WORK ZONE CRASH ANALYSIS AND MODELING TO IDENTIFY FACTORS ASSOCIATED WITH CRASH SEVERITY AND FREQUENCY

by

ISHANI MADURANGI DIAS

B.S., University of Moratuwa, Sri Lanka, 2010
M.S., University of Moratuwa, Sri Lanka, 2012

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

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Department of Civil Engineering
College of Engineering

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Abstract

Safe and efficient flow of traffic through work zones must be established by improving work zone conditions. Therefore, identifying the factors associated with the severity and the frequency of work zone crashes is important. According to current statistics from the Federal Highway Administration, 2,372 fatalities were associated with motor vehicle traffic crashes in work zones in the United States during the four years from 2010 to 2013. From 2002 to 2014, an average of 1,612 work zone crashes occurred in Kansas each year, making it a serious concern in Kansas. Objectives of this study were to analyze work zone crash characteristics, identify the factors associated with crash severity and frequency, and to identify recommendations to improve work zone safety. Work zone crashes in Kansas from 2010 to 2013 were used to develop crash severity models. Ordered probit regression was used to model the crash severities for daytime, nighttime, multi-vehicle and single-vehicle work zone crashes and for work zones crashes in general. Based on severity models, drivers from 26 to 65 years of age were associated with high crash severities during daytime work zone crashes and driver age was not found significant in nighttime work zone crashes. Use of safety equipment was related to reduced crash severities regardless of the time of the crash. Negative binomial regression was used to model the work zone crash frequency using work zones functioned in Kansas in 2013 and 2014. According to results, increased average daily traffic (AADT) was related to higher number of work zone crashes and work zones in operation at nighttime were related to reduced number of work zone crashes. Findings of this study were used to provide general countermeasure ideas for improving safety of work zones.

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Approved by:

Major Professor
Sunanda Dissanayake

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Table of Contents

List of Figures

List of Tables

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Dedication

To my loving parents, Gamini Dias and H. W. Chandralatha

Chapter 1 - Introduction

This chapter defines a highway work zone and explains why work zone safety is an issue. This chapter utilizes the most current work zone crash statistics to describe the situation surrounding work zones throughout the United States and in Kansas, using the latest available work zone crash statistics. This chapter also includes the problem statement and study objectives.

1.1 Work zones and work zone safety

According to the Manual on Uniform Traffic Control Devices (MUTCD) *(1)*, a work zone is defined as "*An area of highway with construction, maintenance, or utility work activities*". Work zones are typically marked by signs, channelizing devices, barriers and/or work vehicles. Measures taken to ensure proper traffic flow and safety within and around work zones are known as Temporary Traffic Control (TTC) devices. A work zone consists of four main components: an advance warning area, a transition area, an activity area, and a termination area. Locations of each component within a typical work zone are illustrated in Figure 1.1. In the advance-warning area road users are informed of the upcoming work zone area. In the transition area, road users are directed out of their normal path using tapering. Actual roadwork takes place in the activity area, which is divided in to three spaces: work space, traffic space, and buffer space. The termination area allows the road user to return to their normal driving path. This area extends from the downstream end of the work zone area to the last TTC device such as "End Road Work" signs, if posted. According to FHWA *(2)*, a work zone crash is defines as A traffic crash in which the first harmful event occurs within the boundaries of a work zone or on an approach to or exit from a work zone, resulting from an activity, behavior, or control related to the movement of the traffic units through the work zone.

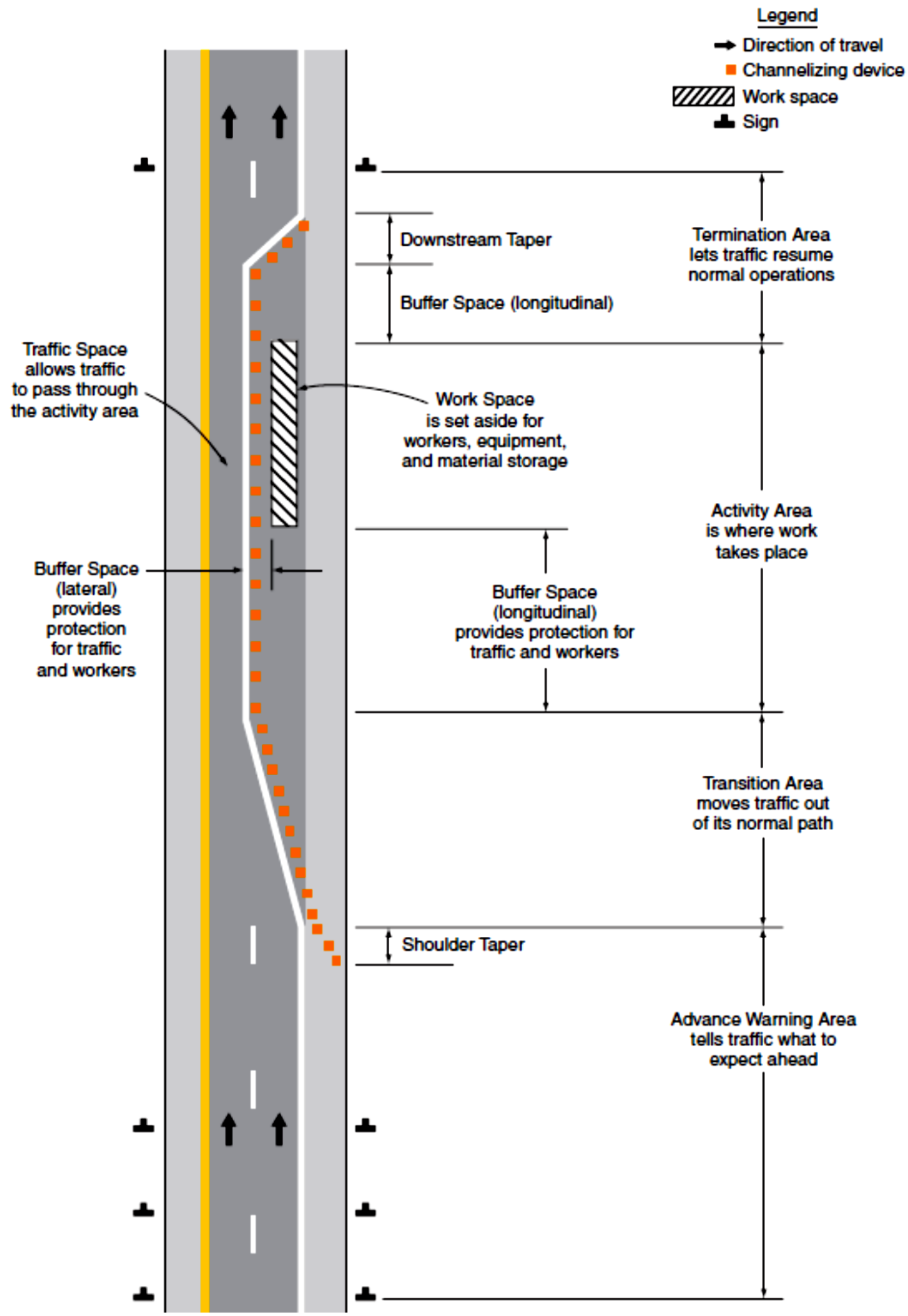

Figure 1.1 Components of a temporary traffic control zone

Source: MUTCD (2009 Edition, Figure 6C-1, page 553) *(1)*

In order to provide a better service to road users, highways must be impeccably maintained, including appropriate roadway rehabilitation when necessary. As a result, road users often encounter construction and maintenance zones during highway travel. Regular maintenance of roads requires an increased number of work zones resulting in heavier traffic. In an effort to reduce traffic congestion due to highway work zones, nighttime highway work has increased, potentially elevating safety risks for highway workers and road users *(3, 4)*. However, relevant authorities are attempting to minimize inconvenience to road users and provide safe passage through work zones by implementing proper traffic control measures and possible detours. According to the Federal Highway Administration (FHWA) *(5)*, 87,606 crashes or 1.6% of total crashes occurred in work zones in 2010; 436 of those crashes were fatal. Furthermore, 2,372 fatalities were associated with motor vehicle traffic crashes in work zones in the United States during the four years from 2010 to 2013 *(5)*. Fatal crash statistics from the National Work Zone Safety Information Clearinghouse (NWZSIC) *(6)* for a 10-year period from 2004 to 2013 showed that an average of 778 work zone fatal crashes occurred annually throughout the United States. During that period, work zone fatal crashes has account for 2.1% of total fatal crashes.

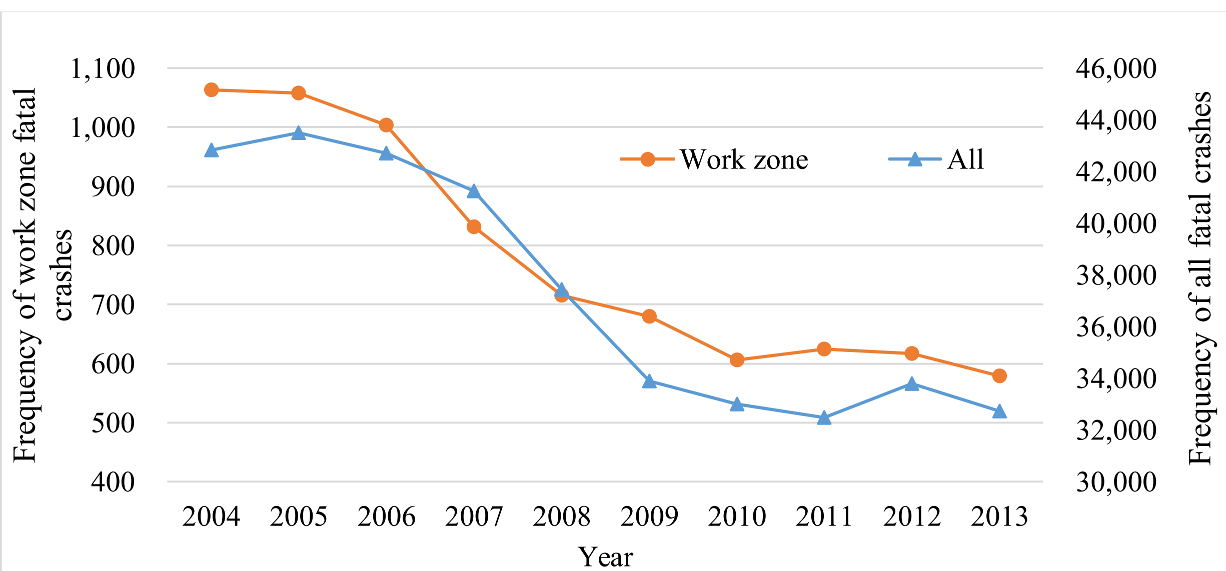

Figure 1.2 Trend in fatal crashes in the United States (2004–2013)

Although average values are given, a reduction in crash frequency was observed throughout the 10-year time period (2004 to 2013), as shown in Figure 1.2. The total number of fatal crashes in the United States has decreased by 24% and the total number of fatal work zone crashes has decreased by 46% during that period. However, this improvement in fatal crash totals could be increased by identifying and strategically addressing work zone safety issues.

1.2 Work zone crashes in Kansas

An average of 411 total fatal crashes and nine work zone fatal crashes occur in Kansas each year. Work zone fatal crashes account for 2.1% of total fatal crashes. Considering the trend in fatal crashes in Kansas, shown in Figure 1.3, fatal crashes have not considerably decreased, although the total number of fatal crashes decreased by 109 from 2004 to 2013 and the number of fatal work zone crashes decreased by 17, the overall number of fatal crashes did not decrease significantly. Published work zone crash statistics by the Kansas Department of Transportation (KDOT) *(7)* were used to plot the chart in Figure 1.3. This is not the situation in which the total number of work zone crashes is considered, because an increase of total number of work zone crashes can be observed from 2009 to 2012 in Kansas. When considering the cost of these work zone crashes, KDOT fact sheets for 2013 stated that the cost of 766 work zone crashes in 2013 was $34,982,000 *(8)*. When compared to crash costs in 2012 *(7)*, it was a 15% increase of cost of one work zone crash.

When the distribution of work zone crash locations was considered, most work zone crashes were found to be located in and around Kansas City, Wichita, and Lawrence, as shown in Figure 1.4. Figure 1.5 shows a close-up for Kansas City, Kan. and Figure 1.6 uses a heat map to show the work zone crash densities in Kansas. A Google fusion table was used to create all the maps. All three figures mentioned above are created using Kansas Crash Analysis and Reporting System (KCARS) data for year 2014.

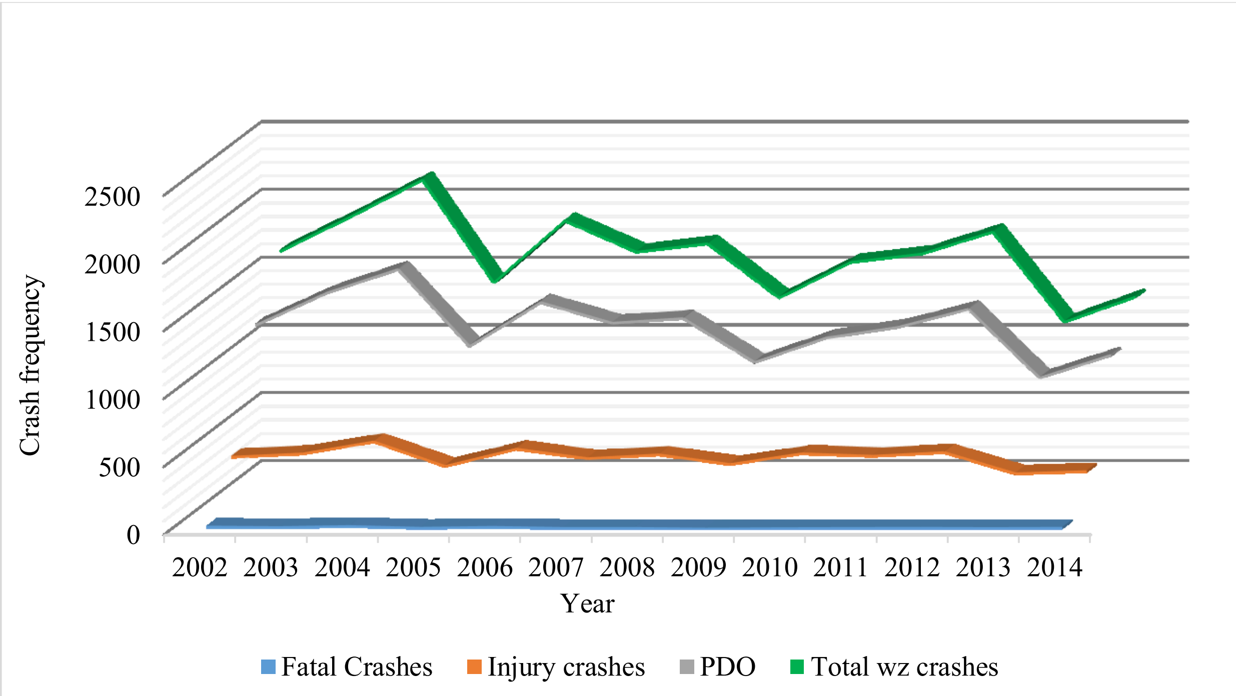

Figure 1.3 Work zone crash frequencies in Kansas with crash severities (2002-2014)

Note: PDO = Property Damage Only, created using KDOT fact sheets *(7)* and KCARS

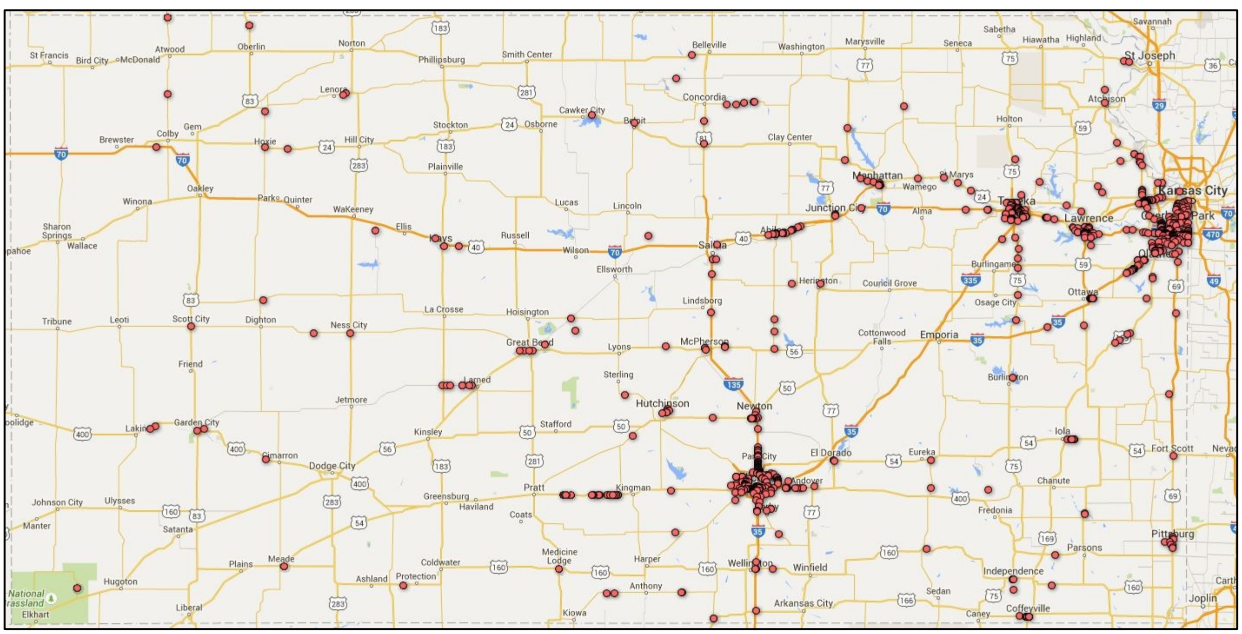

Figure 1.4 Location distribution of work zone crashes for year 2014

Note: Each dot represents one work zone crash.

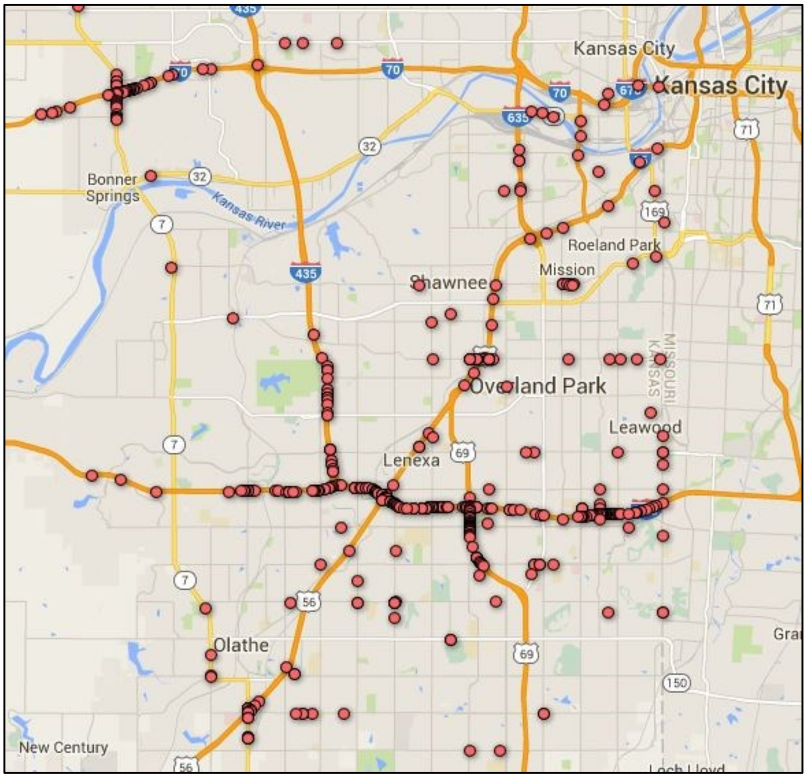

Figure 1.5 Work zone crash locations in and around Kansas City, Kan (2014)

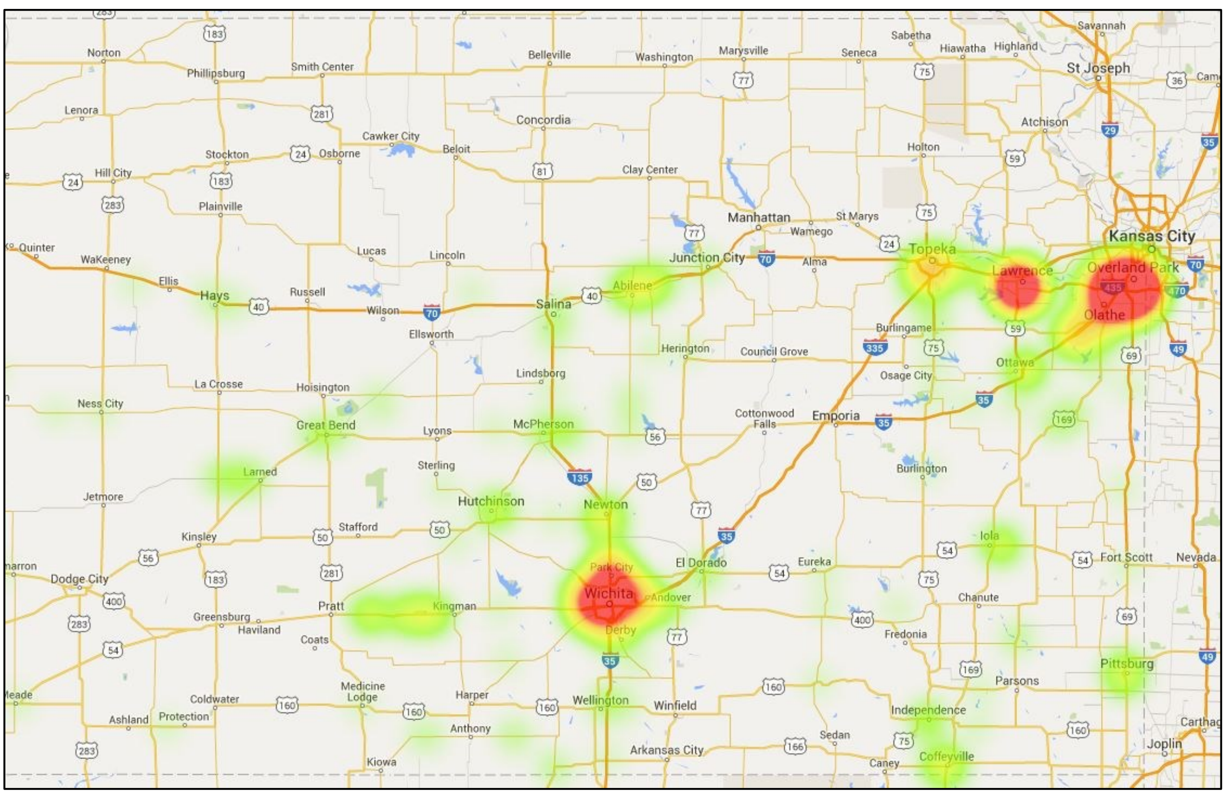

Figure 1.6 Heat map to illustrate the work zone crash densities in Kansas for year 2014

Note: Red shows higher densities with lighter and transparent colors for lower crash densities.

1.3 Problem statement

A large numbers of work zone crashes require necessary action from the responsible agencies reducing this risk. Since the number of work zone crashes in Kansas continues to increase, an investigation of the characteristics and contributing circumstances related to work zone crashes and associated injury severities must be conducted. There were no previous studies that identify such characteristics or to compare nighttime and daytime work zone safety in Kansas. However, advantages and disadvantages of nighttime work zones are available in the literature. Overall, compared to daytime work zones, nighttime highway construction does not result in significantly greater crash risks for motorists traveling through work zones *(9)*. In addition to evaluating the statistics to identify the characteristics associated with work zone crashes, this study fulfills an objective approach to determine whether nighttime work zones are safer than daytime work zones. Identifying these risk factors associated with crash severities and frequency is important in selecting countermeasures to improve work zone safety by reducing the number of work zone crashes and their severities.

1.4 Study objectives

Although crash data was analyzed to determine many aspects of work zone crashes, primary objectives of this study are as follows:

- To identify crash characteristics associated with work zone crash severity and to quantify the effect
- To identify work zone characteristics associated with work zone crash frequency and to quantify the effect
- To discuss recommendations to improve work zone safety in the form of general countermeasure ideas.

Chapter 2 - Literature Review

Although only a few studies have investigated work zone crashes, this chapter describes research approaches and findings from previous studies of work zone crashes. Aspects discussed include challenges for work zone safety improvements, work zone nighttime safety, and a review of light conditions for roadwork zones.

2.1 Characteristics of work zone crashes

Investigation of crash severity of nighttime work zone crashes and identification of characteristics and contributory causes for severe injuries are essential because they help determine countermeasures to prevent severe injuries and save lives.

Ullman et al. *(9)* found that daytime and nighttime distribution of all work zone traffic control types differ significantly for crash types. They identified characteristics of nighttime travel to be low traffic volumes, high percentages of truck traffic, increased operating speeds, reduced visibility, large numbers of drowsy and impaired drivers, and amplified driver expectancy regarding roadwork. Data sources for their study included the New York State Department of Transportation (NYSDOT) Work Zone Accident Database and the Highway Safety Information System (HSIS). Ullman et al. analyzed six years (2000–2005) of NYSDOT work zone data on freeways and expressways, considering variables such as time of crash, time when work activities were typically performed, facility type, work zone situation type at the time of the traffic crash (flagging, lane closure, etc.), crash severity, type of crash, type of worker construction crash if applicable (falls, equipment accident, etc.), and contribution factors to traffic crashes. Crash types considered in their study included rear-end, other multiple-vehicle, single-vehicle run-off-road crashes, intrusion effects (with workers, equipment, debris, etc.), non-intrusion impacts, and impact with truck-mounted attenuators (TMA). Rear-end crashes were the highest percentage of crash types for daytime and nighttime crashes *(9)*. However, they discovered that nighttime and daytime work zone crashes on freeways and expressways differ significantly and that, compared to daytime crashes, a substantially higher percentage of nighttime crashes occur during lane closures.

Bai and Li *(10)* analyzed work zone fatal crashes in Kansas from 1992 to 2004 and investigated dominant contributing factors of those fatal crashes. Crash data from KDOT and original crash records were analyzed. Six categories of information were extracted from crash reports: age and gender of the responsible driver, time information, climatic environment (light, weather, and road surface conditions), crash information (vehicle maneuver before crash, crash severity, etc.), road conditions (road class, number of lanes, speed limit, etc.), and contributory factors (driver factor, pedestrian factor, etc.). SAS® statistical software used for data analysis involved frequency analysis and Chi-square test in order to identify the most significant crash factors. Bai and Li also completed risk factor determination using the Geographic Information System (GIS). When multiple driver errors were involved in a motor vehicle crash, only the responsible driver was considered (fatal), and the crash case was compiled into one record. Pearson Chi-square test and likelihood ratio Chi-square test methods were used to identify possible combinations between dependent variables. Effectiveness of work zone traffic controls, such as flaggers and stop signs/signals, were quantified using the binary logistic regression technique. In addition, logistic regression models were constructed to estimate the conditional probability of truck involvement in fatal work zone crashes *(10)*. Bai and Li identified inattentive driving and misjudged/disregarded traffic controls as the two most frequent human errors for all age groups under all light conditions. In addition, they found that inclement weather conditions and unfavorable road features, such as interchange areas and ramps, do not significantly contribute to fatal work zone crashes. They also found that fatal work zone crashes caused by trucks occur more frequently during the day when light conditions are good, single-vehicle crashes are more likely to occur at night, and nighttime crashes occur primarily on highways with speed limits between 51 and 60 miles per hour *(10)*.

A characteristic identification study on Kansas work zones in 2009 was used to compare work zone crash statistics from five states, including Iowa, Kansas, Missouri, Nebraska, and Wisconsin *(11)*. It was discovered that work zone crashes involving trucks, light-duty vehicles following too close, non-deployment of airbags, sideswipe collision of same-direction vehicles, crashes occurring on roadways, posted speed limits, and crashes occurring while vehicles were making left or right turns in a work zone area have higher propensity for severe injuries *(11)*. Also, injury severity was found to be higher when the driver was male or middle-aged or when the crash occurred on the roadway.

2.2 Crash severity models for work zone crashes

According to Li and Bai *(10)*, data obtained from the Kansas crash database indicated the increased likelihood of fatalities in a severe crash in urban high-speed work zones compared to other work zones. A study by Qi et al. *(12)* on rear-end work zone crashes calibrated the ordered probit model using the stepwise elimination selection method. Rear-end crashes associated with alcohol, darkness, pedestrians, and roadway defects were found to be more severe; rear-end crashes associated with careless backing, stalled vehicles, slippery roadways, and misunderstanding of flagging signals were found to be less severe. Rear-end crashes that occurred in work zones on urban and rural minor roads were found to be more severe compared to rear-end crashes on other roadways. However, due to lack of information, Qi et al. *(12)* did not include driver age and sex, various vehicle characteristics, and light and weather conditions in their severity model. Weng and Meng *(13)* found that middle-aged drivers, who are going straight ahead in their vehicles with medium age and air-bag system, are prone to engage in risky behavior at low work zone speed limits. Katta *(14)* also found that surface condition is significantly associated with work zone severity and wet conditions were less severe than dry conditions.

2.2.1 Nighttime versus daytime crash severities

Many researchers have studied factors that affect crash severity in work zones, and some of the findings are included in this section. Using Kansas crash data from 1992 to 2004, Li and Bai discovered an increased likelihood of fatalities in severe crashes in urban high-speed work zones compared to other work zones *(10)*. Saito and Jin *(15)* conducted spatial and temporal analyses of work zone crashes, concluding that end sections of work zones are most prone to vehicle crashes. They also found that highest crash rates occur in daylight conditions with a "traffic lane marked" control type, no adverse weather conditions, and dry surface condition.

A primary resource for the current study was the National Cooperative Highway Research Program (NCHRP) Report 627 *(9)*. According to Chi-square test results of described in this report, daytime and nighttime distributions of injury severity of all work zone-related crashes for all work zone traffic control types differ significantly. However, this difference in distribution was not proven statistically significant for work zones in which lane closure was the traffic control type. In all cases, Property Damage Only (PDO) crashes were predominant *(9)*. NCHRP report 627 also concluded that when roadwork was active at night with a lane closure, severe crashes increased by 42.3%; that increase was 45.5% for daytime work zone activity. Results also showed that PDO work zone crashes increased by 74.8% at night and 80.8% during the day in work zones. However, work zones without lane closures experienced increased crash severity at night as compared to daytime crashes (41.4% and 17.4%).

Cheng et al. *(16)* identified unpredictable work zone boundaries such as moving lane closures, off-roadway (right), and flagging operation closures as the most dangerous factors impacting fatal and incapacitating crash severities. Garber and Zhao *(17)* used work zone crash data from 1996 through 1999 in Virginia to conclude that PDO is the predominant severity type of work zones crashes, followed by injury and fatal crashes. Bai and Li *(10)* arrived at identical conclusion. In addition, Garber and Zhao *(18)* determined that the activity area was the most prevalent crash location, the termination area was the safest, and most nighttime work zone crashes occurred in the activity area. However, they found no significant difference between the severity of nighttime and daytime work zone crashes. In contrast, some concluded that crash severity for nighttime work zones was more severe than daytime *(19, 20)*, but Nemeth and Migletz disagreed *(21)*. Rebholz et al. *(22)* concluded that work zone crashes during daylight were less severe than crashes occurring in darkness or under artificial illumination. Because this situation was found to be approximately the same for non-work zone crashes, they suggested that increased light may not be effectively increase work zone safety. Saito and Jin *(15)* analyzed work zone crash characteristics using two study sights; their findings on light conditions were inconsistent.

Bai and Li *(23)* asserted that complicated highway alignments (e.g., grades), unfavorable light conditions, truck involvement, alcohol impairment, and disregard of traffic control were potential factors that contribute to increased crash severities in work zones. They stated that head-on collisions could significantly increase crash severity and fatalities. They also found that fatal crashes were specifically related to high speeds, while injury crashes were specifically related to high-traffic volumes.

Descriptive data analysis by Swansen et al., *(24)* revealed that work zone crashes occurring at night were overrepresented in fatal and severe crashes. Therefore, they recommended safety improvements for nighttime conditions, such as better lighting delineation and increased visibility at nighttime work zones. Using Multi Logit Model analysis, they identified factors that likely contribute to various types of injury severities. They considered four categories of crash types: PDO, minor injury (MI), disabling injury (DI) and fatal. They found that straight roads are likely to cause higher crash severities compared to curved roads, and level and grade roads are more likely to cause higher crash severities compared to hillcrest roads. Compared to level roads, grade roads are more likely to cause crashes with increased severity. Snow on the road was more commonly associated with DI and fatal crashes than PDO crashes *(24)*.

Drivers between 35 and 44 years of age, and older than 64 years of age typically show high probabilities of causing fatal crashes *(25)*. Although a majority of older-driver-related crashes occur during the day *(26)*, a majority of severe work zone crashes that occur between 4:00 p.m. and 8:00 p.m. (afternoon peak hours) caused by drivers older than 64 years of age involve fatalities. Li and Bai suggested that poor light conditions, in which the street is dark without streetlights, could increase the probability of fatalities in a severe crash. They also stated that the number-of-lanes variable and the area-information variable (urban/rural) interactively affect the probability of resulting fatalities in severe crashes. These findings were derived from Kansas work zone crash data from 1998 to 2004 *(25)*.

2.2.2 Multi-vehicle versus single vehicle work zone crash severities

Using work zone crash data from 1992 to 2005, Saito and Jin *(15)* found that the highest crash rates in Utah occurred for multivehicle crashes. In their overview of work zone safety, Long, Smith, and Sun *(27)* identified fewer single-vehicle run-off-road crashes, a large percentage of rear-end crashes, and small percentages of head-on, angle, and sideswipe crashes. They also referred to multi-vehicle crashes as congestion-related crashes in their research. According to Bai et al. *(28)*, frequent involvement of heavy vehicles in crashes is a major safety concern in work zones. They determined that multi-vehicle crashes account for a majority of fatal (68%) and injury (70%) crashes in Kansas construction zones, with head-on crashes as the dominant collision pattern among multi-vehicle fatal crashes and rear-end collisions as the dominant pattern in injury crashes *(29)*. Harb et al. *(30)* used freeway crash data from Florida from 2002 to 2004 to develop three models in order to analyze single-vehicle and two-vehicle freeway work zone crashes. Results of this study showed increased likelihood of work zone crashes on straight, level roads compared to roads with geometries such as curves and grades. They also found that drivers are less likely to be involved in work zone crashes compared to non-work zone crashes during rainy weather, possibly because of increasingly cautious driving on upgrade/downgrade roads in the rain.

Garber and Zhao *(18)* asserted that some studies have overrepresented multi-vehicle crashes and other studies have overrepresented heavy vehicle crashes. They found that work zone crashes in Virginia from the years 1996 to 1999 comprised a higher proportion of multi-vehicle crashes than non-work zone crashes. Garber and Woo *(31)* concluded that work zones increase interactions between vehicles, resulting in a proportional increase of multi-vehicle crashes within work zones.

In a study by Ecceles et al.*(32)*, an increased percentage of single-vehicle crashes occurred on roads with high speed limits (55 mph or greater) and roads with extremely low speed limits (25 mph or less) compared to multi-vehicle crashes. Furthermore, they identified that multi-vehicle crashes comprised a larger proportion of work zone crashes than single-vehicle crashes on roads with moderate speed limits (30–50 mph).

Bai and Li *(10)* found that 68% of fatal work zone crashes in Kansas from 1992 to 2004 involved multiple vehicles; two-vehicle crashes were dominant, totaling 53%. According to their frequency analysis, most multi-vehicle crashes occurred in non-intersection areas. Head-on, angle-side impact, and rear-end were the three most frequent collision types, and 26% of total multi-vehicle fatal work zone crashes occurred in daytime non-peak hours (10:00 a.m. – 4:00 p.m.). Bai and Li *(23)* determined that complicated highway alignments, especially grades, unfavorable light conditions, involvement of trucks, alcohol impairment, and disregard of traffic control, are potential factors that contributed to increased crash severities in work zones. They stated that head-on collisions could significantly increase crash severity and cause fatalities. They also found that fatal crashes were related to high speeds and injury crashes were related to high traffic volumes. Using HSIS data from 2000, Khattak and Targa *(33)* studied injury severity and total harm in truck-involved work zone crashes in North Carolina. They found that multi-vehicle, truck-involved collisions caused the most injury and harm compared to other types of crashes. The study also found that such crashes were most injurious when posted speed limits were higher and when they occurred adjacent to the activity/work area rather than in the advance warning area.

2.3 Work zone crash frequency

Chen and Tarko *(16, 34)* studied work zone data from highway projects in Indiana with letting dates in 2009. Because data initially available for the study were limited, a questionnaire survey was administered to obtain additional data. Data available from INDOT included project location, total award, and type of construction. Data obtained from the questionnaires included project starting and ending date, cross-section geometry during the construction period, traffic management details, and whether or not police enforcement was present. Due to lack of traffic volume data during the construction period, traffic volumes for regular road conditions were used with adjustment for seasonal and monthly variations, thereby creating a two-level data structure with a high level that related to a work zone and a low level that related to a month. Crashes were assigned to the two-level work zone database. Negative binomial (NB) distribution was used with a Gamma-distributed dispersion term α to relax the equal mean and variance assumption in order to develop a crash frequency model. Although Poisson distribution is commonly used for crash frequency analysis, the over dispersion of data (variance greater than mean) prevented that distribution from being used for this study.

A random parameters model with monthly observations and a random effects model with monthly observations were estimated to compare the model fitting. The random parameters model was considered superior and consequently given more focus during this study. Variables considered in the models were divided into four groups: exposure variables, roadway characteristics prior to construction, work zone features, and temporal variable. Chen and Tarko *(16, 34)* discovered that crash frequency tends to increase with work zone length at a decreasing rate, and crash density in long (in length) work zones is lower than crash density in short (in length) work zones with identical traffic volume. In addition, (i) wide right-of-way and wide left shoulders experience less crashes in work zones, (ii) urban work zones have more crashes on average than rural work zones, (iii) work zones with a high fraction of parking lanes have significantly less crashes, (iv) freeway work zones with multiple lanes open to traffic during a construction period experience a significantly higher frequency of crashes, and (v) use of a detour sign significantly reduces crashes. Results from temporal variables demonstrated that crash frequency increases in summer and winter months *(16, 34)*.

Yang et al. *(35)* estimated a crash frequency model in order to identify risk factors in work zone safety evaluation. They also studied measurement errors in work zone length. Detailed work zone project data from New Jersey *(36)* were used to examine potential casual factors. Work zone data, crash data and traffic data were obtained as independent sources for this study.

Ozturk et al. *(37)* identified primary modeling methods for crash frequency analysis found in literature as Poisson regression, NB regression, Poisson lognormal, zero inflated Poisson and NB, Conway-Maxwell Poisson, gamma model, generalized additive model, and neural network models. Among these, the most common model is Poisson-gamma/NB regression model. Ozturk et al. *(37)* used an NB model in their study to model monthly crash counts in work zones. New Jersey crash records between 2001 and 2011, straight-line diagrams, and project files were the sources for their study. Results demonstrated that the presence of work zone during nighttime is safer compared to daytime, but a clear relationship between the presence of a work zone and injury crash frequency could not be identified. Work zone length and traffic exposure were shown to greatly affect crash frequency. State highways had increased injury severity compared to interstate highways. In addition, the number of intersections and ramps were positively correlated with crash frequency.

Yang et al. *(36)* attempted to quantify errors in work zone length using project files of 60 work zones from 2004 to 2010 that were obtained from the New Jersey Department of Transportation (NJDOT). Collected information included proposed work zone length, work zone mileposts, and number of lanes operated. Information regarding the time, date, and milepost of the crash, type of crash, road type, and posted speed were extracted from the NJDOT crash record database. Work zone length from the project file was considered and spatial-temporal distributions of work zone crash data were used in the study. Spatial-temporal distribution of work zone crashes was used to illustrate errors in work zone length. Model development of their study focused on quantifying measurement errors in work zone length using full Bayesian estimations rather than the NB model.

A study conducted by Ozturk et al. *(37)* listed parameters considered in work zone frequency models in the literature, such as work duration, annual average daily traffic (AADT), work zone length, number of operating lanes, work zone speed limit, project cost, lane closure, speed reduction, urban indicator, road system, weather, crash rate, intersection, ramp, daytime-nighttime, PDO-injury, control device, and type of work. They classified their data into four crash categories: daytime PDO, daytime injury, nighttime PDO, and nighttime injury. Directional AADT from New Jersey straight-line diagrams for a given milepost and time post of work zones was used to precisely identify traffic. AADT values were adjusted using NJDOT seasonal adjustment factors *(37)*.

The study by Ozturk et al. *(38)* did not include advance warning, transition, and termination areas in project mileposts. Therefore, temporal spatial plots were used to update mileposts in order to capture all work zone-related crashes. Figure 2.4 shows spatio-temporal distribution in the study by Ozturk et al. Using this graph, they concluded that work zone crashes are typically denser near ramps and intersections, but the presence of ramps and intersections was not significant (95% confidence interval) in their duration-based frequency model. Five out of 11 significant parameters in their model included ln(length), ln(traffic), operated lane, speed reduction, and ln(duration).

A study done by Hallmark et al. *(24)* was considered for this current study when planning to collect exposure data. Exposure is the time duration, roadway length, or amount of vehicle travel that a work zone affects. Exposure measurements include hours of lane closure/percentage of hours when one or more lanes are closed, vehicles per hour (vph) - number of vehicles passing in the work zone, vehicles per day (vpd), vehicle miles traveled (VMT) through the work zone, hours of work zone activity/average number of work activity hours per day, and hours of dedicated enforcement in work zone.

Qi et al. *(12)* developed a truncated count data model to identify influencing factors on rear-end crash frequency in work zones in New York. Truncated models were considered because New York Department of Transportation's (NYSDOT's) work zone crash database did not contain information regarding work zones in involving no crashes. Therefore, these models were calibrated based on counts greater than zero. They considered six work zone types not available with KCARS data: appurtenances, bridges, capacity, maintenance, pavement, and safety. Other variable categories included in the Poisson and NB models were control device, layout, lane closure, layout, work zone operation (moving), intersection location, facility type, and AADT. Of the two control methods investigated in their study, flagger-controlled work zones were associated with more rear-end crashes than to work zones controlled by arrow boards. Among the four lane-blockage situations, full-lane and partial-lane blockages were associated with more rear-end crashes than to shoulder-blocked and off-shoulder or median work areas. In addition, results showed that work zones on urban and rural principal arterials tend to have more rear-end crashes compared to other roadway classes. Increased AADT was also associated with increased rear-end crash frequency, however, work zones at intersections were not necessarily associated with more rear-end crashes compared to other locations *(12)*.

Chapter 3 - Methodology and Data

Detailed crash data for this study, comprised of all police-reported crashes in Kansas, were obtained from the KCARS. KDOT defines a work zone crashes as “An accident occurring within a construction zone or a road maintenance zone.” Most current fact sheets for Kansas crashes at the time of this study were for 2013. For this study, filtered work zone crash data from the KCARS database was compared to KDOT fact sheets to test whether or not the filtering formulae were correct. Results from that comparison confirmed that KDOT considers only work zones in the “*On Road*”. As the KCARS manual *(39)* defines it, On Road is the road where the unstabilized situation began. Three work zones types were identified in the *Kansas Motor Vehicle Accident Report*: construction zone, maintenance zone, and utility zone. However, KDOT did not consider utility zones or “*At Road*” work zones as work zones crashes as identified in the fact sheets. At Road is a reference road and the best reference road choice is the nearest cross road/street that has a road/street name *(39)*. Resources such as KANPLAN and KANROAD, are the GIS databases and internet web services provided by KDOT. Those resources are discussed in this chapter.

3.1 Characteristics of work zone crashes

Work zone crashes that occurred in Kansas from 2010 to 2013 were used this analysis. Yearly summaries of work zone crash statistics are included in Appendix A. Contingency table analysis was used to identify any association of crash attributes to nighttime and daytime work zone crashes and to compare work zone crashes and non-work zone crashes. Nighttime and daytime crashes and total crashes were checked individually for any association with the presence of work zones. Characteristics considered for the contingency table analysis included accident class, adverse weather conditions, work zone location, work zone category, road surface type, road surface condition, collision pattern with other vehicles, crash location, alcohol involvement, and crash severity. Because variables of work zone category and work zone location were introduced to KCARS in 2009, work zone data in 2009 or earlier could not be combined with more recent data for model development or other analyses in this study. Driver attributes such as driver age, gender, and use of safety equipment were also considered. All drivers involved in crashes were included in the study on characteristics of work zone crashes instead of only the "*at-fault*" driver. Those statistics are included in Appendix B. Only the "*at_fault*" driver was considered when developing contingency table analysis to determine the association of driver attributes to work zone crashes.

3.1.1 Contingency table analysis using Chi-square test

The Chi-square test is the underlying statistical method in contingency table analysis. This test is used to identify any association between (i) time of crash (nighttime/daytime) and characteristics of work zone crashes and (ii) number of vehicles involved in the crash (single vehicle/multiple vehicles) and characteristics of work zone crashes. The Chi-square test of independence is a common statistical method used to determine any significance association between two variables. Requirements to carry out a Chi-square test include:

- Presence of a representative sample
- Data in a frequency form (not in percentages or ratios)
- Independent individual observations
- Adequate sample size, so that the expected value in any category is greater than five
- Sum of observed frequencies equal to the sum of expected frequencies.

Let X and Y denote two categorical variables, with X having *i* number of levels and Y having *j* number of levels. The *ij* possible combinations of outcomes could be displayed in a table with *i* rows and *j* columns. Table 3.1 shows a contingency table of crash location (X) and time of the crash (Y). Table cells represent *ij* observed frequencies.

Table 3.1 Contingency table using crash location versus time of crash

X = Crash location	Y = Time of crash	
	Nighttime	Daytime
On road	m_{11}	m_{12}
Off road	m_{21}	m_{22}

Table 3.2 Method of calculating expected frequencies

X = Crash location	Y = Time of the crash	
	Nighttime	Daytime
On road	$m_{..} \times \frac{m_{1.}}{m_{..}} \times \frac{m_{.1}}{m_{..}}$	$m_{..} \times \frac{m_{1.}}{m_{..}} \times \frac{m_{.2}}{m_{..}}$
Off road	$m_{..} \times \frac{m_{2.}}{m_{..}} \times \frac{m_{.1}}{m_{..}}$	$m_{..} \times \frac{m_{2.}}{m_{..}} \times \frac{m_{.2}}{m_{..}}$

Table 3.2 contains observed frequencies. Expected frequency (F_e), or expected count, is the number of (statistically) expected counts in a cell if the variables are independent. After hypothesis development, expected values were calculated and the Chi-square was calculated. In this study, Minitab® *(40)* software package was used to calculate Chi-square values. The underlying equations are as follows:

$$Expected\ frequency = \frac{(Row\ i\ Total) \times (Column\ j\ Total)}{Sample\ size}$$ **Equation 3.1**

where $m_{i\,.} = \sum_{j=1}^{n} m_{ij}$; $m_{.\,j} = \sum_{j=1}^{n} m_{ji}$; $m_{.\,.} = \sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij}$.

Chi-Square (χ^2) statistic is calculated using the following equation:

$$(\chi^2) = \sum \frac{(F_o - F_e)^2}{F_e}$$ **Equation 3.2**

where F_o is the observed count of given type of crashes and F_e is the expected number of given type of crashes.

Null hypothesis, H_0: Two tested variables are independent of each other.
Alternative hypothesis, H_1: H_0 is not true.

$$\text{If Chi-Square } (\aleph^2)_{\text{critical}} \begin{cases} > \aleph^2_{\text{estimated}}; \text{ } H_0 \text{ is rejected;} \\ < \aleph^2_{\text{estimated}}; \text{ Not sufficient evidence to reject } H_0 \end{cases}$$

In this example, the null hypothesis asserts that crash location is similar for nighttime and daytime. Obtained *p*-value can also be used to determine the validity of the hypothesis. If the *p*-value is less than or equal to the chosen α level of significance, the conclusion can be made that the variables are associated with each other. If the *p*-value is greater than the chosen α level, the conclusion can be made that not enough evidence is available to conclude that the variables are associated. Confidence level was taken as 95% ($\alpha = 0.05$) for all analyses conducted in this study.

3.2 Work zone crash severity model

Severity models were used in this study to determine the relative effects of various environmental, vehicle, driver, and road factors, as well as contributory causes to crash severity of work zone crashes. Crash severity was the dependent variable in the models that investigated critical factors and contributory causes to increased injury severity. The dependent variable was crash severity in five discrete categories. The categorical nature of the dependent variable facilitated application of logit or probit analysis for the probability of severe crashes compared to less severe categories. Considering the frequent occurrence of models in literature and comparing model fitness values, the ordered probit model was used to model work zone crash severities. As the first step, a crash severity model was developed for all work zone crashes in Kansas from 2010 to 2013 and more models were developed for different categories of work zone crashes. Individual models were developed for daytime work zone crashes, single-vehicle work zone crashes, and multi-vehicle work zone crashes. Then the differences of significant variables and their parameter estimates were compared.

Crash severity in five levels was considered for injury severity models in this study. Those levels are: (i) fatal, (ii) incapacitating injury, (iii) non-incapacitating injury, (iv) possible injury, and (v) Property Damages Only (PDO). Two models were developed for single-vehicle crashes and multiple-vehicle crashes; the ordered probit model was considered for both in order to recognize the behavior of discrete or continuous predictor variables upon an ordered categorical dependent variable. Crash severity was the dependent variable for the models.

3.2.1 Pearson correlation factor

Although each crash record contained 45 variables, correlated variables could not be included in the model. Pearson correlation values were calculated to identify correlated variables. A sample set of correlation coefficients along with their *p*-values are included in Appendix C.

The Pearson correlation factor, which can range from -1 to +1, indicates two things related to the linear relationship between two variables:

- Strength – The larger the absolute value of the coefficient, the stronger the linear relationship between the variables. An absolute value of 1 indicates a perfect linear relationship, and a value of 0 indicates the absence of a linear relationship. Specific objectives and requirements determine whether an intermediate value is interpreted as a weak, moderate, or strong correlation.
- Direction - The sign of the coefficient indicates the direction of the relationship. If both variables tend to increase or decrease together, the coefficient is positive. If one variable tends to increase as the other decreases, the coefficient is negative.

Each correlation factor is coupled with a *p*-value. The *p*-value identifies if the correlation coefficient is significantly different from zero. A coefficient of zero indicates no linear relationship and other decision measures are as follows:

- If the *p*-value is less than or equal to the selected α -level (in this study, α = 0.05), the conclusion is made that the correlation is different from zero.
- If the *p*-value is greater than the selected α -level, no conclusion can be made that the correlation is different from zero.

3.2.2 Ordered probit model

Ordered response models can be derived from a measurement model in which a latent variable *y** ranging from -∞ to ∞ is mapped to an observed ordinal variable *y* (crash severity) for this study *(41)*. According to the measurement equation (Eq. 3.3), the variable *y* provides incomplete information about an underlying *y** which is unobservable.

$$y_i = m \text{ if } \tau_{m-1} \leq y_i^* < \tau_m \text{ for } m=1 \text{ to } J \qquad \textbf{Equation 3.3}$$

The τ's are called thresholds, or cutoff points, and extreme categories *1* and *J* are defined by open-ended intervals with $\tau_0 = -\infty$ and $\tau_J = \infty$. The observed variable *y* is related to *y** according to the following measurement model *(41)*.

$$y_i \begin{cases} 1 \rightarrow \text{No injury} & \text{if } \tau_0 = -\infty \leq y_i^* < \tau_1 \\ 2 \rightarrow \text{Possible injury} & \text{if } \tau_1 \leq y_i^* < \tau_2 \\ 3 \rightarrow \text{Non-incapacitating injury} & \text{if } \tau_2 \leq y_i^* < \tau_3 \\ 4 \rightarrow \text{Incapacitating injury} & \text{if } \tau_3 \leq y_i^* < \tau_4 \\ 5 \rightarrow \text{Fatal injury} & \text{if } \tau_4 \leq y_i^* < \tau_5 = \infty \end{cases}$$

All variables in the crash database were redefined to represent binary responses. Eq. 3.4 represents the structural form for the ordered probit model with binary response:

$$y_i^* = x_i \beta + \varepsilon_i \qquad \textbf{Equation 3.4}$$

where x_i is a row vector with a 1 in the first column for the intercept and the i^{th} observation for x_k in column $k+1$. β is a column vector of structural coefficients with the first element β_0 as the intercept and ε_i as the error term. SAS® 9.4 *(42)* was used to determine all the crash statistics including descriptive statistics and it was also used to develop all the crash severity models.

Log likelihood

Log likelihood is the log likelihood of a fitted model. The largest log likelihood is preferred when comparing two models. The likelihood ratio (LR) Chi-Square statistic can be calculated by

$$LR = -2\ Log\ L(null\ model) - 2\ Log\ L(fitted\ model) \qquad \textbf{Equation 3.5}$$

where *L* (null model) = the model intercept

Akaike Information Criterion

Akaike Information Criterion (AIC) is used to compare models from different samples or non-nested models. Ultimately, the model with the smallest AIC is considered best model. It is a measure of model fit calculated as

$$AIC = -2\ Log\ L + 2p \qquad \textbf{Equation 3.6}$$

where p is the number of parameters estimated in the model, including the intercept and _Sigma. $p = (k - 1) + s$, where k is the number of levels of the dependent variable and s is the number of predictors in the model.

Intercept, also called the constant, is the regression estimate when all predictor variables in the model are evaluated at 0. _Sigma is the estimated standard error of the regression, comparable to the root mean squared error obtained in an Ordinary Least-Squares (OLS) regression. _Sigma is indicative of the level of variance between the outcome and the predicted value. It approximates this quantity for truncated regression.

Schwarz Criterion

Schwarz Criterion (SC), or Bayesian Information Criterion (BIC), is defined as

$$SC = - 2 \text{ Log } L + p^{*}\log (\Sigma \text{ fi}) \quad \textbf{Equation 3.7}$$

where *fi* is the frequency value of the i^{th} observation, and *p* was defined previously. Similar to AIC, SC penalizes for the number of predictors in the model, and the smallest SC is most desirable.

3.2.3 Nighttime and daytime work zone crashes

In this study, nighttime and daytime crashes were defined using the lighting condition at the crash location; the KCARS database defines five light conditions. A daytime crash for this study occurred when the light condition was recorded as "Daylight" in the crash database. All other light conditions, including "Dawn," "Dusk," "Dark: Streetlights on," and "Dark: No street lights" were considered under nighttime conditions and this was also verified with the time of crashes. Daytime vs. nighttime comparison done by Ariditi et al. *(20)* also considered daylight condition to categorize daytime crashes and other light conditions, such as, dark, dark but lighted, dawn etc. as nighttime.

SAS® 9.4 *(42)* was used to run the ordered probit model. First, the pair of variables with the highest correlation was considered. The first model was run by including one of the two variables in the pair, and then the next model was run by replacing that variable with the other variable. For example, SRT_1 and SRT_2 made the pair of variables with the highest correlation (96%). SRT_1 was included in the first model; But in the second model, SRT_1 was eliminated and SRT_2 was included. If SRT_2 had been considered first, followed by SRT_1, the results would not have varied. Model fitness values of those two models were compared, and the variable to be eliminated was determined. Then the next pair of variables was selected and the procedure was repeated until all pairs with correlation higher than 50% were subjected to selection. Upon completion of each step, one variable was removed from the model. Only parameters with *p*-value less than or equal to 0.05 (α) were considered as significant at 95% confidence level. A level of 0.10 for α was also discussed.

3.2.4 Crash severity modeling for single-vehicle and multi-vehicle work zone crashes

Work zone crashes that involved only one vehicle was included in the single-vehicle crashes and work zone crashes involving more than one vehicle were included in the multi-vehicle work zone crashes. The model development procedure is the same for these two models but the variables considered in the models were different. Light condition was added as a variable in both single and multi-vehicle crash-severity models and this was not applicable for the previous two models. Multi-vehicle crash severity model futher differs from the single-vehicle crash severity model, as it includes collision pattern and the number of vehicles involved in the crash.

3.3 Work zone crash frequency model

While the first two sections of this chapter analyzed characteristics of work zone crashes, this section analyzes characteristics of work zones and how they relate to the number of work zone crashes.

3.3.1 Selection of work zones

Although there is a definition for a work zone, isolation of one work zone from another adjacent work zone in the field is difficult. Roadwork always involves a project number and one work zone can be related to several project numbers when they share the same or overlapping road segment and time frame. The work zones selected for this study involves only one project number for each work zone. Projects from years 2014 and 2013 were selected in order to give priority to most recent projects, thereby eliminating the risk of unavailable data. Most recent crash data available at the time of the study was for 2014. Data pertaining to roadworks on Kansas state roads, interstate roads and U.S. highways were the only available data from KDOT. Although one project can continue longer than one year in some cases, work zones related to one project can be isolated within a year as they discontinue the roadwork for many reasons or as they finish the work. Whenever any roadwork is active, KDOT publishes a public comment on various media (e.g. Newspapers, 511 services, etc.) for any active roadwork in order to inform road users of the road closures, detours, etc. These announcements are recorded as “Alerts” with a unique index for every alert. Alert records including public comments and other time and space information were obtained from KDOT during the first step of data collection for this study.

One alert record consisted of the tentative starting date of the roadwork, estimated finishing date, starting and ending log mileposts and their Location Referencing System (LRS) keys, and a descriptive public comment. A section of such a KDOT alert is included in Appendix E. One work zone consisted of multiple alerts records as KDOT kept updating the record as work progressed. However, public comments did not have a proper entry format; so, data extracted from those comments were very limited for some work zones.

Information included in the public comments included not more than the followings:

- If a lane closure is present – how many lanes will be functioning or how many lanes will be closed
- If a ramp closure is present
- Type of road work that will be carried out (e.g., road milling, overlay, application of pavement markings, etc.)
- Working hours – weekdays and/or occasional work on Saturdays, daylight hours, or when work is carried out overnight
- If detours are introduced
- TTC methods used – pilot car, flagger, advance warning boards, arrow boards, cones, or signage
- Speed restrictions and width restrictions for functioning lanes
- Possible delay time duration as an advisory

In order to develop a crash frequency model, a list containing more than 60 randomly selected work zones and their characteristics were gathered from all available data. Then they were plotted for time and space data in order to identify overlapping work zones. Such overlaps that linked to multiple project numbers were removed from further analysis to prevent confusion of characteristics. The updated list of work zones consisted of about 60 work zones.

Crash data were obtained from KCARS similar to the crash severity study. Every crash record consists of longitudes and latitudes, and all work zone crashes for years 2013 and 2014 were plotted in GIS. Crashes for each year were plotted separately for clarity. Work zones did not consist of coordinate information, so space boundaries for each work zone had to be identified manually on a log milepost markers layer published in KANPLAN *(43)* as a GIS web service. KANPLAN is the KDOT's GIS portal, where KDOT delivers transportation GIS services. Some of its map services include, WICHway, State system map, videolog lookup map, rural highway resolutions, KanRoad 511 map, and active work zone locations map.

Because time windows recognized from public comments were tentative dates or estimated dates, exact time durations of work had to be determined before counting the work zone crashes related to a particular work zone. Therefore, there was a need for more detailed data sources. Communications with KDOT engineers revealed that project engineers record day-to-day information about road work activities in project daily diaries, and those diary entries are saved in a Construction Management System (CMS). Upon request, CMS entries for 10 days per work zone and starting and ending entries were obtained from KDOT. The basis of selecting 10 days was the convenience of obtaining data from KDOT. Those entries were requested for the updated list of work zones. Some work zones were removed due to discrepancies in CMS entries and the public comments about their starting and ending dates. The final list of work zones consisted of 51 work zones as included in Appendix F.

When counting the number of crashes within a work zone, crash locations were plotted on top of state logmile markers in ArcGIS™ *(44)*. Work zone crashes on cross roads located within 0.5-mile radius were counted for the work zone when no other work zones were nearby, as shown in Figure 3.1. In such situations, the time frame was also matched with the work zone. An example of a work zone and its crashes are shown in Figure 3.2.

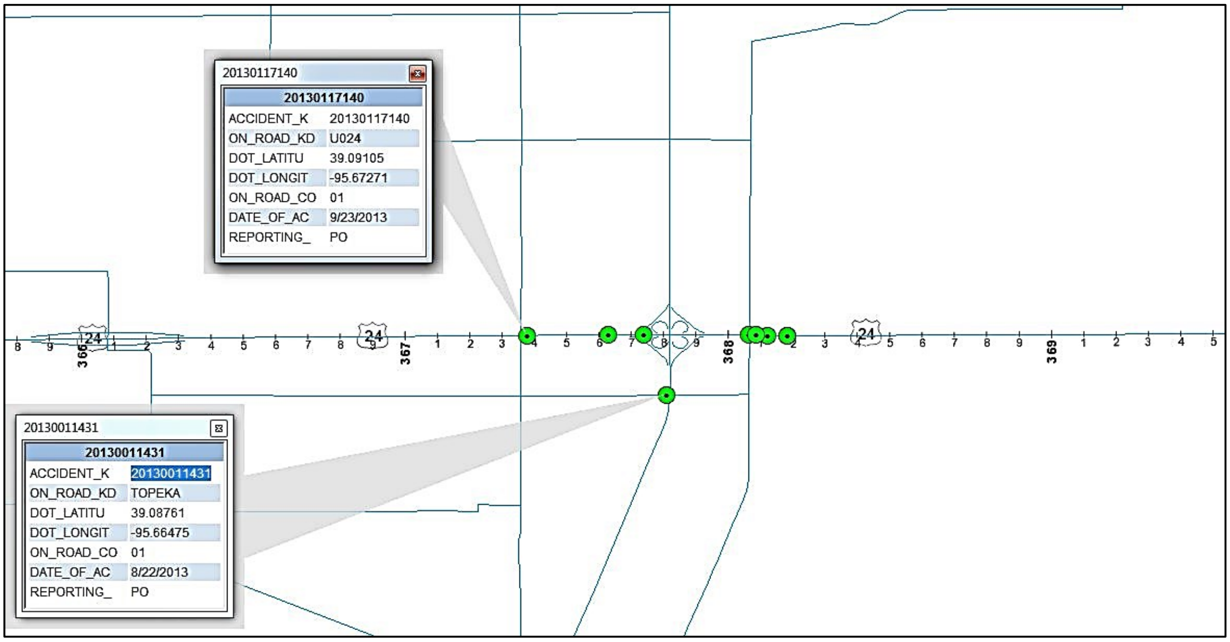

Figure 3.1 Counting surrounding crashes outside the exact work zone space

Figure 3.2 Work zone on I–70 – Project ID: KA-0732-01 (2014)

3.3.2 Selection and definitions of variables for the model

Selected variables and their definitions are shown in Table 3.3. Data for most of the variables were extracted from roadwork alerts and the corresopnding public comments. AADT, road class, and the urban/rural nature were determined using KANPLAN *(43)*. The AADT layer in KANPLAN was a raster map with AADT groups. A raster map is a spatial data model that defines space as an array of equally sized cells arranged in rows and columns *(45)*. A sample of the AADT layer is shown in Figure 3.3. Because some work zones fall on multiple AADT groups, so an approximate AADT common to a majority of crash locations was selected for the work zone. As shown in Figure 3.4, an AADT of 28,500 was selected for that work zone. Four models were developed by considering different forms of crash counts. Urban boundaries in KANPLAN as shown in Figure 3.5 were used to identify whether the work zone falls within urban city limits or rural areas. Functional classification was also identified using color coding used in KANPLAN (Figure 3.5).

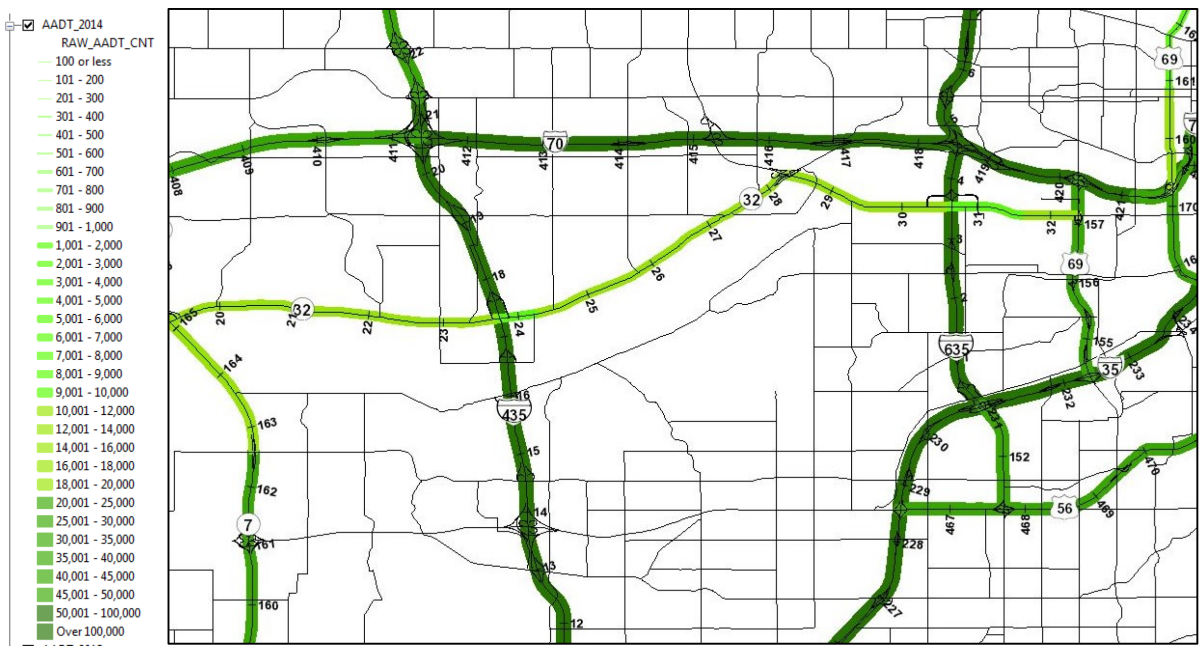

Figure 3.3 AADT raster from KANPLAN

Note: Green color gets darker with the increase of AADT

Table 3.3 Definitions of variables used in the frequency models

Variable Name	Definition	Values	
COUNT	Total number of crashes occurred related to the work zone	Response variable in Model1	
EPDO	Total number of EPDO crashes occurred related to the work zone	Response variable in Model2	
PDO	Total number of fatal and injury crashes related to the work zone	Response variable in Model3	
F_INJ	Total number of PDO crashes related to the work zone	Response variable in Model4	
AADT	Average annual daily traffic	Numerical variable	
MILES	Length of the work zone in miles	Numerical variable	
DAYS	Duration of the work zone in days	Numerical variable	
ADVMSGBO	Advance message boards used to warn drivers	1 = yes	0 = no
ARROWBO	Arrow boards used for traffic control	1 = yes	0 = no
CLASS	Interstate	1	Categorical variable
	Principal Arterial - Other Freeways and Expressways	2	
	Principal Arterial - Other	3	
	Minor Arterial	4	
	Major Collector	5	
DETOUR	Detour for road segment	1 = yes	0 = no
FLAGGER	Presence of a flagger to control traffic	1 = yes	0 = no
NIGHT	At least occasional nighttime work	1 = yes	0 = no
OLANEOFF	One lane closed due to the work zone	1 = yes	0 = no
OLANEON	Only one lane functioning through the work zone	1 = yes	0 = no
PILOTCAR	Operation of a pilot car in the work zone	1 = yes	0 = no
RAMPCLOSR	Ramp closure	1 = yes	0 = no
SPEED_R	Width reduction within the work zone	1 = yes	0 = no
TLANEOFF	Two lanes closed due to the work zone	1 = yes	0 = no
TLANEON	Two lanes functioning through the work zone	1 = yes	0 = no
URBAN	Work zone in an urban area	1 = yes	0 = no
WIDTH_R	Width restriction within the work zone,	1 = yes	0 = no
WKEND	At least occasional roadwork on weekends	1 = yes	0 = no

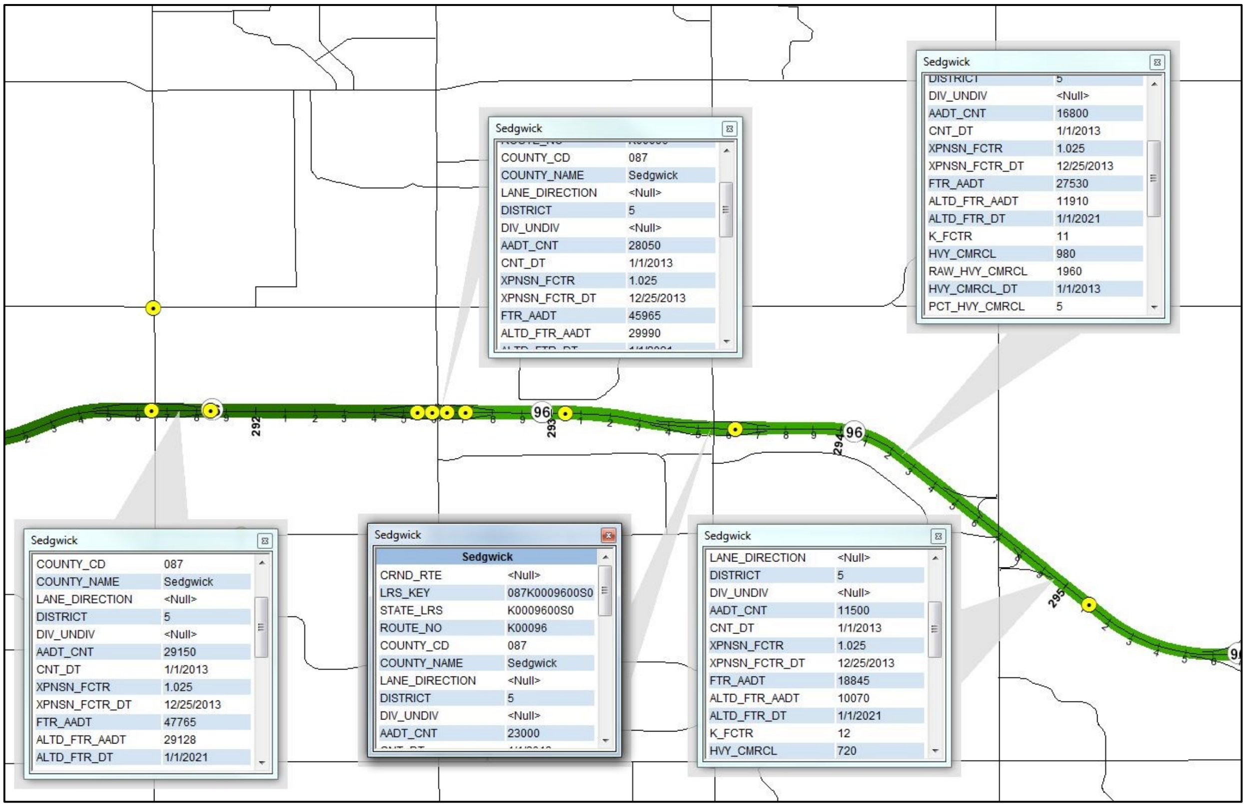

Figure 3.4 AADT groups within one work zone

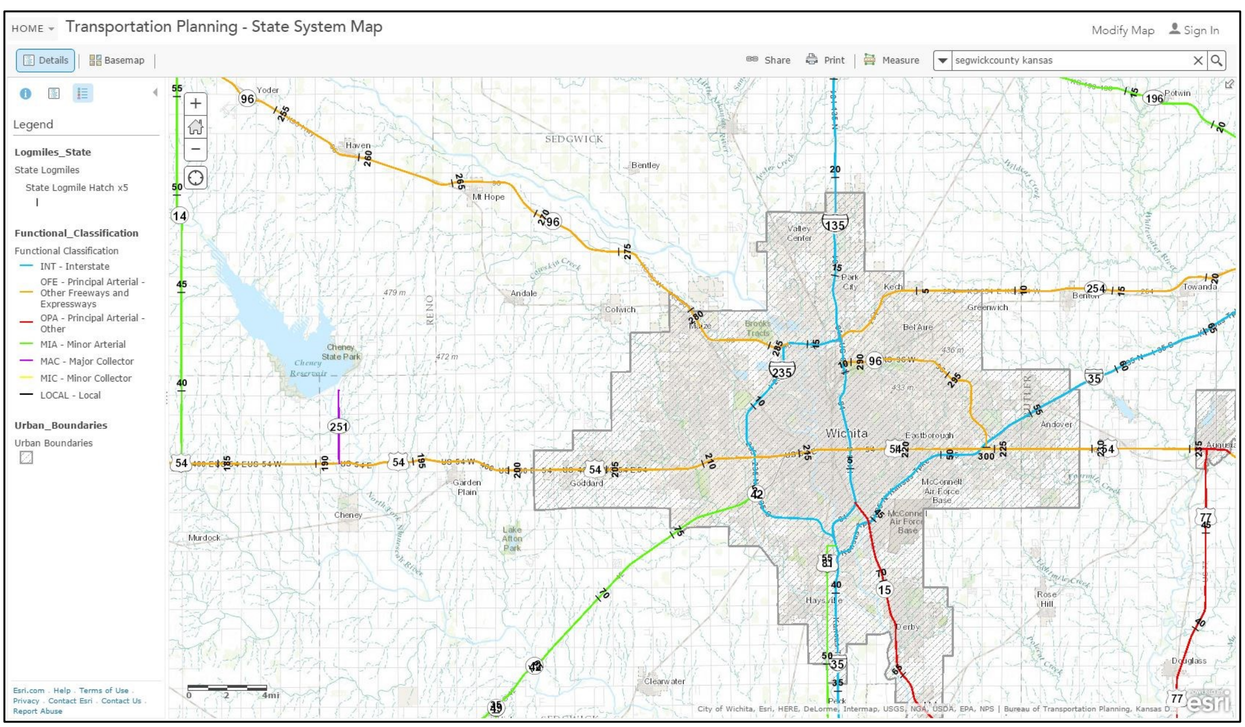

Figure 3.5 Identification of road class and urban boundaries

Crash frequency modeling for total work zone crash counts

Model 1 was developed with consideration of the total crash count related to each work zone. The count does not reflect the crash severities and treats fatal crashes, injury crashes and PDO crashes similarly.

Crash frequency modeling for work zone EPDO crashes

In the literature, work zones crash frequencies have been individually modelled for various severity types. When comparing the road safety at two or more locations, not only the number of total crashes, but also their severity should be taken in to consideration. Hence, considering the crashes in total was seemed insufficient. After modeling total crash counts, equivalent property damage only (EPDO) counts were calculated for each work zone in Model 2. For comparison purposes, the severity of an individual crash at a particular location can be expressed and summed in terms of EPDO crashes *(46)*. This approach assigns a weight to injury crashes and fatal crashes intended to represent their equivalent as a PDO crash.

$$\text{EPDO} = w_1(\text{Number of injury crashes}) + w_2(\text{Number of fatal crashes}) + \text{Number of PDO crashes}$$ **Equation 3.8**

$$w_1 = \text{weight factor to convert injury crashes to PDO crashes} = \frac{\text{average injury crash cost}}{\text{average PDO crash cost}}$$ **Equation 3.9**

$$w_2 = \text{weight factor to convert fatal crashes to PDO crashes} = \frac{\text{average fatal crash cost}}{\text{average PDO crash cost}}$$ **Equation 3.10**

For Kansas, both weight factors are considered as 15 .

Crash frequency modeling for work zone PDO crashes

PDO crashes were modeled in Model 3; response variables were the number of PDO crashes occurring in each work zone.

Crash frequency modeling for work zone fatal and injury crashes

Because there were only few fatal work zone crashes among the selected list of work zones, fatal and injury crashes were not modeled separately. The response variable for Model 4 was a combination of injury and fatal crashes.

3.3.3 Selection of a suitable statistical distribution to model the crash frequency

Historically, counting processes are frequently modeled in a Poisson regression by statistical theory *(47)*, although, zero-inflated negative binomial (ZINB) and zero-inflated Poisson (ZIP), truncated regression, generalized additive model, and multinomial logit regression have also been used to model the work zone crash frequencies in previous studies found in the literature. Decision on selecting the most fitting model was taken separately for each model as described in Chapter 4.

The Poisson regression model

For Poisson regression, the response variable is a count. The random component of the distribution can be given by,

$$E(y_i) = \mu_i$$

where

$E(y_i)$ = expected value of dependent variable y is in observation i, and

μ = mean rate or the expected count.

Poisson assumes that the variance equals the mean and that can be given by,

$$\mathrm{Var}\,(y_i) = E(y_i) = \mu_i$$

In the current study, y is the total crash count per work zone for Model 1, EPDO crash count per work zone for Model 2, PDO crash count per work zone for Model 3, and number of fatal and injury crashes combined for each work zone for Model 4.

More theoretical details about Poisson regression model can be found in many literature and a couple of them are cited here *(41, 48)*.

Let y_i represent the number of crashes at work zone i for a known length and duration, crash occurrence for work zone i is independent.

Probability that the number of work zone crashes equals to y_i for a particular value(s) of x_i is:

$$P(Y_i = y) = \frac{e^{-\mu_i} \mu_i^y}{y!}$$ **Equation 3.11**

The Poisson distribution or its generalization to the NB actually describes crash counts that occur in a fixed time span, for exposure. If this duration or length of time interval varies for individual samples (or for individual work zones, in this case), a standardization is required. In this study, the length of work zone (MILES) and duration of work zone (DAYS) are exposure variables and they are different for each work zone. Therefore, MILES and DAYS were incorporated into the model as natural log values, ln(MILES*DAYS). In addition, coefficient of ln(MILES*DAYS) should be kept as 1.0. When modeling in SAS statistical software, declaring the ln(MIlES*DAYS) variable as an OFFSET in GENMOD procedure, keeps its coefficient as 1.0. Due to large values of AADT, it was also expressed as ln(AADT).

Model fitness values for Poisson regression model

Pearson Chi-Square statistic: The Pearson chi-square is defined as the squared difference between the observed and predicted values divided by the variance of the predicted value summed over all observations in the model.

(http://www.ats.ucla.edu/stat/sas/output/sas_poisson_output.htm)

Log Likelihood: This is described under section 3.2.2

DF and Value: These are the degrees of freedom (DF) and the respective value for the criterion measures. The DF is equal to n-p, where n is the number of observation used and p is the number of parameters estimated.

Value/DF - This is the ratio of Value to DF. If the data set fits the Poisson regression, Value/DF should equal to 1.0.

Algorithm Converged: This is a note indicating that the algorithm for parameter estimates has converged, implying that a solution was found.

The negative binomial (NB) model

Unlike the Poisson regression model, NB allows for overdispersion *(48, 49)*, by adding a dispersion parameter α, expressed as,

$$E(y_i) = \mu_i = \exp(\beta x_i) \quad \textbf{Equation 3.12}$$

$$Var(y_i) = E(y_i)[1+ \alpha E(y_i)] \quad \textbf{Equation 3.13}$$

Based on the parameters, initial development of the Model 1 can be presented as Eq.3.12, but it should be noted that some of the variables were removed due to correlation before the final model was chosen.

$$\ln(COUNT) = \beta_0 + \ln(MILES*DAYS) + \beta_1[\ln(AADT) + \beta_2(PILOTCAR) + \beta(WIDTH\_R) + \beta_3(SPEED\_R) + \beta_4(NIGHT) + \beta_5(WKEND) + \beta_6(FLAGGER) + \beta_7(ARROWBO) + \beta_8(ADVMSGBO) + \beta_9(OLANEON) + \beta_{10}(TLANEON) + \beta_{11}(OLANEOFF) + \beta_{12}(TLANEOFF) + \beta_{13}(DETOUR) + \beta_{14}(RAMPCLOSR) + \beta_{15}(CLASS) + \beta_{16}(URBAN) \quad \textbf{Equation 3.14}$$

Chapter 4 - Results and Discussion

4.1 Characteristics of work zone crashes

Before carrying out contingency table analysis to identify crash characteristics associated with work zone crash frequency, descriptive statistics were used to observe any temporal variation. All values used in the graphs are included in Appendix A. The variables considered can be categorized as road related, vehicle related, user related, environment related, work zone related, and other. Observations made for each of these categories are described below.

- Roadway related
  - Geometry (grade and curvature): As shown in Figure 4.1, a majority of work zone crashes occurred on level and straight roads, with similar results for nighttime and daytime.
  - Number of lanes: Most work zone crashes occurred on four-lane highways regardless of the time of the day.
  - Road type: A majority of crashes occurred on freeways, followed by highways. (Note: Freeways and turnpikes have full access control, highways have no access control, and expressways have partial access control.)
  - Road surface type: Most work zones crashes occurred on asphalt surfaces.
  - Road surface condition: Most of the work zone crashes occurred on dry road surface.
- Vehicle related
  - Occupancy: As shown in Figure 4.2, in both nighttime and daytime, the at-fault driver was not alone and the vehicle occupancy was higher than one. The at-fault-driver was alone in only 10% of daytime work zone crashes.
  - Damage: Only the damages occurring to the at-fault vehicle were considered in this study. Most frequent damage type in daytime crashes was disabling damages and less severe functional damages for nighttime crashes.
  - Heavy vehicle involvement for both daytime and nighttime was less than 20%.

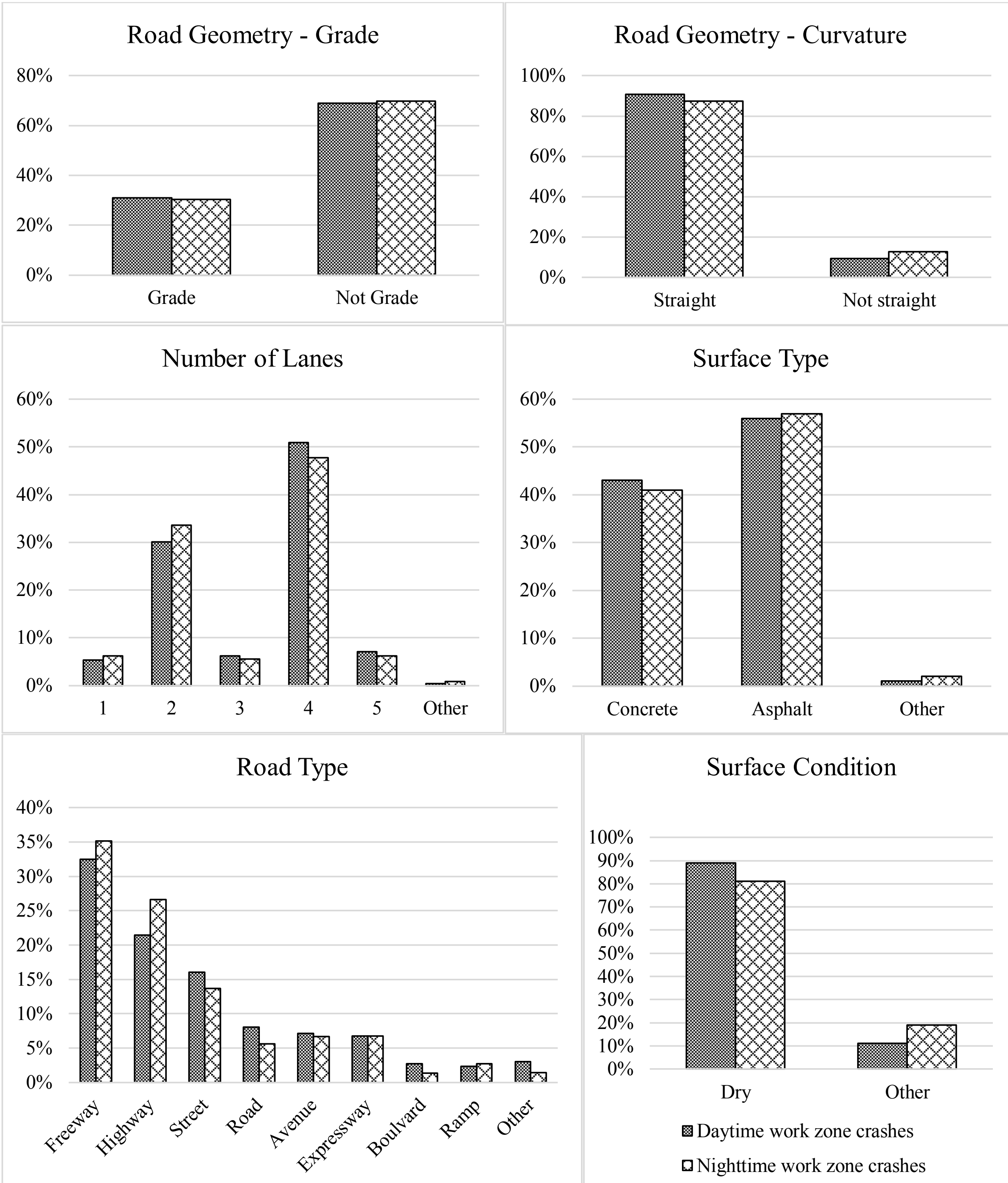

Figure 4.1 Roadway related work zone crash characteristics

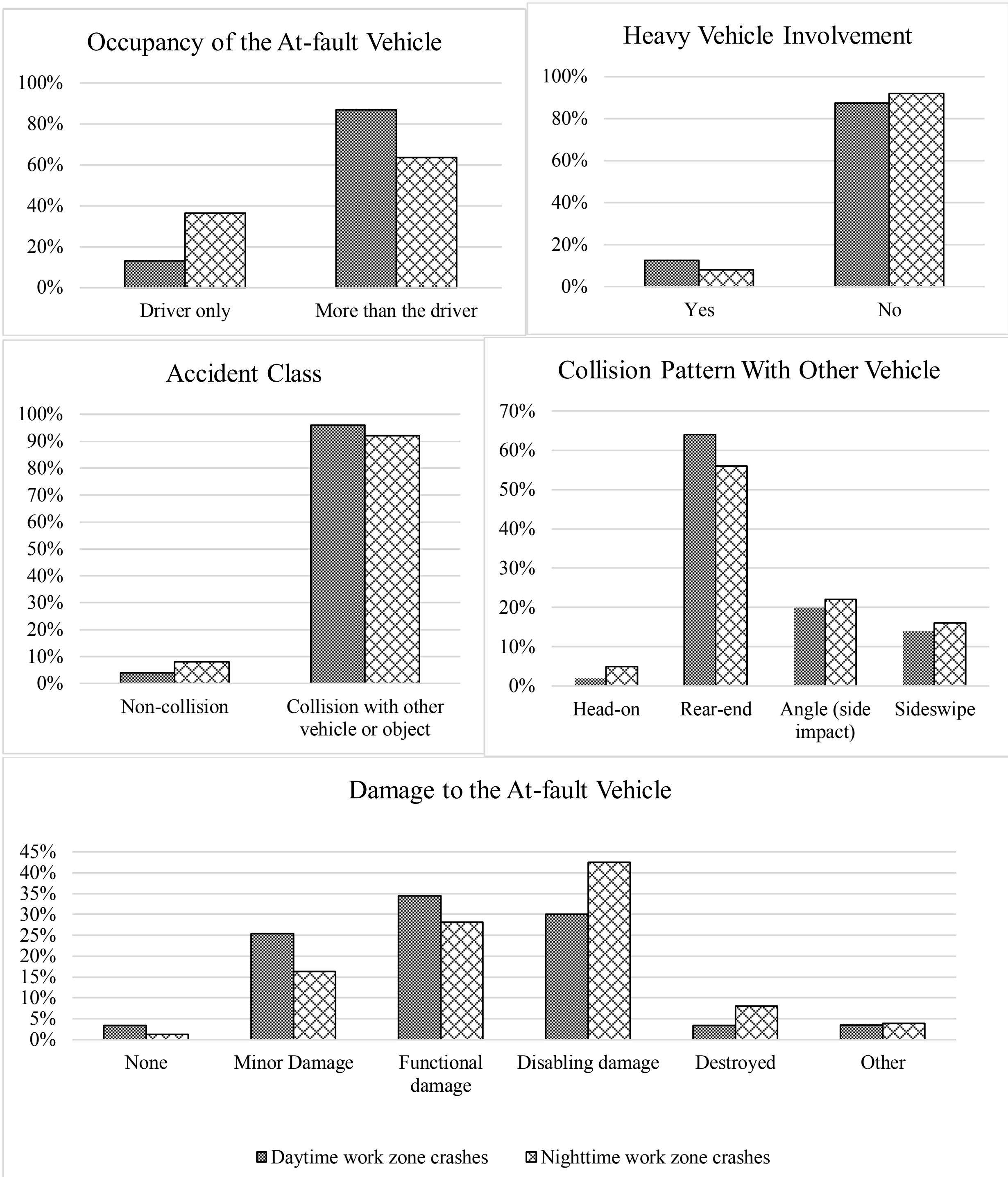

Figure 4.2 Vehicle related work zone crash characteristics, Kansas (2010– 2013)

- User related
  - Driver license compliance: As shown in Figure 4.3, almost all drivers carried a valid driver license.
  - Driver restriction compliance: These are also called graduated driver's licenses. Although approximately 40% restricted drivers accounted for daytime, only approximately 10% of at-fault drivers for nighttime crashes had restricted licenses.
  - Vehicle maneuvering immediately before the crash: Most at-fault drivers were going straight.
  - Driver's license state: Most drivers were local.
  - Ejected/ Trapped: Most drivers were extricated from inside the vehicle.
  - Alcohol involvement: Only 1% of daytime work zone crashes involved alcohol; 11% of nighttime work zone crashes involved alcohol.
  - Driver gender: Frequency of male drivers involved in work zone crashes was slightly higher for both day and night.
  - Safety equipment usage: Seat belt usage and helmet usage is evaluated under this variable and a majority of drivers involved in work zone crashes used safety equipment.
- Environment related
  - Adverse weather: A majority of crashes occurred with no adverse road conditions. Other main categories of adverse weather included rain and snow. Sun or sun glare, cloudy, hazy and breezy were not considered to be adverse under the "other" category.
- Work zone related
  - Work zone category: As shown in Figure 4.4, lane closure was the most frequent work zone category, followed by work on shoulder or median.
  - Work zone location: Most work zone crashes occurred within the activity area.

Figure 4.3 User related work zone crash characteristics, Kansas (2010– 2013)

Figure 4.4 Work zone related crash characteristics, Kansas (2010– 2013)

- Other
    - Accident class: Only the first harmful events were considered in this study. A majority of work zone crashes were collisions with another vehicle.
    - Collision pattern: Most (multi-vehicle) work zone crashes were rear-end crashes.
    - Temporal distribution: Hourly distribution of work zone crashes is illustrated in Figure 4.5 demonstrating that crash frequency has increased towards the end of the day until 7:00 p.m. and then it has decreased. Since most work zones studied in the frequency modeling carried out work during daylight hours, this temporal distribution can be explained by the presence of active roadwork.
    - Crash severity: A majority of work zone crashes were PDO crashes in daytime and nighttime.

The Chi-square test was carried out for all crash characteristics available in the crash database. If the expected value in a particular aspect was less than five, it was combined with another characteristic in order to obtain a meaningful value. All results shown properly combined various aspects.

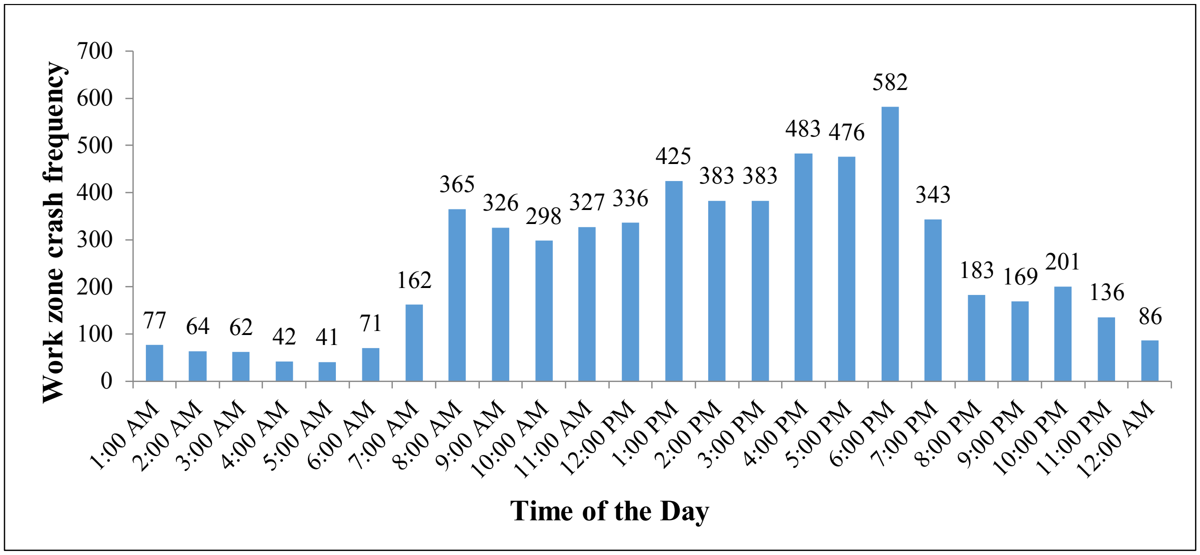

Figure 4.5 Hourly distribution of all work zone crashes in Kansas, 2010 to 2013

Although minimal difference of associated characteristics was observed between daytime and nighttime work zone crashes by descriptive analysis, contingency table analysis stated otherwise. Driver gender, grade of the road, and driver license state were the only variables that were not significantly associated with the time of the day. All other variables were found to be dependent. Results from the contingency table analysis are shown in Table 4.1. A similar analysis was carried out to compare between work zones and non-work zone crashes; results are shown in Table 4.2. According to Table 4.2, accident class is an independent variable between work zone and none work zone crashes during daytime and it is a dependent variable for nighttime crashes. When the total crashes were considered, accident class was an independent variable between work zone and non-work zone crashes. The other variables can be explained in a similar manner.

Table 4.1 Chi-square test results for nighttime versus daytime work zone crashes

Variable	Critical χ^2	Estimated χ^2	DF	*p*-value	Validity of null hypothesis
Accident class	3.841	50.527	1	0.000	Rejected*
Weather condition	3.414	53.642	3	0.000	Rejected
Work zone location	9.488	30.197	4	0.000	Rejected
Work zone category	9.488	52.432	4	0.000	Rejected
Surface type	5.991	8.310	2	0.016	Rejected
Surface condition	3.841	53.395	1	0.000	Rejected
Collision pattern	9.488	41.409	4	0.000	Rejected
Crash location	3.841	76.458	1	0.000	Rejected
Alcohol involvement	3.841	299.732	1	0.000	Rejected
Crash severity (F, I, PDO)	3.841	7.488	1	0.020	Rejected
Driver age	12.600	58.692	6	0.000	Rejected
Driver gender	3.841	1.690	1	0.194	Not enough evidence to reject
Occupancy	3.841	388.401	1	0.000	Rejected
Damage to the vehicle	9.488	171.110	4	0.000	Rejected
Road class (FWY or not)	15.500	46.888	8	0.000	Rejected
Grade of the road	3.841	0.272	1	0.602	Not enough evidence to reject
Geometry of the road	3.841	13.530	1	0.000	Rejected
Heavy vehicle involvement	3.841	19.920	1	0.000	Rejected
Number of lanes	9.488	9.950	4	0.041	Rejected
License compliance	11.100	29.510	5	0	Rejected
Local driver	3.841	2.730	1	0.099	Not enough evidence to reject
License restriction	3.841	645.700	1	0	Rejected
Vehicle maneuvering	16.900	47.970	9	0	Rejected
Use of safety equipment	3.841	63.280	1	0	Rejected
Driver ejection	3.414	35.420	3	0	Rejected

* Rejection of null hypothesis means the variable is significantly different for nighttime versus daytime crashes.

Table 4.2 Association of variables between work zone crashes and non-work zone crashes: Results from contingency table analysis

Variable	*p* values and interpretation					
	Daytime		Nighttime		Total crashes	
Accident class	0.379	Independent	0.000	Dependent	0.159	Independent
Weather	0.000	Dependent	0.251	Independent	0.000	Dependent
Surface type	0.000	Dependent	0.000	Dependent	0.000	Dependent
Surface condition	0.000	Dependent	0.268	Independent	0.000	Dependent
Collision pattern	0.000	Dependent	0.000	Dependent	0.000	Dependent
Alcohol involvement	0.424	Independent	0.150	Independent	0.050	Independent
3-level crash severity	0.000	Dependent	0.291	Independent	0.086	Independent
5-level crash severity	0.001	Dependent	0.035	Dependent	0.052	Independent
Driver age	0.000	Dependent	0.000	Dependent	0.000	Dependent
Driver gender	0.000	Dependent	0.244	Independent	0.000	Dependent
Safety equipment use	0.000	Dependent	0.011	Dependent	0.000	Dependent
Day of crash	0.000	Dependent	0.081	Independent	0.000	Dependent

Note: When p values < 0.05, null hypothesis is rejected at 95% confidence level and variable is considered dependent between the conditions, in this case work zone/non-work zone.

4.2 Crash severity models for work zone crashes

A total of 6,031 work zone crashes were used to develop injury severity models. Figure 4.6 shows summary statistics for work zone crashes from 2010 to 2013.

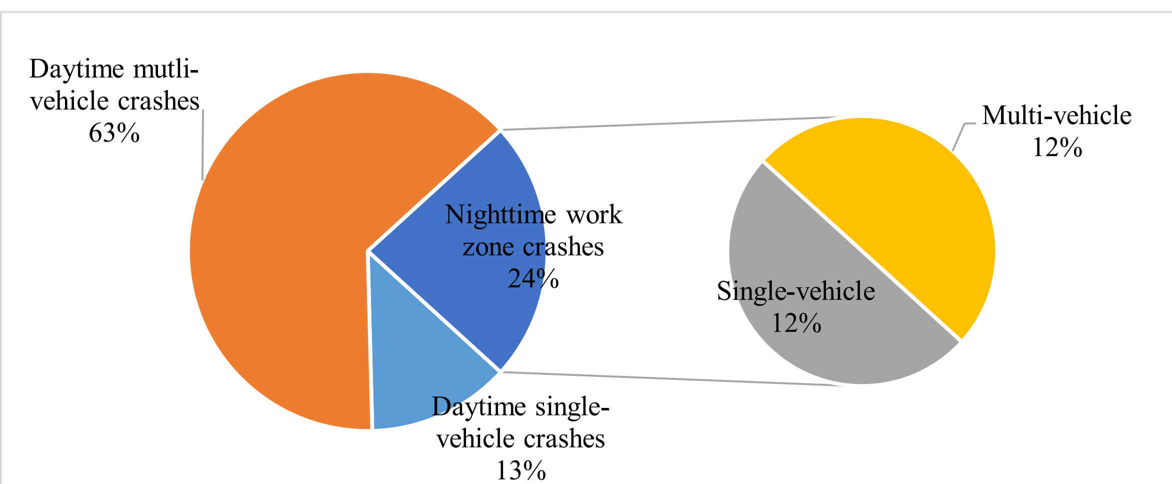

Figure 4.6 Summary of work zone crashes

Although a majority of daytime work zone crashes consisted of multiple-vehicle crashes, the distribution of multiple-vehicle crashes and single-vehicle crashes was equal among nighttime work zone crashes. All variables used in the models are shown in Table 4.4 with their descriptions.

4.2.1 Crash severity modeling for work zone crashes

A total of 5,923 work zone crashes were used to develop the work zone crash frequency model with 33 variables. Correlation between the selected variables are shown in Table 4.3 . Even though nine sets of correlated variables are shown in Table 4.3, only six variables were removed, as the log likelihood, AIC and BIC values remained the same when testing for the 7th set. This means, that removing 'ACL_1' or 'ACl_2' did not make any difference to the model fitness and hence, it was not necessary to remove either of the variables. Finally, out of the 33 variables, 18 variables were found to be significantly associated with the crash severity at 95% confidence level and three more variables were found significant at 90% confidence level.

Table 4.3 Pearson correlation factors for work zone crash severity model

	Variable 1	Variable 2	Pearson Correlation (%)
1	SRT_1	SRT_2	97.15
2	SINGL	ALONE	81.06
3	SR_DRY	WE_1	78.47
4	AGE_1	AGE_2	75.29
5	DAMG_2	DAMG_3	57.95
6	SPDL	FWY	53.06
7	ACL_1	ACL_2	53.00
8	WZ_3	WZ_4	52.91
9	WZC_1	WZC_3	52.17

Table 4.4 Variable description for injury severity models

Variable type	*Variable label*	*Definition*	Mean values of the data				
			Total WZ	**Single -veh.**	**Multi -veh.**	**Night**	**Day**
Crash location	ACL_1	If crash occurred in non-intersection area = 1, otherwise = 0	0.49	0.55	0.46	0.53	0.47
	ACL_2	If crash occurred at an intersection or intersection-related area = 1, otherwise = 0	0.23	0.07	0.28	0.16	0.25
	ACL_3	If crash occurred in an interchange area = 1, otherwise = 0	0.19	0.14	0.21	0.18	0.19
	ACL_4	If crash occurred "on roadway" = 1, otherwise = 0	0.94	0.78	0.99	0.89	0.96
Driver age	AGE_1	If age is between 15 - 25 years = 1, otherwise = 0	0.31	0.25	0.33	0.31	0.31
	AGE_2	If age is between 26 - 65 years = 1, otherwise = 0	0.56	0.63	0.54	0.58	0.55
Alcohol flag	AL_FLG	If alcohol flag is one = 1, otherwise = 0			0.02		
Occupancy	ALONE	If at-fault driver was alone = 1, otherwise = 0	0.18	0.74	0.01	0.37	0.13
Collision pattern	COL_1	If crash was a rear-end collision = 1, otherwise = 0			0.61		
	COL_2	If crash was an angle-side impact = 1, otherwise = 0			0.20		
	COL_3	If crash was a sideswipe = 1, otherwise = 0			0.14		
Damage to the vehicle	DAMG_1	If vehicle damage was minor = 1, otherwise = 0	0.19	0.16	0.20	0.15	0.21
	DAMG_2	If vehicle damage was functional = 1, otherwise = 0	0.35	0.22	0.39	0.28	0.37
	DAMG_3	If vehicle damage was disabling = 1, otherwise = 0	0.38	0.46	0.36	0.47	0.36

Table 4.4 (Contd.) Variable description for injury severity models

Variable type	*Variable label*	*Definition*	Mean values of the data				
			Total WZ	**Single -veh.**	**Multi -veh.**	**Night**	**Day**
Road class	FWY	If crash occurred in a freeway = 1, otherwise = 0	0.29	0.29	0.30	0.32	0.29
Driver gender	GEND	If male = 1, otherwise = 0	0.58	0.62	0.57	0.58	0.59
Geometry of the road	GRADE	If road is on hillcrest or grade = 1, otherwise = 0	0.31	0.32	0.31	0.30	0.31
	STRGT	If road is straight = 1, otherwise = 0	0.90	0.83	0.92	0.88	0.91
Heavy vehicle involvement	HEAVY	If a heavy vehicle was involved = 1, otherwise = 0	0.11	0.10	0.12	0.08	0.12
Number of lanes	LANE_4	If crash occurred on a four-lane highway = 1, otherwise = 0	0.50	0.40	0.54	0.48	0.51
License compliance	LI_COM	If license was valid = 1, otherwise = 0	0.89	0.87	0.90	0.84	0.91
Local driver	LI_KS	If license was issued in Kansas = 1, otherwise = 0	0.76	0.75	0.77	0.73	0.78
License plate restriction	LI_RST	If license has a restriction flag = 1, otherwise = 0	0.33	0.31	0.33	0.31	0.34
Light condition	LIGHT	If crash occurred in daylight = 1, otherwise = 0	0.77	0.52	0.84		
Vehicle maneuvering before the crash	MANU_1	If the vehicle was going straight= 1, otherwise = 0	0.60	0.69	0.57	0.65	0.58
Alcohol involvement	NO_ALC	If no alcohol involvement = 1, otherwise = 0	0.97	0.92	0.98	0.89	0.99
	DU_FLG	If DUI flag is one = 1, otherwise = 0			0.00		
Use of safety equipment	REST	If safety equipment was used = 1, otherwise = 0	0.90	0.87	0.91	0.84	0.92
	ABAG	If airbag was deployed = 1, otherwise = 0	0.06	0.08	0.05	0.08	0.05
Posted speed limit	SPDL	Posted speed limit in mi/h (explanatory variable)	48.34	51.29	47.40	50.27	47.75

Table 4.4 (Contd.) Variable description for injury severity models

Variable type	*Variable label*	*Definition*	Mean values of the data				
			Total WZ	**Single-veh.**	**Multi-veh.**	**Night**	**Day**
Number of vehicles involved	SINGL	If a single-vehicle crash = 1, otherwise = 0	0.24			0.50	0.17
	VEH_2	If only two vehicles were involved = 1, otherwise = 0			0.84		
Road surface condition	SR_DRY	If road surface was dry = 1, otherwise = 0	0.86	0.78	0.89	0.81	0.88
Road surface type	SRT_1	If road surface was concrete =1 , otherwise = 0	0.43	0.37	0.45	0.41	0.43
	SRT_2	If road surface was asphalt = 1,otherwise = 0	0.56	0.59	0.55	0.56	0.56
Driver ejection	TRAPD	If at-fault driver was not ejected = 1, otherwise = 0	0.97	0.94	0.98	0.94	0.97
Adverse weather condition	WE_1	If crash occurred in no adverse weather condition = 1, otherwise = 0	0.89	0.83	0.92	0.85	0.91
Day of the week	WEEK	If crash occurred on a weekday = 1, otherwise = 0	0.81	0.72	0.83	0.72	0.83
Work zone location	WZ_2	If crash occurred in the advance warning area = 1, otherwise = 0	0.13	0.11	0.14	0.11	0.14
	WZ_3	If crash occurred in the transition area = 1, otherwise = 0	0.17	0.13	0.18	0.16	0.17
	WZ_4	If crash occurred in the activity area = 1, otherwise = 0	0.58	0.63	0.57	0.61	0.58
	WZ_5	If crash occurred in the termination area = 1, otherwise = 0	0.04	0.05	0.04	0.05	0.04
Work zone category	WZC_1	If lane closure = 1, otherwise = 0	0.49	0.35	0.54	0.44	0.51
	WZC_2	If lane shift or crossover = 1, otherwise = 0	0.16	0.18	0.15	0.18	0.15
	WZC_3	If work was on shoulder or median = 1, otherwise = 0	0.22	0.25	0.21	0.22	0.22

Table 4.5 Model parameter estimates for crash severity – All work zone crashes

Model Fit Summary			
Number of Observations			5,923
Log Likelihood			-6,345
Maximum Absolute Gradient			2.4218E-10
AIC			12,734
Schwarz Criterion			12,881
Parameter Estimates			
Parameter	Description	Estimate	Approx. Pr > |t|
Intercept		2.4385	<.0001
ABAG	Airbag was deployed	0.4175	<.0001
DAMG_1	Vehicle damage was minor	-0.3573	<.0001
DAMG_2	Vehicle damage was functional	-0.3955	<.0001
MANU_1	Vehicle was traveling straight before the crash	0.0777	<.0001
SINGL	Was a single-vehicle crash	-0.0982	<.0001
TRAPD	At-fault driver was not ejected	-0.7559	<.0001
NO_ALC	No alcohol was involved	-0.1954	0.0002
REST	Safety equipment were used	-0.1205	0.0007
SPDL	Posted speed limit (explanatory variable)	0.0024	0.0011
LIGHT	Crash occurred in daylight	0.0728	0.0020
LI_COM	Driver carried a valid driver's license	0.0996	0.0026
ACL_3	Crash occurred in an interchange area	-0.0801	0.0059
ACL_1	Crash occurred in non-intersection area	-0.0550	0.0136
GEND	Driver was male	0.0425	0.0239
AGE_2	Driver age was between 26 - 65 years	0.0415	0.0286
WZC_3	Work zone category: work on shoulder or median	-0.0697	0.0333
STRGT	Road was straight	-0.0669	0.0334
WZC_1	*Work zone category: lane closure*	*-0.0563*	*0.0561*
LANE_4	*Crash occurred on a four-lane highway*	*-0.0314*	*0.0945*
WZC_2	*Work zone category: lane shift or crossover*	*-0.0578*	*0.0975*
_Sigma		0.7063	<.0001

Crash location

Work zone crashes occurred in non-intersection areas and interchange areas were found to be significant in the model at 95% confidence level and both were related with decreased crash severity.

Driver age

At-fault-drivers of age between 26 and 65 years were found significantly associated with increased work zone crash severities. However, Weng and Meng *(13)* found that young drivers (age ≤ 20 years-old) tend to exhibit more risky driving behavior than the middle-aged drivers who are from 20 to 65 year-old, whereas Abdel-Aty *(50)* found otherwise. According to Traffic Tec, *(51)* an induced exposure analysis could reveal that the crash involvement rate (CIR) in general (without consideration of work zone) is higher with drivers younger than 20 and older than 69. That behavior seems to reflect similarly in the current study as well.

Driver gender

Male drivers were significantly associated with increased work zone crash severities. This finding agreed with the results of a study carried out by Abdel-Aty *(50)*.

Driver ejection

Driver ejection was found significant in the model and crashes where the driver was not ejected were associated with reduced crash severities.

Road geometry

When road geometry was considered, grade of the road was not found to be significant but straight roads were significantly associated with decreased crash severities and this finding agreed with some previous studies *(30, 52)* as well. Another study *(14)* did not found straight or curve geometries of roads as significant variables.

Damage to the vehicle

A minor and functional damage to the vehicle with the at-fault-driver was found to be significantly associated with reduced crash severities compared to disabling damages or destroyed vehicles.

Number of lanes

Number of lanes was found to be significantly associated with reduced work zone crash severity at 90% confidence level. According to Weng and Meng *(13)*, under dark or bad weather conditions, most risky driving maneuvers occur on single-lane roads, whereas drivers are more likely to engage risky driving on multi-lane roads under daylight conditions.

License compliance

Eighty nine percent of the at-fault drivers who were involved with work zone crashes, carried a valid driver's license and that was found to be significantly associated with increased work zone crash severity. This means that, work zone crashes are not necessarily caused by drivers with suspended, revoked, expired, or cancelled licenses.

Light condition

Light condition at the crash was found significantly associated with the crash severity and daytime work zone crashes were found significantly associated with increased crash severities.

Vehicle maneuvering before the crash

Vehicles going straight immediately before the crash was found significantly associated with increased work zone crash severities compared to other vehicles maneuvering actions. A previous study has found that, when compared to going straight and backing, changing lanes, overtaking, and entering, leaving traffic lane had lower odds of higher severity, while turning left, making U-turn had higher odds *(14)*.

Alcohol involvement

Only 3% of the work zone crashes were alcohol involved crashes and those were significantly associated with reduced work zone crash severities. This finding matches with previous literature *(50)*.

Use of safety equipment

Seat belt and helmet usage was found significantly associated with reduced crash severities and air bag deployment was significantly associated with increased crash severities. This finding match with previous literature *(50)*.

Posted speed limit

Increase of posted speed limit was found to be significantly associated with increased crash severities at 95% confidence level and this finding agreed with many previous studies. Meng et al. *(53)* found that, there will be a 62% decrease of individual fatality risk and 44% reduction in individual injury risk, if the mean travel speed is slowed down by 20%. This shows the importance of speed reduction in work zones to reduce crash severity. Also, Elghamrawy et al. *(54)* found that more than 50% of fatal work zone crashes in their study had occurred in roads that had a speed limit higher of 50 mph or higher.

Number of vehicles involved

Single vehicle involvement was found to be significantly associated with reduced crash severity. This result agreed with a previous a study and they added that multi-vehicle crashes were more likely to have fatal/injury crash severity compared to single-vehicle crashes *(14)*.

Road surface type

Road surface type was not found to be significant in the severity model. However, Elghamrawy et al. *(54)* found that as a significant factor and majority of the work zone crashes in their study has occurred in Portland Cement Concrete (PCC) surfaces.

Adverse weather condition

There were no adverse weather conditions during 89% of the work zone crashes and this was not found significant in the model. Although Li and Bai *(52)* found similar results to the current study, a different result was found by Katta *(14)* when they found that poor weather conditions have higher odds of increased crash severities compared to good conditions.

Day of the week

The significance between weekdays were not tested and only the difference between weekdays and weekend was tested in the model. Compared to weekends, work zone crashes occurring in weekdays was not found significantly associated with the crash severity. A previous study found that Tuesday had less effect on severity compared to Monday, and work zone crashes on Thursday were of high severity compared to Monday *(14)*. Remaining days were not significant compared to Monday.

Work zone characteristics

Crash location within a work zone was not found to be significantly associated with crash severity. However, Katta *(14)* found that, advance warning area, transition area and activity area had higher crash severity, compared to crashes before the first warning sign. Work zone category was found to be significantly associated with reduced crash severities and it was not different between categories. Lane closure, lane shift or crossover, and work on shoulders or median were significantly associated with reduced crash severities. According to Katta *(14)*, compared to lane closure, other work zone categories had lower odds of higher crash severity.

4.2.2 Crash severity modeling for nighttime and daytime work zone crashes

The crash severity model for nighttime work zone crashes contained 31 variables after eliminating variables that had Pearson correlation coefficients higher than 0.5. Correlations between the variables are presented in Table 4.6. Backward elimination method was carried out to remove all insignificant variables from the model and parameter estimates for the final model are shown in Table 4.7. In the final model, 10 variables were significant at 95% confidence level; two additional variables became significant when 90% confidence level was considered. Six variables were associated with increased crash severities when considering all 15 variables.

Table 4.6 Pearson correlation factors for nighttime work zone crash severity model

	Variable 1	Variable 2	Pearson Correlation (%)
1	SRT_1	SRT_2	95.5
2	SR_DRY	WE_1	80.8
3	AGE_1	AGE_2	78.4
4	SINGL	ALONE	74.9
5	DAMG_2	DAMG_3	58.2
6	WZ_3	WZ_4	55.2
7	ACL_1	ACL_3	50.7

When crash location within work zones was considered, crashes occurring within advance warning areas or activity areas were related to increased crash severity. The reason for this may be the higher length portions compared to the transition and termination areas. At-fault-driver being a male driver, carrying a valid driver's license, air bag deployment, asphalt road surface, were other characteristics that found to be significantly related with increased work zone crashes at night. Minor or functional damage to the vehicle with the at-fault-driver, no alcohol involvement, use of safety equipment, involvement of only one vehicle, and trapped driver were the characteristics that were significantly associated with reduced work zone crash severities at night.

Table 4.7 Ordered probit model estimates for nighttime work zone crashes

Model Fit Summary			
Number of observations			1385
Log likelihood			-1567
Maximum absolute gradient			4.53E-12
AIC			3163
Schwarz Criterion			3236
Parameter Estimates			
Parameter	Description	Estimate	Approx. Pr > |t|
Intercept		2.3847	<.0001
ABAG	Airbag was deployed	0.3101	<.0001
DAMG_1	Vehicle damage was minor	-0.3192	<.0001
DAMG_2	Vehicle damage was functional	-0.3598	<.0001
TRAPD	At-fault driver was not ejected	-0.9054	<.0001
NO_ALC	No alcohol was involved	-0.2270	0.0008
LI_COM	Driver carried a valid driver's license	0.1817	0.0040
WZ_4	Crash occurred in the activity area	0.1175	0.0110
GEND	Driver was male	0.1024	0.0135
SRT_2	Road surface was asphalt	0.0908	0.0277
SINGL	Was a single-vehicle crash	-0.0906	0.0297
WZ_2	*Crash occurred in the advance warning area*	*0.1392*	*0.0564*
REST	*Safety equipment were used*	*-0.1200*	*0.0729*
_Sigma		0.7503	<.0001

Note: Variables in *italic* are significant at 90% confidence level.

The crash severity model for daytime work zone crashes contained 29 variables after eliminating variables that had correlation coefficients greater than 50%. Out of 29 variables, 10 variables were significant at 95% confidence level. Two more variables became significant when 90% confidence level was considered. Detected correlations between the variables are presented in Table 4.8. Table 4.9 interprets the significant variables for the daytime crash severity model.

Table 4.8 Pearson correlation factors for daytime work zone crash severity model

	Variable 1	Variable 2	Pearson Correlation (%)
1	SRT_1	SRT_2	97.7
2	SINGL	ALONE	82.4
3	SR_DRY	WE_1	77.1
4	AGE_1	AGE_2	74.4
5	DAMG_2	DAMG_3	57.5
6	FWY	SPDL	55.1
7	ACL_1	ACL_2	54.5
8	WZC_1	WZC_3	53.8
9	WZ_3	WZ_4	52.2

Airbag deployment, traveling straight immediately before the crash, higher posted speed limits, drivers of age between 26 and 65, crashes at intersections or intersection-related area, and local drivers were the characteristics that were significantly associated with increased work crash severities during daytime. Minor or functional damage to the at-fault-vehicle, trapped driver, use of safety equipment, driving alone, and crashes occurring on four-lane highways were the factors significantly associated with reduced work zone crash severities during daytime.

A comparison of crash severity models for daytime and nighttime crashes are shown in Table 4.10. Accident location, driver age, occupancy, number of lanes, vehicle maneuvering before the crash, and posted speed limit were found significant only in the daytime work zone crash severity model. Driver gender, alcohol involvement, road surface type, location within work zones, and single vehicle involvement were found significant only in nighttime work zone crash severity model.

Table 4.9 Ordered probit model estimates for daytime work zone crashes

Model Fit Summary			
Number of Observations		4538	
Log Likelihood		-4765	
Maximum Absolute Gradient		3.2161E-10	
AIC		9557	
Schwarz Criterion		9647	
Parameter Estimates			
Parameter	Description	Estimate	Approx. Pr > |t|
Intercept		2.1114	<.0001
ABAG	Airbag was deployed	0.4632	<.0001
DAMG_1	Vehicle damage was minor	-0.3684	<.0001
DAMG_2	Vehicle damage was functional	-0.4101	<.0001
TRAPD	At-fault driver was not ejected	-0.6690	<.0001
MANU_1	Vehicle was traveling straight before the crash	0.0768	0.0002
SPDL	Posted speed limit (explanatory variable)	0.0025	0.0022
REST	Safety equipment were used	-0.1122	0.0073
AGE_2	Driver age was between 26 - 65 years	0.0469	0.0249
ACL_2	Crash occurred at an intersection or intersection-related area	0.0532	0.0436
ALONE	At-fault-driver was driving alone	-0.0888	0.0047
LANE_4	*Crash occurred on a four-lane highway*	*-0.0398*	*0.0555*
LI_COM	*Driver carried a valid driver's license*	*0.0658*	*0.0907*
_Sigma		0.6914	<.0001

Note: Variables in *italic* are significant at 90% confidence level

Table 4.10 Comparison of results from crash severity models for nighttime and daytime work zone crashes

Variable type	Variable label	Description	Day	Night
Crash location	ACL_2	Crash occurred at an intersection or intersection-related area	(+)	
Driver age	AGE_2	Driver age was between 26 - 65 years	(+)	
Occupancy	ALONE	At-fault-driver was driving alone	(-)	
Damage to the vehicle	DAMG_1	Vehicle damage was minor	(-)	(-)
	DAMG_2	Vehicle damage was functional	(-)	(-)
Driver gender	GEND	Driver was male		(+)
Number of lanes	LANE_4	Crash occurred on a four-lane highway	(-)*	
License compliance	LI_COM	Driver carried a valid driver's license	(+)*	(+)
Vehicle maneuvering before the crash	MANU_1	Vehicle was traveling straight before the crash	(+)	
Alcohol involvement	NO_ALC	No alcohol was involved		(-)
Use of safety equipment	REST	Safety equipment were used	(-)	(-)*
	ABAG	Airbag was deployed	(+)	(+)
Posted speed limit	SPDL	Posted speed limit (explanatory variable)	(+)	
Number of vehicles involved	SINGL	Was a single-vehicle crash		(-)
Road surface type	SRT_2	Road surface was asphalt		(+)
Driver ejection	TRAPD	At-fault driver was not ejected	(-)	(-)
Work zone location	WZ_2	Crash occurred in the advance warning area		(+)*
	WZ_4	Crash occurred in the activity area		(+)

*Variable was significant at 90% confidence level

4.2.3 Crash severity modeling for multi-vehicle versus single vehicle work zone crashes

An injury severity model for single-vehicle work zone crashes contained 33 variables after eliminating variables that had correlation coefficients greater than 50%. Correlation between the variables as detected from Minitab is presented in Table 4.11. Final model was developed using backward elimination method, which removes all the insignificant variables from the model. Out of 33 variables, 11 variables were significant at 95% confidence level; one additional variable became significant when 90% confidence level was considered. Table 4.12 interprets the significant variables for the single-vehicle work zone injury severity model.

Table 4.11 Pearson correlation factors for single-vehicle work zone crash severity model

	Variable 1	Variable 2	Pearson correlation (%)
1	SRT_1	SRT_2	91.5
2	SR_DRY	WE_1	75.4
3	AGE_1	AGE_2	73.8
4	ACL_1	ACL_4	58.8
5	WZ_3	WZ_4	50.1

As shown in Table 4.12, air bag deployment, local driver's license, male at-fault driver, crashes on freeways, and absence of adverse weather condition were found to be significantly associated with increased crash severities among single-vehicle work zone crashes. Traveling straight before the crash, trapped driver, and driving alone were found significantly associated with reduced crash severities among single-vehicle work zone crashes.

Crash severity model for multiple-vehicle work zone crashes contained 38 variables after eliminating variables that had correlation coefficients greater than 50%. Correlation between the variables as detected from Minitab is presented in Table 4.13. Out of the 38 variables, 16 variables were significant at 95% confidence level. Two additional variables became significant when 90% confidence level was considered. Table 4.13 interprets the significant variables for the multiple-vehicle work zone injury severity model.

Table 4.12 Ordered probit model estimates for single-vehicle work zone crashes

Model Fit Summary			
Number of Observations			1,441
Log Likelihood			-1,675
Maximum Absolute Gradient			2.1693E-12
AIC			3,377
Schwarz Criterion			3,451
Parameter Estimates			
Parameter	Description	Estimate	Approx. Pr > |t|
Intercept		2.7827	<.0001
ABAG	Airbag was deployed	0.3279	<.0001
DAMG_1	Vehicle damage was minor	-0.4284	<.0001
DAMG_2	Vehicle damage was functional	-0.5077	<.0001
DAMG_3	Vehicle damage was disabling	-0.3128	<.0001
TRAPD	At-fault driver was not ejected	-1.0125	<.0001
ALONE	At-fault-driver was driving alone	-0.1499	0.0013
NO_ALC	No alcohol was involved	-0.1671	0.0293
LI_KS	Driver's license was issued in Kansas	0.1406	0.0036
STRGT	Road was straight	-0.1198	0.0290
GEND	Driver was male	0.0819	0.0523
FWY	Crash occurred on a freeway	0.0922	0.0463
WE_1	*There was no adverse weather condition*	*0.0972*	*0.0760*
_Sigma		0.7735	<.0001

Note: Variables in *italic* are significant at 90% confidence level.

Table 4.13 Pearson correlation factors for multiple-vehicle work zone crash severity model

	Variable 1	Variable 2	Pearson Correlation (%)
1	SRT_1	SRT_2	98.90
2	AL_FLAG	NO_ALC	96.30
3	SR_DRY	WE_1	79.70
4	AGE_1	AGE_2	75.40
5	COL_1	COL_2	62.40
6	DAMG_2	DAMG_3	60.30
7	ACL_1	ACL_2	58.00
8	SPDL	FWY	57.00
9	WZC_1	WZC_3	55.40
10	WZ_3	WZ_4	53.50
11	COL_1	COL_3	50.50

Crashes at non-intersection or interchange areas, rear-end or side-swipe collisions, minor vehicle damages, occurring on freeways or four-lane highways, use of safety equipment, and involvement of only two vehicles were found to be significantly associated with reduced work crash severities involving multiple vehicles.

Since work zone conditions are unfamiliar to the drivers, extra vigilance is required for safe passage. Driving Under Influence (DUI) increases perception reaction time in order to make necessary evasive actions to avoid crashing the vehicle. Therefore, inability to slow the vehicle can result in increased crash severity. According to model results, work zones located on hillcrests or at grades can result in higher injury severities as proven in literature *(23)*.

Fifty-four percent of the target crashes involved at-fault-drivers between 26 and 65 years of age, and this age group was found to be significantly associated with increased crash severities according to the model.

A comparison of single-vehicle and multi-vehicle work zone crash severity model results are shown in Table 4.15.

Table 4.14 Ordered probit model estimates for multi-vehicle work zone crashes

Model Fit Summary			
Number of Observations			4482
Log Likelihood			-4674
Maximum Absolute Gradient			2.3647E-11
AIC			9389
Schwarz Criterion			9524
Parameter Estimates			
Parameter	Description	Estimate	Approx. Pr > |t|
Intercept		1.9041	<.0001
ABAG	Airbag was deployed	0.5412	<.0001
COL_1	Rear-end collision	-0.1333	<.0001
COL_3	Sideswipe collision	-0.2255	<.0001
DAMG_3	Vehicle damage was disabling	0.1683	<.0001
MANU_1	Vehicle was traveling straight before the crash	0.0994	<.0001
REST	Safety equipment were used	-0.1681	<.0001
SPDL	Posted speed limit (explanatory variable)	0.0059	<.0001
TRAPD	At-fault driver was not ejected	-0.5594	<.0001
VEH_2	Only wo vehicles were involved	-0.2184	<.0001
AL_FLG	Alcohol involved crash	0.2223	0.0048
LI_COM	Driver carried a valid driver's license	0.1079	0.0050
LANE_4	Crash occurred on a four-lane highway	-0.0536	0.0100
FWY	Crash occurred on a freeway	-0.0609	0.0333
ACL_3	Crash occurred in an interchange area	-0.0737	0.0374
GRADE	Road is on hillcrest or grade	0.0470	0.0411
DAMG_1	Vehicle damage was minor	-0.0568	0.0416
AGE_2	*Driver age was between 26 - 65 years*	*0.0404*	*0.0541*
ACL_1	*Crash occurred in non-intersection area*	*-0.0507*	*0.0695*
_Sigma		0.6867	<.0001

Note: Variables in *italic* are significant at 90% confidence level

Table 4.15 Comparison of results from crash severity models for single-vehicle and multi-vehicle work zone crashes

Variable type	Variable label	Description	Multi.	Single.
Crash location	ACL_1	Crash occurred in non-intersection area	(-)*	
	ACL_3	Crash occurred in an interchange area	(-)	
Driver age	AGE_2	Driver age was between 26 - 65 years	(+)*	
Alcohol flag	AL_FLG	Alcohol involved crash	(+)	
Occupancy	ALONE	At-fault-driver was driving alone		(-)
Collision pattern	COL_1	Rear-end collision	(-)	
	COL_3	Sideswipe collision	(-)	
Damage to the vehicle	DAMG_1	Vehicle damage was minor	(-)	(-)
	DAMG_2	Vehicle damage was functional		(-)
	DAMG_3	Vehicle damage was disabling	(+)	(-)
Road class	FWY	Crash occurred on a freeway	(-)	(+)*
Driver gender	GEND	Driver was male		(+)*
Geometry of the road	GRADE	Road is on hillcrest or grade	(+)	
	STRGT	Road was straight		(-)
Number of lanes	LANE_4	Crash occurred on a four-lane highway	(-)	
License compliance	LI_COM	Driver carried a valid driver's license	(+)	
Local driver	LI_KS	Driver's license was issued in Kansas		(+)
Vehicle maneuvering before the crash	MANU_1	Vehicle was traveling straight before the crash	(+)	
Alcohol involvement	NO_ALC	No alcohol was involved		(-)
Use of safety equipment	REST	Safety equipment were used	(-)	
	ABAG	Airbag was deployed	(+)	(+)
Posted speed limit	SPDL	Posted speed limit (explanatory variable)	(+)	
Number of vehicles involved	VEH_2	Only wo vehicles were involved	(-)	
Driver ejection	TRAPD	At-fault driver was not ejected	(-)	(-)
Adverse weather condition	WE_1	There was no adverse weather condition		(+)*

According to study data, at-fault vehicle was traveling straight immediately before the crash in 56% of the multi-vehicle crashes; 77% of those crashes resulted in rear-end crashes, 15% resulted in angle-side impact crashes, with only 5% of those crashes being sideswipe crashes. According to the model, rear-end and sideswipe crashes are corresponded to decreased crash severities. However, vehicles that were traveling straight were related to increased crash severities. Elghamrawy et al. *(54)* also found that type of collision was related to crash severity in work zones. In 90% of target crashes, the at-fault driver carried a valid driver's license; that variable became a factor related to higher crash severities due to high exposure. Otherwise, the author does not imply that carrying a valid driver's license is a risk factor.

As referenced by Abraham et al. *(55)* in their evaluation of construction project safety, "the greater the speed at which occupants must absorb the energy released by the vehicle at impact, the greater the probability and severity of injury". Although this is not a unique quality for multi-vehicle work zone crashes, it is also reflected in this model.

According to literature *(54, 56)*, the probability that a driver is belted declines as crash severity increases. Seventy-five percent of work zone crashes that occurred on freeways were PDO crashes, 16% resulted in possible injuries and only 10% consist of crashes resulted in severe injuries (not incapacitating + incapacitating). Only three fatal crashes among target crashes occurred on freeways. Work zone categories were evaluated in order to determine why freeway crashes are related to decreased severities. Although half of the target crashes were categorized for lane closures, only 37% of freeway work zones were included in that category. Twenty percent of freeway work zones included work on shoulders or medians, but 12% accounted for lane shift or crossover. Because 28% of freeway work zone crashes were recorded as unknown or other category, conclusions could not be drawn regarding any relationship between the freeway-work zone category and decreased crash severities. The target crashes consisted of work zone crashes that at least involving at least two vehicles, as related to lesser injury severities in the model. Only 16% of target crashes involved three vehicles or more. Chang and Mannering *(57)* showed that if the driver is totally or partially ejected from the vehicle in non-truck-involved crashes, the likelihood of severe injury increased. Similarly, results of this model confirmed that a driver trapped inside the vehicle is related to lesser crash severities.

When results from multi-vehicle and single-vehicle work zone crashes were compared, the only observed difference in statistically significant factors in both the models was that disabling vehicle damage was related to decreased crash severities in single vehicle crashes and higher crash severities in multi-vehicle work zone crashes. Similar to the temporal comparison in section 4.2.1, air bag deployment was related to higher crash severities in both single-vehicle and multi-vehicle work zone crashes. When the driver-at-fault was not ejected and trapped in the vehicle, decreased crash severities occurred. Lane closure and work on shoulder or median were factors related to lesser crash severities for both models.

4.3 Work zone crash frequency modeling

When all missing data and error records were removed, a total of 51work zones were used for frequency modelling. Project numbers and other features are included in Appendix E. Because crash count was considered in four ways, the descriptive statistics are shown separately for each model. All models started with the same number of variables and likelihood ratios were tested using Type 3 analysis in SAS, which shows whether each variable is significant to include in the model. For categorical variables, such as road class, significance of the road class as one variable was tested instead of the significance of each road class. Theoretically, the other variables can be removed from the model, but all of the variables were considered in order to determine how each variable behaves in the model. Correlation between these variables was then checked using Spearman correlation coefficients.

4.3.1 Work zone crash frequency model for total crash counts (Model 1)

Poisson regression

When the correlations between variables that with coefficients greater than 50% are considered, it was as shown in Table 4.16. Results from Type 3 analysis are shown in Table 4.17, and descriptive statistics for count data are shown in Table 4.18. Variables shown in **bold** font are significant at 95% confidence level. AADT, presence of a pilot car, width restrictions, carrying out roadwork at night, presence of a flagger, use of arrow boards, use of advance message boards to warn drivers, ramp closure, road class and the urban/ rural status were the variables that are significant for the crash count. The correlation matrix for total work zone crash counts is included in Appendix F. Then, stepwise elimination method was carried out manually for each model to remove the highly correlated variables from the model.

Table 4.16 Highest Spearman correlation coefficients between the variables

Variable 1	Variable 2	Spearman correlation coefficients (%)
LnAADT	URBAN	75.4
PILOTCAR	FLAGGER	73.0
LnAADT	CLASS	72.1
PILOTCAR	CLASS	70.9
LnAADT	PILOT CAR	70.6
OLANE ON	TLANEOFF	61.1
PILOTCAR	URBAN	57.8
DETOUR	RAMPCLOSR	54.5
LnAADT	FLAGGER	51.3
RAMPCLOSR	CLASS	50.4

Table 4.17 Significance of variables using Type 3 analysis

Source	DF	Chi-Square	Pr > ChiSq
lnAADT	**1**	**109.36**	**<.0001**
PILOTCAR	**1**	**8.17**	**0.0043**
WIDTH_R	**1**	**23.82**	**<.0001**
SPEED_R	1	0.20	0.6550
NIGHT	**1**	**20.73**	**<.0001**
WKEND	1	0.02	0.8828
FLAGGER	**1**	**10.15**	**0.0014**
ARROWBO	**1**	**18.83**	**<.0001**
ADVMSGBO	**1**	**7.45**	**0.0063**
OLANEON	*1*	*2.86*	*0.0909*
TLANEON	1	0.48	0.4864
OLANEOFF	1	0.40	0.5269
TLANEOFF	1	1.11	0.2930
DETOUR	1	1.32	0.2512
RAMPCLOSR	**1**	**16.35**	**<.0001**
CLASS	**4**	**44.84**	**<.0001**
URBAN	**1**	**15.40**	**<.0001**

Note: DF = Degrees of Freedom, Significant variables are in **bold** for 95% confidence level and in *italics* for 90% confidence level

Table 4.18 Descriptive statistics for total crash counts

Variable	N	Mean	Variance	Minimum	Maximum
COUNT	51	7.921569	80.95373	0	40
DAYS	51	135.8039	6041.52	16	310
MILES	51	8.708039	79.93286	0.4	38.2
AADT	51	21692.02	9.22E+08	450	153000

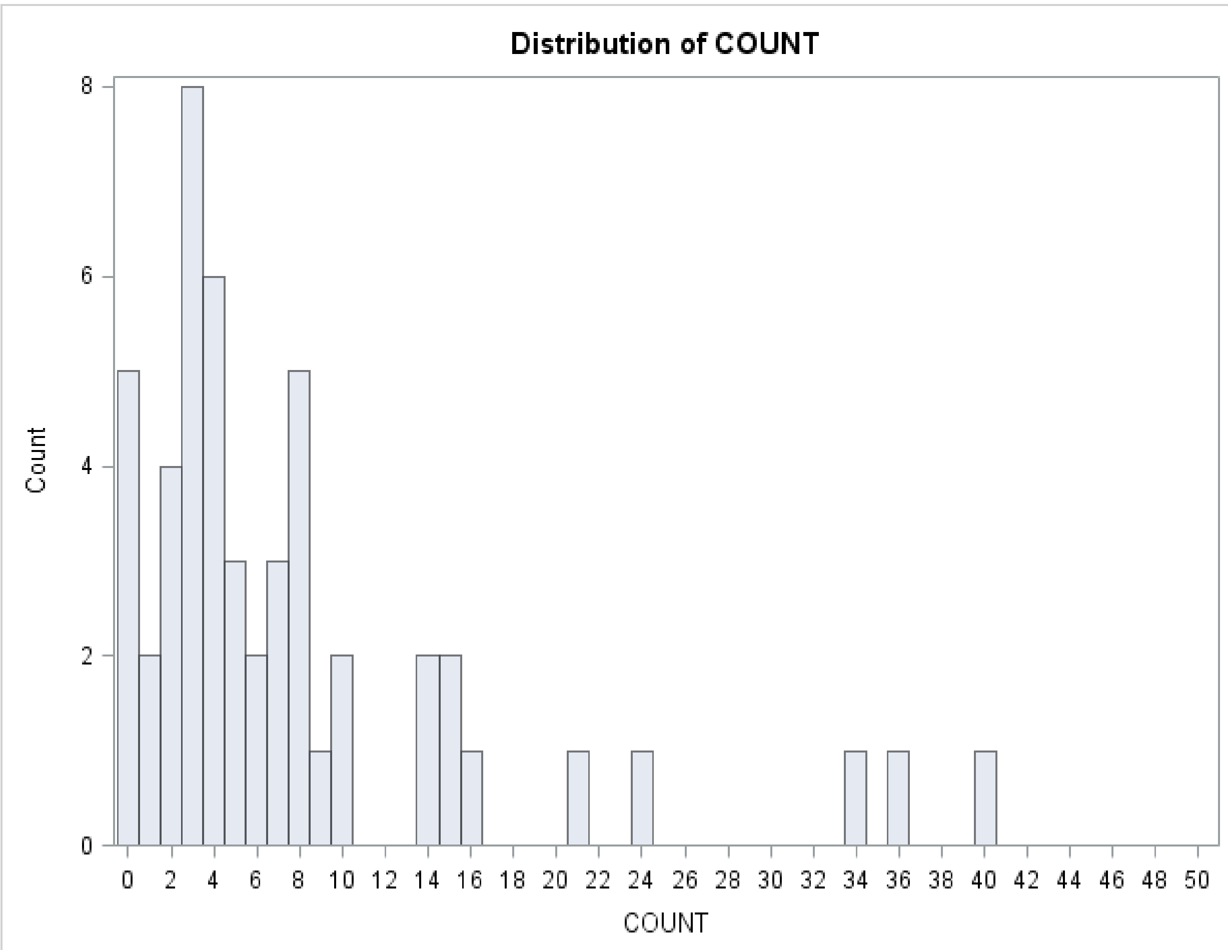

Figure 4.7 Distribution of total crash count data

The distribution plot (Figure 4.7) and descriptive statistics imply that NB is the most suitable distribution to model total crash counts for work zones. However, Poisson regression was carried out first to determine whether the presence of overdispersion for precision.

Table 4.19 Parameter estimates for total crash counts, using Poisson regression

Variable		DF	Description	Estimate	Pr > ChiSq
Intercept				-16.9532	<.0001
lnAADT		**1**	**AADT of traffic flow**	**1.2943**	**<.0001**
PILOTCAR	**1**	**1**	**Presence of a pilot car**	**-1.3238**	**0.0069**
WIDTH_R	**1**	**1**	**Width restriction**	**1.1001**	**<.0001**
SPEED_R	1	1	Speed restriction	-0.0962	0.6539
NIGHT	**1**	**1**	**Work carried out at night at least occasionally**	**-0.9197**	**<.0001**
WKEND	1	1	Work carried out on weekends at least occasionally	0.0287	0.8828
FLAGGER	**1**	**1**	**Presence of a flagger**	**1.3572**	**0.0033**
ARROWBO	**1**	**1**	**Use of arrow boards**	**-1.2219**	**<.0001**
ADVMSGBO	**1**	**1**	**Use of advance message boards**	**0.5011**	**0.0061**
OLANEON	1	1	One lane in operation	-0.4816	0.0909
TLANEON	1	1	Two lanes in operation	-0.3937	0.4916
OLANEOFF	1	1	One lane closed	0.1697	0.5277
TLANEOFF	1	1	Two lanes closed	-0.3014	0.2975
DETOUR	1	1	Availability of a detour	0.2166	0.2517
RAMPCLOSR	**1**	**1**	**Ramp closure**	**-1.1617**	**<.0001**
CLASS	**1**	**1**	**Interstate**	**-0.5821**	**0.0272**
CLASS	2	1	Principal arterial - Other freeways and expressways	0.2068	0.4071
CLASS	**3**	**1**	**Principal arterial - Other**	**-0.6913**	**0.0014**
CLASS	4	1	Minor arterial	0.4871	0.1291
URBAN	**1**	**1**	**Work zone was in an urban area**	**0.8988**	**<.0001**
Scale				1.0000	
Criteria for assessing goodness of fit					
Criterion				Value	Value/DF
Deviance				160	5.3343
Pearson chi-square				267	8.8947
Number of work zones				51	
Log likelihood				553	
Full log likelihood				-164	
AIC (smaller is better)				370	
AICC (smaller is better)				402	
BIC (smaller is better)				411	
Number of observations (work zones)				51	
Note: Significant variables are in **bold** font; DF = degrees of freedom.					

Confirmation of the observations with the mean, variance, and the distribution plot showed that results of the Poisson regression model did not suit the data. Goodness of fit statistics showed that value over degrees of freedom for deviance and Pearson chi-square statistics were higher than 1.00. Before advancing to the NB model, an adjustment was made for overdispersion by including a scale parameter. The scale parameter was estimated by the square root of DEVIANCE/DF. The estimated scale parameter was 2.98, and the scaled Pearson chi-square was fixed to 1.0. AIC and BIC values for the regular Poisson model and the scaled model were identical. The only significant variable found for the scaled Poisson regression was the log of AADT and the entire table with the scaled model is not included because it was not recognized as a better model than the regular Poisson model.

Negative binomial regression

Variables removed due to high correlations were: Urban, Flagger, Class, TLaneOff, and Detour. In a stepwise elimination concept, AIC values were used to compare the models and select the best fitting model in a concept of lesser AIC is better. Model estimates for the final model with its model fitness values are given in Table 4.20. Dispersion, 0.6883 is significantly higher than zero, which also recommended the use of NB regression instead of Poisson. Since the NB model already accounted for overdispersion, Pearson chi-square value did not need to be scaled.

According to model estimates, significant variables were log of AADT and nighttime work. A positive sign of the estimate of a numerical variable indicated that a unit increase in the variable increased the number of total work zone crashes. The multiplicative factor in which the crash count increased was found by considering the exponential value of the estimate. Therefore, a unit increase in ln(AADT) increased the number of work zone crashes by 3 (Assumption: All the other variables are kept constant.) When the categorical variable ‘Night’ is considered, it says that the number of work zone crashes are reduced by 0.32 times when there was nighttime work present (Assumption: All the other variables are kept constant). It was determined as a decrease in the crash count because the sign of the model estimate is negative.

Table 4.20 Model estimates for total crash counts using NB regression model

Criteria For Assessing Goodness Of Fit			
Criterion		Value	Value/DF
Deviance		59.8701	1.2473
Pearson Chi-Square		77.4695	1.6139
Log Likelihood		562.24	
AIC (smaller is better)		317.409	
BIC (smaller is better)		325.136	
Algorithm converged.			
Analysis Of Maximum Likelihood Parameter Estimates			
Parameter		Estimate	Pr > ChiSq
Intercept		-16.7201	<.0001
lnAADT	AADT of traffic flow	1.3504	<.0001
NIGHT	Work carried out at night at least occasionally	-1.4690	0.0003
Dispersion		0.6883	

Variables that were found to be significant for total number of work zone crashes by Ozturk et al. *(38)* were, length of work zone, traffic volume, number of operating lanes, speed reduction and the duration of the work zone. A period based injury crash frequency model was developed by Ozturk et al. *(38)*, and the variable that became significant were: work zone length, nighttime work, traffic volume, number of operated lanes, number of dropped lanes, and the urban/ rural nature. However, length and duration were not treated as exposure variables in their study.

4.3.2 Work zone crash frequency model for EPDO crash counts (Model 2)

The same approach as in Model 1was carried out to model the EPDO but an extremely high EPDO count of 236 was observed in the distribution plot; therefore, that work zone was removed as an outlier. As a result, the total number of work zones considered for this model was 50. The distribution plot and descriptive statistics are shown in Figure 4.8. The correlation matrix for EPDO work zone crash counts is included in Appendix G.

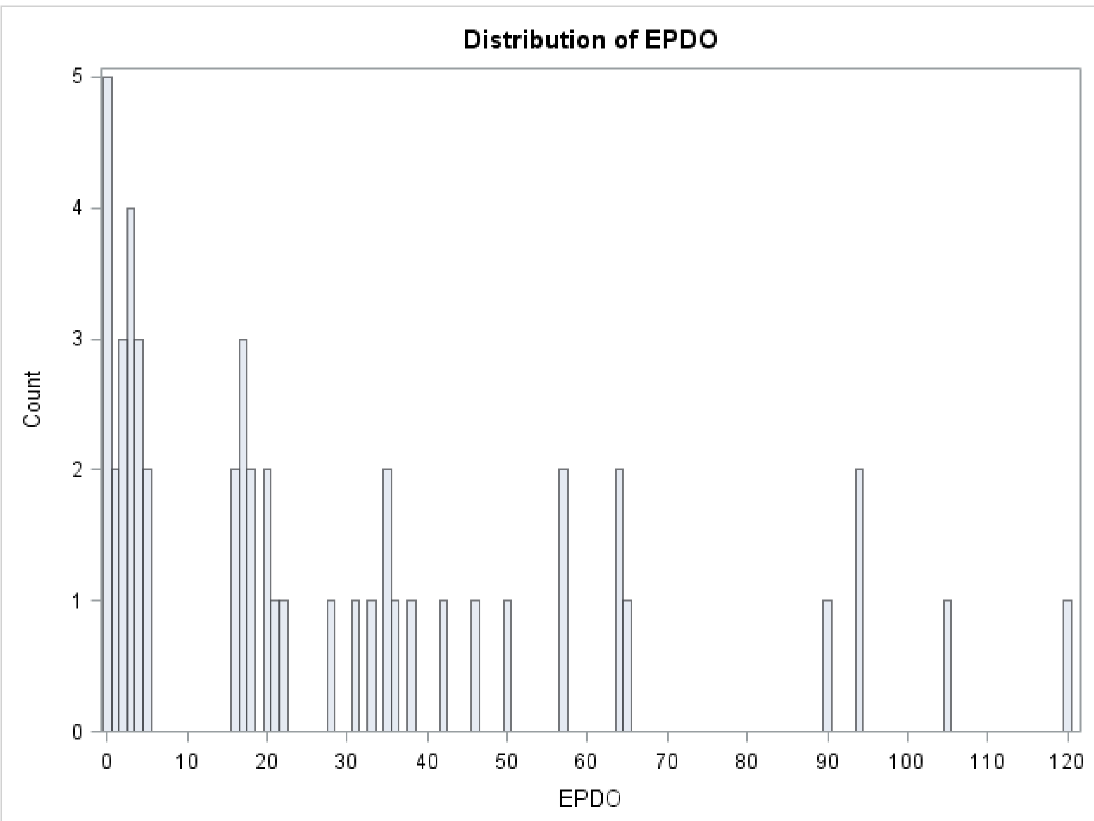

Figure 4.8 Distribution plot for EPDO counts

A scaled Poisson regression was carried out and overdispersion was detected. Thus further analysis was done using NB regression as confirmed by dispersion of 1.34 in the NB regression. Correlation between variables differed as compared to the total crash data. The complete correlation matrix is included in Appendix G. Variables removed from the model after comparing AIC values were, Urban, Class, PilotCar, TLaneOff, RampClosr and Flagger.

Then, highly insignificant variables were removed by the backward elimination method. The final model showed only one significant variable at 95% confidence level, the log of AADT. Model estimates and goodness of fit criteria are shown in Table 4.21.According to the model estimates, a unit increase in lnAADT increases the EPDO crash count by 3. NIGHT was significant at 90% confidence level and the model estimates imply that presence of nighttime work at least occasionally, reduces the number of EPDO crashes 0.36 times.

Table 4.21 Model estimates for EPDO crash counts using NB regression model

Criteria for assessing goodness of fit			
Criterion		Value	Value/DF
Deviance		60.2172	1.2812
Pearson chi-square		64.6352	1.3752
Log likelihood		4048.5724	
AIC (smaller is better)		436.0502	
BIC (smaller is better)		443.6983	
Algorithm converged.			
Analysis of maximum likelihood parameter estimates			
Parameter	Description	Estimate	Pr > ChiSq
Intercept		-11.993	<.0001
lnAADT	AADT of traffic flow	0.9982	<.0001
NIGHT	Work carried out at night at least occasionally	-0.9906	0.0733
Dispersion		1.5276	

4.3.3 Work zone crash frequency model for PDO crash counts (Model 3)

In this part of the study, all PDO crashes were considered for a separate frequency model. Distribution of PDO crash counts considered in the model is shown in Figure 4.9. The correlation matrix for work zone PDO crashes is included in Appendix H and variables removed due to correlation were Urban, Flagger, Class, and PilotCar. AIC values with and without scaled Pearson chi-square for Poisson distribution were identical as was in total crash counts. However, dispersion value of 0.65 in NM confirmed the use of NB over Poisson. After highly correlated variables were removed, backward elimination method was used to remove the highly insignificant variables. Final model estimates are presented in Table 4.22.

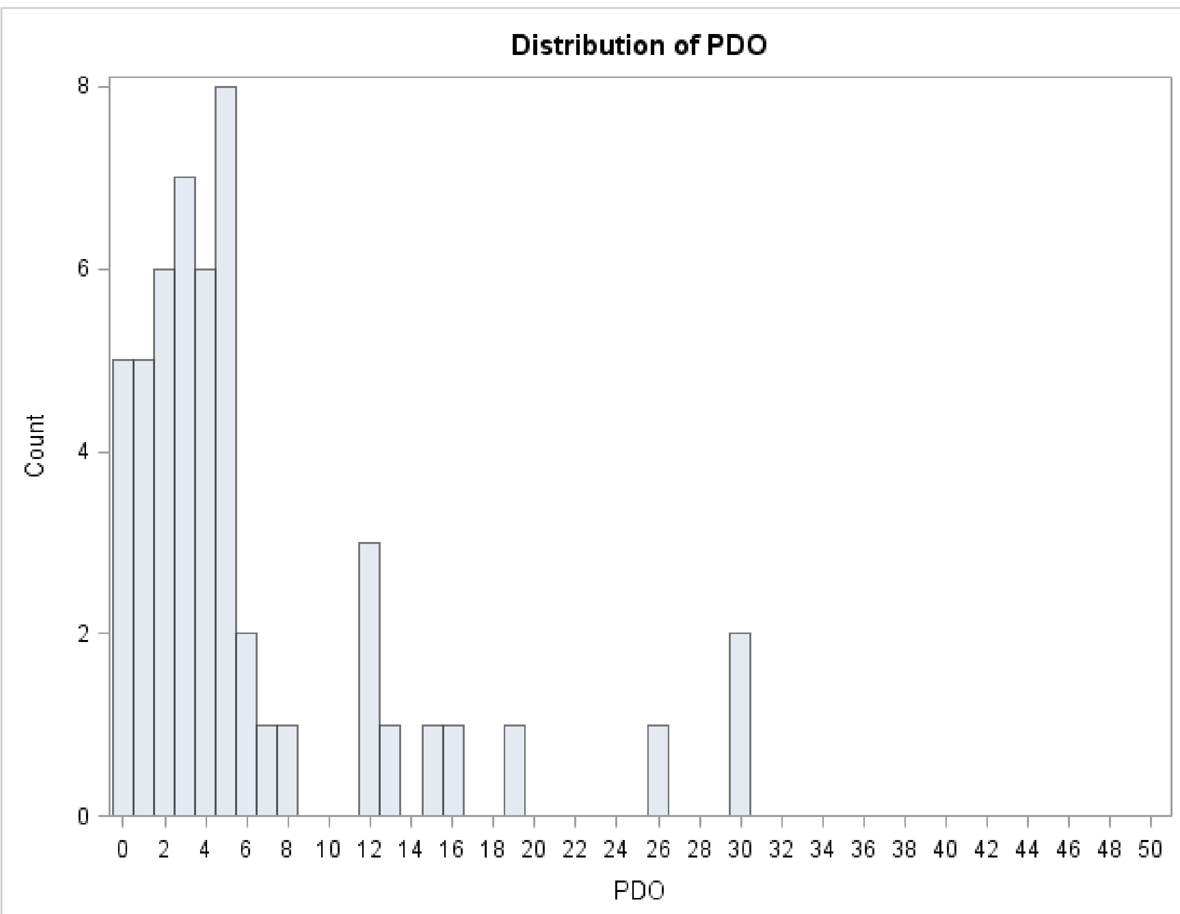

Figure 4.9 Distribution of PDO work zone crashes

Table 4.22 Parameter estimates for PDO crashes using negative binomial regression (MODEL 3)

Criteria for assessing goodness of fit			
Criterion		Value	Value/DF
Deviance		55.6613	1.21
Pearson chi-square		55.0353	1.1964
Log likelihood		356.6	
AIC (smaller is better)		293.6	
BIC (smaller is better)		305.2	
Algorithm converged.			
Analysis of maximum likelihood parameter estimates			
Parameter		Estimate	Pr > ChiSq
Intercept		-16.0874	<.0001
lnAADT	AADT of traffic flow	1.2218	<.0001
NIGHT	Work carried out at night at least occasionally	-1.1010	0.0115
ADVMSGBO	Use of advance message boards	0.8867	0.0248
TLANEON	Two lanes in operation	1.5918	0.0891
Dispersion		0.6531	

LnAADT was found to be significant with a positive sign in model estimate. When the exponential was calculated, it was interpreted as a unit increase of lnAADT increased the number of PDO crashes by 4.0. Roadwork at night was found to be significant with a negative sign for the model estimate. The number of PDO crashes when nighttime work was present at least occasionally, was expected to be 0.33 times less than when no nighttime roadwork was present. Similarly, use of advance message boards (signs) was related to 2.4 times higher numbers of PDO work zone crashes compared to work zones in which advance message boards were not used. This does not imply that use advance message boards causes an increase of PDO. In other words, advance-warning message boards do not help to improve work zone safety.

Although, MUTCD recommends using advance message signs at every work zone, only 20% of work zones considered in this study mentioned using advance message boards. Two functioning lanes in a work zone became significant at 90% confidence level and it showed to be related to five times higher PDO crashes.

Period based PDO crash frequency model was developed by Ozturk et al. *(38)*, and the variable that became significant were: length of work zone, nighttime work, traffic volume, number of operated lanes, number of dropped lanes, speed reduction, urban/ rural nature, and presence of ramp.

4.3.4 Work zone crash frequency model for fatal and injury crash counts (Model 4)

Because there were only a few fatal crashes for the entire set of work zones, development of individual frequency models for fatal crashes and injury crashes did not yield much. Therefore, fatal and injury crashes were combined to build one model. Similar to model 1, 2, and 3, correlation between the variables were determined and the correlation matrix for this data set is included in Appendix I.

However, 39% of the work zones came up with zero counts for fatal and injury crashes combined, and the count distribution is shown in Figure 4.10. When there any many zeros in the count data, some previous studies have chosen to use zero inflated Poisson (ZIP) or zero inflated NB (ZINB). However, it was not recommended by many statisticians. The ZIP model assumes that the data set is a mixture of two sorts of individuals: first group whose counts are generated by the standard Poisson regression model, and the second group, that have zero probability of a count greater than 0 *(58-61)*. This second group is also called the absolute zero group or pure zero group. None of the variables in Model 4 yielded absolute zeros. Therefore, there was no need of considering a zero inflated model. According to many statisticians, having a lot of zeros does not necessarily create the need for a zero-inflated model *(58, 59, 62)*.

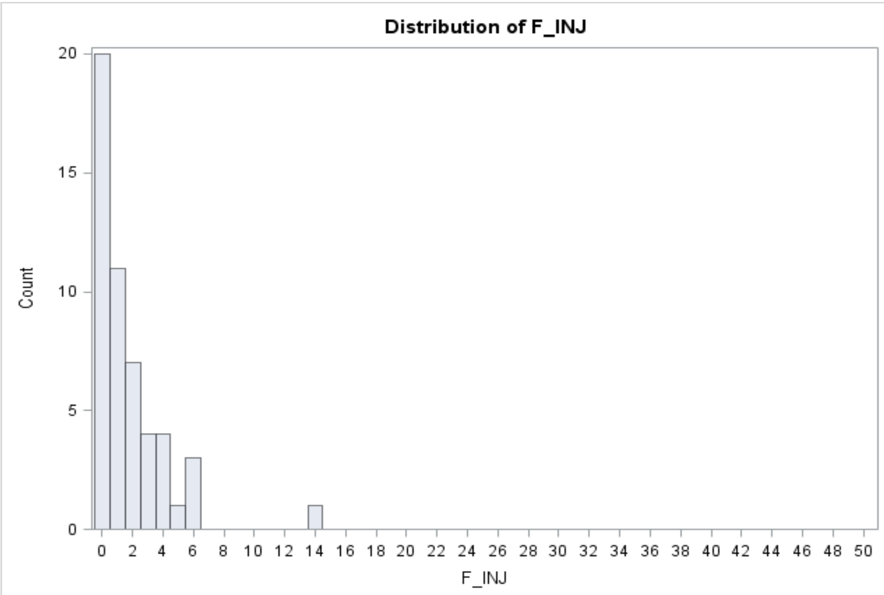

Figure 4.10 Distribution of fatal and injury crashes for work zones

Results from Model 4 revealed five significant variables at 95% confidence level and one variable at 90% confidence interval. Variables significant at 95% confidence level were lnAADT, road class, one functioning lane, nighttime roadwork, and ramp closure. According to the model estimates, a unit increase in ln AADT increased the number of fatal and injury crashes by four. Work zones on class 3 roads (Other principal arterial) were related to 0.3 times less than numbers of fatal and injury crashes on class 5 road (major arterial). Presence of one functioning lane decreased the number of fatal and injury crashes by 0.37 times and nighttime roadwork (at least occasionally) was related to 0.4 times less number in fatal and crashes within no nighttime roadwork. Also, presence of a ramp and a ramp closure has reduced the number of fatal and injury crashes by 0.45times. Width restrictions were found to be significant at 90% confidence interval and it showed that the increase in number of fatal and injury crashes was two folds when there was a width restriction.

Table 4.23 Parameter estimates for fatal and injury crashes using negative binomial regression (MODEL 4)

Criteria for assessing goodness of fit			
Criterion		Value	Value/DF
Deviance		55.7975	1.3609
Pearson chi-square		84.6071	2.0636
Log likelihood		-2.3284	
AIC (smaller is better)		175.5523	
BIC (smaller is better)		196.8024	
Parameter	Description	Estimate	Pr > χ^2
Intercept		-18.5725	<.0001
lnAADT	AADT of traffic flow	1.4432	<.0001
CLASS_3	Road class: Principal arterial - Other	-1.1924	0.0034
OLANEON	One lane in operation	-0.9896	0.0066
NIGHT	Work carried out at night at least occasionally	-0.9375	0.0161
RAMPCLOSR	Ramp closure	-0.7920	0.0301
WIDTH_R	*Width restriction*	*0.7119*	*0.0522*
CLASS_1*	Road class: Interstate	-0.4684	0.2630
CLASS_2*	Road class: Principal arterial - Other freeways and expressways	-0.2437	0.5410
CLASS_4*	Road class: Minor arterial	0.1646	0.7298
Dispersion		0.2032	
LR statistics for Type 3 analysis			
Source		χ^2	Pr > χ^2
lnAADT		35.35	<.0001
CLASS		7.81	0.0989
NIGHT		5.67	0.0173
OLANEON		5.58	0.0182
RAMPCLOSR		3.85	0.0498
WIDTH_R		3.66	0.0558

*Insignificant variables

4.4 Discussion and recommendations

Multiple studies have evaluated the effectiveness of temporary traffic control (TTC) devices used for reducing vehicle speeds within work zones. The primary purpose of such TTC devices is to decrease traffic speed with minimal impact on work progress.

Gambatese et al. *(63)* compared of the vehicle speed within the work zones to the reference speed before the drivers were aware of and entered the work zone. The variance of traffic speed determines the effectiveness of TTC devices; lower variance in speed between vehicles at locations throughout the work zone was considered more effective. However, the effects from each TTC device were difficult to identify individually when multiple devices were used. Therefore, measured effectiveness denoted was a combined effect. Out of the nine treatments (including combined treatments) tested by Gambatese et al. *(63)* and three treatments were found to perform better than the other treatments: police officer parked on site, radar speed monitoring display, and portable changeable message sign (PCMS) signs on both trailer and rollers. Furthermore, they recommended that combination of those TTC devices with a posted speed reduction is suitable for typical highway preservation projects. Other treatments subjected to testing were: typical traffic control plans (TCP), 50 mph signs, police officer patrolling, tubular markers on both sides, drums on both sides, and their combinations.

Many studies evaluated lighting at work zones, and potential safety benefit of enhanced delineation on TTC devices is recognized by the MUTCD. Theiss et al. *(64)* recommended that use of steady-burn warning lights in work zones be discontinued based on the results of their study which compared cost increase due to steady-burn lights to reduced crash costs.

Gambatese and Rajendran *(65)* found that flaggers do not feel comfortable when using 12-Volt spotlight and 12-Volt high-intensity discharge (HID) floodlight systems because of the small amount of light they emit compared to a light tower with 2,000 Watt output. However, when the driver glare is rated by driver questionnaire survey, they found that the average driver glare rating for the 12- Volt spotlight and 12- Volt HID floodlight were significantly better than that of the light tower. Some of the recommendations of their study were: the light equipment should be located on the same side of the road way as the flagger, the light equipment should illuminate the flagger from above at a height of approximately 5-10 ft from the edge of the lane, and the light equipment should be placed approximately at a 15° offset angle to the flagger.

Several safety practices and procedures that are used to improve nighttime work zone safety were evaluated by Abraham et al. *(66)*. The results from the responses obtained from supervisors at different levels in a descending order according to their rating were: increasing public awareness, increasing low enforcement, proper training for traffic control set-up and break down, routine maintenance of traffic control devices, increasing cone/drum taper length, inspection of traffic control devices, reviewing traffic control plans, and reviewing incident management plans. They also studied the responses from the workers and the results varied only slightly *(66)*.

Further recommendations to improve worker safety were: ensuring that backing procedures are in place for mobile construction vehicles, assigning a spotter to direct backing and that good communication between drivers and workers on foot, providing safety training for the duties that workers are assigned to perform developing/implementing specific training on equipment blind areas for roadway construction workers *(67)*. Also, developing, implementing and enforcing procedures that minimize exposure of workers on foot to moving construction vehicles and equipment, and considering installing aftermarket devices (e.g., camera, radar, sonar) on construction vehicles and equipment to help monitor the presence of workers on foot in blind areas were recognized as suitable countermeasures *(67)*. They also added that manufacturers of heavy construction equipment should explore the possibility of incorporating new monitoring technology to help monitor the presence of workers on foot in blind areas *(67)*. Detecting electronic tags worn by workers or by detecting magnetic field generator on equipment using tag-based warning systems that use radio frequency was also recognized as a possible solution *(67)*.

In order to reduce the flagger's exposure to traffic, automated flagger assistance devices (AFADs) were tested by researches to assess their operational and safety effectiveness. However, MUTCD mentions it as a requirement for a flagger to be present with an AFAD at all times. Finely *(68)* found that the violation rate for AFADs was higher than for flaggers, but the flaggers were always able to stop the violators before they faced the oncoming traffic. Hence, they recommended the use of AFADs with more public awareness. According to Patil *(69)*, portable traffic signal (PTS) units were highly visible from a longer distance compared to a flagger and PTS system was found to be easy to install. Furthermore, they recommended that most appropriate location to use a PTS system without a flagger was a two-lane, two-way rural highway with an AADT less than 7,000.

Section 6F of MUTCD *(1)* presents a list of advance warning signs, which includes signs related to work zones. Some of these signs are not included in the Kansas drivers' handbook. Hence, public awareness of these roadwork signs are questionable. On top of the unfamiliar road conditions, unfamiliar road signs can cause more confusion in road users.

Chapter 5 - Conclusions & Recommendation for Future Studies

5.1 Conclusions

The increasing number of work zones on U.S. roadways are becoming necessary in order to maintain and improve road user experience. However, the frequency of work zone crashes, specifically PDO and injury crashes, in Kansas increased from 2009 to 2013 and again from 2013 to 2014. That increase is visible in both PDO crashes and injury crashes but not much among the fatal crashes. Thus an investigation of the characteristics and contributing circumstances related to work zone crashes and associated injury severities must be conducted. The objectives of this study were to model work zone crash severities and frequencies to identify factors associated with increased crash severities and frequencies. In order to fulfil the objectives of this study, work zone information and work zone crash data for Kansas were obtained from KDOT. Several databases maintained by KDOT, such as KCARS and KANPLAN were the primary data sources for this study.

A total of 5,923 crashes occurring from 2010 through 2013 were used to derive ordered probit models representing work zone crash severities. Airbag deployment, traveling straight before the crash, higher posted speed limits, daylight condition, carrying a valid driver's license, at-fault-driver being a male, and at-fault-drivers of age between 26 and 65 years were the factors related to increased work zone crash severities. Minor or functional damage to the vehicle with at-fault-driver, involvement of only one vehicle, trapped driver, no alcohol involvement, use of safety equipment, occurring in interchange areas or non-intersection areas, straight roads, and work zone category were related to reduced crash severities.

In addition to the common crash severity model for work zones, individual crash severity models were developed for daytime, nighttime, single-vehicle and multi-vehicle work zone crashes as well. Detailed comparison between nighttime and daytime models and single-vehicle and multi-vehicle models were carried out. A total of 51 work zones were studied to develop frequency models for total work zone crash counts, EPDO counts, PDO counts, and fatal and injury counts in the work zones.

In order to identify work zone crash characteristics related to crash frequencies, crash frequency models were developed. Negative binomial model was the fitted model for all those cases. According to model results, AADT, use of advance message boards, and two functioning lanes were found to be significantly associated with increased work zone crash frequencies. Work zone crash counts were found to decrease when carrying out roadwork during nighttime at least occasionally.

Overall findings of this study can be summarized and appropriate solutions or countermeasures can be presented as follows. Higher crash severities were observed to be significant during daylight conditions, so nighttime roadwork can be encouraged. This is also convinced by the frequency model when it showed a reduced number of crashes at work zones with nighttime roadwork.

Lesser speed limits were found to be involved with reduced crash severities. Revision of speed limit reductions for work zones, placing flaggers far enough in advance, drone radars, speed monitoring displays, and removable rumble strips can be listed as some of the countermeasures to reduce the operating speed of the traffic flow through work zones *(70)*. Heng et al. *(70)* have discussed these in detail in their study on evaluating work zone speed reduction measures.

Higher traffic volume found to be associated with higher crash frequencies that suggest detours or any means of diversion of traffic to alternate routes. Also, different TTC measures for different groups of AADT could be helpful.

Because, most severe crashes occur within advance warning area and transition area, increase of safety precautions in those sections seems critical. Audible warning vehicle intrusion systems, line-of-sight intrusion warning system and highly mobile barrier systems are some of the countermeasures suggested by Schrock et al. *(71)* in their report on analyzing fatal work zone crashes in Texas.

This study found that straight road segments are associated with reduce crash severities and roads with grades are associated with increased crash severities in multi-vehicle crashes. One solution for this can be advancing the warning area further upstream for work zones with horizontal or vertical curves. Also, it would be safer if the transition area can be located on the tangent of the curve, instead of the curve itself.

Although this study found that seat belt use and drunk driving were found to be related with higher crash severities in work zones, those can be recognized as general road safety issues that are not unique to work zone safety. Drivers being trapped inside the vehicle without ejecting out has also resulted in lesser severities and that is another implication that use of safety belts reduces the crash severity. No alcohol involvement was associated with reduced crash severities and alcohol involved multi-vehicle crashes were associated with increased crash severities. Both these issues (seat belt use and drunk driving) can be addressed using campaigns with thorough advertising and driver education.

5.2 Recommendations for future studies

Work zone crash analyzing could be more effective and meaningful with some more information. This was realized by a brief literature review carried out after the data collection for this study. Different states have different data recording and storing techniques depending on the availability of their resources and Kansas could improve a lot more than its current system. A study carried out in Massachusetts *(72)*, found that only 28 crashes out of 100 work zone crashes were actually related to the work zone. They found it using the crash narratives. In addition, outcomes that are more useful could be obtained if information that is more detailed were recorded work zone crashes, e.g., presence of law enforcement, traffic control devices in use, involvement of work zone activities, involvement of workers in the crash, presence of workers at the time of crash or the active/ inactive status of roadwork.

A study on web-based resources linked to the National Traffic and Road Closure Information carried out of 13 states in the US was carried out by FHWA. The study revealed that 58% of work zones were active or had lane closures primarily during daylight hours, 33% were primarily night work and 9% were active nearly around the clock *(73)*. Fourteen percent of the work zones considered for frequency modeling in the current study had nighttime work at least occasionally and sufficient data was not available further analysis. Ninety two percent of them had one or two lanes closed during their active period.

The AADT data used for this study did not represent actual traffic volumes for specific work zone area, but were rather aggregated data because, work zone related data were not available. This can be noted as a limitation of this study. This situation could be improved if work zoned maintain a traffic volume record along with the construction management system.

Furthermore, all the work zones considered for this study were on state highways as CMS data and the work zone alerts were only available for state highways.

Worker involvement of the work zone crashes have drawn attention of some researches, but not included in this study due to lack of data. One more recommendation for future studies would be to obtain worker involvement information from KDOT, or to encourage them to revise the crash report card to collect those data.

Overall, the major inconvenience for work zone crash analysis was the unavailability of a proper database to obtain work zone related information. Future studies on work zone crashes in Kansas, must have to spend a significant portion of their time to gather the data and work on its precision before proceeding with the model. Many work zones located within city centers were omitted due to overlapping of work zones and inability to relate a crash to a particular project number or a work zone. This could be prevented if the project number was included in the crash report card.

A study on work zone crashes in non-state highways would also be an interesting area to look at. Communication with local authorities and area engineers would be the suitable method of obtaining work zone data, instead of KDOT or a CMS database. Finally, researchers can explore the use of different statistical models rather than ordered probit regression and negative binomial regression.

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Appendix A - Nighttime versus Daytime Work Zone Crash Statistics

Table A.1 Work zone crash frequencies and crash locations, Kansas

Crash location	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
On roadway	1,126	1,154	1,367	765	4,412	325	372	329	232	1,258
Off roadway	46	55	45	49	195	54	34	30	28	146
Total	1,172	1,209	1,412	814	4,607	379	406	359	260	1,404

Table A.2 Work zone crash frequencies and accident classes, Kansas

Accident Class (FHE)*	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Non-collision	48	39	49	28	164	31	29	31	22	113
Collision with other	1,125	1,171	1,365	789	4,450	347	365	330	238	1,280
Total	1,173	1,210	1,414	817	4,614	378	394	361	260	1,393

*FHE = First Harmful Event

Table A.3 Work zone crash frequencies and adverse weather conditions, Kansas

Weather condition	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
No adverse weather	1,030	1,092	1,336	737	4,195	306	345	321	223	1,195
Rain	99	88	61	58	306	42	37	31	27	137
Snow	30	14	7	13	64	25	18	5	7	55
Other	14	16	8	8	46	6	6	3	2	17
Total	1,173	1,210	1,412	816	4,611	379	406	360	259	1,404

Table A.4 Work zone crash frequencies and work zone locations, Kansas

Work Zone Location	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Before first warning sign	51	59	64	37	211	6	11	7	5	29
Advance warning area	131	182	211	119	643	33	51	43	21	148
Transition area	192	209	227	146	774	54	76	53	44	227
Activity area	702	674	823	455	2,654	238	226	232	163	859
Termination area	48	48	54	35	185	22	16	13	15	66
Other	49	38	35	25	147	26	27	13	12	78
Total	1,173	1,210	1,414	817	4,614	379	407	361	260	1,407

Table A.5 Work zone crashes and work zone categories, Kansas

Work zone category	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Lane closure	566	680	650	439	2335	146	202	159	122	629
Lane shift or crossover	190	183	218	107	698	80	69	63	43	255
Work on shoulder or median	227	204	416	169	1016	79	69	90	60	298
Intermittent or moving vehicle	61	38	40	35	174	1	8	8	7	24
Other	70	52	50	26	198	43	27	21	17	108
Total	1,114	1,157	1,374	776	4,421	349	375	341	249	1,314

Table A.6 Work zone crashes and surface types, Kansas

Surface type	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Concrete	466	571	613	342	1,992	140	187	154	98	579
Asphalt	692	625	788	463	2,568	231	213	194	158	796
Other	13	13	11	10	47	7	7	10	3	27
Total	1,171	1,209	1,412	815	4,607	378	407	358	259	1,402

Table A.7 Work zone crashes and surface conditions, Kansas

Surface condition	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Dry	990	1,069	1,303	714	4,076	287	326	309	214	1,136
Other	180	139	106	101	526	90	80	51	45	266

Table A.8 Work zone crashes and collision patterns, Kansas

Collision with other vehicle	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Head-on	13	18	18	9	58	11	7	6	10	34
Rear-end	572	624	803	397	2,396	88	118	117	67	390
Angle-side impact	225	184	212	134	755	47	38	48	21	154
Sideswipe	136	151	152	85	524	30	35	24	25	114
Other	27	21	22	14	84	4	6	1	2	13
Total	973	998	1,207	639	3,817	180	204	196	125	705

Table A.9 Work zone crashes and alcohol involvement, Kansas

Alcohol Involvement	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
No	1,162	1,192	1,396	810	4,560	329	368	330	229	1,256
Yes	11	18	18	7	54	50	39	31	31	151
Total	1,173	1,210	1,414	817	4,614	379	407	361	260	1,407

Table A.10 Work zone crashes and crash severities, Kansas

Crash severity	Daytime Work Zone Crashes					Nighttime Work Zone Crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
PDO	853	896	1,072	610	3,431	278	316	269	201	1,064
Injury	317	312	340	202	1,171	101	86	87	59	333
Fatal	3	2	2	5	12		5	5		10
Total	1,173	1,210	1,414	817	4,614	379	407	361	260	1,407

Table A.11 Driver age distribution among work zone crashes, Kansas

	Daytime work zone crashes					Nighttime work zone crashes				
Driver age	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
<25	641	683	848	463	2,635	202	230	204	151	787
26-35	430	455	578	321	1,784	116	139	137	77	469
36-45	372	373	497	232	1,474	86	104	85	62	337
46-55	385	362	427	227	1,401	83	93	74	61	311
56-65	275	306	318	199	1,098	59	67	78	32	236
66-75	125	139	137	86	487	17	14	18	13	62
>75	83	80	95	68	326	10	6	9	6	31
Total	2,311	2,398	2,900	1,596	9,205	573	653	605	402	2,233

Table A.12 Driver (at-fault) gender distribution among work zone crashes, Kansas

	Daytime work zone crashes					Nighttime work zone crashes				
Driver Gender	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Male	1,293	1,328	1,596	903	5,120	357	372	342	234	1,305
Female	982	941	1,248	666	3,837	199	249	237	146	831
Total	2,275	2,269	2,844	1,569	8,957	556	621	579	380	2,136

Table A.13 Safety equipment usage of at-fault driver in work zone crashes, Kansas

Safety equipment usage	Daytime work zone crashes					Daytime work zone crashes				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Used	2,150	2,160	2,744	1,500	8,554	502	582	545	344	1,973
None Used	45	28	36	24	133	14	17	15	8	54
Total	2,195	2,188	2,780	1,524	8,687	516	599	560	352	2,027

Table A.14 Crash statistics for daytime and nighttime work zone crashes

Crash Attributes	Daytime		Nighttime		*Total number*
	Number	%	Number	%	
Accident Class					
Non-collision	164	4%	113	8%	*277*
Collision with other vehicle or object	4,450	96%	1,280	92%	*5,730*
Total	*4,614*	*100%*	*1,393*	*100%*	*6,007*
Weather Condition					
No adverse weather	4,195	91%	1,195	85%	*5,390*
Rain	306	7%	137	10%	*443*
Snow	64	1%	55	4%	*119*
Other	46	1%	17	1%	*63*
Total	*4,611*	*100%*	*1,404*	*100%*	*6,015*
Work Zone Location					
Before first warning sign	211	5%	29	2%	*240*
Advance warning area	643	14%	148	11%	*791*
Transition area	774	17%	227	17%	*1,001*
Activity area	2,654	59%	859	65%	*3,513*
Termination area	185	4%	66	5%	*251*
Total	*4,467*	*100%*	*1,329*	*100%*	*5,796*
Work Zone Category					
Lane closure	2,335	55%	629	52%	*2,964*
Lane shift or crossover	698	17%	255	21%	*953*
Work on shoulder or median	1,016	24%	298	25%	*1,314*
Intermittent or moving vehicle	174	4%	24	2%	*198*
Total	*4,223*	*100%*	*1,206*	*100%*	*5,429*
Surface Condition					
Dry	4,076	89%	1,136	81%	*5,212*
Other	526	11%	266	19%	*792*
Total	*4,602*	*100%*	*1,402*	*100%*	*6,004*

Table A.14 (Contd.) Crash statistics for daytime and nighttime work zone crashes

Crash Attributes	Daytime		Nighttime		*Total number*
	Number	%	Number	%	
Surface Type					
Concrete	1,992	43%	579	41%	*2,571*
Asphalt	2,568	56%	796	57%	*3,364*
Other	47	1%	27	2%	*74*
Total	*4,607*	*100%*	*1,402*	*100%*	*6,009*
Collision Pattern With Other Vehicle					
Head-on	58	2%	34	5%	*92*
Rear-end	2,396	64%	390	56%	*2,786*
Angle (side impact)	755	20%	154	22%	*909*
Sideswipe	524	14%	114	16%	*638*
Total	*3,733*	*100%*	*692*	*100%*	*4,425*
Crash Location					
On roadway	4,412	2263%	1,258	862%	*5,670*
Off roadway	195	4%	146	10%	*341*
Total	*4,607*	*2267%*	*1,404*	*872%*	*6,011*
Alcohol Involvement					
Yes	4560	99%	1,256	89%	*5,816*
No	54	1%	151	11%	*205*
Total	*4,614*	*100%*	*1,407*	*100%*	*6,021*
Crash Severity					
Not injured	3,287	78%	913	77%	*4,200*
Possible injury	526	12%	124	10%	*650*
Injury - not incapacitating	315	7%	113	10%	*428*
Injury - incapacitating (disabling)	78	2%	27	2%	*105*
Fatal injury	8	0%	6	1%	*14*
Total	*4,214*	*100%*	*1,183*	*100%*	*5,397*
Driver Age					
<25	1,567	34%	524	37%	2,091
26-35	818	18%	304	22%	1,122
36-45	620	13%	193	14%	813
46-55	630	14%	179	13%	809
56-65	490	11%	140	10%	630
66-75	273	6%	42	3%	315
>75	210	5%	20	1%	230
Total	4,608	100%	1,402	100%	6,010

Table A.14 (Contd.) Crash statistics for daytime and nighttime work zone crashes

Crash Attributes	Daytime work zone		Nighttime work zone		Total number
	Number	%	Number	%	
Road geometry - grade					
Grade	1,430	31%	425	30%	1,855
Not Grade	3,179	69%	978	70%	4,157
Total	4,609	100%	1,403	100%	6,012
Road geometry - Curvature					
Straight	4,180	91%	1,225	87%	5,405
not straight	429	9%	178	13%	607
Total	4,609	100%	1,403	100%	6,012
Occupancy of the at-fault vehicle					
Driver only	603	13%	510	36%	1,113
More than the driver	4,006	87%	889	64%	4,895
Total	4,609	100%	1,399	100%	6,008
Damage to the at-fault vehicle					
None	153	3%	17	1%	170
Minor Damage	1,167	25%	228	16%	1,395
Functional damage	1,587	34%	394	28%	1,981
Disabling damage	1,384	30%	595	42%	1,979
Destroyed	156	3%	113	8%	269
Other	159	3%	54	4%	213
Total	4,606	100%	1,401	100%	6,007
Heavy vehicle involvement					
Yes	578	13%	115	8%	693
No	4,031	87%	1,288	92%	5,319
Total	4,609	100%	1,403	100%	6,012
Number of lanes					
1	246	5%	87	6%	333
2	1,386	30%	471	34%	1,857
3	285	6%	77	5%	362
4	2,348	51%	670	48%	3,018
5	326	7%	87	6%	413
Other	18	0%	11	1%	29
Total	4,609	100%	1,403	100%	6,012

Table A.14 (Contd.) Crash statistics for daytime and nighttime work zone crashes

Crash Attributes	Daytime work zone		Nighttime work zone		*Total number*
	Number	%	Number	%	
License compliance					
Not licensed	73	2%	28	2%	101
Valid license	4,181	94%	1,183	91%	5,364
Suspended	102	2%	58	4%	160
Revoked	17	0%	14	1%	31
Expired	23	1%	10	1%	33
Cancelled or denied	1	0%	-	0%	1
Restricted	29	1%	8	1%	37
Total	4,426	100%	1,301	100%	5,727
Local driver					
Kansas	3,571	81%	1,019	79%	4,590
Out of state	828	19%	269	21%	1,097
Total	4,399	100%	1,288	100%	5,687
Vehicle maneuver before unstable situation					
Straight	2,673	59%	917	68%	3,590
Slowing or stopping	401	9%	77	6%	478
Left turn	356	8%	75	6%	431
changing lanes	326	7%	79	6%	405
Avoidance man.	204	5%	66	5%	270
Merging	151	3%	45	3%	196
Right turn	109	2%	24	2%	133
Backing	100	2%	12	1%	112
Passing	50	1%	16	1%	66
Other	156	3%	47	3%	203
Total	4,526	100%	1,358	100%	5,884
Driver ejection					
Trapped	4,525	99%	1,341	98%	5,866
Ejected	23	1%	26	2%	49
Total	4,548	100%	1,367	100%	5,915
Road class					
Freeway	1,497	33%	493	35%	1,990
Other	3,107	67%	910	65%	4,017
Total	4,604	100%	1,403	1	6,007

Appendix B - Work Zone Versus Non-work Zone Crash Statistics

Table B.1 A accident class statistics of work zone and non-work zone crashes: 2010–2013

Accident class	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Day	Night	
Non-collision	164	4%	113	8%	2,170	4%	1,346	5%	277	3,516	2,334	1,459	7,586
Collision with other	4,450	96%	1,280	92%	54,761	96%	24,816	95%	5,730	79,577	59,211	26,096	170,614
Total	4,614	100%	1,393	100%	56,931	100%	26,162	100%	6,007	83,093	61,545	27,555	178,200

Categories in "Non-collision" include overturned, rollover, or other non-collision crashes. Categories for "Collision with other" include collision with pedestrian, motor vehicle in-transport, legally parked vehicle, railway train, pedal cyclist, animal type, fixed object, and other object.

Table B.2 Weather condition statistics of work zone crashes and non-work zone crashes: 2010–2013

Weather	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Day	Night	
No adverse weather	4,195	91%	1,195	85%	50,219	88%	21,824	83%	5,390	72,043	54,414	23,019	154,866
Rain	306	7%	137	10%	4,305	8%	2,727	10%	443	7,032	4,611	2,864	14,950
Snow	64	1%	55	4%	1,722	3%	1,128	4%	119	2,850	1,786	1,183	5,938
Other	46	1%	17	1%	663	1%	470	2%	63	1,133	709	487	2,392
Total	4,611	100%	1,404	100%	56,909	100%	26,149	100%	6,015	83,058	61,520	27,553	178,146

Rain:
(01. rain, mist, drizzle), (02. sleet, hail), (08. freezing rain, mist, drizzle), (14. rain, fog), (16. rain and wind), and (24. sleet and fog)
Snow: (03. snow) and (36. snow and wind)
Other: (04. fog), (05. smoke), (06. strong wind), (07. blowing dust, sand, etc.), and (88. other)

Note: wz = work zone, Non-wz = non-work zone

Table B.3 Surface type statistics of work zone crashes and non-work zone crashes: 2010–2013

Surface type	Work Zone				Non- WZ*				WZ*	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Day	Night	
Concrete	1,992	43%	579	41%	14,831	26%	5,875	23%	2,571	20,706	16,823	6,454	46,554
Asphalt	2,568	56%	796	57%	38,941	69%	18,194	70%	3,364	57,135	41,509	18,990	120,998
Other	47	1%	27	2%	3,074	5%	2,036	8%	74	5,110	3,121	2,063	10,368
Total	4,607	100%	1,402	100%	56,846	100%	26,105	100%	6,009	82,951	61,453	27,507	177,920

Other: gravel, dirt, brick and other

Table B.4 Surface condition statistics of work zone crashes and non-work zone crashes: 2010–2013

Surface condition	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Day	Night	
Dry	4076	89%	1136	81%	47941	84%	20700	79%	5,212	68,641	52,017	21,836	147,706
Other	526	11%	266	19%	8900	16%	5428	21%	792	14,328	9,426	5,694	30,240
Total	4602	100%	1402	100%	56841	100%	26128	100%	6004	82969	61443	27530	177946

Other: wet, snow, ice, mud/dirt/sand, debris (oil, etc.), standing/moving water, slush, and other

Table B.5 Collision pattern statistics of work zone and non-work zone crashes: 2010–2013

Collision pattern with the other Vehicle	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
Head-on	58	2%	34	5%	1,648	4%	802	7%	92	2,450	1,706	836	5,084
Rear-end	2,396	63%	390	55%	10,784	23%	2,348	20%	2,786	13,132	13,180	2,738	31,836
Angle-side impact	755	20%	154	22%	28,484	61%	7,025	61%	909	35,509	29,239	7,179	72,836
Sideswipe	524	14%	114	16%	3,858	8%	1,133	10%	638	4,991	4,382	1,247	11,258
Other	84	2%	13	2%	1,595	3%	259	2%	97	1,854	1,679	272	3,902
Total	3,817	1	705	1	46,369	1	11,567	1	4,522	57,936	50,186	12,272	124,916

Sideswipe = (Sideswipe: opposite direction) and (Sideswipe: same direction)

Note: wz = work zone

Table B.6 Alcohol involvement statistics of work zone and non-work zone crashes: 2010–2013

Alcohol involvement	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
Yes	4,560	99%	1,256	89%	56,252	99%	23,702	90%	5,816	79,954	60,812	24,958	171,540
No	54	1%	151	11%	746	1%	2,508	10%	205	3,254	800	2,659	6,918
Total	4,614	100%	1,407	100%	56,998	100%	26,210	100%	6,021	83,208	61,612	27,617	178,458

Table B.7 Crash severity (3-level) statistics of work zone and non-work zone crashes: 2010–2013

Crash severity	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
PDO	3,431	74%	1,064	76%	40,988	72%	20,289	77%	4,495	61,277	44,419	21,353	131,544
Injury	1,171	25%	333	24%	15,744	28%	5,758	22%	1,504	21,502	16,915	6,091	46,012
Fatal	12	0%	10	1%	266	0%	163	1%	22	429	278	173	902
Total	4,614	100%	1,407	100%	56,998	100%	26,210	100%	6,021	83,208	61,612	27,617	178,458

Table B.8 Crash severity (5-level) statistics of work zone and non-work zone crashes: 2010–2013

Crash severity	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Day	Night	
Not injured	3,553	78%	1057	77%	42,046	76%	19,924	81%	4,610	61,970	45,599	20,981	133,160
Possible injury	578	13%	143	10%	7,137	13%	2,292	9%	721	9,429	7,715	2,435	20,300
Injury - not incapacitating	345	8%	131	10%	5,099	9%	1,943	8%	476	7,042	5,444	2,074	15,036
Injury - incapacitating	84	2%	31	2%	1,034	2%	441	2%	115	1,475	1,118	472	3,180
Fatal injury	8	0%	6	0%	208	0%	129	1%	14	337	216	135	702
Total	4,568	100%	1368	100%	55,524	100%	24,729	100%	5,936	80,253	60,092	26,097	172,378

Note wz = work zone

Table B.9 Driver age group statistics of work zone and non-work zone crashes: 2010–2013

Driver Age	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
<25	2,635	29%	787	35%	32,619	31%	14,556	39%	3,422	47,175	35,254	15,343	101,194
26-35	1,784	19%	469	21%	18,884	18%	7,152	19%	2,253	26,036	20,668	7,621	56,578
36-45	1,474	16%	337	15%	14,929	14%	5,316	14%	1,811	20,245	16,403	5,653	44,112
46-55	1,401	15%	311	14%	15,227	14%	5,111	14%	1,712	20,338	16,628	5,422	44,100
56-65	1,098	12%	236	11%	12,106	11%	3,360	9%	1,334	15,466	13,204	3,596	33,600
66-75	487	5%	62	3%	6,583	6%	1,362	4%	549	7,945	7,070	1,424	16,988
>75	326	4%	31	1%	5,280	5%	686	2%	357	5,966	5,606	717	12,646
Total	9,205	100%	2,233	100%	105,628	100%	37,543	100%	11,438	143,171	114,833	39,776	309,218

Table B.10 Driver gender statistics of work zone and non-work zone crashes: 2010–2013

Driver Gender	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
Male	5,120	57%	1,305	61%	54,592	53%	21,455	60%	6,425	76,047	59,712	22,760	164,944
Female	3,837	43%	831	39%	49,141	47%	14,408	40%	4,668	63,549	52,978	15,239	136,434
Total	8,957	100%	2,136	100%	103,733	100%	35,863	100%	11093	139,596	112,690	37,999	301,378

Table B.11 Statistics of driver's use of safety equipment in work zone and non-work zone crashes: 2010–2013

Safety equipment use	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
Used	8,554	98%	1,973	97%	96515	98%	32191	96%	10,527	128,706	105,069	34,164	278,466
None Used	133	2%	54	3%	2462	2%	1258	4%	187	3,720	2,595	1,312	7,814
Total	8,687	100%	2,027	100%	98,977	100%	33,449	100%	10,714	132,426	107,664	35,476	286,280

Table B.12 Day of crash statistics of work zone and non-work zone crashes: 2010–2013

Day	Work Zone				Non-work Zone				WZ	Non-wz	Total	Total	Total
	Daytime		Nighttime		Daytime		Nighttime		Total	Total	Daytime	Nighttime	
Weekday	3,838	83%	1,006	72%	45,583	80%	18,167	69%	4,844	63,750	49,421	19,173	137,188
Weekends	775	17%	400	28%	11,405	20%	8,029	31%	1,175	19,434	12,180	8,429	41,218
Total	4,613	100%	1,406	100%	56,988	100%	26,196	100%	6,019	83,184	61,601	27,602	178,406

Note: wz = work zone

Appendix C - Sample of Pearson Correlation Matrix: Single-vehicle Work Zone Crashes

	SEVERE	WE_1	SRT_1	SRT_2	SR_DRY	NO_ALC	AGE_0	AGE_1	AGE_2	AGE_3	GEND
WE_1	0.054										
p-value	0.039										
SRT_1	0.024	0									
p-value	0.361	0.999									
SRT_2	-0.017	-0.002	-0.915								
p-value	0.517	0.926	0								
SR_DRY	0.018	**0.754**	-0.007	0.021							
p-value	0.494	**0**	0.793	0.417							
NO_ALC	-0.125	-0.091	-0.068	0.056	-0.076						
p-value	0	0	0.009	0.031	0.003						
AGE_0	0.032	0.036	-0.025	0.053	0.069	0.085					
p-value	0.22	0.171	0.336	0.043	0.008	0.001					
AGE_1	0.026	-0.024	0.006	-0.005	-0.036	-0.104	**-0.536**				
p-value	0.314	0.35	0.817	0.838	0.167	0	**0**				
AGE_2	-0.013	0.001	0.013	0.001	0.023	0.028	0.318	**-0.738**			
p-value	0.612	0.967	0.627	0.954	0.376	0.282	0	**0**			
AGE_3	0.034	0.044	-0.038	0.043	0.041	0.066	**0.581**	-0.175	-0.398		
p-value	0.196	0.091	0.149	0.095	0.118	0.011	**0**	0	0		
GEND	0.035	0.04	-0.007	0.009	0.048	-0.039	0.187	-0.009	0.075	0.053	
p-value	0.176	0.125	0.776	0.718	0.066	0.131	0	0.74	0.004	0.042	
REST	-0.096	-0.036	0.007	0.02	-0.011	0.129	0.272	-0.005	0.186	0.035	0.056
p-value	0	0.17	0.78	0.435	0.686	0	0	0.854	0	0.183	0.032

Appendix D - Identification of "Driver-at-fault"

A total of 4,548 multiple-vehicle work zone crashes occurred from 2010 to 2013. Because more than one driver is given a driver contributing circumstance (CC) and because one driver is given more than one driver CC, the total number CCs is greater than the total number of crashes. The following steps were carried out to identify the driver responsible for a crash:

1. Take all multiple-vehicle crash ID's with all drivers CCs or driver factors (DFs) and related traffic unit numbers.
2. DFs are divided into driver condition, driver distracted by, and driver action at the time of crash. Driver action is more likely to cause the crash, therefore, DFs should be recoded as 1 (1-6), 2 (20-24), and 3 (30-48).
3. Filter out the "00"s because those drivers cannot be the responsible driver.
4. A total of "88" or "99" does not indicate no DF for that driver. Therefore, these records should be filtered and kept separate for future use.
5. Separate DFs for TU#1, TU#2, etc, thereby showing more than one DF for one TU.
6. Consider each TU individually. This study involved up to six vehicles. Therefore, this procedure must be carried out six times.
7. Take a count of crash IDs (00s and 99s must be removed). When the count is more than 1, that driver could be the responsible driver.
8. Include a column of all multiple-vehicle work zone crash IDs without duplicates in a sheet.
9. Add six columns for each TU and enter the number of DFs using *vlookup* for each TU.
10. Add additional six columns for TUs, in which the largest DF for the particular TU is called out using *vlookup*.
11. Add two columns, one for comparison of the number of DFs per TU, and obtain the highest and the next to compare the largest DF. TU # must be called out using "If" command.
12. The last two columns must be used to decide the responsible driver.
13. Both columns should give the TU. If not follow step 14 or 15
14. When the last two columns are different, TU with the largest DF is selected as the responsible driver.
15. When more than one TU have similar DF values (e.g., 3), TU with highest DF count is considered to be the responsible driver.

Table D.1 Driver contributory causes (CCs) for multiple-vehicle work zone crashes (2010-2013)

Code	Driver CC	Frequency	Percentage	Code	Driver CC	Freq.	Percentage
33	Followed too closely	1,482	22%	88	Other	36	1%
24	Inattention (general sense)	1,409	21%	40	Aggressive / Antagonistic driving	35	1%
0	No driver contributing circumstance evident	1,279	19%	47	Wrong side or wrong way	35	1%
30	Failed to yield the right of way	547	8%	39	Reckless / Careless driving	32	0%
35	Too fast for conditions	415	6%	5	Fell asleep or fatigued	27	0%
41	Improper lane change	308	5%	21	Other electronic devices (audio, video, GPS,	25	0%
31	Disregarded traffic signs, signals, or markings	173	3%	38	Over correction / Over steering	18	0%
37	Avoidance or evasive action	131	2%	6	Emotional: Angry, depressed, upset, impatient,	17	0%
99	Unknown	128	2%	34	Exceeded posted speed limit	14	0%
32	Red light running (disregarded traffic signal)	110	2%	3	Under the influence of medication	13	0%
42	Made improper turn	102	2%	36	Impeding or Too slow for traffic	13	0%
22	Other distraction in or on vehicle	99	1%	48	Did not comply with license restrictions	13	0%
2	Under the influence of alcohol	82	1%	4	Ill or Medical condition	11	0%
23	An item or action NOT in or on vehicle	62	1%	1	Under the influence of illegal Drugs	10	0%
43	Improper backing	51	1%	45	Improper or No turn signal	4	0%
44	Improper passing	50	1%	46	Improper parking	3	0%
20	Mobile (cell) phone (calling, texting, other	46	1%	Total		6,780	100%

Appendix E - Sample Work Zone Alert by KDOT

ALERT ID	2904
CONSTRUCTION PROJECT NUMBER	435-46 KA-2100-01
BEGINNING LRS ROUTE	I0043500S0
BEGINNING COUNTY NAME	JOHNSON
ENDING STATE LOG MILE	1.5
BEGINNING STATE LOG MILE	2.3
START DATE	25-Apr-14
EXPIRE DATE	30-Nov-14
WIDTH RESTRICTION	0
SPEED RESTRICTION	0
PUBLIC COMMENT	Occurrence located between 1.75 - ROE - (Route Intersection) and 1.75 - ROE - (Route Intersection) On Friday, April 25, construction work for a new diverging diamond interchange will begin at the existing I-435 and Roe Avenue interchange in Johnson County. Project work includes replacing the existing diamond interchange with a new diverging diamond style interchange, along with reconstruction of the Roe Avenue bridges. Work will take place during daylight hours, Monday through Friday, with some occasional weekend work. Beginning on Friday, April 25 and through the first two weeks of May, project work will include the setting of traffic control, grading work for the eastbound I-435 collector-distributor ramp lane crossover, and drilling investigative core holes for the new bridge piers. There will be periodic lane closures on both I-435 and the collector-distributor system for this early project work. Traffic will be directed through the project work zone via cones and signage. The Roe Avenue Bridge will be closed to all through traffic while the interchange improvements are made. This portion of the project is planned to be completed in 4-5 months and is tentatively scheduled for mid-May through mid-October 2014, weather permitting. Roe Avenue bridge demolition work is scheduled for one weekend sometime in May 2014 with a full closure of I-435 overnight during that same weekend. Project work is scheduled to be completed in late November 2014.

Appendix F - Work Zones Selected for the Frequency Model and Their Features

Project Number			Route		Year	County	Start Date	End Date	Start log mile	End log mile	Total crashes	PDO	Fatal + Injury
KA	2100	1	I	435	2014	Johnson	4/25/2014	11/30/2014	1.5	2.3	40	26	14
KA	733	1	I	135	2014	Sedgwick	6/23/2014	11/26/2014	10.21	17.22	36	30	6
KA	3661	1	U	69	2014	Johnson	10/7/2014	11/30/2014	143.3	144.1	34	30	4
KA	410	4	K	18	2013	Riley	4/11/2013	11/30/2013	188.6	183.2	24	19	5
K	8251	8	U	69	2013	Johnson	3/11/2013	10/31/2013	143.0	144.8	21	15	6
KA	732	1	I	70	2014	Dickinson	3/17/2014	11/8/2014	272.6	284.3	16	16	0
KA	3971	1	K	10	2014	Johnson	9/29/2014	12/10/2014	25.7	36.2	15	12	3
KA	732	1	I	70	2013	Dickinson	5/13/2013	11/30/2013	274.2	284.3	15	12	3
KA	3169	1	I	70	2014	Shawnee	5/27/2014	12/31/2014	359.6	361.9	14	13	1
KA	2833	1	I	70	2013	Wabaunsee	3/20/2013	8/1/2013	341.0	350.0	14	12	2
KA	2814	1	I	635	2013	Wyandotte	7/10/2013	12/20/2013	5.3	6.1	10	4	6
KA	2994	1	K	96	2013	Sedgwick	4/1/2013	9/27/2013	289.6	296.1	10	8	2
KA	2040	1	I	235	2014	Sedgwick	3/12/2014	11/21/2014	8.1	10.1	9	5	4
KA	3297	1	K	96	2014	Sedgwick	5/12/2014	11/14/2014	289.6	300.7	8	6	2
KA	2978	1	U	169	2013	Allen	3/4/2013	11/30/2013	54.3	69.2	8	5	3
KA	718	1	I	70	2013	Sherman	3/18/2013	10/12/2013	0.0	12.3	8	4	4
KA	461	1	U	24	2013	Shawnee	3/28/2013	11/23/2013	367.5	368.3	8	7	1
KA	2783	1	I	35	2014	Johnson	8/4/2014	10/4/2014	223.9	227.0	8	4	4
KA	1003	5	K	7	2014	Wyandotte	5/27/2014	8/30/2014	167.3	166.7	7	6	1
KA	3479	1	K	156	2014	Pawnee	3/6/2014	7/1/2014	75.8	101.0	7	5	2
KA	2092	1	U	73	2014	Wyandotte	5/1/2014	9/30/2014	2.6	3.7	7	5	2
KA	2205	1	K	68	2014	Franklin	4/7/2014	11/26/2014	27.9	29.8	6	5	1
KA	2184	1	U	75	2013	Shawnee	8/1/2013	11/5/2013	146.8	137.8	6	5	1
KA	3099	1	I	135	2013	Saline	5/10/2013	12/20/2013	76.9	96.0	5	3	2

Project Number			Route		Year	County	Start Date	End Date	Start log mile	End log mile	Total crashes	PDO	Fatal + Injury
KA	2213	1	U	54	2013	Kiowa	5/27/2013	10/18/2013	107.2	123.2	5	5	0
KA	3325	1	U	56	2013	Johnson	8/20/2013	10/31/2013	470.4	469.4	5	5	0
N	547	1	U	169	2014	Johnson	4/21/2014	8/30/2014	146.5	147.3	4	4	0
KA	3487	1	U	160	2014	Sumner	5/5/2014	10/3/2014	297.2	316.7	4	1	3
KA	3097	1	I	435	2013	Johnson	6/24/2013	7/25/2013	10.3	13.0	4	3	1
KA	2845	1	I	235	2013	Sedgwick	6/3/2013	7/15/2013	11.5	12.2	4	4	0
KA	2912	1	U	56	2013	Johnson	4/15/2013	8/24/2013	447.5	448.5	4	4	0
KA	2980	1	K	96	2013	Sedgwick	7/15/2013	10/4/2013	279.5	285.0	4	3	1
KA	3604	1	I	35	2014	Johnson	6/2/2014	10/30/2014	203.9	204.3	3	3	0
KA	7431	1	U	24	2014	Shawnee	2/24/2014	12/31/2014	364.4	363.3	3	1	2
KA	739	1	U	36	2013	Norton	5/1/2013	7/5/2013	117.3	122.5	3	2	1
KA	2185	1	U	75	2014	Shawnee	3/13/2014	7/16/2014	138.3	146.8	3	3	0
KA	3529	1	U	73	2014	Leavenworth	7/7/2014	12/30/2014	26.0	16.5	3	2	1
KA	2885	1	U	50	2013	Lyon	4/8/2013	5/17/2013	344.8	350.4	3	3	0
KA	2402	1	U	77	2013	Geary	7/15/2013	11/15/2013	156.8	157.6	3	2	1
U	15	1	U	59	2013	Douglas	3/11/2013	11/1/2013	153.5	154.5	3	3	0
KA	3475	1	U	50	2014	Reno	6/9/2014	11/7/2014	244.5	273.7	2	2	0
KA	3463	1	U	169	2014	Miami	7/10/2014	9/12/2014	137.8	139.4	2	2	0
KA	3445	1	K	9	2014	Norton	4/7/2014	5/16/2014	13.6	29.7	2	1	1
KA	2898	1	U	24	2013	Pottawatomie	6/10/2013	10/13/2013	317.4	329.8	2	2	0
KA	2996	1	U	54	2013	Pratt	4/1/2013	5/24/2013	139.7	144.5	1	1	0
KA	2877	1	K	99	2014	Marshall	4/24/2014	6/30/2014	215.0	196.0	1	1	0
KA	2925	1	K	15	2014	Dickinson	3/16/2014	6/21/2014	177.5	206.6	0	0	0
KA	3611	1	U	36	2014	Republic	6/25/2014	8/8/2014	239.9	253.7	0	0	0
KA	3778	1	K	15	2014	Cowley	9/29/2014	12/19/2014	53.1	61.8	0	0	0
KA	3377	1	K	9	2014	Marshall	7/7/2014	9/22/2014	248.5	286.7	0	0	0
KA	3404	1	U	77	2014	Marshall	8/18/2014	9/3/2014	218.3	194.2	0	0	0

Appendix G - Correlation of Variables for Total Work Zone Crash Counts

Spearman Correlation Coefficients, N = 51

Prob > |r| under H0: Rho=0

	lnAADT	DAYS	MILES	PILOTCAR	WIDTH_R	SPEED_R	NIGHT	WKEND	FLAGGER	ARROWBO	ADVMSGBO	OLANEON	TLANEON	OLANEOFF	TLANEOFF	DETOUR	RAMPCLOSR	CLASS	URBAN
lnAADT	1	0.15785	-0.65291	-0.70623	-0.30431	0.13179	0.34065	0.09552	-0.51334	0.30571	0.41268	-0.13936	0.07686	0.02198	0.15018	0.31866	0.48804	-0.72155	0.75411
		0.2686	<.0001	<.0001	0.0299	0.3566	0.0144	0.5049	0.0001	0.0291	0.0026	0.3294	0.5919	0.8783	0.2929	0.0227	0.0003	<.0001	<.0001
DAYS		1	-0.14328	-0.40342	0.1249	0.18292	0.06582	0.20749	-0.30872	-0.15571	0.08389	-0.35039	-0.05766	0.11935	0.24362	0.23258	0.28569	-0.29698	0.04797
			0.3158	0.0033	0.3825	0.1989	0.6463	0.144	0.0275	0.2752	0.5584	0.0117	0.6878	0.4042	0.0849	0.1005	0.0421	0.0343	0.7382
MILES			1	0.64654	0.31752	-0.1023	0.03875	-0.04033	0.40971	-0.04817	-0.33415	0.3216	-0.2308	-0.00471	-0.21814	-0.2112	-0.17097	0.40754	-0.69346
				<.0001	0.0232	0.475	0.7872	0.7787	0.0028	0.7371	0.0166	0.0214	0.1032	0.9738	0.1241	0.1368	0.2303	0.003	<.0001
PILOTCAR				1	0.275	-0.34966	-0.14688	-0.13183	0.73044	-0.16903	-0.33391	0.26968	-0.09562	-0.12306	-0.29163	-0.36607	-0.36607	0.70961	-0.57846
					0.0508	0.0119	0.3037	0.3565	<.0001	0.2357	0.0166	0.0556	0.5045	0.3896	0.0379	0.0082	0.0082	<.0001	<.0001
WIDTH_R					1	0.17901	0.02408	0.22652	0.22748	-0.01056	-0.19826	-0.14688	0.09562	0.02344	0.05924	-0.18036	0.00179	0.15802	-0.26685
						0.2088	0.8668	0.11	0.1084	0.9413	0.1631	0.3037	0.5045	0.8703	0.6797	0.2053	0.9901	0.2681	0.0584
SPEED_R						1	0.11731	0.09219	-0.06843	0.04949	0.03128	-0.00226	0.12318	0.4502	0.0491	0.07696	0.07696	-0.35197	0.14131
							0.4123	0.5199	0.6333	0.7302	0.8275	0.9875	0.3892	0.0009	0.7323	0.5914	0.5914	0.0113	0.3226
NIGHT							1	0.1377	-0.05347	0.14245	-0.05347	-0.00649	-0.05641	0.08692	0.14132	-0.02408	0.22152	-0.29148	0.29278
								0.3353	0.7094	0.3187	0.7094	0.9639	0.6942	0.5442	0.3226	0.8668	0.1182	0.038	0.0371
WKEND								1	0.02821	-0.15378	0.02821	-0.26538	-0.08699	0.13405	0.21794	-0.13183	0.15225	-0.22631	-0.07583
									0.8442	0.2813	0.8442	0.0598	0.5439	0.3484	0.1244	0.3565	0.2862	0.1103	0.5969
FLAGGER									1	-0.12347	-0.2439	0.19698	-0.06984	0.04109	-0.21302	-0.33391	-0.33391	0.50003	-0.38548
										0.388	0.0846	0.1659	0.6263	0.7746	0.1334	0.0166	0.0166	0.0002	0.0052
ARROWBO										1	0.08643	0.09972	-0.03536	-0.05778	-0.10783	0.01056	0.01056	-0.16169	0.25495
											0.5465	0.4863	0.8054	0.6871	0.4513	0.9413	0.9413	0.257	0.071
ADVMSGBO											1	-0.09005	-0.06984	0.04109	0.19438	0.3047	0.3047	-0.29619	0.20727
												0.5297	0.6263	0.7746	0.1717	0.0297	0.0297	0.0348	0.1445
OLANEON												1	-0.35456	0.18174	-0.61136	-0.09872	-0.22152	0.07639	-0.1788
													0.0107	0.2018	<.0001	0.4907	0.1182	0.5942	0.2094
TLANEON													1	0.07845	-0.061	-0.09562	-0.09562	-0.0449	0.14422
														0.5843	0.6707	0.5045	0.5045	0.7544	0.3126
OLANEOFF														1	-0.39627	-0.02344	-0.02344	-0.15492	-0.01088
															0.004	0.8703	0.8703	0.2777	0.9396
TLANEOFF															1	0.17316	0.05696	-0.14266	0.11631
																0.2243	0.6914	0.318	0.4163
DETOUR																1	0.54464	-0.26834	0.18232
																	<.0001	0.0569	0.2004
RAMPCLOSR																	1	-0.50389	0.26685
																		0.0002	0.0584
CLASS																		1	-0.37222
																			0.0072
URBAN																			1

Appendix H - Correlation of the Variables for Work Zone EPDO Crashes

Spearman Correlation Coefficients, N = 50																	
Prob > |r| under H0: Rho=0																	
	lnAADT	PILOTCAR	WIDTH_R	SPEED_R	NIGHT	WKEND	FLAGGER	ARROWBO	ADVMSGBO	OLANEON	TLANEON	OLANEOFF	TLANEOFF	DETOUR	RAMPCLOSR	CLASS	URBAN
lnAADT	1	-0.70711	-0.26765	0.1755	0.36147	0.04581	-0.51279	0.31805	0.44003	-0.15777	0.08415	0.00325	0.17012	0.35355	0.52884	-0.71205	0.749
		<.0001	0.0602	0.2228	0.0099	0.7521	0.0001	0.0244	0.0014	0.2738	0.5613	0.9822	0.2376	0.0118	<.0001	<.0001	<.0001
PILOTCAR		1	0.26197	-0.3718	-0.15322	-0.11339	0.72887	-0.17331	-0.343	0.27678	-0.098	-0.11645	-0.29939	-0.37868	-0.37868	0.70973	-0.57326
			0.0661	0.0078	0.2881	0.433	<.0001	0.2287	0.0147	0.0517	0.4984	0.4206	0.0347	0.0067	0.0067	<.0001	<.0001
WIDTH_R			1	0.15032	0.01258	0.28855	0.21822	-0.01838	-0.21822	-0.13836	0.09352	0.04088	0.04762	-0.20583	-0.01871	0.12565	-0.2446
				0.2974	0.9309	0.0421	0.1279	0.8992	0.1279	0.338	0.5183	0.7781	0.7426	0.1516	0.8974	0.3846	0.0869
SPEED_R				1	0.10978	0.13488	-0.08104	0.04436	0.02026	0.00701	0.12157	0.47061	0.03979	0.06255	0.06255	-0.39372	0.16871
					0.4479	0.3504	0.5758	0.7597	0.8889	0.9615	0.4004	0.0006	0.7838	0.6661	0.6661	0.0047	0.2415
NIGHT					1	0.15506	-0.05764	0.14077	-0.05764	-0.00332	-0.05764	0.09177	0.13836	-0.02966	0.21747	-0.30698	0.30458
						0.2823	0.6909	0.3295	0.6909	0.9817	0.6909	0.5262	0.338	0.838	0.1292	0.0301	0.0315
WKEND						1	0.0456	-0.14976	0.0456	-0.28646	-0.08468	0.11957	0.2388	-0.11339	0.17985	-0.19198	-0.11317
							0.7532	0.2993	0.7532	0.0437	0.5588	0.4082	0.0949	0.433	0.2114	0.1817	0.4339
FLAGGER							1	-0.12632	-0.25	0.20174	-0.07143	0.04683	-0.21822	-0.343	-0.343	0.49841	-0.3803
								0.382	0.0799	0.16	0.6221	0.7467	0.1279	0.0147	0.0147	0.0002	0.0064
ARROWBO								1	0.08422	0.10194	-0.03609	-0.05521	-0.11026	0.00722	0.00722	-0.17274	0.26296
									0.5609	0.4812	0.8035	0.7033	0.4459	0.9603	0.9603	0.2303	0.065
ADVMSGBO									1	-0.08646	-0.07143	0.04683	0.19094	0.30012	0.30012	-0.31488	0.22018
										0.5505	0.6221	0.7467	0.1841	0.0342	0.0342	0.0259	0.1244
OLANEON										1	-0.35407	0.17815	-0.61003	-0.09391	-0.21747	0.08919	-0.18921
											0.0116	0.2158	<.0001	0.5166	0.1292	0.5379	0.1882
TLANEON											1	0.08028	-0.06235	-0.098	-0.098	-0.05141	0.14869
												0.5794	0.6671	0.4984	0.4984	0.7229	0.3028
OLANEOFF												1	-0.39343	-0.01606	-0.01606	-0.14156	-0.0225
													0.0047	0.9118	0.9118	0.3268	0.8768
TLANEOFF													1	0.16841	0.05146	-0.15706	0.12667
														0.2424	0.7227	0.276	0.3807
DETOUR														1	0.54044	-0.29315	0.1991
															<.0001	0.0388	0.1657
RAMPCLOSR															1	-0.53384	0.28492
																<.0001	0.0449
CLASS																1	-0.35871
																	0.0105

Appendix I - Correlation of the Variables for PDO Work Zone Crashes

Spearman Correlation Coefficients, N = 51

Prob > |r| under H0: Rho=0

	lnAADT	PILOTCAR	WIDTH_R	SPEED_R	NIGHT	WKEND	FLAGGER	ARROWBO	ADVMSGBO	OLANEON	TLANEON	OLANEOFF	TLANEOFF	DETOUR	RAMPCLOSR	CLASS	URBAN
lnAADT	1	-0.70623	-0.30431	0.13179	0.34065	0.09552	-0.51334	0.30571	0.41268	-0.13936	0.07686	0.02198	0.15018	0.31866	0.48804	-0.72155	0.75411
		<.0001	0.0299	0.3566	0.0144	0.5049	0.0001	0.0291	0.0026	0.3294	0.5919	0.8783	0.2929	0.0227	0.0003	<.0001	<.0001
PILOTCAR		1	0.275	-0.34966	-0.14688	-0.13183	0.73044	-0.16903	-0.33391	0.26968	-0.09562	-0.12306	-0.29163	-0.36607	-0.36607	0.70961	-0.57846
			0.0508	0.0119	0.3037	0.3565	<.0001	0.2357	0.0166	0.0556	0.5045	0.3896	0.0379	0.0082	0.0082	<.0001	<.0001
WIDTH_R			1	0.17901	0.02408	0.22652	0.22748	-0.01056	-0.19826	-0.14688	0.09562	0.02344	0.05924	-0.18036	0.00179	0.15802	-0.26685
				0.2088	0.8668	0.11	0.1084	0.9413	0.1631	0.3037	0.5045	0.8703	0.6797	0.2053	0.9901	0.2681	0.0584
SPEED_R				1	0.11731	0.09219	-0.06843	0.04949	0.03128	-0.00226	0.12318	0.4502	0.0491	0.07696	0.07696	-0.35197	0.14131
					0.4123	0.5199	0.6333	0.7302	0.8275	0.9875	0.3892	0.0009	0.7323	0.5914	0.5914	0.0113	0.3226
NIGHT					1	0.1377	-0.05347	0.14245	-0.05347	-0.00649	-0.05641	0.08692	0.14132	-0.02408	0.22152	-0.29148	0.29278
						0.3353	0.7094	0.3187	0.7094	0.9639	0.6942	0.5442	0.3226	0.8668	0.1182	0.038	0.0371
WKEND						1	0.02821	-0.15378	0.02821	-0.26538	-0.08699	0.13405	0.21794	-0.13183	0.15225	-0.22631	-0.07583
							0.8442	0.2813	0.8442	0.0598	0.5439	0.3484	0.1244	0.3565	0.2862	0.1103	0.5969
FLAGGER							1	-0.12347	-0.2439	0.19698	-0.06984	0.04109	-0.21302	-0.33391	-0.33391	0.50003	-0.38548
								0.388	0.0846	0.1659	0.6263	0.7746	0.1334	0.0166	0.0166	0.0002	0.0052
ARROWBO								1	0.08643	0.09972	-0.03536	-0.05778	-0.10783	0.01056	0.01056	-0.16169	0.25495
									0.5465	0.4863	0.8054	0.6871	0.4513	0.9413	0.9413	0.257	0.071
ADVMSGBO									1	-0.09005	-0.06984	0.04109	0.19438	0.3047	0.3047	-0.29619	0.20727
										0.5297	0.6263	0.7746	0.1717	0.0297	0.0297	0.0348	0.1445
OLANEON										1	-0.35456	0.18174	-0.61136	-0.09872	-0.22152	0.07639	-0.1788
											0.0107	0.2018	<.0001	0.4907	0.1182	0.5942	0.2094
TLANEON											1	0.07845	-0.061	-0.09562	-0.09562	-0.0449	0.14422
												0.5843	0.6707	0.5045	0.5045	0.7544	0.3126
OLANEOFF												1	-0.39627	-0.02344	-0.02344	-0.15492	-0.01088
													0.004	0.8703	0.8703	0.2777	0.9396
TLANEOFF													1	0.17316	0.05696	-0.14266	0.11631
														0.2243	0.6914	0.318	0.4163
DETOUR														1	0.54464	-0.26834	0.18232
															<.0001	0.0569	0.2004
RAMPCLOSR															1	-0.50389	0.26685
																0.0002	0.0584
CLASS																1	-0.37222
																	0.0072

Appendix J - Correlation of the Variables for Fatal and Injury Work Zone Crashes

Spearman Correlation Coefficients, N = 51																
Prob > |r| under H0: Rho=0																
	PILOTCAR	WIDTH_R	SPEED_R	NIGHT	WKEND	FLAGGER	ARROWBO	ADVMSGBO	OLANEON	TLANEON	OLANEOFF	TLANEOFF	DETOUR	RAMPCLOSR	CLASS	URBAN
lnAADT	-0.7062	-0.3043	0.1318	0.3407	0.0955	-0.5133	0.3057	0.4127	-0.1394	0.0769	0.0220	0.1502	0.3187	0.4880	-0.7216	0.7541
	<.0001	0.0299	0.3566	0.0144	0.5049	0.0001	0.0291	0.0026	0.3294	0.5919	0.8783	0.2929	0.0227	0.0003	<.0001	<.0001
PILOTCAR	1.0000	0.2750	-0.3497	-0.1469	-0.1318	0.7304	-0.1690	-0.3339	0.2697	-0.0956	-0.1231	-0.2916	-0.3661	-0.3661	0.7096	-0.5785
		0.0508	0.0119	0.3037	0.3565	<.0001	0.2357	0.0166	0.0556	0.5045	0.3896	0.0379	0.0082	0.0082	<.0001	<.0001
WIDTH_R		1.0000	0.1790	0.0241	0.2265	0.2275	-0.0106	-0.1983	-0.1469	0.0956	0.0234	0.0592	-0.1804	0.0018	0.1580	-0.2669
			0.2088	0.8668	0.1100	0.1084	0.9413	0.1631	0.3037	0.5045	0.8703	0.6797	0.2053	0.9901	0.2681	0.0584
SPEED_R			1.0000	0.1173	0.0922	-0.0684	0.0495	0.0313	-0.0023	0.1232	0.4502	0.0491	0.0770	0.0770	-0.3520	0.1413
				0.4123	0.5199	0.6333	0.7302	0.8275	0.9875	0.3892	0.0009	0.7323	0.5914	0.5914	0.0113	0.3226
NIGHT				1.0000	0.1377	-0.0535	0.1425	-0.0535	-0.0065	-0.0564	0.0869	0.1413	-0.0241	0.2215	-0.2915	0.2928
					0.3353	0.7094	0.3187	0.7094	0.9639	0.6942	0.5442	0.3226	0.8668	0.1182	0.0380	0.0371
WKEND					1.0000	0.0282	-0.1538	0.0282	-0.2654	-0.0870	0.1341	0.2179	-0.1318	0.1523	-0.2263	-0.0758
						0.8442	0.2813	0.8442	0.0598	0.5439	0.3484	0.1244	0.3565	0.2862	0.1103	0.5969
FLAGGER						1.0000	-0.1235	-0.2439	0.1970	-0.0698	0.0411	-0.2130	-0.3339	-0.3339	0.5000	-0.3855
							0.3880	0.0846	0.1659	0.6263	0.7746	0.1334	0.0166	0.0166	0.0002	0.0052
ARROWBO							1.0000	0.0864	0.0997	-0.0354	-0.0578	-0.1078	0.0106	0.0106	-0.1617	0.2550
								0.5465	0.4863	0.8054	0.6871	0.4513	0.9413	0.9413	0.2570	0.0710
ADVMSGBO								1.0000	-0.0901	-0.0698	0.0411	0.1944	0.3047	0.3047	-0.2962	0.2073
									0.5297	0.6263	0.7746	0.1717	0.0297	0.0297	0.0348	0.1445
OLANEON									1.0000	-0.3546	0.1817	-0.6114	-0.0987	-0.2215	0.0764	-0.1788
										0.0107	0.2018	<.0001	0.4907	0.1182	0.5942	0.2094
TLANEON										1.0000	0.0785	-0.0610	-0.0956	-0.0956	-0.0449	0.1442
											0.5843	0.6707	0.5045	0.5045	0.7544	0.3126
OLANEOFF											1.0000	-0.3963	-0.0234	-0.0234	-0.1549	-0.0109
												0.0040	0.8703	0.8703	0.2777	0.9396
TLANEOFF												1.0000	0.1732	0.0570	-0.1427	0.1163
													0.2243	0.6914	0.3180	0.4163
DETOUR													1.0000	0.5446	-0.2683	0.1823
														<.0001	0.0569	0.2004
RAMPCLOSR														1.0000	-0.5039	0.2669
															0.0002	0.0584
CLASS															1.0000	-0.3722
																0.0072