Bridge = 1; Driveway = 2; End or beginning-divided highway = 3; Five-point or more = 4; Intersection = 5; Merge lane between on & off ramp = 6; Off ramp =7; On ramp = 8; Railroad crossing = 9;

	Shared-use paths or trails = 10; Traffic circle/roundabout = 11; Tunnel = 12; Underpass = 13; Other = 14; No special feature = 15
RDSURFACE	Dry = 1; Ice = 2; Sand, mud, dirt, and gravel = 3; Snow = 4; Water = 5; Wet = 6; Other = 7
LIGHT	Dark-lighted road = 1; Dark-road not lighted = 2; Dawn = 3; Daylight = 4; Dusk = 5; Other = 6
SPDLMT	Less or equal to 25 mph = 1; 26-40 mph = 2; 41-50 mph = 3; 51-60 mph = 4; 61-70 mph = 5
WZSPDLMT	Less or equal to 25 mph = 1; 26-40 mph = 2; 41-50 mph = 3; 51-55 mph = 4
VEHICLE	Passenger = 1; Pickup and Sport utility = 2; Buses = 3; Police, Firetruck, and EMS = 4; Trucks = 5; Van = 6; Pedestrian = 7; Tractor/semi-trailer = 8; Motorcycles = 9; Other = 10
GENDER	Driver's gender (Male = 1; Female = 0)
ALCOHOL	Alcohol or other drugs suspected (No = 0; Yes = 1; Other impairments = 2)
BELT	Occupant/non-motorist protection system use (No = 0; Yes = 1; Other = 2)
AGE	Continuous variable
OCPNTTOT	Continuous variable
OCPNTS	Continuous variable
UNITS	Continuous variable
SPDIMPACT	Continuous variable

TABLE 4: 2007-2014 North Carolina work zone crashes by severity level

Year	F & A		B & C		PDO		Total
	Count	% to Total	Count	% to Total	Count	% to Total	
2007	45	2.40%	662	34.90%	1188	62.70%	1895
2008	36	2.60%	550	39.60%	804	57.80%	1390
2009	20	1.50%	490	35.80%	859	62.70%	1369
2010	34	1.90%	608	33.80%	1155	64.30%	1797
2011	19	1.10%	559	33.50%	1090	65.30%	1668
2012	31	1.60%	655	33.50%	1270	64.90%	1956
2013	29	1.30%	721	32.50%	1468	66.20%	2218
2014	34	1.30%	801	29.90%	1845	68.80%	2680

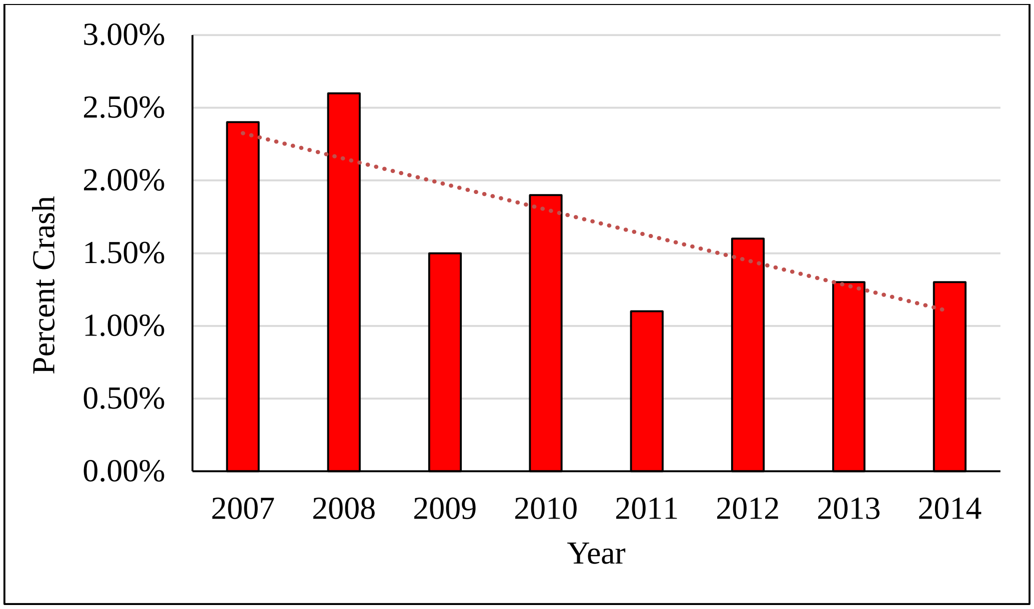

FIGURE 9: Proportion of F & A injury severity type crashes by year

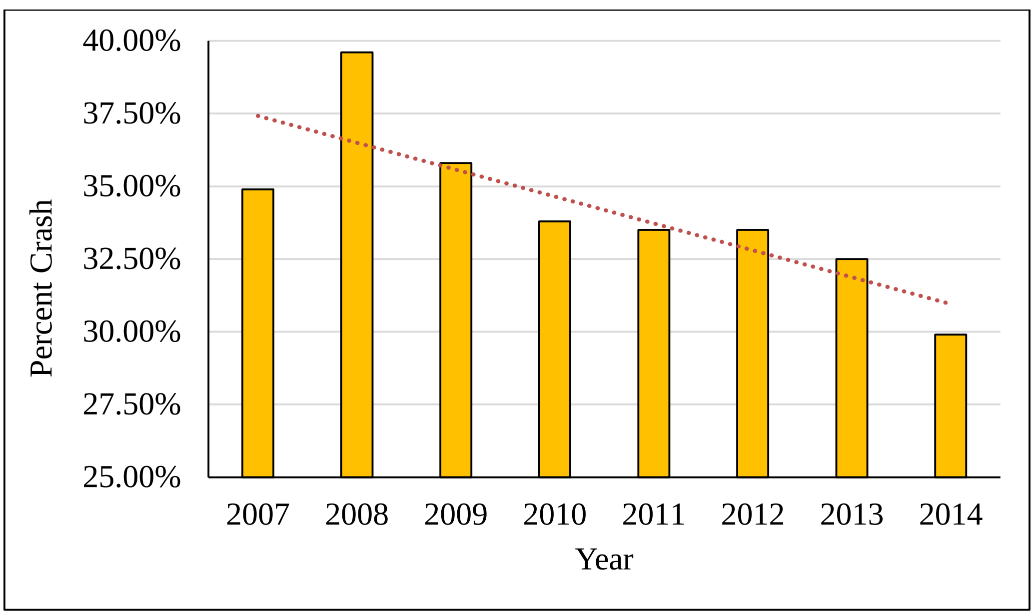

FIGURE 10: Proportion of B & C injury severity type crashes by year

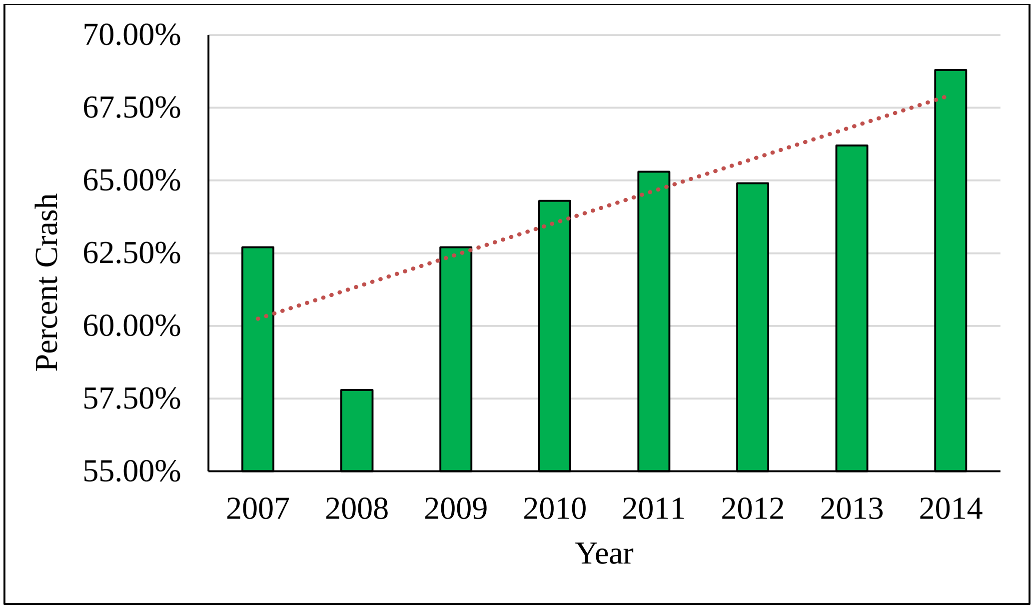

FIGURE 11: Proportion of PDO crashes by year

4.3 Research Hypothesis

The primary goal of this research is to better identify and quantify work zone risk factors that contribute to injury severity in work zones, so as to mitigate those risks through preventative measures. To achieve this goal, it is necessary to have a direction and a basis for the study. Development of a hypothesis for this study, educated predictions based on prior observations, studies, and trends that have been observed within work zone crashes, is a necessary starting point for this study. These predictions were developed through prior research found during the literature review. The predictions that were developed for testing in this study are as follows:

- Since construction work zones have been observed to have the highest driver casualty risks, it is predicted that they may contribute to the largest quantity of severe crashes in comparison to the other types of work zones, making it the work zone type with the highest risk of severe crashes.

- Due to the reduction in lanes that often occurs in the transition area of the work zone, it is predicted that an increase in the risk will lead to more severe crashes in this area as drivers attempt to shift lanes and there is less space to accommodate higher traffic volumes.
- The activity area of the work zone where work is taking place is predicted to have the highest overall risk when compared to the other areas of the work zone. This is due to the constantly changing nature of traffic patterns and conditions in this area of the work zone.
- Contributing factors such as speed and the presence of alcohol or other substances are predicted to result in higher severity crashes in all types and areas of work zones.
- Research done on prior studies have shown that adverse weather and road conditions do not seem to be a major factor in work zone crash severity or quantity. Therefore, it is predicted that environmental conditions such as rain, snow, road surface conditions, or poor visibility as contributing factors, will not have a major impact on the quantity, severity, or risk in work zone crashes.

4.4 MNL Model Estimations and Validations

To reiterate, a total of 26 candidate independent variables are considered in the development of work zone crash prediction models. However, before any model is developed, it is necessary to conduct statistical tests to analyze possible relationships between the variables. SPSS and SAS software were utilized to develop correlation matrices for the independent variables. The purpose of the matrices is to examine, foresee and limit any potential bias that may occur when developing the models. Pearson Correlation Matrix is used to determine linear relationships between the continuous independent variables, whereas the Polychoric Correlation Matrix is used to determine possible correlations between the discrete independent variables. The results obtained from this analysis are shown in Tables 5 and 6. In this research, a significant correlation was determined to exist between the independent variables if the correlation coefficient was found to fall within (-0.1, +0.1) range. Therefore, to prevent multicollinearity, independent variables that were found to have a strong correlation with other independent variables were removed.

In the development process of the models, it is necessary to determine variables that have a statistically insignificant effect on the dependent variables. They are independent variables with a significance level greater than 0.05. The model was re-run and statistically insignificant data removed, until all variables were found to be statistically significant.

TABLE 5: Pearson correlation matrix

Variables	OCPNTTOT	UNITS	OCPNTS	SPDIMPACT	AGE
OCPNTTOT	1.000	0.473	0.696	-0.159	0.036
UNITS		1.000	0.025	-0.328	0.031
OCPNTS			1.000	-0.014	0.037
SPDIMPACT				1.000	-0.087
AGE					1.000

TABLE 6: Summary of Polychoric correlation matrix coefficients

Variables	RD	RDCONF	RDCHAR	SEASON	DAY	CRASHTYPE	WORKZONE	WZACTIV	WZMARKED	B4&AFTER	WEATHER	RDFEATURE	RDSURFACE	LIGHT	SPDLMT	WZSPDLMT	VEHICLE	GENDER	ALCOHOL	BELT	TIME
RD	1.000	0.587	-0.153	-0.017	-0.074	-0.166	0.154	-0.073	-0.091	0.056	-0.016	-0.286	-0.015	0.088	-0.487	-0.381	-0.015	-0.058	-0.045	-0.083	-0.056
RDCONF		1.000	-0.070	-0.017	-0.102	-0.180	0.218	-0.039	-0.123	0.047	-0.064	-0.175	-0.061	0.121	-0.506	-0.392	0.008	-0.078	-0.012	-0.109	-0.047
RDCHAR			1.000	0.001	-0.013	0.103	-0.086	0.060	0.016	0.012	-0.098	0.100	-0.090	0.008	0.077	0.058	-0.009	0.007	-0.046	0.069	0.064
SEASON				1.000	0.002	-0.012	-0.065	-0.068	0.007	-0.057	0.074	-0.015	0.109	-0.128	-0.018	-0.007	-0.040	-0.010	0.036	0.022	0.004
DAY					1.000	-0.030	-0.114	-0.211	0.001	-0.035	0.026	0.031	0.052	-0.081	0.048	0.056	-0.058	0.014	0.128	0.017	0.022
CRASHTYPE						1.000	-0.024	0.195	0.087	0.053	-0.110	0.145	-0.149	0.106	0.089	0.069	0.089	0.018	-0.029	0.135	0.070
WORKZONE							1.000	0.187	-0.315	0.266	-0.126	0.001	-0.164	0.078	-0.006	-0.086	-0.011	-0.048	-0.047	-0.007	-0.041
WZACTIV								1.000	0.211	0.156	-0.277	0.102	-0.328	0.225	0.014	0.035	0.082	0.012	-0.139	0.013	-0.086
WZMARKED									1.000	-0.100	-0.020	0.124	-0.012	-0.004	0.099	0.128	-0.018	-0.009	0.039	0.027	0.014
B4&AFTER										1.000	-0.130	0.052	-0.129	0.063	0.085	-0.023	0.002	-0.001	-0.041	0.021	0.011
WEATHER											1.000	-0.032	0.848	-0.052	0.004	0.016	-0.045	-0.014	-0.016	0.026	-0.003
RDFEATURE												1.000	-0.002	-0.002	0.279	0.281	-0.021	0.010	0.022	0.020	0.017
RDSURFACE													1.000	-0.092	0.015	0.038	-0.076	-0.022	-0.003	0.027	0.005
LIGHT														1.000	-0.059	-0.040	0.046	-0.048	-0.331	-0.058	-0.155
SPDLMT															1.000	1.000	-0.027	0.061	-0.029	0.069	0.023
WZSPDLMT																1.000	-0.053	0.048	-0.017	0.066	0.008
VEHICLE																	1.000	0.345	0.161	0.085	-0.033
GENDER																		1.000	-0.027	-0.257	-0.033
ALCOHOL																			1.000	0.381	-0.041
BELT																				1.000	0.027
TIME																					1.000

There are several methods that can be used to interpret variables within MNL models. Koppelman and Bhat (2006) stated that the simplest and most widely used model utilizes a reference group and a base outcome comparison. One of the variables is set to zero, while the other variables in the reference group are numerically compared to this base outcome. The base outcome comparison selection is arbitrary; however, this does not affect the quality or interpretation of the results from the model. The results will only appear to be different based on what is chosen as the base outcome comparison (Koppelman and Bhat, 2006). In the models utilized in this study, the F & A severity level is utilized as a base outcome comparison, while the B & C and PDO severities are compared based on a variety of alternatives. These alternatives are tested to determine how each one affects the probability of Type B & C and PDO crash severity levels.

4.4.1 MNL Model Estimation Results

Crash severity, the dependent variable, was coded as 1, 2, and 3 and inputted into the SAS software for the purpose of model estimation. As shown in Table 3, each number was representative of the dependent variables, F & A type injuries, B & C type injuries, and PDO, respectively. Overall, there were a total of 14,973 recorded work zone crashes in North Carolina from 2007 to 2014. A breakdown of this total shows that 248 of these crashes were F & A injury severity level, 5,046 were types B & C injury severity level crashes, and the remaining 9,679 crashes were PDO (Table 21). Of the 19 candidate variables that were retained as shown in Table 7, several are only significant in one of the dependent variable categories. These include the day (Saturday), gender, presence of alcohol, and other impairments for the B & C type injury. The number of occupants is significant in the PDO category. MNL Model results can be interpreted based off of the values of the coefficients in each category. A higher positive coefficient is an indicator that a certain independent variable has a higher probability of occurring with the associated dependent variable than the base outcome comparison. The inverse of this statement also applies, a lower negative numerical coefficient indicates that a certain independent variable has a lower probability of occurring with the associated dependent variable than the base outcome comparison. An example of this, as seen in Table 7, is type B & C and PDO crashes in active work zones (WZACTIV/Ongoing), the probability of which is more likely to result in type F & A crashes, as the coefficients of the type B & C and PDO dependent variables are higher than the base outcome comparison.

4.4.1.1 MNL Model based on Work Zone Type

Determining the type of work zone where crashes occurred can lead to a better understanding of the nature of the work zone type and its contributing factors. To achieve the goals of this study, work zones were analyzed as three different types: construction work zones, maintenance work zones, and utility work zones.

4.4.1.1.1 Construction Work Zone MNL Model Estimated Results

There were a total of 12,075 construction work zone crashes that occurred within the 2007-2014 time frame (Table 21), which constitutes the vast majority of the crashes involved in the work zone type category. In this model there were 12 candidate variables that were retained where the number of occupants and age are only significant in the PDO category. Gender and presence of alcohol are significant for the type B & C type injuries (Table 8).

TABLE 7: Overall work zone MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	3.3463	<.0001	5.0108	<.0001
RD (State highway)	-0.269	0.0528	-0.3425	0.0135
RDCONF (Positive)	0.8333	0.0023	1.0018	0.0002
DAY (Saturday)	0.4411	0.0424	-	-
WZACTIV (Ongoing)	0.343	<.0001	0.3833	<.0001
LIGHT (Other)	-1.7647	0.0165	-1.4826	0.0345
UNITS	-0.4455	<.0001	-0.8942	<.0001
OCPNTS	-	-	-0.1996	<.0001
SPDLMT (26-40 mph)	0.6112	0.022	1.0917	<.0001
SPDLMT (41-50 mph)	0.8039	<.0001	1.1334	<.0001
SPDIMPACT	-0.0215	<.0001	-0.0231	<.0001
AGE	-0.0202	<.0001	-0.0285	<.0001
GENDER	-0.2888	0.0002	-	-
ALCOHOL	0.3615	0.0508	-	-
ALCOHOL (Other)	-1.1878	<.0001	-	-
BELT (Used)	1.036	<.0001	1.3168	<.0001
BELT (Other)	-	-	0.7765	0.0005
TIME (3:00-5:59 AM)	-0.9642	0.0002	-1.2626	<.0001
TIME (9:00-11:59 AM)	0.4531	0.0417	0.5968	0.0072
TIME (3:00-5:59 PM)	0.6506	0.0018	0.8193	<.0001
Number of parameters	32			
Number of observations read	14998			
Number of observations used	14973			
Log likelihood at convergence	-19834.37			
Log likelihood null	-81456.18			
ρ^2	0.76			
Adjusted ρ^2	0.76			

TABLE 8: Construction work zone MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	2.9494	<.0001	4.6232	<.0001
WZACTIV (Ongoing)	0.3195	<.0001	0.3849	<.0001
B4&AFTER (In work)	-0.2361	0.0601	-0.2883	0.0209
UNITS	-0.3711	0.0001	-0.7512	<.0001
OCPNTS	-	-	-0.1344	0.0079
SPDIMPACT	-0.0174	<.0001	-0.0152	<.0001
AGE	-	-	-0.00987	<.0001
GENDER	-0.3322	<.0001	-	-
ALCOHOL	0.4769	0.0265	-	-
ALCOHOL (Other)	-1.0982	0.0008	1.1793	<.0001
BELT (Used)	1.1696	<.0001	1.4941	<.0001
BELT (Other)	-	0.0051	1.2787	<.0001
TIME (3:00-5:59 AM)	-0.6806	0.0286	-1.0305	0.0015
Number of parameters	19			
Number of observations read	12102			
Number of observations used	12075			
Log likelihood at convergence	-16127.42			
Log likelihood null	-41168.86			
ρ^2	0.61			
Adjusted ρ^2	0.61			

4.4.1.1.2 Maintenance Work Zone MNL Model Estimated Results

With 2,561 crashes that occurred in the maintenance work zone areas during the years studied (Table 21), this group of crashes made up the second highest group of crashes analyzed in the work zone type category. Table 9 shows that a total of 7 candidate variables were retained for this model, where the number of vehicles involved in crash, age, and occupant/non-motorist protection system use (other) are only significant in the PDO category.

TABLE 9: Maintenance work zone MNL logit model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	3.9728	<.0001	5.1447	<.0001
UNITS	-	-	-0.6511	0.0026
SPDIMPACT	-0.0249	0.0032	-0.0266	0.0016
AGE	-	-	-0.0205	0.0291
ALCOHOL (Other)	-2.073	0.0002	-2.3206	<.0001
BELT (Other)	-	-	2.2909	0.0075
TIME (3:00-5:59 AM)	-1.4783	0.0014	-1.7672	0.0001
TIME (9:00-11:59 AM)	1.1657	0.0373	1.3065	0.0194
Number of parameters	11			
Number of observations read	2563			
Number of observations used	2561			
Log likelihood at convergence	-3633.48			
Log likelihood null	-5670.97			
ρ^2	0.36			
Adjusted ρ^2	0.36			

TABLE 10: Utility work zone MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	-1.3265	0.144	0.1321	0.881
OCPNTS	3.6335	0.0001	3.0402	0.0012
Number of parameters	2			
Number of observations read	334			
Number of observations used	334			
Log likelihood at convergence	-477.45			
Log likelihood null	-921.44			
ρ^2	0.48			
Adjusted ρ^2	0.48			

4.4.1.1.3 Utility Work Zone MNL Model Estimated Results

Utility work zones made up the smallest number of work zone type category with a total of 334 crashes that fall into this category (Table 21). In this model, many of the variables were determined to be insignificant, leaving only the candidate variable: number of occupants in a single vehicle involved in crash (Table 10).

4.4.1.2 MNL Models based on Different Locations within the Work Zone Area

To further analyze and understand the nature of work zone crashes, it is important to determine the impact that different segments of a work zone play on the distribution of crash severity. Work zone classification and division often differs on a state by state basis. While the MUTCD is used on a national scale, this differs from the system employed by the NCDOT. As previously mentioned, the MUTCD divides work zones into the following four areas: Advance Warning, Transition, Activity, and Termination Area.

The following information is based on the DMV 349 crash report data element dictionary and the dataset used for this research. The advance warning area is classified as the area after the first warning sign and before lane shifts and lane closures. The transition/activity area is where lanes are closing and shifting (NCDOT 2011), and also where work zone activity occurs. The final area of the work zone is the termination area.

4.4.1.2.1 Advance Warning Area MNL Model Estimated Results

The smallest number of crashes occurred in the advance warning area, with 2,892 crashes recorded for the time period analyzed in the work zone area type category. Table 11 shows that a total of 6 candidate variables were retained for this model, where the estimated speed of each vehicle at moment of impact is only significant in the PDO category.

TABLE 11: Advance warning area MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	4.1622	<.0001	5.6787	<.0001
RD (State highway)	-0.6719	0.0278	-0.7227	0.0173
UNITS	-0.4589	0.0042	-0.9068	<.0001
OCPNTS	-0.0193	0.0001	-0.0169	0.0004
SPDLMT (41-50 mph)	-0.0252	0.0028	-0.0315	0.0002
SPDLMT (51-60 mph)	-1.7824	0.0035	-1.1707	0.0394
SPDIMPACT	-	-	1.0135	0.0098
Number of parameters			11	
Number of observations read			2901	
Number of observations used			2892	
Log likelihood at convergence			-4009.89	
Log likelihood null			-7194.72	
ρ^2			0.44	
Adjusted ρ^2			0.44	

4.4.1.2.2 The Transition/Activity Area MNL Model Estimated Results

5,236 of the crashes happened in the transition/activity area (Table 21), constituting a considerable number of the total crashes recorded for the time period analyzed in the work zone area type category. In this model, there were 12 candidate variables that were retained. The number of occupants, occupant/non-motorist protection system use (other), and crash time (9:00-11:59 AM and 3:00-5:59 PM) are only significant in the PDO category, while other impairments are significant in case of the type B & C type injuries (Table 12).

TABLE 12: Transition/Activity area MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	4.0944	<.0001	5.9884	<.0001
RD (State highway)	-0.4807	0.0353	-0.6522	0.0043
UNITS	-0.6307	0.0002	-1.0733	<.0001
OCPNTS	-	-	-0.3002	0.0004
SPDLMT (41-50 mph)	1.1726	0.0003	1.5909	<.0001
SPDLMT (51-60 mph)	0.4292	0.0372	0.723	0.0006
SPDIMPACT	-0.0285	<.0001	-0.0308	<.0001
AGE	-0.0233	0.0009	-0.0295	<.0001
ALCOHOL (Other)	-1.7264	<.0001	-	-
BELT (Used)	0.9226	0.0007	1.1793	<.0001
BELT (Other)	-	-	1.4648	0.001
TIME (9:00-11:59 AM)	-	-	0.7379	0.0341
TIME (3:00-5:59 PM)	-	-	0.6102	0.0341
Number of parameters	19			
Number of observations read	5243			
Number of observations used	5236			
Log likelihood at convergence	-6816.22			
Log likelihood null	-47456.86			
ρ^2	0.86			
Adjusted ρ^2	0.86			

4.4.1.2.3 Termination Area MNL Model Estimated Results

The majority of crashes studied are found in the termination area for the time period analyzed in the work zone area type category. 6,841 crashes were reported in this area (Table 21). Table 13 shows that a total of 13 candidate variables were retained for this model, where the vehicle speed limit (61-70 mph), age, and occupant/non-motorist protection system use (other) are only significant in the PDO category.

TABLE 13: Termination area MNL model estimated results

Explanatory Variables	B & C		PDO	
	Coef.	P-value	Coef.	P-value
Constant	4.2835	<.0001	5.5701	<.0001
WZACTIV (Ongoing)	0.7866	<.0001	0.8365	<.0001
UNITS	-0.506	0.0001	-0.851	<.0001
SPDLMT (41-50 mph)	0.8129	0.0074	0.9258	0.0074
SPDLMT (61-70 mph)	-	-	0.6624	0.0024
SPDIMPACT	-0.0216	0.0003	-0.0217	0.0471
AGE	-	-	-0.0113	0.0003
GENDER	-0.3064	0.0082	-	<.0001
BELT (Used)	1.2008	<.0001	1.2987	<.0001
BELT (Other)	-	-	1.2549	0.0014
TIME (3:00-5:59 AM)	-1.1461	<.0001	-1.4473	<.0001
TIME (12:00-2:59 PM)	-0.5642	0.0087	-0.5386	0.0117
TIME (3:00-5:59 PM)	0.7666	0.0113	1.0158	0.0008
TIME (6:00-8:59 PM)	0.6704	0.0474	0.8471	0.012
Number of parameters	22			
Number of observations read	6853			
Number of observations used	6841			
Log likelihood at convergence	-9196.24			
Log likelihood null	-20739.04			
ρ^2	0.56			
Adjusted ρ^2	0.56			

4.4.2 Validation and Performance Evaluation

The data splitting approach was used to validate the fitted model. Due to the large size of the sample, the data is divided into two groups. One group contained 80% of observations, which were randomly sampled for model estimation. The second group contained the remaining 20% of the observations, for the purpose of validation. Table 14 shows the summary of both the numbers of observations used and validation groups of the dataset for each MNL model.

TABLE 14: Summary of observations

MNL Models	Total # of Observations	80% of Observations Used	20% for Validation
Overall Work Zone	18716	14973	3743
Construction Work Zone	15094	12075	3019
Maintenance Work Zone	3201	2561	640
Utility Work Zone	417	334	83
Advance Warning Area	3615	2892	723
Transition/Activity Area	6545	5236	1309
Termination Area	8551	6841	1710

To begin, the first set was used to fit the model. Then the fitted model was taken and applied to the validation sample. Its performance was evaluated by different summary measures. The MFE and MAD were computed to this end.

A MFE value of zero is ideal. A MFE value greater than 0 indicates that the model tends to over-forecast, whereas a negative MFE value indicates that the model tends to under-forecast. The MFE is expressed as:

$$\mathrm{MFE} = \frac{1}{n}\sum(\mathrm{X_a} - \mathrm{X_e}) \qquad \text{(Eq. 14)}$$

where,

$\mathrm{X_a}$ = is the actual outcome,

$\mathrm{X_e}$ = is the estimated outcome, and,

n = is the total number of observations.

The MAD measures the average absolute error in the model's estimate. The MFE is a measure of a model bias, whereas the MAD indicates the absolute size of the errors in the model. In other words, a model estimate tends to over-forecast (or under-forecast) with an average error of MAD units. The MAD is expressed as:

$$\text{MAD} = \frac{1}{n} \sum |X_a - X_e| \qquad \text{(Eq. 15)}$$

where,

X_a = is the actual outcome,

X_e = is the estimated outcome, and,

n = is the total number of observations.

As a result, Equations 14 and 15 evaluate the difference between the observed sample shares of crashes by severity and their corresponding proportions predicted by the model. Table 15 shows the different proportions whereas Table 17 shows the computed results.

TABLE 15: Sample shares and predicted shares

MNL Models Sample Observations	Sample Shares (%)			Estimated Shares (%)		
	F & A	B & C	PDO	F & A	B & C	PDO
Overall Work Zone	1.69	33.65	64.66	1.42	30.50	60.94
Construction Work Zone	1.56	33.33	65.11	1.14	30.01	69.33
Maintenance Work Zone	2.03	35.99	61.97	2.51	26.02	52.36
Utility Work Zone	0.00	39.51	60.49	0.39	28.13	51.22
Advance Warning Area	1.63	35.30	63.07	1.28	29.18	69.92
Transition/Activity Area	1.53	33.00	65.47	1.94	37.37	70.65
Termination Area	1.75	33.51	64.74	1.33	28.57	60.11

4.4.2.1 Models Goodness of Fit and Forecasting Performance

The likelihood ratio index is used to measure goodness of fit for discrete choice models. The purpose of this test is to determine the performance of an estimated model against a model that has all of its parameters equal to zero. The product of this are the statistic rho-squared (ρ^2) and the Adjusted rho-squared (Adjusted ρ^2), and they produce values set between 0 and 1. Equations 16 and 17 show how to compute these values. Table 16 displays both the adjusted rho squared values and rho squared values for the MNL models. These values fall between 0.36 and 0.86, which is satisfactory for the purposes of this study.

$$\rho^2 = 1 - \frac{LL(\hat{\beta})}{LL(0)} \quad \text{(Eq. 16)}$$

$$\text{Adjusted } \rho^2 = 1 - \left[\frac{LL(\hat{\beta}) - N}{LL(0)}\right] \quad \text{(Eq. 17)}$$

where,

$LL(\hat{\beta})$ = is the value of the log-likelihood function at convergence,

$LL(0)$ = is its value when all parameters except the constant are set equal to zero, and,

N = is the number of parameters.

TABLE 16: Summary of goodness of fit statistics

MNL Models	N	$LL(\hat{\beta})$	$LL(0)$	ρ^2	Adjusted ρ^2
Overall Work Zone	32	-19834.37	-81456.18	0.76	0.76
Construction Work Zone	19	-16127.42	-41168.86	0.61	0.61
Maintenance Work Zone	11	-3633.48	-5670.97	0.36	0.36
Utility Work Zone	2	-477.45	-921.44	0.48	0.48
Advance Warning Area	11	-4009.89	-7194.72	0.44	0.44
Transition/Activity Area	19	-6816.22	-47456.86	0.86	0.86
Termination Area	22	-9196.24	-20739.04	0.56	0.56

Table 17 shows that the overall work zone model had the best fit to the dataset, with each injury severity type being very well-predicted, most notably the B & C and PDO injury severity types. The utility work zone model shows the least prediction in the F & A injury severity type, likely due to the very small amount of data associated with the F & A severity level within the utility work zone. Out of all of the model predictions shown in Table 17, the most accurate were found within the PDO injury severity category, while the B & C severity type predictions were reasonably accurate relative to the actual data. The F & A injury severity type had the least prediction performance compared to the B & C and PDO. This is likely due to the very small number of occurrences within that particular type of injury severity in the dataset. Since F & A injury severity crashes only make up 1.1% of the overall crashes, any deviation from the actual data will show up as a significant inaccuracy within the percent correctness.

TABLE 17: Summary of MNL models percent correct

MNL Models Sample Observations	Shares		
	F & A	B & C	PDO
Overall Work Zone	84%	91%	94%
Construction Work Zone	73%	90%	94%
Maintenance Work Zone	77%	72%	84%
Utility Work Zone	61%	71%	85%
Advance Warning Area	79%	83%	89%
Transition/Activity Area	73%	87%	92%
Termination Area	76%	85%	93%

4.5 Identify Crash Severity Contributing Factors

Since there is one work zone dataset that is being divided into different categories based on the area of and type of work zone, the candidate variables are analyzed for significance relative to each type and area of work zones. Those candidate variables that are deemed significant for a type or area of a work zone are then considered contributing factors towards crashes that occur within that work zone type or area.

The variables that were selected as candidate independent variables are listed in Table 18. They include several different types of conditions that could potentially affect the severity of the crash. Crash roadway location, road configuration, the work zone activity at the time of the crash, and the location of the crash within the temporary traffic control zone. A number of driver and vehicle characteristics were included, such as the age and gender of the driver, the number of vehicles involved, whether or not a seatbelt was being used, alcohol or other drug impairment, as well as the number of occupants in the vehicle. Some other factors that are also included are the ambient light in the area of the crash, the day of the week the crash occurred, as well as the time of day recorded.

Table 18 displays these variables with the MNL model results for the overall work zone, and the work zone types and areas. This table can be interpreted in the way that the candidate variables are being analyzed to see if there is enough repetition in the quantities of crashes with an associated variable, which can then be used to determine which variables can be considered contributing factors for the different work zone types or areas.

TABLE 18: Crash severity contributing factors identified by seven MNL models

Explanatory Variables	MNL Models						
	OWZ	CON	MNT	UTL	AWA	T&A	TER
RD (State highway)	Y				Y	Y	
RDCONF (Positive)	Y						
DAY (Saturday)	Y						
WZACTIV (Ongoing)	Y	Y					Y
B4&AFTER (In work)		Y					
LIGHT (Other)	Y						
UNITS	Y	Y	Y		Y	Y	Y
OCPNTS	Y	Y		Y	Y	Y	
SPDLMT (26-40 mph)	Y						
SPDLMT (41-50 mph)	Y				Y	Y	Y
SPDLMT (51-60 mph)					Y	Y	
SPDLMT (61-70 mph)							Y
SPDIMPACT	Y	Y	Y		Y	Y	Y
AGE	Y	Y	Y			Y	Y
GENDER	Y	Y					Y
ALCOHOL	Y	Y					
ALCOHOL (Other)	Y	Y	Y			Y	
BELT (Used)	Y	Y				Y	Y
BELT (Other)	Y	Y	Y			Y	Y
TIME (3:00-5:59 AM)	Y	Y	Y				Y
TIME (9:00-11:59 AM)	Y		Y			Y	
TIME (12:00-2:59 PM)							Y
TIME (3:00-5:59 PM)	Y					Y	Y
TIME (6:00-8:59 PM)							Y

Y: Yes; OWZ: Overall Work Zone; CON: Construction Work Zone; MNT: Maintenance Work Zone; UTL: Utility Work Zone; AWA: Advance Warning Area; T&A: Transition/Activity Area; TER: Termination Area.

4.6 Risk Determination

The contributing factors to the crash severity in the different types and areas of work zones have been identified utilizing the MNL models. This data provides an insight into what risks and factors contribute to higher crash severities within work zones. The study of these contributing factors will allow identification and selection of countermeasures for implementation.

Areas or types of work zones with higher F & A injury severity types are considered higher risk, with considerable importance placed on the contributing factors to these crashes in those work zones and areas. Any work zone types and areas that also have large quantities of PDO crashes are also considered, due to the considerable effect these crashes can have on the roadways that they occur on. Factors that contribute to severe crashes in work zone areas were identified to be state highway roads, the ongoing work zone activity at the time of the crash, the location of the crash within the temporary traffic control zone, the number of vehicles involved in the crash, the gender of the driver involved in the crash, the use of alcohol or other impairments, the time of the day, and the vehicle authorized speed limit.

4.6.1 Work Zone Type

The likelihood of crashes occurring within the construction work zone type was nearly 5 times higher than the maintenance work zone type, which contained the second greatest quantity of crashes as seen in Table 14. In fact the construction work zone type contained 81% of the total crashes that were observed (Table 21). As shown in Table 18, the construction work zone type also had the most severe contributing factors associated with it. The probability of severe injury crashes occurring in the construction work zone type was higher than any other work zone types.

Crashes within utility work zone made up 2% of the total crashes observed. As seen in Table 14, the utility work zone had the lowest quantities of crashes recorded, although it is still important to consider them. As shown in Table 10, the OCPNTS (occupants) variable is representing the number of people involved in the crash. The probability of F & A type crashes in utility work zones was found to increase as the number of people involved in the crash also increased.

4.6.2 Location of Crash within the Temporary Traffic Control Zone

With regards to the location of the crash within the work zone, a very large number of the crashes were found to occur in the transition/activity area, where lane reduction most often happens to allow for work to occur on the road while traffic flows. The transition/activity area is the higher risk locations having a considerable percentage of injury severity crashes and making up 35% of the crashes within the work zone areas as shown in Table 14.

The termination area had even more crashes than the transition/activity area with 45% of the crashes. As seen in Table 18, many of the variables that were repeating in the transition/activity area was also found within the termination area. Table 8 showed that the crashes within the construction work zone transition/activity area was found to have a higher risk in comparison to the advance warning area and termination area.

4.6.3 Work Zone Activity at Time of the Crash

The MNL models show that the probability of a crash to be a F & A injury severity type crash was higher than other injury severity types occurring while construction work zone activity took place specifically at the termination area, see Tables 8 and 13.

4.6.4 Road Classification

The state highway road type was found to have a higher risk in comparison to other types of roadway, with the utility work zone type having the largest percentage of F & A injury severity type crashes occurring in comparison to construction and maintenance work zone types. Table 19 shows that the likelihood of F & A injury severity type crashes occurring within the state highway utility work zone type was 4 times higher than the other work zone types.

4.6.5 Number of Vehicles Involved in Crash

In the case of crashes occurring within construction and maintenance work zones, Tables 8 and 9 showed that the probability of a crash to be an F & A injury severity type crash was less than that of PDO and B & C injury severity type crashes as the number of vehicles involved increases. With more vehicles involved in a crash in any area of a work zone, there was a considerably higher likelihood of PDO crashes.

4.6.6 Driver's Gender Involved in Crash

There is a considerable disparity between the number of crashes caused by males and females on nearly every type of work zone, with males consistently causing more number of the crashes. Overall, males caused nearly 30% more crashes. There is an even greater disparity where F & A injury severity type crash is concerned, with males causing nearly 3 times as many of these types of crashes as seen in Table 19. One major contributing factor of this could be males having risky driving habits, as shown in Figures 12 and 13, both of which detail alcohol and other substance impairment.

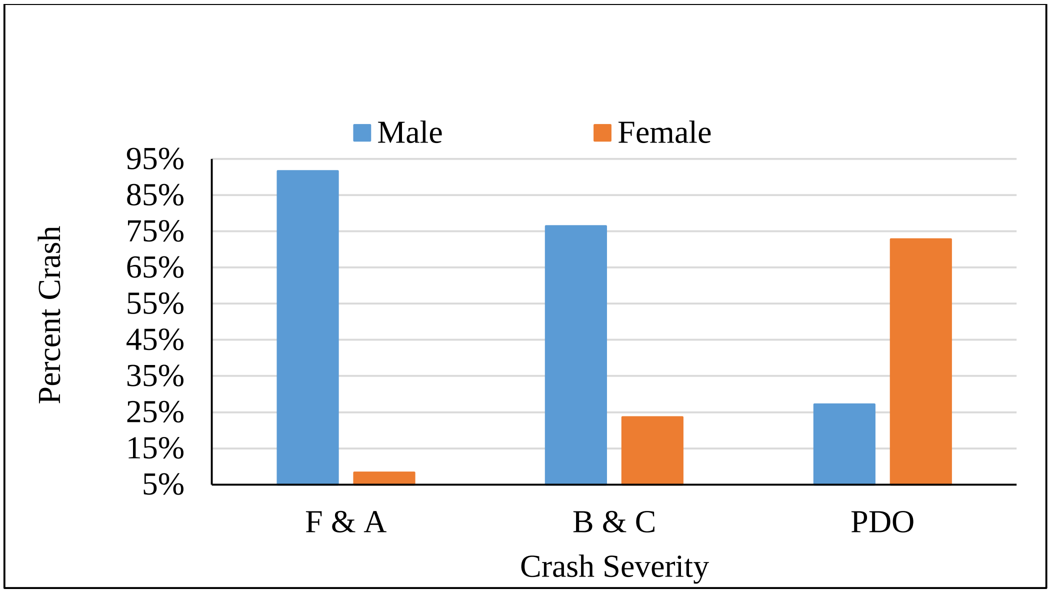

FIGURE 12: Proportion of gender in alcohol-related crashes by crash severity

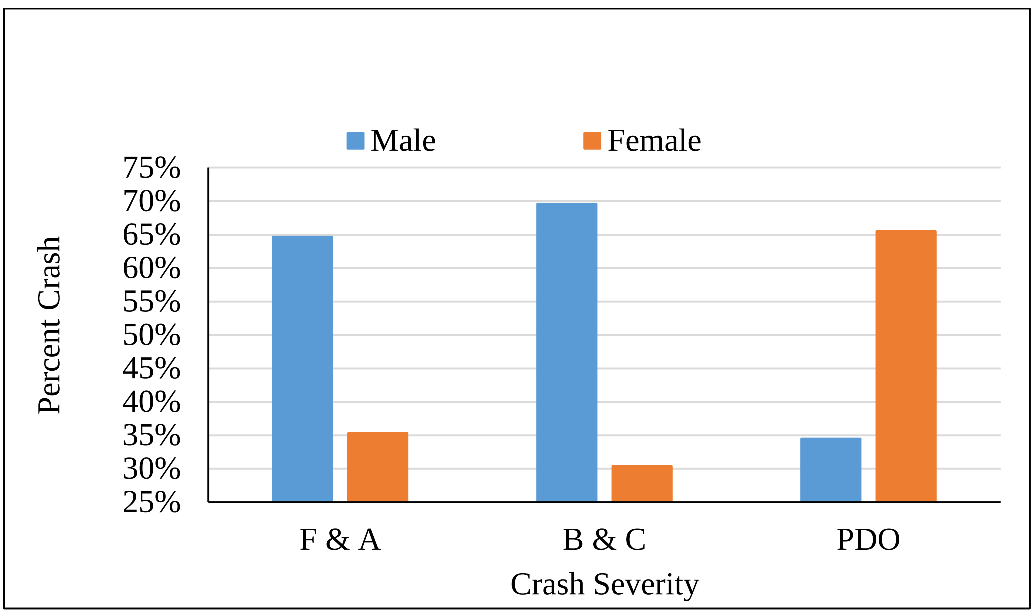

FIGURE 13: Proportion of Gender in other types of impairment-related crashes by crash severity

4.6.7 Alcohol and Other Impairments

Tables 19 and 20 show that higher percentages of F & A injury type crashes, found within all types and areas of work zones, were associated with alcohol or other drugs consumption. Table 8 also showed that the probability of F & A injury type crashes occurring in the construction work zone type was higher than any of other work zone types when alcohol was used by the vehicle driver or non-motorist investigated at the time of crash occurred. These percentages are somewhat disproportionate with respect to the number of crashes that they represent, which can be interpreted as alcohol being one of the more common intoxicants involved in vehicular crashes.

4.6.8 Crash Time

With more drivers on the roads, the likelihood for crashes also seemed to increase during the peak hours. Table 7 showed that the probability of a crash to be a F & A injury severity type crashes during the morning and evening peak hours was higher than other injury severity types, specifically between the hours of 9:00-11:59 AM and 3:00-5:59 PM. This could be influenced by more drivers driving at higher speeds during these peak hours.

4.6.9 Vehicle Authorized Speed Limit

The speed limit was a consistently concerning factor percentage-wise, within every category, within all areas of the work zones. This is due to the number of entries associated with them as shown in Table 20. The vehicle speed of 41-50 mph and 51-60 mph within the transition/activity area and termination area were found to have a higher risk in comparison to the advance warning area, see Tables 11, 12, and 13. While the overall work zone MNL model showed that even with a lower speed of 26-40 mph or a normal speed of 41-50 mph, the probability of a crash to be F & A injury severity type crashes occurring in a work zone was higher than other injury severity types.

4.6.10 Conclusions of Risk Determination

Based on the risk determination findings above, the research hypothesis predictions from Chapter 4 section 3 were evaluated.

- The findings from the risk determination show that the construction work zone by far had the largest number of crashes overall as well as the highest quantity of F & A and B & C injury severity type crashes. This supports the prediction made in the research hypothesis regarding the quantity and severity of crashes found within that work zone type.
- The work zone transition/activity area was found to have higher risk in comparison to the advance warning area. This made up 35% of the crashes within the work zone areas while the advance warning area made up only 20%, supporting the research hypotheses which stated that an increased risk of more severe crashes will occur in the transition area of the work zone.
- The activity area of the work zone where work is taking place was found to have a higher risk of severe crashes occurring within that particular area, supporting the previously stated hypotheses relating to work zone activity at time of the crash. In fact, the risk of severe crashes was higher than other injury severity type occurring while construction work zone activity took place specifically at the termination area.
- Alcohol was found to be a significant factor in the severity of crashes occurring within work zone. There was a noticeable jump in the F & A injury severity types

when alcohol was brought into the picture. In addition to alcohol, another analyzed factor was the speed within the work zone. It was found to be a consistent contributing factor to higher severity crashes across all areas of the work zone. All of these contributing factors follow the predictions in the hypothesis, as they contributed to an increased risk of severe crash occurrence.

- Weather conditions were found to have no apparent impact on the crash data. This supports the prediction made in the hypothesis, as well as the previous studies referenced.

4.7 Overview of Work Zone Crash Severity Statistics

Overall, F & A injury severity level crashes constituted 2% to 3% of the crashes within each work zone type and area, with the highest number of crashes in this severity level being found in the construction work zone type. The B & C injury severity level crashes ranged between 33% and 37% of the crashes in each work zone type and area. PDO severity level varied between 61% and 65% for each work zone type and area, see Table 21. Over 80% of the data represented in Table 20 actually falls in the construction work zone type, with over 12,000 crashes reported within that category. Tables 19 and 20 summarize the contributing factors statistics to the crash severity in the different types and areas of work zones have been identified utilizing the MNL models.

TABLE 19: Summary of contributing factors to the crash severity in the different types of work zones

Explanatory Variables	Overall Work Zone						
	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)
RD (State highway)	2355	58	2%	893	38%	1404	60%
RDCONF (Positive)	7122	73	1%	2140	30%	4909	69%
DAY (Saturday)	1622	23	1%	561	35%	1038	64%
WZACTIV (Ongoing)	9210	113	1%	3099	34%	5998	65%
B4&AFTER (In work)	5232	88	2%	1711	33%	3434	65%
LIGHT (Other)	26	1	4%	7	27%	18	69%
UNITS (1)	3261	64	2%	1038	32%	2159	66%
UNITS (2)	9778	134	1%	3018	31%	6626	68%
UNITS (3)	1585	34	2%	793	50%	758	48%
UNITS (4)	291	12	4%	169	58%	110	38%
UNITS (5)	63	4	6%	36	57%	23	37%
UNITS (6)	16	3	19%	10	63%	3	19%
UNITS (7)	4	1	25%	3	75%	0	0%
OCPNTS	14974	252	2%	5067	34%	9679	64%
SPDLMT (26-40 mph)	1073	11	1%	353	33%	709	66%
SPDLMT (41-50 mph)	3409	36	1%	1198	35%	2175	64%
SPDLMT (51-60 mph)	7812	132	2%	2632	34%	5048	64%
SPDLMT (61-70 mph)	2486	42	2%	760	31%	1684	67%
SPDIMPACT	14998	252	2%	5067	34%	9679	64%
AGE	14973	252	2%	5067	34%	9679	64%
GENDER (Male)	8797	181	2%	2612	30%	6005	68%
GENDER (Female)	6201	71	1%	2456	40%	3674	59%
ALCOHOL	730	36	5%	275	38%	419	57%
ALCOHOL (Other)	220	17	8%	23	10%	180	82%
BELT (Used)	14225	173	1%	4815	34%	9237	65%
BELT (Other)	468	13	3%	82	18%	373	79%
TIME (3:00-5:59 AM)	484	26	5%	167	35%	291	60%
TIME (9:00-11:59 AM)	2488	33	1%	836	34%	1619	65%
TIME (12:00-2:59 PM)	3123	57	2%	1051	34%	2015	65%
TIME (3:00-5:59 PM)	3537	37	1%	1177	33%	2323	66%
TIME (6:00-8:59 PM)	1707	31	2%	566	33%	1110	65%

Explanatory Variables	Construction Work Zone						
	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)
RD (State highway)	1794	40	2%	661	37%	1093	61%
RDCONF (Positive)	6053	71	1%	1770	29%	4212	70%
DAY (Saturday)	1369	27	2%	447	33%	895	65%
WZACTIV (Ongoing)	7204	88	1%	2345	33%	4771	66%
B4&AFTER (In work)	4158	66	2%	1321	32%	2771	66%
LIGHT (Other)	25	1	4%	6	24%	18	72%
UNITS (1)	2606	45	2%	804	31%	1757	67%
UNITS (2)	7939	115	1%	2405	30%	5419	69%
UNITS (3)	1223	29	2%	593	48%	601	50%
UNITS (4)	253	8	3%	139	55%	106	42%
UNITS (5)	63	2	3%	40	63%	21	34%
UNITS (6)	16	3	19%	11	69%	2	12%
UNITS (7)	2	0	0%	2	100%	0	0%
OCPNTS	12077	202	2%	3994	33%	7906	65%
SPDLMT (26-40 mph)	858	10	1%	282	33%	566	66%
SPDLMT (41-50 mph)	2696	25	1%	974	36%	1697	63%
SPDLMT (51-60 mph)	6586	114	2%	2156	33%	4316	65%
SPDLMT (61-70 mph)	1804	30	2%	503	28%	1270	70%
SPDIMPACT	12102	202	2%	3994	33%	7906	65%
AGE	12075	202	2%	3994	33%	7906	65%
GENDER (Male)	7176	144	2%	2077	29%	4955	69%
GENDER (Female)	4926	58	1%	1917	39%	2951	60%
ALCOHOL	591	31	5%	222	38%	338	57%
ALCOHOL (Other)	188	11	6%	14	7%	163	87%
BELT (Used)	11494	136	1%	3809	33%	7549	66%
BELT (Other)	376	9	2%	57	15%	310	83%
TIME (3:00-5:59 AM)	394	22	6%	140	36%	232	58%
TIME (9:00-11:59 AM)	1787	32	2%	579	32%	1176	66%
TIME (12:00-2:59 PM)	2402	41	2%	803	33%	1558	65%
TIME (3:00-5:59 PM)	2967	31	1%	955	32%	1981	67%
TIME (6:00-8:59 PM)	1552	27	2%	505	33%	1020	65%

Explanatory Variables	Maintenance Work Zone						
	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)
RD (State highway)	480	7	1%	197	41%	276	58%
RDCONF (Positive)	1010	14	1%	329	33%	667	66%
DAY (Saturday)	211	1	0%	79	37%	131	63%
WZACTIV (Ongoing)	1781	27	2%	655	37%	1099	61%
B4&AFTER (In work)	990	18	2%	372	38%	600	60%
LIGHT (Other)	1	0	0%	1	100%	0	0%
UNITS (1)	580	12	2%	221	38%	347	60%
UNITS (2)	1627	19	1%	537	33%	1071	66%
UNITS (3)	304	6	2%	168	55%	130	43%
UNITS (4)	42	3	7%	25	60%	14	33%
UNITS (5)	9	2	22%	4	44%	3	33%
UNITS (6)	1	0	0%	1	100%	0	0%
UNITS (7)	1	0	0%	1	100%	0	0%
OCPNTS	2561	42	2%	956	37%	1565	61%
SPDLMT (26-40 mph)	176	2	1%	51	29%	123	70%
SPDLMT (41-50 mph)	558	3	1%	183	33%	372	66%
SPDLMT (51-60 mph)	1148	18	2%	473	41%	657	57%
SPDLMT (61-70 mph)	636	13	2%	217	34%	406	64%
SPDIMPACT	2563	42	2%	956	37%	1565	61%
AGE	2561	42	2%	956	37%	1565	61%
GENDER (Male)	1463	32	2%	490	33%	941	65%
GENDER (Female)	1100	10	1%	466	42%	624	57%
ALCOHOL	118	5	4%	38	32%	75	64%
ALCOHOL (Other)	21	5	24%	5	24%	11	52%
BELT (Used)	2439	37	2%	914	37%	1488	61%
BELT (Other)	75	1	1%	15	20%	59	79%
TIME (3:00-5:59 AM)	67	6	9%	27	40%	34	51%
TIME (9:00-11:59 AM)	580	3	1%	221	38%	356	61%
TIME (12:00-2:59 PM)	691	17	2%	229	33%	445	65%
TIME (3:00-5:59 PM)	461	5	1%	169	37%	287	62%
TIME (6:00-8:59 PM)	178	2	1%	76	43%	100	56%

Explanatory Variables	Utility Work Zone						
	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)
RD (State highway)	95	6	6%	37	39%	52	55%
RDCONF (Positive)	41	0	0%	15	37%	26	63%
DAY (Saturday)	7	1	14%	1	14%	5	72%
WZACTIV (Ongoing)	284	7	2%	94	33%	183	65%
B4&AFTER (In work)	112	4	4%	45	40%	63	56%
LIGHT (Other)	0	0	0%	0	0%	0	0%
UNITS (1)	38	2	5%	9	24%	27	71%
UNITS (2)	254	4	2%	83	33%	167	65%
UNITS (3)	37	3	8%	15	41%	19	51%
UNITS (4)	5	0	0%	5	100%	0	0%
UNITS (5)	0	0	0%	0	0%	0	0%
UNITS (6)	0	0	0%	0	0%	0	0%
UNITS (7)	0	0	0%	0	0%	0	0%
OCPNTS	334	9	3%	112	34%	213	64%
SPDLMT (26-40 mph)	57	0	0%	17	30%	40	70%
SPDLMT (41-50 mph)	149	3	2%	53	36%	93	62%
SPDLMT (51-60 mph)	108	3	3%	39	36%	66	61%
SPDLMT (61-70 mph)	14	0	0%	1	7%	13	93%
SPDIMPACT	334	9	3%	112	34%	213	64%
AGE	334	9	3%	112	34%	213	64%
GENDER (Male)	184	5	3%	60	33%	119	64%
GENDER (Female)	150	4	3%	52	35%	94	62%
ALCOHOL	17	2	12%	3	18%	12	70%
ALCOHOL (Other)	3	0	0%	2	67%	1	33%
BELT (Used)	307	6	2%	99	32%	202	66%
BELT (Other)	12	1	8%	6	50%	5	42%
TIME (3:00-5:59 AM)	1	0	0%	0	0%	1	100%
TIME (9:00-11:59 AM)	74	0	0%	28	38%	46	62%
TIME (12:00-2:59 PM)	113	2	2%	38	34%	73	64%
TIME (3:00-5:59 PM)	68	1	1%	25	37%	42	62%
TIME (6:00-8:59 PM)	15	2	13%	5	33%	8	53%

TABLE 20: Summary of contributing factors to the crash severity in the different areas of work zones

Explanatory Variables	Advance Warning Area							Transition/Activity Area							Termination Area						
	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)	Total # of Crash	F & A	Percent (%)	B & C	Percent (%)	PDO	Percent (%)
RD (State highway)	480	12	3%	185	39%	283	58%	920	20	2%	342	37%	558	61%	939	27	3%	348	37%	564	60%
RDCONF (Positive)	1396	23	2%	449	32%	924	66%	2351	28	1%	659	28%	1664	71%	3390	30	1%	1009	30%	2351	69%
DAY (Saturday)	291	3	1%	96	33%	192	66%	535	9	2%	171	32%	355	66%	773	13	2%	279	36%	481	62%
WZACTIV (Ongoing)	1985	28	1%	719	36%	1238	63%	3437	52	2%	1094	32%	2291	66%	3837	31	1%	1293	34%	2513	65%
B4&AFTER (In work)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5243	89	2%	1729	33%	3425	65%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LIGHT (Other)	2	0	0%	0	0%	2	100%	16	1	6%	5	31%	10	63%	7	0	0%	2	29%	5	71%
UNITS (1)	420	5	1%	136	32%	279	67%	1222	22	2%	391	32%	809	66%	1609	29	2%	517	32%	1063	66%
UNITS (2)	1971	25	1%	627	32%	1319	67%	3373	48	1%	1007	30%	2318	69%	4472	58	1%	1389	31%	3025	68%
UNITS (3)	420	11	3%	206	49%	204	48%	535	13	2%	267	50%	255	48%	597	15	3%	287	48%	295	49%
UNITS (4)	69	6	9%	44	64%	19	27%	89	1	1%	52	58%	36	40%	137	7	5%	72	53%	58	42%
UNITS (5)	12	1	8%	9	75%	2	17%	17	2	12%	9	53%	6	35%	32	1	3%	21	66%	10	31%
UNITS (6)	5	0	0%	4	80%	1	20%	7	3	43%	3	43%	1	14%	5	0	0%	5	100%	0	0%
UNITS (7)	3	1	33%	2	67%	0	0%	0	0	0%	0	0%	0	0%	1	0	0%	1	100%	0	0%
OCPNTS	2892	49	2%	1028	36%	1824	62%	5236	89	2%	1729	33%	3425	65%	6842	110	2%	2292	33%	4451	65%
SPDLMT (26-40 mph)	178	1	1%	63	35%	114	64%	378	7	2%	114	30%	257	68%	512	4	1%	170	33%	338	66%
SPDLMT (41-50 mph)	665	9	1%	221	33%	435	66%	1216	10	1%	432	36%	774	63%	1526	10	1%	541	35%	975	64%
SPDLMT (51-60 mph)	1211	17	1%	459	38%	735	61%	2763	42	2%	899	33%	1822	65%	3884	76	2%	1282	33%	2526	65%
SPDLMT (61-70 mph)	816	18	2%	272	33%	526	65%	790	15	2%	220	28%	555	70%	847	10	1%	256	30%	581	69%
SPDIMPACT	2901	49	2%	1028	35%	1824	63%	5243	89	2%	1729	33%	3425	65%	6853	110	2%	2292	33%	4451	65%
AGE	2892	49	2%	1028	36%	1824	62%	5236	89	2%	1729	33%	3425	65%	6841	110	2%	2292	34%	4451	64%
GENDER (Male)	1709	26	2%	522	31%	1161	67%	3111	67	2%	914	29%	2130	69%	4014	79	2%	1196	30%	2739	68%
GENDER (Female)	1192	23	2%	506	42%	663	56%	2132	22	1%	815	38%	1295	61%	2839	31	1%	1096	39%	1712	60%
ALCOHOL	104	5	5%	40	38%	59	57%	271	15	6%	94	35%	162	59%	341	18	5%	133	39%	190	56%
ALCOHOL (Other)	29	3	10%	4	14%	22	76%	90	11	12%	5	6%	74	82%	111	4	4%	14	13%	93	83%
BELT (Used)	2782	41	1%	988	36%	1753	63%	4930	54	1%	1635	33%	3241	66%	6525	77	1%	2195	34%	4253	65%
BELT (Other)	83	2	2%	18	22%	63	76%	190	3	2%	30	16%	157	82%	195	4	2%	29	15%	162	83%
TIME (3:00-5:59 AM)	72	3	4%	25	35%	44	61%	162	8	5%	65	40%	89	55%	253	17	7%	89	35%	147	58%
TIME (9:00-11:59 AM)	568	6	1%	215	38%	347	61%	871	9	1%	269	31%	593	68%	989	15	2%	338	34%	636	64%
TIME (12:00-2:59 PM)	734	15	2%	248	34%	471	64%	1075	16	1%	334	31%	725	68%	1352	31	2%	477	35%	844	63%
TIME (3:00-5:59 PM)	694	11	2%	262	38%	421	60%	1233	16	1%	432	35%	785	64%	1648	11	1%	513	31%	1124	68%
TIME (6:00-8:59 PM)	289	9	3%	104	36%	527	182%	582	11	2%	198	34%	373	64%	844	9	1%	265	31%	570	68%

TABLE 21: Summary of work zone crash severity statistics

Severity	Overall Work Zone		Construction Work Zone		Maintenance Work Zone		Utility Work Zone		Advance Warning Area		Transition/Activity Area		Termination Area	
	Crash Number	Percent (%)	Crash Number	Percent (%)	Crash Number	Percent (%)	Crash Number	Percent (%)	Crash Number	Percent (%)	Crash Number	Percent (%)	Crash Number	Percent (%)
F & A	248	2%	202	2%	42	2%	9	3%	49	2%	88	2%	109	2%
B & C	5046	34%	3994	33%	956	37%	112	34%	1028	35%	1723	33%	2281	33%
PDO	9679	65%	7879	65%	1563	61%	213	64%	1815	63%	3425	65%	4451	65%
Total # of Crash	14973	100%	12075	100%	2561	100%	334	100%	2892	100%	5236	100%	6841	100%

4.8 Potential Countermeasures

By default, having a work zone in place presents a hazard to motorists. However, it is important to consider different ways of reducing the risk while commuting through a work zone, while also more effectively studying the nature of the crashes themselves so that fewer could potentially happen if the causes are understood.

4.8.1 Work Zone Parameters and Arrangement

To enhance the safety of work zones for workers and commuters, it is important to analyze the work activity on highway traffic to make improvements and adjustments to the traffic control plan. Many of the current advanced warning systems and traffic control methods could likely be improved so that they can be more effective at garnering driver’s attention. Improving these warnings may not necessarily be about the quantity of warnings, but it could potentially be how the driver reacts to them that is most important to consider. Development of different types of warning systems that drivers pay more attention to could result in a reduction in the risk of crashes occurring.

There was a considerable percentage of F & A injury severity crashes that occurred within the utility work zone. This could potentially be attributed to the traffic control measures utilized within this type of work zone, such as small traffic cones or flashing lights, but no barriers, and no control present at all to alert a work zone area. Improved layout of traffic control or advanced warning systems in the utility work zone could reduce the risk of severe injury crash, as it garners driver’s attention of workers at the work zone.

The work zone transition/activity area was found to be one of the more risk prone areas of the work zone, where lanes were being closed down and traffic bottlenecked and became dangerous as drivers attempted to merge to other lanes in crowded traffic. More gradual lane reductions or a longer work area could reduce the risk of severe injury crash, as it allows more time for drivers to merge and for people to adjust to a different traffic pattern.

4.8.2 Speed and Time

With speed reduction measures in place within construction work zones, it is more important to ensure that these speed limits are being followed by motorists using law enforcement within peak hours. Patrolling and stationary police vehicles have been used to control and enforce speed limits within work zones, and have been observed to be effective in that task. Further, law enforcement presence could also help reduce the number of crashes between the hours of 9:00-11:59 AM and 3:00-5:59 PM, where there was an increased possibility of F & A severity type crashes compared to other injury severity type crashes. This could also help reduce driver distraction within the work zones during morning and evening peak traffic hours.

4.8.3 Alcohol and Other Impairment Use

Crash severity is heavily impacted by human factors, one of the most prominent being drinking and driving. Increasing compliance and enforcement of existing traffic laws can reduce the number and severity of crashes. Education and reinforcement of the laws and consequences associated with alcohol and drug use behind the wheel serves as a first line deterrent against drunk and impaired driving. Further and constant police enforcement along with appropriate punitive consequences for such offenders are both necessary to help reduce the number of crashes where alcohol and other impairments are involved.

4.8.4 Nationalized Accident Reporting

As there is not an accepted standard definition of what a work zone is considered, researching work zones is almost entirely done on a state by state basis as seen in the introduction. In fact, states that are even adjacent to one another can have completely different definitions for the boundaries of the work zone and how to interpret each crash. Often there are differences in what information is required to be recorded by the reporting police officer and details relating to the work zone parameters are not recorded. Informing the police on what details are important in regards to the work zone crash itself and standardizing them could lead to more consistent and reliable data nationwide.

4.9 Summary of Chapter 4

This chapter shows the results from the estimates of the MNL models, including goodness of fit, variable significance, and model validation. Models and their predictions were tested on the basis of percent correctness relative to the original data. The overall work zone model was found the best fit to the dataset, with each injury severity type being very well-predicted, most notably the B & C and PDO injury severity types.

Variable significance was determined based on the statistical significance of each candidate variable on each independent area or type of work zone. Therefore, the candidate variables selected for each type of model varies based on what candidate variables were determined significant for that area or type of work zone. These candidate variables that were statistically significant for each work zone area or type are considered contributing factors.

The research hypothesis was compared to the results from the MNL models and all of these were proven to be true, including the speed, the impact that alcohol or other impairments have on the severity of crashes, and how certain areas in the work zone are particularly more dangerous than others. For several of these contributing factors, some possible countermeasures to help reduce the numbers of crashes were developed and explained. These included risk reduction measures such as adjustments to the traffic control plans to enhance safety for workers and traveling public, the improvement of geometry design along the work zone transition/activity area by increasing the taper distance, and the police enforcement of work zone to reduce speed limits as well as driver distraction within the work zones during morning and evening peak traffic hours.

CHAPTER 5: CONCLUSIONS

In this study, MNL models were used to analyze different factors that influence crash severities in work zone areas in North Carolina between the years of 2007 – 2014. These models may also provide a starting point to develop countermeasures to improve safety in the work zones.

The proposed methodology aimed to define the study area and data collection processes used, along with the source of the data to be used in the statistical models that followed. The data was obtained from TEAAS, and then analyzed and extracted, to develop a research database for use in the model. The model developed was a discrete choice model, MNL model. It was validated using 20% of the available dataset, and an error metric.

The data obtained from the TEAAS included a multitude of factors and characteristics that could be taken into account, of which could be divided into human, environmental, and vehicular factors. These factors and characteristics were used to develop the candidate variables, with an initial total of 26. The research hypothesis was then developed after the crash trends were noted. The research hypothesis was composed of several educated estimates based off of prior research done during the literature review. Predictions were made about certain types of work zones that may have the most or least severe crashes, and predictions made about the effects of driving behaviors such as drinking and driving or the impact of weather on crash severity.

After development of the research hypothesis, the candidate independent variables were tested for possible correlations. The variables were tested for statistical significance for each MNL model, which were representative of the work zone types, areas, and the overall work zone in its entirety. The estimated results from each of the MNL models were then obtained, utilizing the variables that were found to be statistically significant, and the results were used to measure goodness of fit for the MNL models. Each model and its dependent variables were then compared to the original data to determine the percent correctness of the models data.

The variables that were retained after using the MNL models were considered contributing factors, and included the work zone activity at the moment of the crash, the location of the crash within the temporary traffic control zone, and the number of vehicles involved and the driver's gender. Besides those variables, speed, the presence of alcohol and other impairments alongside the time of the crash were also found to be contributing factors. These were analyzed in the risk determination section, which interpreted the results obtained from the MNL models.

The hypothesis was then analyzed using the results from the MNL models and the risk determination, all of the hypothesis were proven to be correct, such as the construction work zone constituting the vast majority of the crashes, and the influence of alcohol on the crash severity. The weather variable had no impact on the crash severity within the work zones in the MNL models as predicted in the hypothesis and in prior research.

Using the findings from the risk determination, a number of countermeasures for reducing crash severity were developed. These countermeasures ranged from adjustments to the traffic control plans to improve worker and commuter safety, to increased law enforcement monitoring in the morning and evening peak traffic hours, which were found to have more F & A injury severity type crashes than any other time periods, to increasing the length of the work zone transition/activity area, to allow for more time for vehicles to merge into other lanes as the number of lanes is reduced in the work zone. Another recommendation from the study was nationalized crash and work zone definition reporting, so that consistent reporting systems can be developed for the continental United States, allowing more in depth and detailed research.

This research utilized MNL models to determine what factors contributed to higher crash severity levels. From this research it was found that one of the most dangerous areas in the work zone was the transition/activity area. It was also determined that alcohol and other forms of impairment whilst in work zones contributed to considerably higher crash rates and higher levels of crash severity, while speed was a consistent factor in the crash severity in all of the crashes.

The results obtained with this research can be referenced to provide details on the specific risk factors for work zone crashes alongside potential countermeasures to mitigate and potentially eliminate those risks. These results will be helpful to government agencies, the highway industry, as well as traffic safety engineers & researchers. Such a thorough research foundation will lead to a more intricate understanding of these high risk work zone traffic environments.

Data for the number of freeway lanes overall, the number of lanes that were assigned to the work zone, along with the accurate traffic volume during the time period where the work zone is active, was not available within the dataset utilized in the study.

Often, Average Annual Daily Traffic (AADT) statistics are available for predicting the volume of traffic along a certain section of freeway. However, it was determined that this would be a biased method of forecasting work zone traffic volume, as the time span that work zones take place can vary based on what work is being done. The AADT data would only be useful for the time frame in which the work zone was taking place. Perhaps more importantly, the probability can be expressed by the total number of crashes divided by the total number of vehicles. Therefore, AADT data was not utilized in this study.

With regards to the geographic location of the work zone on the freeway segment that the crash occurred on, it was important to consider the area around the freeway. Whether the freeway work zone was in a dense urban zone or in a rural area often affects the traffic that these sections experience. However, this factor was not able to be considered due to the lack of data related to the geographic location of the crash. Therefore, this factor was not able to be used in the models for this study.

These variables can impact not only crash severity, but also the design of the work zone itself. The impact that lane reduction and traffic volume, as well as the geographic location of the work zone, have on the crash severity all warrant further research.

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