DETERMINING THE EXTENT AND CHARACTERISTICS OF OVERREPRESENTATION OF LARGE TRUCK CRASHES IN DAYTIME AND NIGHTTIME WORK ZONES

A Thesis

by

NAVEEN MOKKAPATI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Civil Engineering

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Approved by:

Chair of Committee, Gene H. Hawkins, Jr.
Committee Members, Dominique Lord
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ABSTRACT

Determining the Extent and Characteristics of Overrepresentation of Large Truck Crashes in Daytime and Nighttime Work Zones. (December 2007)

Naveen Mokkapati, B.Tech., Indian Institute of Technology Madras

Chair of Advisory Committee: Dr. Gene H. Hawkins, Jr.

The growth of vehicle travel in the United States has accelerated wear on the interstate highway system leading to frequent pavement repair and rehabilitation projects. The presence of work zones not only causes traffic congestion and backup but also increases the crash risk. Therefore, the FHWA (Federal Highway Administration) has allotted a significant amount of funds to improve work zone traffic safety and operations.

This thesis compares truck and automobile crash characteristics in work zones with those of non-work zones and thus identifies engineering countermeasures to improve work zone truck safety. The researcher used a contingency analysis approach in this study. First, he categorized the North Carolina crash data using different variables. Once categorized, the Breslow-Day test is used to compare the odds of truck and automobile crashes between work zones and non-work zones. Overall, the researcher did not find a significant difference between odds of truck and automobile crashes compared to previous studies. The researcher believes that the difference in results between the present study and the previous studies could either be due to differences in the approach used or better truck management techniques employed by the North Carolina DOT (Department of Transportation).

The researcher also identified that the maintenance projects performed during the day had a significantly higher odds of truck crashes relative to that of automobiles in work zones compared to control sections when workers were present, either with a lane closure or without a lane closure. The researcher believes that the results from the day maintenance projects and its subcategories are the key findings of this study. Therefore,

these key findings are used to identify the possible reasons and countermeasures for any disproportionate change in truck to automobile crashes. The identified list of countermeasures includes the use of law enforcement, a smart work zone system, a dynamic late merge system, CMS (Changeable Message Signs), speed display signs, and a CB (Citizen Band) Wizard. These countermeasures were checked for cost effectiveness using a benefit cost (B/C) analysis. The researcher found that law enforcement, smart work zones with costs lower than or equal to half a million dollars, CMS, speed display signs, and the CB Wizard have B/C ratios greater than one and seem to be worthwhile for deployment in work zones. Smart work zones with significantly higher costs of 2.5 million dollars, for example, could be deployed using a more detailed analysis of work zone characteristics. Finally, dynamic late merge system could be used if the site conditions indicate a crash reduction potential of at least 10 – 15 percent.

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This research work uses the data collected for an NCHRP (National Cooperative Highway Research Program) Project 17-30 “Traffic Safety Evaluation of Nighttime and Daytime Work Zones.” I would like to thank the TTI research team of this NCHRP project, Dr. Ullman and Melisa Finley, for providing continuous funding to work on my thesis. I also thank Yusuf Mohammed Shah for providing HSIS (Highway Safety Information System) data and answering my questions about the data. I appreciate Srinivas Geedipally’s help in using SAS (Statistical Analysis Software) to reduce the data. Finally, I would like to extend my special thanks to Jayashankar and Kristin for reviewing my thesis.

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DEFINITIONS

Term	Definition
Normal roadways	Non-work zones
Maintenance projects	Work zone projects involving pavement repair and rehabilitation, bridge work, and guardrail installation
Reconstruction projects	Work zone projects involving pavement widening
Day Reconstruction projects	Reconstruction projects at daytime
Night Reconstruction projects	Reconstruction projects at nighttime
Diary data	Work zone data
Twilight	Dusk/Dawn
Auto Crashes	Non-truck involved crashes
Truck Crashes	Truck involved crashes
Severe Crashes	Fatal + Injury Crashes (without PDO crashes)

INTRODUCTION

The population of the United States is growing at a rapid rate resulting in an ever-growing increase in travel demand. However, the highway lane miles available to meet that demand have remained almost constant over the last two decades. The statistics compiled by the FHWA indicate that the vehicle miles traveled (VMT) increased dramatically by 79 percent from 1982 to 2002, while the lane miles grew by a meager 3 percent, as illustrated in Figure 1 (*1*). With the increase in traffic volumes, roadways have started deteriorating quicker, leading to more frequent repair and rehabilitation. According to the FHWA, roadway improvement projects extend to an average of 23,745 miles of road per year from 1997 to 2001 (*1*). Furthermore, 3110 work zones were active on the National Highway System (NHS) during the summer of 2001. With the advent of SAFETEA-LU (Safe Accountable Flexible Efficient Transportation Equity Act – A Legacy for Users) which provides a significant increase in the funding for construction and maintenance projects, work zones are expected to grow in the future years.

The effect of work zones on road users is phenomenal. The FHWA estimates that 24 percent of non-recurring delay to motorists is due to the presence of road maintenance and construction work projects (*2*). One of the FHWA surveys indicated that work zones are the second highest rated attribute for motorist dissatisfaction, the first being traffic flow (*3*). Unfortunately, delay and traffic congestion are not the only problems associated with an increase in work zones. There are also safety-related issues due to the presence of work zones. According to FARS (Fatality Analysis Reporting System) and GES (General Estimates System) data, 1028 fatalities and 41,000 injuries were reported in work zones for the year 2003 compared to 693 fatalities and 36,000 injuries during 1997 as indicated in Table 1 (*4*, *5*). These data show the increase in crashes in work zones over the recent years. This does not prove that the crashes will increase due to the presence of work zones, but it gives an inclination for the researchers

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This thesis follows the style and format of *Transportation Research Record.*

to look into the safety effects of work zones on the road users. Various studies are available in the literature to corroborate that work zones, in fact, increase the crash likelihood of the driving public (*6, 7, 8, 9, 10, 11, 12, 13, 14, 15*).

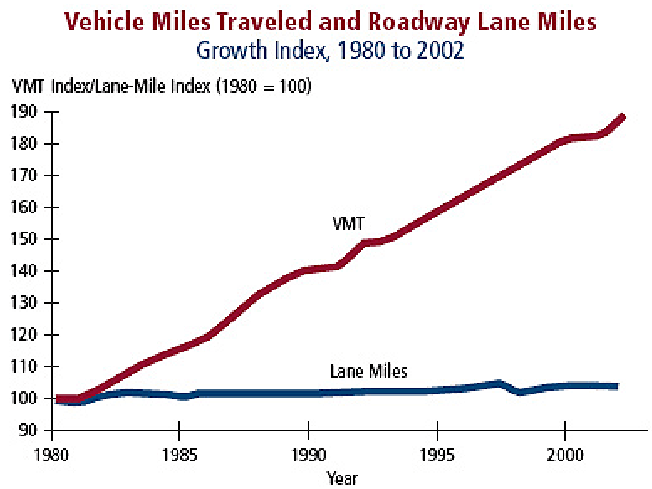

Figure 1 Growth in vehicle miles traveled and roadway lane miles.

This thesis will focus on large truck crashes, which could be more likely involved in a work zone related crash, due to their large size, limited maneuverability, and narrow lanes in work areas. Furthermore, large truck crashes typically are severe in nature, with a good chance of being a newsworthy event, if fatalities are involved. Also, economic losses due to large truck crashes are expected to be higher than automobile crashes. As a result, it is necessary to deploy effective countermeasures to reduce truck crashes. The Federal Motor Carrier Safety Administration (FMCSA) has collected data and found that 24 percent of the fatal crashes occurring in the work zones are large truck crashes (*16*). Furthermore, Table 1 indicates a higher percentage of truck-involved work zone crashes compared to total work zone crashes. With commercial trucks representing approximately 10.3 percent of all motor vehicles registered and 16.1 percent of total vehicle miles traveled, one might be inclined to say that the large truck crashes may be overrepresented in the work zones.

Table 1 Total and Work Zone Fatal Truck Crash Percentages (*4*)

Year	Total fatal crashes	Total vehicles involved in a fatal crash	Total large trucks involved in a fatal crash	Total work zone fatal crashes	Total vehicles involved in a work zone fatal crash	Total large trucks involved in a work zone fatal crash
1995	37,241	56,499	4,525 (8.45 %)	665	1,125	177 (17.26 %)
1996	37,494	57,347	4,822 (8.14 %)	635	1,078	177 (15.82 %)
1997	37,324	57,060	4,983 (7.98 %)	594	1,047	167 (14.28 %)
1998	37,107	56,922	5,000 (8.45 %)	681	1,185	210 (17.41 %)
1999	37,140	56,820	4,977 (8.76 %)	770	1,290	239 (16.91 %)
2000	37,526	57,593	5,044 (8.76 %)	966	1,585	268 (18.53 %)
2001	37,862	57,918	4,892 (8.78 %)	877	1,522	265 (17.72 %)
2002	38,491	58,426	4,665 (8.73 %)	1035	1,709	244 (15.95 %)
2003	38,477	58,877	4,791 (8.41 %)	919	1,662	263 (16.42 %)
2004	38,444	58,729	4,963 (8.01 %)	933	1,657	286 (15.73 %)
Average	37,711	57,619	4,866 (8.45 %)	808	1,386	230 (6.60 %)

PROBLEM STATEMENT

Previous studies have indicated that large trucks are overrepresented in work zones (*6, 7, 8, 9, 10, 11, 12, 13, 14, 15*). However, none of the studies could show whether the overrepresentation is due to differences in exposure between large trucks and automobiles or a greater crash risk for large trucks in work zones (*17*). Furthermore, there is a need to better understand the possible underlying causes behind the higher truck crash rate in work zones, if it truly exists. Finally, there is still limited knowledge as to whether the characteristics of work zone-involved truck crashes are similar to that of automobile work zone crashes. Without a clear understanding of these characteristics and possible causes, it is not possible to identify potential countermeasures that could be employed to reduce the large truck crashes in work zones. These factors indicate a need to conduct research that will identify various issues relating to work zone truck safety.

RESEARCH OBJECTIVES

The main objective of this thesis is to identify appropriate countermeasures to reduce large truck crashes in work zones based on the extent and characteristics of such crashes. For this purpose, data collected for NCHRP Project 17-30 "Traffic Safety Evaluation of Nighttime and Daytime Work Zones" will be used. These data include work zone project files and HSIS crash data for 19 reconstruction or maintenance projects in North Carolina. The objective of this study is sub-divided into the following three parts:

- Compare the truck and automobile crash characteristics in work zones with that of the non-work zones.
- Identify the possible factors for any disproportionate change in truck to auto crash characteristics between work zones and non-work zones.
- Recommend potential countermeasures to reduce truck crashes in work zones using the list of possible factors.

THESIS ORGANIZATION

This thesis is organized into seven sections presenting all the activities conducted to complete this research effort. In the first section, the researcher introduces the problem to the reader through various statistics and identifies the objectives of this study. In the second section, he reviews previous literature on truck and automobile work zone crash characteristics and their countermeasures. Furthermore, the researcher looks at various issues with truck safety on normal roadways. In the third section, he describes both the diary and HSIS crash data used in the data analysis. In the fourth section, he outlines the analysis procedure and identifies the variables to be used in the study. In the fifth section, he presents all of the results from the analysis in two parts: first, he categorizes work zone crashes by different variables, and then he discusses various trends observed. Later, the results obtained from the odds ratio analysis are discussed. In the sixth section, he identifies different countermeasures which can potentially reduce truck crashes in work zones. In the seventh section, the researcher ends the thesis with a summary of the study as well as recommendations for future work.

LITERATURE REVIEW

The review of literature is presented in the following manner: first, the researcher provides a comprehensive literature review on total work zone crash characteristics and truck work zone crash characteristics. Second, he discusses a few research efforts related to work zone truck crashes. Third, in order to get a better perspective on truck crashes in general, the researcher discusses a few studies relating to truck safety in normal roadways. Finally, a detailed literature review is provided on various countermeasures to reduce work zone crashes.

PREVIOUS STUDIES ON WORK ZONE CRASH CHARACTERISTICS

Over the past three decades, researchers conducted many studies to examine the effect of work zones on road user safety (*6, 7, 8, 9, 10, 11, 12, 13, 14, 15*). Most of them focused on long term freeway work zones. Typically, the studies compared crash rates between the pre-work zone period and the during-work zone period. However, the results of each study varied significantly. This variation could be due to the differences in approaches used, study location, and the accuracy of the data. The following sub-section presents a review of the previous research findings on work zone crash characteristics.

Crash Rate

Almost all of the earlier studies agree that work zones increase crash frequency. In 1978, Nemeth and Migletz conducted a before-, during-, and after-work zone study on Ohio's rural interstate system and found that there is a statistically significant increase in the accident rate due to work zones (*13)*. In the same year, a comprehensive study conducted by Midwest Research Institute found an overall increase in the accident rate of 6.8 percent for 79 work zone projects in seven states. Interestingly, 31 percent of the projects were subject to a decrease in accident rates during work zone periods, and 24 percent of the projects experienced a 50 percent increase in the accident rate (*14)*. In

1988, Rouphail et al. performed a comparison study of short term and long term urban freeway work zones. The results indicated an overall increase of 88 percent in the accident rate in the during- work zone period compared to the before-work zone period. However, the short term work zones were observed to have a constant accident rate (*15)*. In 1989, Hall and Lorenz studied New Mexico work zone crashes and found an increase of 26 percent in work zone crashes compared to non-work zones (*9)*. Although there is variability in the findings among these studies, they generally indicate that work zones increase crashes by 20 to 30 percent on average.

A few studies went into detail and identified that the crash rates could be reduced by using an optimal combination of traffic control devices. For example, Garber and Woo found that a combination of cones, flashing arrows, and flaggers on multi-lane highway work zones and a combination of cones, flaggers, or static signs and flaggers on two-lane highway work zones resulted in the smallest number of crashes (*18*).

Crash Severity

Previous studies showed mixed results for the effect of work zones on crash severity. Most researchers found that the severity of work zone crashes is not statistically different from that of non-work zone crashes (*6, 10*). However, other studies concluded that work zone crashes are more severe than those in non-work zones (*7, 8, 9*). Surprisingly, some researchers even found that work zone crashes are less severe than those of non-work zones (*12*). They substantiated their results by saying that the frequent and typically less severe rear-end and sideswipe crashes in work zones reduce the overall crash severity. The mixed results could be explained by the different approaches used by each of the studies and the lack of accurate work zone data.

Crash Location

The location of the crash within the work zone is a critical factor influencing the design of traffic control plans. Nemeth and Migletz found that 39.1 and 16.6 percent of crashes occurred in longitudinal buffer areas and construction areas respectively (*13)*. Garber and Zhau found that 70 percent of crashes are in the activity area (*8*). Khattak and Targa also found that many (44.9 percent) work zone crashes happen near the work zone activity area (*6)*. However, none of these studies could capture the effect of the variability in lengths of the activity areas over different types of work zones.

Crash Type

Most of the previous literature indicates that rear-end crashes increase dramatically in work zones compared to non-work zones. Graham et al. found 16.6 percent increase in the rear-end crashes in the during-work zone period compared to the before-work zone period (*14*). Rouphail et al. also found that rear-end crashes increased almost 50 percent in the during-work zone period (*15*). Two more studies also corroborated the previous findings about rear-end crashes (*8, 11*). However, most researchers were indefinite about sideswipe crashes. Many of them found that sideswipe crashes are not frequent in work zones (*9, 14, 15*). But others found the opposite result that sideswipe crashes increase in the during-work zone periods compared to non-work zones (*10*). Some of the variability could be explained due to difference in geographic location, crash reporting accuracy, and analysis methods.

Contributing Factors

Nemeth and Migletz found that excess speeding is the dominant factor in most work zone crashes (*13*). Hall and Lorenz found “following too closely” and “lane change” to be the predominant contributing factors in work zones (*9*). Pigman and Agent found “congestion” as a common factor for work zone crashes. The study also indicated “struck or avoiding construction equipment,” “material on roadway,” “related to flagger,”, and “vehicle merging too late” as other frequently occurring factors (*10*).

Other Crash Characteristics

Most studies found that multi-vehicle collisions are overrepresented in work zones (*7, 9, 15*). This looks reasonable due to more rear-end crashes and higher speed variance between the normal roadway segment and the work zone area. Nemeth and Migletz found that nighttime accidents happen more frequently in the transition area (*13*). Researchers were indefinite about the relation between crash severity and time of day. Pigman and Agent found that nighttime crashes are more severe in work zones while Nemeth and Migletz found daytime crashes to be more severe (*10, 13*). Ullman et al. found that crashes during active night work periods are more frequent than those during both inactive night periods and daytimes (*19*). As mentioned earlier, there could be many reasons for this discrepancy.

PREVIOUS STUDIES ON WORK ZONE TRUCK CRASH CHARACTERISTICS

While the previous sub-section explained the characteristics of work zone crashes, the following sub-section will present details about earlier researchers' findings on work zone truck crash characteristics. Most of the previous studies on work zone safety gave basic information on truck crashes. There are very few research papers available in the literature which looked at work zone truck crashes in detail.

Crash Rate

Previous studies indicated that the percentage of truck crashes is higher in work zones compared to non-work zones. Hall and Lorenz found that work zone crashes involving trucks increased by 44 percent compared to 23.8 percent for crashes not involving trucks (*9*). Based on a simple before and during study without a control section, Pigman and Agent found that large trucks comprised 25.7 percent of work zone crashes, compared to only 9.6 percent of crashes outside the work zones (*10*). Three other studies also found that truck crashes are higher in work zones (*7, 11, 12*). One of the reasons for this overrepresentation could be due to more trucks passing through work zones when they are active or when lanes are closed. As we know, the time of day patterns of trucks are different from those of the automobiles (see Figure 2). Trucks tend to avoid peak hours and travel more during nighttime. In the same way, long term work zones are typically active during off-peak and nighttimes. Since the frequencies of active work zones and trucks are similar, the higher work zone truck crashes could very well be explained due to higher truck volumes in work zones during work activity. However, none of the studies could identify the true overrepresentation of truck crashes considering the hourly variation of truck volumes.

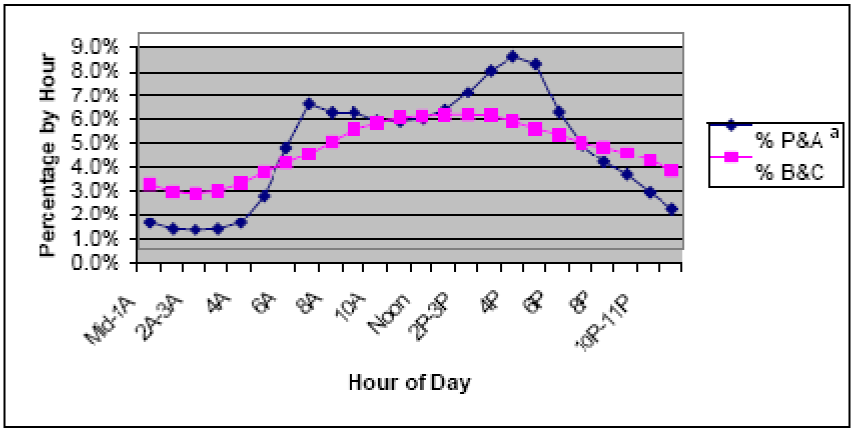

Figure 2 Hourly volume percent on Ohio rural interstates by vehicle type (*20*).
[a] P&A indicates cars and B&C indicates trucks.

Crash Severity

Similar to total crashes, there is no consensus on whether the severity of work zone truck crashes is higher or lower than non-work zones. Khattak and Targa conducted a detailed study on the impact of work zones on truck crash severity or total harm (*6*). They defined total harm in terms of dollar value by assigning economic cost to each injury level. In other words, total harm is computed as a weighted sum of the number of injuries, where weights are economic cost of each injury severity type. Their economic cost consists of:

- Medical costs including hospital, physician, rehabilitation, prescriptions, and related costs.
- Pain, suffering, and quality of life that a family loses because of a death or injury.
- Emergency service costs including police, fire, ambulance, and helicopter services.
- Victim work-loss costs including wages, fringe benefits, and household work.
- Employer costs including value of time lost, extra work, and distractions for supervisors and coworkers that injuries cause.
- Traffic delay costs including value of time lost in traffic jams caused by crashes.
- Property damage costs including costs to repair or replace damaged vehicles and property.

Khattak and Targa found that the work zone truck crashes on two-way undivided roads are more severe but less frequent than two-way divided and protected (with a barrier in the median) roads (*6*). Furthermore, severity of truck crashes increases with any of the following: higher speed limits, more warning signs, larger number of vehicles, or more people involved. They also indicated that work zone truck crashes involving collisions with a pedestrian, animal, bicyclist, head on, and angle are more severe than other crash types. Overall, they found that truck crashes are less severe in work zones than non-work zones. However, Lin et al. found that there is no significant change in truck crash severity in work zones, and Pigman and Agent indicated that the truck crashes are more severe in work zones (*7*, *10*).

Crash Location

Table 2 shows the percentages of work zone total crashes and work zone truck crashes in different locations of the work zone (*6*). Clearly, the percentages indicate that there is no significant difference in crash location for total work zone crashes and truck work zone crashes.

Table 2 Distribution of Total and Truck Work Zone Crashes in Different Work Zone Areas (*6*)

Location	% work zone crashes	% work zone truck crashes
Before work area	21.2 %	21.7 %
In work area approaching taper	33.9 %	33.7 %
Adjacent to actual work area	44.9 %	44.6 %

Crash Type

Past researchers indicated that sideswipe crashes, followed by rear-end crashes, are the predominant crash types in work zone truck crashes. As an example, Lin et al. found that 44 percent of all work zone truck crashes are same-direction sideswipe compared to 25 percent of non-work zone truck crashes which are sideswipe crashes and 25 percent of total work zone crashes which are sideswipe. They also found that sideswipe crashes are even higher when the lanes are closed. Nearly 30 percent of work zone truck crashes are rear-end crashes, compared to 24 percent in non-work zone truck crashes and more than half in total work zone crashes (*7*).

The researchers indicated that right angle, head on, left turn and striking parked vehicles, and single vehicle crashes are more common in non-work zones than in work zones. When comparing work zone truck and total work zone crashes, they found that total work zone crashes have higher percent of right angle, head on, left turn, and single vehicle crashes (*7*). American Transportation Research Institute (ATRI) conducted a study on work zone safety and found that work zones have more frequent occurrences of total and truck rear-end fatal crashes compared to non-work zones (*17*).

Contributing Factors

Lin et al. performed a descriptive analysis on truck crashes in work zones and found driver's fault to be the prime causal factor in 70 percent of the crashes. More specifically, driver inattention, improper lane change, and failure to yield ROW are found to be the most frequent work zone truck crash causes. The researchers also indicated that most sideswipe crashes were due to limited or obstructed view. Therefore, they recommended improved lane closure layout and traffic sign placement in work zones, particularly at the time of lane closure (*7*).

Other Crash Characteristics

Nemeth and Migletz indicated that large truck crashes are more frequent at night (*13)*. Ried et al. indicated that, in work zones, a truck striking other vehicles occurs more frequently than a truck being struck (*21*). Ha and Nemeth recommended that trucks be restricted to one of the open lanes to enhance the truck safety in work zones (*22*). Finally, Benekohal et al. found that truck drivers prefer work zone advance warning signs to be posted 1.25 miles ahead of the work zone, rather than the current MUTCD standard of 0.5 mile (*23*).

Most of the studies discussed in the earlier sub-sections used crash and work zone data to identify the major safety concerns in both work zones and trucks in work zones. However, in 1995 Benekohal et al. took a different approach realizing the limited availability of work zone crash data. He did a massive survey on truck driver concerns in work zones and their assessment of work zone features. The survey indicated that nearly 90 percent of truck drivers find work zones to be more hazardous than normal road sections. Surprisingly, half of the drivers admitted that they were exceeding the work zone speed limit. Furthermore, most drivers expressed their primary concerns in work zones as the pavement edge drop off, construction materials, lack of shoulder, lane width, and visibility and clarity of the flagger's message. Finally, truck drivers' least preferred concrete barriers. This could be due to the limited maneuverability of trucks when barriers are present (*23*).

It is important to note that most of the earlier studies were dependent on the work zone code in the crash database to know whether a crash is due to the presence of a work zone or not. However, this code is subject to a judgment call from a police officer, who is not a traffic engineer. Moreover, crash databases typically do not include other important information such as whether work is active or not, whether lanes were closed, crash location, traffic control plans, etc. Keeping in mind these limitations, Ullman et al. conducted a detailed study of fatal crashes in Texas work zones. They made the effort to visit the actual crash sites and perform a post-crash analysis to identify the contributing factors and other relevant information. As shown in the Figure 3, the researchers found that 45 percent of truck crashes were completely unrelated to a work zone. Approximately eight percent of the crashes could be directly attributable to some aspect of the work zone and another four percent could specifically be attributed to the work zone set up and removal times. However, researchers stated that another 39 percent of the crashes were indirectly influenced in some manner by the work zone, either by altering the crash likelihood or by affecting the ultimate severity of the crash (*24*).

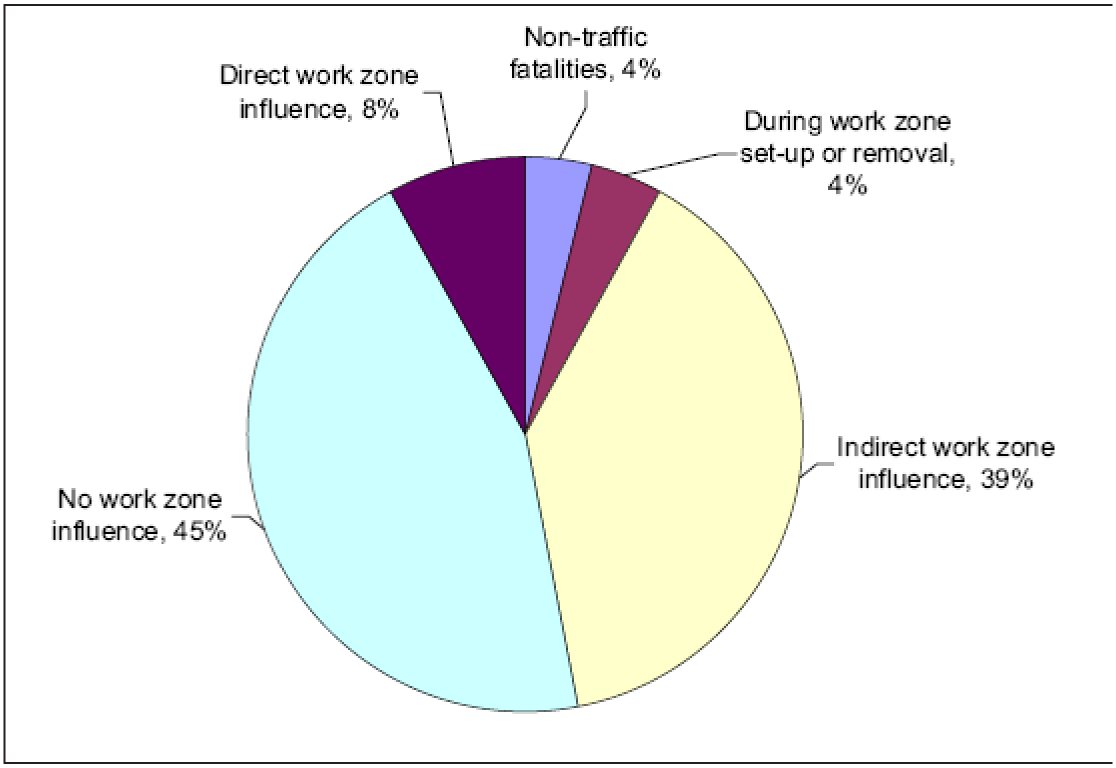

Figure 3 Work zone influence on crash chain-of-events (*24*).

TRUCK SAFETY ON NORMAL ROADWAYS

The literature review for this study would be incomplete if it did not address the characteristics of truck crashes on normal roadways. The following is a brief discussion on these crashes.

In 2002, Agent and Pigman investigated the impact of trucks on interstate highway safety (*25*). They identified various countermeasures to improve truck safety based on discussions with members of the trucking industry as well as Kentucky crash data for the years 1998 to 2000. Each of the countermeasures is grouped into roadway, truck, and driver characteristics. For the roadways, the study recommended additional parking facilities, audible rumble strips, increased use of median barriers, ITS devices like CMS, Highway Advisory Radio (HAR), and CB radio for real time congestion and weather information, lane use restrictions for higher number of lane roads, and truck climbing lanes for steep upgrades. In the case of trucks, the study recommended proper rear-end protection, adequate lighting, and reflective material on the rear of the truck, and the use of ITS technologies to warn drivers about closeness to an object, drowsiness, and any other impending dangers. Finally, in the case of drivers, the study recommended the use of seat belts, strict laws on trucking companies to assign proper driving schedules, and mandatory truck driving school providing important information on various frequently occurring hazards.

Recently, in 2006, the FHWA and the National Highway Traffic Safety Administration (NHTSA) jointly conducted a nationwide study of large truck crash causal factors (*26*). Sample data from 967 crashes, along with 1000 characteristics for each crash, were collected at 24 sites in 17 states from 2001 to 2003. The results indicated that driver recognition and decision errors were the most common types of driver mistakes coded for both trucks and passenger vehicles. However, truck drivers had less frequent driving performance problems (e.g., asleep, sick, fatigue) than passenger vehicle drivers. Furthermore, the study found that in crashes between trucks and passenger vehicles, fatigue was more frequent for passenger vehicle drivers while speeding was more frequent for truck drivers. Finally, brake problems were found to be coded for 30 percent of truck crashes compared to 5 percent in passenger vehicles.

TECHNOLOGIES USED TO IMPROVE WORK ZONE SAFETY

In this sub-section, the researcher looked into previous research examining various technologies to improve work zone safety of both trucks and automobiles.

Work Zone Speed Limits

None of the previous studies looked at the safety effect of reduced work zone speed limits separately for trucks and automobiles, so the researcher provides the results of a study that evaluated the effect of reduced work zone speed limits on the total crashes. As a part of NCHRP 3-41, Migletz et al. determined the effect of work zone speed limits on mean speeds, speed limit compliance, 85^{th} percentile speeds, and speed variance. They found that reduction in speed limits generally decreased the mean and 85^{th} percentile traffic speeds. However, the speed variance in work zones seemed to decrease up to a 10 mph speed limit reduction and then increase for speed limit reductions of 15 mph or more. Furthermore, crash frequency followed the same pattern as speed variance. This indicated that work zone speed limit reduction of 10 mph is an effective way to reduce work zone crashes when work is active. However, speed limit reductions of 15 mph or more should be avoided except for special situations. Overall, the study indicated that work zone speed limits by themselves are not effective in reducing crash frequencies, and other methods have to be identified (*27*).

Police Presence

Previous studies have identified that the presence of police in work zones has a positive effect on reducing traffic speeds with the disadvantages being additional funds allotted to police officers and an increase in traffic congestion. Richards et al. evaluated the effectiveness of law enforcement on Texas highways. The study indicated that a stationary car reduced mean speeds by 5-12 mph (6 to 22 percent) while a circulating patrol car reduced mean speeds by 2-3 mph (3 to 5 percent). Therefore, a circulating patrol car seemed to be a relatively ineffective way to reduce work zone speeds even though it covers a large area (*28*). Migletz et al. found from a survey of work zone contractors that the contractors felt police presence was not effective because speeds increased when the police left the work zone (*27*). Later, Benekohal's study confirmed this by finding that during one hour immediately following the departure of police from work zone car speeds increased by 2.4-3 mph, but truck speeds increased only by 0.3-0.4 mph (*29*). Therefore, presence of police can still be used, as it is effective for trucks. Though law enforcement seems to have a positive impact on crashes, TTI researchers indicated the following common problems in their study as found from enforcement agencies (*30*):

- Difficulties in apprehending violators within the work zone (due to a lack of shoulders, restricted lane widths, etc.),
- Difficulties in keeping track of whether work zone personnel are present at a work zone (relevant in states with legislation requiring workers to be present in order to impose higher fines for traffic violations),
- Difficulties in remembering to mark that a traffic infraction occurred in a work zone,
- Difficulties in enforcing laws that were viewed as particularly “complex” (i.e., requiring workers be present, special traffic controls, certain speed limit restrictions), and
- Truck drivers talk to each other using a CB wizard. Therefore, they typically know where the police are conducting speed enforcement.

In another TTI report, Ullman et al. recommends the use of enforcement pullout areas at a spacing of every two to three miles in order to avoid some of the above mentioned implementation issues (*31*).

Increased Fines

Many states follow double fine laws in work zones in order to reduce vehicle speeds and improve safety. However, a study done by TTI indicated that increased fines had no significant impact on reducing the fatal crash frequencies in work zones. Changes in fatal crash frequencies after implementation of the increased fine law were found to vary from an 87 percent decrease to a 299 percent increase, but 12 of the 14 states included in the study had no significant difference in the number of crashes before and after law implementation. Furthermore, in a telephone survey with the enforcement agencies, TTI researchers found the following issues related to court support on double fine speeding tickets issues in work zones (*30*):

- Citations dismissed due to the belief that an officer does not have the authority to influence the fine that is being imposed,
- Fines reduced when the driver does not have the means to pay the additional fines,
- Citations dismissed because the drivers were not adequately warned of the additional fine for work zone violations,
- Citations dismissed because the enforcement officer could not verify that workers were present in the work zone when the citation was issued, and
- Lower fines issued by the courts when the citation is issued in a work zone.

The study indicated that police officers tended to avoid enforcing work zone areas because of the above-mentioned reasons. Overall, the increase in fines does not seem to be effective in reducing traffic speeds in work zones.

Photo Radar

In this technique, the license plate of the speeding vehicle is photographed, and the owner of the vehicle receives a speeding ticket. These systems are currently available in many states for normal roadways but not in work zones. There are still pilot programs being conducted to see the reliability of these systems in work zones. Though this technique is in a fledgling state, experts are expecting to see improvement in work zone safety by using this system (*12*).

Changeable Message Signs

Changeable message signs, commonly known as CMS, are traffic control devices that provide real time information to motorists about the changing conditions in the area. They are frequently used in work zones. Furthermore, they are very flexible and cost effective to use for both long term and short term operations. In 1985, Richards et al. compared the effectiveness of different work zone speed control techniques and indicated that CMS, if used alone, produced moderate results. However, when combined with other devices like static signs or flashing CMS, they could be very effective (*28*). In 1998, Garber and Srinivasan conducted a two-phase study where they examined the effectiveness of CMS signs in comparison with static signs. They found that CMS signs are more effective in decreasing the mean speeds and speed variances than static signs. They also found that duration of exposure did not have any influence on the effectiveness of CMS signs. Finally, the researchers recommended the use of a second CMS for a long work zone, as drivers tend to speed up with the increasing distance from CMS signs (*32*).

Drone Radar

A drone radar is a passive radar system used to reduce the speed of vehicles traveling through work zones by activating the radar detectors of vehicle. A study done by Benekohal indicated that drone radar is effective in reducing traffic speeds only for short periods of time. After continuous use of this system, motorists became aware that it was not police radar and thus did not decrease their speeds. Therefore, the researchers recommended the use of drone radar in combination with law enforcement to confuse drivers (*29*).

Speed Displays

In this technique, speeds will be displayed to the speeding vehicle in real time. This system is similar to photo radar. The latter provides the feedback a few days later while the former gives real time information to drivers. Fontaine and Carlson did a study on the effectiveness of speed displays on two-lane rural high speed-low AADT (Annual Average Daily Traffic) facilities. They found that speed displays were effective with speed reductions up to 10 mph (*33*). Another study by Britain found the same result that speed displays are very effective in reducing speeds in work zones. In fact, they also found that the effectiveness of speed displays exists even after 20 weeks of operation. It is interesting to see that these reductions were achieved without any police presence or other extra enforcement (*12*). Figure 4 illustrates a speed display sign on the shoulder of a highway.

Figure 4 Speed display.

Smart Work Zones Using ITS

Smart work zones are currently being deployed in many parts of the United States. These are the systems used to inform motorists about the real time traffic conditions. First, the smart work zone system monitors the speeds and volume of the approaching traffic. Then it determines if there is a traffic backup or some other incident based on a pre-assigned algorithm. After incident detection, ITS devices like changeable message signs and highway advisory radios will be used to warn the motorists to slow down or detour their path (*12*). In general, the smart work zone systems are expensive to deploy in a work zone. In a recent TRB paper, Fontaine and Edara evaluated the benefits of smart work zones and indicated that these systems were likely to ease congestion. However, they advised agencies to conduct their own site-specific studies before making the decision to deploy smart work zones. The researchers further indicated that there were no quality data to quantify the safety improvements in work zones due to these ITS devices (*34*).

Temporary Transverse Rumble Strips

Temporary transverse rumble strips are rows of raised pavement markings placed on the pavement perpendicular to the travel path. They produce an audible vibration in the steering wheel and warn drivers to slow down as they are approaching a work zone. Fontaine and Carlson found that the rumble strips produced minimal speed reductions for passenger cars and 3 to 4 mph speed reductions in trucks. The researchers suggested that rumble strips were not very effective in rural maintenance projects because they took longer to install and were not reusable once installed at a particular location (*33*). Bernhart et al. evaluated the effectiveness of orange rumble strips in work zones to reduce speeds. They found that the rumble strips were not thick enough to produce considerable audible sound to trucks. Though thicker strips might have a greater impact, the researchers believed that thick strips may cause adverse safety effects on smaller vehicles (*35*). In summary, though rumble strips seem to be ineffective in reducing vehicular speeds, the researcher believes that they increase driver attention leading to improved safety in work zones. Figure 5 illustrates a temporary transverse rumble strip laid on a highway.

Figure 5 Temporary transverse rumble strips.

Late Merge Strategy

Many alternative lane merge strategies have been proposed in work zones in recent years. One among them is the late merge strategy. There are two types of late merge strategies: static and dynamic. Initially, Penn DOT came up with the static late merge strategy in order to reduce the road rage between the drivers who early merge and late merge to the open lane. In this strategy, vehicles traveling on both open and closed lanes are advised through signs to stay in their lanes until the taper. At the lane closure taper, vehicles in each of the lanes take the right of way one after another. This merging technique was well received by the drivers. It not only increased the throughput of the work zone but also reduced the queue backup, which may potentially reduce the number of rear-end crashes. Furthermore, the frustration levels of drivers are also decreased by giving them the flexibility to use both lanes. However, the problem with static late merge occurs at times of uncongested conditions when the drivers face difficulties in yielding right of way. Therefore, McCoy and Pesti proposed the use of dynamic late merge in which the traffic backup is detected using ITS devises. Once detected, variable message signs could be used to inform drivers about the use of both lanes for merging.

However, the researchers found that the dynamic late merge might still have problems in the transition state when the traditional merging converts to late merging. In this state, the traffic flow conditions between open and closed lane would be different, potentially leading to a higher accident rate. Therefore, the study recommended that more research be conducted on the implementation of this strategy in work zones (*36*).

Effective Lane Width

Typically, lane widths are reduced in work zones to increase the work space for contractors while still allowing vehicles to pass through the work zone. However, from the results of this study, it is found that the odds of sideswipe truck crashes are significantly higher than auto crashes in work zones compared to control sections, when lanes are closed. This significance is found to be even higher at facilities with a low number of lanes. Despite the fact that lane width data in work zones is not available in the study; frequent sideswipe truck crashes in work zones do indicate that truck drivers face difficulty in passing through narrow lane widths. However, the researcher could not identify any previous studies pertaining to the relationship between truck and automobile safety with work zone lane width.

Advance Warning Sign Placement

According to MUTCD 2003, the first work zone advanced warning sign should be placed approximately 800m (2640 ft or 0.5 mile) ahead of the work zone for freeways (*37, 38*). However, in the Benekohal et al. survey, 95 percent of truck drivers were found to prefer that work zone warning signs be placed more than 1.25 mile upstream of the work zone (*23*). Thus, this survey indicated that truck drivers prefer higher advance warning placement. Therefore, if the contractor finds that the queue backup is longer than the first advance warning sign, then additional signs can be installed.

CB Wizard

The CB Wizard alert system informs truck drivers of work activity and lane closure information through Citizen Band (CB) radio channels. Ullman et al. suggested that the CB Wizard was effective in reducing truck speeds and increasing truck volume percentages in open lane compared to closed lane (*31*). Bernhart et al. also indicated that truck speeds and truck volume percentage in closed lane were reduced due to CB Wizard. In their survey, the researchers found that truck drivers appreciated the warning and merged early to the open lane. They also pointed that even though the CB Wizard is targeted to trucks, positive effects were identified in all the vehicle types (*35*).

SUMMARY

First, the researcher presented the extent and characteristics of total work zone, truck work zone and truck non-work zone crashes. Crash rates were consistently higher in both total and truck work zone crashes relative to non-work zones, but crash severity had an inconsistent effect due to work zones for both truck and total crashes. Some researchers found that crash severity increases due to work zones. However, others indicated that crash severity is either not affected or reduced due to work zones. Most researchers found that the actual work area experiences higher number of crashes than other areas in the work zone. However, no one could identify whether this trend is occurring due to the difference in actual work area lengths over the work zones. Rear-end crashes are found to be over represented in work zones. In truck crashes, there is a slightly different trend. Sideswipe crashes, followed by rear-end, were found to be higher in truck crashes. Overall, drivers' fault seemed to be the most frequent causal factor for both total and truck work zone crashes.

Second, the researcher looked into various studies evaluating the effects of different technologies in reducing speeds and improving lane changing abilities of vehicles. The researcher qualitatively weighed the advantages and disadvantages of each countermeasure and suggests that law enforcement, CMS signs, and speed display signs are effective in reducing speeds. Moreover, CB Wizard and late merge strategy are found to be effective in improving lane-changing abilities of vehicles.

DATA COLLECTION

In this thesis, the researcher presents a comparison of the safety impacts of work zones on automobiles and trucks. Using the comparison results, he identifies appropriate countermeasures to reduce truck crashes in work zones. The data used in this thesis were collected for the NCHRP Project 17-30 “Traffic Safety Evaluation for Nighttime and Daytime Work Zones.” The data include crash, roadway, and work zone data for 19 long term freeway work zone projects in North Carolina completed in the past five to six years, with durations greater than one month.

DATA DESCRIPTION

There are two sources of data for this study: field data and data from the HSIS crash database.

Field Data Collection

As part of NCHRP Project 17-30, TTI researchers contacted the North Carolina DOT and identified potential work zone projects (*39*). Furthermore, the researchers went to North Carolina and reviewed the project diaries, traffic control plans, and other useful documentation containing work zone types, AADT, speed limits, presence of detours, and other details. However, the traffic control data were not available consistently for all of the work zone projects. Moreover, if a project did have some traffic control data, the researcher could not clearly understand whether the traffic control was consistently used throughout the project. Due to these limitations, the researcher could not use much of the traffic control data in the analysis. The following data were successfully extracted:

- Beginning and end mile point limits of the project,
- Project start and end dates,
- General type of work performed, and

- Daily information on
  - when work actually occurred and
  - the number and direction of lanes closed.

First, the during-work zone periods were identified using the project start date and end date. These are the time periods when the work zone is physically present on the freeway, with either active or inactive work. Then the before-work zone periods were assumed to be three years before the during-work zone period. This is the time when the roadway is normal, i.e., without any work zone. The researcher assumed three years as the before-work zone period because a period shorter than three years would have a regression to mean effect, while a longer period would have more geometric changes to the roadway section. In the case of work zones shorter than a year, the before period was also truncated to less than a year, corresponding to the months when the work zone was present. For example, the work zone I-4415 (details are provided in Appendix A) started on January 27, 2003 and ended on November 24, 2003. In order to avoid seasonal variations, the before period was also defined as January 27 to November 24 for the previous three years. Of the 19 work zone projects, the majority were pavement rehabilitation projects, along with one bridge work, one guard rail installation, and three pavement widening projects. The researcher believed that the bridge work and guard rail projects could be considered as maintenance type of projects. Therefore, there were 16 maintenance projects and three reconstruction projects.

Table 3 indicates the extent of the characteristics of work zones used in this study. The length of the work zones varied significantly from 1.6 miles to 30.2 miles, with the average length being 7.4 miles. Furthermore, the minimum and maximum durations of the project were one and half months to six years respectively. Traffic volumes also had a broad range from 19,000 to 117,000 vehicles per day. The posted roadway speed limits of the project sites in the before-work zone period ranged from 55 mph to 70 mph. The safety of the work zone project sites (measured in terms of crashes per 1000 mile days) varied from 10.0 to 197.4 in the before-work zone period.

Table 3 Characteristics of 19 Work Zones Used in This Study

Variable	Minimum	Average	Maximum	Total
Project Length (miles)	1.6	7.4	30.2	140.1
Project Duration (days)	44	572	2114	10860
Before Period AADT (vehicles per day)	19,000	55,000	117,000	-
Speed Limit (mph)	55	-	70	-
Total Crashes per 1000 mile days (Before Period Work Zone Section)	10.0	48.9	197.4	-
Total Crashes (Before Period Work Zone Section)	4	240	714	4567
Total Crashes per 1000 mile days (During Period Work Zone Section)	0	61.4	248.2	-
Total Crashes (During Period Work Zone Section)	0	224	1211	4265

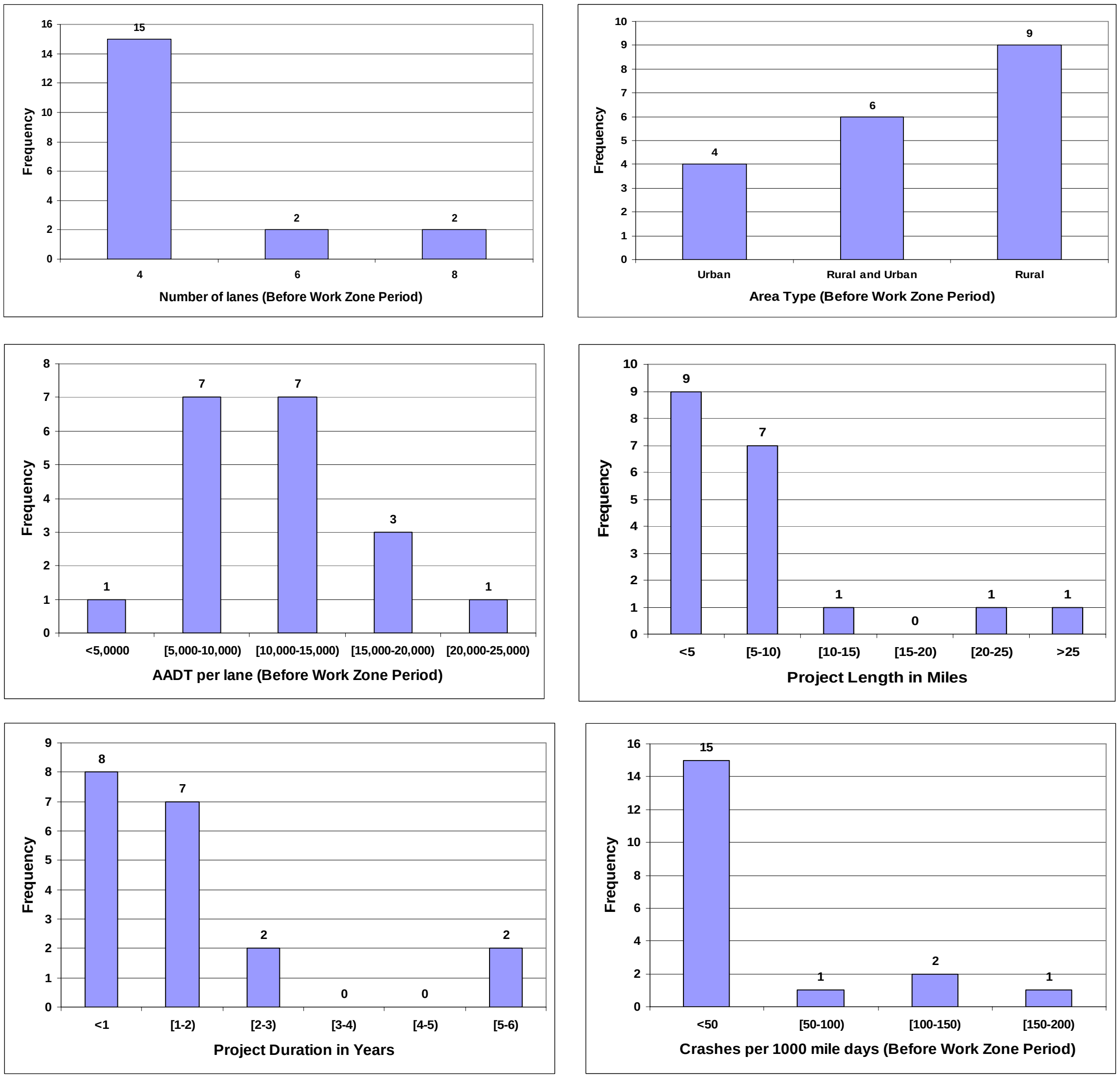

Figure 6 Distribution of variables among 19 work zones.

In Figure 6, the researcher provides histograms indicating the distribution of six variables (number of lanes, area type, AADT per lane, project length, project duration, and crashes per 1000 mile days in the before-work zone period) among 19 work zones used in this study. Of the 19 work zones, 15 had four lanes, two had six lanes, and the remaining two had eight lanes. When the work zones are categorized into rural and urban interstates, nine of the projects were located in rural areas, four in urban areas, and the remaining six encompassed both rural and urban areas. In the case of AADT per lane variable, 14 work zones were in the range of 5000 to 15,000 vehicles per lane per day. The traffic conditions in these work zones were in between free flow and near congested conditions. In the remaining projects, four were in near congested condition, and one was in near free flow condition. As indicated earlier, the lengths of 16 of the 19 work zones used in this study were in the range of one to ten miles. Furthermore, the duration of 15 of the 19 work zones was less than two years. Finally, 15 of the 19 work zones had less than 50 crashes per 1000-mile days.

Control sections were used in this study to factor out the influence of external factors like weather, increase in traffic volume, etc. These sections were selected at a distance of two miles upstream and downstream of the work zone section. For example, the work zone I-4412 extended from milepost 8.1 to 11.4 in Mecklenburg County. Therefore, the upstream control section extended from 0 to 6.09, and the downstream control section extended from 13.41 to 21.09 in the same county (see Figure 7). The researcher believes that two miles is a reasonable gap between work zone and control sections both for upstream and downstream sections. In the upstream section, MUTCD provides a guideline of 0.5 miles or more for advance warning placement. Therefore, the probability of queues extending up to two miles was low. Furthermore, the presence of ramps would dampen the influence of queue backup to more than two miles. In the case of the downstream section, the researcher believes that the control section might not work well because the traffic volume through the downstream control section depended on the work zone bottleneck. Therefore, the researcher used only upstream control section in the analysis.

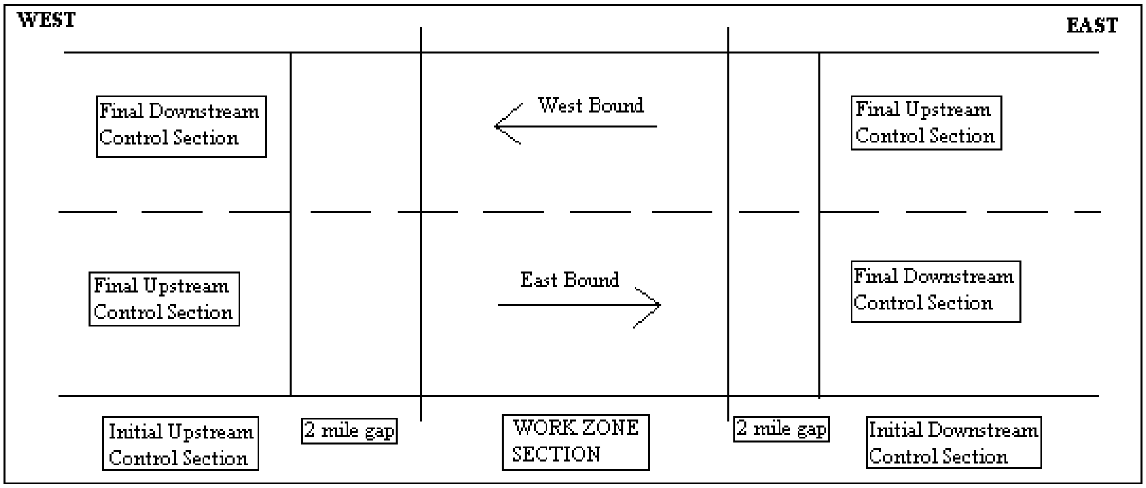

Figure 7 An illustration of separating upstream and downstream control sections

The researcher conducted a check to make sure that there were no work zones in the before-work zone period and control sections. In this check, the researcher identified the roadway sections that had a change in number of lanes. The researcher believed that an increase in the number of lanes indicated some kind of construction activity happening in those roadway sections. Therefore, these roadway sections were not used in the analysis of this study. The roadway sections with an increase in the number of lanes are presented in Table 4. As can be seen in Table 4, there were increases in the number of lanes even in the work zone sections during the before period. Therefore, some of the work zones had to be shortened to maintain uniformity in the length of roadway sections both in before and during periods. For example, the work zone I-4017 has some construction activity in the work zone section from mile points 6.5 to 7.14 in the before period. First, the work zone section from 6.5 to 7.14 is removed from the before period. In order to maintain uniformity in the length of a work zone section in the before and during periods, the work zone section from 6.5 to 7.14 is also removed from during period. Both the original start and end milepost of work zones as well as revised mileposts are documented in Appendix A.

Table 4 Roadway Sections Removed from the Analysis Based on Geometric Check

Control/Treatment	County Route	Project No.	Start Milepost	End Milepost
Treatment	3110000085	I-4017	0	2.39
Treatment	3510000085	W-4439	8.9	10.89
Treatment	4010000040	I-2201F	11.03	12.19
Treatment	6710000040	I-4017	6.5	7.14
Treatment	9110000040	I-2204BA	0	1.2
Control	6710000040	I-4017	4.4	1.57
Control	9110000040	I-2204BA	3.21	4.48

HSIS Crash Data

The researcher requested the HSIS crash data for all the roadways where work zones were present. HSIS is a crash database maintained by the University of North Carolina Highway Safety Research Center (HSRC) and LENDIS Corporation, under the contract of FHWA. HSIS uses the data collected by state DOTs for highway management programs. Typically, HSIS data is reliable and has few quality issues. Therefore, the researcher used this data in the analysis. Appendix A provides details about the routes and their respective counties requested from the HSIS. The dataset obtained from HSIS includes three separate tables containing crash, vehicle, and roadway inventory data for each of the years from 1995 to 2004. The following list contains the variables used in this study and thus requested from HSIS. The researcher provides specific details for each of these variables in the next section. General information on these variables can be obtained from the North Carolina guidebook on the HSIS website (*40*).

- AADT,
- Vehicle type,

- Number of lanes,
- Severity of crash,
- Number of vehicles,
- Surface condition,
- Road curvature,
- Lighting condition,
- Weather,
- Contributing factors,
- Manner of collision,
- Speed limit,
- Functional class,
- Crash date and time,
- Crash location (i.e., milepost, highway), and
- Crash direction.

In total, 91,572 crashes were requested from the HSIS crash database extending 544 miles of North Carolina roadway sections in 26 county routes over 10 years. Using the before and during periods as well as control and treatment section limits, crashes were extracted from the HSIS dataset using Statistical Analysis Software. In total, 23,739 crashes were extracted for all the 19 work zone projects and for four cases:

- Control section in the before period,
- Control section in the during period,
- Treatment section in the before period, and
- Treatment section in the during period.

Of these, a total of 4,641 crashes are identified as involving trucks. It was not clear from the data whether a truck or car initiated these crashes. A summary of crash frequencies and crash rates for each of the above four cases is provided for both trucks and automobiles in Appendix A.

This study analyzed the crash data separately for both the directions. Therefore, upstream and downstream control sections of a work zone were assigned separately based on the direction of crash. Since NC DOT follows compass direction of a crash, there were directions Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE) in the crash data. Therefore, the researcher looked at the North Carolina map and assigned these crashes along the main lane direction. There were a few crashes whose crash directions could not be determined with certainty. For instance, if the interstate is traversing along a northeast–southwest direction, there were crashes coded SE. It was difficult for the researcher to assume the direction of the crash in this situation. Therefore, crashes of this kind were removed from the analysis. On the whole, only 138 (0.6 percent) out of 23,739 crashes fell into this category. Moreover, there were very few crashes with unknown direction or time of occurrence. These crashes were also removed from the analysis. For documentation purposes, there were 10 (0.04 percent) unknown direction crashes and 6 (0.03 percent) crashes with unknown crash time. Finally, there were 582 (2.45 percent) crashes which involve vehicles traveling in opposite directions in the main lanes. These crashes were analyzed separately from the whole data.

The total lengths of upstream and downstream control sections as well as work zone sections for each of the projects were reasonably close in order to make comparisons. In total, approximately 162 miles of upstream control section, 148 miles of downstream control section, and 140 miles of work zone section were used in this study. A sum of 16,361 days of before-work zone periods and 10,860 days of during-work zone periods were used in this analysis. When the length of the control and treatment sections are multiplied with the before and during periods for each project, a total of 241,770 mile-days of before control, 121,978 mile-days of before treatment, 125,292 mile-days of during control and 74,147 mile-days of during treatment were available in the data set. Appendix A includes these exposure values for each project.

If one looks at the exposure of the during-work zone treatment more closely, eight percent of the time work was active with a lane closure, 15.6 percent of time work was active without a lane closure, 3.6 percent of time work was inactive with a lane closure, and the rest of the time was work inactive without lane closure. The researcher again subdivided the four categories by time of day. The results indicated that there was more work zone activity during the daytime (17.12 percent) than the nighttime (5.30 percent). However, the percentage of lane closures in nighttime during active work hours (53 percent) was higher than that of the daytime (27 percent). Work inactive lane closures were found to be higher at nights (2.35 percent) than days (0.82 percent). Finally, the percentage of work activity in twilight hours (14 percent) was lower than that of daytime and nighttime because the contractor tends to avoid working in peak hours when traffic volumes were significant. Appendix A includes a summary of the exposure data in mile-days for each of these categories as well as for each of the project.

In order to get a better sense of the times when work is active and lanes are closed in different work zone projects, the researcher identified the following from the data: 18 of the 19 work zone projects had work activity at daytime and 16 of them had work activity at nighttime. Furthermore, 12 of the work zones had day lane closures whereas 16 had night lane closures. Overall, lane closures were present in all the work zones at some point of time.

ANALYSIS PROCEDURE

In this section, the researcher introduces the reader to the statistical methodology used in this study. Later, he explains the data reduction and analysis procedures.

METHODOLOGY

A two by two contingency analysis is used for this study. For each of the crash characteristics, two contingency tables are developed separately for work zone and control sections, as shown in Table 5 and Table 6. In the tables, n is the crash frequency. If one assumes n_{abc} as a general term used in Table 5 and Table 6, then a is the condition with 1 as work zone and 2 as control sections; b is the time period with values 1 indicating before and 2 indicating during periods; and c is the vehicle type with values 1 indicating truck and 2 indicating auto.

Table 5 2x2 Contingency Table for Work Zone Section

	Trucks	**Autos**	
Work zone section - before	n_{111}	n_{112}	n_{11+}
Work zone section - during	n_{121}	n_{122}	n_{12+}
Total	n_{1+1}	n_{1+2}	n_{1}

Table 6 2x2 Contingency Table for Control Section

	Trucks	**Autos**	
Control section - before	n_{211}	n_{212}	n_{21+}
Control section - during	n_{221}	n_{222}	n_{22+}
Total	n_{2+1}	n_{2+2}	n_{2}

First, the Breslow-Day (B-D) test is conducted to verify the homogeneity of odds ratios (*41*). The odds ratio for Table 5 can be defined as the odds of having a truck crash in the before-work zone period to the during-work zone period. The null hypothesis for the B-D test can be written as (*41*):

$$OR_1 = OR_2$$

$$\text{where } OR_2 = \frac{\mu_{111} * \mu_{122}}{\mu_{121} * \mu_{112}} \text{ and } OR_2 = \frac{\mu_{211} * \mu_{222}}{\mu_{221} * \mu_{212}}$$

$$\text{where } E(n_{abc}) = \mu_{abc}$$

The Breslow-Day test helps us to know whether there is an increase, decrease, or non-significant change in odds of truck crashes relative to automobiles in work zones from that of non-work zones, after accounting for external factors. The researcher uses p-values to indicate the significant differences in a statistical test. He assumes a p-value less than 0.05 as significant difference. The significance levels of all the statistical tests are provided in the Appendix D.

The results of this study depend significantly on the procedure used for categorizing the crash data. The researcher believes that good engineering judgment is required to find associations between various crash characteristics. The researcher uses the following procedure to categorize crash data. First, all crashes are divided into 15 broad categories, as shown in Appendix B. Then, for each broad category, the odds ratio of truck crashes relative to that of automobile crashes is compared between work zones and non-work zones. Later, all of the crashes in each of the broad categories are subdivided into five crash types (rear-end, sideswipe, run-off road, and fixed object crashes), and each crash type is again divided into various accident, roadway, and work zone characteristics. The sub categories used for each broad category differ based on the type of broad category. That is, the subdivisions for rear-end crashes are not same as that of the fixed object crashes. For each subdivision, a chi-square analysis is conducted with the help of 2x2x2 contingency tables, as explained earlier.

DATA REDUCTION AND ANALYSIS

First, the crash data are sorted into before and during periods as well as control and work zone sections. Then, each crash from the HSIS database is matched with that of the work zone project information. Finally, the following accident, roadway and work zone variables are identified and categorized.

Accident Characteristics

Most of the accident characteristics such as severity, number of vehicles, surface condition, road curvature, lighting condition, weather, and manner of collision are available directly in HSIS crash data. So the researcher did not have to do any additional work associating these variables to crash data. However, some of the variables like vehicle type, contributing factors, and direction of vehicle involved in a crash are available in the HSIS vehicle data. The researcher merged these variables into HSIS crash data using SAS. Moreover, the time of day variable is assigned separately based on crash time and month of the year.

Before discussing the variables used in this study, the researcher describes the procedure used to merge the vehicle, roadway, and crash data. SAS has a feature which merges two or more data sets using one or more matching variables. The matching variable is the variable which is available in both datasets to be merged. In the case of merging roadway and crash data, there are two steps. First, the "county route" variable of the crash data is matched with that of the roadway data. Then, the "milepost" variable in the crash data will be matched so that it lies between the beginning and end milepost of a county route in the roadway data. The result is a merged dataset containing variables from both crash and roadway data. The same procedure can be used for combining vehicle and crash data. The only difference is that the matching variable in this case is "case no." In addition, one must note that there is no method to merge vehicle and roadway data without the interim step of combining with crash data. A sample of merged dataset is provided in Appendix A.

Vehicle Type

In order to study the differences between crash likelihood due to work zones for trucks and for automobiles, the variable "vehicle type" is obtained for each of the crashes showing whether the crash involves a truck or not. Therefore, there are two vehicle types: truck and non-truck. Using the HSIS codes for different vehicle types, the researcher has defined a truck as any of these vehicles: single unit truck with two or more axles, truck/trailer, truck/tractor, tractor/semi-trailer, tractor/doubles, and unknown heavy truck.

Time of Day

The researcher believes that the crash likelihood changes largely with the time of the day. Keeping in mind the sample size restrictions, three times of day are selected in this study and defined in the Table 7.

Table 7 Three Categories for Time of Day

	Start time	**End time**
Day	Sunrise time + half an hour	Sunset time - half an hour
Night	Sunset time + half an hour	Sunrise time - half an hour
Twilight	Sunset time - half an hour	Sunset time + half an hour
	Sunrise time - half an hour	Sunrise time + half an hour

It is a well-known fact that the sunrise and sunset times vary by day, but it would be more complex to identify these timings for each day and separate the crashes into day, night, and twilight categories. Therefore, average sunrise and sunset times are identified for each month for the 19 work zone projects using the U.S. Naval Observatory website (*42*). Then the crashes are divided into day, night, and twilight times based on different sunrise and sunset timings of each month. Table 8 provides the start and end times of day and night periods for all the months. Further details about how these numbers were computed is explained in Appendix C.

Table 8 Start and End Times of Day, Night, Dusk and Dawn by Month

Month	Day start time	Day end time	Night start time	Night end time	Dawn start time	Dawn end time	Dusk start time	Dusk end time
Jan	7:56	17:00	18:00	6:56	6:57	7:55	17:01	17:59
Feb	7:36	17:30	18:30	6:36	6:37	7:35	17:31	18:29
Mar	6:58	17:57	18:57	5:58	5:59	6:57	17:58	18:56
Apr	6:16	18:22	19:22	5:16	5:17	6:15	18:23	19:21
May	5:44	18:47	19:47	4:44	4:45	5:43	18:48	19:46
June	5:33	19:05	20:05	4:33	4:34	5:32	19:06	20:04
July	5:45	19:03	20:03	4:45	4:46	5:44	19:04	20:02
Aug	6:08	18:37	19:37	5:08	5:09	6:07	18:38	19:36
Sept	6:31	17:55	18:55	5:31	5:32	6:30	17:56	18:54
Oct	6:56	17:13	18:13	5:56	5:57	6:55	17:14	18:12
Nov	7:25	16:43	17:43	6:25	6:26	7:24	16:44	17:42
Dec	7:51	16:38	17:38	6:51	6:52	7:50	16:39	17:37

Severity

A typical KABCO scale (Killed, Type A injury, Type B injury, Type C injury, Property Damage Only) is used in this study. In general, Killed indicates a fatality, Type A injury indicates a incapacitating injury, Type B injury indicates a non-incapacitating injury, Type C injury indicates a possible injury and PDO (Property Damage Only) indicates no injury. These categories are coded in a crash report or electronic database based on police officers' judgment. Though the PDO crashes are not reported consistently, they are still used in this analysis because of the small sample sizes of fatal and injury crashes. The researcher found from the Highway Safety Research Center (HSRC) that NC DOT changed its PDO crash threshold from $500 to $1000 in 1996. As the analysis period for this study is 1995 to 2004, there would be a higher number of PDO crashes in the year 1995, which creates uncertainty in the analysis. Therefore, the researcher conducted a separate analysis with and without PDO crashes. In this thesis, the researcher indicated crashes with PDO as total crashes and crashes without PDO as severe or fatal + injury crashes.

Number of Vehicles

According to Rouphail et al., multi-vehicle crashes, particularly rear-end crashes, are overrepresented in work zones compared to normal roadway sections. This trend is attributed to the increased speed variations between the lane closure and upstream segments (*43*). For this study, this variable is categorized into two vehicle collisions, and collisions involving more than two vehicles.

Surface Condition

The researcher believes that surface condition affects the braking characteristics of a vehicle. A wet road will have a longer braking distance than a dry road. This distance will be even longer during ice and snow conditions. Furthermore, work is not active during rain, ice or snowy conditions. In this study, three “surface condition” categories are taken: dry, wet and ice/snow.

Road Curvature

Horizontal and vertical curves have a negative impact on the operational characteristics of trucks. When these curves are present in a work zone, the trucks may have a greater tendency to roll over. Therefore, the researcher has taken the roadway curvature as a covariate to see how truck and auto crashes behave with different roadway curvatures. This study considers four categories for “road curvature”: straight-level, straight-grade, curve-level, and curve-grade. It would have been more interesting if the researcher could have known whether grade was upward or downward, but unfortunately, HSIS crash database does not provide this information.

Lighting Condition

The researcher is interested in knowing whether a lighted roadway has a similar proportion of effect on trucks and automobiles in the work zones. For this purpose, he uses the variable “lighting condition” and categorizes it into two subsets: lighted roadway at night and roadway not lighted at night.

Weather

Adverse climatic conditions may increase the crash frequency, especially for trucks. Trucks typically have a long haul. Therefore, it is hard for the drivers to plan ahead for the weather changes. This study considers five categories for weather: Clear, Cloudy, Rain, Snow, and Sleet/Hail.

Manner of Collision and Contributing Factors

One of the objectives of this study is to identify the underlying causes for the increase in truck crashes during work zone. Therefore, both the variables “manner of collision” and “contributing factors” are obtained for each of the truck crashes. The researcher specifically looked at crashes involving rear-end, sideswipe, run off the road, and fixed object crashes while the contributing factors considered are speeding, improper lane change, careless driving, failure to yield Right of Way (ROW), following too closely, operating defective vehicle, disregard traffic control, improper passing, and alcohol use. All the above categories were selected because the earlier studies have identified them as the major crash types and contributing factors in work zones.

Direction of Crash

For a study evaluating the effect of work zones on truck crashes, it is important to know the direction of the crash. In the HSIS database, the variable “dir_trvl” is coded based on the assessment of a police officer about the vehicle direction of travel before the crash occurrence. The police officer uses compass direction to indicate the direction of travel.

Roadway Characteristics

All of the roadway characteristics are extracted from the HSIS roadway inventory data and matched to the crash data. For this study, the researcher used four roadway characteristics relating to permanent condition: AADT per lane, speed limit, number of lanes and area type. There are other characteristics like median width, lane width, shoulder width, etc. which are important in a study analyzing safety issues. However, these characteristics change in the work zone period and there is no accurate information available on these characteristics in the diary files.

AADT per Lane

Many earlier studies showed that the AADT of a roadway has a large impact on crash likelihood. Therefore, the researcher used the AADT per lane as a categorical variable. The criteria used for categorizing is based on the level of service of the roadway segment. LOS (Level of Service) greater than ‘C’ was assumed to have a high AADT per lane and the rest a low AADT per lane. The Highway Capacity Manual recommends that LOS be quantified by density. Furthermore, the manual provides a range of density values to represent LOS. The researcher used these tables and identified that a density higher than 26 vehicles per mile was equivalent to LOS greater than ‘C’. In other words, a roadway segment with density higher than 26 vehicles per miles was categorized as high AADT per lane roadways and the remaining as low AADT per lane roadways. Density of a roadway segment is calculated using the following equation:

$$Density = \frac{K * D * AADT}{PHF * f_{HV} * (n) * (speed)}$$

where *PHF* is peak hour factor assumed as 0.85

K is the proportion of AADT on a roadway segment during the design hour, i.e. the hour in which 30th highest hourly traffic flow of the year takes place. It is assumed to be 0.1

D is the directional split, or the proportion of traffic in heavier direction. It is assumed to be 0.6

f_{hv} is the heavy vehicle factor assumed to be 0.80

n is number of lanes obtained (from HSIS dataset)

speed is the speed limit of the roadway in miles per hour (from HSIS dataset)

Speed Limit

Earlier studies observed that speeding was the most significant contributing factor in work zone crashes. Therefore, selecting an appropriate speed limit and providing adequate enforcement to ensure that drivers follow that speed limit is important. An unusually low speed limit should be avoided to maintain the credibility of drivers on work zone traffic signs. The researcher attempted to identify whether the reduction of speed limit has a varied effect on trucks compared to automobiles. The speed limits used in this study were the posted speed limits before the work zone was in place. The diary files did not clearly indicate whether the contractors had reduced the speed limits during work zone period. For analysis purposes, speed limits were categorized into four subsets: 55 mph, 60 mph, 65 mph, and 70 mph.

Number of Lanes

For a greater number of lanes, sideswipe crashes will increase due to more points of contact between vehicles. The researcher believes that these crashes will be higher for trucks due to their massive size and limited maneuverability. This study considers three categories for “number of lanes”: four lanes, six lanes, and eight lanes.

Area Type

It is not unusual to expect that crash frequency and characteristics differ in urban and rural freeways. Some of these differences can be attributed to higher traffic volumes, more lanes, and better roadway lighting conditions in urban areas compared to rural. Therefore, the crashes are analyzed separately for urban and rural freeways.

Work Zone Characteristics

Work zone characteristics were obtained from diary data. As part of NCHRP Project 17-30, the diary data for the 19 projects were entered into spreadsheets and formatted into eight columns:

- Date,
- Start time,
- End time,
- Number of hours of activity,
- Number of lanes closed,
- Direction of lanes closed,
- Lane closure start time,
- Lane closure end time, and
- Lane closure number of hours.

The last three were used only when there were long term lane closures, that is, the period when there were lane closures without any work activity. The researcher added three more columns (Work active/inactive, Number of lanes closed, Direction of lanes closed) to the crash data by merging work zone diary data and crash data.

In this study, the researcher used three work zone characteristics: work zone type, work activity, and number of lanes closed. The results would have been more interesting if there were traffic control data in each of the work zone. Unfortunately, most of the work zones used in this study did not have this information.

Work Zone Type

Each work zone project was divided into two major types, based on the Ullman et al. study (*19*). The first category was road work, where temporary traffic control devices used for lane closure will be removed after completion of work activity. The majority of the projects in this category were typical pavement repair and rehabilitation works. On the other hand, the second category contained projects involving major reconstruction and pavement widening. For these projects, long term roadway geometric changes like lane shifts, median crossovers, and shoulder, ramp, or acceleration/deceleration lane closures, etc. likely existed throughout the project. In statistical terms, this categorical variable had two possible values: projects with and without long term geometric changes.

Work Activity

It was of particular interest in this study to verify whether the change in crash likelihood for trucks was due to the work activity or the change in work zone geometrics (lane shifts, median crossovers, and shoulder, ramp, or acceleration/deceleration lane closures). In order to analyze these effects separately, the "work activity" variable was used. It had two possible values:

- Work is occurring at the time of crash and
- Work is inactive at the time of crash.

The researcher believes that the location of the work activity plays a vital role in the crash occurrence. In fact, work activity on the traffic side of a barrier can have a significant impact on the traffic flow compared to the work activity behind a barrier. However, due to lack of traffic control plans for each of the work zones, it is hard to identify precisely the location where a work activity took place. The researcher did have information on whether the work zone is a major reconstruction or a pavement rehabilitation type of project. It is widely believed that most of the major reconstruction projects will have a barrier, with work activity being done behind the barrier. On the other hand, pavement rehabilitation projects typically do not have a barrier, and work activity can sometimes take place on the traffic side, which adversely affects the traffic flow. The researcher compared the odds of truck and auto crashes in work zones with that of non-work zones for both major reconstruction and pavement rehabilitation projects.

Number of Lanes Closed

A lane closure in a work zone has an adverse effect on traffic. Therefore, lanes are sometimes closed at night when traffic volumes are lower. Irrespective of whether the lanes are closed during day or night, travelers have to change their normal path and merge or cross over in order to traverse through the work zone. This puts an additional workload on drivers and leads to higher crash likelihood. Moreover, the direction of lane closure is important; as it gives a better understanding of whether the crash has occurred due to the presence of a work zone lane closure. Hence, this study categorized this variable into two subsets: no lane closure and lane closure, separately for both the directions.

RESULTS

The results of this study are presented in two sub-sections: the first sub-section provides descriptive statistics to give the reader an understanding of the available sample sizes. The second sub-section discusses all the results of the 2x2x2 contingency tables.

DESCRIPTIVE ANALYSIS

Work zone crashes from all 19 projects were combined and descriptive statistics were computed to compare the characteristics of truck and auto crashes. A simple chi-square test of homogeneity of multinomial proportions was conducted to see whether there was any difference between the vehicle types in different categories like severity, crash type, etc. The researcher assumed that a p-value less than 0.05 indicated a significant difference between truck and automobile crash proportions. The null hypothesis for this chi-square test is provided below.

$$H_0 : \left(p_j\right)_{Auto} = \left(p_j\right)_{Truck} \text{ for each category j}$$

$$H_1 : \left(p_j\right)_{Auto} \neq \left(p_j\right)_{Truck} \text{ for any one of category j}$$

Table 9 shows the auto and truck work zone crash frequencies and percentages reported by different severity levels. The percentages are computed as the number of auto or truck crashes in that severity level divided by the total auto or truck crashes. Clearly, there is no significant difference in severity between auto and truck crash proportions. Therefore, work zones do not seem to cause more severe truck crashes than auto crashes.

Table 9 Comparison of Auto and Truck Work Zone Crashes by Severity

Severity	Work Zone auto crashes	Work Zone truck crashes
Fatal injury	24 (1%)	7 (1%)
Class A injury	45 (1%)	9 (1%)
Class B injury	237 (7%)	66 (7%)
Class C injury	860 (26%)	250 (27%)
No injury	2169 (65%)	581 (64%)
Total	3335	913
	$\chi^2 = 1.70$, df = 4	p-value = 0.79

In Table 10, the percentages of auto and truck work zone crashes are presented for each of the crash types. Based on the chi-square test, there is a significant difference in proportions of crash types between autos and trucks. The percentages of run off the road, fixed object, and rear-end types of collisions are higher for autos, while sideswipe crash percentages are higher for trucks. Higher sideswipe truck crash proportions could be due to narrow lane widths in work zones or due to the large size of trucks.

Table 10 Comparison of Auto and Truck Work Zone Crashes by Crash Type

Crash type	Work Zone auto crashes	Work Zone truck crashes
Run off road	306 (11%)	51 (7%)
Fixed object	640 (23%)	63 (9%)
Rear-end, slow or stop	1498 (54%)	338 (48%)
Sideswipe, same direction	306 (11%)	257 (36%)
Total	2750	709
	$\chi^2 = 289.32$, df = 3	p-value < 0.005

Table 11 presents the proportions of auto and truck work zone crash trends by the number of vehicles involved. Clearly, the proportion of work zone truck crashes with more than two vehicles is significantly higher than that of autos. This statement is further supported by the earlier findings that rear-end and sideswipe crashes, which involve more than one vehicle, are higher in trucks than autos.

Table 11 Comparison of Auto and Truck Work Zone Crashes by Number of Vehicles Involved in a Crash

Number of units	Work Zone auto crashes	Work Zone truck crashes
1	1210 (36%)	87 (9%)
2	1690 (50%)	645 (71%)
More than 2	481 (14%)	181 (20%)
Total	3381	913
	$\chi^2 = 235.16$, df = 2	p-value < 0.005

In Table 12, the proportions of trucks and automobile crashes by road surface are provided. Work zone truck crashes seem to be less prone to wet surface collisions than autos. This could be due to better handling of trucks by professional truck drivers in wet surface conditions compared to average automobile drivers. This finding is again supported by differences in weather conditions between trucks and automobiles. As can be seen in Table 13, the proportion of truck crashes in rainy conditions is statistically significantly less than that of automobiles.

Table 12 Comparison of Auto and Truck Work Zone Crashes by Road Surface

Road Surface	Work Zone auto crashes	Work Zone truck crashes
Dry	2602 (78%)	765 (85%)
Wet	582 (17%)	113 (13%)
Ice	87 (3%)	13 (1%)
Snow	46 (1%)	6 (1%)
Total	3317	897
	$\chi^2 = 21.65$, df = 3	p-value < 0.005

Table 13 Comparison of Auto and Truck Work Zone Crashes by Weather

Weather	Work Zone auto crashes	Work Zone truck crashes
Clear	2238 (66%)	653 (72%)
Cloudy	626 (19%)	170 (18%)
Rain	411 (12%)	70 (8%)
Snow	55 (2%)	12 (1%)
Sleet, hail, freezing rain/drizzle	39 (1%)	6 (1%)
Total	3369	911
	$\chi^2 = 18.09$, df = 4	p-value < 0.005

Table 14 presents percentages of truck and auto crashes by functional class. Though the urban interstates tend to have higher traffic volumes and congestion levels, there is no significant difference found between truck and automobile crash proportions for rural and urban interstate facilities.

Table 14 Comparison of Auto and Truck Work Zone Crashes between Rural and Urban Interstates

Functional class	Work Zone auto crashes	Work Zone truck crashes
Rural Interstate	1084 (32%)	311 (34%)
Urban interstate	2297 (68%)	602 (66%)
Total	3381	913
	$\chi^2 = 1.31$, df = 1	p-value = 0.25

Table 15 indicates that the truck crash proportion in daytime is significantly higher than for autos. This could be due to higher traffic volumes in the daytime, making trucks hard to maneuver (like lane changes, merging, median crossovers, etc).

Table 15 Comparison of Auto and Truck Work Zone Crashes by Lighting Condition

Light	Work Zone auto crashes	Work Zone truck crashes
Daylight	2314 (69%)	691 (76%)
Dusk	87 (3%)	14 (2%)
Dawn	61 (2%)	14 (2%)
Dark – lighted roadway	136 (4%)	24 (3%)
Dark – roadway not lighted	774 (23%)	169 (19%)
Dark – unknown lighting	5 (0%)	0 (0%)
Total	3377	912
	$\chi^2 = 20.38$, df = 5	p-value < 0.005

As can be seen in Table 16, truck crash proportions are significantly higher than that of automobiles when work is active either with a lane closure or without a lane closure. This partially indicates that trucks are more negatively influenced by the workers' presence in work zones and furthermore by the closure of lanes. As mentioned earlier, this may also be due to difference in time of day distributions of truck and automobile volumes, which could lead to higher percentage of trucks passing through the active work zones.

Table 16 Comparison of Auto and Truck Work Zone Crashes by Work Activity and Lane Closure

Activity-Lane Closure	Work Zone auto crashes	Work Zone truck crashes
Active lane closure	197 (6%)	104 (11%)
Active no lane closure	653 (19%)	222 (24%)
Inactive lane closure	26 (1%)	10 (1%)
Inactive no lane closure	2505 (74%)	577 (63%)
Total	3381	913
	$\chi^2 = 53.37$, df = 3	p-value < 0.005

Table 17 indicates that truck crash proportions are significantly higher in work zones with lower speed limits compared to automobile crashes. This trend is the opposite for higher speed limits. That is, truck crash proportions are lower at high speed limits. This could be due to the fact that work zones where lower speed limits are in place have geometric constraints (crossovers, lane shifts, limited shoulders, narrowed lanes, etc.), which may affect trucks more than automobiles.

Table 17 Comparison of Auto and Truck Work Zone Crashes by Speed Limit

Speed Limit	Work Zone auto crashes	Work Zone truck crashes
55 mph	1112 (33%)	355 (39%)
60 mph	271 (8%)	84 (9%)
65 mph	1420 (42%)	368 (40%)
70 mph	578 (17%)	106 (12%)
Total	3381	913
	$\chi^2 = 22.85$, df = 3	p-value < 0.005

Table 18 also indicates that trucks are involved in a higher percentage of “improper lane change” and “failure to yield right of way” related work zone crashes than automobiles. “Failure to yield right of way” crashes are rare on freeways. They might occur due to conflicts between merging vehicles and vehicles on freeways. The results show that the truck drivers face difficulties in changing lanes and yielding right of way to other vehicles. This may be due to lack of truck-friendly traffic control plans, work zone signs, and pavement markings. However, one has to keep in mind that the assigned crash contributing factors were based on individual police officers’ opinions. Although this thesis did not get individual crash reports to verify the contributing factors, the researcher believes that the contributing factors provided in the crash database will give reasonable findings on the areas where truck drivers are facing problems.

Table 18 Comparison of Auto and Truck Work Zone Crashes by Contributing Factors

Contributing factors	Work Zone auto crashes	Work Zone truck crashes
Speeding	1880 (66%)	386 (51%)
Improper lane change	262 (9%)	184 (24%)
Failed to yield ROW	75 (3%)	68 (9%)
Follow too closely	217 (8%)	37 (5%)
Careless driving	215 (8%)	31 (4%)
Operating defective equipment	50 (2%)	24 (3%)
Alcohol use	87 (3%)	5 (1%)
Disregard traffic control	35 (1%)	15 (2%)
Improper passing	14 (0%)	5 (1%)
Total	3266	847
	$\chi^2 = 231.13$, df = 8	p-value < 0.005

In summary, the researcher used descriptive analysis to gain knowledge about the proportions of truck and automobile crashes in work zones, when categorized by different variables. He will not be using the results from this sub-section in the final recommendations because this sub-section compares truck and automobile crashes only in work zones. However, the odds ratio analysis described in the next sub-section compares the odds of truck crashes and automobile crashes in work zones relative to control sections, which is more accurate.

CONTINGENCY TABLE ANALYSIS

The results of the two 2x2 tables based on the Breslow-Day test are provided below. Initially, the researcher planned to divide work inactive lane closures into four categories by time of day and work zone type. However, due to limited sample sizes, he combined these four categories into one category — total work inactive lane closure period. Furthermore, in order to explore the data, the researcher added two more broad categories: twilight period and crashes involving vehicles from the opposite direction. Finally, some of the broad categories were combined to give general trends in work zones. The researcher believes that the broad categories can be combined together if the trends observed in these categories are identical. Therefore, using the results obtained, two general categories (all reconstruction projects and all work zone projects) were also analyzed and findings were discussed.

Though the researcher analyzed the data with upstream and downstream control sections separately, he believes that downstream sections would not work well due to work zone effect on the downstream traffic volumes and speeds. Therefore, the results from upstream section are only presented in the Appendix D.

Reconstruction Projects

There are only three reconstruction projects out of 19 work zones used in this study. Furthermore, the researcher found that there were not many crashes during lane closure times. In fact, the duration of lane closure periods in reconstruction projects was limited. Therefore, this study could not provide any findings for reconstruction projects during lane closure times. On the other hand, the researcher had a large enough sample size and was able to do valid statistical tests during no lane closure times both when work is active and inactive. The results are provided for daytime and nighttime separately in the following sub-section. A summary of all the key significant findings for reconstruction projects is provided in Table 19.

Table 19 Summary of Results for Reconstruction Projects

Broad Categories	Crash Type (No. of crashes)	Significant factors in Total crashes (p-value)	Significant factors in Fatal + Injury crashes (p-value)
Day active no lane closure - Reconstruction	Total (605)	Low AADT per lane (0.013), high speed limit (0.001), two vehicles with low AADT (0.042), and more lanes (0.007)	Straight grade (0.001)
	Rear-end (361)	Straight grade (0.02)	No significant differences
Day inactive no lane closure - Reconstruction	Total (878)	No significant differences	Straight grade (0.015)
	Rear-end (482)	Straight grade (0.01)	No significant differences
Night active no lane closure - Reconstruction	Total (55)	No significant differences	No significant differences
Night inactive no lane closure - Reconstruction	Total (500)	No significant differences	No significant differences
All reconstruction projects	Total (2324)	High speed limits (0.033), and more than two vehicles with low AADT (0.049)	Straight grade (0.005)
	Rear-end (1204)	Straight grade (0.003), and more than two vehicles with low AADT (0.035)	Total (0.031), straight grade (0.007), '55mph' speed limit (0.024), and urban (0.049)

Day Reconstruction Projects

The results for reconstruction projects during both work activity and inactivity in daytime are provided below.

Total Crashes: The results indicated that the odds of truck crashes relative to automobile crashes is not significantly different in work zones than control sections, for daytime reconstruction projects without a lane closure, either when work is active or inactive. However, at times of work activity, the odds of truck crashes relative to automobile crashes were significantly higher in work zones than control sections during daytime reconstruction projects in low AADT and high speed limit facilities. This contradicts the earlier finding that trucks tend to have a lower crash proportions on high speed limit roadways compared to automobiles. The researcher believes that the difference in the results may be either due to the presence of workers or temporary geometrics in reconstruction projects, which could have an adverse effect on truck crashes compared to autos. The difference could also be due to the fact that the descriptive analysis only indicates the difference between truck and auto crashes within work zones, not the changes relative to before work zone conditions. Furthermore, the higher odds ratio of truck crashes in low AADT roadways was found to be due to two-vehicle collisions. This confirms the earlier hypothesis in the descriptive analysis where the researcher found that trucks are more prone to multi-vehicle collisions compared to automobiles in work zones. The researcher also found that a greater number of lanes (greater than six lanes in both directions) were associated with higher odds ratio of truck crashes at day reconstruction projects when work was active. However, more lanes did not have a differential effect on trucks compared to autos in work zones than in control sections when there was no work activity. This indicates that the presence of work activity in areas with higher numbers of lanes can have adverse impact on truck safety. Adverse weather conditions or bad pavement surface did not seem to have significantly different odds of truck crashes relative to automobile crashes in day reconstruction projects compared to control sections either, when work was active or inactive (see Table 19).

Crash Type: The results indicate that the odds of rear-end truck crashes relative to the odds of rear-end automobile crashes were not significantly different in reconstruction projects compared to control sections at daytime. However, straight roadways with grade had higher odds of rear-end truck crashes relative to that of the autos in day reconstruction projects compared to day control sections (see Table 19). HSIS crash data did not provide clear information on whether the grade was upwards or downwards. Furthermore, it was not known whether the truck is hitting the auto or vice versa. With these limitations, researcher can only hypothesize that grade in day reconstruction projects has a significant impact on work zone rear-end truck crashes. Sideswipe, runoff the road, and fixed object truck crash odds ratios relative to that of the automobiles were not found to be significantly different from that of automobiles in day reconstruction projects either when work was active or inactive.

Severe Crashes: Similar to total crashes, there was no significant difference found between odds of severe truck crashes and odds of automobile crashes in day reconstruction projects compared to control sections. However, the odds of severe truck crashes relative to automobile were found to be higher on roadway sections with grade in the reconstruction projects compared to control sections at daytime either when work was active or inactive (see Table 19).

Night Reconstruction Projects

Overall, night reconstruction projects did not have a significant difference between odds of truck crashes relative to odds of automobile crashes in work zones when compared to control sections, either when work was active or inactive, without a lane closure (see Table 19). The sample size was too low (less than five in any of the cells of contingency analysis tables) to provide valid results for the work active lane closure category.

Even categorizing total crashes by AADT per lane, severity, functional class, speed limit, and weather conditions did not show any difference between odds of truck crashes relative to odds of automobile crashes in reconstruction projects compared to control sections at nighttimes, either when work was active or inactive, without a lane closure. The researcher was able to analyze crashes by different crash types only for the work inactive with no lane closure category. He failed to identify any differences by crash types in this category. As mentioned earlier, there were only three reconstruction projects out of the 19 total work zones. Though the overall sample size was large, when separated into day, night and twilight categories, the number of crashes got smaller. Therefore, the researcher could not identify any significant differences between odds of truck crashes relative to automobile crashes in night reconstruction projects compared to control sections.

Summary of All Reconstruction Projects

After combining both day and night crashes for reconstruction projects, the researcher found that the odds of total truck crashes relative to total automobile crashes were not significantly different in reconstruction projects compared to control sections. However, the odds of truck crashes relative to automobile crashes were significantly higher in reconstruction projects than control sections for the two subcategories high speed limit roadway sections and more than two vehicles involved collisions with low AADT (see Table 19). None of the three crash types, rear-end, sideswipe, and run off the road, showed any significant difference between the odds of truck crashes relative to automobile crashes in reconstruction projects compared to control sections. However, the odds of rear-end truck crashes involving more than two vehicle collisions relative to automobile crashes of a similar category were significantly higher in reconstruction projects compared to control sections. Moreover, the odds of severe rear-end truck crashes relative to automobile crashes were found to be significantly higher in reconstruction projects compared to control sections. The odds ratio of severe rear-end truck crashes relative to automobile crashes was found to be significantly higher in work zones in urban and low speed characteristics, when compared to the control sections (see Table 19). The researcher believes that the reason for this trend could be the presence of long queues in urban work zones due to high traffic volumes, especially when lanes were closed.

Maintenance Projects

The researcher was able to divide the crash data in the 16 maintenance projects into finer subcategories to provide more detailed results. A summary of all the key significant findings for maintenance projects is provided in Table 20.

Table 20 Summary of Results for Maintenance Projects

Broad Categories	Crash Type (No. of crashes)	Significant factors in Total crashes (p-value)	Significant factors in Fatal + Injury crashes (p-value)
Day active lane Closure – Maintenance	Total (176)	Total (<0.001), speeding (0.001), improper lane change (0.012), low AADT (<0.001), rural (<0.001), high speed limit (<0.001), and fewer lanes (0.001).	Total (0.008), speeding (0.043), low AADT (0.028), rural (<0.001), high speed limit (<0.001), and fewer lanes (0.002).
	Rear-end (88)	Total (0.044), rural (0.019), and high speed limit (0.044)	No significant differences
	Sideswipe (28)	Total (0.002), Improper lane change (0.008), low AADT (0.002), PDO (0.003), rural (0.005), and fewer lanes (0.011)	Sample size not adequate to conduct statistical test for this category
Day active no lane Closure – Maintenance	Total (122)	Total (0.031), speeding (0.045), low AADT (0.037), rural (0.025), and high speed limit (0.012)	No significant differences
	Rear-end (44)	Total (0.013), low AADT (0.025), rural (0.007), and high speed limit (0.011)	No significant differences
Night active lane Closure – Maintenance	Total (60)	No significant differences.	No significant differences.
Night active no lane Closure - Maintenance	Total (30)	No significant differences.	No significant differences.
Day inactive no lane closure - Maintenance	Total (910)	No significant differences.	No significant differences.
Night inactive no lane closure – Maintenance	Total (392)	Total (0.001), speeding (0.005), low AADT (0.002), urban (0.005), and fewer lanes (0.004)	Total (0.028), speeding (0.041), '70' speed limit (0.037), and fewer lanes (0.016)
	Rear-end (62)	Total (0.018), speeding (0.003), low AADT (0.005),and rural (0.043)	Total (0.041), and low AADT (0.038)
	Sideswipe (43)	Improper lane change (0.011), and urban (0.043)	No significant differences

Day Maintenance Projects with Work Activity and Presence of Lane Closure

The results for maintenance projects during work activity and lane closure in the daytime are provided below.

Total Crashes: Overall, trucks seemed to have a major adverse effect due to the presence of lane closures with work being active in daytime maintenance projects. The major contributing factors for the higher odds of truck crashes relative to odds of automobile crashes in this category were found to be speeding and improper lane change. Furthermore, odds of both injury and non-injury truck crashes relative to odds of automobile crashes were found to be significantly higher in day maintenance projects compared to control sections when work was active with a lane closure (see Table 20).

The odds of truck crashes relative to automobile crashes were significantly higher in day maintenance projects compared to control sections during work activity and lane closure with low AADT, rural, and high speed limit characteristics. The reason could be due to high speeds maintained by trucks on rural and low AADT interstate facilities. Furthermore, four lane facilities with a lane closure seemed to have significantly higher odds of truck crashes relative to automobile crashes in day maintenance projects compared to control sections during work activity and lane closure (see Table 20). This may be due to the large size of trucks, which makes lane changes more difficult while merging or during crossover maneuvers. A clearer indication will be obtained when one looks at the category of sideswipe crashes.

Contrary to the day reconstruction projects, grade of roadway section seemed to have no significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections. Weather conditions seem to have no effect on the odds of truck crashes relative to auto crashes in day maintenance projects compared to control section during work activity and lane closure, which was similar to that of reconstruction projects. This could be due to better handling by seasoned truck drivers in bad weather situations.

Crash Type: The odds of truck rear-end crashes relative to auto rear-end crashes were found to be significantly higher in day maintenance projects compared to day control sections when work was active with a lane closure. However, it was strange to see that odds of "speeding" and "more than two vehicles involved" rear-end truck crashes relative to auto crashes were not significantly different in this work zone situation compared to control section. But the odds of rear-end truck crashes relative to rear-end auto crashes were found to be significantly higher in this work zone situation in rural and high speed limit characteristics compared to similar control sections (see Table 20). This may be due to higher traffic volumes in the daytime, along with the presence of lane closure.

The odds of sideswipe truck crashes relative to sideswipe auto crashes were found to be significantly higher in day maintenance projects compared to day control sections when work was active with a lane closure. The major contributing factor for this is found to be improper lane change. This statement is supported by the significantly higher odds of truck crashes relative to auto crashes in this work zone situation with four lane facilities compared to similar control sections. Furthermore, as in rear-end crashes, low AADT and rural interstates were found to be significantly associated with higher odds of sideswipe truck crashes relative to sideswipe of auto crashes in this work zone situation compared to control section (see Table 20). This result indicates that truck drivers seem to face difficulty while changing lanes during lane closures.

Severe Crashes: The results for severe crashes were almost identical to that of total crashes. Due to low sample sizes, not as many comparisons were made for severe crashes as for total crashes. The results indicated that odds of "speeding" related truck severe crashes relative to auto crashes were significantly higher in this work zone situation compared to control section. Furthermore, the odds of severe truck crashes relative to severe auto crashes were significantly higher in this work zone situation with low AADT, rural, and high speed limit characteristics compared to control section. As in total crashes, the odds of truck severe crashes relative to auto crashes were higher in this work zone situation with low number of lane facilities compared to control section (see Table 20). These results suggest that variability of PDO crash reporting does not have much affect on the results of this category.

Day Maintenance Projects with Work Activity and No Lane Closure

The results for maintenance projects during work activity and no lane closure at daytime are provided below.

Total Crashes: As a whole, the odds of truck crashes relative to the odds of auto crashes were significantly higher in day maintenance projects compared to the control section when work was active without a lane closure. One of the significant contributing factors for the higher odds of truck crashes was found to be speeding. In fact, this statement is supported by other variables like AADT, functional class, and speed limit of the interstate. In other words, low AADT, rural, and high speed limit roadway facilities were found be significantly associated with higher odds of truck crashes relative to automobile crashes in this work zone situation compared to control section (see Table 20). One has to realize that the descriptive analysis in this section indicates that trucks are not as highly associated with speeding crashes as automobiles. However, speeding was identified as a significant factor for higher odds of truck crashes in work active no lane closure day maintenance projects. This indicates that workers' presence could have a negative influence on speeding truck crashes.

Crash Type: The odds of truck rear-end crashes relative to that of auto crashes were found to be significantly higher in this work zone situation compared to the control section. Most of the results for day maintenance work inactive rear-end crashes were similar to that of the earlier case of day maintenance work active rear-end crashes. Low AADT and rural interstates were found to be associated with higher odds of rear-end truck crashes relative to the odds of rear-end automobile crashes in this work zone situation compared to the control section (see Table 20).

The results of sideswipe crashes did not indicate a significant difference between odds of truck crashes relative to automobile crashes in this work zone situation compared to control section. In fact, none of the subcategories of sideswipe crashes with reasonable sample sizes (each cell in the contingency table has more than five crashes) showed any difference between odds of truck crashes relative to automobile crashes in this work zone situation compared to control section (see Table 20). This indicates that the odds of sideswipe truck crashes are higher when lanes are closed compared to no lane closure, even when work is active.

Severe Crashes: Contrary to total crashes, the odds of severe truck crashes relative to severe automobile crashes were not significantly different in day maintenance projects with work activity and no lane closure compared to similar control sections. Moreover, none of the subcategories with valid sample sizes to conduct statistical tests showed any significant difference between odds of severe truck crashes and that of automobile crashes in this work zone situation compared to control section (see Table 20).

Day Maintenance Projects with No Work Activity

The results for maintenance projects during no work activity in the daytime are provided below.

Total Crashes: There was no significant difference found between odds of total truck crashes relative to automobile crashes in day maintenance projects when work was not active compared to the control section. This looks to be reasonable. Typically, maintenance projects involve works like paving, pavement repairs, etc. There would not be any permanent geometric changes. After workers leave the work area, there would not be much difference between a work zone and a normal roadway. Therefore, it is not surprising to see no significant difference between odds of truck crashes relative to auto crashes in this work zone condition compared to control section. Furthermore, subcategories of total crashes, their crash types and severity, were also found to be not significantly different between the odds of truck crashes relative to automobile crashes in this work zone situation compared to the control section (see Table 20).

Night Maintenance Projects with Work Activity

The researcher did not have adequate sample sizes to conduct statistical tests separately for work activity with lane closure and without lane closure. Therefore, he combined both the categories and provided the results below.

Total Crashes: The results did not indicate any significant difference between odds of total truck crashes relative to automobile crashes at night maintenance projects with work activity either with or without lane closure. It showed that truck drivers face similar difficulties as drivers of automobiles. None of the subcategories of total crashes and their crash types showed any significant difference between odds of truck crashes relative to auto crashes in this work zone condition relative to comparison section.

The researcher believes that sample size is one of the reasons for not finding any significant difference between odds of truck crashes relative to automobile crashes in night maintenance projects compared to control sections. In this study, most of the work in maintenance projects was conducted in the daytime, leaving the work zones inactive at night. Therefore, this study could not identify problems faced by truck drivers at work active night maintenance projects.

Night Maintenance Projects with Work Inactivity

Surprisingly, the odds of truck crashes relative to automobile crashes were significantly lower in night maintenance projects with work inactivity compared to control sections (see Table 20). Typically, odds of truck crashes relative to auto crashes should either be higher or not significantly different in this work zone condition. However, it is interesting to see lower odds of truck crashes relative to auto crashes in this case. In order to identify the reasons behind this trend, the researcher looked at crash rates in terms of crashes per mile-day, in both before and during periods of work zone and control sections, separately for trucks and automobiles. He found that truck crashes were decreasing in nighttime inactive periods of maintenance projects. The major decrease in crashes was found to be in rear-end and speeding types of crashes (see Table 20). This indicates that the truck drivers may be slowing down at night while passing through a work zone. Furthermore, the odds ratio of severe truck crashes relative to auto crashes was found to be significantly lower in this work zone condition than in the control sections (see Table 20).

Summary of Maintenance Projects

In summary, day maintenance projects seem to have higher odds of truck crashes relative to auto crashes, compared to control sections when work is active. However, there is no significant difference in odds of truck crashes relative to automobile crashes when work is inactive. On the other hand, night maintenance projects have no significant difference between odds of truck crashes relative to automobile crashes when work is active and lower odds of truck crashes relative to automobiles when work is inactive.

As the maintenance projects have mixed results in different categories, it would be hard to provide any meaningful results through aggregation. Therefore, the researcher has not presented any results for maintenance projects in general.

Summary on All Work Zone Projects

In order to get a general idea of trends and also to compare with earlier studies, the researcher combined crashes from construction and maintenance projects. Surprisingly, odds of total truck crashes relative to auto crashes were found to be not significantly different in work zones compared to control sections (see Table 20). This contradicts the results from earlier studies, which stated that truck crashes were significantly higher than those of automobiles. The researcher believes that the difference in results is either due to differences in approach used or better work zone truck management strategies by North Carolina DOT. Moreover, none of the subcategories of total crashes and crash types had any significant difference between odds of truck crashes relative to auto crashes in work zones compared to control sections.

Table 21 Summary of Results for Other Broad Categories

Broad Categories	Crash Type (No. of crashes)	Significant factors in Total crashes (p-value)	Significant factors in Fatal + Injury crashes (p-value)
All work zone projects	Total (4176)	No significant differences	No significant differences
Twilight periods	Total (375)	No significant differences	No significant differences
Inactive lane closure period	Total (35)	No significant differences	No significant differences
Crashes involving vehicles traveling opposite directions	Total (89)	Daytime (0.05)	Daytime (0.017)

Inactive Lane Closure Periods

As mentioned earlier, the inactive lane closure periods were very limited in the 19 work zones. Only projects I-3606, I-3309A, I-4025, I-2807A, I-2511BB had lane closures with no work activity. In total, only six percent of the work zone duration had work inactive lane closures. Furthermore, only 35 crashes were found to occur in all five projects during work inactive no lane closure. Therefore, the sample sizes did not allow the researcher to identify the differences between odds of truck crashes relative to automobile crashes at these time periods. In general, the odds of truck crashes relative to auto crashes seem to have no significant difference during inactive lane closure periods compared to control sections (see Table 21).

Twilight Periods

Based on the time of day divisions, twilight periods are just two hours per day in duration. Though these are the peak periods for commuting automobile traffic, one cannot expect many truck crashes at these times as truck drivers tend to schedule their trips at off-peak hours. Moreover, work zones typically will either start after these periods or end before these periods to avoid high traffic volumes. As a result, there were not many twilight crashes during work activity. Overall, results indicated no significant difference between odds of truck crashes relative to auto crashes in twilight periods when work is inactive compared to control sections, and sample sizes were not large enough to provide conclusions when work is active (see Table 21).

Two Direction Collisions

As mentioned earlier, all collisions involving vehicles traveling in opposite direction were analyzed separately. It is very rare to see these kinds of crashes on interstates, which typically have barriers or grass medians to separate the opposite directions. The results indicated that the odds of these truck crashes relative to auto crashes were not significantly different from the control sections (see Table 21). However, in the daytime, the odds of truck crashes relative to auto crashes were found to be significantly higher in these types of crashes occurring in work zones compared to control sections (see Table 21). Moreover, the odds of daytime severe truck crashes relative to auto crashes were significantly higher in these types of crashes occurring in work zones compared to control sections. This looks reasonable considering the severity of crashes between vehicles traveling opposite direction on interstates, especially when trucks are involved.

SUMMARY OF FINDINGS

All of the significant findings from the research work are summarized here.

- Results from total and severe crashes were found to be nearly identical. The slight differences identified in some of the categories were due to smaller sample sizes in severe crashes.
- Grade seemed to have an adverse effect on rear-end truck crashes of reconstruction projects.
- Speeding and more lanes seemed to have a statistically significant adverse impact on truck safety in day reconstruction projects. However, there were no significant differences between odds of truck crashes relative to automobile crashes in night reconstruction projects compared to control sections.
- The odds of truck crashes relative to automobile crashes were found to be significantly higher in day maintenance projects compared to control sections, when work is active with a lane closure with the main contributing factors being speeding and improper lane change. The odds of rear-end and sideswipe truck crashes relative to auto crashes were also found to be significantly higher in this category.
- Speeding was found to be the major factor for higher odds of truck crashes relative to auto crashes in day maintenance projects compared to control sections when work is active without a lane closure. The odds of rear-end truck crashes relative to auto crashes were also significantly higher in this category.
- Most of the earlier studies found that truck crashes were significantly higher than those of autos in work zones. However, this study indicated that odds of truck crashes relative to auto crashes were not significantly different in work zones compared to control sections. The researcher believes that the difference in result could either be due to differences in approach used or better truck management strategies implemented by North Carolina DOT.
- There were higher odds of total and severe truck crashes relative to auto crashes at daytime in vehicles traveling opposite direction in work zones compared to control sections.

LIMITATIONS OF THE STUDY

The researcher lists the limitations of the study, which might have affected the accuracy of the obtained results.

- The researcher conducted multiple tests on the same data set. This may have a few type I errors (false significance). Since this research was an exploratory study, some type I errors would provide conservative results. In order to get more accurate results in future evaluations, a correction for multiplicity should be applied.
- As found in any other traffic safety study, this research also had limited sample size availability. Furthermore, traffic control data like lane width, shoulder width, and use of ITS devices were not available in the data set. Therefore, most of the reasoning in the findings were hypothesized and not confirmed.
- In this study, the researcher used the vehicle contributing factor from the HSIS crash database. One has to note that the contributing factor codes provided in the crash data were based on police officers’ discretion. In other words, if another police officer had been present at the same accident location, he may have coded the contributing factors for the accident differently. An ideal way to solve this problem is to use police crash reports. The police crash reports have more detailed information and drawings explaining the way in which a crash has occurred. These drawings would help the researcher in extracting more information such as who is at fault in a crash (truck or car), the crash location relative to work zone, etc.

RECOMMENDATIONS

In the previous section, the researcher compared the odds of truck and automobile crashes on freeway work zones relative to control sections, and identified similarities and differences between both vehicle types. In this section, the researcher identifies the key findings of this study and suggests recommendations to improve truck safety in work zones.

KEY FINDINGS

For reconstruction projects, the researcher could not identify any differences between odds of truck and automobile crash characteristics when separated into subcategories like crash type due to limited available sample sizes. On the other hand, in maintenance projects when work was active, odds of truck crashes were statistically higher than that of automobile crashes at daytime and not statistically different at nighttime in work zones compared to control sections. Furthermore, at inactive periods of maintenance projects, odds of truck crashes were not statistically different from that of automobile crashes at daytime and lower at nighttime in work zones compared to control sections. In summary, from the available sample sizes, the researcher found that the trucks are adversely affected during maintenance projects at daytime when work was active. Therefore, the researcher provides recommendations based on the findings of only this category.

The findings of day maintenance projects indicated that the odds of rear-end and sideswipe truck crashes were significantly higher than that of automobiles in work zones compared to control sections, when work was active with a lane closure. The main contributing factors noted in the crash reports for these types of crashes were speeding and improper lane changes. On the other hand, only odds of rear-end truck crashes were significantly higher than that of automobiles in work zones compared to control sections when work was active without a lane closure. The contributing factor for these crashes was also speeding. The next sub-section discusses the probable causes for the higher odds of rear-end and sideswipe truck crashes in day maintenance projects. Since the crash dataset could not clearly identify whether a truck hit a car or vice versa, the researcher hypothesized both cases. The reader should note that there could be a third scenario where a truck hit another truck. However, the sample sizes of truck hitting truck crashes were only two percent of the total crashes. Therefore, this case was not considered while providing recommendations.

CAUSES AND RECOMMENDATIONS

The researcher provided recommendations separately for rear-end and sideswipe crashes. Figure 8–Figure 10 are line diagrams indicating the possible reasons for higher odds ratios of rear-end and sideswipe truck crashes than for auto crashes in work zones compared to the control sections. Further, the diagrams provide engineering countermeasures to mitigate the higher odds ratio of truck crashes. The line diagram starts with the outcome and then indicates the possible action causing that outcome. Later, the researcher identifies the potential reasons for the actions. Finally, he presents engineering countermeasures for each of the reasons, which could reduce the possible actions.

Sideswipe Crashes

The results indicated that the odds of sideswipe crashes were significantly higher in trucks compared to that of automobiles in work zones than the control sections, when work was active with a lane closure. The main contributing factor was found to be improper lane change. First, if a truck hit a car, the possible actions causing this could be the truck sideswiping a car while changing lanes at the lane closure taper, the truck swerving out of its lane due to a hazard ahead, or the truck failing to slow down and swerving. Let us look at each of the situations separately. When the truck hits the car while changing lanes near the lane closure taper, a likely reason could be that the truck did not merge into the open lane early enough. Trucks take a longer time to change lanes than automobiles. Therefore, the researcher believes that trucks should be provided with greater advance warning so that they can merge into the open lane early. Furthermore, additional advance warning should be such that it alerts the truck drivers if they are inattentive or fatigued. Previous research indicated that CB Wizard could alert the truck drivers and lead them to change lanes early (*31*,*35*). Smart work zones using ITS devices like CMS signs should be deployed to notify the drivers to merge into the open lane at various distances from the taper, depending on the level of congestion (*12*).

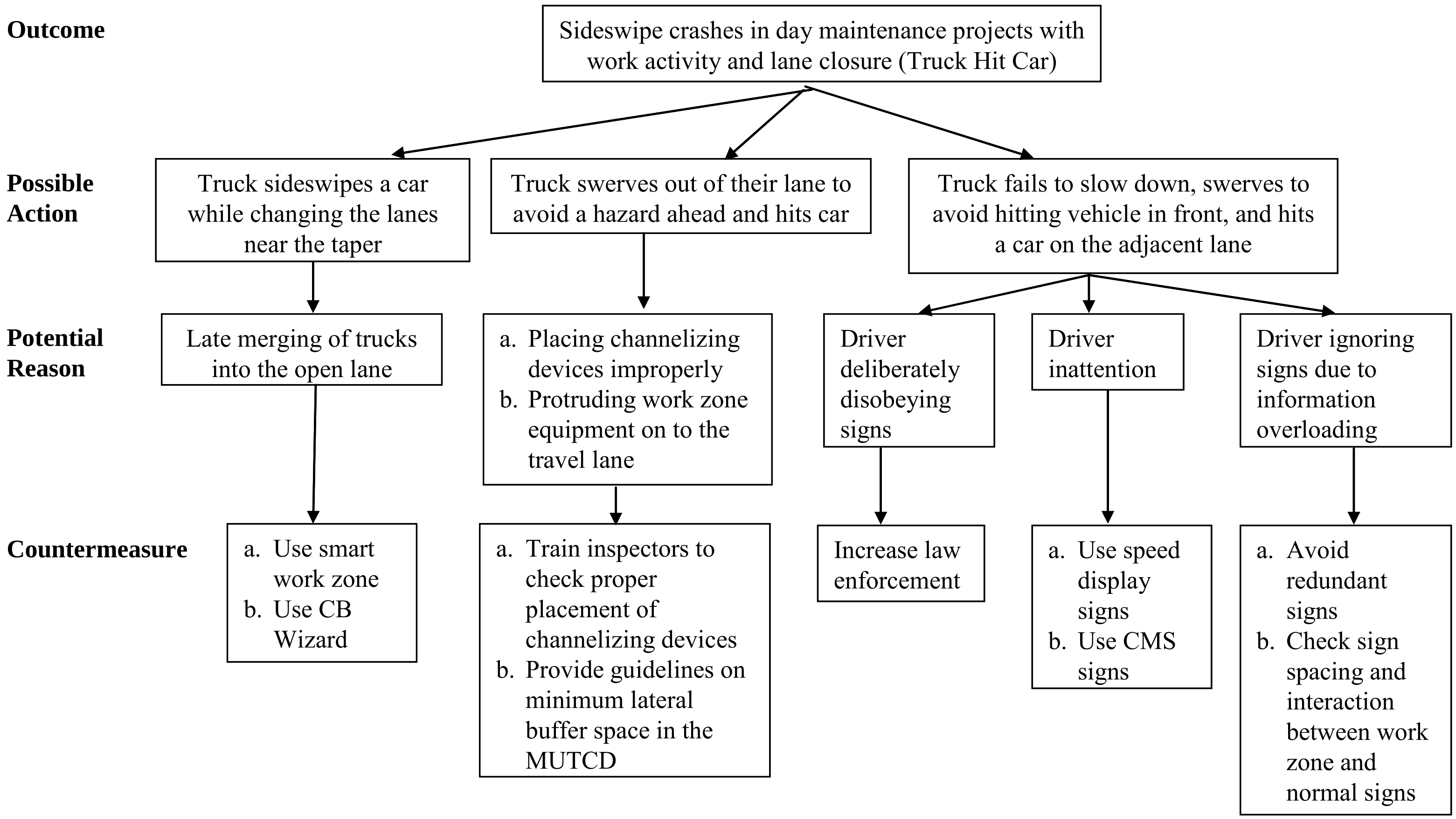

Figure 8 Line diagram for sideswipe crashes (truck hit car).

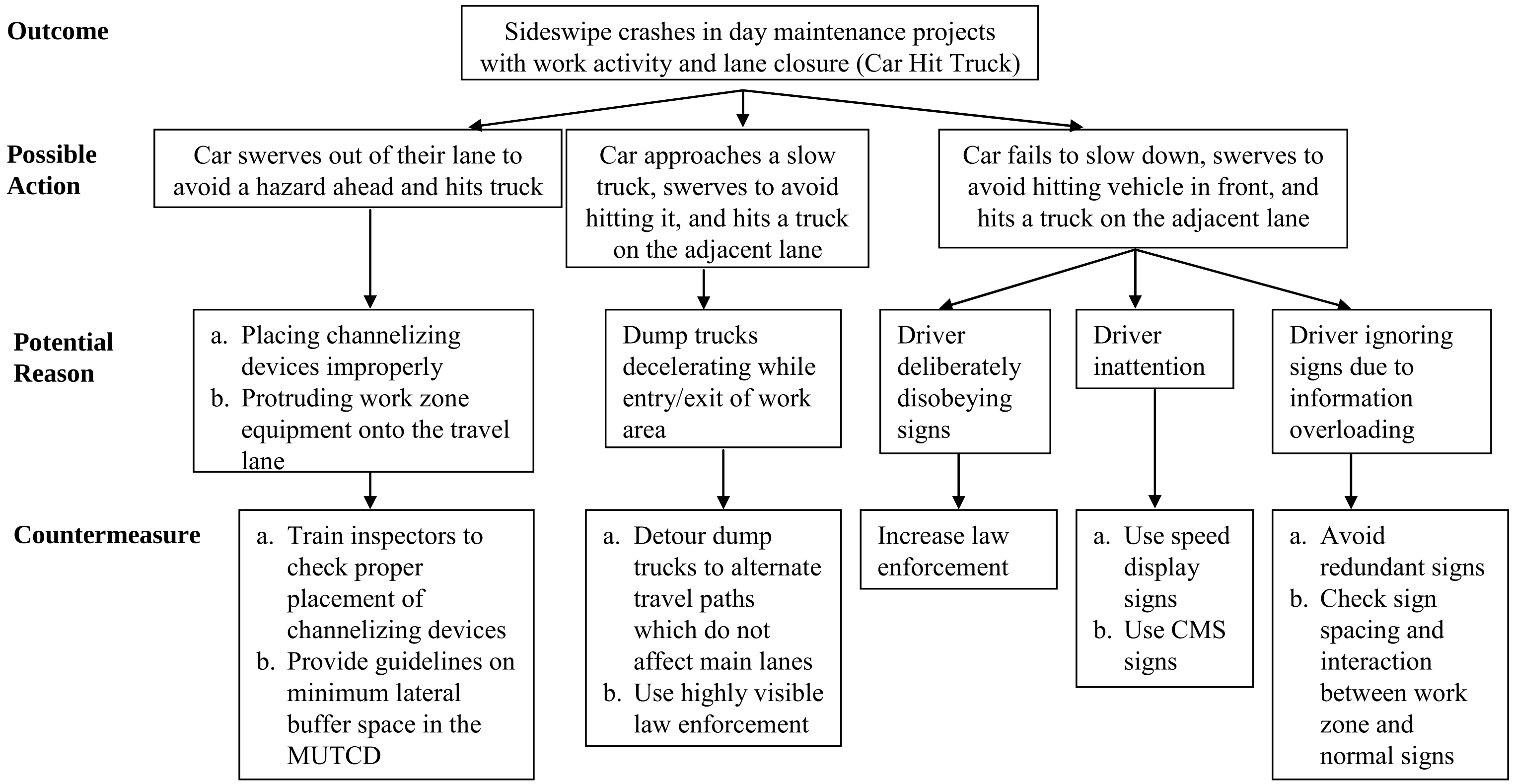

Figure 9 Line diagram for sideswipe crashes (car hit truck).

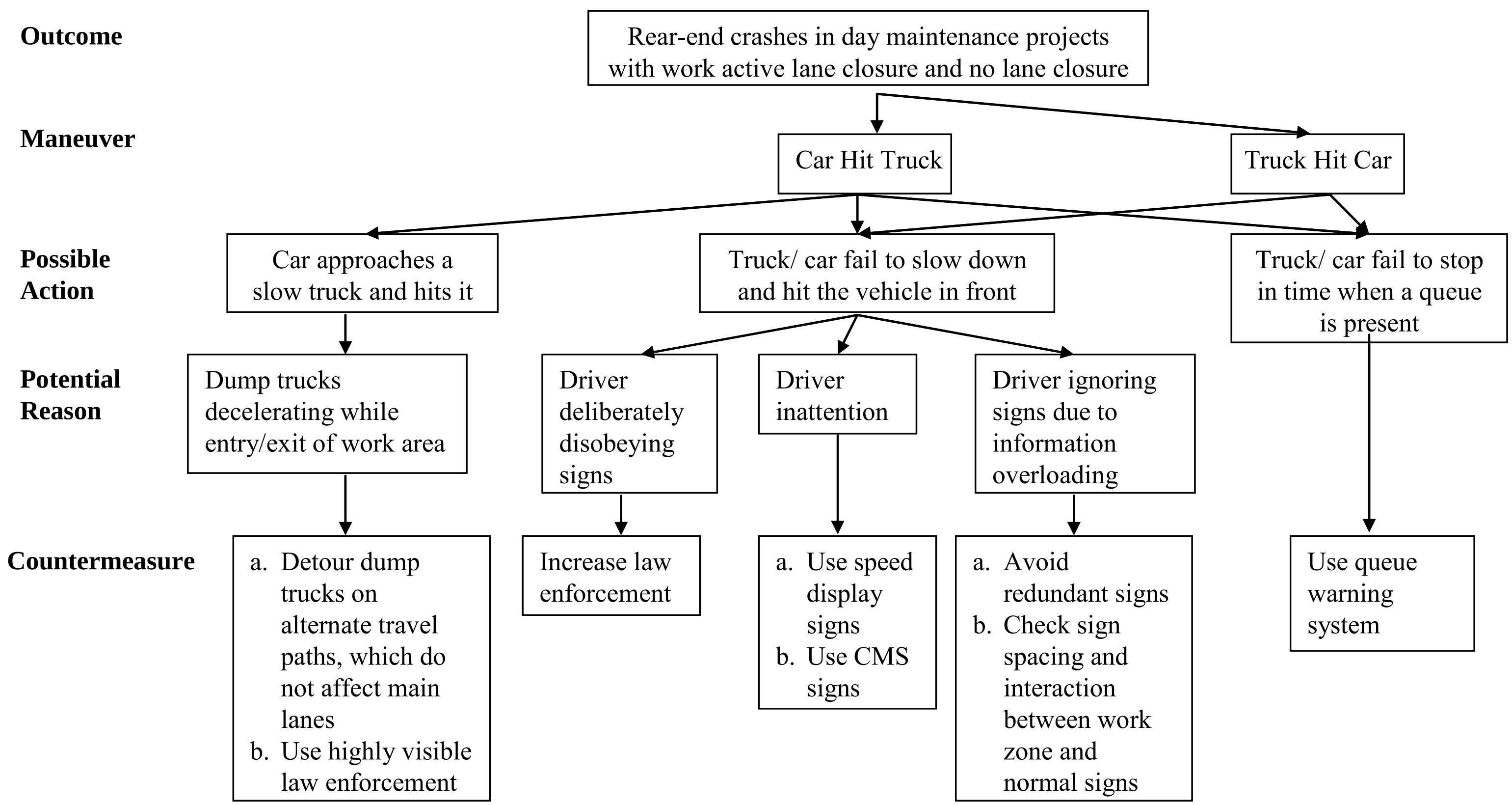

Figure 10 Line diagram for rear-end crashes.

The second possible cause is that the truck swerves out of its lane due to a hazard in the travel path and hits a car. The possible reasons for this maneuver could be improper placement of channelizing devices like drums, cones, etc. or protrusion of work zone equipment into the travel lane. Channelizing devices are placed in the work zones to separate the travel lanes and work areas. Sometimes contractors reduce the travel lane width to increase the size of the work area by placing the channelizing devices toward the travel lane by one or two feet. This would have a significant effect on 8–9 foot-wide trucks. Sometimes, even though the contractor has positioned the channelizing devices properly, one or two cones can move out of alignment and obstruct the travel way. This can make the truck drivers swerve out of their paths and hit vehicles in the adjacent lane. The researcher recommends that inspectors be trained to make sure that the channelizing devices are placed in correct alignment and do not hinder the travel lane. If the inspectors are already being trained to check these devices, then either more focused training should be used or the DOT should look for other ways to improve safety. Furthermore, work zone equipment or workers can unintentionally come closer to the travel lane. Equipment containing protrusions are especially risky. The current MUTCD has an optional lateral buffer space. However, the researcher believes that the work zone equipment should be placed as far from the travel lanes as possible. In fact, the researcher recommends that MUTCD provide guidelines, using future research, with a minimum lateral buffer space between travel lane and work area. Though these issues can also occur at night, the researcher could not identify a disproportionate change in odds of truck crashes relative to automobiles in the nighttime analyses because of lower traffic volume. Lower volumes would provide a better chance to maneuver and avoid these traffic control devices.

Finally, trucks may fail to slow down in work zones, swerve due to a vehicle in front, and sideswipe a car in the adjacent lane. Though the percentage of trucks exceeding the speed limit is lower, this scenario is possible. The most likely reasons for trucks not slowing down could be drivers disobeying work zone speed limits, driver inattention, and drivers ignoring signs due to information overloading. The third case is more applicable to urban work zones where there is high interaction between work zone and normal signs. For drivers disobeying work zone speed limits, law enforcement is the best solution. These drivers are deliberately traveling at high speeds, and thus a police officer would warn them to slow down and comply with the speed limits. In the case of inattentive drivers, more effective signs should be provided to catch their attention. The researcher recommends CMS signs and speed display signs as the effective speed control measures to reduce speeds of inattentive drivers. However, there are still a few new technologies like photo enforcement and innovative flashing warning lights, which are in the testing stage, and the effectiveness of these methods is not very clear. Finally, for drivers ignoring signs due to information overloading, the researcher recommends frequent checks of work zone sign inventory and the removal of redundant signs. Furthermore, signs should be spaced in such a way that the presence of both work zone and normal signs would not cause any additional information loading on the motorist.

If a car hits a truck, the possible actions causing this could be a car swerving out of its lane to avoid a hazard ahead and hitting truck, a car approaching a slow-moving truck and swerving to avoid hitting it, or a car failing to slow down and swerving to avoid hitting a vehicle in its path. As shown in the line diagram, the reasons and countermeasures for cars to swerve out of their lane to avoid a hazard or to not slow down in work zones are similar to that of trucks. In the case of cars approaching slow moving trucks, the possible reasons are the entry and exit of dump trucks. In general, maintenance projects need a lot of asphalt to rehabilitate the pavements, and thus dump trucks frequently enter and exit the work zone. During entry and exit, dump trucks operate at very low speeds making high speed cars swerve to avoid hitting them. The researcher recommends that alternate travel paths be identified for dump trucks for entry and exit to avoid hindering main lane traffic flow. If alternate travel paths are not possible, highly visible law enforcement has to be deployed upstream of the entry and exit of the dump trucks to alert freeway traffic to slow down.

Rear-End Crashes

Rear-end crashes were significantly higher in trucks than automobiles when work was active both with a lane closure and without a lane closure. The main contributing factor was found to be speeding. Hence, the reasons and countermeasures are provided commonly for both work active lane closure and no lane closure.

If a truck rear-ends a car, then the possible action causing the crash could be failure to stop in front of a queue or failure to slow down and therefore hit the vehicle in front of it. The first scenario indicates that trucks may not have sufficient time to respond when approaching a queue. A real-time queue warning system should be used to alert the drivers at various distances upstream of the work zones, depending on the queue lengths. Furthermore, a static sign indicating “WATCH FOR STOPPED TRAFFIC” may also be used. However, these signs might mislead the driver if there is no queue present at the upstream of the work zone. Therefore, these signs should be avoided unless queues are present all the time. If a truck fails to slow down in work zones, the reasons and countermeasures would be similar to those described for sideswipe crashes. Contrarily, if a car rear-ends truck, there could be three probable reasons: car approaching slow moving truck and hitting it, car failing to slowdown and hitting the vehicle in front of it, or car failing to stop in time when queue is present. The reasons and countermeasures for the first two cases were discussed earlier in the sideswipe crashes sub-section and are applicable here. In the case of cars failing to stop in time, the reason could be that advance warning sign did not alert the driver early enough to stop before a queue. As mentioned earlier, a queue warning system should be used to warn the drivers well ahead about the queue presence.

Summary

Based on the reasons discussed in earlier sub-sections, the researcher provides the following list of recommendations.

- During lane closure periods of day maintenance projects, the agencies should consider using smart work zones and CB Wizard to warn the truck drivers to change lanes well ahead of the taper.
- The agencies should consider training inspectors to check for proper placement of channelizing devices. The FHWA should consider adding guidelines to the MUTCD on minimum lateral buffer space between the travel path and work area.
- The agencies should consider using law enforcement, CMS signs, and speed display signs during work activity in day maintenance projects. Furthermore, inspectors could check for redundant work zone signs and maintain adequate spacing between work zone and normal signs.
- Traffic control plans should attempt to identify alternate travel paths for dump trucks to enter and exit work zones. If these paths are not available, then highly visible law enforcement should be considered upstream of the entry and exit of the dump trucks to warn the freeway traffic about the slow moving dump truck.
- The agencies should consider using a real time queue warning system to warn drivers about the queue presence.

BENEFIT COST ANALYSIS

The researcher conducted a benefit cost (B/C) analysis to verify whether the recommended countermeasures were cost effective for use in a work zone. He analyzed the following six countermeasures in the B/C analysis: law enforcement, smart work zone system, dynamic late merge system, changeable message sign (CMS), speed display sign, and CB Wizard. The basic approach used for the B/C analysis consists of following steps. First, the actual crash frequencies were computed for each work zone in the during period, separated by vehicle type and crash severity. The researcher considered trucks and automobiles as the two vehicle types, and fatal + injury and PDO as the two crash severity categories in this analysis. In other words, he used a total of four crash categories: fatal + injury truck crashes, fatal + injury automobile crashes, PDO truck crashes, and PDO automobile crashes. The fatal and injury crashes were combined because of very small sample sizes for fatal crashes (one percent of total crashes). The computed crash frequencies for the four categories were then multiplied by their respective crash costs and Crash Reduction Factors (CRFs) to determine the safety benefit (the numerator in the B/C ratio) in each work zone. Cost (the denominator in the B/C ratio) was computed as the cost of deploying each countermeasure in a particular work zone, i.e., the cost of a countermeasure in each work zone varies depending on the characteristics of that work zone like duration, project length, etc. In the next step, the computed benefit and cost of all 19 work zones were combined to get total benefit and total cost. Finally, the B/C ratio for a particular countermeasure was computed as total safety benefit divided by the total cost.

A great deal of uncertainty is present in this analysis. First, there were no good quality data to estimate the safety benefits of the countermeasures recommended in this study. Furthermore, the cost of the countermeasures varies by region, manufacturer, availability, and work zone characteristics. Therefore, the researcher used a sensitivity analysis to look at the conditions under which the countermeasures were cost effective. To begin with, the researcher considered three scenarios for cost of countermeasure: minimum, average, and maximum cost. Furthermore, he used three scenarios for CRFs. Previous research conducted on Accident Modification Factors (AMFs) and CRFs indicated that most of the traffic control devices as well as law enforcement typically have a range of 5 to 25 percent crash reduction, with an average of 15 percent (*44, 45, 46*). Therefore, the researcher used 5, 15, and 25 percent as the three scenarios for CRFs.

Benefits

This sub-section provides the details of how researcher computed the safety benefits. As mentioned earlier, the researcher multiplied the crash frequencies of four categories with their respective crash costs and a common CRF to compute the safety benefits. The following equation expresses this process.

$$B_{ij} = CRF_i * (n_{j(A_{FI})} * C_{(A_{FI})} + n_{j(A_{PDO})} * C_{(A_{PDO})} + n_{j(T_{FI})} * C_{(T_{FI})} + n_{j(T_{PDO})} * C_{(T_{PDO})})$$

where *i* indicates each of the three scenarios for CRF (5, 15, and 25 percent)

j is a work zone

B_{ij} is the safety benefit in work zone *j*

CRF_i is crash reduction factor

A_{FI} is Fatal + Injury auto crash

T_{FI} is Fatal + Injury truck crash

n_j is number of crashes

C is crash cost

The researcher showed the crash costs used in the above equation as projected crash costs in Table 22. He used the original automobile and truck crash costs obtained from FHWA and FMCSA and projected them to current dollar amounts, i.e. project crash costs, applying a growth rate of three percent. Furthermore, since the number of fatal and injury crashes were smaller, the costs for these crashes were combined through a weighted average, which was obtained using the percentage of crashes for each crash type.

Costs

The researcher provides details in this sub-section on the procedure used for computing the cost (denominator in the B/C ratio). The costs are calculated as the costs of deploying a countermeasure in a particular work zone. These costs vary based on several variables like work zone duration, number of traffic control devices used, life span of the traffic control device, etc. The researcher identified these variables and indicated their relationship with countermeasure costs in Table 23.

Table 22 Automobile and Truck Crash Costs (*54, 55*)

Crash Type	Crash Costs (Original)		Crash Costs (Projected by 3% growth)		Crash Type (%)	Average Crash Cost	
	Auto (1994)	Truck (2006)	Auto (2007)	Truck (2007)	Auto and Truck	Auto	Truck
Fatal	$2,600,000	$3,604,518	$3,818,188	$3,712,654	1 %	$147,944	$218,524
Type A Injury	$180,000	$525,189	$264,336	$540,945	1 %		
Type B Injury	$36,000	$180,323	$52,867	$185,733	7 %		
Type C Injury	$19,000	$78,215	$27,902	$80,561	26 %		
Property Damage Only	$2,000	$5,114	$2,937	$5,267	65 %	$2,937	$5,267

Table 23 Equations for Countermeasure Cost Calculations

Countermeasure	Equation used to calculate the cost incurred for deploying a countermeasure in a given work zone
Law enforcement	24 * Cost of Officer per hour * Number of Officers in a Work Zone * Duration of Work zone * % of day work activity
Smart Work Zone system	Cost of Smart Work Zone system
Dynamic Late Merge System	Cost of Dynamic Late Merge System per day * Duration of Work zone
Changeable Message Sign	Capital cost of CMS $* i * \left[\frac{(1+i)^{n_1}}{(1+i)^{n_1}-1}\right] * \frac{1}{365} *$ Duration of Work zone*Number of CMS in a work zone
Speed Display Sign	Capital cost of Speed display sign $* i * \left[\frac{(1+i)^{n_2}}{(1+i)^{n_2}-1}\right] * \frac{1}{365} *$ Duration of Work zone*Number of Speed display signs in a work zone
CB Wizard	Capital cost of CB Wizard $* i * \left[\frac{(1+i)^{n_3}}{(1+i)^{n_3}-1}\right] * \frac{1}{365} *$ Duration of Work zone*Number of CB Wizards in a work zone

As mentioned earlier, three different scenarios were considered for countermeasure costs: minimum, average, and maximum cost. To determine these costs, the researcher first obtained the minimum, average, and maximum values for each of the variables used in calculating the cost of a countermeasure (see Table 24). Then the researcher used the values from each of the three scenarios and calculated the countermeasure costs for all three scenarios using the equations in Table 23.

The researcher made the following assumptions about the different variables for the three different cost scenarios. First, the researcher used two law enforcement officers as the minimum value and six officers as the maximum value. In the minimum case, the researcher assumed one stationary officer for each direction of the work zone at the upstream end. In the maximum case scenario, the researcher assumed two stationary officers and one circulating officer on each direction of the work zone at the upstream end. The researcher believes that the minimum and maximum cost scenario incorporates both longest and shortest work zones used in this thesis. Second, the cost of a smart work zone system was assumed as a lump sum amount varying from $100,000 to $2,500,000 for a given work zone. On the other hand, traffic control devices like CMS, speed display sign, and CB Wizard were amortized using a federal interest rate of five percent. The researcher believes that the traffic control devices individually are cheaper and can be bought by the contractor on a permanent basis. However, the smart work zone system needs more complex devices, and contractors will lease these devices depending on their requirement.

Table 24 Variables Used for Countermeasure Cost Calculations

Variable	Minimum	Average	Maximum
Cost of Officer per hour (*47*)	$35	$52.5	$70
Number of Officers in a Work Zone	2	4	6
Cost of Smart Work Zone (*48*)	$100,000	$500,000	$2,500,000
Cost of Dynamic Late Merge System per day (*49,50*)	$1,350	$1,800	$2,700
Capital cost of CMS (*51*)	$47,000	$82,000	$117,000
Life Span of CMS (n_1) (*51*)	12	10	5
Federal Interest Rate (i)	5%	5%	5%
Number of CMS in a Work Zone	2	4	6
Capital cost of Speed Display Sign (*52*)	$5,000	$10,000	$15,000
Life Span of Speed Display Sign (n_2)(*52*)	12	10	5
Number of Speed Display Signs in a Work Zone	2	4	6
Capital cost of CB Wizard (*53*)	$4,000	$5,500	$7,000
Life Span of CB Wizard (n_3)	6	5	3
Number of CB Wizards in a Work Zone	2	4	6

B/C Ratio

The researcher computed the B/C ratio for a particular countermeasure using the following equation:

$$\text{B/C Ratio} = \frac{\sum_j B_j}{\sum_j C_j}$$

where B_j is the safety benefit in work zone j

C_j is cost of deploying a countermeasure in work zone j.

Findings

Table 25 presents the B/C ratios for all six countermeasures in different scenarios. The results indicated that the B/C ratios were greater than one for all the cases except a few scenarios in smart work zone and dynamic late merge systems. The smart work zone system does not seem to be very cost effective in the maximum cost scenario. Crash reductions of at least 20 to 25 percent are needed to justify the high cost of a smart work zone system. An engineer must independently evaluate the characteristics of a work zone and make a judgment call as to whether deploying such a high cost smart work zone system would provide a 20 to 25 percent of crash reduction. On the other hand, dynamic late merge system seems to be expensive when crash reductions are near five percent. In other words, the B/C ratios indicate that a minimum of 10 to 15 percent reduction in crashes is required to make dynamic late merge system a cost effective countermeasure. The remaining four countermeasures, law enforcement, CMS, speed display sign, and CB Wizard, were found to be cost effective in all the scenarios.

Table 25 B/C Ratios for Different Scenarios of Countermeasure Costs and CRF's

Recommended Countermeasure	B/C Ratio								
	Minimum Cost			Average Cost			Maximum Cost		
CRF	**0.05**	**0.15**	**0.25**	**0.05**	**0.15**	**0.25**	**0.05**	**0.15**	**0.25**
Law Enforcement	3.9	11.6	19.4	1.3	3.9	6.5	1.0	1.9	3.2
Smart Work Zone	6.7	20.0	33.3	1.3	4.0	6.7	0.3*	0.8*	1.3
Dynamic Late Merge	0.9*	2.6	4.3	0.6*	1.9	3.2	0.4*	1.3	2.2
Changeable Message Sign	40.1	120.4	200.6	10.0	30.1	50.1	2.6	7.9	13.1
Speed Display Sign	377.2	1131.6	1885.9	82.2	246.5	410.8	20.5	61.4	102.4
CB Wizard	270.0	810.0	1350.0	83.7	251.2	418.7	23.3	69.8	116.4

* Indicates that the B/C ratio is less than one.

Conclusions

The researcher provides the following conclusions from the benefit cost analysis:

- Law enforcement during work activity at day time, smart work zones with costs lower than or equal to half a million dollar, CMS, speed display signs, and CB Wizard were found to be cost effective to be used in work zones. Therefore, agencies should consider deploying law enforcement during day work activity times and use other traffic control devices (smart work zone system, CMS, speed display signs, and CB Wizard) at all the times.
- Smart work zone with significantly higher costs like 2.5 million dollars might be useful only when an engineer can identify at least 20 to 25 percent crash reduction potential.
- Dynamic late merge system should be considered for deployment in a work zone if there is an indication of at least 10–15 percent reduction in crashes.

SUMMARY OF RECOMMENDATIONS

The researcher has identified that the odds of truck crashes were significantly higher than those of automobiles in freeway maintenance projects, compared to control sections, in the daytime when work is active. In the remaining categories, the researcher could not find any differences between the odds of truck and automobile crashes. Even if identified, the reasons for higher odds of truck crashes were not very clear due to limited sample sizes. Therefore, the researcher believes that the influence of work active day maintenance projects on truck safety is the key finding from this study. Therefore, his recommendations are based on findings for the subcategories of the day maintenance projects.

The researcher presents the following six recommendations: law enforcement during work activity at daytime, smart work zones, dynamic late merge system, CMS, speed display sign, and CB Wizard. He conducted a benefit cost analysis to look at the economic feasibility of each of the countermeasures under different sets of conditions.

The analysis indicated that law enforcement during work activity at daytime, smart work zones with costs lower than or equal to half a million dollar, CMS, speed display sign, and CB Wizard could be used in the work zones. Smart work zones with significantly higher costs could be used when there is an indication of at least a 20 to 25 percent of crash reduction potential. Finally, dynamic late merge systems should be considered if there is a crash reduction potential of at least 10 to 15 percent

SUMMARY AND FUTURE WORK

The researcher separated this section into two sub-sections: the first sub-section provides a summary of this research work, and the second sub-section lists the future potential research to be conducted.

SUMMARY

The primary objective of this study was to identify the similarities and differences in truck and automobile work zone crashes and thus provide recommendations to improve truck safety in work zone. To achieve this objective, the researcher categorized the crash data in two levels. First, the crashes were divided into broad categories using the following variables: time of day, work zone type, work activity state, and lane closure state. Second, the crashes were categorized by crash type and then sub-divided using various variables (shown in Appendix B). Once the crashes were categorized, the Breslow-Day test was used to compare odds of truck and automobile crashes between work zones and non-work zones. Moreover, control sections were used to account for external factors. Various findings were obtained from each of the comparisons between different subcategories. In reconstruction projects, the researcher could not find any significant difference between odds of truck and automobile crashes in work zones compared to control sections either when work is active or inactive. Sample sizes for reconstruction projects were not large enough to identify any significant differences between subcategories of truck and automobile crashes. On the other hand, maintenance projects in the daytime had significantly higher odds of truck crashes than automobiles in work zones compared to control sections when work was active. However, maintenance projects in night work active periods did not have a significant difference between odds of truck and automobile crashes in work zones compared to control sections. Furthermore, daytime maintenance projects during inactive periods showed no significant difference between the odds of truck and automobile crashes, while nighttime inactive periods of maintenance projects had lower odds of truck crashes than automobiles in work zones compared to control sections. Finally, the researcher believes that the results from the day maintenance projects were the key findings of this study and thus used these findings to identify potential recommendations, which could improve work zone truck safety.

The odds of sideswipe truck crashes were found to be significantly higher than automobile crashes in daytime maintenance projects compared to control sections when work was active with a lane closure. The main contributing factor noted for the significance of this crash type was found to be improper lane change. Furthermore, rear-end truck crashes were found to be significantly higher than that of automobile crashes in day maintenance projects compared to control sections when work was active both with and without a lane closure. The main contributing factor for the significance of this crash type was found to be speeding. The researcher hypothesized various scenarios causing these findings and thus identified the reasons and countermeasures for each of the scenarios. The list of identified countermeasures includes the use of law enforcement, smart work zones, dynamic late merge system, CMS signs, speed display signs, and CB Wizard. Based on the B/C analysis, the researcher found that the use of law enforcement, smart work zones with costs lower than or equal to half a million dollar, CMS signs, speed display signs, and CB Wizard have B/C ratios greater than one. Smart work zones, with significantly higher costs of up to 2.5 million dollars, can be deployed if the work zone characteristics indicate a potential crash reduction of 20 to 25 percent. In the case of a dynamic late merge system, the researcher found that the work zone characteristics should indicate a crash reduction potential of at least 10 to 15 percent to deploy this system.

Even though this study provides good recommendations to the DOTs for improving their truck safety, there are still some limitations. First, this study did not have traffic volume data and thus the researcher could not quantify the extent of the difference between truck and automobile crashes. Second, there were no traffic control data for conditions during work zones; such as lane width, shoulder width, speed limits, use of CMS signs, etc. This limited the researcher’s ability to provide some of the recommendations. Finally, this research used multiple tests on the same dataset, which may have led to Type I errors. Since this was an exploratory study, the researcher believes that few Type I errors showing false significant results did not have an adverse effect on the results of this study.

FUTURE WORK

The following list presents the potential areas where more research should be conducted in order to improve work zone truck safety:

- Hourly traffic volumes of both trucks and automobiles should be collected in order to identify the extent of difference in crash rates between automobile and trucks for different categories.
- More studies should be conducted on the effects of permanent work zone geometric changes on truck safety. More specifically, researchers should look at the effects of reduced lane width and shoulder width, increases in the advance warning sign placement, sign retroreflectivity, and median crossover curve, among others, on truck safety in work zones.
- Important data like crash location relative to work zone, whether a truck or car initiated the crash, etc. should be collected to better identify the possible reasons for higher odds of truck crashes than autos in work zones compared to control sections in different work zone scenarios.

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APPENDIX A

DATA DESCRIPTION TABLES

Appendix A includes all of the summary tables describing both the diary data and HSIS crash data used in this study. Table A-1 –Table A-4 indicate the start time, end time, control section limits, and work zone section limits of all the North Carolina work zone projects used in this study. Table A-5 and Table A-6 provide the revised start and end mileposts of control and work zone sections based on the geometric check. Table A-7 provides the general characteristics of 19 work zone projects. Table A-8-Table A-9 indicate the time of day at which work activity took place and lanes are closed in each of the project. Table A-9 – Table A-22 describe the crash data in various ways. Table A-9 and Table A-12 indicate the total mileage and crashes requested from the HSIS for each year and county route.

Table A-1 Description of North Carolina Work Zone Projects 1

No.	Project Number	County	Highway	Work Zone Type	BEFORE Time Period Beginning Date	BEFORE Time Period End Date	BEFORE Time Period Total Length (Days)	DURING Time Period Beginning Date	DURING Time Period End Date	DURING Time Period Total Length (Days)
1	I-2201F	Guilford	I-40	Pavement Widening	9/15/1995	9/14/1998	1096	9/15/1998	10/1/2003	1843
2	I-2204BA	Durham/Wake	I-40	Pavement Widening	8/13/1998	8/12/2001	1096	8/13/2001	11/26/2003	836
3	I-2511BB	Rowan	I-85	Pavement Widening	8/5/1995	8/4/1998	1096	8/5/1998	5/18/2004	2114
4	I-2807A	Surry	I-77	Pavement Repair/Rehab	4/13/1997	4/12/2000	1096	4/13/2000	11/19/2001	586
5	I-3102A	Nash/Halifax	I-95	Pavement Repair/Rehab	8/6/1999	8/5/2002	1096	8/6/2002	12/1/2003	483
6	I-3308A	Iredell	I-77	Pavement Repair/Rehab	5/23/1998	5/22/2001	1096	5/23/2001	5/20/2004	1094
7	I-3309A	Iredell	I-77	Pavement Repair/Rehab Bridge Work	7/31/1997	7/30/2000	1096	7/31/2000	12/1/2001	489
8	I-3606	Wilson	I-95	Pavement Repair/Rehab	6/4/1998	6/3/2001	1096	6/4/2001	3/28/2003	663
9	I-4017	Orange/Durham	I-85/40	Guardrail Installation	10/2/1997	6/29/1998	814	10/2/2000	6/29/2001	271
					10/2/1998	6/29/1999				
					10/2/1999	6/29/2000				
10	I-4025	Yadkin/Surry	I-77	Bridge Work	12/6/1998	12/5/2001	1096	12/6/2001	5/13/2003	524
11	I-4030	Cleveland	I-85	Pavement Repair/Rehab	11/2/1997	7/30/1998	814	11/2/2000	7/30/2001	271
					11/2/1998	7/30/1999				
					11/2/1999	7/30/2000				

Table A-2 Description of North Carolina Work Zone Projects 2

No.	Project Number	County	Highway	Work Zone Type	BEFORE Time Period Beginning Date	BEFORE Time Period End Date	BEFORE Time Period Total Length (Days)	DURING Time Period Beginning Date	DURING Time Period End Date	DURING Time Period Total Length (Days)
12	I-4036	Rowan/Davidson	I-85	Pavement Repair/Rehab	4/10/1998 4/10/1999 4/10/2000	7/20/1998 7/20/1999 7/20/2000	306	4/10/2001	7/20/2001	102
13	I-4403	Robeson	I-95	Pavement Repair/Rehab	9/9/1998 9/9/1999 9/9/2000	10/22/1998 10/22/1999 10/22/2000	132	9/9/2001	10/22/2001	44
14	I-4408	Pender/Hanover	I-40	Pavement Repair/Rehab	7/2/1998 7/2/1999 7/2/2000	2/22/1999 2/22/2000 2/22/2001	708	7/2/2001	2/22/2002	236
15	I-4412	Mecklenburg	I-85/40	Pavement Repair/Rehab	5/22/1999	5/21/2002	1096	5/22/2002	6/28/2003	403
16	I-4414	Alamance/Guilford	I-85/40	Pavement Repair/Rehab	6/3/1999	6/2/2002	1096	6/3/2002	6/28/2003	391
17	I-4415	Johnston	I-95	Pavement Repair/Rehab	1/27/2000 1/27/2001 1/27/2002	11/24/2000 11/24/2001 11/24/2002	907	1/27/2003	11/24/2003	302
18	I-4741	Davie/Forsyth	I-40	Pavement Repair/Rehab	3/15/2001 3/15/2002 3/15/2003	7/30/2001 7/30/2002 7/30/2003	414	3/15/2004	7/30/2004	138
19	W-4439	Gaston	I-85	Pavement Repair/Rehab	5/16/2000 5/16/2001 5/16/2002	7/24/2000 7/24/2001 7/24/2002	210	5/16/2003	7/24/2003	70

Table A-3 Original Control and Work Zone Sections of North Carolina Work Zone Projects 1

		Control Limits (Upstream)			Control Limits (Downstream)			Work Zone Limits		
No.	**Project Number**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**
1	I-2201F	0 (Guilford)	2.99 (Guilford)	2.99	14.2 (Guilford)	18.35 (Guilford)	4.15	5 (Guilford)	12.19 (Guilford)	7.19
2	I-2204BA				3.21 (Wake)	27.29 (Wake)	24.08	9.361 (Durham) 0 (Wake)	12.781 (Durham) 1.2 (Wake)	4.62
3	I-2511BB	2.31 (Rowan)	4.59 (Rowan)	2.28				6.6 (Rowan)	12.8 (Rowan)	6.20
4	I-2807A				11.92 (Surry)	17.28 (Surry)	5.36	0.55 (Surry)	4.55 (Surry)	4.00
5	I-3102A	8.17 (Nash)	15.7 (Nash)	7.53	6 (Halifax)	22.99 (Halifax)	16.99	18.35 (Nash) 0 (Halifax)	26.27 (Nash) 2.35 (Halifax)	10.27
6	I-3308A	0 (Iredell)	7.3 (Iredell)	7.30	34.99 (Iredell)	38.48 (Iredell)	3.49	14.72 (Iredell)	23.37 (Iredell)	8.65
7	I-3309A	7.31 (Iredell)	12.71 (Iredell)	5.40	29.58 (Iredell)	34.98 (Iredell)	5.40	23.38 (Iredell)	27.57 (Iredell)	4.19
8	I-3606	3 (Wilson)	3.99 (Wilson)	0.99	0.62 (Nash)	8.16 (Nash)	7.54	6 (Wilson)	15 (Wilson)	9.00
9	I-4017	0 (Orange)	4.47 (Orange)	4.47	4.4 (Durham)	13.74 (Durham)	9.34	7.45 (Orange) 6.5 (Orange) 17.9 (Orange) 5.87 (Durham)	16 (Orange) 13.44 (Orange) 1.51 (Durham) 9.36 (Durham)	21.81

Table A-4 Original Control and Work Zone Sections of North Carolina Work Zone Projects 2

		Control Limits (Upstream)			Control Limits (Downstream)			Work Zone Limits		
No.	**Project Number**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**
10	I-4025	0 (Yadkin)	10.09 (Yadkin)	10.09	6.56 (Surry)	11.91 (Surry)	5.35	12.1 (Yadkin) 0 (Surry)	13.73 (Yadkin) 0.54 (Surry)	2.17
11	I-4030	14.49 (Gaston)	17.24 (Gaston)	2.75				0 (Cleveland)	7.6 (Cleveland)	7.60
12	I-4036	0 (Rowan)	2.3 (Rowan)	2.3	7.19 (Davidson)	22.42 (Davidson)	15.23	18.06 (Rowan) 0 (Davidson)	19.44 (Rowan) 5.18 (Davidson)	6.56
13	I-4403	0 (Robeson)	23.99 (Robeson)	23.99	30.01 (Robeson)	38.65 (Robeson)	8.64	26 (Robeson)	28 (Robeson)	2.00
14	I-4408	0 (Sampson) 0 (Duplin)	20.19 (Sampson) 27.8 (Duplin)	47.99				1.83 (Pender) 0 (Hanover)	25.71 (Pender) 6.36 (Hanover)	30.24
15	I-4412	0 (Mecklenburg)	6.09 (Mecklenburg)	6.09	13.41 (Mecklenburg)	21.09 (Mecklenburg)	7.68	8.1 (Mecklenburg)	11.4 (Mecklenburg)	3.30
16	I-4414	18.36 (Guilford)	25.49 (Guilford)	7.13	3.01 (Alamance)	16 (Alamance)	12.99	27.5 (Guilford) 0 (Alamance)	29.57 (Guilford) 1 (Alamance)	3.07
17	I-4415	2.56 (Johnston)	20.14 (Johnston)	17.58	2 (Wilson)	2.99 (Wilson)	0.99	22.15 (Johnston)	30.34 (Johnston)	8.19
18	I-4741	0 (Davie)	15.69 (Davie)	15.69	2.89 (Forsyth)	23.15 (Forsyth)	20.26	17.7 (Davie) 0 (Forsyth)	19.3 (Davie) 0.88 (Forsyth)	2.48
19	W-4439	1.64 (Gaston)	2.2 (Gaston)	0.56	17.25 (Gaston)	19.43 (Gaston)	2.18	8.9 (Gaston)	12.48 (Gaston)	3.58

Table A-5 Revised Control and Work Zone Sections of North Carolina Work Zone Projects 1

		Control Limits (Upstream)			Control Limits (Downstream)			Work Zone Limits		
No.	**Project Number**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**
1	I-2201F	0 (Guilford)	2.99 (Guilford)	2.99	14.2 (Guilford)	18.35 (Guilford)	4.15	5 (Guilford)	11.03 (Guilford)	6.03
2	I-2204BA				4.48 (Wake)	27.29 (Wake)	22.81	9.361 (Durham)	12.781 (Durham)	3.42
3	I-2511BB	2.31 (Rowan)	4.59 (Rowan)	2.28				6.6 (Rowan)	12.8 (Rowan)	6.20
4	I-2807A				11.92 (Surry)	17.28 (Surry)	5.36	0.55 (Surry)	4.55 (Surry)	4.00
5	I-3102A	8.17 (Nash)	15.7 (Nash)	7.53	6 (Halifax)	22.99 (Halifax)	16.99	18.35 (Nash) 0 (Halifax)	26.27 (Nash) 2.35 (Halifax)	10.27
6	I-3308A	0 (Iredell)	7.3 (Iredell)	7.30	34.99 (Iredell)	38.48 (Iredell)	3.49	14.72 (Iredell)	23.37 (Iredell)	8.65
7	I-3309A	7.31 (Iredell)	12.71 (Iredell)	5.40	29.58 (Iredell)	34.98 (Iredell)	5.40	23.38 (Iredell)	27.57 (Iredell)	4.19
8	I-3606	3 (Wilson)	3.99 (Wilson)	0.99	0.62 (Nash)	8.16 (Nash)	7.54	6 (Wilson)	15 (Wilson)	9.00
9	I-4017	0 (Orange)	1.57 (Orange)	1.57	4.4 (Durham)	13.74 (Durham)	9.34	7.45 (Orange) 7.14 (Orange) 17.9 (Orange) 5.87 (Durham)	16 (Orange) 13.44 (Orange) 1.51 (Durham) 9.36 (Durham)	21.17

Table A-6 Revised Control and Work Zone Sections of North Carolina Work Zone Projects 2

		Control Limits (Upstream)			Control Limits (Downstream)			Work Zone Limits		
No.	**Project Number**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**	**Starting Mile point**	**Ending Mile point**	**Length (miles)**
10	I-4025	0 (Yadkin)	10.09 (Yadkin)	10.09	6.56 (Surry)	11.91 (Surry)	5.35	12.1 (Yadkin) 0 (Surry)	13.73 (Yadkin) 0.54 (Surry)	2.17
11	I-4030	14.49 (Gaston)	17.24 (Gaston)	2.75				0 (Cleveland)	7.6 (Cleveland)	7.60
12	I-4036	0 (Rowan)	2.3 (Rowan)	2.3	7.19 (Davidson)	22.42 (Davidson)	15.23	18.06 (Rowan) 0 (Davidson)	19.44 (Rowan) 5.18 (Davidson)	6.56
13	I-4403	0 (Robeson)	23.99 (Robeson)	23.99	30.01 (Robeson)	38.65 (Robeson)	8.64	26 (Robeson)	28 (Robeson)	2.00
14	I-4408	0 (Sampson) 0 (Duplin)	20.19 (Sampson) 27.8 (Duplin)	47.99				1.83 (Pender) 0 (Hanover)	25.71 (Pender) 6.36 (Hanover)	30.24
15	I-4412	0 (Mecklen-burg)	6.09 (Mecklenburg)	6.09	13.41 (Mecklen-burg)	21.09 (Mecklen-burg)	7.68	8.1 (Mecklenburg)	11.4 (Mecklenburg)	3.30
16	I-4414	18.36 (Guilford)	25.49 (Guilford)	7.13	3.01 (Alamance)	16 (Alamance)	12.99	27.5 (Guilford) 0 (Alamance)	29.57 (Guilford) 1 (Alamance)	3.07
17	I-4415	2.56 (Johnston)	20.14 (Johnston)	17.58	2 (Wilson)	2.99 (Wilson)	0.99	22.15 (Johnston)	30.34 (Johnston)	8.19
18	I-4741	0 (Davie)	15.69 (Davie)	15.69	2.89 (Forsyth)	23.15 (Forsyth)	20.26	17.7 (Davie) 0 (Forsyth)	19.3 (Davie) 0.88 (Forsyth)	2.48
19	W-4439	1.64 (Gaston)	2.2 (Gaston)	0.56	17.25 (Gaston)	19.43 (Gaston)	2.18	10.89 (Gaston)	12.48 (Gaston)	1.59

Table A-7 General Characteristics of North Carolina Work Zone Projects

No.	Project Number	Rural/Urban	Before period speed limit in mph (From HSIS)	AADT in before period (From HSIS)	Number of lanes (From HSIS)	Number of lanes closed predominantly
1	I-2201	Urban	55	93,000	4	1, 2
2	I-2204	Urban	65	117,000	6	1, 2
3	I-2511	Rural and Urban	65	56,000	4	1-4
4	I-2807	Rural	70	22,000	4	1, 2
5	I-3102	Rural	70	36,000	4	1, 2
6	I-3308	Rural and Urban	55,65,70	48,000	4	1, 2
7	I-3309	Rural	70	29,000	4	1, 2
8	I-3606	Rural and Urban	70	32,000	4	1, 2
9	I-4017	Rural and Urban	55,60,65	50,000	4	1
10	I-4025	Rural	70 (changed to 65mph in 2000)	31,000	4	2
11	I-4030	Rural	65	36,000	4	1
12	I-4036	Rural	65	64,000	4	1, 2
13	I-4403	Rural	65	40,000	4	1
14	I-4408	Rural	70	19,000	4	1, 2
15	I-4412	Urban	60	112,000	8	2
16	I-4414	Rural and Urban	55, 65	80,000	8	2, 3
17	I-4415	Rural	65,70	35,000	4	1
18	I-4741	Rural and Urban	65	45,000	4	1, 2
19	W-4439	Urban	55	98,000	6	2

Table A-8 Work Activity and Lane Closure Information of North Carolina Work Zone Projects

		Work Conducted		Lane Closures	
No.	**Project Number**	**Day**	**Night**	**Day**	**Night**
1	I-2201F (C104975)	Yes	Yes	No	Yes
2	I-2204BA (C200203)	Yes	Yes	No	Yes
3	I-2511BB (C104952)	Yes	Yes	Yes	Yes
4	I-2807A (C105373)	Yes	Yes	Yes	Yes
5	I-3102A (C200429)	Yes	Yes	Yes	Yes
6	I-3308A	No	Yes	No	Yes
7	I-3309A (C105452)	Yes	Yes	Yes	Yes
8	I-3606 (C200168)	Yes	Yes	Yes	Yes
9	I-4017 (C105447)	Yes	Yes	No	Yes
10	I-4025 (C200227)	Yes	Yes	Yes	Yes
11	I-4030 (C105491)	Yes	No	Yes	No
12	I-4036 (C105489)	Yes	Yes	No	Yes
13	I-4403 (C105573)	Yes	No	Yes	No
14	I-4408 (C200171)	Yes	No	Yes	No
15	I-4412 (C200240)	Yes	Yes	No	Yes
16	I-4414 (C200446)	Yes	Yes	Yes	Yes
17	I-4415 (C200584)	Yes	Yes	Yes	Yes
18	I-4741 (C200871)	Yes	Yes	Yes	Yes
19	W-4439 (C200577)	Yes	Yes	No	Yes

Table A-9 Start and End Milepost of Each County Route Requested from HSIS 1

County	Highway	County Route (HSIS code)	Start milepost	End milepost	Length (miles)
Alamance	I-40	10000040	0	16	16
Cleveland	I-85	2210000085	0	8.17	8.17
Davidson	I-85	2810000085	0	22.42	22.42
Davie	I-40	2910000040	0	19.3	19.3
Duplin	I-40	3010000040	0	27.98	27.98
Durham	I-40	3110000040	0	12.78	12.78
Durham	I-85	3110000085	0	13.74	13.74
Forsyth	I-40	3310000040	0	23.15	23.15
Gaston	I-85	3510000085	0	19.43	19.43
Guilford	I-40	4010000040	0	29.57	29.57
Halifax	I-95	4110000095	0	22.99	22.99
Iredell	I-77	4810000077	0	38.48	38.48
Johnston	I-95	5010000095	0	30.34	30.34

Table A-10 Number of Crashes in Each County Route Requested from HSIS 1

County	Highway	Number of Crashes										
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Alamance	I-40	248	311	268	288	302	387	273	409	452	403	3341
Cleveland	I-85	47	58	39	31	62	84	69	55	76	86	607
Davidson	I-85	137	155	157	188	216	218	209	257	303	358	2198
Davie	I-40	69	102	88	91	100	109	107	156	196	250	1268
Duplin	I-40	64	75	70	76	81	99	98	129	133	139	964
Durham	I-40	242	296	294	374	379	434	384	561	725	658	4347
Durham	I-85	332	283	266	397	294	286	298	363	490	514	3523
Forsyth	I-40	213	264	330	291	266	280	347	376	449	446	3262
Gaston	I-85	327	289	339	337	395	455	394	458	501	556	4051
Guilford	I-40	454	756	704	773	926	1047	953	894	923	657	8087
Halifax	I-95	144	188	193	156	166	178	162	231	306	346	2070
Iredell	I-77	194	255	306	287	286	331	325	417	541	485	3427
Johnston	I-95	208	294	223	261	219	335	305	263	372	401	2881

Table A-11 Start and End Milepost of Each County Route Requested from HSIS 2

County	Highway	County Route (HSIS code)	Start milepost	End milepost	Length (miles)
Mecklenburg	I-85	5910000085	0	21.09	21.09
Nash	I-95	6310000095	0	26.27	26.27
New Hanover	I-40	6410000040	0	6.36	6.36
Orange	I-40	6710000040	0	19.22	19.22
Orange	I-85	6710000085	7.45	16	8.55
Pender	I-40	7010000040	0	25.69	25.69
Robeson	I-95	7710000095	0	38.65	38.65
Rowan	I-85	7910000085	0	19.43	19.43
Sampson	I-40	8110000040	0	20.15	20.15
Surry	I-77	8510000077	0	17.28	17.28
Wake	I-40	9110000040	0	27.29	27.29
Wilson	I-95	9710000095	0	16.38	16.38
Yadkin	I-77	9810000077	0	13.73	13.73
Total					**544.44**

Table A-12 Number of Crashes in Each County Route Requested from HSIS 2

County	Highway	Number of Crashes										
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Mecklenburg	I-85	665	580	579	717	734	914	892	1080	1208	1197	8566
Nash	I-95	95	148	120	165	119	196	172	225	318	326	1884
New Hanover	I-40	23	28	31	34	28	37	47	37	68	71	404
Orange	I-40	134	191	120	134	165	218	235	237	311	258	2003
Orange	I-85	43	49	41	50	66	80	98	118	121	134	800
Pender	I-40	46	68	73	66	72	164	180	131	151	172	1123
Robeson	I-95	263	270	286	265	283	322	264	343	372	408	3076
Rowan	I-85	183	170	216	239	330	295	283	336	364	298	2714
Sampson	I-40	27	34	47	40	48	55	56	72	75	80	534
Surry	I-77	64	58	63	88	117	87	80	80	94	92	823
Wake	I-40	440	588	560	760	926	896	796	894	959	992	7811
Wilson	I-95	59	110	69	89	73	129	101	141	105	108	984
Yadkin	I-77	57	64	46	75	57	92	77	145	87	129	829
Total		**8768**	**9676**	**9522**	**10268**	**10708**	**11728**	**11207**	**12412**	**13706**	**13572**	**111567**

Table A-13 Sample HSIS Crash Data

cnty_rte	milepost	caseno	alcflag	num_unit	acc_date	report	severity	acctype	Mharm_ac	locality	light
10000040	7.48	100002487	N	2	06JAN2000:18:30:00	N	5	28	28	3	4
10000040	7.782	100003295	N	2	07JAN2000:17:07:00	D	5	21	21	3	1
10000040	8.46	100004448	N	1	09JAN2000:15:00:00	I	3	19	19	3	1
10000040	2.6	100004450	N	1	09JAN2000:15:30:00	D	5	19	19	3	1
10000040	1.42	100005388	N	1	10JAN2000:08:10:00	I	4	19	19	3	3
10000040	15.22	100005389	N	1	10JAN2000:08:20:00	I	4	18	18	1	1
10000040	6.21	100005392	N	2	10JAN2000:14:50:00	N	5	13	13	3	1
10000040	8.95	100006402	N	1	11JAN2000:14:30:00	N	5	18	18	1	1
10000040	9.1	100010741	N	3	18JAN2000:11:00:00	D	5	27	28	5	1
10000040	7.98	100010876	N	1	18JAN2000:08:35:00	I	4	19	19	3	1
10000040	9.15	100010887	N	2	18JAN2000:09:30:00	I	3	27	27	3	1
10000040	11.22	100010891	N	2	18JAN2000:13:30:00	I	4	30	30	1	1
10000040	6.98	100010894	N	2	18JAN2000:11:15:00	D	5	28	28	3	1
10000040	2.2	100010908	N	2	18JAN2000:11:00:00	D	5	13	30	3	1
10000040	11.38	100010917	N	1	18JAN2000:13:45:00	D	5	19	19	1	1
10000040	6.17	100011245	N	1	18JAN2000:03:15:00	I	3	19	19	3	4
10000040	1.92	100011246	N	1	18JAN2000:10:45:00	D	5	19	19	1	1
10000040	6.01	100011279	N	2	18JAN2000:07:05:00	D	5	13	30	3	3
10000040	7.53	100011283	N	1	18JAN2000:12:30:00	D	5	19	19	3	1
10000040	8.45	100011284	N	1	18JAN2000:12:30:00	D	5	19	19	3	1
10000040	7.53	100011285	N	1	18JAN2000:12:30:00	I	3	19	19	3	1
10000040	13.99	100011286	N	1	18JAN2000:09:50:00	D	5	19	19	5	1
10000040	3.28	100011289	N	2	18JAN2000:10:00:00	D	5	23	23	3	1
10000040	14.92	100011293	N	2	18JAN2000:06:30:00	D	5	30	30	1	3
10000040	9.35	100011296	N	1	18JAN2000:11:00:00	D	5	19	19	5	1

Table A-14 Sample HSIS Roadway Data

cntyrte	begmp	endmp	SPD_LIMT	NO_LANES	PCT_TRK1	AADT	LSHLDWID	MEDWID	RSHLDWID	func_cls	year
10000040	0	0.93	65	8	16	80300	10	22	10	9	2000
10000040	0.93	2.29	65	8	27	80300	10	22	10	9	2000
10000040	2.29	3.2	65	8	23	98000	10	22	10	9	2000
10000040	3.2	3.29	65	8	16	98000	10	22	10	9	2000
10000040	3.29	3.38	65	8	16	98000	10	22	10	9	2000
10000040	3.38	3.98	65	8	23	98000	10	22	10	9	2000
10000040	3.98	6.11	65	8	23	101000	10	22	10	9	2000
10000040	6.11	6.49	65	8	23	100000	10	22	10	9	2000
10000040	6.49	6.93	65	8	23	100000	10	22	10	9	2000
10000040	6.93	7.41	65	8	23	100000	10	22	10	9	2000
10000040	7.41	7.46	65	8	23	100000	10	22	10	9	2000
10000040	7.46	7.57	65	8	23	100000	10	22	10	9	2000
10000040	7.57	7.78	65	8	23	100000	10	22	10	9	2000
10000040	7.78	8.11	65	8	24	95000	10	22	10	9	2000
10000040	8.11	8.16	65	8	24	95000	10	22	10	9	2000
10000040	8.16	8.25	65	8	24	95000	10	22	10	9	2000
10000040	8.25	8.45	65	8	24	95000	10	22	10	9	2000
10000040	8.45	8.69	65	8	24	95000	10	22	10	9	2000
10000040	8.69	8.85	65	8	24	95000	10	22	10	9	2000
10000040	8.85	9.07	65	8	24	91000	10	22	10	9	2000

Table A-15 Sample HSIS Vehicle Data

caseno	vehno	spdlim	trvl_spd	dir_trvl	contrib1	vehtype	maneuver	mostharm	rd2objst	drv_rest	drv_inj
100002487	1	65	70	W	12	5	4	28	0	3	5
100002487	2	65	65	W	0	1	4	28	0	3	5
100003295	1	65		E	0	5	1	21	0	3	5
100003295	2	65	5	E	8	4	12	21	0	3	5
100004448	1	65	70	W	6	1	4	48	6	3	3
100004450	1	65	65	E	7	1	4	61	4	2	5
100005388	1	65	65	E	7	1	4	48	5	3	4
100005389	1	65	60	W	0	1	4	13	6	3	4
100005392	1	65		W	0	1	4	13	1	3	5
100006402	1	65	65	N	0	4	4	18	1	3	5
100010741	1	65	30	E	7	1	4	28	1	3	5
100010741	2	65	35	E	0	1	4	28	1	3	5
100010876	1	65	55	E	7	4	4	48	6	3	4
100010887	1	65	45	W	7	14	4	27		3	5
100010887	2	65	50	W	0	4	5	27	5	3	3
100010891	1	65	40	E	0	14	4	30	5	3	5
100010891	2	65	55	E	7	1	5	30	5	3	4
100010894	1	65	40	W	0	14	4	28	1	3	5
100010894	2	65	40	W	7	4	5	28	1	3	5
100010897	1	65	55	E	7	2	4	48	0	3	5
100010908	1	65	50	E	0	14	4	30	0	3	5
100010908	2	65	55	E	7	1	5	30	0	3	5
100010917	1	65	65	N	7	1	4	48	5	3	5
100010927	1	65	40	W	0	14	4	28		3	5
100010927	2	65	45	W	7	1	4	28		3	5

Table A-16 Sample Merged Data

Matching Variables			Work Zone Variables		Roadway Variables		Accident Variables		Vehicle Variables	
caseno	cnty_rte	milepost	Work activity	#lanes_closed	NO_LANES	SPD_LIMT	time	date	truck_acc	speeding_flag
100000005	5910000085	9.45			8	60	130	20000101	1	0
100000012	6310000095	14.1			4	70	1930	20000101	0	1
100000088	4810000077	18.371			4	55	1315	20000101	0	0
100000100	5910000085	20.684			4	65	821	20000101	0	1
100000131	9110000040	16.383			8	65	254	20000101	0	1
100000179	4810000077	8.98			4	65	920	20000101	0	1
100000180	4810000077	16.18			4	65	720	20000101	0	0
100000206	3110000040	11.254			6	65	2021	20000102	0	1
100000226	3510000085	14.86			4	60	1325	20000102	0	1
100000287	6310000095	5.85			4	70	155	20000102	0	1
100000290	6310000095	26.17			4	70	530	20000102	0	1
100000401	9710000095	10.02			4	70	1545	20000102	0	1
100000571	4010000040	10.462	INACTIVE	0	4	55	1249	20000101	0	0
100000645	9110000040	21.37			6	65	544	20000101	0	0
100000674	3010000040	18.63			4	70	1800	20000102	0	0
100000721	6710000040	0.52			8	55	2030	20000102	0	1
100000797	4810000077	15.78			4	65	755	20000103	0	0
100000871	8110000040	6.13			4	70	1200	20000102	0	0
100000882	3110000040	1.492			4	65	1449	20000103	0	0
100000974	4010000040	15.88			6	55	1720	20000103	0	0

Table A- 17 Summary of Crash Counts for each Work Zone

Project Number	Before Control		Before Treatment		During Control		During Treatment	
	Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
I-2201F (C104975)	223	77	487	174	558	157	938	273
I-2204BA (C200203)	766	149	488	63	709	87	468	62
I-2511BB (C104952)	31	19	129	75	57	25	461	169
I-2807A (C105373)	3	3	53	19	15	5	34	16
I-3102A (C200429)	166	31	231	41	146	23	164	26
I-3308A	167	49	221	95	161	36	327	113
I-3309A (C105452)	79	27	28	18	29	13	23	12
I-3606 (C200168)	32	7	153	43	35	10	135	23
I-4017 (C105447)	132	23	485	115	63	14	178	31
I-4025 (C200227)	72	30	46	23	52	15	37	15
I-4030 (C105491)	38	11	79	43	16	4	40	16
I-4036 (C105489)	32	9	58	24	18	3	12	6
I-4403 (C105573)	28	12	4	0	6	4	0	0
I-4408 (C200171)	142	9	242	16	60	5	131	7
I-4412 (C200240)	480	84	549	165	275	61	252	78
I-4414 (C200446)	575	135	121	34	218	44	65	19
I-4415 (C200584)	151	50	145	34	62	19	66	34
I-4741 (C200871)	233	40	27	7	102	14	17	7
W-4439 (C200577)	10	5	22	10	4	3	8	2
Total	**3360**	**770**	**3568**	**999**	**2586**	**542**	**3356**	**909**

Table A-18 Summary of Crash Rates (in Crashes per 1000 mile days) for each Work Zone

Project Number	Before Control		Before Treatment		During Control		During Treatment	
	Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
I-2201F (C104975)	28.5	9.8	73.7	26.3	42.4	11.9	84.4	24.6
I-2204BA (C200203)	30.6	6.0	130.2	16.8	37.2	4.6	163.7	21.7
I-2511BB (C104952)	12.4	7.6	19.0	11.0	11.8	5.2	35.2	12.9
I-2807A (C105373)	0.5	0.5	12.1	4.3	4.8	1.6	14.5	6.8
I-3102A (C200429)	6.2	1.2	20.5	3.6	12.3	1.9	33.1	5.2
I-3308A	14.1	4.1	23.3	10.0	13.6	3.0	34.6	11.9
I-3309A (C105452)	6.7	2.3	6.1	3.9	5.5	2.5	11.2	5.9
I-3606 (C200168)	3.4	0.7	15.5	4.4	6.2	1.8	22.6	3.9
I-4017 (C105447)	14.9	2.6	28.1	6.7	21.3	4.7	31.0	5.4
I-4025 (C200227)	4.3	1.8	19.3	9.7	6.4	1.9	32.5	13.2
I-4030 (C105491)	17.0	4.9	12.8	7.0	21.5	5.4	19.4	7.8
I-4036 (C105489)	6.0	1.7	28.9	12.0	10.1	1.7	17.9	9.0
I-4403 (C105573)	6.5	2.8	15.2	0.0	4.2	2.8	0.0	0.0
I-4408 (C200171)	4.2	0.3	11.3	0.7	5.3	0.4	18.4	1.0
I-4412 (C200240)	31.8	5.6	151.8	45.6	49.6	11.0	189.5	58.7
I-4414 (C200446)	26.1	6.1	36.0	10.1	27.7	5.6	54.1	15.8
I-4415 (C200584)	9.0	3.0	19.5	4.6	11.1	3.4	26.7	13.7
I-4741 (C200871)	15.7	2.7	26.3	6.8	20.6	2.8	49.7	20.5
W-4439 (C200577)	17.4	8.7	65.9	29.9	20.9	15.6	71.9	18.0
Total	**13.9**	**3.2**	**29.3**	**8.2**	**20.6**	**4.3**	**45.3**	**12.3**

Table A-19 Exposure Data for All Work Zone Projects

Project Number	Before Control (in mile days)	Before Treatment (in mile days)	During Control (in mile days)	During Treatment (in mile days)
I-2201F (C104975)	7377.24	6608.88	13159.02	11113.29
I-2204BA (C200203)	24999.76	3748.32	19069.16	2859.12
I-2511BB (C104952)	2498.88	6795.2	4819.92	13106.8
I-2807A (C105373)	5874.56	4384	3140.96	2344
I-3102A (C200429)	26873.92	11255.92	11843.16	4960.41
I-3308A	11825.84	9480.4	11804.26	9463.1
I-3309A (C105452)	11836.8	4592.24	5281.2	2048.91
I-3606 (C200168)	9348.88	9864	5655.39	5967
I-4017 (C105447)	8880.74	17232.38	2956.61	5737.07
I-4025 (C200227)	16922.24	2378.32	8090.56	1137.08
I-4030 (C105491)	2238.5	6186.4	745.25	2059.6
I-4036 (C105489)	5364.18	2007.36	1788.06	669.12
I-4403 (C105573)	4307.16	264	1435.72	88
I-4408 (C200171)	33976.92	21409.92	11325.64	7136.64
I-4412 (C200240)	15091.92	3616.8	5549.31	1329.9
I-4414 (C200446)	22051.52	3364.72	7866.92	1200.37
I-4415 (C200584)	16842.99	7428.33	5608.14	2473.38
I-4741 (C200871)	14883.3	1026.72	4961.1	342.24
W-4439 (C200577)	575.4	333.9	191.8	111.3
Total	**241770.8**	**121977.8**	**125292.2**	**74147.33**

Table A-20 Daytime Exposure Data During Work Zone Period by Work Activity and Lane Closure

Project Number	Work Active Lane Closure- day (in mile days[a])	Work Active No Lane Closure- day (in mile days[a])	Work Inactive Lane Closure- day (in mile days[a])	Work Inactive No Lane Closure- day (in mile days[a])
I-2201F (C104975)	12.9 (0.12%)	2674.6 (24.07%)	0 (0%)	2502.1 (22.51%)
I-2204BA (C200203)	5 (0.18%)	571.3 (19.98%)	0 (0%)	752.7 (26.33%)
I-2511BB (C104952)	237.9 (1.81%)	3021.4 (23.05%)	211.6 (1.61%)	2605.7 (19.88%)
I-2807A (C105373)	568.2 (24.24%)	147.2 (6.28%)	102.5 (4.37%)	309.2 (13.19%)
I-3102A (C200429)	653 (13.16%)	371.9 (7.5%)	0 (0%)	1272.8 (25.66%)
I-3308A	67.3 (0.71%)	131.7 (1.39%)	0 (0%)	4217.6 (44.57%)
I-3309A (C105452)	258.9 (12.64%)	193.4 (9.44%)	120.3 (5.87%)	378 (18.45%)
I-3606 (C200168)	626.4 (10.5%)	431.4 (7.23%)	51 (0.86%)	1642.5 (27.53%)
I-4017 (C105447)	0 (0%)	295.1 (5.14%)	0 (0%)	2284.4 (39.82%)
I-4025 (C200227)	162.1 (14.25%)	35.1 (3.09%)	119.9 (10.54%)	202.9 (17.84%)
I-4030 (C105491)	20.7 (1.01%)	238.4 (11.58%)	0 (0%)	695.7 (33.78%)
I-4036 (C105489)	4.3 (0.64%)	18.7 (2.8%)	0 (0%)	341.4 (51.03%)
I-4403 (C105573)	2.6 (3.01%)	4.8 (5.47%)	0 (0%)	32.6 (37.02%)
I-4408 (C200171)	556.7 (7.8%)	793.3 (11.12%)	0 (0%)	1795.2 (25.16%)
I-4412 (C200240)	0.7 (0.05%)	4.4 (0.33%)	0 (0%)	627.8 (47.21%)
I-4414 (C200446)	3.8 (0.32%)	11.9 (0.99%)	0 (0%)	552.9 (46.06%)
I-4415 (C200584)	267.8 (10.83%)	261.8 (10.59%)	0 (0%)	674.7 (27.28%)
I-4741 (C200871)	24.5 (7.16%)	12.3 (3.61%)	0 (0%)	145.3 (42.47%)
W-4439 (C200577)	1.1 (1.02%)	1.8 (1.61%)	0 (0%)	59 (53%)
Total	**3473.9 (4.69%)**	**9220.6 (12.44%)**	**605.3 (0.82%)**	**21092.5 (28.45%)**

[a] Percentage in the brackets indicates percent of time when the work zone project is in that category.

Table A-21 Nighttime Exposure Data During Work Zone Period by Work Activity and Lane Closure

Project Number	Work Active Lane Closure- night (in mile days[a])	Work Active No Lane Closure- night (in mile days[a])	Work Inactive Lane Closure- night (in mile days[a])	Work Inactive No Lane Closure- night (in mile days[a])
I-2201F (C104975)	203.2 (1.83%)	234.6 (2.11%)	0 (0%)	4568.9 (41.11%)
I-2204BA (C200203)	137.7 (4.82%)	258.6 (9.05%)	0 (0%)	898 (31.41%)
I-2511BB (C104952)	387.7 (2.96%)	276.3 (2.11%)	279.8 (2.14%)	5005.5 (38.19%)
I-2807A (C105373)	32.2 (1.38%)	2.8 (0.12%)	471 (20.09%)	517.3 (22.07%)
I-3102A (C200429)	102.8 (2.07%)	25.1 (0.51%)	0 (0%)	2125.7 (42.85%)
I-3308A	893.7 (9.44%)	524.8 (5.55%)	0 (0%)	2846.8 (30.08%)
I-3309A (C105452)	3.4 (0.16%)	3.1 (0.15%)	318.5 (15.55%)	604.1 (29.48%)
I-3606 (C200168)	7.8 (0.13%)	6 (0.1%)	443.7 (7.44%)	2264 (37.94%)
I-4017 (C105447)	162.2 (2.83%)	310.6 (5.41%)	0 (0%)	2219.1 (38.68%)
I-4025 (C200227)	3.7 (0.33%)	0.1 (0.01%)	229 (20.14%)	290.8 (25.57%)
I-4030 (C105491)	0.1 (0.01%)	5 (0.24%)	0 (0%)	930.3 (45.17%)
I-4036 (C105489)	37.5 (5.6%)	59.3 (8.86%)	0 (0%)	153.2 (22.89%)
I-4403 (C105573)	0.4 (0.4%)	0.4 (0.41%)	0 (0%)	40.2 (45.69%)
I-4408 (C200171)	11.3 (0.16%)	13.1 (0.18%)	0 (0%)	3368.3 (47.2%)
I-4412 (C200240)	28.9 (2.18%)	29.5 (2.22%)	0 (0%)	529.1 (39.78%)
I-4414 (C200446)	66.1 (5.5%)	72.2 (6.02%)	0 (0%)	394.5 (32.87%)
I-4415 (C200584)	5.4 (0.22%)	4.7 (0.19%)	0 (0%)	1056.1 (42.7%)
I-4741 (C200871)	8.4 (2.46%)	5.7 (1.66%)	0 (0%)	117.8 (34.43%)
W-4439 (C200577)	4.1 (3.71%)	4.1 (3.7%)	0 (0%)	31.8 (28.61%)
Total	**2096.5 (2.83%)**	**1836 (2.48%)**	**1742.1 (2.35%)**	**27961.3 (37.71%)**

[a] Percentage in the brackets indicates percent of time when the work zone project is in that category.

Table A-22 Twilight Exposure Data During Work Zone Period by Work Activity and Lane Closure

Project Number	Work Active Lane Closure-Twilight (in mile days[a])	Work Active No Lane Closure-Twilight (in mile days[a])	Work Inactive Lane Closure-Twilight (in mile days[a])	Work Inactive No Lane Closure-Twilight (in mile days[a])
I-2201F (C104975)	7.3 (0.07%)	119.5 (1.08%)	0 (0%)	790.3 (7.11%)
I-2204BA (C200203)	5 (0.18%)	31.8 (1.11%)	0 (0%)	198.9 (6.96%)
I-2511BB (C104952)	38.9 (0.3%)	138.1 (1.05%)	51.1 (0.39%)	853 (6.51%)
I-2807A (C105373)	22.4 (0.96%)	7.2 (0.31%)	81.6 (3.48%)	82.5 (3.52%)
I-3102A (C200429)	75 (1.51%)	38.8 (0.78%)	0 (0%)	295.3 (5.95%)
I-3308A	79.8 (0.84%)	57.6 (0.61%)	0 (0%)	643.8 (6.8%)
I-3309A (C105452)	8.3 (0.4%)	4.8 (0.23%)	52.1 (2.54%)	104.1 (5.08%)
I-3606 (C200168)	32.9 (0.55%)	30 (0.5%)	65 (1.09%)	366.2 (6.14%)
I-4017 (C105447)	0.5 (0.01%)	12.1 (0.21%)	0 (0%)	452.9 (7.89%)
I-4025 (C200227)	3.8 (0.33%)	2.9 (0.26%)	42.2 (3.72%)	44.6 (3.92%)
I-4030 (C105491)	0.6 (0.03%)	10.5 (0.51%)	0 (0%)	158.3 (7.69%)
I-4036 (C105489)	4.6 (0.69%)	8.7 (1.3%)	0 (0%)	41.6 (6.21%)
I-4403 (C105573)	0 (0.05%)	0.1 (0.14%)	0 (0%)	6.9 (7.82%)
I-4408 (C200171)	27.7 (0.39%)	38.7 (0.54%)	0 (0%)	532.3 (7.46%)
I-4412 (C200240)	1.4 (0.11%)	1.3 (0.1%)	0 (0%)	106.7 (8.02%)
I-4414 (C200446)	6.1 (0.51%)	12.2 (1.01%)	0 (0%)	80.6 (6.72%)
I-4415 (C200584)	21.3 (0.86%)	19.3 (0.78%)	0 (0%)	162.3 (6.56%)
I-4741 (C200871)	1.6 (0.46%)	1 (0.29%)	0 (0%)	25.6 (7.47%)
W-4439 (C200577)	0.4 (0.4%)	0.5 (0.47%)	0 (0%)	8.3 (7.47%)
Total	**337.7 (0.46%)**	**535.1 (0.72%)**	**292 (0.39%)**	**4954.1 (6.68%)**

[a] Percentage in the brackets indicates percent of time when the work zone project is in that category.

APPENDIX B

CATEGORIES USED FOR DATA ANALYSIS

Appendix B contains tables indicating the categories used for separating the data. To begin with, 15 broad categories were used to divide the crashes as shown in Table B-1. Crashes were then subcategorized by crash type in each of the broad categories. Finally, the “crash type” subcategory was further divided using different variables, as shown in Table B-2 – Table B-7. The results for each of these categories are indicated in Appendix D.

Table B-1 Broad Categories

No	Category	Sample Size
1	Day active no lane closure - Reconstruction	605
2	Day inactive no lane closure - Reconstruction	878
3	Night active no lane closure - Reconstruction	55
4	Night inactive no lane closure - Reconstruction	500
5	Day active lane closure – Maintenance	176
6	Day active no lane closure – Maintenance	122
7	Day inactive no lane closure - Maintenance	910
8	Night active lane closure – Maintenance	60
9	Night active no lane closure - Maintenance	30
10	Night inactive no lane closure – Maintenance	392
11	Twilight periods	375
12	Inactive lane closure period	35
13	Crashes involving vehicles traveling opposite directions	89
14	All reconstruction projects	2324
15	All work zone projects	4176

Table B-2 Subcategories of Total Crashes – 1

VARIABLE	CATEGORY - Total crashes
Contributing factor	Speeding
	Follow too closely
	Improper lane change
	Failure to yield ROW
	Improper passing
	Careless driving
	Operating defective vehicle
	Alcohol crashes
	Disregard traffic control
AADT	High AADT per lane
	Low AADT per lane
Severity	Fatal + injury
	PDO
Functional class	Rural
	Urban
Road character	Straight-level
	Straight-grade
	Curve-level
	Curve-grade
	Straight
	Curve
Speed limit	55 mph
	60 mph
	65 mph
	70 mph
	Less than or equal to 60 mph
	Greater than 60 mph
Number of vehicles	Two vehicles - high AADT
	> 2 vehicles - high AADT
	Two vehicles - low AADT
	> 2 vehicles - low AADT
	Two vehicles
	> 2 vehicles
Surface condition	Dry
	Wet
	Ice/Snow
	Wet/Ice/Snow

Table B-3 Subcategories of Total Crashes – 2

VARIABLE	CATEGORY - Total crashes
Number of lanes	4
	6
	8
	GE 6
Weather	Clear
	Cloudy
	Rain/snow/ sleet/hail
	Cloudy/rain/snow/ sleet/hail
Roadway lighting	Roadway lighting at night
	Roadway no lighting at night

Table B-4 Subcategories of Sideswipe Crashes

VARIABLE	CATEGORY – Sideswipe crashes
Contributing factor	Speeding
	Improper lane change
	Failure to yield ROW
	Improper passing
AADT	High AADT per lane
	Low AADT per lane
Severity	Fatal + injury
	PDO
Functional class	Rural
	Urban
Road character	Straight-level
	Straight-grade
	Curve-level
	Curve-grade
	Straight
	Curve
Number of lanes	4 lanes
	6 lanes
	8 lanes
	Greater than or equal to 6 lanes

Table B-5 Subcategories of Rear-End Crashes

VARIABLE	CATEGORY – Rear-End crashes
Contributing factor	Speeding
	Follow too closely
AADT	High AADT per lane
	Low AADT per lane
Severity	Fatal + injury
	PDO
Functional class	Rural
	Urban
Road character	Straight-level
	Straight-grade
	Curve-level
	Curve-grade
	Straight
	Curve
Speed limit	55 mph
	60 mph
	65 mph
	70 mph
	Less than or equal to 60 mph
	Greater than 60 mph
Number of vehicles	Two vehicles - high AADT
	> 2 vehicles - high AADT
	Two vehicles - low AADT
	> 2 vehicles - low AADT
	Two vehicles
	> 2 vehicles
Surface condition	Dry
	Wet
	Ice/Snow
	Wet/Ice/Snow

Table B-6 Subcategories of Runoff the Road Crashes

VARIABLE	CATEGORY – Runoff the road crashes
Contributing factor	Speeding
	Careless Driving
	Operating defective vehicle
	Alcohol crashes
AADT	High AADT per lane
	Low AADT per lane
Severity	Fatal + injury
	PDO
Functional class	Rural
	Urban
Road character	Straight-level
	Straight-grade
	Curve-level
	Curve-grade
	Straight
	Curve
Number of lanes in both directions	4 lanes
	6 lanes
	8 lanes
	Greater than or equal to 6 lanes
Speed limit	55 mph
	60 mph
	65 mph
	70 mph
	Less than or equal to 60 mph
	Greater than 60 mph
Surface condition	Dry
	Wet
	Ice/Snow
	Wet/Ice/Snow
Weather	Clear
	Cloudy
	Rain/snow/ sleet/hail
	Cloudy/rain/snow/ sleet/hail
Roadway lighting	Roadway lighting at night
	Roadway no lighting at night

Table B-7 Subcategories of Fixed Object Crashes

VARIABLE	CATEGORY – Fixed object crashes
Contributing factor	Speeding
	Careless Driving
	Operating defective vehicle
	Alcohol crashes
AADT	High AADT per lane
	Low AADT per lane
Severity	Fatal + injury
	PDO
Functional class	Rural
	Urban
Road character	Straight-level
	Straight-grade
	curve-level
	curve-grade
	Straight
	Curve
Speed limit	55 mph
	60 mph
	65 mph
	70 mph
	Less than or equal to 60 mph
	Greater than 60 mph
Weather	Clear
	Cloudy
	Rain/snow/ sleet/hail
	Cloudy/rain/snow/ sleet/hail
Roadway lighting	Roadway lighting at night
	Roadway no lighting at night
Object struck	Guardrail
	Shoulder barrier
	Median
	Bridge
	Underpass
	Construction barrier

APPENDIX C

DAY AND NIGHT PERIODS IN 19 NORTH CAROLINA WORK ZONES

Appendix C tabulates the sunrise and sunset times for each month as well as for each project. The following is the procedure used to divide day and night periods for each month.

First, maps downloaded from MapQuest™ were used to identify the town nearest the work zone location. The nearest town was entered into the U.S. Naval Observatory website at http://aa.usno.navy.mil/data/docs/RS_OneYear.html. This website provided a table with the sunrise and sunset times for every day of a year. The researcher downloaded this information for all 19 work zone projects. Then average estimates of sunrise and sunset times were calculated for each month for each project. These average sunrise and sunset times along with nearest town locations are provided in the Table C-1 and Table C-2 for each month and each project respectively.

Table C-1 Sunrise and Sunset Times of Each Work Zone Project for the First Six Months of a Year

Project Number	Nearest town	January		February		March		April		May		June	
I-2201F	Greensboro	7:27	17:29	7:06	17:59	6:28	18:27	5:46	18:53	5:13	19:18	5:02	19:37
I-2204BA	Durham	7:24	17:26	7:03	17:56	6:25	18:23	5:42	18:49	5:10	19:14	4:59	19:33
I-2511BB	Salisbury	7:29	17:33	7:08	18:02	6:31	18:29	5:49	18:55	5:17	19:20	5:06	19:38
I-2807A	Elkin	7:32	17:33	7:11	18:03	6:33	18:31	5:50	18:57	5:17	19:23	5:06	19:41
I-3102A	Rocky Mount	7:19	17:21	6:58	17:51	6:20	18:19	5:38	18:44	5:06	19:10	4:55	19:28
I-3308A	Statesville	7:31	17:34	7:10	18:04	6:33	18:31	5:50	18:57	5:18	19:22	5:07	19:40
I-3309A	Statesville	7:31	17:34	7:10	18:04	6:33	18:31	5:50	18:57	5:18	19:22	5:07	19:40
I-3606	Wilson	7:19	17:22	6:58	17:52	6:21	18:19	5:39	18:45	5:06	19:10	4:56	19:28
I-4017	Durham	7:24	17:26	7:03	17:56	6:25	18:23	5:42	18:49	5:10	19:14	4:59	19:33
I-4025	Elkin	7:32	17:33	7:11	18:03	6:33	18:31	5:50	18:57	5:17	19:23	5:06	19:41
I-4030	Kings Mountain	7:32	17:37	7:11	18:06	6:34	18:33	5:53	18:58	5:21	19:22	5:11	19:40
I-4036	Salisbury	7:29	17:33	7:08	18:02	6:31	18:29	5:49	18:55	5:17	19:20	5:06	19:38
I-4403	St. Pauls	7:21	17:29	7:01	17:58	6:25	18:23	5:44	18:48	5:13	19:12	5:02	19:30
I-4408	Burgaw	7:16	17:25	6:57	17:54	6:21	18:19	5:40	18:43	5:09	19:07	4:59	19:25
I-4412	Charlotte	7:29	17:35	7:09	18:04	6:32	18:31	5:51	18:56	5:19	19:20	5:09	19:38
I-4414	Gibsonville	7:26	17:28	7:05	17:58	6:27	18:26	5:45	18:52	5:12	19:17	5:01	19:36
I-4415	Micro	7:20	17:24	6:59	17:53	6:22	18:20	5:40	18:46	5:08	19:11	4:57	19:29
I-4741	Winston (-Salem)	7:29	17:31	7:08	18:01	6:30	18:29	5:48	18:54	5:15	19:20	5:04	19:38
W-4439	Gastonia	7:31	17:37	7:11	18:06	6:34	18:32	5:52	18:57	5:21	19:22	5:10	19:40
Average		7:26	17:30	7:06	18:00	6:28	18:27	5:46	18:52	5:14	19:17	5:03	19:35

Table C-2 Sunrise and Sunset Times of Each Work Zone Project for the Last Six Months of a Year

Project Number	Nearest town	July		August		September		October		November		December	
I-2201F	Greensboro	5:14	19:34	5:38	19:07	6:01	18:26	6:26	17:43	6:56	17:12	7:22	17:07
I-2204BA	Durham	5:11	19:31	5:34	19:04	5:58	18:22	6:23	17:39	6:52	17:08	7:18	17:04
I-2511BB	Salisbury	5:18	19:36	5:41	19:09	6:04	18:28	6:29	17:46	6:57	17:15	7:23	17:11
I-2807A	Elkin	5:18	19:39	5:42	19:12	6:05	18:30	6:31	17:47	7:00	17:16	7:26	17:11
I-3102A	Rocky Mount	5:07	19:26	5:30	18:59	5:53	18:18	6:18	17:35	6:47	17:04	7:13	16:59
I-3308A	Statesville	5:19	19:38	5:42	19:11	6:06	18:30	6:31	17:47	6:59	17:17	7:25	17:12
I-3309A	Statesville	5:19	19:38	5:42	19:11	6:06	18:30	6:31	17:47	6:59	17:17	7:25	17:12
I-3606	Wilson	5:08	19:26	5:31	18:59	5:54	18:18	6:19	17:35	6:47	17:05	7:13	17:00
I-4017	Durham	5:11	19:31	5:34	19:04	5:58	18:22	6:23	17:39	6:52	17:08	7:18	17:04
I-4025	Elkin	5:18	19:39	5:42	19:12	6:05	18:30	6:31	17:47	7:00	17:16	7:26	17:11
I-4030	Kings Mountain	5:23	19:38	5:45	19:12	6:08	18:31	6:32	17:49	7:00	17:20	7:26	17:15
I-4036	Salisbury	5:18	19:36	5:41	19:09	6:04	18:28	6:29	17:46	6:57	17:15	7:23	17:11
I-4403	St. Pauls	5:14	19:28	5:36	19:02	5:59	18:22	6:22	17:40	6:50	17:11	7:15	17:07
I-4408	Burgaw	5:11	19:23	5:32	18:57	5:54	18:18	6:18	17:36	6:45	17:07	7:10	17:04
I-4412	Charlotte	5:21	19:36	5:43	19:10	6:06	18:29	6:30	17:47	6:58	17:18	7:24	17:13
I-4414	Gibsonville	5:13	19:33	5:36	19:06	6:00	18:25	6:25	17:41	6:55	17:11	7:21	17:06
I-4415	Micro	5:09	19:27	5:32	19:00	5:55	18:19	6:20	17:36	6:48	17:06	7:14	17:02
I-4741	Winston (-Salem)	5:16	19:36	5:39	19:09	6:03	18:27	6:28	17:44	6:57	17:14	7:24	17:09
W-4439	Gastonia	5:22	19:38	5:44	19:11	6:07	18:31	6:31	17:49	6:59	17:19	7:25	17:15
Average		5:15	19:33	5:38	19:07	6:01	18:25	6:26	17:43	6:55	17:13	7:21	17:08

APPENDIX D

TABULATED RESULTS OF CONTINGENCY ANALYSIS

Appendix D provides all of the results of the contingency analysis. These tables were used to identify the differences between odds of truck and automobile crashes in work zones compared to that of non-work zones. The numbers in each of the following tables indicate p-values of the Breslow-Day test. A typical value of 0.05 is used as the criterion for identifying the significant difference between trucks and automobiles in each of the categories. In order to identify the significant p-values clearly, an asterisk (*) symbol is used adjacent to the p-value. Furthermore, up and down arrows are provided adjacent to the p-values to indicate the higher or lower odds of truck crashes relative to automobiles in work zones compared to control sections. A blank cell in any of the tables indicates that the sample size is not sufficient to conduct valid statistical tests. Finally, three significant digits are used in all the tables. Therefore, a p-value of ‘0’ indicates that it is less than 0.001.

Unfortunately, not all of the tables have all the variables and their subcategories. Since there were many subcategories and the data are limited, some of the categories which had very low sample sizes were eliminated from these tables. Also, none of the findings were based on the low sample size categories. The criterion for low sample size was chosen as normally done for any contingency analysis. That is, an expected value of 5 is needed in each of the cells of both the 2x2 contingency tables. Some of the subcategories were combined so that large enough sample sizes are achieved in order to do a valid Breslow-Day test. For example, “Speed limit less than or equal to 60 mph” is a combination of the two subcategories “speed limit = 55mph” and “speed limit = 60mph.” The results of these combined categories were presented here only when the sample sizes in the upstream subcategories is not large enough That is, results of “Speed limit less than or equal to 60 mph” are provided only when one of the results of “55mph” and “60mph” is not available in the upstream control sections. This is done to remove redundancy in the results.

Table D-1 Daytime Results for Reconstruction Projects–Work Active No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.081↑	0.309↑
Contributing factor	Speeding	0.465↑	0.209↑
	Improper lane change	0.567↑	0.625↑
AADT per lane	High	0.585↑	0.935↑
	Low	0.013*↑	0.163↑
Severity	Fatal + Injury	0.309↑	0.309↑
	PDO	0.182↑	
Area Type	Rural	0.152↑	0.969↑
	Urban	0.179↑	0.294↑
Road character	Straight-level	0.061↑	0.875↓
	Straight-grade	0.139↑	0.001*↑
	Straight	0.024*↑	0.216↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-2 Daytime Results for Reconstruction Projects–Work Active No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Speed limit	55 mph	0.936↓	0.888↑
	65 mph	0.005*↑	0.161↑
	<= 60 mph	0.896↓	0.984↑
	> 60 mph	0.001*↑	0.135↑
Number of vehicles	Two vehs - high AADT	0.501↑	0.816↑
	> 2 vehs - high AADT	0.546↑	0.527↑
	Two vehs - low AADT	0.042*↑	0.516↑
	Two vehs	0.153↑	0.475↑
	> 2 vehs	0.34↑	0.433↑
Surface condition	Dry	0.114↑	0.393↑
	Wet	0.544↑	
	Wet/Ice/Snow	0.526↑	
Number of lanes in both directions	4	0.413↑	0.78↑
	6	0.018*↑	0.374↑
	>= 6	0.007*↑	0.275↑
Weather	Clear	0.029*↑	0.085↑
	Cloudy	0.77↓	0.18↓
	Cloudy/rain/snow	0.804↓	0.539↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-3 Daytime Results for Reconstruction Projects by Crash Type–Work Active No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.677↑	0.175↑
Contributing factor	Speeding	0.654↑	0.141↑
AADT per lane	High	0.792↑	0.824↑
	Low	0.241↑	0.145↑
Severity	Fatal + injury	0.175↑	0.175↑
	PDO	0.461↓	
Area Type	Rural	0.899↓	
	Urban	0.751↑	0.157↑
Road character	Straight-level	0.726↓	0.556↑
	Straight-grade	0.02*↑	
	Straight	0.479↑	0.086↑
Speed limit	55 mph	0.982↓	0.21↑
	65 mph	0.198↑	0.314↑
	<= 60 mph	0.855↓	0.369↑
	> 60 mph	0.17↑	0.321↑
Number of vehicles	Two vehs - high AADT	0.955↓	
	> 2 vehs - high AADT	0.512↑	
	Two vehs - low AADT	0.914↑	
	Two vehs	0.803↓	0.754↑
	> 2 vehs	0.207↑	0.121↑
Surface condition	Dry	0.648↑	0.12↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-4 Daytime Results for Reconstruction Projects by Crash Type–Work Active No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.87↑	
Contributing factor	Improper lane change	0.9↑	
AADT per lane	High		
Severity	PDO	0.661↑	
Area Type	Urban	0.826↑	
Road character	Straight-level	0.869↑	
	Straight	0.939↑	
Number of lanes in both directions	6	0.701↑	
	>= 6	0.779↑	
	Runoff road	0.927↓	
Road character	Straight	0.917↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-5 Daytime Results for Reconstruction Projects–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes p-value	Fatal + Injury Crashes p-value
	Total	0.35↑	0.815↑
Contributing factor	Speeding	0.779↓	0.51↑
	Follow too closely		
	Improper lane change	0.665↑	0.654↓
	Failure to yield ROW		
AADT per lane	High	0.463↑	0.873↓
	Low	0.941↓	0.962↓
Severity	Fatal + Injury	0.815↑	0.815↑
	PDO	0.35↑	
Area Type	Rural	0.951↓	0.955↑
	Urban	0.411↑	0.885↑
Road character	Straight-level	0.343↑	0.444↓
	Straight-grade	0.227↑	0.015*↑
	Straight	0.201↑	0.742↑
	Curve	0.427↓	
Speed limit	55 mph	0.464↑	0.64↑
	65 mph	0.295↑	0.903↑
	<= 60 mph	0.468↑	0.752↑
	> 60 mph	0.245↑	0.81↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-6 Daytime Results for Reconstruction Projects–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Number of vehicles	Two vehs - high AADT	0.368↑	0.882↑
	> 2 vehs - high AADT	0.266↑	0.6↑
	Two vehs - low AADT	0.759↓	0.551↓
	> 2 vehs - low AADT	0.128↑	0.491↑
	Two vehs	0.435↑	0.874↑
	> 2 vehs	0.094↑	0.476↑
Surface condition	Dry	0.178↑	0.557↑
	Wet	0.684↓	0.532↓
	Wet/Ice/Snow	0.635↓	0.714↓
Number of lanes in both directions	4	0.368↑	0.832↑
	6	0.554↑	0.088↓
	>= 6	0.583↑	0.176↓
Weather	Clear	0.019*↑	0.097↑
	Cloudy	0.059↓	0.018*↓
	Rain/snow	0.483↓	0.966↓
	Cloudy/rain/snow	0.039*↓	0.058↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-7 Daytime Results for Reconstruction Projects by Crash Type–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.384↑	0.063↑
Contributing factor	Speeding	0.524↑	0.086↑
AADT per lane	High	0.509↑	0.55↑
	Low	0.483↑	0.22↑
Severity	Fatal + injury	0.063↑	0.063↑
	PDO	0.487↓	
Area Type	Rural	0.6↓	
	Urban	0.727↑	0.134↑
Road character	Straight-level	0.927↓	0.16↑
	Straight-grade	0.01*↑	
	Straight	0.288↑	0.031*↑
Speed limit	55 mph	0.597↑	0.091↑
	65 mph	0.083↑	0.062↑
	<= 60 mph	0.7↑	0.182↑
	> 60 mph	0.142↑	0.173↑
Number of vehicles	Two vehs - high AADT	0.93↑	
	> 2 vehs - high AADT	0.269↑	
	Two vehs - low AADT	0.999↓	0.498↑
	> 2 vehs - low AADT	0.135↑	0.235↑
	Two vehs	0.974↓	0.306↑
	> 2 vehs	0.088↑	0.088↑
Surface condition	Dry	0.2↑	0.012*↑
	Wet	0.597↓	
	Wet/Ice/Snow	0.857↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-8 Daytime Results for Reconstruction Projects by Crash Type–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes p-value	Fatal + Injury Crashes p-value
	Sideswipe	0.895↑	
Contributing factor	Improper lane change	0.862↑	
AADT per lane	High		
Severity	PDO	0.681↑	
Area Type	Urban	0.915↑	
Road character	Straight-level	0.868↑	
	Straight	0.831↓	
Number of lanes in both directions	6	0.699↑	
	>= 6	0.893↑	
	Runoff road	0.508↑	
AADT per lane	Low	0.969↓	
Severity	PDO	0.435↑	
Area Type	Urban	0.353↑	
Road character	Straight-level	0.308↑	
	Straight	0.364↑	
Number of lanes in both directions	4	0.984↓	
Speed limit	55 mph		
	65 mph	0.89↓	
	<= 60 mph	0.347↑	
	> 60 mph	0.968↓	
Surface condition	Dry	0.205↑	
Weather	Clear	0.136↑	
	Cloudy/rain/snow	0.487↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-9 Nighttime Results for Reconstruction Projects–Work Active No Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.161↑	
AADT per lane	High	0.085↑	
Severity	PDO	0.076↑	
Area Type	Urban	0.061↑	
Road character	Straight-level	0.804↓	
	Straight	0.32↑	
Speed limit	55 mph	0.198↑	
	<= 60 mph	0.224↑	
Number of vehicles	Two vehs	0.106↑	
Surface condition	Dry	0.116↑	
Number of lanes in both directions	4	0.948↑	
Weather	Clear	0.43↑	
Roadway lighting at night	Inadequate	0.259↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-10 Nighttime Results for Reconstruction Projects–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.853↓	0.967↑
Contributing factor	Speeding	0.249↑	
	Improper lane change	0.478↓	
AADT per lane	High	0.414↑	0.504↑
	Low	0.376↓	0.54↓
Severity	Fatal + Injury	0.967↑	0.967↑
	PDO	0.926↓	
Area Type	Rural		
	Urban	0.525↑	0.642↑
Road character	Straight-level	0.2↓	0.273↓
	Straight-grade	0.283↑	
	Straight	0.613↓	0.572↓
Speed limit	55 mph	0.946↓	0.827↓
	65 mph	0.582↑	
	<= 60 mph	0.967↓	0.854↓
	> 60 mph	0.541↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-11 Nighttime Results for Reconstruction Projects–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Number of vehicles	Two vehs - high AADT	0.328↑	
	Two vehs - low AADT	0.34↑	
	Two vehs	0.276↑	0.574↑
Surface condition	Dry	0.747↑	0.767↑
	Wet	0.086↓	
	Wet/Ice/Snow	0.242↓	
Number of lanes in both directions	4	0.468↓	
	6	0.585↑	
	>= 6	0.521↑	
Weather	Clear	0.879↓	0.695↑
	Rain/snow	0.52↓	
	Cloudy/rain/snow	0.787↓	
Roadway lighting at night	Adequate	0.817↑	
	Inadequate	0.634↓	0.971↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-12 Nighttime Results for Reconstruction Projects by Crash Type–Work Inactive No Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.642↑	
Contributing factor	Speeding		
Area Type	Urban	0.902↑	
Road character	Straight-level	0.675↓	
	Straight	0.856↑	
Speed limit	55 mph	0.88↓	
	65 mph		
	<= 60 mph	0.766↓	
	> 60 mph		
Number of vehicles	Two vehs	0.577↑	
Surface condition	Dry		

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-13 Results for All Reconstruction Projects 1

VARIABLE	Subcategory	Total Crashes p-value	Fatal + Injury Crashes p-value
	Total	0.321↑	0.525↑
Contributing factor	Speeding	0.529↑	0.17↑
	Follow too closely	0.622↓	
	Improper lane change	0.95↑	0.691↓
	Failure to yield ROW	0.672↓	
	Operating defective vehicle	0.237↓	
AADT per lane	High	0.397↑	0.716↑
	Low	0.515↑	0.759↑
Severity	Fatal + injury	0.525↑	0.525↑
	PDO	0.394↑	
Area Type	Rural	0.969↓	0.781↓
	Urban	0.369↑	0.457↑
Road character	Straight-level	0.645↑	0.304↓
	Straight-grade	0.087↑	0.005*↑
	Curve	0.519↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-14 Results for All Reconstruction Projects 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Speed limit	55	0.869↑	0.704↑
	65	0.079↑	0.311↑
	<= 60	0.932↑	0.806↑
	> 60	0.033*↑	0.384↑
Number of vehicles	Two vehicles - high AADT	0.381↑	0.587↑
	> 2 vehs - high AADT	0.67↑	0.544↑
	Two vehicles - low AADT	0.168↑	0.844↑
	> 2 vehs - low AADT	0.049*↑	0.4↑
Surface condition	Dry	0.136↑	0.378↑
	Wet	0.289↓	0.881↓
	Wet/Ice/Snow	0.315↓	0.806↓
Number of lanes	4	0.525↑	0.806↓
	6	0.159↑	0.718↑
	>= 6	0.102↑	0.732↑
Weather	Clear	0.043*↑	0.088↑
	Cloudy	0.367↓	0.24↓
	Rain/snow	0.365↓	0.726↓
Roadway Lighting at night	Adequate	0.719↑	
	Inadequate	0.907↑	0.775↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-15 Results for All Reconstruction Projects–Rear-End Crashes

VARIABLE	Subcategory	Total Crashes p-value	Fatal + Injury Crashes p-value
	Rear-End	0.619↑	0.031*↑
Contributing factor	Speeding	0.772↓	0.068↑
	Follow too closely		
AADT per lane	High	0.538↑	0.162↑
	Low	0.24↑	0.141↑
Severity	Fatal + injury	0.031*↑	0.031*↑
	PDO	0.197↓	
Area Type	Rural	0.302↑	
	Urban	0.994↓	0.049*↑
Road character	Straight-level	0.365↓	0.236↑
	Straight-grade	0.003*↑	0.007*↑
Speed limit	55	0.704↑	0.024*↑
	65	0.14↑	0.08↑
	<= 60	0.889↓	0.069↑
	> 60	0.161↑	0.144↑
Number of vehicles	Two vehicles - high AADT	0.879↓	0.364↑
	> 2 vehs - high AADT	0.199↑	
	Two vehicles - low AADT	0.877↑	0.497↑
	> 2 vehs - low AADT	0.035*↑	0.141↑
Surface condition	Dry	0.324↑	0.014*↑
	Wet	0.509↓	0.939↓
	Wet/Ice/Snow	0.558↓	0.796↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.

↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.

Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-16 Results for All Reconstruction Project–Sideswipe Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.631↑	
Contributing factor	Improper lane change	0.463↑	
AADT per lane	High	0.653↓	
Severity	PDO	0.554↑	
Area Type	Urban	0.723↑	
Road character	Straight-level	0.973↑	
	Straight	0.657↑	
Number of lanes	6	0.881↑	
	>= 6	0.954↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-17 Results for All Reconstruction Projects–Runoff the Road Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Runoff road	0.299↑	0.755↓
Contributing factor	Speeding	0.514↓	
AADT per lane	High	0.216↑	
	Low	1↓	
Severity	Fatal + injury	0.755↓	0.755↓
	PDO	0.239↑	
Area Type	Rural	0.808↑	
	Urban	0.239↑	
Road character	Straight-level	0.113↑	
	Straight	0.175↑	
Number of lanes in both directions	4	0.912↓	
Speed limit	55		
	65	0.695↑	
	<=60	0.364↑	
	> 60	0.58↑	
Surface condition	Dry	0.033*↑	
Weather	Clear	0.057↑	
	Cloudy/rain/snow	0.63↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-18 Daytime Results for Maintenance Projects–Work Active Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0*↑	0.008*↑
Contributing factor	Speeding	0.001*↑	0.043*↑
	Improper lane change	0.012*↑	
AADT per lane	Low	0*↑	0.028*↑
Severity	Fatal + Injury	0.008*↑	0.008*↑
	PDO	0.009*↑	
Area Type	Rural	0*↑	0.006*↑
	Urban	0.518↑	
Road character	Straight-level	0*↑	0.002*↑
	Straight-grade	0.231↑	
	Straight	0*↑	0.009*↑
Speed limit	65 mph	0.002*↑	
	70 mph	0.004*↑	0.113↑
	> 60 mph	0*↑	0.007*↑
Number of vehicles	Two vehs - low AADT	0.023*↑	0.311↑
	> 2 vehs - low AADT	0.305↑	0.425↑
	Two vehs	0.017*↑	0.116↑
	> 2 vehs	0.208↑	0.507↑
Surface condition	Dry	0.022*↑	0.012*↑
Number of lanes in both directions	4	0.001*↑	0.002*↑
Weather	Clear	0.03*↑	0.016*↑
	Cloudy	0.139↑	
	Cloudy/rain/snow	0.07↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-19 Daytime Results for Maintenance Projects by Crash Type–Work Active Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.044*↑	0.146↑
Contributing factor	Speeding	0.183↑	0.272↑
AADT per lane	Low	0.097↑	0.331↑
Severity	Fatal + injury	0.146↑	0.146↑
	PDO	0.172↑	
Area Type	Rural	0.019*↑	0.165↑
Road character	Straight-level	0.006*↑	0.009*↑
	Straight-grade	0.888↓	
	Straight	0.023*↑	0.095↑
Speed limit	65 mph	0.204↑	
	70 mph	0.024*↑	
	> 60 mph	0.044*↑	0.322↑
Number of vehicles	Two vehs - low AADT	0.156↑	0.352↑
	> 2 vehs - low AADT	0.438↑	
	Two vehs	0.105↑	0.116↑
	> 2 vehs	0.26↑	
Surface condition	Dry	0.178↑	0.275↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-20 Daytime Results for Maintenance Projects by Crash Type–Work Active Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.002*↑	
Contributing factor	Improper lane change	0.008*↑	
AADT per lane	Low	0.002*↑	
Severity	PDO	0.003*↑	
Area Type	Rural	0.005*↑	
Road character	Straight-level	0.008*↑	
	Straight	0.005*↑	
Number of lanes in both directions	4	0.011*↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-21 Daytime Results for Maintenance Projects–Work Active No Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.031*↑	0.292↑
Contributing factor	Speeding	0.045*↑	0.512↑
AADT per lane	Low	0.037*↑	0.433↑
Severity	Fatal + Injury	0.292↑	0.292↑
	PDO	0.058↑	
Area Type	Rural	0.025*↑	0.159↑
	Urban	0.123↑	
Road character	Straight-level	0.056↑	0.986↑
	Straight-grade	0.729↓	
	Straight	0.166↑	0.698↑
Speed limit	65 mph	0.07↑	0.416↑
	70 mph	0.051↑	
	> 60 mph	0.012*↑	0.147↑
Number of vehicles	Two vehs - low AADT	0.168↑	0.319↓
	> 2 vehs - low AADT	0.156↑	
	Two vehs	0.085↑	0.535↓
	> 2 vehs	0.165↑	
Surface condition	Dry	0.122↑	0.227↑
Number of lanes in both directions	4	0.076↑	0.06↑
Weather	Clear	0.4↑	0.399↑
	Cloudy/rain/snow	0.068↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-22 Daytime Results for Maintenance Projects by Crash Type–Work Active No Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.013*↑	0.086↑
Contributing factor	Speeding	0.14↑	0.269↑
AADT per lane	Low	0.025*↑	0.162↑
Severity	Fatal + injury	0.086↑	0.086↑
Area Type	Rural	0.007*↑	0.095↑
Road character	Straight-level	0.042*↑	
	Straight	0.06↑	0.121↑
Speed limit	65 mph	0.168↑	0.649↑
	> 60 mph	0.011*↑	0.214↑
Number of vehicles	Two vehs - low AADT	0.096↑	
	Two vehs	0.067↑	
Surface condition	Dry	0.012*↑	0.087↑
	Sideswipe	0.157↑	
AADT per lane	Low	0.186↑	
Area Type	Rural	0.561↑	
Road character	Straight-level	0.097↑	
	Straight	0.212↑	
Number of lanes in both directions	4	0.544↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-23 Daytime Results for Maintenance Projects–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.908↓	0.609↓
Contributing factor	Speeding	0.889↓	0.413↓
	Improper lane change	0.648↑	0.721↓
	Failure to yield ROW	0.933↓	
	Careless Driving	0.308↓	
	Operating defective vehicle	0.402↑	
AADT per lane	High	0.221↓	
	Low	0.523↑	0.461↓
Severity	Fatal + Injury	0.609↓	0.609↓
	PDO	0.557↑	
Area Type	Rural	0.578↓	0.077↓
	Urban	0.904↓	0.802↑
Road character	Straight-level	0.861↓	0.603↓
	Straight-grade	0.423↓	0.542↓
	Curve-grade	0.504↑	
	Straight	0.553↓	0.276↓
	Curve	0.377↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-24 Daytime Results for Maintenance Projects–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Speed limit	55 mph	0.555↑	
	60 mph	0.156↑	0.758↑
	65 mph	0.266↓	0.078↓
	70 mph	0.154↓	0.096↓
	<= 60 mph	0.216↑	0.426↑
	> 60 mph	0.112↓	0.018*↓
Number of vehicles	Two vehs - high AADT	0.196↓	
	Two vehs - low AADT	0.719↑	0.488↓
	> 2 vehs - low AADT	0.171↓	0.37↓
	Two vehs	0.946↓	0.729↓
	> 2 vehs	0.106↓	0.209↓
Surface condition	Dry	0.238↓	0.639↓
	Wet	0.026*↑	0.717↓
	Ice/Snow	0.111↓	
	Wet/Ice/Snow	0.204↑	0.503↓
Number of lanes in both directions	4	0.503↓	0.846↓
	8	0.273↑	0.754↓
	>= 6	0.245↑	0.708↓
Weather	Clear	0.154↓	0.251↓
	Cloudy	0.201↑	0.858↑
	Rain/snow	0.5↑	0.754↑
	Cloudy/rain/snow	0.093↑	0.652↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-25 Daytime Results for Maintenance Projects by Crash Type-Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.763↓	0.606↓
Contributing factor	Speeding	0.254↓	0.464↓
AADT per lane	High	0.129↓	
	Low	0.949↓	0.481↓
Severity	Fatal + injury	0.606↓	0.606↓
	PDO	0.99↓	
Area Type	Rural	0.448↑	0.816↓
	Urban	0.446↓	0.679↓
Road character	Straight-level	0.734↑	0.675↑
	Straight-grade	0.533↓	
	Straight	0.748↓	0.668↓
Speed limit	60 mph	0.951↓	
	65 mph	0.584↓	0.097↓
	70 mph	0.557↑	
	<= 60 mph	0.838↓	0.577↑
	> 60 mph	0.794↓	0.212↓
Number of vehicles	Two vehs - high AADT	0.077↓	
	Two vehs - low AADT	0.521↑	0.758↓
	> 2 vehs - low AADT	0.246↓	0.496↓
	Two vehs	0.806↑	0.943↓
	> 2 vehs	0.235↓	0.448↓
Surface condition	Dry	0.149↓	0.381↓
	Wet	0.024*↑	
	Wet/Ice/Snow	0.043*↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-26 Daytime Results for Maintenance Projects by Crash Type–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.449↑	0.867↓
Contributing factor	Speeding	0.745↑	
	Improper lane change	0.72↑	0.94↓
AADT per lane	High	0.827↑	
	Low	0.393↑	0.871↓
Severity	Fatal + injury	0.867↓	0.867↓
	PDO	0.363↑	
Area Type	Rural	0.72↓	
	Urban	0.312↑	0.993↑
Road character	Straight-level	0.726↑	0.938↑
	Straight-grade	0.757↓	
	Straight	0.829↑	0.819↓
Number of lanes in both directions	4	0.814↑	0.741↑
	8	0.711↑	0.549↓
	>= 6	0.488↑	0.426↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-27 Daytime Results for Maintenance Projects by Crash Type–Work Inactive No Lane Closure 3

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Runoff road	0.974↓	
Road character	Straight		
	Fixed object	0.71↑	
Contributing factor	Speeding	0.683↑	
AADT per lane	Low	0.88↑	
Severity	PDO	0.333↑	
Area Type	Rural	0.339↓	
	Urban	0.231↑	
Road character	Straight-level	0.504↓	
	Straight	0.847↓	
Speed limit	> 60 mph	0.225↓	
Weather	Clear	0.875↑	
	Cloudy/rain/snow	0.84↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-28 Nighttime Results for Maintenance Projects–Work Active Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.175↑	
Contributing factor	Speeding	0.941↓	
AADT per lane	Low	0.185↑	
Severity	PDO	0.185↑	
Area Type	Urban	0.439↑	
Road character	Straight-grade	0.832↓	
	Straight	0.251↑	
Speed limit	55 mph	0.882↓	
	<= 60 mph	0.731↓	
Number of vehicles	Two vehs - low AADT	0.247↓	
	Two vehs	0.315↓	
Surface condition	Dry	0.079↑	
Number of lanes in both directions	4	0.235↑	
Weather	Clear	0.063↑	
Roadway lighting at night	Inadequate	0.275↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-29 Nighttime Results for Maintenance Projects by Crash Type–Work Active Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.462↓	
Contributing factor	Speeding	0.305↓	
AADT per lane	Low	0.224↓	
Road character	Straight	0.686↓	
Surface condition	Dry	0.601↓	
	Sideswipe	0.86↓	
AADT per lane	Low	0.987↓	
Severity	PDO	0.867↓	
Area Type	Urban	0.359↓	
Road character	Straight	0.737↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-30 Nighttime Results for Maintenance Projects–Work Active No Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.656↑	
AADT per lane	Low	0.592↑	
Surface condition	Dry	0.375↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-31 Nighttime Results for Maintenance Projects–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.001*↓	0.028*↓
Contributing factor	Speeding	0.005*↓	0.041*↓
	Improper lane change	0.117↓	
	Careless Driving	0.823↑	
AADT per lane	Low	0.002*↓	0.079↓
Severity	Fatal + Injury	0.028*↓	0.028*↓
	PDO	0.019*↓	
Area Type	Rural	0.138↓	0.206↓
	Urban	0.005*↓	0.179↓
Road character	Straight-level	0.006*↓	0.079↓
	Straight-grade	0.103↓	0.313↓
	Straight	0.002*↓	0.087↓
Speed limit	55 mph	0.162↓	
	60 mph	0.026*↓	
	65 mph	0.145↓	0.87↑
	70 mph	0.046*↓	0.035*↓
	<= 60 mph	0.015*↓	
	> 60 mph	0.021*↓	0.189↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-32 Nighttime Results for Maintenance Projects–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Number of vehicles	Two vehs - low AADT	0.001*↓	0.012*↓
	Two vehs	0.001*↓	0.006*↓
Surface condition	Dry	0.015*↓	0.022*↓
	Wet	0.091↓	
	Wet/Ice/Snow	0.042*↓	0.668↓
Number of lanes in both directions	4	0.004*↓	0.016*↓
	8	0.099↓	
	>= 6	0.198↓	
Weather	Clear	0.022*↓	0.018*↓
	Cloudy	0.783↓	
	Rain/snow	0.03*↓	
	Cloudy/rain/snow	0.066↓	0.803↓
Roadway lighting at night	Adequate	0.032*↓	
	Inadequate	0.013*↓	0.138↓

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-33 Nighttime Results for Maintenance Projects by Crash Type–Work Inactive No Lane Closure 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.018*↓	0.041*↓
Contributing factor	Speeding	0.003*↓	
AADT per lane	Low	0.005*↓	0.038*↓
Severity	Fatal + injury	0.041*↓	0.041*↓
	PDO	0.186↓	
Area Type	Rural	0.043*↓	
Road character	Straight-level	0.093↓	
	Straight	0.07↓	
Speed limit	> 60 mph	0.079↓	
Number of vehicles	Two vehs - low AADT	0.002*↓	
	Two vehs	0.011*↓	
Surface condition	Dry	0.055↓	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-34 Nighttime Results for Maintenance Projects by Crash Type–Work Inactive No Lane Closure 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.118↓	
Contributing factor	Improper lane change	0.011*↓	
AADT per lane	Low	0.223↓	
Severity	PDO	0.224↓	
Area Type	Rural	0.958↓	
	Urban	0.043*↓	
Road character	Straight-level	0.023*↓	
	Straight	0.096↓	
Number of lanes in both directions	4	0.206↓	
	8	0.406↓	
	>= 6	0.405↓	
	Fixed object	0.58↑	
AADT per lane	Low	0.551↑	
Road character	Straight	0.525↑	
Speed limit	> 60 mph	0.918↑	

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.
↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-35 Results for All Work Zone Projects 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.54↑	0.961↑
Contributing factor	Speeding	0.909↓	0.622↑
	Follow too closely	0.547↑	0.155↑
	Improper lane change	0.648↑	0.415↓
	Failure to yield ROW	0.41↑	0.81↑
	Careless Driving	0.439↓	0.384↓
	Operating defective vehicle	0.93↑	
	Alcohol crashes	0.985↑	0.506↑
	Disregard Traffic control	0.624↓	
AADT per lane	High	0.802↓	0.821↑
	Low	0.189↑	0.989↑
Severity	Fatal + injury	0.961↑	0.961↑
	PDO	0.462↑	
Area Type	Rural	0.353↑	0.667↓
	Urban	0.915↑	0.66↑
Road character	Straight-level	0.561↑	0.53↓
	Straight-grade	0.824↓	0.344↑
	Curve-level	0.601↓	0.731↑
	Curve-grade	0.406↓	
	Curve	0.269↓	0.96↑

* Indicates statistically significant difference between odds of truck crashes relative to automobile crashes in work zones compared to control sections.

↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.

Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-36 Results for All Work Zone Projects 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Speed limit	55	0.333↓	0.833↓
	60	0.692↑	0.801↓
	65	0.211↑	0.517↑
	70	0.859↑	0.25↓
Number of vehicles	Two vehicles - high AADT	0.898↓	0.688↑
	> 2 vehs - high AADT	0.956↓	0.908↑
	Two vehicles - low AADT	0.243↑	0.559↓
	> 2 vehs - low AADT	0.388↑	0.559↑
Surface condition	Dry	0.635↑	0.767↑
	Wet	0.934↓	0.523↓
	Ice/Snow	0.087↓	0.583↓
Number of lanes	4	0.866↑	0.887↓
	6	0.512↑	0.737↓
	8	0.504↑	0.874↑
Weather	Clear	0.419↑	0.461↑
	Cloudy	0.947↑	0.354↓
	Rain/snow	0.211↓	0.681↓
Roadway Lighting at night	Adequate	0.082↓	0.763↓
	Inadequate	0.558↓	0.536↓

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-37 Results for All Work Zone Projects–Rear-End Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.871↓	0.356↑
Contributing factor	Speeding	0.591↓	0.628↑
	Follow too closely	0.471↑	0.225↑
AADT per lane	High	0.988↓	0.213↑
	Low	0.329↑	0.608↑
Severity	Fatal + injury	0.356↑	0.356↑
	PDO	0.555↓	
Area Type	Rural	0.211↑	0.646↑
	Urban	0.6↓	0.369↑
Road character	Straight-level	0.872↓	0.403↑
	Straight-grade	0.192↑	0.323↑
	Curve		
Speed limit	55	0.649↓	0.137↑
	60	0.599↓	0.582↓
	65	0.186↑	0.465↑
	70	0.494↓	0.226↓
	<= 60	0.67↓	0.197↑
Number of vehicles	Two vehicles - high AADT	0.469↓	0.378↑
	> 2 vehs - high AADT	0.399↑	0.464↑
	Two vehicles - low AADT	0.67↑	0.811↓
	> 2 vehs - low AADT	0.211↑	0.214↑
Surface condition	Dry	0.936↓	0.336↑
	Wet	0.579↑	0.854↓
	Wet/Ice/Snow	0.865↓	0.902↓

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Table D-38 Results for All Work Zone Projects–Sideswipe Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Sideswipe	0.406↑	0.554↓
Contributing factor	Speeding	0.377↑	0.682↓
	Improper lane change	0.729↑	0.446↓
	Failure to yield ROW	0.079↑	
AADT per lane	High	0.698↑	
	Low	0.167↑	0.967↓
Severity	Fatal + injury	0.554↓	0.554↓
	PDO	0.195↑	
Area Type	Rural	0.504↑	0.723↓
	Urban	0.51↑	0.907↓
Road character	Straight-level	0.694↑	0.451↓
	Straight-grade	0.477↑	
	Straight	0.508↑	0.655↓
	Curve	0.836↓	
Number of lanes	4	0.662↑	0.688↑
	6	0.728↑	
	8	0.431↑	0.772↓
	>= 6	0.739↑	0.277↓

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Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-39 Results for All Work Zone Projects–Runoff the Road Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Runoff road	0.458↑	0.952↓
Contributing factor	Speeding	0.609↓	
AADT per lane	High	0.09↑	
	Low	0.375↓	
Severity	Fatal + injury	0.952↓	0.952↓
	PDO	0.466↑	
Area Type	Rural	0.457↓	
	Urban	0.198↑	
Road character	Straight-level	0.249↑	
	Straight-grade		
	Straight	0.478↑	
Number of lanes in both directions	4	0.532↑	
	>= 6	0.358↓	
Speed limit	55	0.911↑	
	65	0.977↓	
	<= 60	0.125↑	
	> 60	0.685↓	
Surface condition	Dry	0.061↑	
	Wet	0.51↓	
	Wet/Ice/Snow	0.254↓	
Weather	Clear	0.132↑	
	Cloudy	0.323↑	
	Rain/snow	0.203↓	
	Cloudy/rain/snow	0.77↓	
Roadway Lighting at night	Inadequate		

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Table D-40 Results for All Work Zone Projects–Fixed Object Crashes

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Fixed object	0.198↑	0.707↓
Contributing factor	Speeding	0.945↑	
AADT per lane	High	0.782↑	
	Low	0.218↑	0.457↓
Severity	Fatal + injury	0.707↓	0.707↓
	PDO	0.082↑	
Area Type	Rural	0.376↑	
	Urban	0.384↑	0.829↑
Road character	Straight-level	0.487↑	0.323↓
	Straight-grade	0.63↑	
	Straight	0.392↑	0.324↓
Speed limit	55	0.823↑	
	65	0.692↑	
	70	0.946↑	
	<= 60	0.126↑	
	> 60	0.526↑	0.297↓
Weather	Clear	0.105↑	
	Cloudy	0.668↓	
	Rain/snow	0.949↑	
	Cloudy/rain/snow	0.768↓	0.612↓
Roadway Lighting at night	Inadequate	0.052↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.

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Table D-41 Results for All Work Zone Projects–Work Inactive Lane Closure

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.223↑	
AADT per lane	Low	0.235↑	
Severity	PDO	0.165↑	
Area Type	Rural	0.807↑	
Road character	Straight	0.612↑	
Speed limit	65 mph	0.129↑	
	> 60 mph	0.067↑	
Number of vehicles	Two vehs - low AADT	0.189↑	
Surface condition	Dry	0.19↑	
Weather	Clear	0.402↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.

Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-42 Results for All Work Zone Projects–Twilight Periods 1

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.425↓	0.498↓
Contributing factor	Speeding	0.168↓	0.787↑
	Improper lane change	0.815↓	
AADT per lane	High	0.992↓	0.78↑
	Low	0.533↓	0.466↓
Severity	Fatal + Injury	0.498↓	0.498↓
	PDO	0.62↓	
Area Type	Rural	0.179↓	
	Urban	0.992↓	0.838↑
Road character	Straight-level	0.631↓	0.486↓
	Straight-grade	0.401↓	
	Straight	0.431↓	0.478↓

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-43 Results for All Work Zone Projects–Twilight Periods 2

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
Speed limit	55 mph	0.331↓	0.895↑
	60 mph		
	65 mph	0.978↓	0.553↓
	70 mph	0.534↓	
	<= 60 mph	0.422↓	0.934↑
	> 60 mph	0.72↓	0.524↓
Number of vehicles	Two vehs - high AADT	0.963↑	
	Two vehs - low AADT	0.797↑	0.889↓
	Two vehs	0.777↓	0.955↑
	> 2 vehs	0.727↓	
Surface condition	Dry	0.662↓	0.6↓
	Wet	0.401↓	
	Wet/Ice/Snow	0.335↓	
Number of lanes in both directions	4	0.572↓	0.628↓
	6	0.593↓	
	8	0.93↓	
	>= 6	0.372↓	
Weather	Clear	0.901↓	0.908↓
	Cloudy	0.513↓	
	Rain/snow	0.417↓	
	Cloudy/rain/snow	0.267↓	0.228↓

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-44 Results for All Work Zone Projects by Crash Type–Twilight Periods

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Rear-End	0.248↓	0.854↓
Contributing factor	Speeding	0.194↓	0.992↓
AADT per lane	High	0.879↑	
	Low	0.284↓	
Severity	Fatal + injury	0.854↓	0.854↓
	PDO	0.187↓	
Area Type	Urban	0.447↓	0.964↑
Road character	Straight-level	0.168↓	
	Straight	0.258↓	0.959↓
Speed limit	55 mph	0.76↓	
	65 mph	0.146↓	
	<= 60 mph	0.977↑	
	> 60 mph	0.116↓	
Number of vehicles	Two vehs - low AADT	0.243↓	
	Two vehs	0.13↓	
	> 2 vehs		
Surface condition	Dry	0.215↓	0.823↓
	Sideswipe	0.452↑	
AADT per lane	Low	0.837↑	
Severity	PDO	0.601↑	
Area Type	Urban	0.441↑	
Road character	Straight-level	0.408↑	
	Straight	0.332↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-45 Results for All Work Zone Projects–Crashes Involving Vehicles Traveling Opposite Direction

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.256↑	0.104↑
Contributing factor	Speeding	0.159↑	
AADT per lane	High	0.89↓	
	Low	0.302↑	
Severity	Fatal + Injury	0.104↑	0.104↑
	PDO	0.996↑	
Area Type	Rural		
	Urban	0.99↑	0.405↑
Road character	Straight-level	0.179↑	0.166↑
	Straight	0.245↑	0.146↑
Speed limit	65 mph	0.857↑	
	> 60 mph	0.561↑	0.154↑
Number of vehicles	Two vehs - high AADT	0.595↑	
	Two vehs - low AADT	0.446↑	
	Two vehs	0.123↑	0.024*↑
Surface condition	Dry	0.145↑	0.108↑
Number of lanes in both directions	4	0.667↑	
Weather	Clear	0.302↑	0.046*↑
	Cloudy/rain/snow	0.632↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

Table D-46 Daytime Results for All Work Zone Projects–Crashes Involving Vehicles Traveling Opposite Direction

VARIABLE	Subcategory	Total Crashes	Fatal + Injury Crashes
		p-value	p-value
	Total	0.05*↑	0.017*↑
AADT per lane	Low	0.064↑	
Severity	Fatal + Injury	0.017*↑	0.017*↑
	PDO	0.636↑	
Area Type	Urban	0.246↑	
Road character	Straight-level	0.06↑	
	Straight	0.045*↑	0.023*↑
Speed limit	65 mph	0.353↑	
	> 60 mph	0.191↑	
Number of vehicles	Two vehs - low AADT	0.132↑	
	Two vehs	0.03*↑	
Surface condition	Dry	0.023*↑	
Number of lanes in both directions	4	0.539↑	
Weather	Clear	0.141↑	

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↑ & ↓ Indicate higher and lower odds of truck crashes relative to automobile crashes in work zones compared to control sections respectively.
Blank cells indicate that the sample size is not adequate to conduct valid statistical test.

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Conferences:	Hawkins.G and N.Mokkapati. Minimum Signal Sight Distance Guidelines. Presented at the Transportation Research Board (TRB) Conference, Washington D.C., January 2007.