EXPLORING RELATIONSHIP BETWEEN DRIVER'S ROADWAY FAMILIARITY, DISTRACTED DRIVING, RECKLESS DRIVING, AND INJURY SEVERITY ON WORK ZONE CRASHES

HAMZA M. BANI KHALAF

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We hereby approve this thesis for

HAMZA M. BANI KHALAF

candidate for the Master of Science degree for the

Department of Civil and Environmental Engineering

and the

CLEVELAND STATE UNIVERSITY'S

College of Graduate Studies

Committee Chairperson, Dr. Emmanuel Kidando

Department & Date

Committee Member, Dr. Jacqueline M. Jenkins

Department & Date

Committee Member, Dr. Angela Kitali

Department & Date

Committee Member, Dr. Stephen F. Duffy

Department & Date

Student's Date of Defense: December 1, 2023

DEDICATION

With Profound Gratitude and Thankfulness to The Almighty God

Dedicating this work to my beloved mother, an unwavering source of love throughout this research journey. As she bravely battles cancer, my heartfelt prayers are for her full healing and the joy of witnessing her beautiful smile once more.

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ABSTRACT

Motor vehicles have been an integral part of the American way of life, providing an unprecedented degree of mobility. Yet for all its advantages, motor vehicle crashes claim the lives of over 31,000 people in the United States every year, leaving more than three million injured. To prevent these crashes, the causes must be understood and addressed. This study developed a Bayesian Networks (BN) model – a model for reasoning "what-if" questions – to explore the relationship between drivers' roadway familiarity, distracted driving, reckless driving, and crash severity at work zones. This study examined the crashes that occurred in Ohio between 2017 and 2022. The data used in this research was retrieved from the Ohio Department of Public Safety database. Findings from the BN revealed that familiar drivers were more likely to engage in distracted or reckless driving, especially in work zones at interchanges and intersections. The research shows that the probability of distracted driving crashes is twice as high for familiar drivers at interchanges compared to intersections. Furthermore, work zones with lane closures increase the likelihood of rear-end crashes. However, work zones with lane shifts or crossovers decrease the odds of rear-end crashes. It is important to note that rear-end crashes in interchange areas are more dangerous and result in more severe injuries than intersection work zone crashes. Male drivers are more likely to be involved in distraction-related crashes in intersections, whereas female drivers tend to be more distracted in interchange areas.

Keywords: Work Zone; Roadway Familiarity; Distracted Driving; Injury Severity; Bayesian Networks.

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CHAPTER I

INTRODUCTION

1.1 Problem Statement

Traffic injuries and fatalities are growing problem globally. The number of road traffic fatalities and injuries keeps increasing around the world, with approximately 1.3 million deaths and up to 50 million injuries per year (World Health Organization (WHO), 2023). In 2022, the National Highway Traffic Safety Administration (NHTSA) reported that over 31,000 fatalities were caused by motor vehicles in the US, which is 25.5 percent higher than ten years ago (NHTSA, 2022). This number is even higher than the total fatalities in Europe for the same year. The European Commission reported around 20,600 people were killed in road crashes in Europe in 2022 (European Commission, 2023).

Work zones are among the contributors to crash occurrences and fatalities. These spots often require changes to traffic flow, lower speed limits, narrower lanes, and the presence of construction workers and equipment (Khattak et al., 2002). These alterations can cause a notable degree of conflicts that may result in hazardous situations. Meanwhile expanding and improving road networks has become crucial as the age of highways and streets in the United States (U.S.) increases (H. Yang, Ozbay, Ozturk, Xie, et al., 2015). The population of the United States has been increasing since 2017 and is now estimated to be around 10 million people (United Nations - World Population Prospects (WPP), 2022), urban areas are experiencing increased transportation demand. As a result, both federal and state government agencies have been allocating resources toward maintaining, expanding, and improving the current highway networks. The U.S. Department of Transportation announced a budget of $142 billion for transportation infrastructure in 2023, a 44 percent increase from $98.1 billion in 2017 (U.S. Department of Transportation, 2022). The allocated funding will aid in improving safety, upgrading the nation's infrastructure to meet future challenges, and addressing backlogs. Therefore, highway work zone numbers will continue to grow.

Recent data indicates approximately two deaths and almost 120 injuries occur daily in work zones across the country (NHTSA Fatality Analysis Reporting System (FARS), 2022). According to the Ohio Statistics and Analytics for Traffic Safety (OSTATS), there were 25,481 crashes in Ohio's work zones between 2017 and 2021. Among them, 88 were fatal crashes resulting in the death of 97 people, and 9,157 individuals were injured. In 2021 alone, there were 29 fatalities in Ohio's work zone crashes, an increase of 53 percent from the 19 deaths in 2020 (OSTATS, 2022).

Efforts are continuously actively researching ways to improve work zone safety across the country. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have significantly promoted work zone safety through their programs and guidelines. In 2000, they launched National Work Zone Awareness Week, which helped raise awareness about work zone safety (Federal Highway Administration (FHWA), 2023). Additionally, they have developed a Manual on Uniform Traffic Control Devices (MUTCD) that provides uniform standards for traffic control devices, including those required in work zones. These initiatives aim to ensure the safety of both workers and motorists in work zones.

Although there have been efforts to improve work zone safety, it remains a nationwide concern. Studies on crash characteristics have shown that work zone crashes are often caused by human errors such as following too close, inattentive driving, and misjudging distances, all of which can increase the likelihood of work zone crashes (Chambless et al., 2002; Mohan & Gautam, 2002). Studies have also consistently demonstrated a higher risk of crashes within work zones (Bhatti et al., 2011; Ozturk et al., 2014). This is mainly due to drivers being distracted or driving carelessly. Drivers often fail to comply with posted speed limits, disregarding signs, and traffic controls due to inattention or engaging in dangerous driving behaviors (Arnold, 2003; Bai & Li, 2007; Bharadwaj et al., 2019a; Blackman et al., 2014; Khattak et al., 2002; Li & Bai, 2009; Lu et al., 2008a). Additionally, speeding (Garber, 2002a) and inadequate traffic control (Ha & Nemeth, 1995) significantly contribute to the occurrence of work zone crashes.

Work zones can exist within interchange areas along freeways and intersections. Previous research found that freeway segments influenced by interchanges have a much higher rate of crashes than those located further away from interchanges (Cai et al., 2018;

Kiattikomol et al., 2008). Further, according to crash statistics provided by (D Lord et al., 2005), around 43 percent of all crashes in the U.S. happen at or near intersections. However, the presence of work zones in these segments can pose an additional hazard.

Limited research has been conducted on work zones within interchange areas on freeways and intersections. However, one study in Kansas investigated factors that influence work zone crashes and crash severity (Dias Ishani Madurangi, 2010). Based on the paper's results, higher AADT causes more work zone crashes. Still, the study's focus did not encompass interchange or intersection areas. A New York study found that intersections within work zone do not have a higher incidence of rear-end crashes than other locations. The study's author suggests that drivers may be more attentive and focused when navigating through intersections, which could explain this finding (Yi Qi et al., 2005). Another study was conducted in Portugal to measure the risk factors associated with road work zone crashes. The results revealed that angle crashes are more common in urban areas, specifically in or near road intersections (Santos et al., 2021).

Previous research has also shown that drivers familiar with the route are more distracted (Wu & Xu, 2018a). The familiarity of drivers with the highway or location also plays a crucial role in driving abilities and safety. Familiarity determines the knowledge and comfort level of drivers with specific driving environments, vehicles, and roads. It has been shown that a driver's confidence and performance can be affected by their familiarity (Wu & Xu, 2018a). For instance, research indicates that high-speed and distracted driving are common problems when drivers are near their homes (P. Colonna et al., 2016a; Intini et al., 2019a; Wu & Xu, 2018a). Due to the problem that familiarity level with the road could pose when driving within work zones, to the best of the author's knowledge, no previous research was clearly held to link between the safety of drivers navigating work zones and their familiarity level with the road.

Overall, studies have conclusively provided evidence that work zones pose a significant threat to drivers due to reckless behaviors such as distracted driving, speeding, and noncompliance with traffic controls developed with particular emphasis on mitigating risk in these areas. Additionally, studies have indicated that drivers familiar with the road may be more prone to distractions and engage in hazardous behaviors. Further, unfamiliar drivers need to learn what to expect. However, previous research has not established a direct correlation between the risk associated with being a familiar driver and the risks posed by work zones. Consequently, there needs to be a more comprehensive understanding of the extent of this risk and potential solutions to mitigate such threats. Thus, the first phase of this study explored the relationship between a driver's familiarity with the road, distracted driving, reckless driving, and the severity of crashes that occur in work zones. Furthermore, the second phase of this study investigated the potential high risk associated with interchange and intersection areas within work zones. It determined the extent of this risk when it correlated to crashes in work zones. Recommendations are provided based on the results of this study. The insights obtained from this study will be valuable in expanding current national standards and improving safety measures.

1.2 Study Objectives

This research investigates critical factors such as driver familiarity with the roadway, driver characteristics, distracted driving, and road conditions and their relationship to crash injury severity at work zones. To fully understand these factors, the probabilistic relationship between them must be investigated. Moreover, work zones can exist on different areas of roads, such as interchanges and intersection or approach to intersection. The road conditions and driver behavior change depending on where they drive on the road. While work zones are known to have a high occurrence of crashes, which often result in more severe outcomes than crashes in non-work zones, the link between driver familiarity with the roadway and the presence of a work zone on the likelihood of a crash has not been fully explored. In response to that, this research focuses on the following aspects:

- Explore the probabilistic relationship between driver's roadway familiarity, distracted driving, reckless driving, and crash injury severity at work zones.
- Investigate the relationship of work zone location on the roadway, such as an intersection and interchange areas with driver characteristics, distraction driving, reckless driving, and crash severity.
- Compare the results for different work zone locations on the roadway and identify recommendations to improve work zone safety.

1.3 Research Questions

The following section addresses the research questions that form the foundation of this study by identifying the factors that affect the safety of work zones, and understanding these factors, thereby minimizing the probability of crash occurrence by proposing recommendations. To do so, this thesis seeks to answer the following questions:

1. Does familiarity with the road increase the probability of distraction or reckless driving crashes in a work zone?

2. Does familiarity with the road increase injury severity for work zone crashes, considering factors such as weather, presence of workers, and collision type?

3. Do interchanges and intersection areas increase the probability of distraction, reckless driving, and severity of work zone crashes?

1.4 Scope of Study

This study focuses on crash data in Ohio from 2017 to 2022, explicitly investigating work zone crashes. The study will first analyze critical factors in the data and their contribution to work zone crashes and injuries. Next, the data will be divided into three groups: 1) Work zone crashes that occurred in Ohio state between 2017 and 2022, excluding work zone crashes within interchanges and intersections, and 2) Work zone crashes within interchange areas. Interchanges were chosen as one of the target locations for this study due to their unique characteristics and high traffic volume; drivers sometimes must pay attention to essential safety factors in those areas. 3) Work zone crashes within intersections or approaches to intersections. The research also will compare work zone crashes based on their location on the road and provide recommendations for enhancing safety and traffic flow in these crucial areas.

1.5 Study Contribution

Studying the probabilistic relationship between driving behavior and driver characteristics – distracted driving, driver road familiarity, driver age, and gender – and crash injury severity at work zones can provide important contribution that strongly impact driver behaviors when maneuvering within work zones. This research results can also inform additional safety concerns that DOTs should consider in future work zones near weaving areas and intersections. Regarding the first objective of this study, a

Bayesian Networks (BN) model will be developed – a model for reasoning "what-if" questions – to explore the relationship between drivers' roadway familiarity, distracted driving, at-fault, and crash severity at work zones. In the second stage, the same BN optimal structure will be used in the comparison to understand the impact of work zone location on the roadway (interchanges and intersections) with driver characteristics, distraction driving, reckless driving, and crash severity.

CHAPTER II

LITERATURE REVIEW

2.1 Work Zone Safety

Previous research showed that work zones have significantly affected the drivers' safety while maneuvering them, regardless of the work zone type (Weng & Meng, 2011a). Research has shown that work zones increase traffic conflicts, leading to severe traffic crashes (Meng et al., 2010; Ullman et al., 2006). The literature review revealed several factors that could contribute to work zone crashes. For instance, road geometry, environmental conditions, vehicle characteristics, and human errors (Yang et al. 2015). Starting with the impact of road geometry on work zone safety, a study conducted in Lebanon, the Middle East, addressed the effects of various design elements on drivers' behavior through work zones. The authors of this study compared the current and proposed work zone geometry by building the proposed geometry through a simulator. For example, they increased the lane width, markings, etc. They found that the proposed work zone geometry significantly improved the drivers' behavior compared to the existing work zone geometry. Further, the visibility conditions profoundly affected driver behavior through the simulator. The pavement markings used along the proposed work zone reduce the vehicles' lateral fluctuations by 50 percent compared to the contemporary design (Nahed et al., 2023). The study has limitations as drivers' behaviors in a simulated environment will somewhat vary from their actual actions during real-life driving. Other research studied one of the key geometric features of a road, how it influences work zone crashes: the number of lanes. Weng and Meng's study revealed that drivers are more likely to engage in dangerous behavior on multi-lane roads than on roads with fewer lanes, regardless of the driving conditions. This finding highlights the importance of considering how different road geometries affect work zone safety (Weng & Meng, 2012).

The use of advanced technologies in vehicles has shown promising results in improving work zone safety. In a study conducted by Genders and Razavi, the deployment of connected vehicle technology was researched for its effect on traffic safety in a network with work zones. The authors conducted experiments in a microsimulation environment to assess the impact of using vehicle-to-vehicle (VTV) communication to share information about work zones with the drivers. Sending messages to the drivers to reroute using VTV's shortest travel time and dynamic route guidance algorithm to avoid work zones can lead to an increase in traffic safety between 5 to 10 percent. However, this model is limited to the obstacles of achieving driver compliance, and these results are valid only when assuming the most conservative behavior model, where most drivers do not modify their behavior (Genders & Razavi, 2016). Another research analyzed the effect of the environment, vehicle, and driver characteristics and found that factors such as weather, lightning condition, no traffic devices, and old vehicles are associated with the risky driving behavior at work zones. Weng and Meng conducted a study to analyze how vehicle characteristics affect risky driving behavior in work zones. The study discovered that driving old vehicles is linked to dangerous driving behavior at work zones. The authors provided evidence supporting this finding, as old vehicles generally have inferior braking capabilities and poor mechanical standards (Weng & Meng, 2012).

Li and Bai conducted a study using logistic regression analysis to determine the impact of risk factors on the probability of fatality in severe crashes. The study was based on work zone crash data in Kansas. The results showed that vehicle type is a significant risk factor in work zones. Specifically, heavy trucks' involvement in a severe work zone crash increased the chances of causing fatalities three times more than other vehicles (Li et al., 2009). One limitation of Li and Bai's study is the relatively small sample size of crashes examined. The study focused on a total of 85 fatal crashes and 620 injury crashes, which may not fully represent the entire spectrum of road safety incidents and could potentially limit the generalizability of the findings.

Driver characteristics can have an impact on work zone safety. According to studies, middle-aged male drivers are more likely to engage in risky driving behavior than middle-aged female drivers (Weng & Meng, 2012). Even when substance-use such as alcohol and marijuana use, were investigated, male drivers engaged in risky driving behaviors more than female drivers (Elliott et al., 2006). Further, when severe work zone crashes occur, the research proved that being a male diver could almost double the odds of having fatality in this case (Li et al., 2009). However, (Weng & Meng, 2011b) have found that female drivers have a 93 percent higher casualty risk than male drivers in work zones, which contradicts the previous studies. Investigate conditional logistic regression to investigate work-zone crashes and develop countermeasures to minimize work-zone hazards. The study found that drivers younger than 25 years old and those older than 75 years old have the highest relative crash involvement ratio (Harb et al., 2008). Moreover, severe crashes caused by senior drivers older than 64 and drivers aged between 35 and 44 were more likely to result in fatalities (Li et al., 2009). On the other hand, (Weng & Meng, 2011b) revealed that middle-aged drivers are more likely to be injured or killed in work zones than young drivers. Further, after surveying drivers across different age groups on their preferred speeds for various work zone layouts, researchers found that older drivers prefer higher speeds (Steinbakk et al., 2019).

Traffic congestion caused by work zones can frustrate drivers (T.H. Maze et al., 2000). Studies have identified driver inattention and careless driving as the most common contributing factors to crashes in work zones. Moreover, driver distraction can exacerbate the situation in work zones (Bharadwaj et al., 2019b; Lu et al., 2008b). Hence, it is imperative to consider driver distraction as another significant factor that causes crashes in work zones. Therefore, it is crucial to take into account driver distraction as a significant factor that causes crashes in work zones. Several studies showed that driver distraction diminishes the driver's environmental awareness and affects their judgment and decision-making abilities, ultimately impacting their control over the vehicle's safety (Farmer et al., 2010; Morris et al., 2015; Ranney et al., 2001).

A recent study investigated the impact of visual and cognitive distractions on drivers' mental workload. The study found that drivers have better vehicle control when they are not distracted compared to when they are distracted by visual or cognitive factors. The study also revealed that visual distractions significantly impact drivers more than cognitive distractions. Therefore, drivers must pay more attention to visual distractions, particularly when navigating complex working zones (Y. Yang et al., 2023). However, the study has some limitations. The driving simulator used in the experiment may not accurately represent a real-life driving experience. The study only involved young drivers with limited driving experience aged between 22 and 27. Also, the study has investigated only the warning section of the work zone. Thus, the results of the study may not apply to the other sections of the work zone such as the active or the termination area of the work zone. A study conducted by Ullman shared the same objective as the previous study - assessing the extent of distracted driving, specifically visual distraction, on Texas roadways. However, the author found that nearly one in five motorists are visually distracted in some manner while driving as they approach a work zone. Additionally, the study showed that this rate of visual distraction decreased as they got closer to the work zone (Ullman, 2022).

While driving, engaging in phone calls is one of the most common distractions for drivers. A study was conducted by (Jeffrey W. Muttart et al., 2007) to assess drivers' behavior when they engage in hands-free cell phone conversations while driving through a work zone. The study used virtual worlds to simulate various work zone geometry. The drivers were asked to respond to a series of short sentences mimicking a hands-free cell phone conversation on one trip, while on the other portion of the journey, no sentences were read to the drivers. During the trip, a lead vehicle ahead of the driver occasionally brakes in the work zone activity area. The lead vehicle would stop after an advanced clue that traffic ahead would stop or for no apparent reason, most often after passing a roadside obstacle. The advanced driving simulator study revealed that drivers not engaged in a cell phone task could reduce their speed earlier in response to a slowing lead vehicle than drivers involved. Additionally, drivers on the cell phone were more likely to brake hard and less likely to make a mirror glance when changing lanes (Jeffrey W. Muttart et al., 2007). As in the previous study, earlier research by (McEvoy et al., 2005) aimed to investigate the impact of drivers' mobile phone use on road safety. The findings revealed that using a mobile phone while driving increases the probability of a crash leading to an injury. Furthermore, it was observed that using a hands-free phone is not any safer. The risk of crashes due to mobile phone usage remains consistent across all genders and age groups, be it young or older drivers and male or female drivers (McEvoy et al., 2005). A study conducted in Queensland, Australia, by (Debnath et al., 2015) adopted a qualitative approach to gather insights from workers in work zones. It involved interviewing 66 workers from various work zones in. The aim was to understand the contributing factors to hazards in the work zones and to assess the effectiveness of current or future approaches to mitigate them. Workers identified excessive vehicle speeds, driver distraction, and aggression toward roadworkers as the most common hazards in work zones.

Limited research has been conducted on the manner of crashes that occur in work zones. One such study was conducted by Nicholas and Ming, which examined the characteristics of work zone crashes in Virginia between 1996 and 1999. The results of the study showed that rear-end collisions were the most common type of accident in work zones. It is worth noting that the study used proportionality tests due to the lack of speed and volume data, which are relatively simple statistical methods and may not capture complex relationships or interactions among variables (Garber, 2002b). A study was conducted to compare fatal crash activity within work zones with fatal crashes in non-work zone locations. The study revealed that angle and head-on crashes were the primary causes of fatal work zone crashes (Daniel et al., 2000). However, the study had limited scope as it only used data from three work zone crashes. This small sample size hinders the generalization of findings to other work zone crashes. Therefore, the insights gained from this study may not accurately represent the diversity and complexity of work zone crash scenarios. In summary of the literature review related to work zone safety, several factors could affect work zone safety. A simulation study conducted by (Nahed et al., 2023) revealed that improving the design of work zones enhanced driver safety. (Weng & Meng, 2012) also found that multi-lane roads increased risky driving behavior compared with fewer lanes roads. However, none of these studies have linked the risk from road geometry attributes with other attributes such as distraction on work zone safety. Moreover, studies investigating vehicle characteristics revealed that they could affect driver safety in a work zone. For instance, Genders and Razavi's V2V study showed that autonomous vehicles increased safety at work zones. On the other hand, Weng and Meng found that old vehicles increased dangerous driving behavior in work zones due to inferior braking capabilities and poor mechanical standards. Li and Bai's study also revealed that heavy trucks increased the fatality rate in work zones. Nonetheless, after reviewing and addressing the limitations of previous studies, this study proposes a probabilistic approach using the Bayesian Network.

Various studies have indicated that driver characteristics, such as age, gender, and the influence of drugs or alcohol, play a significant role in ensuring work zone safety.

However, different studies have reported conflicting results regarding the impact of specific driver characteristics, such as gender and male. For instance, Li and Bai found that male drivers are more likely to cause severe crashes, while Weng and Meng suggested the opposite for construction and utility work zones. Further summary, distraction has been investigated throughout many simulating studies, and few investigated this attribute throughout actual field data and linked this attribute with other attributes that could directly or indirectly influence this attribute, as will be discovered from the BN optimal network in this study.

2.2 Driver's Roadway Familiarity

Familiarity with a road can be easily described as the level of knowledge a driver has of a specific road due to their long or frequent driving experience (Intini et al., 2019b; Yoh et al., 2017). For example, if a driver commutes from home to their workplace five days a week for several years, they may be highly familiar with the road. Previous studies investigated familiar and unfamiliar drivers by studying the relationship between driving tasks and performances with a focus on familiarity (A. R. Hale & Hommels, 1990; Aasman Jans and Michon, 1992; Intini et al., 2019b). Studies have shown that driver familiarity has an impact on road safety. Familiar drivers tend to be less focused on the driving task (Burdett, Charlton, et al., 2018; Yanko & Spalek, 2014) and may exhibit aggressive driving behavior (Wu & Xu, 2018b). On the other hand, unfamiliar drivers are more likely to be at fault in crashes (Kim et al., 2012).

The previous section of this literature supports that work zones could impact driver safety. Further, familiar and unfamiliar drivers can impact work zone safety as well. For instance, long-distance work zones with complex layouts may require drivers to shift lanes to avoid hitting workers. Driving within a work zone highlights the need for drivers to stay focused, especially at the beginning of a work zone. The following studies show this impact on work zone safety. A study revealed that individuals experience longer dwell times on familiar roads, indicating a limitation in their ability to react to environmental inputs (Young et al., 2018). Further, as previous studies supported the idea of familiar drivers being less focused and mind wandering, it sometimes can impact their safety when maneuvering in such areas.

Previous research emphasized the relationship between road familiarity and speed choice. The findings revealed that an increase in speed were noticed when drivers are more familiar with the road (Bertola et al., 2012; Charlton & Starkey, 2013; P. Colonna et al., 2016b; P. and B. Colonna et al., 2015; Martens & Fox, 2007). Further, Wu and Xu analyzed road observations, including in-vehicle activities, speed, and deceleration distance. The findings revealed that drivers familiar with the roads were likelier to speed and decelerate at shorter distances from intersections. It was concluded that distracted driving was more prevalent on familiar roads (Wu & Xu, 2018a).

Driver age could contribute to extra driving difficulties while driving. A study found that elderly familiar drivers performed more poorly than middle-aged familiar drivers while trying to navigate to a destination (Read et al., 2011). Another study applied Generalized Mixed Effects regression for data collected from instruments placed in vehicles for 29 participants aged 65 years and older for four months. The study showed that older drivers were less likely to take a suggested low-risk route when they were more familiar with alternate routes (Payyanadan et al., 2019). Also, the behavior of drivers, whether they are familiar or unfamiliar with the road, could also be influenced by their gender. Previous research showed that females reported higher risk perception levels than males on both familiar and unfamiliar roads (N Budak et al., 2021). Additionally, a study conducted in the Middle East by (Rosenbloom et al., 2007) found that female drivers committed more traffic violations while traveling on familiar roads than on unfamiliar ones, including speeding and dangerous behaviors.

Unfamiliar drivers showed to be more at fault when they involved in crashes. A study used logistic regression analysis to estimate the factors associated with being classified at-fault among crashes-involved motorists with focus on familiarity. The study found that unfamiliar drivers were more likely to be at fault when the crash risk was assessed. Further, the study found that unfamiliar drivers were associated to crash causation due to factors such as going the wrong way, making improper maneuvers, and disregarding controls (Kim et al., 2012). (Yannis et al., 2007) supports the previous finding that unfamiliar drivers were more likely to be at fault in crashes compared to familiar drivers, specifically at junctions (Yannis et al., 2007). similarly, (Harootunian et al., 2014) found that unfamiliar drivers in Vermont, USA, were more to be at fault especially in single-vehicle crashes.

There was a contradiction in the results of previous research when it comes to the involvement of the familiar and unfamiliar drivers to as specific type of crash. For instance, (Baldock et al., 2005) revealed that an over involvement for familiar drivers in rear end crashes compared to unfamiliar drivers. This could be because familiar drivers' tendency for shorter headways (Yanko & Spalek, 2013) or braking at shorter distance from intersections (Wu & Xu, 2018a). On the other hand, (Yan et al., 2005) revealed that unfamiliar drivers were more likely to be involved in rear end crashes in case of signalized intersection.

Studies have employed two methods to differentiate between unfamiliar and familiar drivers: frequency-based and distance-based. The latter involves measuring the distance between the driver's residence and the crash location or evaluating if the driver's license and vehicle are registered in the same state or city as the crash location (Sivak & Schoettle, 2010; Vahedi Saheli, 2022). The choice of method depends on the study design and the methodology used. (Intini et al., 2019c) indicates that the average driving distance of drivers is typically on roads close to their residence, requiring a flexible definition of average commuting distance instead of a fixed threshold. In some countries, the distance between the driver's residence and the crash location is shorter compared to the United States, highlighting the cultural and geographical differences in driver behavior. The daily commute in the United States is also different compared to other countries (Burdett, Starkey, et al., 2018; Intini et al., 2019a; Litman, 2003).

According to the literature, familiarity can impact roadway safety. Familiar drivers tend to be less focused, exhibit aggressive behavior, experience longer dwell times, have a wandering mind, speed, and decelerate at shorter distances from intersections. On the other hand, unfamiliar drivers are more likely to be at fault in crashes, make wrong turns, maneuver improperly, and disregard traffic controls. Furthermore, rear-end crashes are more frequently associated with familiar drivers than unfamiliar drivers. To determine drivers' familiarity, previous researchers have employed one of two methods: distance-based or frequency-based methods, depending on the study type and other factors. It is worth noting that previous studies have yet to link these findings to work zones, which will be investigated in this study.

2.3 Interchange Areas Safety

Interchange areas are more prone to crashes than other basic segments. This is because vehicles entering or exiting the freeway can cross with traffic already on the freeway over a short distance, leading to potentially dangerous situations and crashes (Rim et al., 2023). A study conducted by (Pulugurtha & Bhatt, 2010) collected data from 25 weaving sections in the Las Vegas metropolitan area. The study used Poisson distribution to evaluate the impact of weaving section characteristics on crash rate. The study found that an increase in the length of the weaving segment resulted in a decrease in crashes. This was similar to Cirillo's study findings, which investigated the effect of the length of the weaving segment on the crash rate. (Cirillo, 1970) found that the crash rate decreased with an increase in the length of the weaving segment if the average daily traffic was greater than 10,000 vehicles.

There are three main types of Interchange ramps. Type "A" (also known as ramp weave) requires each vehicle to change at least one lane within the weaving area. Type "B" is unique because one weaving movement can be done without any lane change, while the other requires a maximum of one lane change. In Type "C" weaving sections, one weaving movement is carried out without any lane change, while the second movement requires at least two-lane changes (Roess et al., 2004).

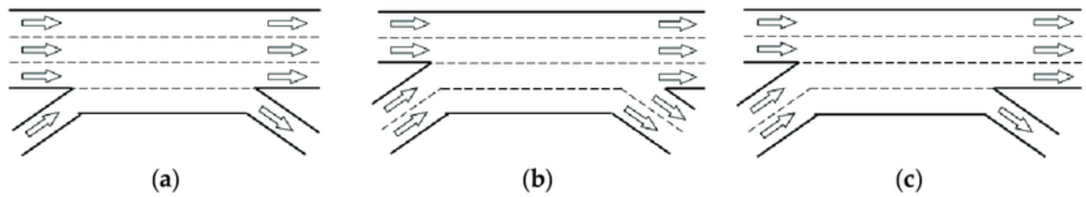

Figure 1. Types of weaving sections. (a) Type A weaving section; (b) Type B weaving section; (c) Type C weaving section (Mao et al., 2019a).

For proper maneuvering, drivers need to make one or more lane changes. A study conducted in California analyzed crash data that occurred on three types of weaving segments. The study showed no significant difference among the three types in terms of overall crash rates. However, the study also revealed significant differences in crash causality, the types of crashes that occur within these types in terms of their severity and the period in which the crash is most likely to occur (Golob et al., 2004). A recent study analyzed traffic crash data from Florida and identified factors contributing to the risk of causing crashes at interchange areas. The results revealed that driver characteristics, including age, gender, distraction, and alcohol involvement, had a statistically significant impact on the crash casualty (X Gu et al., 2022).

A recent study examined the microscopic characteristics of driving behavior in weaving segments. It identified the turbulence from lane changes and traffic volume in these sections. The study found that the turbulence caused by merging and diverging vehicles during lane changes was the highest. Additionally, higher traffic volume resulted in greater turbulence (van Beinum et al., 2018). Golob and Recker conducted a study in California to examine the impact of weather and lighting conditions on the type of crashes that occur in weaving areas. The study found that during daylight, multiple vehicle crashes were more likely to occur on wet roads than on dry or wet roads during darkness. This is because drivers are overconfident in their performance and their vehicle's performance, which is a confidence overshadowed by visual limitations imposed by darkness. On the other hand, rear-end crashes were more likely to occur on dry roads during daylight (Golob & Recker, 2003).

Various studies have emphasized the significance of reducing speed in work zones and suggested using traffic control devices to manage and decrease speed throughout work zones. (Coast et al., 2012; Richards et al., 1985; C. Wang et al., 2002) are some examples of such studies. However, a study in Ottawa focused on the traffic behavior in freeway merging areas. The study revealed that lower merging speeds resulted in more crashes on acceleration lanes, thus highlighting the risk associated with decreasing speed because of work zones in weaving segments and its impact on crash occurrence (Ahammed et al., 2008). Studies have shown that weaving segments of roads have a higher crash rate than other segments. However, longer weaving segments have fewer crashes. The type of weaving segment (A, B, or C) did not affect the crash rate. Factors such as the driver's age, gender, distraction, and alcohol consumption significantly impacted crash causality. Lane changes caused higher turbulence within the weaving segments than the traffic volume attribute. (Golob & Recker, 2003) implied that overconfidence in drivers affected their performance in these segments. Studies have also shown that work zones cause vehicles to slow down while maneuvering within them. However, (Ahammed et al., 2008) found that lower merging speeds resulted in more crashes. None of these studies has investigated work zone crashes within weaving segments. Thus, this study will go through work zone crashes within weaving segments for five years with data collected from Ohio.

CHAPTER III

DATA ANALYSIS

3.1 Data Sources

This study examined the crashes that occurred in Ohio between 2017 and 2022. The data used in this research was retrieved from the Ohio Department of Public Safety (ODPS) database, which included information such as document numbers, unit numbers, and coordination for each crash. This information facilitated the gathering of additional data from various files and merging them into one file. For each crash, the corresponding Average Annual Daily Traffic (AADT) counts were obtained from the Transportation Information Mapping System (TIMS) database managed by the Ohio Department of Transportation (ODOT) for the year of 2022. The AADT volume at each crash location was accurately assigned by merging the data using QGIS software. Figure 2 displays an overview of all crashes, except those within interchange areas and intersections, represented as individual red dots on the map.

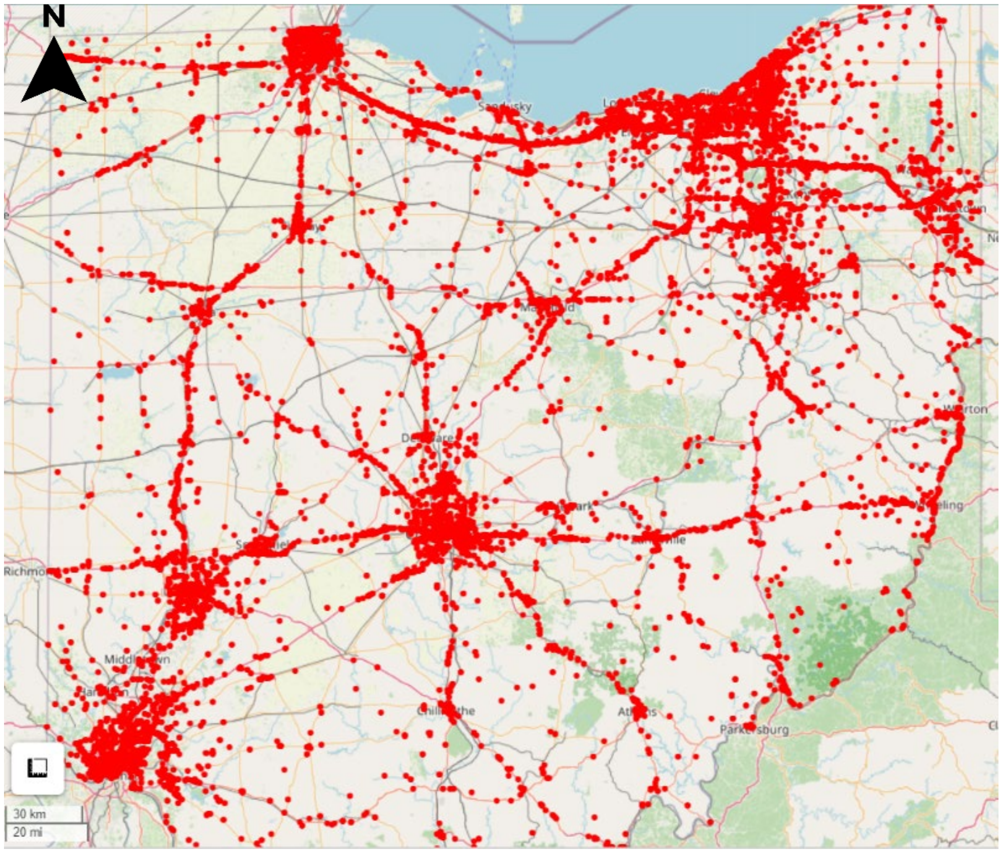

Figure 2 Map of Work Zone Crashes in Ohio 2017 – 2022 Except Crashes Occurred in interchanges and Intersection Areas

Figure 3 shows crashes within interchange areas, with a closer view of one interchange area segment that illustrates the exact location of work zone-related crashes. Lastly, Figure 4 exclusively highlights intersection work zone crashes, with an example of crashes in the university district to provide a closer examination of crashes near intersections. These figures collectively help to convey the spatial patterns and distribution of crashes for this study.

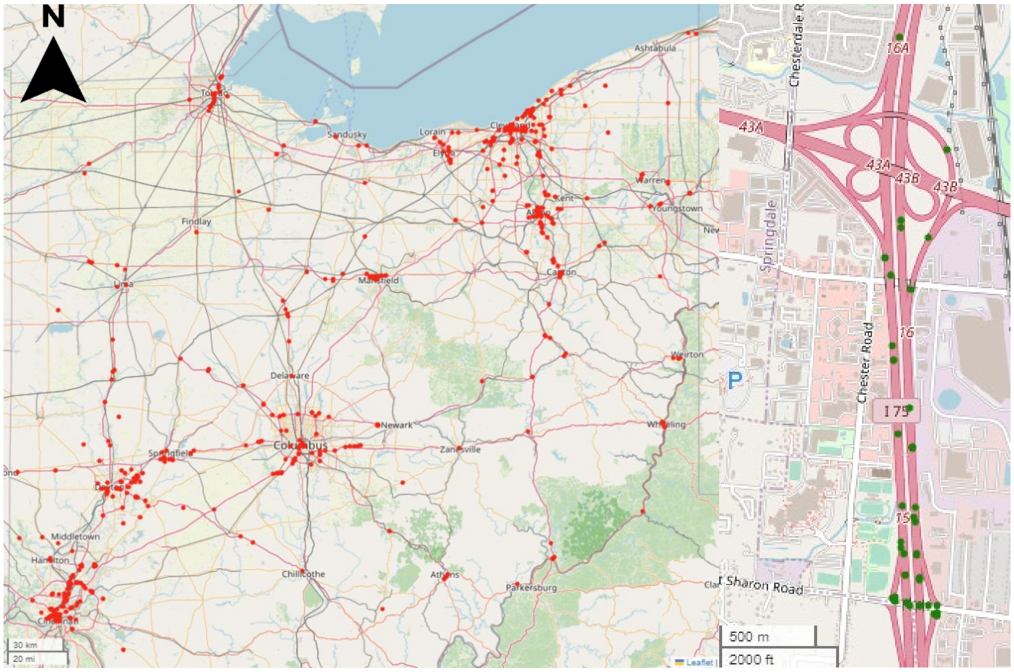

Figure 3 Map of Work Zone Crashes in Ohio 2017 – 2022 Occurred in Interchange Areas Only (On the right, an example of one interchange area.)

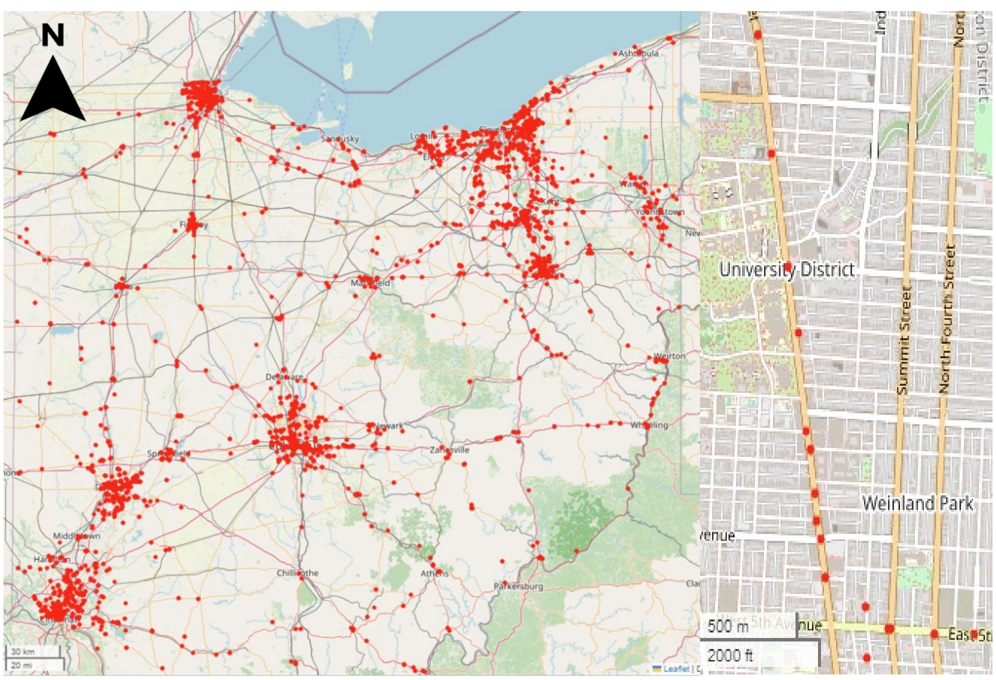

Figure 4 Map of Work Zone Crashes in Ohio 2017 – 2022 Occurred in Intersection/Approach Only (On the right, an example of intersection areas.)

3.2 Data Description

The process of selecting variables of interest to evaluate the probabilistic relationship between them began by considering the most critical factors that can directly affect the occurrence of work zone crashes. These factors fall into three categories: driver characteristics, environment factors, and traffic factors. The driver's age, gender, familiarity level, reckless driving, distracted driving, and alcohol involvement are all driver characteristic factors. On the other hand, weather conditions, roadway configuration, and work zone type are environmental factors that may affect the occurrence and severity of work zone crashes. Additionally, AADT was included to gain a better understanding of the impact of traffic volume on work zone crashes. The data was divided into three separate datasets. Table 1 presents the datasets and the selected attributes with their descriptive statistics. First, the interchange areas work zone crashes dataset. Second, the intersection/approach to intersection work zone crashes dataset. The third dataset has work zone crashes that occurred at all facility types except for interchange areas and intersections. There was a similarity in the percentage distribution across categories. For example, the attribute called "worker present" had two categories: "yes" indicated that workers were present on the site, and "no" indicated that there were no workers in the work zone when the crash occurred. Table 2 shows that approximately 35.7 percent of work zone crashes with a worker present occurred in interchange area work zone sites, 39.6 percent occurred in intersection work zones, and 38.5 percent occurred in other types of work zones. Few variables displayed differences in the percentage distribution among the three datasets. For instance, the attribute of roadway configuration demonstrated a significant difference. Specifically, 70.6 percent of the crashes that took place within the interchange area occurred on a divided roadway, and 24.4 percent of the crashes that occurred near an intersection happened on a divided approach for that intersection. Moreover, 67.5 percent of the remaining crashes took place on divided roadways.

Table 1: Descriptive Analysis of Variables

Variable	Category	Value	Interchange area		Intersection/approach		All types of facilities (excluding interchange and intersection)	
			Count	Percentage (%)	Count	Percentage (%)	Count	Percentage (%)
Driver familiarity	Yes	1	783	57.7	3,932	71.8	13,743	52
	No	0	573	42.3	1,541	28.2	12,663	48
Driver gender	Male	1	846	62.4	3,175	58	17,125	64.9
	Female	0	510	37.6	2,298	42	9,281	35.1
Alcohol involvement	Yes	1	25	1.9	71	1.3	443	1.7
	No	0	1,331	98.2	5,402	98.7	25,963	98.3
Driver age	Older adults (older than 65 years)	2	167	12.3	814	14.9	2,900	11
	Between 35 and 65 years old	1	580	42.8	2,453	44.8	12,243	46.4
	Younger than or equal 35	0	609	44.9	2,206	40.3	11,263	42.6
Weather condition	Wet, snow, and ice	1	110	8.1	537	9.8	2,720	10.3
	Clear and dry conditions	0	1,246	91.9	4,936	90.2	23,686	89.7
Worker present	Yes	1	485	35.7	2,167	39.6	10,157	38.5
	No	0	871	64.2	3,306	60.4	16,249	61.5
Manner of collision	Rear-end	1	572	42.2	2,247	41.1	13,048	49.4
	Head-on, sideswipe, and angle	0	784	57.8	3,226	58.9	13,358	50.6
Work zone type	Lane closure	2	579	42.7	2,914	53.2	12,398	46.9
	Lane shift/crossover	1	263	19.4	763	14	4,931	18.7
	Other	0	514	37.9	1,796	32.8	9,077	34.4
Injury severity	Injury	1	359	26.5	1,562	28.5	7,420	28.1
	Property damage	0	997	73.5	3,911	71.5	18,986	71.9
	Yes	1	110	8.1	419	7.7	1,475	5.6

Variable	Category	Value	Interchange area		Intersection/approach		All types of facilities (excluding interchange and intersection)	
			Count	Percentage (%)	Count	Percentage (%)	Count	Percentage (%)
Distracted driving	No	0	1,246	91.9	5,054	92.3	24,931	94.4
Reckless driving	Yes	1	790	58.3	3,414	62.4	14,325	54.2
	No	0	566	41.7	2,059	37.6	12,081	45.8
Automation status	Other	2	71	5.2	1,493	27.3	8,545	32.4
	Yes	1	6	0.5	15	0.3	91	0.3
	No	0	1,279	94.3	3,965	72.4	17,770	67.3
AADT (vpd)	More than 30,000	2	371	27.4	403	7.4	10,599	40.1
	Between 10,000 – 30,000	1	437	32.2	2,758	50.4	7,635	28.9
	Less than 10,000	0	548	40.4	2,312	42.2	8,172	31
Roadway configuration	Divided roadway	1	958	70.6	1,334	24.4	17,835	67.5
	Undivided roadway	0	398	29.4	4,139	75.6	8,571	32.6

3.3 Data Processing

For processing the data and preparing the data sets for BN analysis, Python language was used. The data obtained from the ODPS database were originally divided between three files: crash statistics, person statistics, and unit statistics. Each file comes with a different set of attributes that include detailed information about each crash. These three files were merged carefully using a unique document number for each crash, and the number of units in that crash. Later, AADT counts file was merged with ODPS datasets using QGIS by comparing each crash coordinates to the nearest known AADT volume segment.

The approach shown in Figure 5 was used to identify driver familiarity. The driver's zip code of residence was obtained from their license in the database. Latitude and longitude information from the database were used to locate the zip code for the crash location. The ZIP Code module in Python was used to search for zip codes in the United States based on their coordinate position. However, some coordinates were found manually using Google Maps. The distance between the driver's residence and the crash location was the key metric to differentiate between familiar and unfamiliar drivers. The driver's distance from their residence was calculated based on the zip code associated with them. The driver's distance from their residence was calculated by determining the shortest time travel route connecting the crash location and the center of the town or city associated with the driver's zip code.

A driver who resides outside of Ohio state is considered unfamiliar since their residence zip code is associated with a different state. All travel distances and durations between the driver's residence and the crash location were obtained using a unique Google Maps API key. This key enabled the function to retrieve information from the Google Maps database, including the shortest travel time between the two locations. The use of this information provided more accurate measurements of distance and duration.

In this study, a 24-minute threshold was used to determine whether the driver was familiar with the route or not. If the duration was less than or equal to 24 minutes, the driver was considered familiar. Conversely, if the duration was greater than 24 minutes, the driver was considered unfamiliar with the road. The decision to use 24 minutes as the threshold value was based on a survey conducted by the United States Census Bureau. The survey collected information about commuting in American communities. The latest five-year estimates data profiles for Ohio indicated an average commute time of 23.7 minutes (United States Census Bureau, 2022). However, because the durations retrieved from Google Maps Clouds were integer numbers, 23.7 minutes rounded to the closest integer value was 24 minutes.

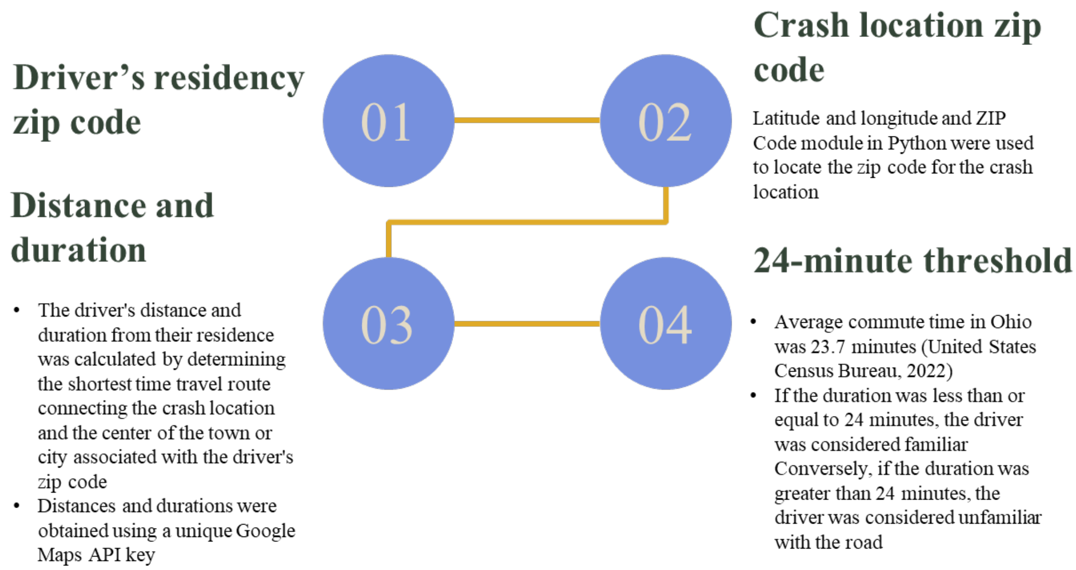

Figure 5 Approach to Identify Driver Familiarity

In this research, the data processing from the raw data to the final dataset is depicted on Figure 6. First, all files are merged into a single file using "document" and "unit numbers" for each crash. Then, the data is separated into two different datasets. Next, the Zip Code for each crash is retrieved from latitude and longitude. The data is saved, and the processing continues to obtain the distance and duration between the drivers' and crashes' zip codes using the Google Maps database.

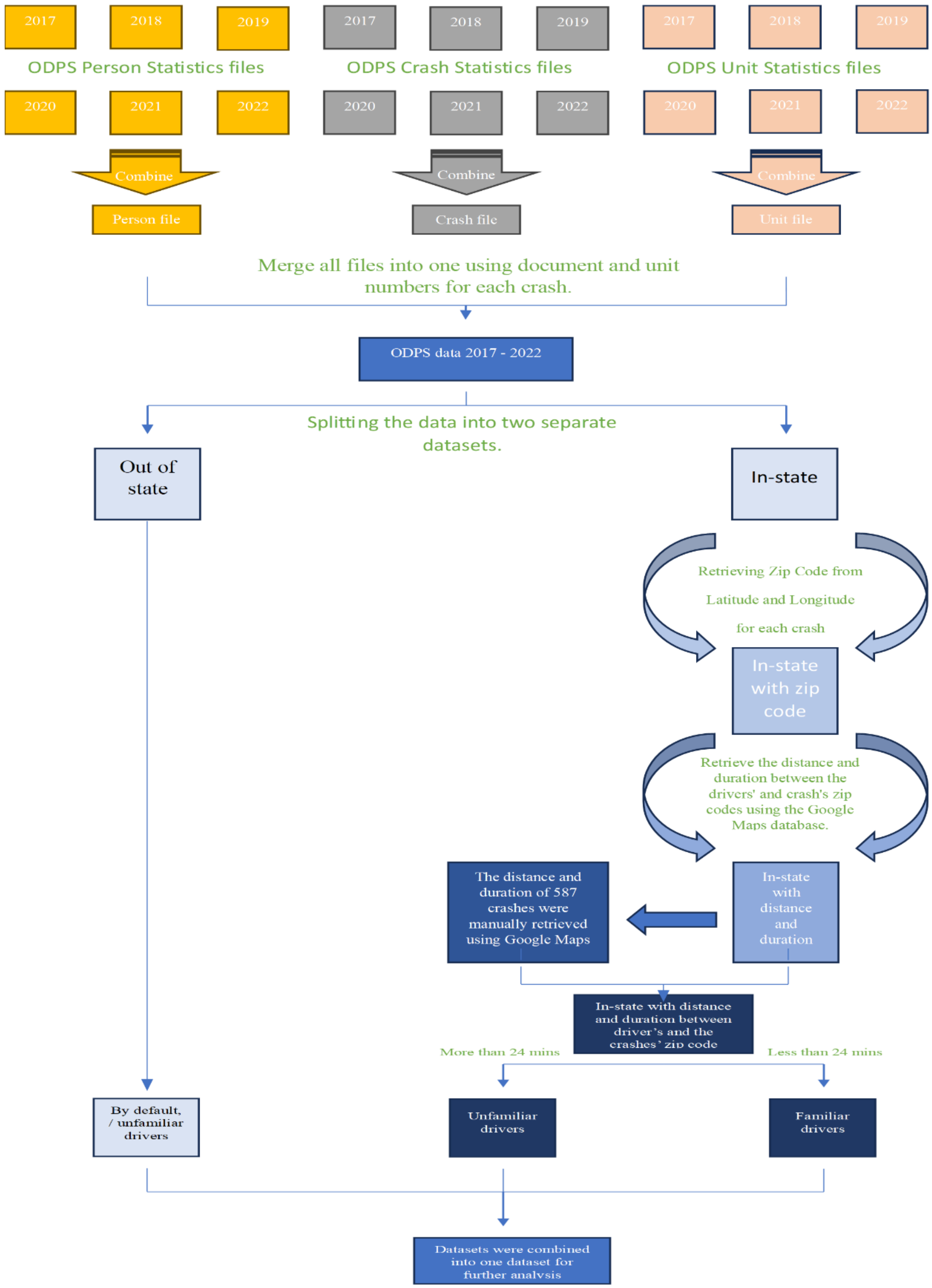

Figure 6 Data Processing

This research merged crash data and AADT counts with QGIS spatial analysis. The process involved creating two different layers: the first layer showed road segments with known AADT values, forming a network of connected red lines, as shown in Figure 7, and the second layer represented work zone crashes as yellow dots on the map. Using the "merge by nearest" option in QGIS, each crash was associated with its nearest known AADT value, establishing a comprehensive dataset correlating specific crash locations with the corresponding AADT values. This approach helps to improve our understanding of the spatial relationship between traffic volume and crash occurrences.

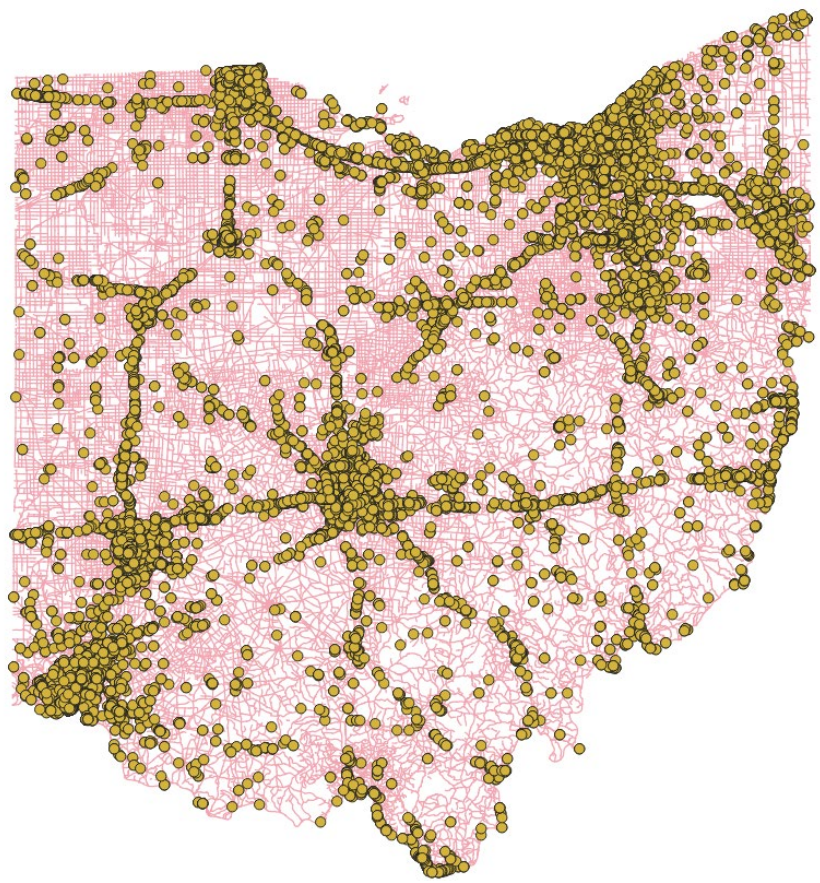

Figure 7 Merging Work zone crashes and AADT Counts Using QGIS

To categorize the AADT the box plot for the data was first analyzed as shown in figure 8.

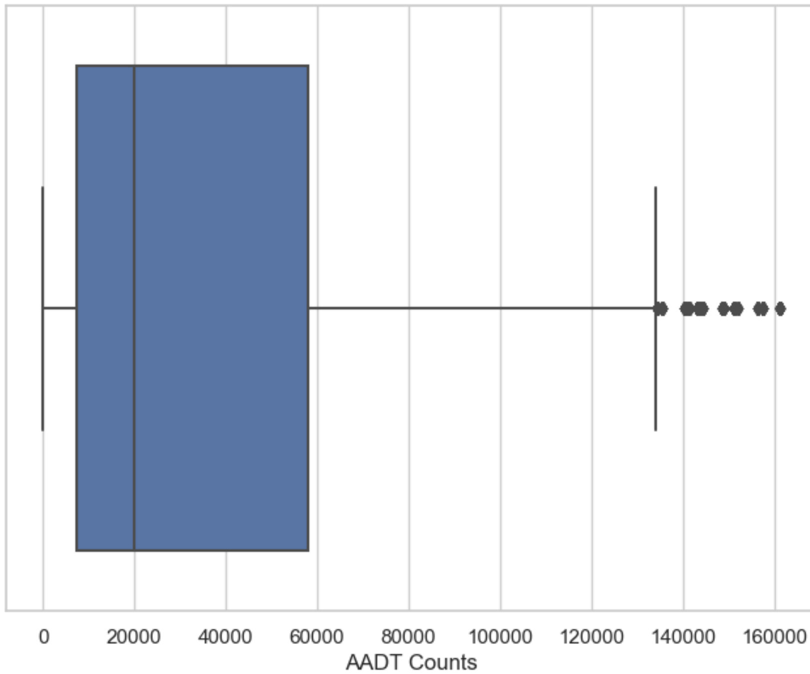

Figure 8 AADT Counts Box Plot

Based on Figure 8, it can be observed that most crashes occur in AADT volume between 10,000 and 60,000 vehicle per day. Therefore, three categories have been adopted in this study based on the AADT volume: more than 30,0000, between 10,000 and 30000, and less than 10,000. These categories correspond to high, medium, and low volume categories, respectively.

CHAPTER IV

METHODOLOGY

4.1 Bayesian Network

Bayesian Network (BN) is one of the machine learning algorithms that use condition probability distributions to represent the probabilistic connection between variables. The BN model uses a graphical model of nodes and edges to show the probability relationship between variables. The edge arcs show the direction of the influence from a parent node to a child node (Kidando et al., 2019; Novat et al., 2022). Several studies have successfully employed the BN model to infer highway safety risks, traffic flow forecasting, crash severity, and many other applications in the transportation field (Castillo et al., 2008; Sun et al., 2006; L. Wang & Yang, 2018; Wenhui et al., 2021). BN is a beneficial model for estimating the joint probability distribution between all attributes in smaller networks and getting a more accurate prediction relationship (Sun et al., 2006).

4.2 Input Datasets

After distinguishing the driver's familiarity and assigning the nearest AADT count for each crash, the dataset was divided into three final datasets that will be used in the BN model. As illustrated in Figure 9, there are three input datasets. The interchange areas dataset comprises 1,356 work zone crashes, while the intersection/approach to intersection dataset comprises 5,473. For the dataset that included all facility types except for interchange areas and intersections, 26,406 crashes were used.

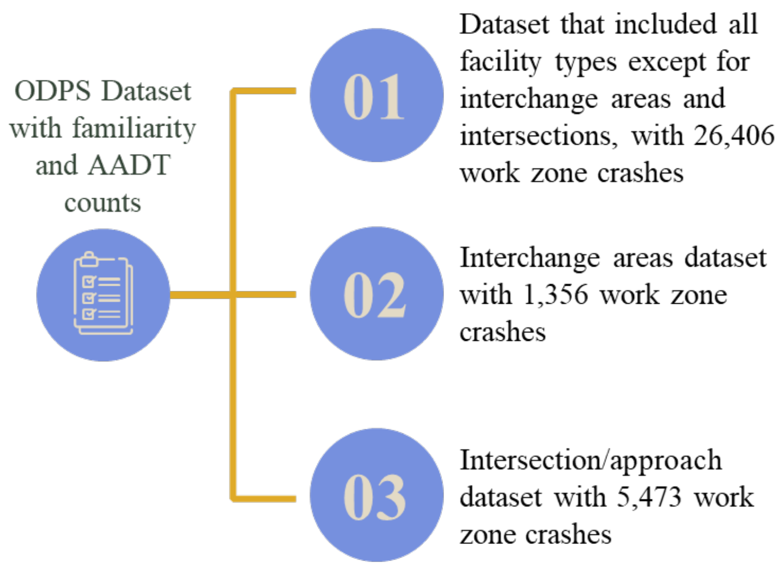

Figure 9 Input Datasets for BN Modeling

4.3 Optimal BN Structure

To obtain the optimal BN, this study adopted a hybrid approach where the network structure was trained using the input three datasets and later refined using expert knowledge. In learning the network structure, Akaike Information Criterion (AIC) Scoring Search Metric (Equation 1) was used in a greedy hill climbing optimization algorithm. This graphical representation is also known as the directed acyclic graph

(DAG). This algorithm iteratively adds and removes edges to find the best possible network while monitoring the networks' AIC score. When the AIC score does not continue to improve after several iterations, the search stops (Cong et al., 2018; Stylianou & Dimitriou, 2018).

$$AIC = 2 * LL + 2 * n \quad (1)$$

where, LL is the maximized log-likelihood; n is the number of parameters in a BN.

Previous research referred to the space in which BN allows experts to employ their knowledge to build the network (Nadkarni & Shenoy, 2001). During the stage of expert knowledge modification, the BN structure is modified based on two considerations, the first being conditional independence. Any network model can be one of two options: a dependence map (D-map) or an independence map (I-map) (Pearl, 1988). A D-map confirms that the relationship between nodes is genuinely dependent. On the other hand, an I-map confirms that concepts found to be separate are indeed conditionally independent when given other variables. Bayesian networks are I-maps. If there is no arc from a variable to its successors in the network for a sequence of variables, it implies conditional independence between the variables. The use of BN helped in modeling the probabilistic relationships among the variables of interest in this study. These variables include driver familiarity with the road, distracted driving, reckless driving, and injury severity. BNs facilitated the conditional independence modeling, which helped make accurate inferences. This is because it specifies the relevance of information on one variable in making inferences about another variable (Nadkarni & Shenoy, 2001).

Secondly, considering cause-effect relationships, it is important to consider how experts connect information and predict future events when thinking about cause-effect relationships. These reasoning methods are essential for decision-making as they help draw inferences and anticipate potential outcomes. In this study, the approach used for reasoning the cause-effect relations is called the abductive process which refers to a type of reasoning process where conclusions are drawn by working backward from effects to potential causes, which is the opposite direction of traditional causation reasoning deductive reasoning (Winston, 1984). For instance, in this study, when observing a crash reported as reckless driving related (the effect) and concludes that the driver is maybe familiar with the crash location (a potential cause of the reckless driving), the experts here are using what called abductive reasoning.

The optimal BN structure is displayed in Figure 8. This structure was used for all three datasets in this research to compare work zones at intersections and at interchange areas. Four variables are directly dependent on injury severity in this network: worker presence, manner of collision, reckless driving, and weather conditions. These four variables are also referred to as hypothesis variables. Reckless driving is linked to three hypothesis variables: distracted driving, familiarity of the driver, and driver age. Distracted driving is the child node for three variables: alcohol involvement, driver gender, and driver familiarity. Other variables, such as AADT, roadway configuration, and work zone type, were observed to influence the variables of interest through the hypothesis variables.

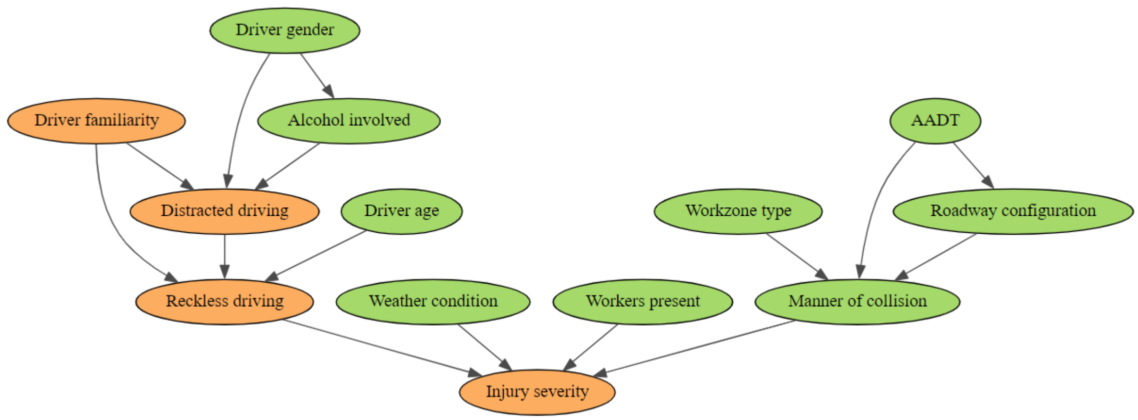

Figure 10 Optimized BN Structure

4.4 Probabilistic Inference

The target variable (child node, e.g., distracted driving) and its parent variables (e.g., alcohol involvement, driver gender, and driver familiarity) were assessed using a predictive inference once the optimal network structure had been determined. This analysis is also known as sensitivity analysis. The sensitivity analysis involves assigning evidence to the network structure and examining the effect on the target variable. In other words, the BN can therefore be used in "what-if" scenarios. For instance, analysts might inquire and get a response to the question, "What happens to the predicted probability of a driver being involved in distracted driving given that the driver is familiar with the road?" Equation 2 below was used to query the BN and extract the response for all variables of interest, including the nodes for the familiarity of the driver, reckless driving, distracted driving, and injury severity. Equation 2, i is the predicted probability of the child node given x parent (i.e., the evidence of a target variable).

$$\mathrm{P}\ (\mathrm{Child} = \mathrm{i} | \ \mathrm{Evidence}_x = 1) \quad (2)$$

4.5 BN Model Outputs

After determining the probabilities in both steps, the BN model generated percentages that represent the probabilistic relationships between variables with positive or negative signs. The percentage change for each inquiry related to the attributes of interest was calculated using equation 3 in the optimal BN structure.

$$Probability\ Change = \frac{Observed\ Probability - Predicted\ Probability}{Observed\ Probability} \qquad (3)$$

The analysis of individual evidence prediction inference was conducted to explore the probabilistic relationship between driver's roadway familiarity, distracted driving, reckless driving, and crash injury severity at work zones. The probabilities were estimated by querying the optimal BN and setting evidence probability to 1 on the driver familiarity. The following section shows the results of the observed, after-sensitivity, and changed probabilities for all relevant variables.

CHAPTER V

RESULTS DISCUSSION

The results of the BN analysis for three datasets are presented in Table 2. These datasets include the interchange areas dataset, the intersection/approach to intersection dataset, and the dataset that covers all facility types except for interchange areas and intersections. Table 2 displays the observed probabilities, after-sensitivity probabilities, and changed probabilities for all relevant variables.

Table 2: Bayesian Network Sensitivity Analysis Results

Hypothesis variable	Category	Interchange area		Intersection/approach		All work zone crashes (excluding interchange/intersection)	
		Distracted driving					
		(Observed probability = 8%)		(Observed probability = 7.66%)		(Observed probability = 5.6%)	
		Sensitivity	Change (%)	Sensitivity	Change (%)	Sensitivity	Change (%)
Driver familiarity	Yes	9.61	20.12	7.95	3.88	6.09	8.75
	No	5.80	-27.49	6.90	-9.89	5.07	-9.50
Alcohol involved	Yes	32.08	301.18	29.09	279.93	17.53	212.74
	No	7.54	-5.66	7.37	-3.68	5.40	-3.63
Driver gender	Male	7.85	-1.88	8.18	6.78	5.76	2.81
	Female	8.25	3.11	6.94	-9.36	5.31	-5.19

		Reckless driving					
		(Observed probability = 57.88%)		(Observed probability = 62.48%)		(Observed probability = 54.22%)	
Driver familiarity	Yes	59.50	2.80	63.71	1.96	54.93	1.19
	No	55.66	-3.83	59.36	-5.00	53.58	-1.29
Driver age	Older adults (older than 65 years)	61.00	5.39	63.52	1.66	53.59	-1.28
	Between 35 and 65 years old	65.17	12.59	65.83	5.35	59.80	10.16
	Younger than or equal 35	50.08	-13.47	58.38	-6.57	48.47	-10.72
		Injury severity					
		(Observed probability = 26.71%)		**(Observed probability = 28.43%)**		**(Observed probability = 27.91%)**	
Manner of collision	Rear-end	32.85	23.00	28.90	1.67	35.45	27.01
	Head-on, sideswipe, and angle	22.21	-16.84	28.10	-1.16	20.60	-26.19
Weather condition	Wet, snow, and ice	24.76	-7.28	26.39	-7.16	29.87	7.00
	Clear and dry conditions	26.88	0.64	28.65	0.78	27.69	-0.80
Worker’s present	Yes	28.14	5.38	26.23	-7.73	28.64	2.61
	No	25.91	-2.99	29.87	5.07	27.46	-1.63
		Manner of collision					
		(Observed probability = 42.26%)		**(Observed probability = 41.02%)**		**(Observed probability = 49.23%)**	
Work zone type	Lane closure	47.51	12.41	43.87	6.94	50.4	2.37
	Lane shift/crossover	43.64	3.27	35.70	-12.96	46.90	-4.73
	Other	35.65	-15.65	38.66	-5.76	48.90	-0.67

5.1 All Work Zone Crashes (Excluding Interchange and Intersection Crashes)

All work zone crashes on a road, boulevard, avenue, highway, parkway, and any place not influenced by intersection or interchange area were included in the dataset examined through BN optimal structure. Figure 11 displays the observed and predicted probabilities for all work zone crashes, excluding interchanges and intersections. This analysis aimed to determine the probability change at the child node based on observing a specific parent variable. In other words, the optimal BN was used to provide probabilistic answers to what-if questions. To respond to this type of query, an optimal BN was queried. Then, the evidence probability was set to 1, as shown in Figure 11-b, and the probability change was recorded.

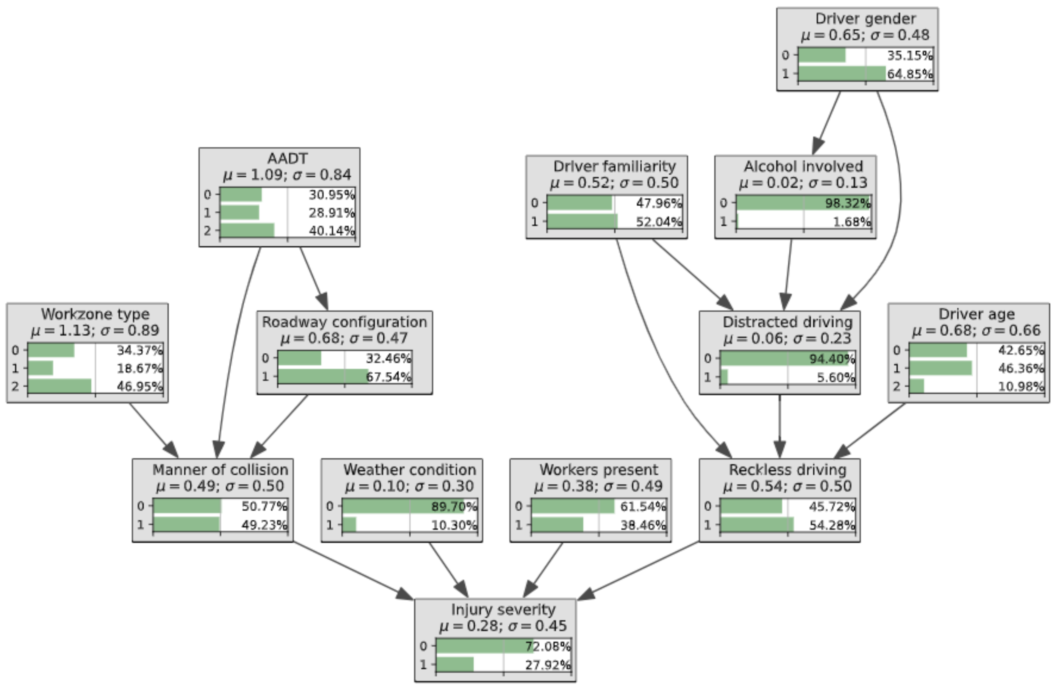

Figure 11 (a) Observed Probability (Unconditional Analysis)

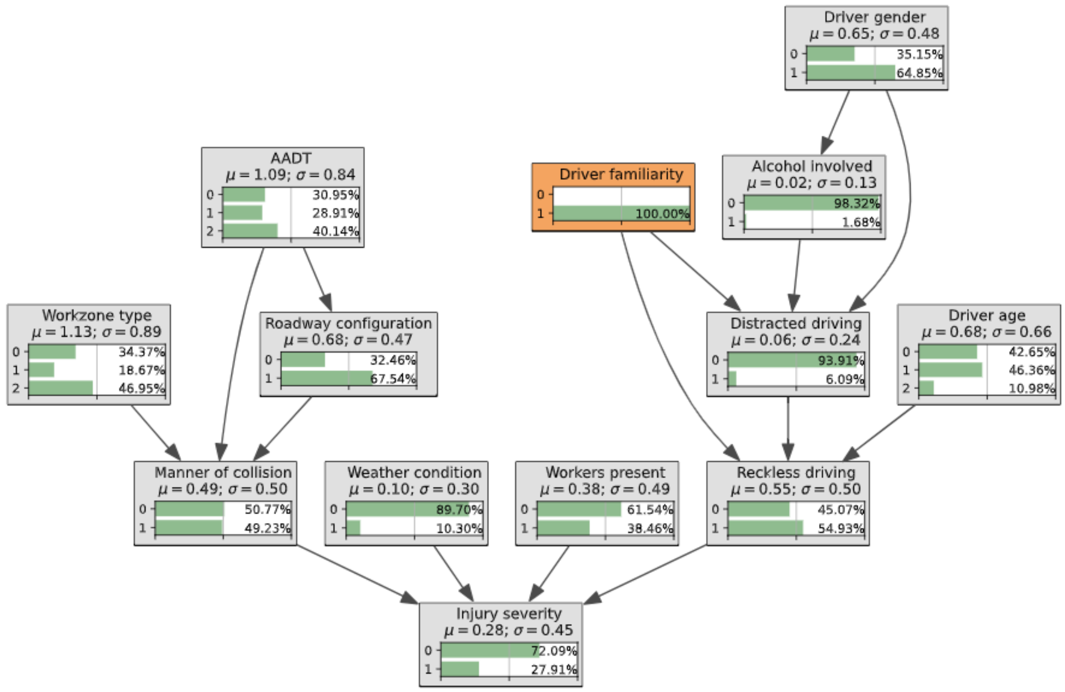

Figure 11 (b) Predicted Probability (Sensitivity Analysis)

Figure 11 Observed (a) and Predicted (b) Probabilities for All Work Zone Crashes Excluding Interchange and Intersections.

5.1.1 Distracted Driving Attribute

Based on the data presented in the optimal BN and Table 2, it can be observed that the likelihood of distracted-related crashes increased by 8.75 percent when the driver was familiar with the road (familiar driver = 1) and certainty was applied. Conversely, the probability of distracted work zone crashes decreased by 9.5 percent when the driver was unfamiliar with the road. Drivers who are familiar with the road assume they know the road. They know the speed, the signals, and where to stop and not. This high level of familiarity gives them more room not to be 100 percent focused on the driving task, and they could be distracted with the second task rather than the driving task. Previous research didn't primarily consider work zone crashes but explored the frequency of drivers reporting experiencing mind wandering during their daily commutes. The research found that familiar drivers are more likely to be found mind wandering than focusing on the driving task (Burdett, Charlton, et al., 2018).

When alcohol is involved, the probability of distraction in the work zone increases by 212.74 percent. This finding reveals how alcohol involvement increased the percentage of work zone crashes that were observed with distraction. This result matches previous research, which showed that intoxicated drivers are more likely to be involved in distracting driving and react slowly to unexpected features on the roadway (Shyhalla, 2014), and these features could be work zones.

The comparison of driver gender on distracted driving reveals that male drivers have a greater probability than female drivers to be involved in a distracted work zone crash. According to Table 2, male drivers have a change in the probability of around 2.81 percent. Whereas the probability of female drivers in distracted work zone crashes drops by 5.19 percent. Research by (Yagil, 1998) suggested that male drivers have a less normative desire to comply with traffic regulations than female drivers. As a result, male drivers might extend their pattern of disobeying traffic laws to distracted behavior.

5.1.2 Reckless Driving Attribute

Taking advantage of the rich information provided by the BN, the observed probability of reckless driving work zone crashes was perceived at 54.22 percent. Table 2 shows familiar drivers are more likely to be in a work zone crash caused by reckless driving than unfamiliar drivers. The likelihood determined by sensitivity analysis shows that familiar drivers' probability of being reckless increased by 1.19 percent. In contrast, unfamiliar drivers' probability decreases by 1.29 percent. Reckless driving could be driving at an unsafe speed, making an improper turn, opening a door into a roadway, running a red light, and many other behaviors. Many studies focused on the direct behavioral observations of familiar and unfamiliar drivers (Rosenbloom et al., 2007; Wu & Xu, 2018b) . For instance, (Wu & Xu, 2018b) showed that familiar drivers have more speeding tendencies than unfamiliar drivers. (Rosenbloom et al., 2007) showed that familiar drivers are more prone to traffic violations than unfamiliar drivers. It should be noted that none of the above studies has focused on work zone locations.

This study divided the drivers' age into three categories: younger adults (below 35), adults (between 35 and 65), and older adults (above 65). According to Table 2, reckless driving in work zones is less likely to be caused by younger and older adults than adult drivers aged 35 to 65. The findings show that drivers below 35 and above 65 years old have a probability decrease of 10.72 percent and 1.28 percent in work zone crashes caused by reckless driving. However, adult drivers aged 35 to 65 have an increased probability of 10.16 percent. The results of this study match the previous findings of (Weng & Meng, 2012), who found that middle-aged drivers are more likely to take risky behaviors at work zones.

5.1.3 Injury Severity Attribute

There is a direct correlation between injury severity and weather conditions, manner of collision, and worker presence. The BN results, table 2, shows that wet, snowy, and icy roads, especially on boulevards, avenues, highways, and parkways, have a greater likelihood of injury severity than clear and dry roadway conditions. Wet, snowy, and icy roads raise the estimated probability of injury severity by 7 percent. Severe weather conditions Increase the burden on the driver to navigate work zones safely. However, the issue with wet, snow, and icy roads is when the vehicle itself behaves unexpectedly (the driver is no longer able to control the vehicle), resulting in crashes that might be more severe than in normal weather circumstances. This finding appears to disagree with the research findings by (Ghasemzadeh & Ahmed, 2019) that indicated that crashes during unfavorable weather conditions at work zones are likely to be less severe. However, the authors noted that interactions between adverse weather and other contributing factors might raise the severity of work zone crashes. The BN results also demonstrate a probabilistic correlation between the severity of the crash injury and the workers' present attributes. The analysis findings show that while work zones are active, the likelihood of injury severity increases. The predicted probability rises by 2.61 percent. When a work zone is active, and workers are present, this may affect the driver's judgment before a crash to avoid hitting the workers. This can worsen the severity of the crash. Furthermore, the workers' presence on the road may put them in danger of being hit by a vehicle.

According to the comparison of the manner of collision attribute on the injury severity node, the outcomes of rear-end work zone crashes increase the crash injury severity probability by 27.01 percent. On the other hand, the outcomes of head-on, sideswipe, and angle crashes reduce the injury severity probability percentage by 26.19. The results from this study contradict previous studies. Several studies have found that head-on and angle collisions are the most harmful (Huang et al., 2011; Kidando et al., 2021). However, the previous studies' focus was not on work zone crashes.

5.1.4 Manner of Collision Attribute

According to Table 2, work zones with lane closures increase the probability of rear-end crashes by 2.37 percent. Conversely, work zones with lane shifts or crossovers decrease the likelihood of rear-end crashes by 4.73 percent. Rear-end crashes are the most common type of crashes in work zones, as stated by the (Federal Highway Administration, 2019). This current study helped to identify the reason behind the increase in rear-end crashes. It was found that the occurrence of these crashes is significantly affected by the type of work zone, whether it involves a lane closure, lane shift, or crossover. The study compared the probability of crashes across different work zones and collision manners. This is a crucial perspective since previous research has not focused on comparing work zone types and collision manners.

5.2 Interchange work zone crashes

In the analysis conducted using work zone crash data that occurred within interchange areas, Figure 12 (a) illustrates the observed probabilities. The evidence probability was then set to 1, as depicted in Figure 12 (b), and the corresponding probability change was recorded.

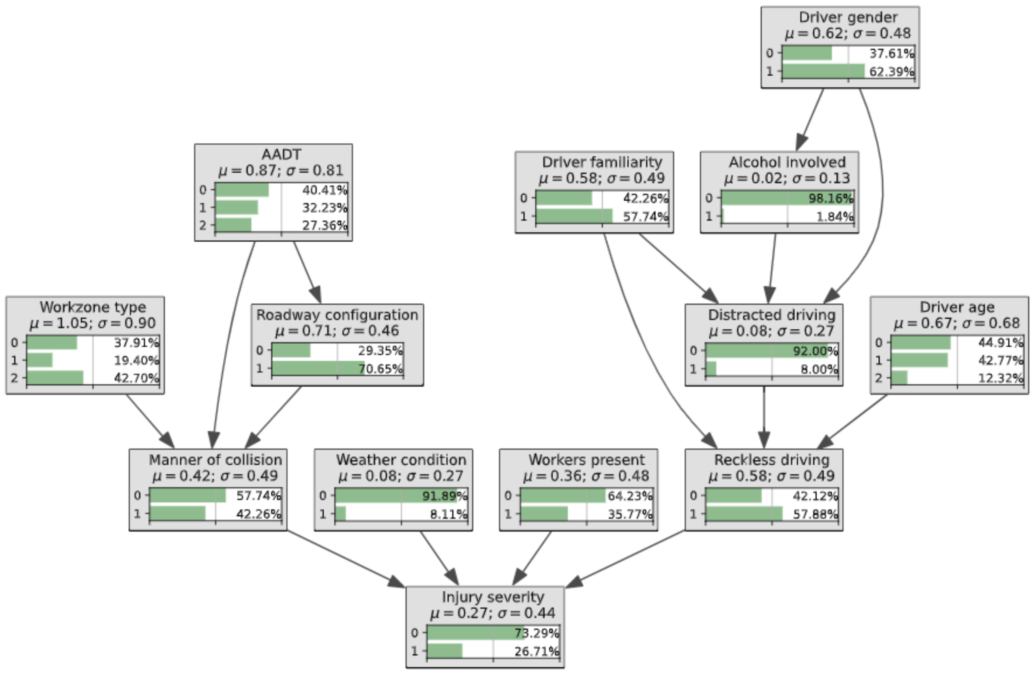

Figure 12 (a) Observed Probability (Unconditional Analysis)

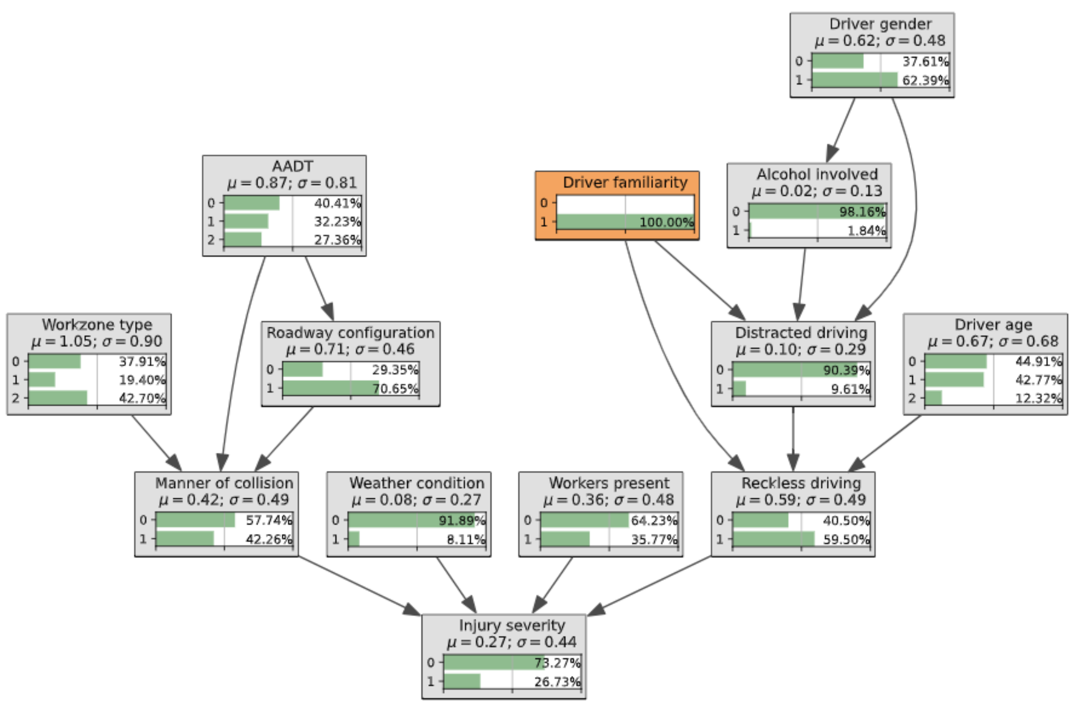

Figure 12 (b) Predicted Probability (Sensitivity Analysis)

Figure 12 Observed (a) and Predicted (b) Probabilities for Interchange Area Work Zone Crashes.

5.2.1 Distracted Driving Attribute

The results shown in Table 2 highlight that a familiar driver increases the probability of being distracted in work zone crashes that occur within interchange areas. The probability changes increased by 20.12 percent for familiar drivers. On the other hand, unfamiliar drivers are at less risk of being distracted in work zones within interchange areas, with the probability of change dropping by 27.49 for those unfamiliar with the road. This finding indicates that familiar drivers with the road need to be more aware that maneuvering within interchange areas with or without work zones demands a higher percentage of focus than any other type of road or facility. The literature indicates that interchange areas are more prone to crashes than other basic segments. This is because vehicles entering or exiting the freeway can cross with traffic already on the freeway over a short distance, leading to potentially dangerous situations and crashes (Rim et al., 2023). However, when it comes to unfamiliar drivers, the results showed that they focus more on the driving task.

BN analysis was able to show the impact of alcohol involvement on the child node distraction. The results showed a finding that intoxicated drivers increased the number of crashes caused by distraction by roughly 301.18 percent. An increase of more than 300 percent in the probability change indicates that more precautionary measures to avert this problem and lower the probability of not noticing the work zone of the drivers even if they were intoxicated, which could be done by adding traffic control devices work very effectively in such situations.

Previous research suggests that female drivers are more prone to distracted driving crashes than male drivers in work zones within interchange areas, with a 3.11

percent higher rate of such crashes. However, male drivers experience a 1.88 percent decrease in distracted driving crashes in these areas. Various gender-specific factors could contribute to such crashes in work zones. A previous study discovered that female drivers were more likely to be involved in distracted driving crashes (Billah et al., 2022). However, this study did not focus on work zone accidents.

5.2.2 Reckless Driving Attribute

According to Table 2, drivers who are familiar with the road have a higher probability of being involved in reckless driving in work zone crashes in weaving areas, with a 2.80 percent increase in probability. On the other hand, drivers who are not familiar with the road show a decrease in the probability change of 3.83 percent. This trend is also observed in other facilities away from interchange areas. The possible explanation for this observation is that familiar drivers are more likely to violate traffic rules, speed, and cut corners while driving as compared to unfamiliar drivers (Bertola et al., 2012; P. Colonna et al., 2016b; Rosenbloom et al., 2007; Wu & Xu, 2018b).

Interchange work zones pose a higher risk of reckless driving crashes for drivers belonging to the age categories over 65 years and between 35 and 65 years, as compared to younger drivers below 35 years of age. The probability of being involved in a reckless driving crash increased by 5.39 percent for older adults and 12.59 percent for mid-adults. However, it decreased by 13.47 percent for younger drivers. As older drivers experience a decline in vision, hearing, and reaction time, they are more prone to be at fault in complex and dangerous situations, such as interchange work zones. Previous research has also established that older adult drivers are more likely to be at fault in roadway crashes (Toups et al., 2022). Regarding the mid-age category, overconfidence and taking risks could be why this category is recognized as having a higher rate of involvement in reckless driving crashes. For instance, in this study based on the optimal BN, alcohol involvement has an indirect relationship with the attribute of interest (reckless driving). Previous research found that confidence in the ability to drive after consuming alcohol increased steadily with age (Soames Joa, 1990).

5.2.3 Injury Severity Attribute

According to BN, the severity of injuries in work zone crashes within interchange areas is directly linked to weather conditions. The study confirms that crashes resulting in property damage are more likely to occur on wet, snowy, and icy roads within interchange areas, as opposed to those resulting in injuries. The likelihood of a crash resulting in an injury decreases by 7.28 percent when the roads are wet or snowy, while in clear weather, dry roads increase the probability of injury by 0.64 percent. It is possible that the slippery pavements during rainy, snowy, or icy weather may be an explanation for this finding. This conclusion is consistent with previous studies on the factors contributing to traffic crashes in weaving sections. The research shows that in weaving areas, collisions with fixtures are more likely to occur during the winter (Mao et al., 2019b). It is now generally accepted that unfavorable weather conditions can result in more property damage crashes, especially in interchange areas with or without work zones.

Notably, workers present on the work site within interchange areas have increased the injury severity of those work zone crashes. The probability of crashes resulting in injuries has increased by 5.38 percent. One possible explanation is that weaving areas with higher speeds than other types of roads could affect the driver's behavior in case of a crash. Higher speeds keep the driver from having time to decide about the correct behavior.

It has been found that rear-end crashes increase the probability of crash injury severity by 23 percent compared to head-on, sideswipe, and angle crashes in work zone crashes that occur in interchange areas. On the other hand, head-on, sideswipe, and angle crashes are less likely to result in crashes with injuries in interchange work zones by 16.84 percent. Previous research shows that rear-end crashes occur at speeds beyond 55 km/hr (34 mph), which can be critical and lead to more severe outcomes, increasing the risk of injury (Jurewicz et al., 2016). According to (Zhang et al., 2014), the average running speed on ramps in merging areas was 60-70 km/h (37-43 mph), which is greater than the threshold speed found by Jurewicz.

5.2.4 Manner of Collision Attribute

The present study confirmed that lane closure and lane shift/crossover work zone types have increased the probability of rear-end crashes at interchange work zones by 12.41 percent and 3.27 percent, respectively. A similar pattern of results was obtained in a previous study, which found that 58.5 percent of interchange crashes were rear-end crashes on freeway interchange sections (Mallipaddi & Anderson, 2020). It is worth noting that the previous study does not consider work zone crashes at interchange areas and found more than 50 percent of general rear-end crashes in that study's data volume. Notably, current study suggests that a 12.41percent increase in rear-end crashes comes from lane closure work zones. A 3.65 percent increase in rear-end crashes comes from lane shifts or crossover work zones in highway weaving segments.

5.3 Intersection work zone crashes

In the analysis conducted using work zone crash data that occurred only within the intersection or approach to intersection areas, Figure 12 (a) illustrates the observed probabilities. Figure 12 (b) shows the predicted probability after the sensitivity analysis.

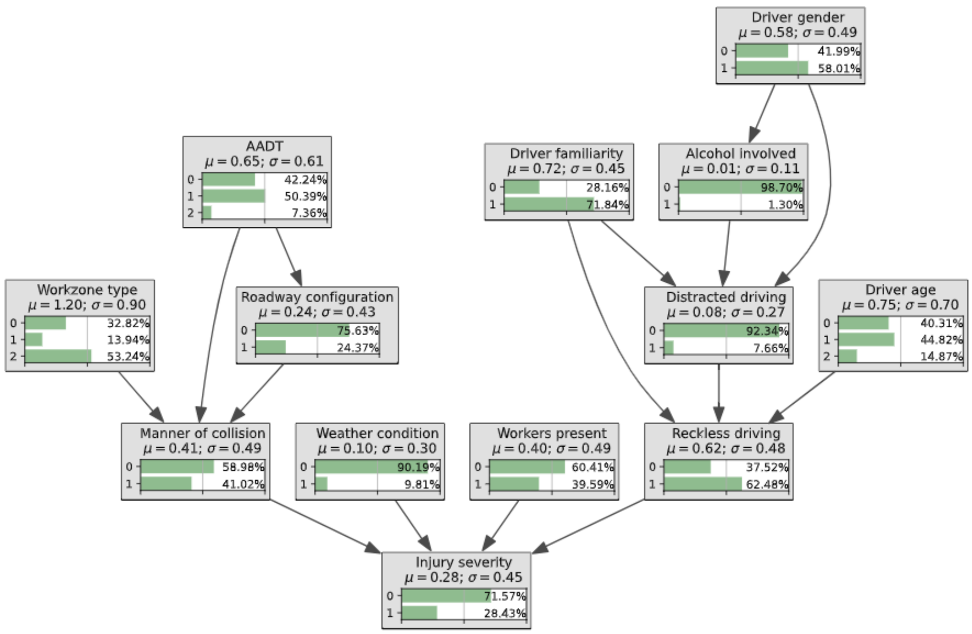

Figure 13 (a) Observed Probability (Unconditional Analysis)

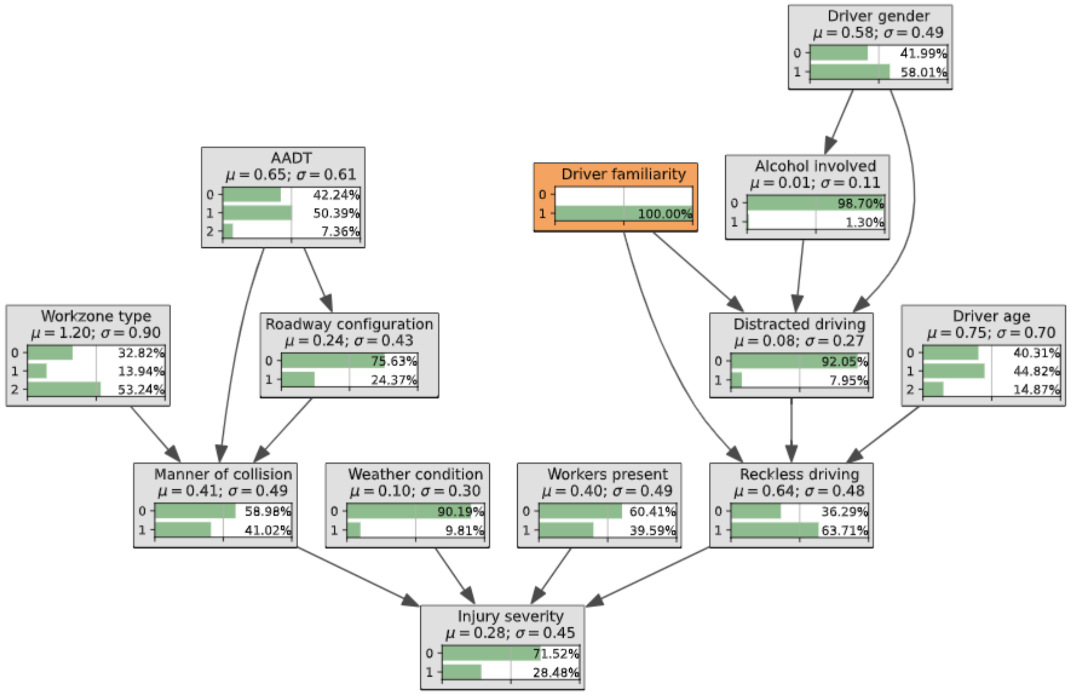

Figure 13 (b) Predicted Probability (Sensitivity Analysis)

Figure 13 Observed (a) and Predicted (b) Probabilities for Intersection Area Work Zone Crashes.

5.3.1 Distracted Driving Attribute

Analysis on crashes in intersection work zones suggests that drivers familiar with the road are more likely to get distracted and cause a crash by 3.88 percent. Conversely, drivers unfamiliar with the road are less likely to be distracted, reducing the probability of crashes by 9.89 percent. This analysis implies that familiarity with the road increases the chances of getting distracted, regardless of the road type. This finding is consistent with the earlier conclusions in the study, which suggest that drivers who are familiar with the road are more prone to getting distracted and causing accidents because such drivers are more likely to be found mind wandering than focusing on the driving task (Burdett, Charlton, et al., 2018). Work zones change the standard intersection that every driver knows or maneuvers through before to an entirely new intersection with different geometry. For instance, a lane could be closed, changing the traffic from two lanes to only one lane. Furthermore, after finishing the tasks assigned to the first lane in that intersection, the next day, it could be opened and then closed on the other lane. In other words, work zones at intersections require a high percentage of driver focus and following the rules and traffic control signs to navigate through work zones in intersections safely.

The chances of a crash happening due to distraction increase by 279.93 percent when alcohol is involved. Intersections with work zones require drivers to be extra careful and attentive to pass safely. Intoxicated drivers may be unable to handle the additional challenges that work zones pose for that intersection and may need to realize that the intersection has changed. However, traffic controls like lane close signs, shifting traffic light arrows, tapers, and rounding the work area with tapers (without closing the lane) are typically used to regulate intersections with work zones. These devices inform drivers about what to expect and what to do. However, alcohol can impair a driver's ability to focus and interact effectively in such situations.

According to results in Table 2, male drivers are 6.78 percent more likely to cause distracted-related work zone crashes in intersections than a decrease of 9.36 for female drivers. Previous study shows that male drivers tend to be less willing to comply with traffic regulations than female drivers (Yagil, 1998). Intersections in work zones have strict traffic control devices and regulations to ensure their effectiveness for all approaches. They require a high level of commitment from drivers of both genders to pass through them safely.

5.3.2 Reckless Driving Attribute

The result of this analysis is then found that familiar drivers are at higher risk to be involved in a reckless driving work zone crash at intersections. The probability for familiar drivers has increased by 1.69 percent and decreased by 5 percent for unfamiliar drivers. As mentioned previously, familiar drivers have more speeding tendencies than unfamiliar drivers (Wu & Xu, 2018b). Familiar drivers are more prone to traffic violations than unfamiliar drivers (Rosenbloom et al., 2007). Also, familiar drivers showed increased curve-cutting behaviors compared to unfamiliar drivers (Bertola et al., 2012; P. Colonna et al., 2016b). All these behaviors contribute to familiar drivers being at higher risk of driving recklessly.

In intersections or approaches to intersection work zones, older drivers aged more than 65 and mid age drivers between 35 – 65 increased the probability of observing reckless driving-related crashes by 1.66 percent and 5.35 percent, respectively. On the other hand, younger drivers aged less than 35 are less likely to observe reckless driving behaviors when a crash occurs.

5.3.3 Injury Severity Attribute

Another promising finding was that the probability of observing injuries in work zone crashes at intersections decreased by 7.16 percent when the weather is rainy, snowy, or icy. The probability change increased by 0.78 percent when the weather is clear. On wet, snowy, and icy roads, drivers are more cautious to avoid slipping or losing control. Specialty at intersections with speed limits are usually low. Furthermore, workers on the site at intersection work zones had decreased the chance of observing injuries in crashes that occur there by 7.73 percent. While the workers are not on site, the probability increased by 5.07 to observe crash injuries. One possible reason for this finding is that lower speeds typically result in fewer injuries. Previous research indicated the likelihood of being involved in a severe crash increased with higher vehicle speeds (Moore et al., 1995). However, intersections have a low speed compared with other facilities in the transportation network.

At intersections work zones, rear-end crashes still increase the probability of crash severity by a small percentage of 1.67, and head-on, sideswipe, and angle crashes also decrease the probability of severity by a small percentage of 1.16. While rear-end crashes at intersections may not always result in the most severe injuries, they can still cause significant damage and disruption to the surrounding environment or the vehicle body.

5.3.4 Manner of Collision Attribute

Table 2 provides significant findings regarding the impact of the lane closure and lane shift/cross-over work zones on the probability of rear-end crashes. The analysis shows that the lane closure work zone increases the chances of rear-end crashes by 6.94 percent. In contrast, the lane shift or cross-over work zone decreases the probability of rear-end crashes by 12.96 percent. Previous research has shown that work zones with lane closures tend to have more rear-end crashes than those with lane shifts. Although the previous study does not specifically focus on intersections, its findings are consistent with this research findings (Yi Qi et al., 2013). There could be various reasons for this finding. One of the reasons could be the reduced visibility of other vehicles, as lane closures can make it harder for drivers to see the vehicles in front of them, particularly at intersections. Another reason could be unexpected traffic patterns, such as lane closures in work zones, which may confuse drivers and make it difficult for them to anticipate the actions of other vehicles. Additionally, drivers often follow too closely in work zones, making it harder for them to avoid rear-ending the vehicle in front of them if it stops suddenly at an intersection or in the approach to an intersection.

5.4 Comparison

This research aimed to determine whether the location of a work zone on the road impacts safety or not. To achieve this, the study compared work zones located in interchange areas and intersections or approaching intersection areas. This comparison provides a valuable tool for decision-making. It enables the development of evidence-based recommendations to enhance work zone safety. The optimal BN was used for both locations to ensure a fair comparison of results. The present study confirmed the findings about the impact of driver familiarity on distraction and reckless driving. A comparison of familiar and unfamiliar drivers revealed that familiar drivers were more likely to engage in distracted or reckless driving, especially in work zones at interchanges and intersections. Specifically, the results indicate that the probability of distracted driving crashes was higher for familiar drivers at interchange areas compared to intersections. The probability of such crashes was approximately 20.12 percent for interchange areas and only 3.88 percent for intersections. It is crucial to increase commuters' awareness of how familiarity with the road can impact their driving safety. Even if a driver is accustomed to the roads they are driving on, it is important to remain focused on the road and the driving task. This is especially true after addressing any previous issues found while driving.

In line with the previous findings, intoxicated drivers increase the likelihood of distracted driving crashes by over 20 percent at interchange areas compared to intersections. Interchanges are often located in areas with higher traffic volumes and speeds, and they are more complex and have more potential conflict points. For example, drivers at an interchange may need to merge onto or off a highway, make a sharp turn, or cross several lanes of traffic. Moreover, work zones can make it more difficult for drivers to see other vehicles and make safe decisions. Because of the complexity of interchange work zone areas and the massive increase in distraction that intoxicated drivers experience within those areas. More traffic control devices should be installed on the site to mitigate this risk. A further study can determine the optimal number of traffic control devices such as signs, channelizing devices, portable traffic signs, and flagger stations.

The driver's gender impacted the likelihood of distraction driving crashes in interchange and intersection areas. The study revealed that male drivers were more likely to cause distraction driving crashes in intersections than in interchange areas. On the other hand, female drivers were at a higher risk of being distracted while driving in interchange areas than intersections.

The severity of injuries in both intersection and interchange work zones is affected similarly by weather conditions. Research shows that when roads are wet, snowy, or icy, there is a decrease of approximately 7 percent in the likelihood of crashes with injuries occurring in both locations of work zones.

The presence of workers in work zones has led to a decrease in the likelihood of injuries occurring in intersection or approach to intersection work zones. The decrease in probability was approximately 12 times greater at intersections compared to interchange areas. According to Table 2, the probability of injuries increased by 5.38 percent at interchange areas and decreased by 7.73 percent at intersections.

According to Table 2, there has been a significant increase in rear-end crashes in work zones located at intersections and interchanges. Lane closures at these spots have led to a 6.94 percent increase in intersection crashes and a 12.41 percent increase in interchange crashes. These results show that lane closures in work zones have a greater impact on rear-end crashes in interchange areas as compared to intersections. Furthermore, lane shift and cross-over work zones reduced rear-end crashes at intersections by 12.96 percent while increased rear-end crashes at interchanges by only 3.27 percent. Based on the results, contractors must avoid lane closure at intersections, approach intersections, and interchange areas, which could minimize rear-end crash occurrence.

Observing injury severity at work zone crashes has increased by roughly 23 percent in interchange areas due to rear-end crashes. In contrast, at intersections, the increase has been only 1.67 percent. This significant difference in the probability change between the two locations for work zones suggests that rear-end crashes are more dangerous and result in more severe injuries in interchange areas than in intersections. This could be attributed to the higher speed at interchange areas compared to intersections, as previous research indicates that rear-end crashes happen at speeds beyond 55 km/hr (34 mph), which can be critical and lead to more severe injuries, thereby increasing the risk of injury (Jurewicz et al., 2016). According to (Zhang et al., 2014), the average running speed on ramps in merging areas was 60-70 km/h (37-43 mph), which is higher than the threshold speed found by Jurewicz.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

The thesis argues that a probabilistic relationship exists between a driver's familiarity with a roadway, distracted driving, reckless driving, and crash injury severity in work zones. The study compares the results for different work zone locations, specifically interchange areas and intersections. It also identifies recommendations to improve work zone safety. The research used data from The Ohio Department of Public Safety (ODPS) database for work zone crashes between 2017 and 2022. The study provides a valuable tool to differentiate the driver’s familiarity. The analysis began by measuring the distance and duration of the crash using the Google database based on the driver's distance from their residence. The shortest travel route connecting the crash location and the town center or city associated with the driver's zip code was calculated. Commuters who spent more than 24 minutes were considered familiar drivers. In comparison, those commuting for less than 24 minutes were considered unfamiliar drivers. A BN model was used in the analysis to illustrate the probabilistic relationship between variables. BN is known for machine learning algorithms addressing what-if questions. The model can be employed to investigate and respond to queries like, "What happened to the probability of a driver involved in reckless driving given that the driver is familiar with the road?" Greedy hill-climbing optimization algorithms and expert knowledge are used to create meaningful connections between BN nodes.

On this basis, it can be concluded that:

- Familiar drivers are more likely to be involved in distracted driving crashes in work zones than unfamiliar drivers.
- Intoxicated drivers increased distracted-related crashes by a considerable increase of around 200 percent in work zones in general. However, in interchange areas, the probability for intoxicated drivers goes beyond 300 percent to be involved in distracted-related crashes.
- In addition, the finding suggests that male drivers are more likely to be involved in distracted work zone crashes than female drivers.
- Furthermore, the research indicates that familiar drivers have a slightly higher chance of observing reckless driving in work zone crashes, increasing the probabilistic percentage by less than one percent.
- Work zones with lane closure increase the probability of rear-end crashes. On the other hand, work zones with lane shifts or crossovers decrease the odds of rear-end crashes.

- According to the comparison of the manner of collision attribute on the injury severity node, the outcomes of rear-end work zone crashes increase the crash injury severity probability. On the other hand, the outcomes of head-on, sideswipe, and angle crashes reduce the injury severity probability percentage.
- The comparison of familiar and unfamiliar drivers revealed that familiar drivers were more likely to engage in distracted or reckless driving, especially in work zones at interchanges and intersections. Specifically, the results indicate that the probability of distracted driving crashes was twice as high for familiar drivers at interchange areas compared to intersections.
- Intoxicated drivers increase the likelihood of distracted-related crashes by over 20 percent at interchange areas compared to intersections.
- Male drivers increase the likelihood of distraction-related crashes in intersections than in interchange areas. On the other hand, female drivers increase the probability of distracted driving in interchange areas than intersections.
- Lane closures in work zones doubly increase the probability of rear-end crash occurrence in interchange areas than intersections.
- Rear-end crashes are more dangerous and result in more severe injuries in interchange areas than in intersections.

Based on the results, to minimize rear-end crash occurrence, contractors must avoid lane closure at intersections, approach to intersections, and interchange areas. More traffic control devices (TCDs) are essential to prevent distracted driving. These devices provide accurate and concise information about the road ahead and use advanced targeted technology to warn drivers who may be intoxicated in interchange areas. Further research can investigate the most appropriate type of TCDs and how many should be installed in those areas to increase the overall interchange or intersection safety. This helps to reduce the likelihood of encountering distracted-related crashes on the road.

It is crucial to conduct further research to examine the impact of autonomous vehicles on work zone safety. Additionally, it is essential to investigate the probabilistic relationship between the impact of autonomous vehicles and other variables studied. This research recommends organizing a national campaign to raise all drivers' awareness about the risk of familiarity and the potential distraction driving crash outcomes while commuting to and from work. This can be achieved by working with community councils in cities across the United States. Furthermore, this study recommends avoiding lane closures, particularly at interchange areas, due to a significant increase in injury probability during crashes in those locations.

The limitations of the present research naturally include that the data retrieved for this research covers the period of 2017 to 2022, which was greatly affected by the COVID-19 pandemic in 2020 and 2021. The writer of this thesis chose to focus solely on work zone crashes and the probabilistic relationships between the relevant attributes without considering the pandemic's impact. The location of the crash was a crucial factor in the analysis. In contrast, the specific time and date of the crashes were not considered. Future research could address this issue and offer further insights by comparing the results before and after the pandemic to determine if any changes in driver behavior occurred. For this study, a 24-minute threshold value to distinguish between drivers familiar with the route and those not. The United States Census Bureau surveyed the commuting duration of Ohio's drivers and found it to be 27.7 minutes. However, since the Google database only provides durations with integer minute values, the author decided to round off the survey value of 27.7 to the nearest integer, which is 24 minutes. There is no fixed threshold value for differentiating drivers' familiarity, and different values may be used as indicated in the literature.

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