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Work Zone Safety Analysis

FINAL REPORT

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16. Abstract

This report presents research performed analyzing crashes in work zones in the state of New Jersey so as to identify critical areas in work zones susceptible to crashes and key factors that contribute to these crashes. A field data collection on New Jersey roadways was performed for a select number of work zones to provide a better understanding of driver behavior in New Jersey work zones. The research also sought to identify where data needs are limited in evaluating work zone crashes in New Jersey and make recommendations on how the gaps in these needs can be addressed. Innovative strategies that hold potential for reducing work zone crashes were also identified.

Crash frequency and crash severity models were developed to identify factors that contribute to number and severity of crashes in work zones. Negative binomial models were used to estimate: total number of crashes; frequency of injury crashes; and frequency of property damage only crashes. Binary logistic regression models were used to estimate severity for crashes where the driver is at fault, for drivers and for occupants in crashes at work zones. Recommendations on the operation and design of the work zone to reduce crash frequency and severity are presented based on the findings of the study.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

Introduction

Work zone safety continues to be a priority area for our nation as well as for the State of New Jersey. Of the 30,797 fatal crashes due to motor vehicle crashes that occurred in the US in 2009, 1.9% or 582 fatal crashes occurred in work zones (FARS). Between 1998 through 2009 there were on average 833 fatal crashes per year in the U.S. in work zones. More than 80 percent of these crashes occurred in construction or long-term work zone areas. New Jersey experiences approximately 10 fatal crashes per year in work zones. On average there are approximately 6700 work zone fatal and non-fatal crashes every year in New Jersey. Of these crashes, 4800 are in construction work zones and 3100 are within State jurisdiction. Approximately 25% of the 6700 work zone crashes involve injuries.

Research Objectives and Approach

The overall objective of this research was to perform an analysis of crashes in work zones in the state of New Jersey so as to identify critical areas in the work zones susceptible to crashes and key factors that contribute to these crashes. In addition, based on the findings of the work zone crash analysis, the research sought to identify countermeasures for reducing work zone crashes. Fatal and severe injury crashes occurring in construction work zone in New Jersey were analyzed so as to determine controllable factors that account for variation in crashes among construction work zones

Summary of the Literature Review

The literature review included a review of studies performed to evaluate crashes in work zones; work zone crash countermeasures; and crash analyses literature. Much research has been performed evaluating crashes in work zones. Some studies focused exclusively on fatal crashes, some on fatal and severe injury crashes, and others on all crashes. Several factors have been identified as contributing to work zone crashes. In one study where fatal crashes in work zones was investigated, the most predominant contributing factor to the fatal crashes in work zones was careless driving which was identified in 39% of the crashes[64]. Other contributing factors identified included failure to yield right of way (10%), no improper driving action (8%), alcohol-under influence (6%) and drove left of center (5%). In another study work zone crashes were categorized into one of five work zone areas[65]. The research found that the activity area of the work zone was more susceptible to crashes regardless of road type. The study also found that the termination area was the safest area in the work zone.

The single effective approach for reducing fatal and injury crashes in work zones is by achieving speed limit compliance within the work zone. Several studies have been performed showing that although drivers reduce speeds in the vicinity of active work zones, these speeds are significantly higher than the posted speed limit [17]. This observed driver non-compliance for posted speed limits in work zones might be due to several variables including the use of unreasonably low speed limits within the work zone as well as maintaining reduced speed limits in place after the work activity is removed [67].

Several speed reduction strategies were identified as holding potential for reducing speeds in New Jersey work zones. These strategies include: photo radar; variable speed limits; and perceptual countermeasures. A review of the literature found three states, Illinois, Maryland and Oregon, have tested photo radar or Automated Speed Enforcement (ASE) within work zones. These states overall reduction in speeds using photo radar. A study on the use of Variable Speed Limit (VSL) systems to improve safety and mobility in work zones showed that speed limit compliance remained poor throughout the study period when VSL was used with the mean travel speed about 5 to 10 mph above the posted speed limit[73].

Summary of the Work Performed

Frequency Descriptive Analysis

New Jersey work zone crashes that occurred between 2004 and 2010 were explored and accident frequency related to time of occurrence, spatial information, seasonal information, and light condition information determined. The research showed the following season trends in crashes with the total number of work zone accidents during the winter season lower than for the other seasons. Weekday work zone crashes were found to be significantly higher than weekend crashes. Friday had the greatest number of work zone accidents during the seven-year period. Daytime and off-peak hours are most likely to see more work zone crashes because of the strongest presence of construction during this part of the day. Rear-end crashes are the most frequent work zone crash type, representing 44 percent of total work zone crashes. Side swipe and fixed-object crashes are also significant types. State highways and interstate highways account for 67.2 percent of all work zone accidents in New Jersey. 71.4 percent of work zone accidents happened in daylight conditions. 18.5 percent crashes occurred when the street lights were turned on.

Severity Descriptive Analysis

Between 2004 and 2010, 39,208 work zone crashes were reported in New Jersey, with 75.8 percent of them property damage only (PDO) crashes, 24.0 percent (9,402) of them involving personal injuries, and 0.2 percent (93) involving fatalities. Although the number of fatalities is relatively low, there are several personal injury crashes. The research showed the following:

- Construction zones are more prone to PDO, injury, and fatal crashes, while maintenance and utility zones experience almost the same level of PDO and injury crashes. Construction zones dominate each type of severity as traffic exposure to more construction zones in the state increases.

- The greater proportion of injury crashes is likely to occur under poor light conditions. Pearson's chi-squared test (χ^2 = 88.609, df = 2) indicated that there is a significant association between crash severity and lighting conditions.
- Adverse weather and road surface conditions do not affect the severity of work zone crashes.
- The most prevalent severity on each type of roadway is PDO, which was more than 70 percent. About 27 percent of crashes that occurred on state highways were injury crashes, which had the largest proportion compared to other types of roadways.
- There is no significant association between crash severity and road alignment given a significance level of 0.05.
- There is an association between crash severity and the existence of different roadway medians.
- Crashes involving two vehicles have resulted in the lowest proportion of injury, which was about 20 percent. This percentage is followed by single-vehicle crashes at 26 percent. There is a significant association between crash severity and the number of vehicles involved.
- The more people involved in a crash, the more likely the accident will result in injury.
- Crashes involving trucks seem to be less likely to cause injury or fatality compared to crashes without trucks. Together the portion of injury and fatal crashes is about 15 percent for truck-involved crashes, whereas it is about 26 percent for crashes involving no truck.
- More than 76 percent of all work zone crashes that did not involve alcohol did not result in any injuries compared to less than 60 percent of alcohol-involved work zone crashes. Alcohol-involved crashes were three times as likely to be fatal as non-alcohol–involved crashes.
- The percentages for PDO, injury, and fatal crashes occurring during nighttime (20:00–06:00) were 73.2 percent, 26.2 percent, and 0.6 percent, respectively. Injury and fatal crashes together are slightly higher compared to those crashes occurring during other periods.
- More than 80 percent of crashes are injury crashes if pedestrians or pedal-cyclists were involved in the collision. Other collisions that were expected to result in more than 30 percent injury crashes are head-on and angular collisions, left- or U-turn collisions, and right-angle collisions.

<u>Spatial and Temporal Analysis of Work Zones</u>

The spatial and temporal distributions of work zone crashes were determined by plotting these crashes. Crashes from 60 verified work zones were used, with their location, duration, and number of accidents. The total number of accidents at these 60 sites is 5,382. Work zones were separated into five locations: advance warning area, transition area, buffer area, work area, and termination area. The crash counts and crash rates are estimated for each specific work zone component. Considering crash counts, risk priority is defined in the following order:

1. Activity area (77.6 percent)
2. Advanced warning area (14.8 percent)
3. Transition area (4.1 percent)
4. Termination area (3.5 percent)

Crash Frequency Modeling

We used the New Jersey crash database (2004–2010) to construct the statistical models of crashes in the work zones. The objective of statistical modeling is to identify the factors that contribute to work zone crash frequency in New Jersey. In this study, we made an attempt to estimate Negative Binomial (NB) models in which the dependent variable is the number of accidents that occurred every three months in a work zone. We built three statistical models to analyze the contributing factors. The general model was used to investigate the duration effect of work zones by using all counts for the full period. Property damage and injury crash models were also developed to examine the seasonal crash counts.

Considering the crash information available from the NJDOT crash database, work zone project files, straight-line diagrams, and the variables used in previous CF models,[9,10,11] seven categories of variables are selected: length, light conditions, annual average daily traffic, posted speed, number of lanes, road type, and three-month occurrence.

Interpretation of the NB Model for Total Number of Crashes:

- Duration of the work zone is the most significant parameter related to total number of crashes for the general model.
- Length of the work zone is also a significant factor for crash occurrence.
- The frequency of work zone crashes is higher for daytime traffic than for nighttime traffic; nighttime produces fewer crashes.
- As expected, crash frequency increases by an increment of AADT values. Because AADT represents daily traffic for each lane, the number of operated lanes is significant for reflecting exposure to traffic.
- Speed reduction affects work zone crash occurrence positively. An increase in the variance of speed change results in more crashes.
- Work zone speed limit is not within the significance level of 0.05 but it is still within the acceptable range for the model.
- Road type, the number of lane drops, and the summation of intersection and ramp number parameters are not significant for this model.
- The alpha number is not close to zero, which means that overdispersion occurred. The NB regression is more appropriate for this dataset than the Poisson regression.
- The intercept value is significant for the general model.

Crash Severity Modeling

Work zone crash data between 2006 and 2010 were used to develop crash severity models. Three units of analysis are of interest in this study. The first is the injury severity of the crash level, considering driver faults. The second unit is the injury severity of drivers; the third is the injury severity of occupants. For crash-level analysis, crash severity is defined according to the highest level of severity occurring to the victims involved in the crash. Of 26,602 work zone crashes, only 42 (0.16 percent) are classified as fatal. To simplify analysis, the number of injury and fatal crashes were combined and denoted as injury crashes in this study. Each work zone crash in the crash dataset was categorized as either injury or noninjury. The binary logistic regressions were fitted using the Generalized Linear Model in the statistical software R.

Crash-level Analysis

For crash-level analysis, factors associated with the driver at fault were considered in the model. It should be noted that the original dataset was limited by the unavailability of at-fault driver information. To address this problem, a new dataset was created based on the following assumptions:

- *Driver at fault* is defined as the driver under the influence (DUI) or who has apparent contributing circumstances.
- For single-vehicle crashes, the driver of the vehicle is automatically considered the driver at fault.
- For multiple-vehicle crashes, if only one driver is involved in the crash who has a driver error, that person is considered the driver at fault.
- For multiple-vehicle crashes, if multiple drivers are involved in the crash, drivers who do not have any error ("none" in the driver error column) are excluded from the dataset. If more than one driver is left in the dataset for a particular crash after the above step, a random selection is made among them.

Time and Environmental Characteristics

- The likelihood of injury for a work zone crash occurring at nighttime is 1.147 times that of daytime.
- Age of the driver at fault did not significantly contribute to the injury risk of work zone crashes. However, if the driver at fault were female, the outcome of the crash was more likely to be an injury crash compared to a crash caused by a male driver.
- The at-fault driver driving a light-duty vehicle such as a motorcycle or scooter leads to greater injury risk (OR: 1.627).

Road and Work Zone Characteristics

- State highways are found to be associated with increased injury risk compared to lower-level roads.

- Increased injury risk is associated with: high speed limit in work zones; barrier medians; maintenance zones compared to utility work zones.
- Modeling results suggested that the presence of traffic-control devices did not significantly reduce injury risk. Indeed, most such controls are found to be associated with greater injury risk. The intervention of traffic-control devices may cause more severe vehicle conflicts; thus, their use in work zones needs to be further examined.

Crash Characteristics

- An increase in the number of vehicles and people involved in a crash increases the likelihood of injury crashes.
- Injury propensity of a crash involving light vehicles is about 69 percent higher.
- Compared to rear-end or side-swipe crashes, crash types such as right-angle, head-on, or fixed-object collisions are prone to cause severe crashes. Injury risk of an overturn crash is about 13 times higher than crashes in the same direction
- Driver errors, such as unsafe speed, inattention, and following too close, are found to contribute to crash severity level. Unsafe speed is associated with the largest Odds Ratio (1.616), which indicates the significant relationship between driving speed and crash severity.
- Inattentive driving or following too close may increase the injury risk of work zone crashes by about 20 percent.
- Compared to vehicles going straight ahead, vehicles making turns, interacting with others, or moving slowly lead to less severe crashes.

<u>Field Data Collection</u>

New Jersey drivers have particular driving characteristics and New Jersey has distinct traffic and geometric conditions that may impact the contributing factors associated with work zone crashes in New Jersey. Historical crash data is limited in capturing driver behavior in construction work zones. For this reason, field data were collected in a number of work zones for the purpose of better understanding driver behavior and identifying factors that may lead to unsafe driving behavior in New Jersey work zones. The data collection also serves to provide preliminary data that could be used to identify the types of countermeasures that should be considered for New Jersey conditions.

Forty hours of data were collected in four work zones on the following roadways in New Jersey: I-78, NJ-21, I-295 and I-80. On I-78, the work zone was located in the westbound local lanes from milepost 55.13 to 55.46. At this location, I-78 is a three lane freeway with the left lane closed during construction. On NJ-21, the work zoned is in the westbound lanes from milepost 9.0 to 9.7. At this location, NJ-21 is a three lane freeway with a left lane closure and traffic shift during construction. On I-295, the work zone is in the northbound local lanes from milepost 27.71 to 33.22. At this location, I-295 is a three lane freeway with the left lane closed during construction. On I-80, the work zone is in the northbound local lanes from milepost 42.8 to 44.20. At this location, I-80 is a four lane freeway with the left lane closed and traffic shift during construction.

Each work zone is unique and driver behavior is significantly impacted by the work zone configuration and roadway operation. Speed-flow relationships for each work zone upstream, entering, within and exiting the work zone show that the location of the work zone with the lowest speeds and greatest variability in speeds is entering the work zone. This larger variation in speeds as vehicles enter the work zone results in a larger potential for vehicle-vehicle crashes.

In addition to determining existing driver compliance to speed limits, a second objective of the field data study was to better understand driver behavior with regard to lane changes within the work zone. Lane change behavior at locations upstream, entering, within and downstream of the work zone was studied at each of the work zones studied.

The study indicated that improper lane changing entering the work zone may impact safety. Behavior where drivers merge into the lane that is signed to be closed, can have negative consequences on the work zone safety. This behavior suggests that countermeasures aimed at improving safety at work zone areas in New Jersey should include strategies to impact lane changing entering the work zone.

CONCLUSIONS AND RECOMMENDATIONS

The following provide recommendations to improve work zone safety in New Jersey:

Work Zone Crash Data Collection

The crash report form should be modified to reflect work zone–specific characteristics, including the following information:

- Accurate crash location within the work zone (that is, advanced warning, buffer, termination)
- Number of closed lanes and number of operating lanes
- Left-, middle-, or right-lane closure; shoulder closure
- Operating hours
- Presence of workers or equipment
- Work zone speed limit
- Detour or full-road closure information, including duration
- Channelization details of the work zone (concrete barrier)
- Workers or equipment involved in an accident

Crash Frequency

- The duration of the work zone project should be minimized to reduce work zone crash occurrence.
- Keeping project lengths shorter reduces the number of work zone crashes.
- To avoid exposure resulting from heavy traffic (AADT), traffic should be diverted to alternate routes when appropriate conditions exist.
- State highways in our models have significantly more work zone crashes than interstate highways. Hence, work zone safety strategies should be compared among different road systems.
- Operating work zones during nighttime keeps the number of injury and PDO crashes lower.
- Speed reduction should only be applied for necessary operating conditions.
- Lane closing strategies should be revised to minimize the number of lane drops for necessary conditions.

Crash Severity

- Nighttime crashes were found to be more severe than daytime crashes in our severity models. Therefore, visibility, alertness, and awareness of both drivers and workers should be improved in the vicinity of work zones.
- To reduce injury risk, a lower speed limit should be posted, but special attention should be paid to transitioning from normal speed to reduced speed.
- Young drivers and female drivers are more likely to be involved in injury crashes. Safety education or training programs should be provided for these specific groups.
- If the site has higher truck traffic flow, their interaction with other road users should be monitored and controlled.
- Opposite crashes (that is, head-on, angular, and side swipe) are likely to be injury crashes. Therefore, when median crossover is needed in some work zones, traffic-control strategies should be carefully studied to prevent opposite-direction crashes.
- Special enforcement should be used for all traffic violations within the work zone to keep drivers' level of attention high.

- Safety strategies for maintenance work zones should be improved, because model results show that maintenance work zones have higher injury risk than construction and utility work zones.

- Operators of light-duty vehicle such as scooters and motorcycles should drive more carefully in work zone sites. Driver education programs should be designed to address this issue.

INTRODUCTION

The American Recovery and Reinvestment Act of 2009 (Recovery Act), which was signed into law in February, 2009, committed $150 billion in new infrastructure. This investment increased funding to our nation's roads, bridges, and mass transit systems, providing $1 billion for New Jersey's transportation infrastructure. It will stimulate New Jersey's economy by creating or supporting thousands of transportation-related jobs and making long-term improvements to our roads, bridges and transit system. New projects from the Economic Recovery initiative will bring great opportunities as well as the possibility of safety and mobility impacts due to an increasing number of work zones.

The Manual of Uniform Traffic Control Devices (MUTCD, 2009) [63] provides guidance on promoting safe and efficient movement of road users through or around Temporary Traffic Control (TTC) zones while protecting workers, responders to traffic incidents, and equipment. Despite this guidance, work zone safety continues to be an area of priority for our nation as well as for the State of New Jersey. Of the 30,797 fatal crashes due to motor vehicle crashes that occurred in the US in 2009, 1.9% or 582 fatal crashes occurred in work zones (FARS). Table 1 shows the fatal crashes in work zones in the U.S. from 1998 through 2009. During this time period there was an average of 833 fatal crashes per year in the U.S. in work zones. More than 80 percent of these crashes occurred in construction or long-term work zone areas.

BACKGROUND

Table 1 also shows the fatal crashes in work zones in New Jersey. New Jersey experiences approximately 10 fatal crashes per year in work zones. On average there are approximately 6700 work zone fatal and non-fatal crashes every year in New Jersey. Of these crashes, 4800 are in construction work zones and 3100 are within State jurisdiction. Approximately 25% of the 6700 work zone crashes involve injuries.

Work Zone Components

Work zone literature uses several general terms commonly associated with work zones and work zone lane closures. Figure 1 graphically depicts these components of a traffic control zone. General terms that will be used throughout this review include the advance warning area, the transition area, the activity area (which includes lateral and longitudinal buffer space, traffic space, and work space), and the termination area. These definitions are further defined in the *Manual on Uniform Traffic Control Devices* (MUTCD, 2009) [63]. The transition area is only applicable to work zone regions where the normal traffic pattern must be diverted. For the purposes of this review, a work zone is defined as any road section where maintenance or improvement activities occur adjacent to or on the active roadway.

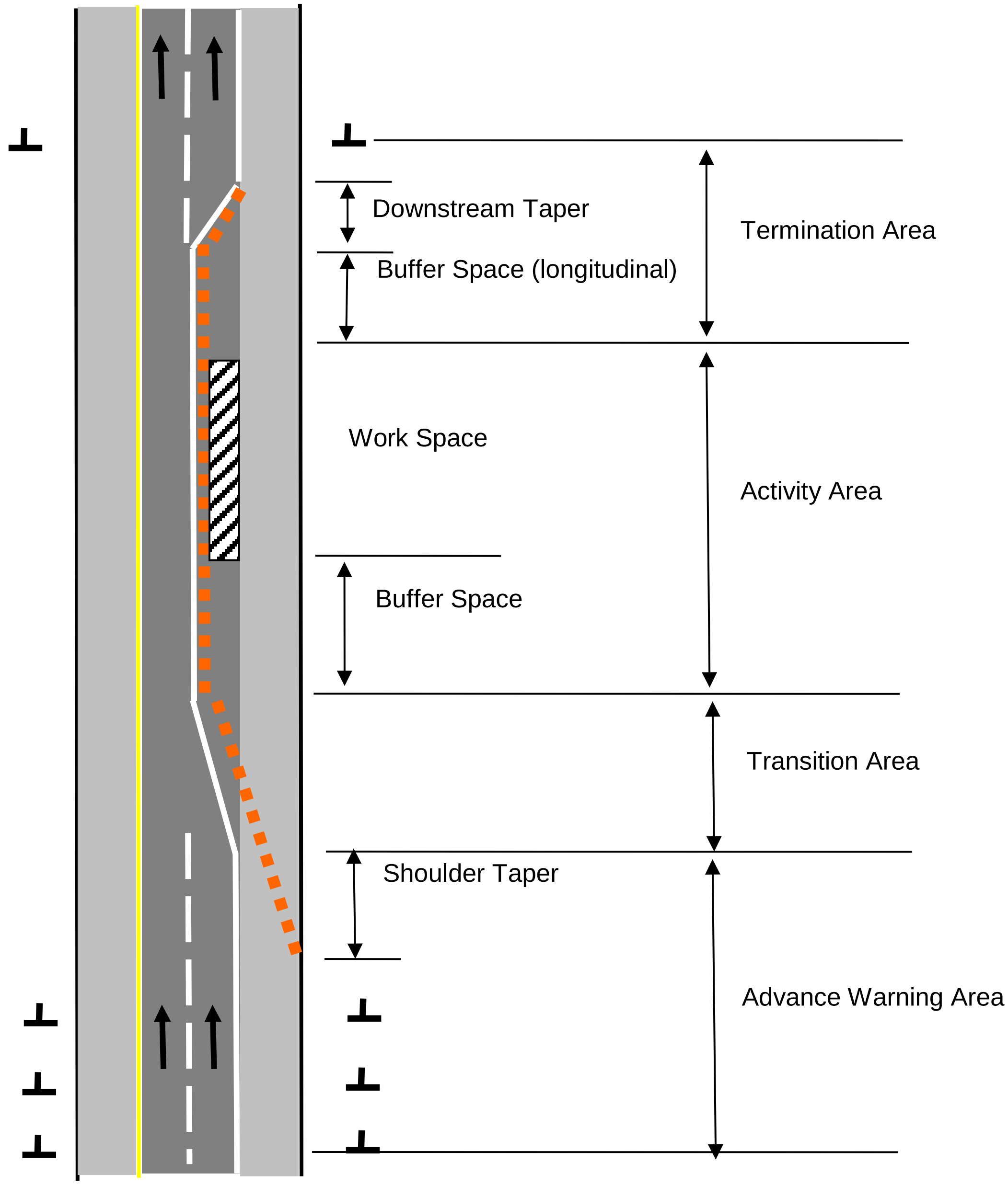


Figure 1. Component Parts of a Temporary Traffic Control Zone (MUTCD, 2009)[(63)]

The *advance warning area* is the section of highway where road users are informed about the upcoming work zone or incident area. The advance warning area may vary from a single sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to a series of signs in advance of the Temporary Traffic Control (TTC) zone activity area. Advance warning may be eliminated when the activity area is sufficiently removed from the road users' path so that it does not interfere with the normal flow.

The *transition area* is that section of highway where road users are redirected out of their normal path. Transition areas usually involve strategic use of tapers. In mobile operations, the transition area moves with the work space.

The *activity area* is the section of the highway where the work activity takes place. It is comprised of the work space, the traffic space, and the buffer space. The work space is that portion of the highway closed to road users and set aside for workers, equipment, and material, and a shadow vehicle if one is used upstream. The work space may be stationary or may move as work progresses. The traffic space is the portion of the highway in which road users are routed through the activity area. The buffer space is a lateral and/or longitudinal area that separates road user flow from the work space or an unsafe area, and might provide some recovery space for an errant vehicle.

Table 1. Fatal Crashes in Work Zones in the US and NJ

	Type of Work Zone											
	Construction		Maintenance		Utility		Work Zone, Type Unknown		Total		% of All Fatal Crashes	
Year	US	NJ	US	NJ	US	NJ	US	NJ	US	NJ	US	NJ
1998	577	7	47	2	10	0	47	0	681	9	1.8%	1.3%
1999	649	4	65	1	10	0	46	0	770	5	2.1%	0.8%
2000	775	25	84	1	12	0	43	0	914	26	2.4%	3.9%
2001	714	4	86	2	8	0	69	0	877	6	2.3%	0.9%
2002	890	7	77	0	11	0	57	0	1035	7	2.7%	1.0%
2003	824	8	74	2	21	0	63	1	982	11	2.6%	1.7%
2004	725	5	92	0	15	0	99	0	931	5	2.4%	0.7%
2005	750	7	91	1	12	0	84	1	937	9	2.4%	1.3%
2006	678	8	92	2	16	0	109	0	895	10	2.3%	1.4%
2007	555	11	84	1	9	0	84	0	732	12	2.0%	1.8%
2008	504	5	61	0	14	0	83	1	662	6	1.9%	1.1%
2009	441	9	54	0	14	1	73	0	582	10	1.9%	1.8%

Source: FARS Database

The *termination area* is used to return road users to their normal path. A longitudinal buffer space may be used between the work space and the beginning of the downstream taper.

RESEARCH OBJECTIVES

The overall objective of this research was to perform an analysis of crashes in work zones in the state of New Jersey so as to identify critical areas in the work zones susceptible to crashes and key factors that contribute to these crashes. In addition, based on the findings of the work zone crash analysis, the research seeks to identify countermeasures for reducing work zone crashes.

Specific objectives to be accomplished in the proposed research include:

- To perform a comprehensive literature review, identifying methodological approaches used in to evaluate work zone crashes and the findings from State Departments of Transportation studies on work zone crashes;

- To analyze fatal and severe injury crashes occurring in construction work zone in New Jersey so as to determine controllable factors that account for variation in crashes among construction work zones in New Jersey;

- Identify where data needs are limited in evaluating work zone crashes in New Jersey and make recommendations on how the gaps in these needs can be addressed; and

- Identify innovative as well as tested strategies that may hold potential for reducing work zone crashes in New Jersey.

RESEARCH APPROACH

The tasks performed to achieve the objectives include the following:

PHASE I. Conduct a literature search of state-of-practice

PHASE II. Research Approach

Task II-1. Develop Research Exit Criteria.
Task II-2. Refined Literature Search.
Task II-3. Perform Work Zone Crash Analysis

Sub-Task II-3.1. Descriptive Analysis of NJ Work Zone Crash Data
Sub-Task II-3.2. Statistical Analysis of NJ Work Zone Crash Data
Sub-Task II-3.3. Estimation of Models using NJ Work Zone Crash Data
Sub-Task II-3.4. Exploration of Other Data Sources For More Detailed Work Zone Crash Data and Analysis of This Data
Sub-Task II-3.5. Recommendations

Task II-4. Field Data Collection
Task II-5. Recommendations
Task II-6. Presentation, Implementation, and Training
Task II-7. Final Report

The research began with a comprehensive review of the literature covering: (1) current state of the practice on work zone crash analysis; (2) statistical approaches for identifying key factors that contribute to work zone crashes; and (3) countermeasures used to reduce work zone crashes.

Following the literature review, work was performed to analyze New Jersey work zone crashes. The crash analysis involved first providing descriptive statistics of work zone crashes in New Jersey. A statistical analysis of the crash data was then performed to determine statistical differences between types of work zone crashes. To identify causal relationships between crash occurrences and factors, statistical models were developed. Finally recommendations on significant factors affecting work zone crashes were developed.

A field data collection in New Jersey roadways was performed in a select number of work zones. The intent of the data collection was to identify critical locations within the work zone where NJDOT should focus its attention in an effort to reduce work zone crashes. The field data collection provided a better understand of driver behavior in New Jersey work zones.

Finally, recommendations are made on factors identified as being significant that contribute to work zone crashes. Recommendations on how to address gaps in crash data analysis that would need to be filled to promote on-going monitoring of New Jersey work zone crashes were developed. A pilot study designed to test the most promising countermeasures identified for reducing work zone crashes is identified.

LITERATURE REVIEW

Previous Work Zone Crash Analyses

Much research has been performed evaluating crashes in work zones. Some studies focused exclusively on fatal crashes, some on fatal and severe injury crashes, and others on all crashes. Lu et. al (2008) [64] investigated the characteristics of fatal crashes at work zones in Florida to identify the factors that contribute to these crashes. The study used four years of fatal crashes and investigated the impact of drivers' ages, time of crash, environmental conditions, crash types, contributing factors and other variables. The study found that middle age drivers, ages 25 to 64 years, had the highest percent of fatal crashes or 64% of all fatal crashes. The highest percent of fatal crashes occurred during the nighttime period from 10 pm to 6 am with 48 percent of fatal crashes. Forty-one of fatal crashes occurred during lighted conditions and 70% of crashes occurred during dry weather conditions. The most predominant contributing factor to the fatal crashes in work zones was careless driving which was identified in 39% of the crashes. Other contributing factors identified included failure to yield right of way (10%), no improper driving action (8%), alcohol-under influence (6%) and drove left of center (5%).

Daniel et. al (2000) [17] performed a study on fatal crashes in work zones for the Georgia Department of Transportation. The predominant type of collision occurring within Georgia work zones involving fatal crashes were single vehicle crashes and sideswipe in the opposite direction. The two types of collisions represented 63 percent of the crashes. Fatal crashes primarily involved passenger vehicles with these vehicles accounting for 80 percent of vehicles involved in fatal crashes. Fifty percent of the fatal crashes studies occurred between 12 midnight and 6 AM. Sixty-five percent occurred during the weekday with 60 percent of the weekend crashes occurring on Saturdays. Sixty-one percent of the crashes occurred on rural roadways with the largest percent of crashes occurring on roadways classified as rural principal arterial non-interstate roadways. The study concluded that the resources aimed at reducing fatal crashes should be targeted to: construction work zones rather than maintenance work zones; resurfacing and/or widening construction projects; work zones located on rural principal arterial non-interstate roadways; both idle as well as work zones in progress; and work zones during daylight and dark conditions.

Li and Bai (2008) [34] investigated the characteristics of fatal and injury crashes in highway work zones in Kansas to determine the difference between fatal and injury crashes. The study also sought to recommend countermeasures to reduce work zone crashes based on the differences between fatal and injury crashes. Data for fatal and injury crashes in highway work zones between 1992 and 2004 were utilized in the study. All of the 157 work zone fatal crashes were used in the analysis. As the data were in a format that made it time consuming to use, a sample of 460 injury crashes was used in the analysis compared to a total of 4443 injury crashes that occurred within the study period. The variables compared between fatal and injury crashes included variables describing the driver at fault, time, environment conditions, road conditions crash scene information and other contributing factors.

The study found that male drivers were at fault for the majority of both fatal and injury crashes in Kansas work zones. Young drivers, between the age of 15 and 24, were frequently involved in severe crashes. Teenage drivers between 15 and 19 years old caused 16 percent of all work zone crash injuries. The time period with the highest injury crash frequency was daytime non-peak (10:00 am to 4:00 pm). This time period had the second highest fatal crash frequency. Both fatal and injury crashes occurred during favorable weather and road surface conditions. A majority of fatal and injury crashes occurred in work zones on interstate highways and other principal arterials. Most of these crashes occurred in rural areas within 51-70 mph speed zones. The study confirmed that high speeds contributed to the increase of crash severity in the work zone. Inattentive driving contributed to more than half of fatal and injury crashes. Overall the research showed significant differences in the factors that contributed to injury and fatal crashes. Complicated geometric highway alignments, unfavorable light conditions, involvement of heavy vehicles, alcohol impairment, and disregarding traffic control, were potential factors that contributed to the increase of crash severity in work zones.

In some studies, crashes were identified not only within the work zone but within the component parts of the work zone. Garber and Zhao (2002) [(65)] investigated work zone crashes in Virginia between 1996 and 1999. Using crash data obtained from police crash records, crashes were categorized into one of five work zone areas including: advance warning area, transition area, longitudinal buffer area, activity area, and termination area. Crashes were also categorized by severity type, collision type, road type and time of day. Table 2 shows the percent of crashes in each of the work zone areas.

Table 2. Percent of Crashes by Location Within Work Zone

Work Zone Area	**Percent of Work Zone Crashes**
Advance Warning Area	10%
Transition Area	13%
Longitudinal Buffer Area	5%
Activity Area	70%
Termination Area	2%

As the table shows, the majority of work zone crashes, 70%, occurred within the activity area of the work zone. The next highest percent of crashes occurred within the transition area, with 13% of crashes occurring within this area. The crashes were further characterized by road type and proportionality tests performed to determine differences in the proportion of crashes in each area of the work zone for each road type. Differences between work zone area crashes for different road types were also determined.

The research found that the activity area of the work zone was more susceptible to crashes regardless of road type. The study also found that the termination area was the safest area in the work zone. A study of the fatal crashes showed that 76 percent of fatal crashes occurred in the activity area of the work zone, compared to 70 percent for all crashes in the work zone. Proportionality tests showed that there was no significant difference between the proportions of fatal crashes in each area of the work zone or between the road types.

Table 3 shows the distribution of collision types by work zone area. Rear-end crashes represent 52 percent of all work zone crashes. In the advance warning area, rear end crashes are significantly higher than in the other work zone areas with 83% of all crashes. The percentage of sideswipe in the same direction collisions is significantly higher in the transition area (26%), than in the advance warning area (2%).

Table 3. Collision Type Distribution by Work Zone Crash Area (Garber, 2002) (65)

Work Zone Area	Advance Warning Area	Transition Area	Longitudinal Buffer Area	Activity Area	Termination Area	All Work Zone Crashes
Angle	5%	2%	7%	16%	100%	13%
Fixed Object in Road	1%	7%	9%	4%	0%	4%
Fixed Object Off Road	6%	7%	12%	14%	0%	12%
Rear End	83%	54%	51%	47%	0%	52%
Sideswipe Same Direction	2%	26%	12%	9%	0%	11%
Other[1]	3%	4%	9%	10%	0%	8%

[1] Other crashes include backed into, head on, miscellaneous or other, non-collision, pedestrian and sideswipe opposite direction.

Work Zone Crash Countermeasures

Speed Reduction Strategies

A single effective approach for reducing fatal and injury crashes in work zones is by achieving speed limit compliance within the work zone. Several studies have been performed showing that although drivers reduce speeds in the vicinity of active work zones, these speeds are significantly higher than the posted speed limit (Daniel, et. al, 2000) (17). This observed driver non-compliance for posted speed limits in work zones might be due to several variables. A study performed by the Wisconsin Department of Transportation identified the two major reasons for work zone crashes are speeding and inattentive driving. Drivers appear to select speeds based on their perception of the safety of the roadway, rather than posted speeds. In a survey of drivers who had just driven through a work zone, 54% of the drivers surveyed believed the work zone to be more hazardous than a non-work area (Benekohal et. al, 1992) (66). Although 79% of the drivers said the posted speed limit was reasonable, only 59% complied with this speed limit. Driver non-compliance to work zone speed limits is also attributed to the use of unreasonably low speed limits within the work zone as well as maintaining reduced speed limits in place after the work activity is removed (Richards and Dudek, 1986) (67). These actions can undermine the credibility of the work zone speed limit and increase non-compliance of the posted speed. Effective work zone speed control implementation must consider the need for speed reduction, determine a reasonable speed, select a speed reduction treatment based on practical cost, and then select an appropriate location for treatment (Dudek et. al, 1985) (67).

Speed reduction strategies can be classified as either passive or active speed control measures. Passive speed control refers to devices that provide speed information in a non-intrusive manner. A static speed limit sign, for example, is considered a passive speed control measure. Exclusive use of passive control is appropriate at locations where the hazards are obvious to drivers and can be detected easily in time to permit drivers to adjust speed as appropriate.

Active control refers to techniques that restrict movement, display real-time information, provide dynamic information or enforce compliance to a passive control (Richard and Dudek, 1986) (67). Speed reduction strategies can be grouped into seven broad categories. These categories include: signing/flagging, radar, lighted guidance devices, pavement devices, driver information devices, law enforcement, and other general strategies. Table 4 summarizes the individual strategies associated with each category and Table 5 provides the expected speed reduction for some strategies used for reducing speed in work zones.

Table 4. Work Zone Speed Reduction Strategies (Source: Daniel, 1999) [68]

1. SIGNING/FLAGGING	• STOP/SLOW Sign Paddle • Flagging • Static Signs • Changeable Message Signs • Changeable Message Signs with Radar and Speed Message • Speed Monitoring Displays
2. RADAR	• Unmanned/Drone Radar • Radar-Emulator • Radar-Activated Horn • Photo-Radar
3. DRIVER INFORMATION	• Highway Advisory Radio • Public Awareness Campaigns
4. LAW ENFORCEMENT	• Circulating Marked Police Car • Stationary Police Car • Uniformed Police Traffic Controller
5. PAVEMENT DEVICES	• Rumble Strips • Temporary Pavement Marking • Lane Width Reduction • Transverse Paint Stripes
6. LIGHTED DEVICES	• Pulsing Guidance Devices • Strobe Lights • Steady-Burn Lights • Warning Lights on Service Vehicles
7. OTHER STRATEGIES	• Automated License Plate Reading System • Direction Indicator Barricade

Table 5. Expected Speed Reduction of Work Zone Treatments (Source: Fitzsimmons et. al, 2009) [69]

Treatment	Speed Reduction	Other Benefits
Advance Warning	74% of drivers reduced speed at first sign or near work zone	
Variable Speed Limit	• Mixed results, may have reduced speeds for vehicles at higher speeds • Nighttime decrease of 3-10 mph	
Changeable or Variable Message Signs	• 66% of survey respondents indicated they slowed with presence of signs • Reduced speeds near sign by 6-7 mph but not sustained • Reduction in 85th percentile speed of 2-9 mph • 7 mph decrease in mean speed • 2 mph reduction in 85th percentile speed	
Signs Feedback Signs	• 4 to 5 mph reduction in mean speed • 5 mph decrease in 85th percentile speeds • 3.7 mph reduction in mean speed	
Drone Radar	• 6 to 33% reduction in vehicles traveling above speed limit • Decrease in % of vehicles traveling 15 mph over the posted speed limit • Reduced number of vehicles traveling more than 10 mph over the speed limit • 1 to 2 mph reduction • 3-6 mph decrease in mean speed	
Automated Flagger	• No effect on approach speeds	• Drivers know where and when to stop • Can replace flaggers in some instances

Public Awareness Campaigns	0.2 to 1.8 mph speed reduction during daytime	
Double Fine	Found both increases and decreases in mean speed	
Enforcement	85% of responding states report reduction in speeds	
Automated Enforcement	No Information Available	
Transverse Pavement Markings	• Decrease in 85th percentile speeds • Up to 4 kph decrease	Increase safety to due to retro reflectivity
Temporary Rumble Strips	• Reduction in 85th percentile speeds • Around 1 mph reduction in mean speed • Reduction of 2 mph in mean speed	
Wider Pavement Marking	No Information Available	
Dynamic Lane Merger	No Information Available	• Found reduction in aggressive behavior • Improved travel speeds
Automated Work Zone System		Felt rear-end crashes and congestion were reduced

Other Crash Countermeasures

Li and Bai (2009) [35] reported on the effectiveness of a new traffic warning sign to reduce crashes associated with inattentive driving in work zones. The new sign is assembled using the hazard warning flashers of vehicles. Speeds collected within three rural one-lane, two-way work zones with and without the use of the sign showed mean speeds were reduced when the sign was used. The proportion of high speed vehicles were also reduced with drivers responding that the sign capture the attention of most drivers as they approached the work zone.

Focused Review on Speed Reduction Strategies

Based on discussions with the Research Project Selection and Implementation Panel (RPSIP), several speed reduction strategies were identified as holding potential for reducing speeds in New Jersey work zones. The following provides a review of these strategies.

Photo Radar in Work Zones

A review of the literature found three states that have tested photo radar or Automated Speed Enforcement (ASE) within work zones. Table 6 summarizes the results of those tests.

Table 6. Summary of Literature on Photo Radar Enforcement in Work Zones

Author	State	Results
Benekohal et. al (2009) [70]	Illinois	Average speeds for sampled cars were reduced between 4.3 and 8.0 mph and free-flowing car mean speeds were reduced between 4.2 and 7.9 mph.
Franz and Chang (2011) [71]	Maryland	Of the five datasets collected before and during the automated speed enforcement, two data sets showed a general reduction in aggressive motorists. One data set showed increased speeds during the enforcement period.
Joerger (2010) [72]	Oregon	Installed on non-interstates. Speeds reduced by 28.3%. Speed reductions were temporary and did not persist beyond the departure of the photo radar enforcement van.

The State of Oregon authorized the use of photo radar in work zones on Oregon highways. Radar use is restricted to state work zones and is valid until December 31, 2014 (Joerger, 2010) [72]. The research sought to evaluate the impact of photo radar on speed reduction in work zones. The impact of photo radar was tested on US30-Lower Columbia River Highway in Portland, Oregon. The project extended for two miles through an industrial area with heavy traffic volumes and a large number of trucks. The roadway has 4 lanes plus a continuous left turn lane.

Radar traffic sensors were used to collect the data. The radar unit selected was the Wavetronix SmartSensor HD which collects traffic volume, vehicle classification, average speed, individual vehicle speed and lane occupancy. Data were collected at four periods: (1) prior to implementation of the work zone or photo radar enforcement; (2) with implementation of work zone signage but without photo radar enforcement; (3) with implementation of work zone signage and during periods of photo radar enforcement; and (4) with the work zone and photo radar signs/equipment removed completely.

Photo radar enforcement was performed using the Portland Police Bureau who had utilized this enforcement since 1996. Overall, the study found photo radar enforcement had a substantial impact on reducing the number of speeding vehicles in a construction work zone. Speed was reduced by an average of 27.3% at the traffic sensor site within the work zone. A greater reduction in speeding would be expected if the enforcement covered both directions of travel. The speed reduction, however, was temporary and did not persist beyond the departure of the photo radar enforcement equipment.

Benekohal et. al (2009) [70] also investigated the effectiveness of automated speed photo-radar enforcement in work zones in Illinois. Data were collected at three locations in two work zones located on interstate highways for three scenarios: (1) with no speed enforcement present; (2) with the speed photo enforcement (SPE) van deployed in the work zone; and (3) after the SPE van left the work zone with no speed enforcement present. Data were collected using a camcorder and two markers placed off the shoulder and 200 feet apart and were recorded for every fifth vehicle in the traffic stream and for all free-flowing vehicles. The data collected included the times at which vehicles passed the two markers, the vehicle type, lane used and whether the vehicle was free flowing or in platoon. This data was then used to determine speed of vehicles. One hour of data collection was used. The mean speeds for sampled vehicles and for free-flowing vehicles in the work zones were reduced with the presence of the SPE van.

As shown in Table 7, average speeds for sampled cars were reduced between 4.3 and 8.0 mph and free-flowing car mean speeds were reduced between 4.2 and 7.9 mph. Statistical tests show the reductions were significant. The presence of SPE also showed a drastic reduction in the percentage of cars exceeding the speed limit. The percentage of free-flow cars exceeding the speed limit when the SPE van was present ranged 8.3% to 45.5% compared to the percentage exceeding the speed limit when the

Table 7. Speed Reduction Due to Speed Photo-Radar Enforcement (Benekohal, 2008)[70]

	Free-Flowing Passenger Cars		**Sample Cars**	
	Shoulder Lane	**Median Lane**	**Shoulder Lane**	**Median Lane**
Data Set 1	6.4	4.2	5.1	4.3
Data Set 2	6.3	5.4	7.1	6.3
Data Set 3	7.9	7.7	8.0	7.7
	Free-Flowing Passenger Heavy Vehicles		**Sample Heavy Vehicles**	
	Shoulder Lane	**Median Lane**	**Shoulder Lane**	**Median Lane**
Data Set 1	3.4	4.2	3.7	2.9
Data Set 2	6.9	4.0	5.1	3.9
Data Set 3	5.6	6.4	4.0	6.1

van was not present of 30.4% to 93.2%. The average speeds of heavy vehicles was also reduced in the presence of SPE. Average speeds for sampled heavy vehicles were reduced between 2.9 and 6.1 mph and free-flowing car mean speeds were reduced between 3.4 and 6.9 mph.

The ability to maintain lower average speeds after the SPE was removed was also studied. This is referred to as a "halo effect". The study found a reduction of between 1.8 and 2.7 mph for free-flowing heavy vehicles when the SPE van was removed. The average speeds for free-flow cars reduced by 1.2 mph in the shoulder lane and the average speeds for sampled cars reduced between 1.6 and 1.7 after the SPE van was removed.

Maryland State Highway Administration began a pilot program utilizing two mobile Automated Speed Enforcement (ASE) vehicles in three highway work zones in October 2009 (Franz and Chang, 2011) [71]. In the initial stages of the program, only citations were issued to motorists traveling 12 mph above the posted speed limit. At the same time, promotion and media campaigns actively broadcast the program to the public. Citations were then issued in the next phase of the program with the citation issued to the vehicle registrant. To assess the performance of the pilot program, speed and volume data were collected upstream, at, downstream and far downstream of the ASE vehicle before and during the ASE deployment periods. The effect of the ASE was reported at two locations: Southbound I-95 Express Toll Lane (ETL) in Baltimore, Maryland; and Westbound I-695. Drivers traveling within the work zone during and after the ASE deployment were classified as either conservative, normal or aggressive drivers. Conservative drivers are those drivers traveling between 1 mph and the posted speed limit (PSL). Normal drivers travel between (PSL+1) mph and (PSL +10) mph. Aggressive drivers travel greater than (PSL +10) mph. At the I-695 locations, both during and after the ASE deployment, there was a reduction in aggressive drivers approaching the enforcement location. Aggressive drivers reduced from 45% to 20.3% during the deployment and reduced from 40.2% to 26.3% after the deployment. The study found that aggressive driving increased past the enforcement location with aggressive driving increasing from 20.3% at the enforcement location to 86.6% far downstream during the deployment period. After the deployment, aggressive drivers increased from 26.3% at the enforcement location to 78.9% far downstream of the enforcement location. Overall the reduction in work zone speeds was localized to the enforcement location. Speeds after the enforcement returned to and exceeded speeds at the upstream location.

At I-95, there was an increase in both the percentage of aggressive drivers and mean speed as drivers approached the enforcement location. Before the ASE deployment, speeds increased from a mean speed of 55.2 mph upstream of the enforcement location to 58.6 mph at the enforcement location. During the enforcement deployment, there was a smaller increase in the mean speed from 54.1 mph upstream of the enforcement location to 55.2 mph at the enforcement location. The authors state that despite the increase in mean speed, the percentage of aggressive drivers approaching the enforcement location became “more stable” during the enforcement. The authors indicate that this stability resulted in a reduction in the spatial speed variation.

Variable Speed Limits

Variable speed limits have been proposed as a means of managing speeds in work zones. Previous studies have shown VSLs can produce significant safety and mobility benefits. Results from studies conducted in Germany, the United Kingdom and The Netherlands showed a reduction in crashes between 10 and 30 percent after VSLs were installed (Fudala and Fontaine, 2010) [(73)]. The mean and variance of the speed also decreased with increases in vehicle throughput of between 3 and 5 percent. Many of the VSL systems that have been deployed were done so in conjunction with automated speed enforcement. In some cases the VSL was not traffic responsive, changing based on time or day or some fixed control.

Table 8 summarizes studies from three states where variable speed limits have been implemented. Fudala and Fontaine (2010) [(73)] evaluated the potential of Variable Speed Limit (VSL) systems to improve safety and mobility in work zones. The research focused on the use of this technology on heavily traveled urban freeways to determine the best configuration for use and to examine the impacts on extremely congested urban freeways.

Table 8 . Summary of Literature on Variable Speed Limits in Work Zones

Author	**State**	**Results**
Fudala and Fontaine (2010) [(73)]	Virginia	Speed limit compliance remained poor throughout the study period with the mean travel speed about 5 to 10 mph above the posted speed limit.
Kwon et. al (2007) [(74)]	Minnesota	Between 6 and 7 am the average 1-min maximum speed difference was reduced from 35%. The average total throughput increased by 7.1%. Speeds increased with driver compliance to the speed limits of between 20% to 60%.
Pesti et. al (2004)[1] [(75)]	Nebraska	No significant change in demand flows in response to the speed messages with no significant increase in vehicle diversion.

[1]Not a true variable speed limit deployment. Average measured speeds were displayed to motorists.

The effectiveness of the VSL system was determined by examining an in-field study and simulation. A VSL system was deployed in July 2008 on a long-term construction work zone on the Woodrow Wilson Bridge (WWB) between Virginia and Maryland. The effectiveness of VSLs over a range of system designs, driver characteristics, and roadway network characteristics were evaluated using a simulation test bed.

The work zone was approximately 5.2 mi long in the northbound direction and 4.9 mi long in the southbound direction with one and two-lane closures. Within the work area were five interchanges and a draw bridge that occasionally opened during the overnight hours. Twelve VSL signs were utilized with the total cost of the system to Virginia Department of Transportation (VDOT) of $3.2 million for 2 years, including hardware, software, training, and operational support. Prior to the VSL, the speed limit for the roadway was 55 mph. The VSL provides regulatory speeds with a minimum and maximum allowable speed of 35 and 50 mph, respectively. When no lanes were closed, the maximum speed limit was displayed in static mode. Figure 2 and Figure 3 show images of the variable speed limit signs within the work zone.

Cumulative volume and occupancy data were gathered from microwave sensors and compared to threshold values. The average threshold volumes within a zone were then used to define a desired speed limit. Before speeds were implemented, they were manually approved by the control center. Speed limits were retained for a minimum of 20 minutes to allow sufficient time for officers to be notified of changes and enforce new limits.

Figure 2. Variable Speed Limit Sign Placement (Fudala, 2010) [(73)]

Figure 3. Sign Alerting Drivers to VSL (Fudala, 2010) [(73)]

The general findings about placement of VSL in work Zones include the following:

- Changes in location of lane closures made some locations of the VSL signs to not be ideally suited to influence travel conditions leading up to a lane closure;

- The VSL was active only during night lane closures, thus limiting the number of vehicles that would have exposed to the system if it was active during the day. In addition, in some cases, for night lane closures, VSLs were not active.

- Placing the VSL signs on the right side of the roadway made it difficult for vehicles in the median lane to see the signs.

- The configuration of the work zone made it difficult to include law enforcement on the roadway. Therefore, not law enforcement was provided.

An empirical analysis of the performance of the system could not be performed. However, the study concludes that speed limit compliance remained poor throughout the study period with the mean travel speed about 5 to 10 mph above the posted speed limit.

Kwon et. al (2007) [74] explored the use of a variable advisory speed limit system for work zones (VASLS-WZ). The goal of the system is to reduce the speed of the upstream flow sequentially to the same level as that of the downstream flow by using two variable advisory speed limits. Advisory speed limits are provided to drivers approaching a congested work zone segment. The VASLS-WZ was implemented on I-494 in Minnesota in a 2.5 mile long work zone with a posted speed limit of 55 mph. Two variable advisory speed limit signs are located using downstream travel speeds, and one advisory sign is placed upstream and uses speed measurements at both upstream and downstream locations. The upper limit of the advisory speed limit at the upstream sign was set to 50 mph, while the downstream sign was set to 45 mph. The downstream speed limit reflects the current posted advisory speed limit. Speed data is obtained from detectors every 30 seconds through a wireless communication network. This speed data is then used by an algorithm to determine the advisory speed limit. Speed limits were updated every 1 minute at 5-mph increments using data measured for the previous 90 seconds.

The study showed that for the period of 7:00 to 8:00 a.m., the average 1-min maximum speed difference was reduced from 18.4 mph to 14.1 mph (−23%), with the statistical significance level at 1% after the implementation of the VASLS-WZ. During the 6:00 to 7:00 a.m. weekday period, the average 1-min maximum speed difference within the work zone was reduced from 13.0 mph to 8.4 mph (−35%) at a significance level of α=7%. The average total throughput between 6:00 and 7:00 a.m. increased by 7.1%, and increased by 2.2% from 5:00 to 9:00 a.m. was 2.2%. Speed levels during the same time periods increased from 47.2 mph to 48.5 mph at α = 1%. Driver compliance level which was determined by correlating the speed differences upstream and downstream of the speed limit signs showed compliance levels between 20% to 60%.

Pesti et. al (2004) [(75)] evaluated the effect of condition-responsive advisory speed messages on vehicle speeds in advance of work zones on a rural interstate highway in Nebraska. Although not a true variable speed limit deployment, the Work Zone Speed Advisory System (WZSAS) provided real-time speed advisory information to drivers by means of portable changeable message signs with the objective to encourage diversion to alternate roués when the work zone was under congested conditions. The WZSAS included: (1) a video detection system, (2) two portable Changeable Message Signs (CMSs), and (3) a control system. Speeds were measured at two locations upstream of the work zone using the video detection system. An average of the measured speeds was then displayed on two portable CMSs located at upstream points in advance of the work zone.

Changeable message signs were placed on the shoulders of the roadway at two locations upstream of the work zone. One sign was located 4.5 miles in advance of the work zone and 1.6 miles in advance of an exit from the roadway. The second CMS was located 6.8 miles upstream of the work zone and 3.8 miles in advance of an exit. When the average speed in the work zone went below 55 mph, the CMS signs were activated. The activated signs used the message " I-680 SPEED ADVISORY" on the first sign and " AVERAGE SPEED XX MPH" on the second sign.

To evaluate the WZSAS, traffic speed and volume data were collected using the video detection system at two locations in advance of the WZSAS system. Volume data were also collected using tube counters at an exit ramp upstream of the WZSAS system. Data were collected for four weeks without the WZSAS and four weeks using the WZSAS.

A comparison was made of traffic demands before and after the deployment of the WZSAS to determine the extent of diversion. The study showed no significant change in total peak period demand flows in response to the speed messages with no significant increase in vehicle diversion. The researchers conclude this system may have been more effective under heavier traffic demands and more severe congestion.

Perceptual Countermeasures

Perceptual countermeasures have been used as a means of reducing speeds in a variety of settings including within work zones. Perceptual countermeasures can be defined as "…manipulations of the roadway or roadside environment designed to increase drivers' estimation or feeling of speed" (Allpress, 2010) [(76)]. The intent is to lead to an increased sense of danger with a resulting reduction in speed. Two types of perceptual countermeasures were studied within work zones. The following describes the impact of these measures on reducing speeds in work zones. Table 9 identifies two studies performed of the use of perceptual countermeasures in work zones.

Table 9. Summary of Literature on Perceptual Countermeasures in Work Zones

Author	Location	Device
Allpress (2010) [76]	New Zealand	Traffic Cone Placement
Meyer (1999) [77]	Kansas	Optical Speed Bar

Cone Placement

Allpress et. al (2010) [76] investigated the use of perceptual countermeasures as a means for reducing speeds within work zones. The study tested the effectiveness of two different arrangements of traffic cones placed at the entrance to a highway work zone to reduce speeds. In the study, work zones drivers were required to reduce their speeds from 100 km/h to 50 km/h (60 mi/hr to 30 mi/hr). Drivers were required to pass through a 3.5 m (11.5 ft) wide passage of evenly or decreasingly spaced cones. Figure 4 shows the work site layout and Figure 5 shows the cone arrangement used in the study.

Data were collected on the Flood Free Highway in New Zealand. The roadway has a normal operating speed limit of 100 km/h (62 mph) but was reduced to 50 km/h (31 mph) during the construction period. Vehicular speed, headway and time of day were recorded using Metrocount 5600 Series Vehicle Classifier System traffic-counting devices. These devices consist of two pneumatic tubes, spaced 1m apart. Data were collected at three counter locations as shown in Figure 4. Counter 1 measured speeds prior to the work zone, counter 2 was installed at the start of the roadwork site, 75 m after the initial 50 km/h speed restriction sign and directly after travelling through the cone arrangements. Counter three measured speeds after the vehicle traveled a considerable distance through the work zone.

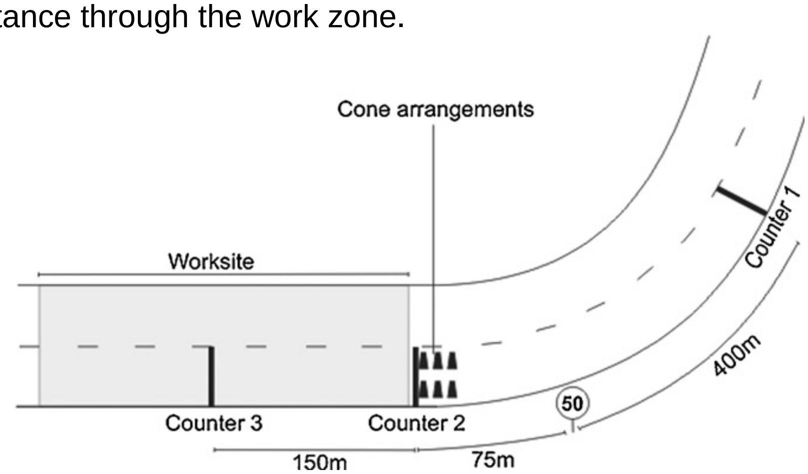


Figure 4. Worksite Layout (Allpress, 2010) [76]

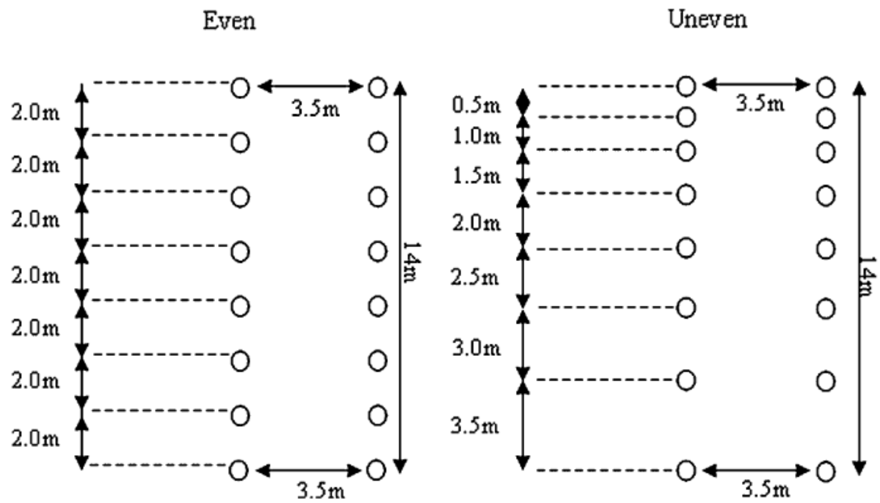


Figure 5. Cone Arrangement (Allpress, 2010) (76)

The study found that both the evenly spaced and the decreasingly spaced cones were effective in reducing speeds. The unevenly spaced cones had the largest reduction in speed of 9.47 km/h (6 mph). The study found that not only were vehicles passing through cones traveling slower, but the slower speeds were maintained 150 m into the work site. At this location, vehicles were still traveling 3.8 km/h slower than the baseline. The cone arrangements also reduced the proportion of speeding vehicles traveling equal to, or greater than, 70 km/h.

Optical Speed Bars

Meyer (1999) (77) examined the use of optical speed bars to reduce speeds and speed variations in highway work zones. Optical speed bars refer to a traffic control device that consists of a series of transverse stripes that are spaced at gradually decreasing distances and give the driver an increased perception of speed resulting in slower speeds. The exact reasoning why optical speed bars influence speed is uncertain, however, the impact of these devices on reducing speed is significant.

There are several patterns of optical speed bars used including straight bars and chevron designed bars. To better understand the relationship between the patterns used and the impact of speed, the Kansas Department of Transportation tested various optical speed bar designs in a construction project. The test patterns, which are shown in Figure 6, included: a leading pattern, a primary pattern, and a work zone pattern.

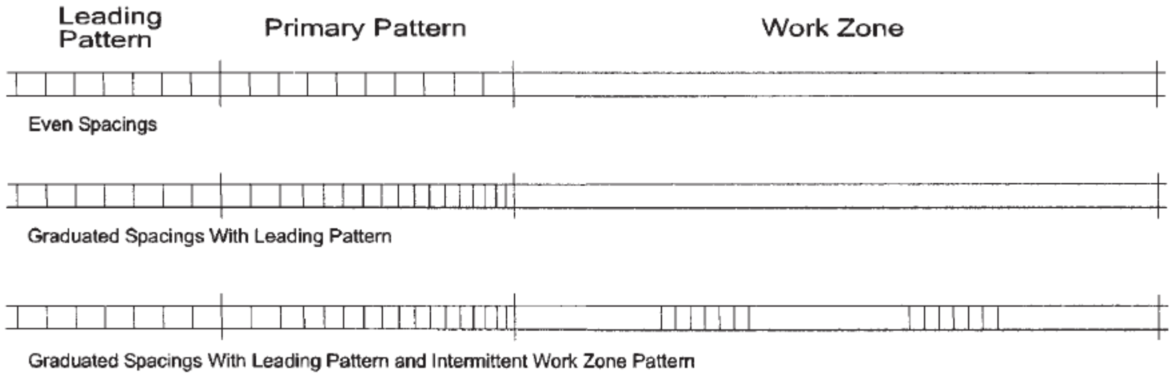


Figure 6. Optical Speed Bar Test Pattern (Meyer, 1999) [77]

The work zone pattern consists of four 30.5 m (100ft) uniform patterns, spaced 152.5 m (500 ft) apart. Speeds were collected at the beginning, end and midpoint of the work zone pattern. Simulation was used to evaluate the performance of the test patterns. An application of the optical speed bars performed in 2004 showed reductions in the mean and 85th percentile speeds (Meyer, 2004) [78]. The magnitudes of the reductions, however, were small but statistically significant (95% confidence level). Despite the significance, the reductions were too small to be of practical significance.

Crash Analyses Literature Review

Much of the U.S. highway infrastructure is aging, and the need for maintenance, rehabilitation, and upgrading of the existing networks increases. Consequently, road users are increasingly exposed to work zone activities. Nationally, about 23,745 miles of federally-aided roadway improvement projects were underway annually from 1997 to 2001. [1] On average, motorists encountered an active work zone for every 100 miles driven on the national highway system.[2] The number can be much larger considering other work zones deployed on municipal, county, and state roads.

The presence of so many work zones directly affects the safety of road users and highway workers. According to the latest safety statistics, 667 work zone fatalities occurred in the United States in 2009. Approximately 85 percent of those killed in work zone were drivers and passengers, and the remaining 15 percent were workers. In addition to these fatalities, more than 40,000 injuries resulted from motor vehicle crashes in work zones.[1] As shown by many studies [see reference 3–13], crash rates increase in the presence of work zones compared to the normal road conditions. This rise can be attributable to the complexity of the work zone circumstance that interrupts continuing traffic flow and creates many traffic conflicts. However, precise reasons why more crashes occur at work zones may still not be clear. A complete understanding of the risk factors associated with work zone crash occurrence is essential for the development of effective temporary traffic control countermeasures to reduce the number of fatalities and injuries and to enhance traffic operation and safety within work zones. However, many site- and state-specific factors need to be further analyzed to better understand the reasons for work zone accidents.

The purpose of this study is to identify the potential contributory factors that affect the safety performance of work zones in New Jersey. We carefully analyzed work zone crash data obtained from the crash database of New Jersey Department of Transportation (NJDOT). The database provides comprehensive information about work zone–related accidents in the state. A number of fields in the database can be used to explore factors that may contribute to work zone safety (see Appendix A). In addition, a relatively large amount of detailed work zone project files were obtained to further examine factors that cannot be addressed using crash data only.

The research team uses the aforementioned data as well as other available data sources and statistical methods to explore work zone safety issues in New Jersey. The major tasks involved in the study to achieve the goal are summarized as follows:

- **Comprehensive review of previous research.** Previous research provides support for efficiently conducting our study as they suggest hints on what kind of safety issues may exists at work zones, which factors may affect the safety performance, and what kind of countermeasures may be used, and so on. Particularly, we examined studies that were focused on descriptive analysis of individual factors, and studies on work zone crash frequency and injury severity modeling.

- **Descriptive analysis of work zone crashes.** Most of the studies dealing with work zone safety depend heavily on descriptive analysis [(See references 13–24)]. Such analysis is a useful way to study safety at work zones, but statistically robust and comparative analysis was also conducted in the current study. Factors that may contribute to work zone crash occurrence and crash severity are individually examined. Some special factors and characteristics, such as crash distribution within work zones, were also explored based on detailed work zone information.

- **Statistical modeling of work zone crash data.** The best way to identify causal relationships between accidents and factors likely to affect their occurrence and severity is to estimate models that clearly identify these relationships. This study focused on the development of work zone crash frequency (CF) models as well as severity models. Both traditional and improved modeling techniques are applied and compared for the frequency models. Different levels of severity models are also developed.

- **Recommendations.** Based on the above-mentioned multistep analysis and modeling of the work zone crash data, recommendations about the most likely reasons affecting accidents can be made at a given level of statistical significance. Moreover, the developed models can be used to quantify the effect of reducing certain factors on both the frequency and severity of work zone crashes.

The next section provides a detailed overview of related research and examines the need for this study. This section is followed by the descriptive analysis. The CF models and severity models are then developed, and their results are separately presented and discussed. Finally, the findings are concluded and recommendations are presented.

Review of Studies on Descriptive Analysis of Work Zone Crashes

The majority of the previous research conducted on work zone accidents focused on the descriptive statistics of work zone crash data to determine the relationship among work zone and crash severity, crash rate, type, location, and other factors. Table 10 summarizes some of the reviewed studies that use work zone crash data for descriptive statistical analysis. We also provide a short discussion of each factor based on the review of the literature.

Table 10. List of Reviewed Work Zone Studies Using Descriptive Statistics

Authors	**Study Area**	**Number of Sites**	**Number of Crashes**	**Issue**
Rouphail et al. (1988)[14]	Illinois	Three long term and 23 short term	–	Short-term work zones
Hall and Lorenz (1989)[15]	New Mexico	114	–	Accident rates
Pigman and Agent (1990)[16]	Kentucky	–	2013	Accident rates
Daniel et al. (2000)[17]	Georgia	–	181	Crash characteristics
Zhao and Garber (2001; 2002)[18, 19]	Virginia	–	1484	Crash location
Chambless et al. (2002)[20]	Alabama, Michigan, and Tennessee	–	–	Crash characteristics
Shrock et al. (2004)[21]	Texas	77	–	Fatal work zone crash characteristics
Arditi et al. (2007)[22]	Illinois	–	121	Crash time
Ullman et al. (2008)[13]	New York, California, North Carolina, Ohio, Washington	–	20462	Crash time
Jin et al. (2008)[23]	Utah	202	–	Crashes by highway type
Dissanayake and Akepati (2009)[24]	Iowa, Kansas, Missouri, Nebraska, Wisconsin	–	–	Crash Location

Crash Severity

Crash records provide information about the consequences of accidents—namely, property damage, injury, and death. This type of information is used in the literature to identify crash severity.

There is no consensus in the literature whether the work zones are a reason for more severe crashes. Some studies reported that work zone crashes were significantly more severe than non–work zone crashes.[16, 19] In contrast, some researchers concluded that there is no significant difference between work zone and regular crashes in terms of severity[15, 20]; in other words, injury and fatal crashes in focused work zones do not differ significantly from injury and fatal crashes in non–work zones. What's more, there are some cases in which work zone crashes were found to be less severe than regular crashes.[14]

Crash Rate

Rouphail et al. (1988)[14] determined that the crash rate increased by an average of 88 percent in the presence of work zones in comparison to the before period and decreased by an average of 34 percent in the after period. For short-term work zone sites, a constant accident rate of 0.80 crashes per mile-day of construction or maintenance was observed in the same study. Hall and Lorenz (1989)[15] found that the crash rate increased by 26 percent during the construction period. Garber and Woo (1990)[5] reported that the crash rates at work zones on multilane highways in Virginia increased on the average by 57 percent, and the crashes at work zones on two-lane urban highways in Virginia increased about 168 percent on the average. The research by Pigman and Agent (1990)[16] also shows increasing crash rates in work zones (14 out of 19 work zone sites experienced increasing crash rates compared to the before period). Contrary to other studies described above, Jin et al. (2008)[23] observed lower crash rates during construction periods on Urban non-interstate highways in Utah.

Crash Location

In a work zone, a crash might occur in one of five locations: advance warning area, transition area, buffer area, work area, or termination area (see Figure 7). Zhao and Garber (2001)[18] and Garber and Zhao (2002)[19] found that the activity area is the most predominant location, whereas the termination area is the safest location in a work zone. The study by Pigman and Agent (1990)[16] concluded that the most predominant crash location is the advance warning area. The studies described above clearly show that there is a need to address specific locations within the work zone to better identify the crash factors.

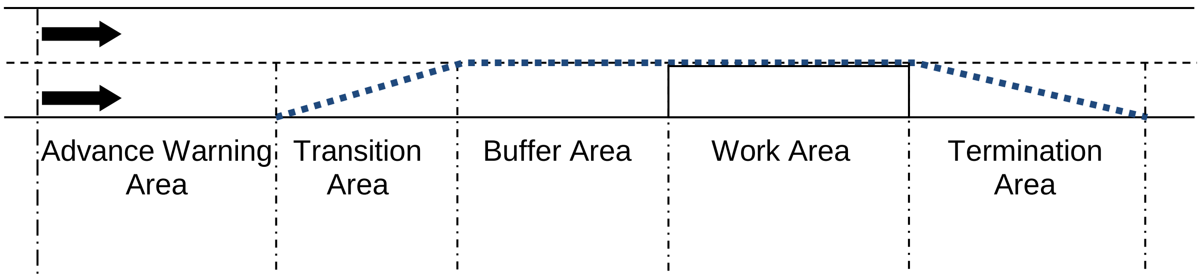


Figure 7. Component Segments of the Work Zone

Rural interstate[16, 20] was found to be more prone to work zone crashes. In contrast to this finding, Garber and Zhao (2002)[19] claimed that urban highways had a much higher percentage of work zone crashes than rural highways. Jin et al. (2008)[23] reported that the effect of highway class is not statistically significant in terms of the difference of mean crash rates during construction and non-construction.

Crash Time

The research by Arditi et al. (2007)[22] concludes that nighttime construction is nearly five times more dangerous than daytime construction. In contrast, Dissanayake and Akepati (2009)[24] concluded that most work zone crashes occurred in clear daylight conditions and no adverse weather conditions. Ullman et al. (2008)[13] examined the safety of nighttime and daytime work zones using a different approach. Unlike the traditional approach of normalizing crashes based on vehicular miles, they considered increased crash risk to all drivers as a comparative measure. According to their approach, “higher traffic volumes during the day mean that the same number of crashes will produce a much lower crash rate per million-vehicle-miles (mvm).” They found that nighttime work zones do not have greater crash risk for an individual driver than daytime work zones. They also found percentage increases in crash risk at work zones requiring temporary lane closure were the same during day and night.

Crash Type

There is strong agreement in the literature that rear-end crashes are the most frequent work zone crash type.[see references 5, 14, 15, 16, 19, 20, and 25] Daniel et al. (2000)[17] found that single-vehicle crashes, angle, and head-on crashes were the leading cause of fatal work zone crashes. Another important issue is truck involvement in work zone crashes. Researchers found that heavy truck–related crashes increased the probability of multiple vehicle involvement and fatalities in a work zone crash.[16, 21]

Other Factors

Bryden et al. (1998)[26] found that one-third of all work zone accidents involved impacts with work zone traffic control devices and safety features introduced into the roadway environment by construction activity; 37 percent of those accidents caused serious injury. Daniel et al. (2000)[17] found that fatal work zone crashes are affected by variables such as the type of collision, light conditions, truck involvement, and roadway functional classification. Schrock et al. (2004)[21] found that the key variables contributing to fatal work zone crashes are roadway type, weather and lighting conditions, alcohol or drug use, and truck involvement. In 8 percent of the investigated crashes, the work zone had a direct influence (such as improper traffic plan layout or a missing traffic control device), whereas the work zone had an indirect influence (such as a vehicle struck a traffic control device) in 39 percent of the crashes. In addition, work zones have no influence on 45 percent of the crashes. The study by Dissanayake and Akepati (2009)[24] analyzed several crash characteristics, such as injury severities, weather conditions, vehicle characteristics, roadway characteristics, vehicle maneuvers, and alcohol involvement. They reported that most of the crashes in work zones occurred because of the absence of traffic control devices, and "*the top three driver-contributing factors to crashes were inattentive driving, exceeding the speed limit or driving too fast for conditions, and failing to yield right of way*."

Data-collection Issues

Some of the work zone safety studies also pointed to issues about data needs. They recommended the inclusion of the work zone–related variables summarized in Table 11:

Table 11. Suggested Variables in the Literature for Inclusion in Crash Databases

Variable	Wang et al. (1996)[25]	Garber and Zhao (2001)[19]	MMUCC (2008)[27]
Configuration of work zone		*	
Law enforcement presence			*
Location of crash	*	*	*
Posted speed limit		*	
Type of work zone	*		*
Near the work zone?			*
Worker involvement in a crash		*	
Worker presence activity	*	*	*

The NJ Crash Database and Straight Line Diagrams provide most of the critical information needed to conduct a descriptive analysis of work zone crashes. Table 12 presents the comparison of the variables used in some of the previous studies.

Crash Statistics	**Garber & Zhao (2001; 2002)[18, 19]**	**Chambless et al. (2002)[20]**	**Schrock et al. (2004)[21]**	**Arditi et al. (2007)[22]**	**Ullman et al. (2008)[13]**	**Dissanayake et al. (2009)[24]**
Roadway type	X	X	X			
Rural/urban		X				
Weather conditions			X	X		X
Lighting conditions			X	X		X
Alcohol involvement			X			
Large truck inv.	X		X			
Work zone location	X		X			
Activity type			X	X		
Collision type	X				X	
Crash time	X	X			X	
Single and multiple veh.	X					X
Primary crash cause		X				X
Posted speed limit		X				X
Persons involved				X		
Number of work zones				X		
Traffic control cond.					X	X
Annual average daily traffic (AADT)				X	X	
Maneuver before crash						X
Vehicle type						X

Table 12. Comparison of Descriptive Crash Statistics

Crash Statistics	**Garber & Zhao (2001; 2002)**[18, 19]	**Chambless et al. (2002)**[20]	**Schrock et al. (2004)**[21]	**Arditi et al. (2007)**[22]	**Ullman et al. (2008)**[13]	**Dissanayake et al. (2009)**[24]
Roadway type	X	X	X			
Rural/urban		X				
Weather conditions			X	X		X
Lighting conditions			X	X		X
Alcohol involvement			X			
Large truck inv.	X		X			
Work zone location	X		X			
Activity type			X	X		
Collision type	X				X	
Crash time	X	X			X	
Single and multiple veh.	X					X
Primary crash cause		X				X
Posted speed limit		X				X
Persons involved				X		
Number of work zones				X		
Traffic control cond.					X	X
Annual average daily traffic (AADT)				X	X	
Maneuver before crash						X
Vehicle type						X

Review of Work Zone Crash Frequency Modeling

Although CF models have been extensively used in road safety analysis, only a few studies have specifically focused on modeling work zone crash occurrence.[see references 7–11, and 28] Several statistical techniques have been employed to analyze CF among these existing studies. For instance, a few studies developed negative regression (NB) models to predict the expected number of crashes.[see references 8–10,28] Pal and Sinha (1996)[7] also modeled crashes at interstate work zones in Indiana and found that a normal regression model outperformed the classical NB and Poisson models. Similarly, Qi et al. (2005)[11] constructed the truncated NB regression model and truncated Poisson regression model to analyze the rear-end crashes at work zones in New York. The truncated NB regression model was found to have better predictive power. Other than these empirical models, Elias and Herbsman[29] used the Monte Carlo simulation approach to develop a crash rate probability distribution function that considered the intrinsic scarcity of work zone crash data. Despite model differences, factors most commonly found to significantly affect work zone CF included the length of the work zone, duration, and average daily traffic (ADT). Generally, the modeling results showed that work zone CF increased with increasing ADT, duration, and work zone length.

A possible reason why few studies explored the casual factors associated with work zone CF is the deficiencies of work zone data, as stated in Pal and Sinha (1996),[7] Wang et al. (1996),[25] Zhao and Garber (2001),[18] and Bourne et al. (2010).[30] For instance, work zone crash data derived from police crash reports were usually subject to a number of uncertainties.[25] Explanatory variables such as ADT, work zone length, and duration were also found to be subject to measurement errors. For example, the presence of significant bias was found when using the estimated ADT instead of the actual volume during work zone conditions.[8,9,10] Problems in defining the length of certain work zones, such as bridge works and those involving detours, were identified by several studies.[9,25] Moreover, the exact starting date or ending date of a specific work zone may not be readily available to calculate the duration of that work zone project.[9] If work zone data with deficiencies were used to develop predictive models, such models would clearly lead to biased estimates of the parameters. Therefore, to develop more reliable models, measurement errors associated with work zone data should also be carefully addressed.

Review of Work Zone Crash Severity Modeling

A limited number of studies have specifically modeled links between work zone crash attributes and the severity levels road users have sustained.[see references 11,31–41] These studies have (partially) investigated the effect of user attributes, road conditions, environmental conditions, vehicle characteristics, crash characteristics, and work zone configurations on work zone crash severity. Table 13 provides a summary of these modeling studies. Depending on the objective, the unit of analysis varies across studies and includes crash level of severity, vehicle level of severity, driver severity, and occupant severity. In most modeling efforts, severity is categorized as an ordinal dependent variable of multiple levels (no injury, injury, and fatal). Advanced statistical techniques have been employed to analyze the links among crash severity and other, related independent variables. As seen from Table 13, the popular methods used in crash severity analysis concentrated on logistic regression (LR) for fatality analysis and ordered probit (OP) modeling for the multiple-level injury spectrum.

Injury severity of work zone crash is determined by several factors, mentioned above. Findings from literature synthesis are, to a large extent, consistent. Factors most commonly found to increase work zone crash severity include high speed limit in the work zone,[see references 31,32,34,35,38–41] driving at night time[see references 11,32,34,35,and 41] driving under influence of alcohol or drugs,[11] vehicle age,[40,41] the number of vehicles and people involved in the crash,[11,31,32] and truck-involved crashes.[see references 11,34,35,41] In contrast, the deployment of safety equipment such as seat belts and airbags appears to significantly decrease the level of injury severity.[see references 38, 40 and 41] In addition, work zones with flagger control reduced the level of injury severity.[11,34] Interestingly, adverse weather was also found to decrease the level of injury severity.[31,38,41]

However, studies also report conflicting findings on factors such as light condition, user age, gender, and number of lanes. For instance, Li and Bai (2008, 2009)[34,35] found that poor light conditions increased the level of injury severity, while others that good light conditions may increase it.[38,41] Li and Bai (2008, 2009)[34,35] concluded that male drivers are associated with increased crash severity, while Weng and Meng (2011)[41] suggested the opposite for construction and utility work zones. Akepati and Dissanayake (2011)[38] observed that young drivers are associated with higher-severity crashes, but Li and Bai (2008, 2009)[34,35] and Weng and Meng (2011)[41] both reported the opposite. Elghamrawy (2011)[39] and Weng and Meng (2011)[41] both found that crash injury severity positively correlated with the number of lanes, whereas Li and Bai (2008)[34] and Meng and Weng (2011)[40] found a negative correlation between severity and the number of lanes.

Based on our review of previous research, significant gaps remain in understanding the relationships between work zone crash injury severities and potential risk factors. For instance, little has been noted on the comparisons between different victims (driver vs. occupant) involved in a crash in a work zone. Different roles between driver and occupants in a vehicle determine the dissimilarity of consequences suffered in the crash. Therefore, understanding the differences in risk factors between driver and occupants is valuable for constructing effective safety strategies toward specific users.

Table 13. Summary of Work Zone Crash Injury Severity Modeling Studies

Category	Reference	Khattak & Targa (32)	Qi et al. (11)	Li & Bai (33,34,35)	See et al. (36)	Elghamrawy (39)	Khattak et al. (31)	Weng & Meng (41)	Akepati & Dissanayake (38)	Meng et al. (37)	Meng & Weng (40)
	Methodology	OP, OLS	OP	LR	LR	OL	OP, OLS	LR	OP	QRA	LR, GA
	Unit of analysis	Crash Level	Crash Level	Crash Level	Crash Level	Crash Level	Crash/Vehicle Level	Driver Level	Driver Level	Occupant Level	Occupant Level
Timeline	Time of day			X	X	X					
	Day of week			X				X			
Environmental conditions	Light condition	X		X		X	X	X	X	X	X
	Weather condition	X		X	X	X	X	X	X		X
	Road surface condition			X		X		X	X		X
Road conditions	Road class		X	X		X					
	Road alignment			X	X			X			
	Roadway divided by median	X				X	X				
	Median width						X				
	Road surface type			X							
	Number of lanes			X		X		X			X
	Lane width					X					
	Posted speed limit	X		X		X	X	X	X		X
	Area information		X	X	X						
	Road special feature			X		X					
	ADT				X	X					
Road user attributes	Driver age			X			X	X	X		
	Driver gender			X			X	X	X		
	Driver race						X				
	Driver vision obstruction						X				
	Occupant age									X	
	Occupant gender										X
	Driver license state										
	Driving under the influence						X				
	Seat position										X
Vehicle characteristics	Vehicle type						X		X	X	
	Vehicle age							X			X
	Traveling speed						X				X
Work zone information	Type of work zone	X	X			X	X	X			
	Traffic control	X	X	X		X	X	X	X		X
	Workers present								X		
	Work zone activity	X					X				X
	Work zone duration		X								
	Type of work being done	X	X				X		X		
	Work effect on the roadway	X	X		X		X				
Crash Information	Location within work zone	X	X				X		X		
	Number of vehicles involved	X	X	X			X			X	X
	Number of persons involved	X					X				
	Cell phone use										
	Alcohol consumption				X					X	X
	Truck involved in crash		X	X				X			X
	Light vehicle involved in crash										
	Hazardous material involved										
	Crash type	X					X		X	X	
	Contributing circumstances		X	X					X		X
	Vehicle precrash actions						X		X		X
	First/most harmful event	X					X	X	X		
	Incident location		X	X	X	X			X		X
	Restraint use							X	X		X
	Airbag deployment							X	X		X

Note: LR = logistic regression; OP = ordered probit model; OL = ordered logit model; OLS = ordinal least squares model; QRA = quantitative risk assessment; GA = genetic algorithm

DESCRIPTIVE ANALYSIS OF NJ WORK ZONE CRASH DATA

Brief Introduction

Crash data used in subsequent analysis were obtained from the crash database of NJDOT. Crash-related attributes, including roadway characteristics, environmental conditions, crash characteristics, driver information, vehicle information, and occupant information, are collected for each crash in the database. The original data are kept in four separate tables: an accident table (crash summary), a driver table (driver information), a vehicle table (vehicle information), and an occupant table (occupant information). In the accident table, each crash is described by a single data row regardless of the number of vehicles involved. The other three tables contain information about each individual (vehicle or person) in a row, because multiple vehicles, drivers, or occupants may be involved in the same crash. A unique case number is shared among these tables to link essential information about the crash, drivers, vehicles, and occupants involved in the same crash.

A column in the accident table identifies whether a crash occurred at a temporary traffic control zone. The temporary traffic control zone is further divided into five categories, as shown in Table 14. In this preliminary analysis, a *work zone crash* is defined as a construction, maintenance zone, or utility zone crash. Therefore, the crashes with code state 2, 3, and 4 were extracted for analysis.

Table 14. Types of Work Zone Records in the New Jersey Crash Database

Code State	Explanation
1	No
2	Yes: Construction zone
3	Yes: Maintenance zone
4	Yes: Utility zone
5	Yes: Incident zone

Each type of work zone is defined as follows:

- **Construction zone.** A *construction zone* is defined as a roadway construction zone that displays signs warning of construction lasting longer than one day. The construction zone begins at the first construction sign and ends at the last sign, as per *Manual on Uniform Traffic Control Devices* part VI.
- **Maintenance zone.** A *maintenance zone* is defined as any short-term work zone set up for one day or less.
- **Utility zone.** A utility zone is either a construction or maintenance zone established by any public or private utility.

The frequency and severity characteristics of work zone crashes that occurred between 2004 and 2010 are explored in the following two sections, respectively.

Frequency Descriptive Analysis

New Jersey work zone accident frequency and related parameters are described in order—time of occurrence, spatial information, seasonal information, and light condition information—of work zone crashes for 2004 to 2010.

Crash Frequency by Temporal Information

Annual work zone accidents between 2004 and 2010 are shown in Figure 8. The average yearly work zone crash number for the given period is about 5,601. The lowest number of work zone crashes occurred during 2005. The largest number of work zone crashes was observed in 2010. Compared to the average yearly number of work zone crashes, the crashes increased more than 20 percent in the year 2010.

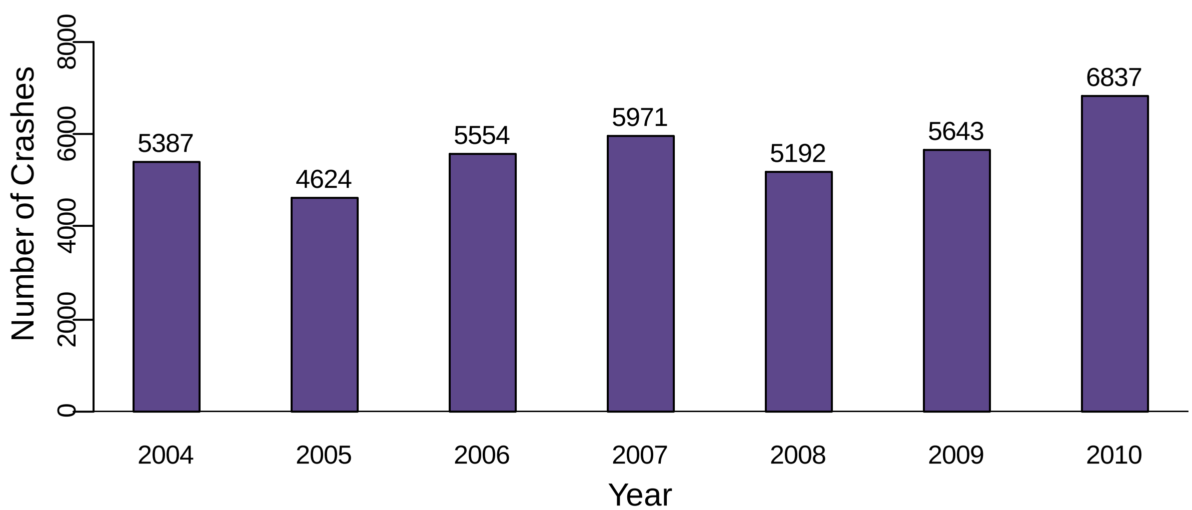


Figure 8. Yearly Distribution of Work Zone Crashes in New Jersey

Monthly distribution of work zone crashes over the studied seven years is shown in Figure 9. The total number of work zone accidents during the winter season is lower than for the other seasons. Minimum numbers are observed for January and February; maximum numbers are observed for August and October. More work zone crashes are expected during the summer and fall seasons, which are convenient for the construction process.

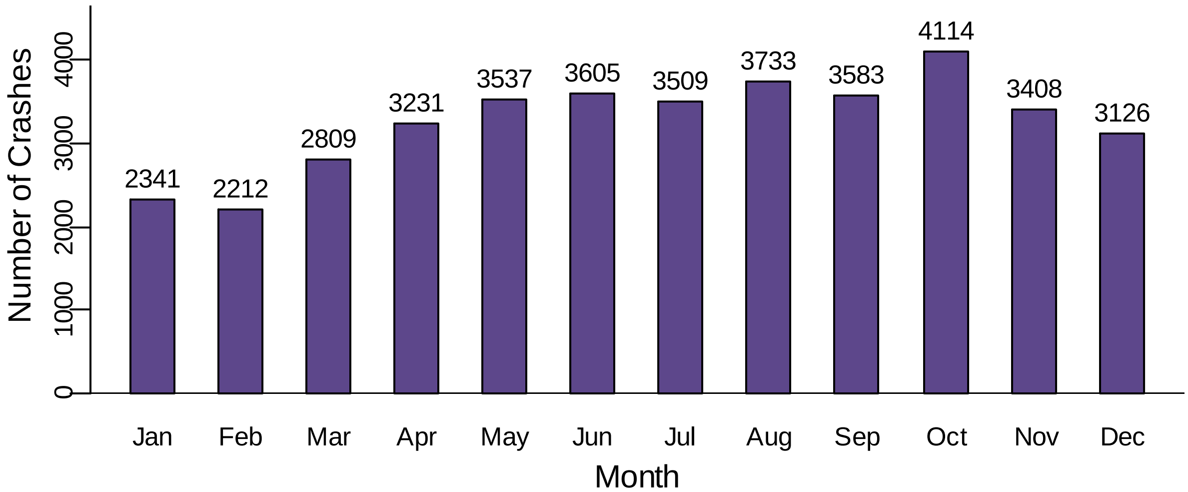


Figure 9. Monthly Distribution of Work Zone Crashes in New Jersey

Figure 10 shows the total number of accidents per day of the week. The number of weekday work zone crashes is significantly higher than weekend work zone crashes. Friday had the greatest number of work zone accidents during the seven-year period.

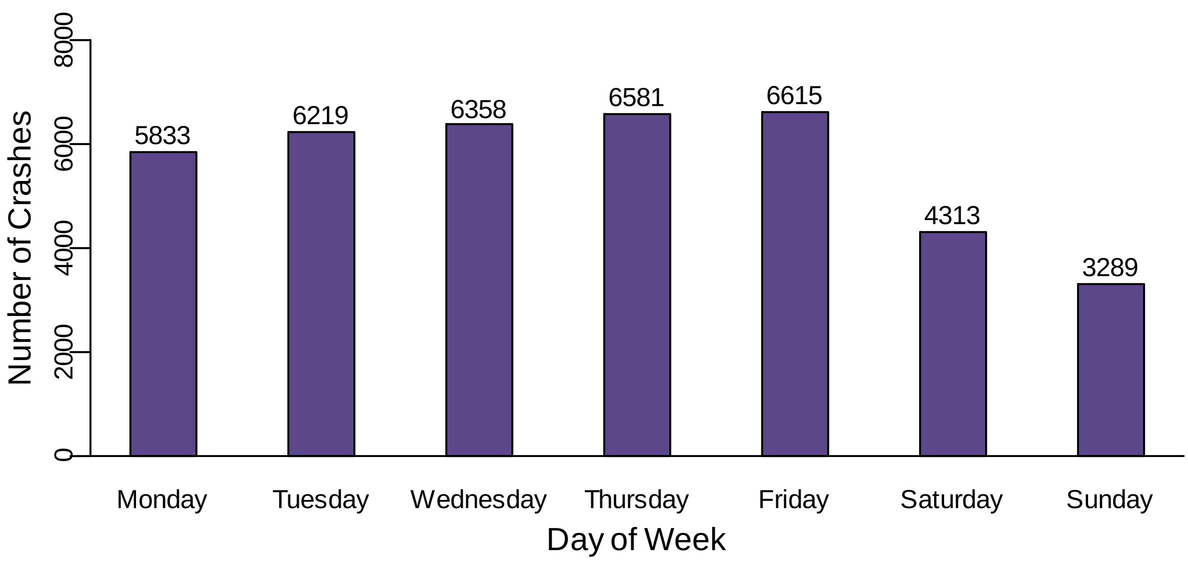


Figure 10. Daily Distribution of Work Zone Crashes in New Jersey

The hourly distribution of all observed work zone crashes is shown in Figure 11. According to the table, 9.3 percent of work zone crashes appeared between hours 0 and 7, 16.4 percent between hours 7 and 10, 39 percent between hours 10 and 16, 18.8 percent between hours 16 and 19, and 15.8 percent between hours 19 and 24. Daytime and off-peak hours are most likely to see more work zone crashes because of the strongest presence of construction during this part of the day. Peak value for the hourly distribution is between 15:00 and 15:59, with 2,762 work zone crashes.

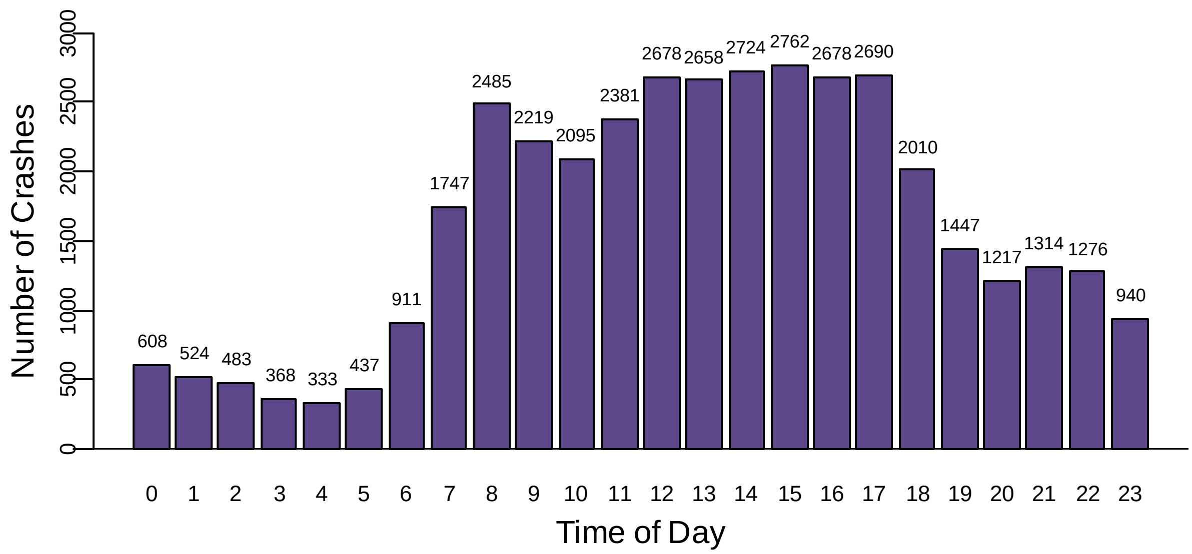


Figure 11. Hourly Distribution of Work zone crashes

Crash Frequency by Crash Types

Rear-end crashes are the most frequent work zone crash type, representing 44 percent of total work zone crashes. Side swipe and fixed-object crashes are also significant types. Crash types are investigated according to the total number of vehicles involved in the work zone accident. Figure 12 shows the distribution of all crash types by the number of crashes.

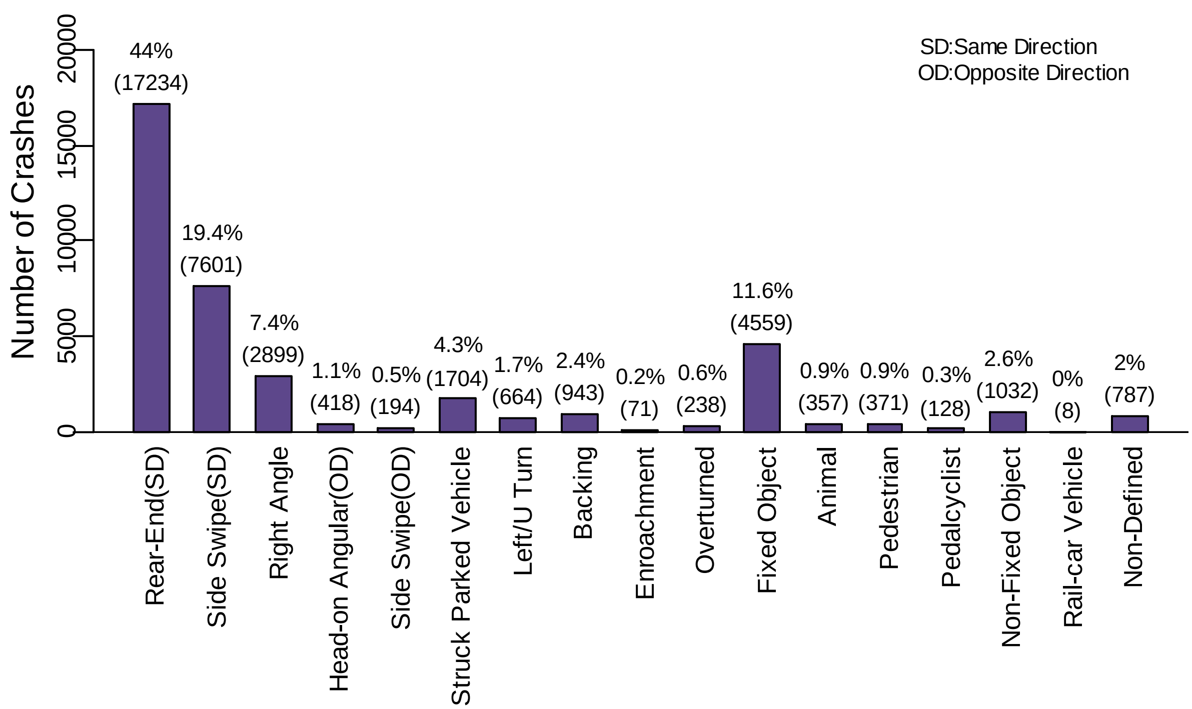


Figure 12. Work zone Crashes by Crash Type

Figure 13 shows the relationship between work zone crash types and the number of vehicles involved in the accident. As is apparent, the distribution of crash types for single-vehicle work zone crashes is completely different from the work zone crashes in which two or more vehicles are involved. Significant crash types for single-vehicle accidents are collision with fixed and non-fixed objects. Most pedestrian and animal accidents are observed in single-vehicle accidents. Accordingly, by increasing the number of vehicles involved in work zone crashes, the rear-end crash percentage increased among other crash types. The side-swipe crash type proportion decreased when three or more vehicles were involved in the work zone accident.

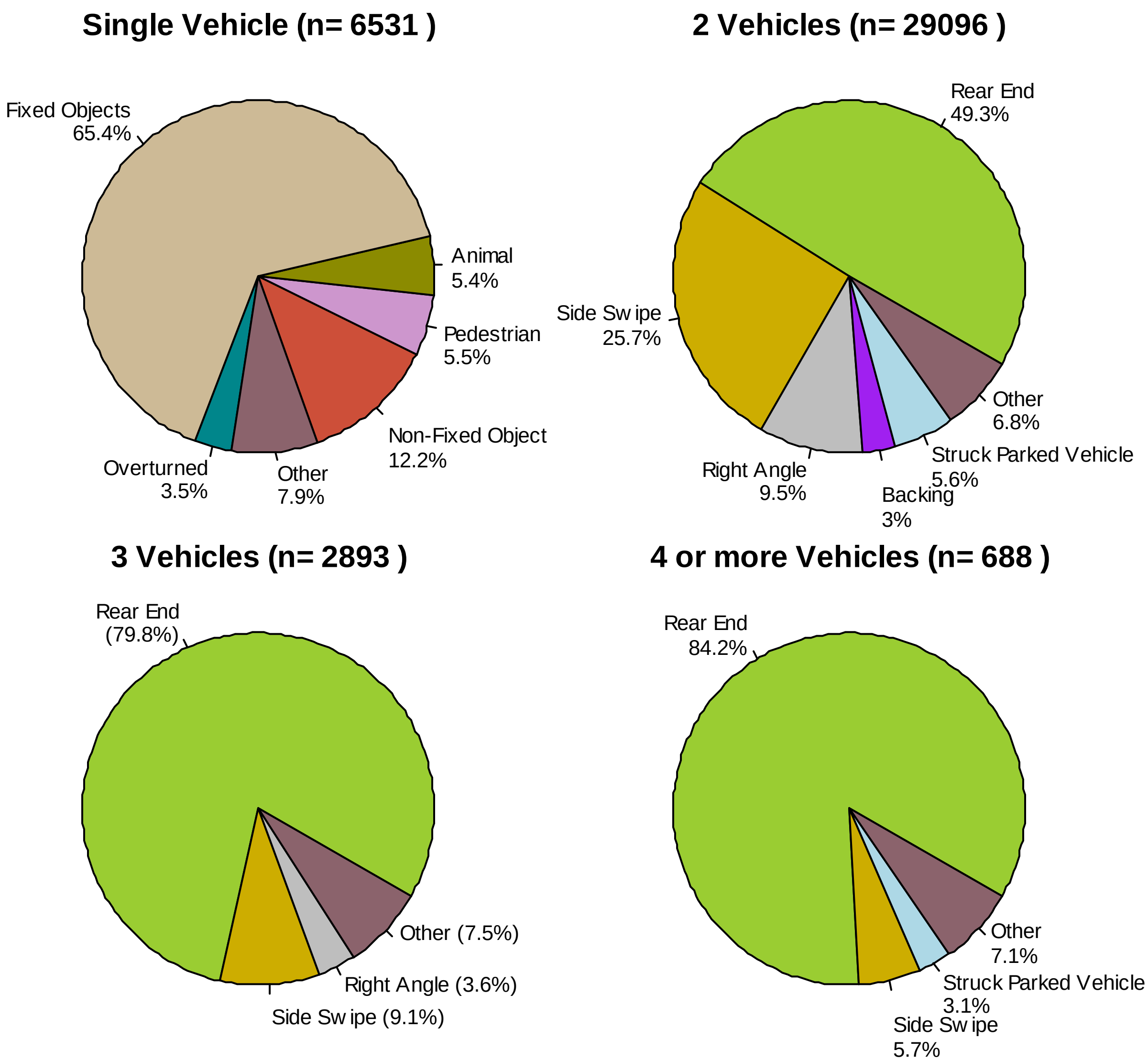


Figure 13. Crash Type by Total Number of Vehicles Involved

Crash Frequency by Road Characteristics

Spatial information for work zone accidents is described in this section according to the road system, posted speed, and road character. The number of accidents and percentage values for each category are shown in Figure 14 and Figure 15.

As shown in Figure 14, state highways and interstate highways take account for 67.2 percent of all work zone accidents in New Jersey.

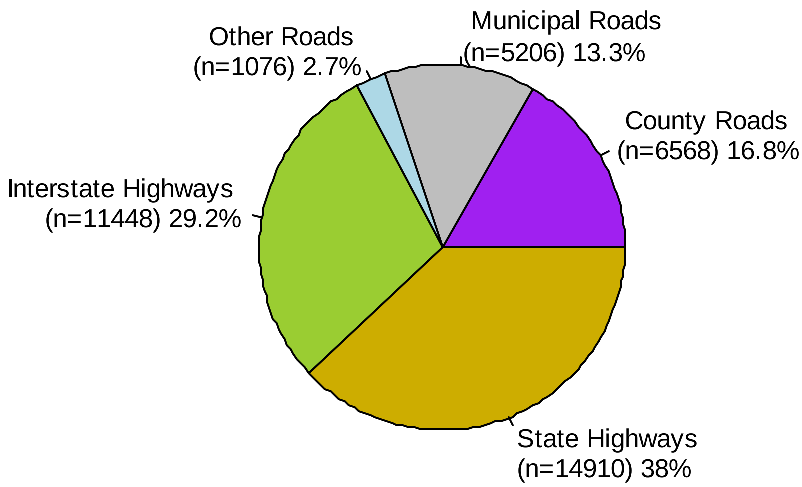


Figure 14. Work Zone Crashes by Road Class

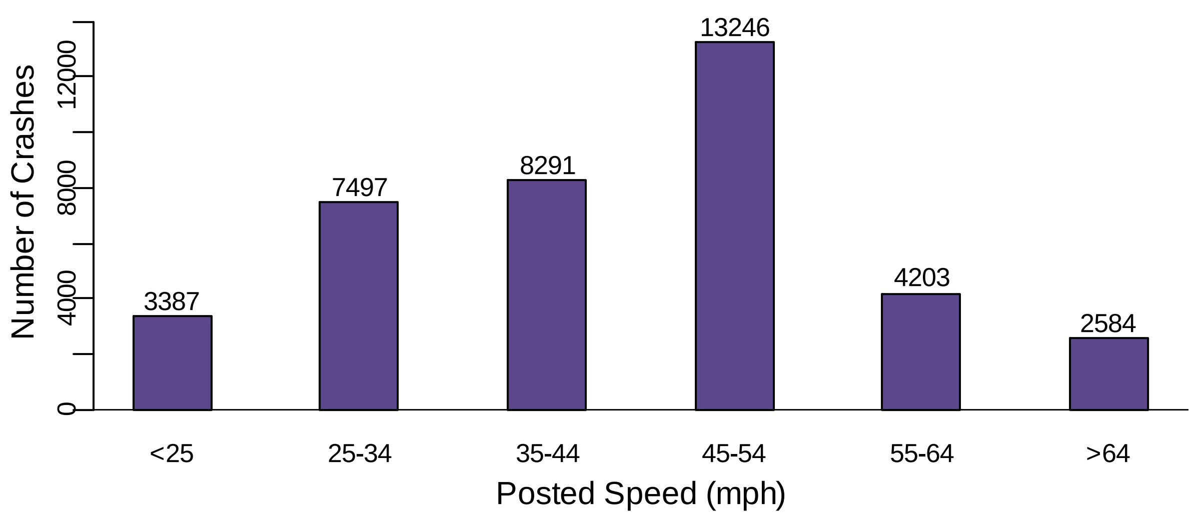


Figure 15. Total Number of Work Zone Crashes by Posted Speed Limit

There is no clear information about posted speed—whether it reflects reduced work zone speed. If the speed limit from the crash records matches the road system information, we may conclude that what is seen on the posted speed is correct. From

Figure 14, the number of work zone crashes on the interstate highways (11,448) is almost twice the number of work zone crashes having a posted speed greater than or equal to 55 mph (6,787). If we consider that the minimum limit is 45 mph for state highways and 55 mph for interstate highways, the over-45 mph percentage should be 67.2 percent. The over-45 mph percentage is 51 percent. We can conclude that the majority of the posted speed information reflects reduced work zone speed (Figure 15).

Road character distribution for work zone accidents is shown in Figure 16. Most of the work zone accidents occurred on straight and level roads. These percentages are related to the distribution of the road character for New Jersey. Road character affects drivers' ability to recognize a work zone visually.

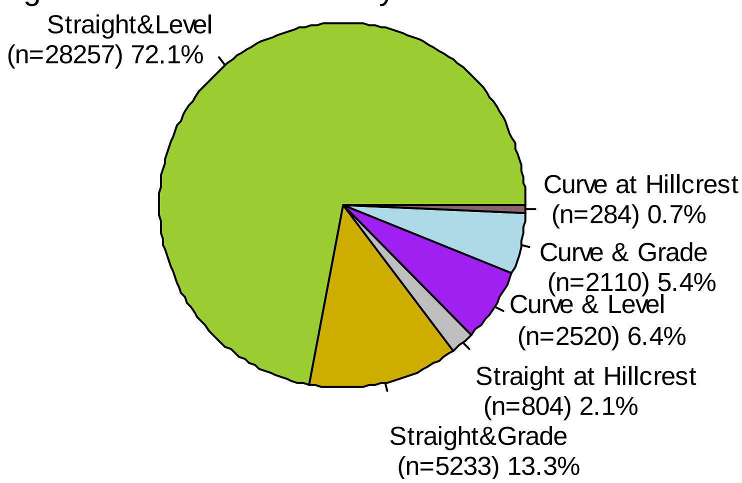


Figure 16. Road Character Distribution for Work Zone Crashes

<u>Crash Frequency by Environmental Conditions</u>

As shown in Figure 17, 71.4 percent of work zone accidents happened in daylight conditions. 18.5 percent crashes occurred when the street lights were turned on. About 10 percent work zone crashes occurred when the light conditions was not good (dawn, dusk, and dark), As Figure 11 showed, most accidents happened during the day, which supports high proportion of work zone crashes during daylight condition.

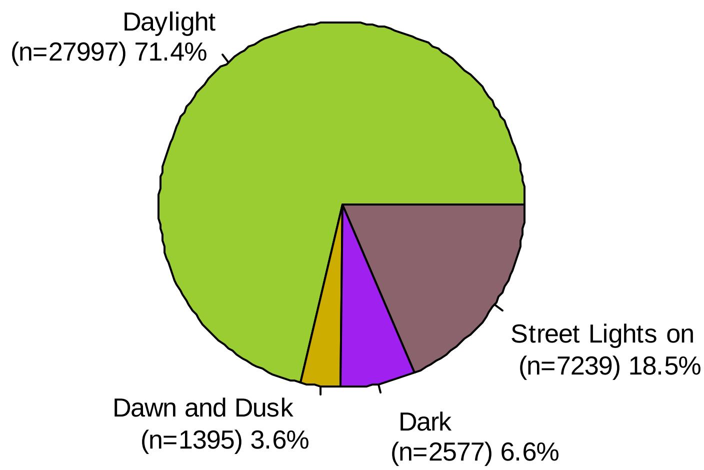


Figure 17. Light Conditions for Work Zone Crashes

Road surface condition distribution for work zone accidents is represented by Figure 18. As shows, most work zone accidents happened on a dry road surface.

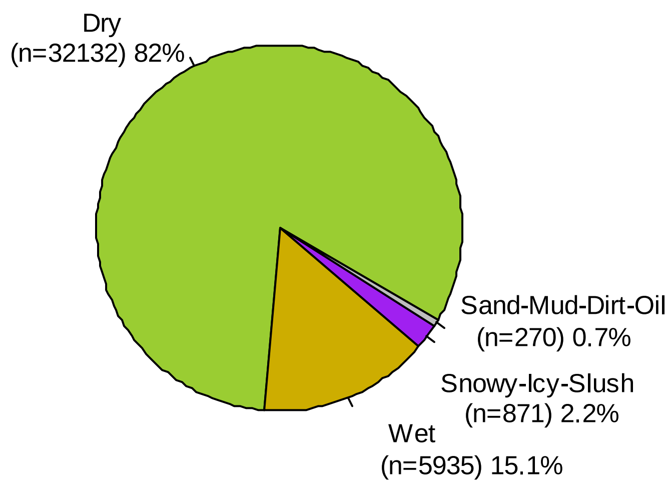


Figure 18. Road Surface Condition for Work Zone Crashes

Weather conditions for work zone crashes are represented by four categories: clear, rainy, overcast, and adverse. Adverse weather conditions are defined as a combination of snow, blowing snow; severe crosswinds; fog, smog, or smoke, sleet, hail, or freezing rain; and blowing sand or dirt. Crash types were investigated for these weather condition categories. Figure 19 shows major crash types for each weather category. “Other” represents an insignificant representation of crash types for specific weather conditions. Interestingly, the rear-end crash ratio decreased from good weather conditions (45.9 percent) to bad weather conditions (27 percent); the fixed-object crash ratio increased from clear weather conditions (9.9 percent) to adverse weather conditions (30.4 percent). The ratio for side-swipe, right-angle, and struck-parked-vehicle crash types were close for all weather conditions.

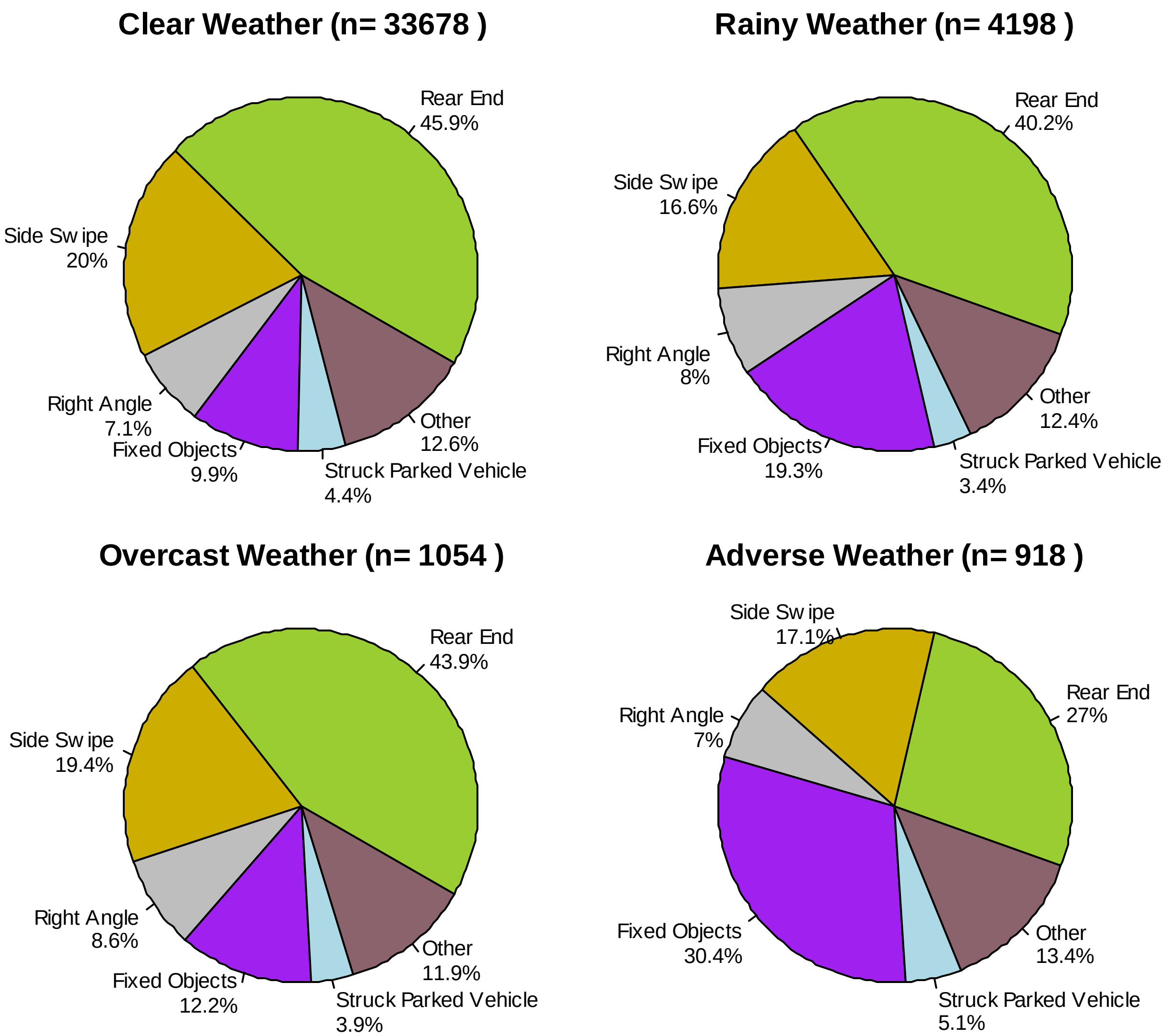


Figure 19. Crash Types for Different Weather Conditions

Severity Descriptive Analysis

To prioritize locations and conditions with the most severe accident occurrences, it is important to classify work zone crashes by severity. Table 15 provides an overview of work zone crashes by severity. Between 2004 and 2010, 39,208 work zone crashes were reported in New Jersey, with 75.8 percent of them property damage only (PDO) crashes, 24.0 percent (9,402) of them involving personal injuries, and 0.2 percent (93) involving fatalities.

Table 15. New Jersey Work Zone Crash Severity Statistics (2004–2010)

Crash Severity	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**
PDO	4024	3450	4102	4619	3957	4294	5267	29713
Personal injury	1354	1158	1438	1341	1223	1336	1552	9402
Fatal	9	16	14	11	12	13	18	93

Although the number of fatalities is relatively low, there are several personal injury crashes. Clearly, it is important first to focus on these crashes to have a better understanding of their causes. Therefore, we studied the characteristics of crash severity in detail. Important contributory factors were examined to guide the development of work zone safety countermeasures in the future.

Severity Distributions by Work Zone Type

Figure 20 shows the breakdown of work zone crashes according to severity and control zone types. Because there is no accurate control zone information for 2004 and 2005 crash records, they are excluded from this analysis. Construction zones are more prone to PDO, injury, and fatal crashes, while maintenance and utility zones experience almost the same level of PDO and injury crashes. Construction zones dominate each type of severity as traffic exposure to more construction zones in the state increases.

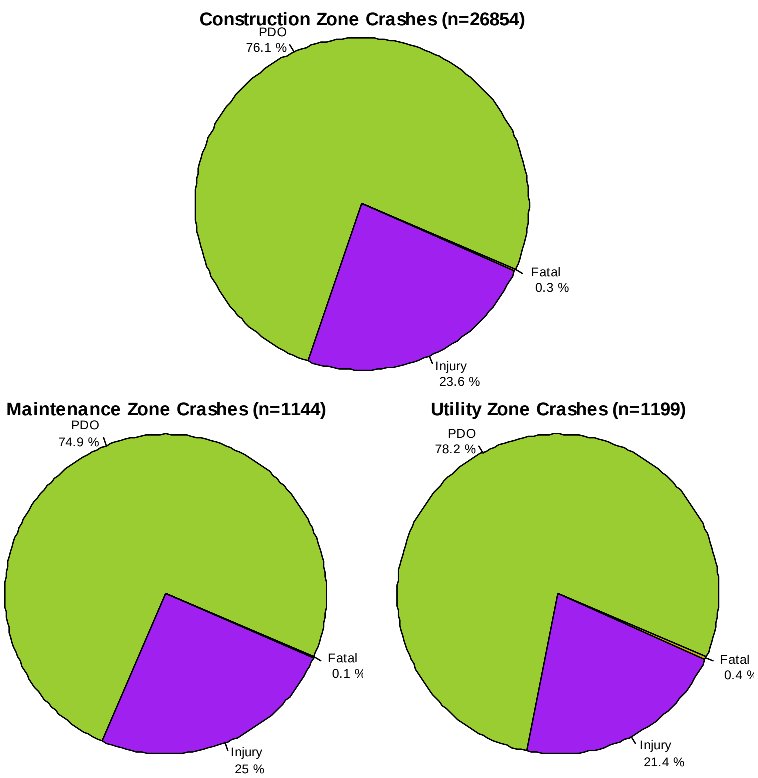


Figure 20. Crash Severity Distributions at Different Work Zones

Severity Distribution by Environmental Condition

Environmental conditions include lighting conditions, weather conditions, and road surface conditions. Figure 21 illustrates the severity distribution of work zone crashes by lighting condition. The greater proportion of injury crashes is likely to occur under poor light conditions such as dawn, dusk, and darkness. The fatal crash portion is 0.6 percent under poor light conditions, which is higher than the 0.1 percent under daylight conditions. Pearson's chi-squared test (χ^2 = 88.609, df = 2) indicated that there is a significant association between crash severity and lighting conditions.

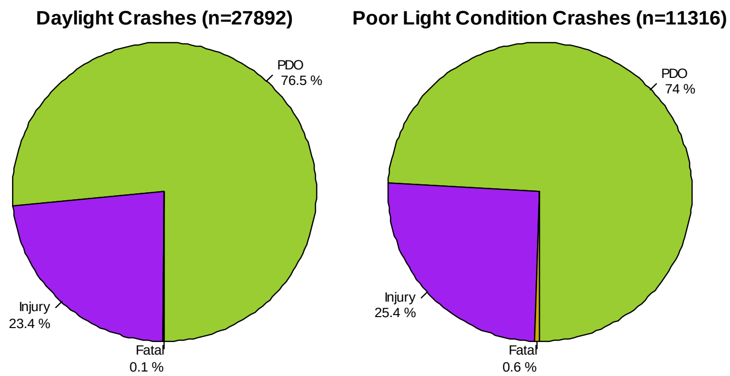


Figure 21. Crash Severity Distributions Under Different Light Conditions

An analysis of the severity distribution of work zone crashes by weather and road surface conditions is shown in Figure 22 and Figure 23, respectively. Approximately 24 percent of injury crashes occurred under both clear and poor weather conditions. Similarly, there is no obvious difference between injury and fatal crashes on dry and wet road surface conditions. It seems that adverse weather and road surface conditions do not affect the severity of work zone crashes. Statistically, Pearson's chi-squared test (χ^2 = 0.243, df = 2 for weather conditions and χ^2 = 0.233, df = 2 for road surface conditions) indicated that there is no significant association between crash severity and weather and road surface conditions.

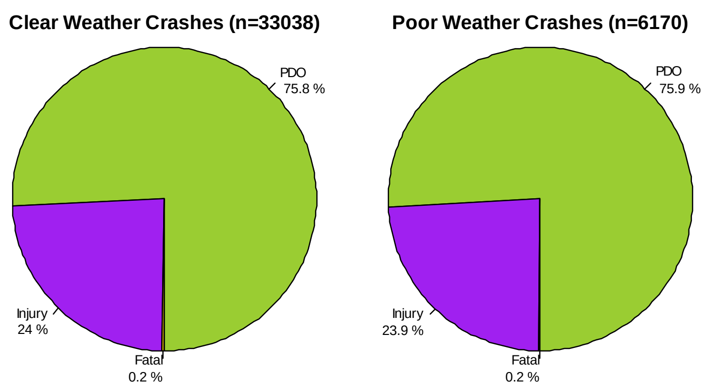


Figure 22. Crash Severity Distributions Under Different Weather Conditions

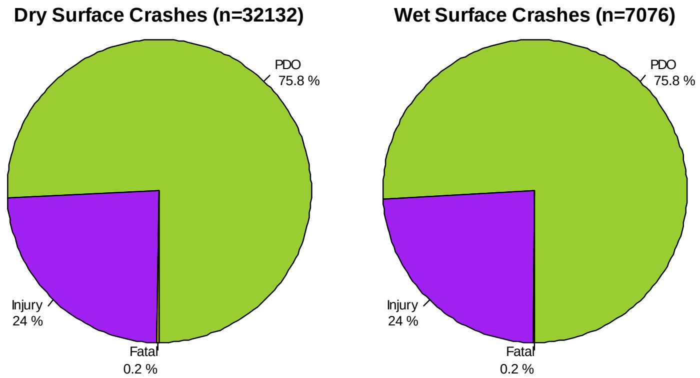


Figure 23. Crash Severity Distributions Under Different Road Surface Conditions

Severity Distribution by Road Characteristic

Crash severity distributions among different types of roadways were examined. Figure 24 shows the severity distribution for interstate highways, state highway, county roads, and municipal and other roads. As seen, the most prevalent severity on each type of roadway is PDO, which was more than 70 percent. About 27 percent of crashes that occurred on state highways were injury crashes, which had the largest proportion compared to other types of roadways. Notably, the proportion of injury crashes that occurred on county roads was larger than that of interstate highways. Municipal and other types of roads have the lowest proportion of injury—about 19 percent. Pearson's chi-squared test (χ^2 = 223.095, df = 6) indicated that there is a significant association between crash severity and roadway type.

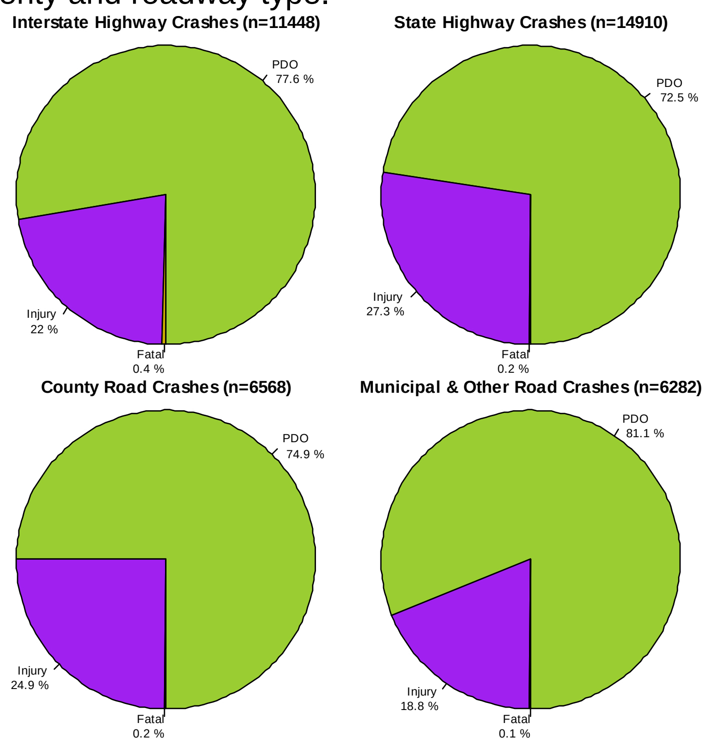


Figure 24. Crash Severity Distributions for Different Types of Roadways

Figure 25 illustrates the crash severity distributions under different road alignment conditions. About 24 percent of work zone crashes on straight roads were injury, 0.3 percent of those are fatal, and 75 percent resulted in no injury. The results are comparable to crashes occurring on curved roadways. The *p* value of the Pearson's chi-squared test (χ^2 = 5.441, df = 2) is 0.066, suggesting that there is no significant association between crash severity and road alignment given a significance level of 0.05.

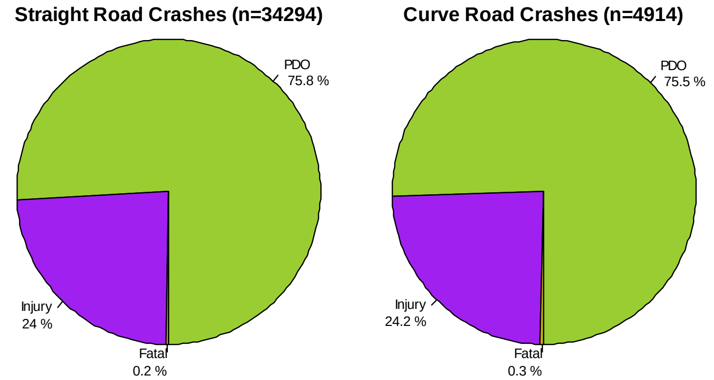


Figure 25. Crash Severity Distributions for Different Road Alignments

Figure 26 shows that about 25 percent of work zone crashes that occurred on roads with medians (barrier median, curbed median, and grass and painted medians) were injuries or fatal, compared to about 23 percent of other work zone crashes occurring on roads without a median. Pearson's chi-squared test (χ^2 = 29.326, df = 6) suggests the association between crash severity and the existence of different roadway medians.

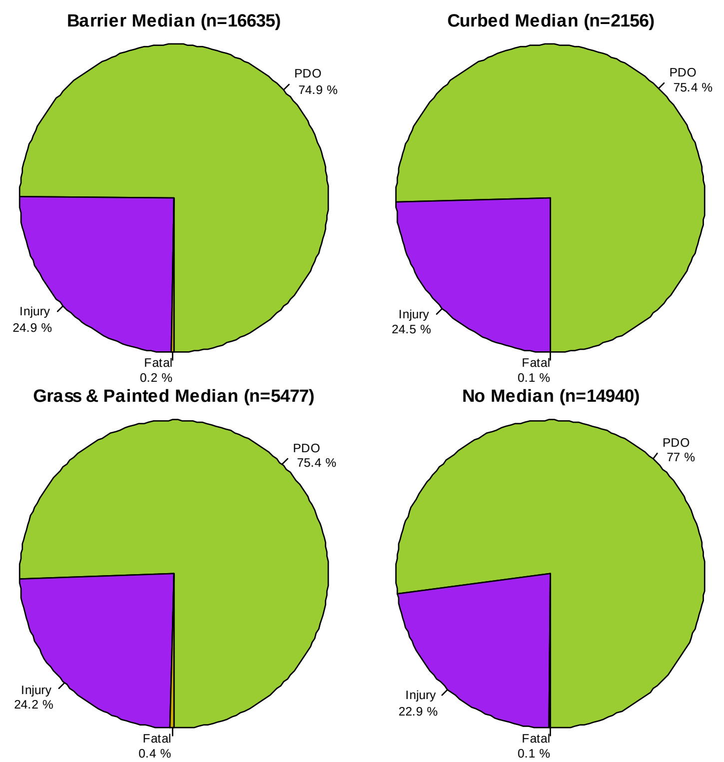


Figure 26. Crash Severity Distributions by Road Median

Figure 27 examined crash severity distributions by road surface type. For roads with a blacktop surface, about 24 percent of work zone crashes were injury related and fatal, compared to about 22 percent of other work zone crashes occurring on roads with other surface types. Pearson's chi-squared test (χ^2 = 8.466, df = 2) provides a *p* value of 0.015, which suggests the association between crash severity and surface types.

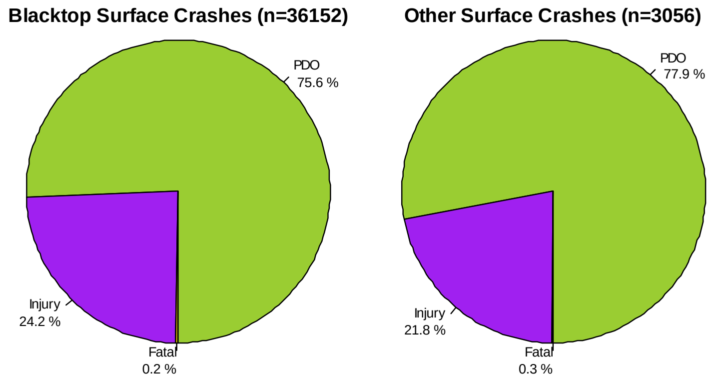


Figure 27. Crash Severity Distributions by Road Surface Type

We examined the crash severity distributions under different speed limits, as well. Figure 28 shows that lower speed limits (25 mph or less) resulted in a lower proportion of injury crashes. However, higher speed limits (more than 25 mph) can result in 4–5 percent more injury crashes compared to cases with lower speed limits. Crashes occurring in work zones with speed limits beyond 61 mph resulted in the highest portion of fatal crashes (0.6 percent). Pearson's chi-squared test (χ^2 = 106.722, df = 6) indicated that there is a significant association between crash severity and the posted speed limit.

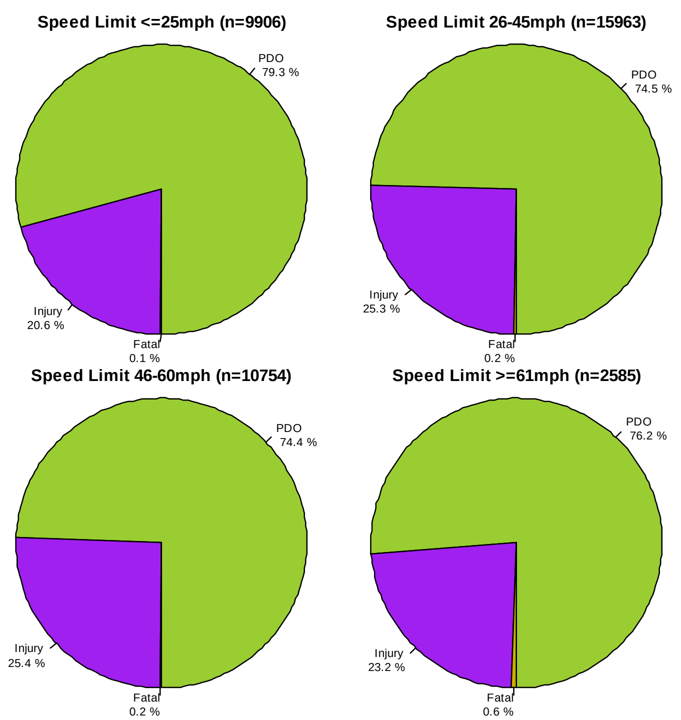


Figure 28. Crash Severity Distributions by Posted Speed Limit

Severity Distribution by Number of Vehicles Involved

The severity distributions for single- and multiple-vehicle–involved crashes are shown in Figure 29. It has been seen that crashes involving two vehicles have resulted in the lowest proportion of injury, which was about 20 percent. This percentage is followed by single-vehicle crashes at 26 percent. When crashes involved three or more vehicles, the proportion of injury crashes almost doubled. The figure indicated that about 44 percent and 57 percent of crashes involving three and four or more vehicles, respectively, include injury. Moreover, for crashes involving four or more vehicles, 0.8 percent were fatal crashes—the highest value compared to crashes involving fewer than four vehicles. Pearson's chi-squared test (χ^2 = 1383.398, df = 6) indicated that there is a significant association between crash severity and the number of vehicles involved.

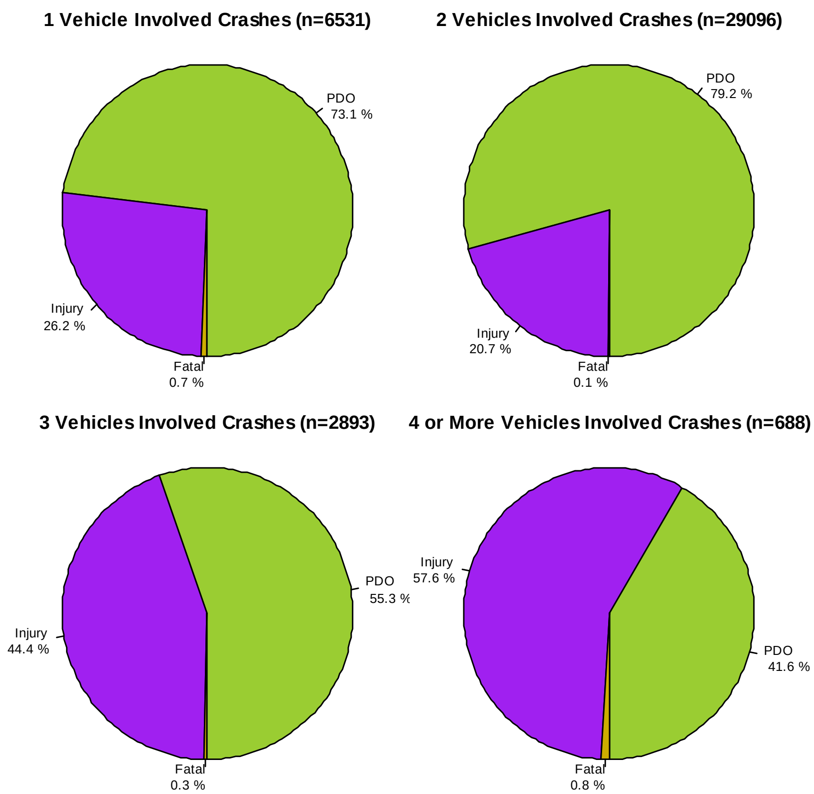


Figure 29. Crash Severity Distributions by Number of Vehicles Involved

Severity Distribution by Number of Occupants Involved

Figure 30 shows the severity distributions by the number of occupants involved. As seen from the figure, about 20 percent are injury crashes for those involving one or two occupants (including drivers). For crashes involving three or more occupants (including drivers), about 28–34 percent are injury crashes. The more people involved in a crash, the more likely the accident will result in injury. Pearson's chi-squared test (χ^2 =

818.329, df = 6) indicated that there is significant association between crash severity and the number of occupants involved in the crash.

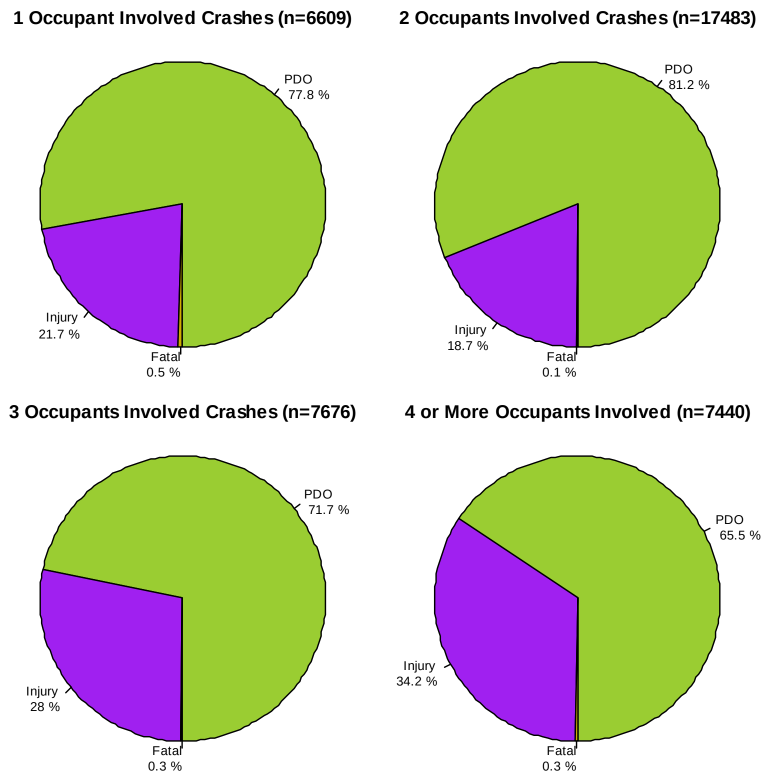


Figure 30. Crash Severity Distributions by Number of Occupants Involved

Severity Distribution by Types of Vehicles Involved

Figure 31 shows how the severity of truck-involved work zone crashes compared to all other non-truck–involved work zone crashes. More than 84 percent of truck-involved crashes resulted in PDO, compared to 73.8 percent of non-truck–involved crashes. Notably, crashes involving truck seem to be less likely to cause injury or fatality. Together the portion of injury and fatal crashes is about 15 percent for truck-involved crashes, whereas it is about 26 percent for crashes involving no truck. Pearson's chi-squared test (χ^2 = 366.943, df=2) indicated that there is a significant association between crash severity and the involvement of a truck in the crash.

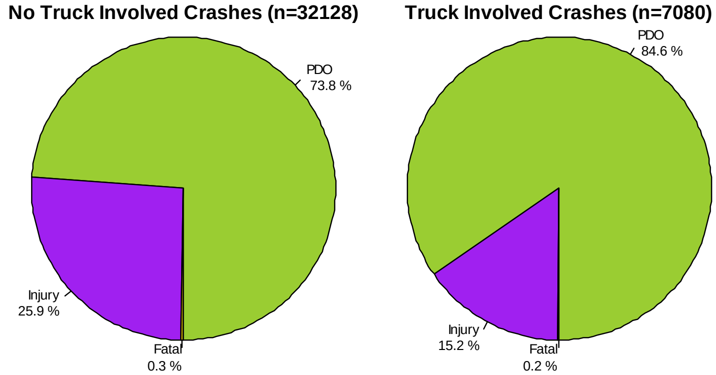


Figure 31. Severity Distributions of Truck-Involved Crashes

Figure 32 shows the severity of crashes involving light vehicles such as motorcycles and scooters. More than 76 percent of crashes are PDO if no such vehicles are involved. Clearly, if the crashes involved these vulnerable vehicles, it is more likely to be an injury or fatal crash compared to crashes involving no such vulnerable vehicles. These vulnerable vehicles are seldom protected as other vehicles, such as trucks and passenger cars. Pearson's chi-squared test (χ^2 = 276.290, df=2) indicated that there is a significant association between crash severity and the involvement of light vehicles.

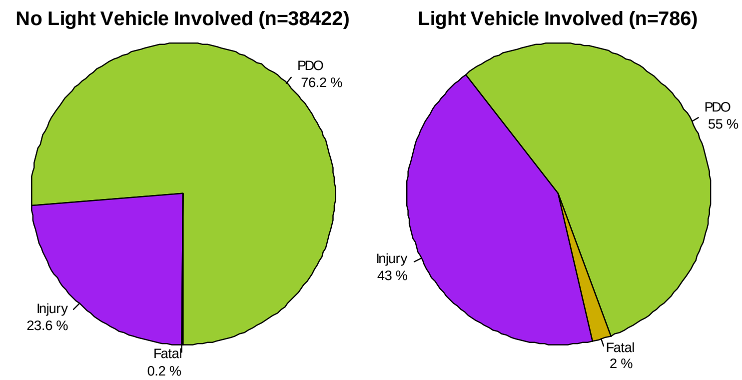


Figure 32. Severity Distributions of Light Vehicle–Involved Crashes

Severity Distribution by Alcohol Use

Figure 33 shows the severity of alcohol-involved work zone crashes compared to all other non-alcohol–involved work zone crashes. More than 76 percent of all work zone crashes that did not involve alcohol did not result in any injuries compared to less than 60 percent of alcohol-involved work zone crashes. Alcohol-involved crashes were three times as likely to be fatal as non-alcohol–involved crashes. Alcohol-involved crashes were about 1.7 times more likely to cause an injury than non-alcohol–involved crashes. Pearson's chi-squared test (χ^2 = 183.424, df=2) indicated that there is a significant association between crash severity and the involvement of alcohol.

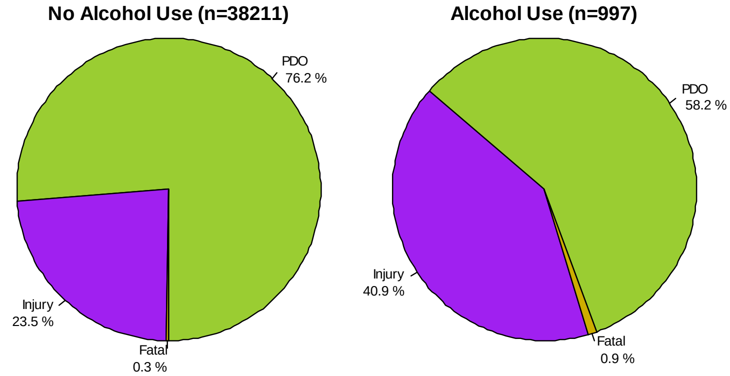


Figure 33. Severity Distributions of Alcohol Use–Involved Crashes

Severity Distribution by Time

Severity distributions for different time periods were examined in Figure 34. The percentages for PDO, injury, and fatal crashes occurring during nighttime (20:00–06:00) were 73.2 percent, 26.2 percent, and 0.6 percent, respectively. Injury and fatal crashes together are slightly higher compared to those crashes occurring during other periods. To determine whether crash severity is associated with time period, we conducted a Pearson's chi-squared test. The chi-square statistic is χ^2 = 95.768 (df = 6), and the *p* value is less than 0.05. Therefore, we can conclude that crash severity is indeed associated with time periods.

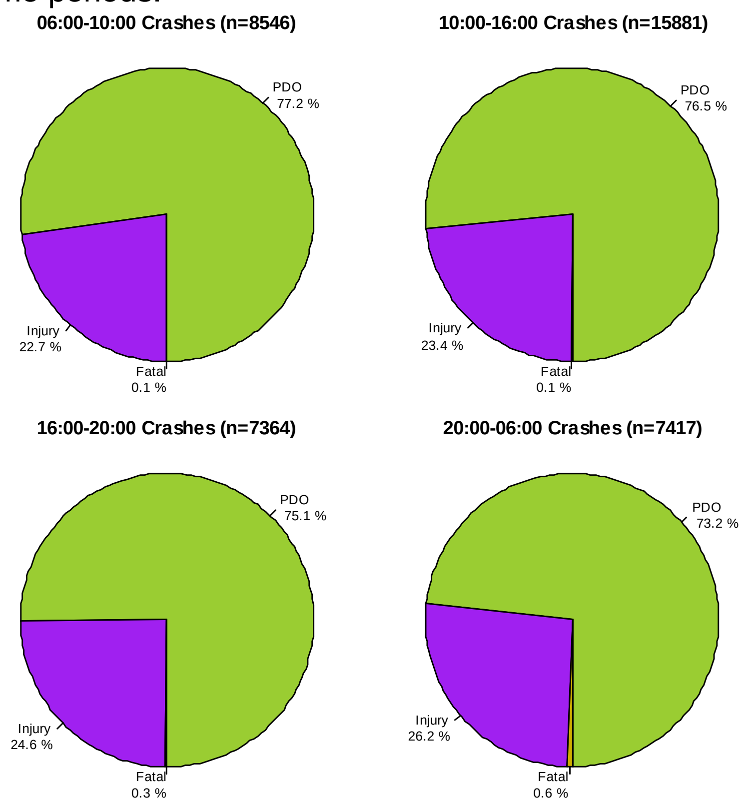


Figure 34. Severity Distributions at Different Time Periods

Severity Distribution by Crash Type

Table 16 presents detailed information about work zone crash severity distributions by crash type. Clearly, more than 80 percent of crashes are injury crashes if pedestrians or pedal-cyclists were involved in the collision. More than 4 percent of crashes involving pedestrians are fatal crashes. This is expected, as pedestrians are less protected in vehicle–pedestrian collisions. If the crashes were overturn collisions, a high proportion of injury (67 percent) will occur. Moreover, about 2.5 percent of overturn collisions caused fatalities. Other collisions that were expected to result in more than 30 percent injury crashes are head-on and angular collisions, left- or U-turn collisions, and right-angle collisions. Notably, there were eight railcar–vehicle collisions that resulted in one injury and one fatal crash. The chi-square statistic is χ^2 = 3695.471 (df = 32), and the *p* value is less than 0.05. Therefore, we can conclude that crash severity is significantly associated with crash type.

Table 16. Work Zone Crash Severity Statistics by Crash Type (2004–2010)

Crash Type	Total Number	Property Damage		Personal Injury		Fatal	
		Number	Percent	Number	Percent	Number	Percent
Rear end	17234	12088	70.14	5136	29.80	10	0.06
Side swipe	7601	6843	90.03	754	9.92	4	0.05
Right angle	2899	2017	69.58	875	30.18	7	0.24
Opposite (head on, angular)	418	220	52.63	193	46.17	5	1.20
Opposite (side swipe)	194	150	77.32	44	22.68	0	0.00
Struck parked vehicle	1704	1531	89.85	168	9.86	5	0.29
Left turn/U turn	664	438	65.96	224	33.73	2	0.30
Backing	943	890	94.38	52	5.51	1	0.11
Encroachment	71	59	83.10	12	16.90	0	0.00
Overturned	238	71	29.83	161	67.65	6	2.52
Fixed object	4559	3470	76.11	1063	23.32	26	0.57
Animal	357	332	93.00	25	7.00	0	0.00
Pedestrian	371	33	8.89	322	86.79	16	4.31
Pedal-cyclist	128	19	14.84	107	83.59	2	1.56
Non-fixed object	1032	934	90.50	94	9.11	4	0.39
Railcar–vehicle	8	6	75.00	1	12.50	1	12.5%
Unknown	787	612	77.76	171	21.73	4	0.51

Spatial and Temporal Analysis of Work Zones

Work zone crashes are plotted for each direction separately. Therefore, clustering of the work zones can be visible by direction. This spatial representation does not consider the severity of these accidents. Figure 35 shows the temporal–spatial distribution of work zone crashes on Route 35 between mileposts 56.0 and 57.0 and between January 2006 and December 2008.

Length of project and mileposts for the projects are the most important information interpreted from the project file gathered from NJDOT. Although project files are not included with the schedule of the project, the duration of the projects are decided by temporal and spatial analysis. By clustering work zone accidents by time and space, we come up with better estimates of work zone location and duration. First, we verified work zones by project milepost information. The area within the project length does not represent all crashes related to that specific work zone. More work zone crashes were observed around project location, because advance warning and termination areas are not included within project mileposts. Therefore, length and duration values of the work zones are adjusted by temporal–spatial analysis of work zone crashes to prepare the work zone database. In Figure 35, the black box shows project mileposts, and the red-dashed box shows the adjusted work zone location and time borders. Of course, with this technique, we can determine work zones that would be representative of all the work zones in New Jersey. For this purpose, we identified the project-verified work zones on the top 11 roadways listed in Table 17 in terms of work zone crashes.

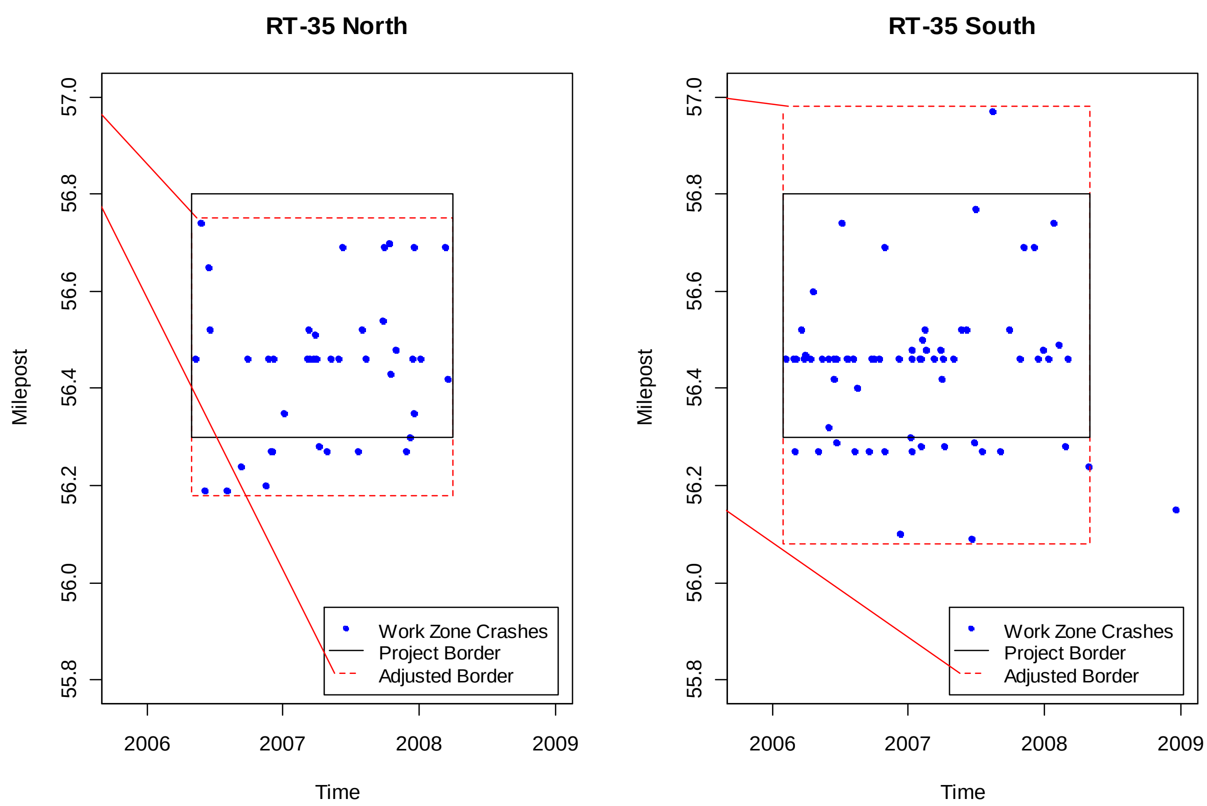


Figure 35. Spatial–Temporal Determination of the Work Zone Information

Time of occurrence is available for each work zone accident. We can identify accident clusters in two dimensions—namely, time and space—to better understand spatial and temporal distribution of work zone accidents. We picked milepost and length information for the project from project files. Sample project files and regarded information is provided in Figure 36 and Figure 37 for the work zone at Route 35. Because we do not have information regarding the duration of the work zones, we extracted this information from the accident database.

Table 17 provides a breakdown of 60 verified work zones, with their location, duration, and number of accidents. The total number of accidents at these 60 sites is 5,382. Explanatory variables related to the work zones can be used to conduct a detailed analysis and expose the contributing factors affecting work zone crashes. The work zones associated with a reference number are verified using NJDOT project files.

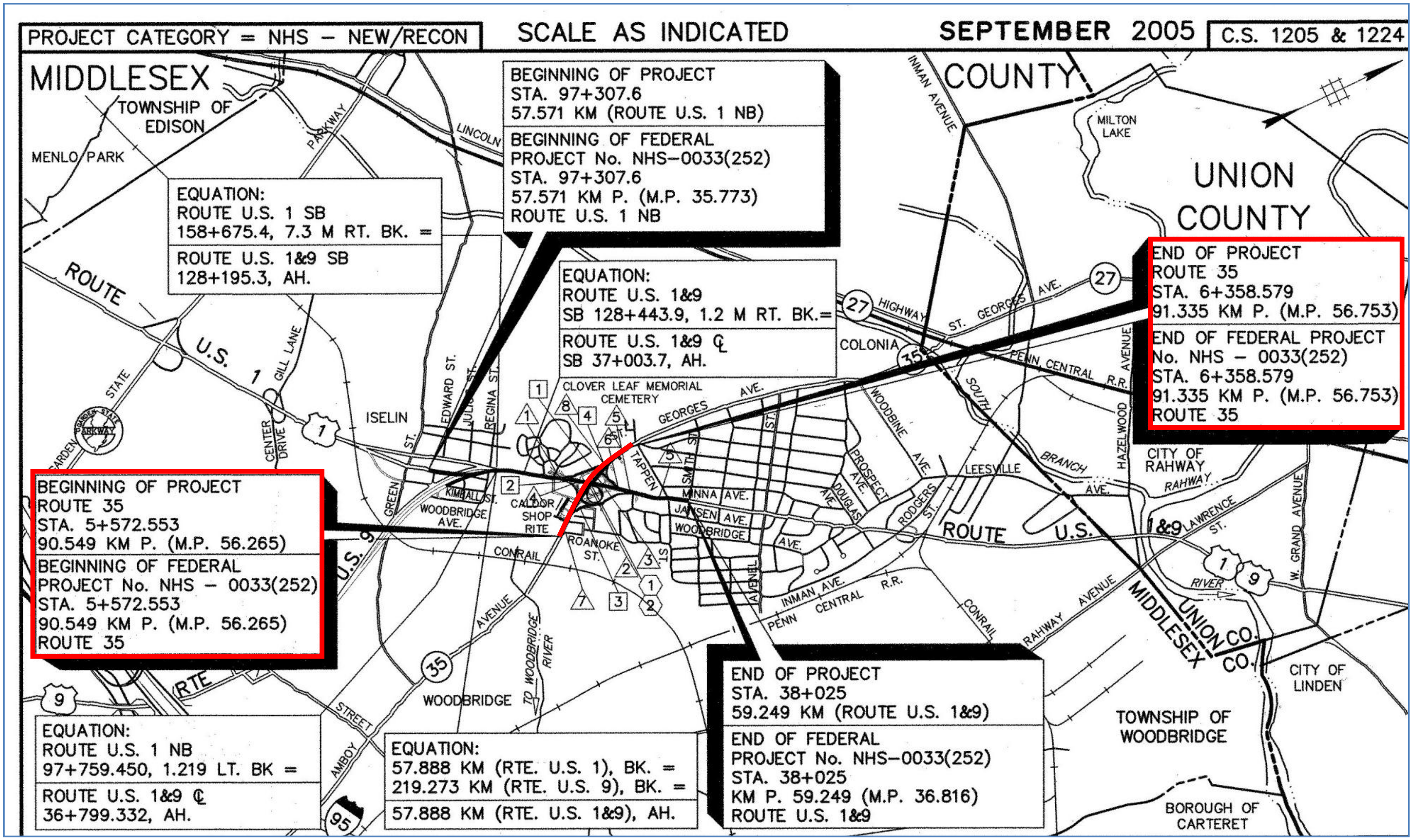


Figure 36. Project Plan First Page, with Work Zones from Figure 35 (Route 35)

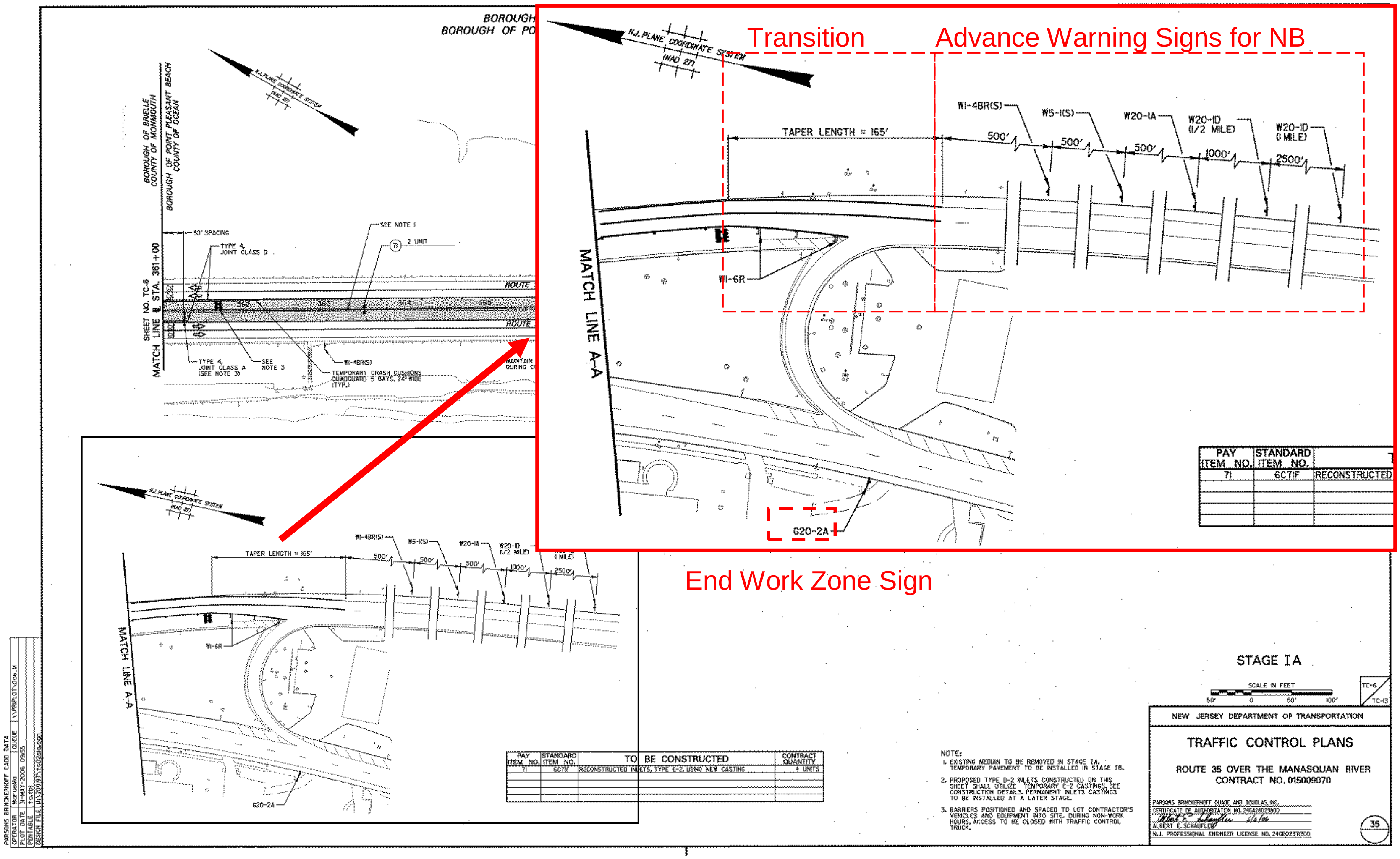


Figure 37. Work Zone Components Information Gathered from Project Plans

Table 17. Verified Work Zone List by Project Plan

Road	Work Zone	Direction	Date Start	Date End	Project Mile Start	Project Mile End	Number of Crash	Adjusted Length
US1	1	North	9/1/2006	9/30/2009	32.2	34.6	423	3.3
	2	South	7/1/2006	10/31/2009	32.2	34.6	217	2.8
	3	North	4/1/2006	12/31/2010	58.5	60.5	196	2.8
	4	South	4/1/2006	12/31/2010	58.5	60.5	181	2.8
	5	North	3/1/2006	12/31/2008	61.1	63.0	81	1.9
	6	South	3/1/2006	11/30/2008	61.1	63.0	93	1.8
	7	North	2/1/2006	1/31/2008	35.8	36.9	87	1.0
	8	South	2/1/2006	10/31/2007	35.8	36.9	89	1.0
	9	North	5/1/2006	2/29/2008	38.0	39.8	58	2.3
	10	South	6/1/2006	8/31/2008	38.0	39.8	93	2.0
	11	North	7/1/2004	5/31/2007	43.6	44.5	62	2.2
	12	South	7/1/2004	5/31/2007	43.6	44.5	54	2.2
I78	13	East	6/1/2007	1/31/2008	29.7	30.5	14	1.2
	14	West	8/1/2007	3/31/2008	29.7	30.5	35	1.1
	15	East	7/1/2006	12/31/2006	50.6	52.8	64	3.3
	16	West	7/1/2006	11/30/2006	50.6	52.8	80	4.1
	17	East	1/1/2004	8/31/2007	4.5	7.4	154	3.2
	18	West	2/1/2004	11/30/2007	4.5	7.4	102	3.0
NJ18	19	North	8/1/2005	10/31/2009	40.6	42.8	299	2.3
	20	South	8/1/2005	8/31/2009	40.6	42.8	292	2.1
US46	21	East	11/1/2004	5/31/2008	57.2	57.9	87	0.6
	22	West	10/1/2004	7/31/2008	57.2	57.9	103	0.9
	23	East	1/1/2005	1/31/2008	55.3	56.8	65	2.4
	24	West	8/1/2005	1/31/2009	55.3	56.8	166	2.2
	25	East	3/1/2005	5/31/2008	60.5	61.2	35	1.0
	26	West	7/1/2005	6/30/2008	60.5	61.2	22	1.2
	27	East	1/1/2005	9/30/2007	54.4	54.9	18	0.5
I287	28	North	8/1/2007	5/31/2010	0.1	5.9	299	6.2
	29	South	8/1/2007	12/31/2010	0.1	5.9	291	6.4
I280	30	East	10/1/2007	12/31/2007	3.4	4.8	8	1.7
	31	West	9/1/2007	3/31/2008	3.4	4.8	32	1.6
	32	East	11/1/2006	11/30/2008	11.8	12.5	29	0.9
	33	West	10/1/2006	11/30/2008	11.8	12.5	79	1.0
	34	East	7/1/2006	12/31/2008	14.4	14.6	74	2.0
	35	West	6/1/2006	9/30/2008	14.4	14.6	75	2.3
I295	36	North	6/1/2007	10/31/2008	14.3	24.5	106	11.4
	37	South	6/1/2007	10/31/2008	14.3	24.5	86	10.7
	38	North	1/1/2004	12/31/2004	32.1	41.0	267	11.1
	39	South	1/1/2004	12/31/2004	32.1	41.0	309	11.4

Road	Work Zone	Direction	Date Start	Date End	Project Mile Start	Project Mile End	Number of Crash	Adjusted Length
I80	40	East	1/1/2004	9/30/2005	67.0	67.8	143	3.7
	41	West	1/1/2004	11/30/2005	67.0	67.8	150	4.4
US9	42	North	7/1/2004	12/31/2006	114.4	115.3	76	2.0
	43	South	7/1/2004	7/31/2006	114.4	115.3	45	1.6
	44	North	9/1/2004	7/31/2006	111.0	111.6	32	0.8
	45	South	10/1/2004	7/31/2006	111.0	111.6	32	1.0
	46	North	11/1/2004	7/31/2006	112.3	112.9	51	1.7
	47	South	3/1/2005	7/31/2006	112.3	112.9	58	1.4
	48	South	3/1/2004	1/31/2006	132.0	132.8	14	0.7
NJ35	49	North	5/1/2007	8/31/2008	14.4	14.9	30	1.0
	50	South	12/1/2006	12/31/2008	14.4	14.9	29	1.4
	51	North	7/1/2006	8/31/2007	23.3	23.6	14	0.3
	52	South	6/1/2006	8/31/2007	23.3	23.6	23	0.6
	53	North	4/1/2006	4/30/2008	56.3	56.8	50	0.7
	54	South	2/1/2006	4/30/2008	56.3	56.8	76	1.0
	55	North	1/1/2004	10/31/2005	50.9	52.3	23	1.7
	56	South	1/1/2004	12/31/2005	50.9	52.3	31	1.8
	57	North	2/1/2004	1/31/2005	21.2	21.9	25	1.2
	58	South	1/1/2004	2/28/2005	21.2	21.9	13	0.8
NJ23	59	North	10/1/2005	11/30/2007	4.8	5.8	30	1.0
	60	South	2/1/2006	12/31/2008	4.8	5.8	47	1.8

Crash Location Distribution within Work Zones

Work zones are separated into five locations: advance warning area, transition area, buffer area, work area, and termination area. This information is available for some verified work zones listed in Table 17 (project files provided by NJDOT). Crash distribution is investigated for these sub-locations and shown as a pie chart in Figure 38. As with previous studies, work zone accidents are predominantly located within the activity area.

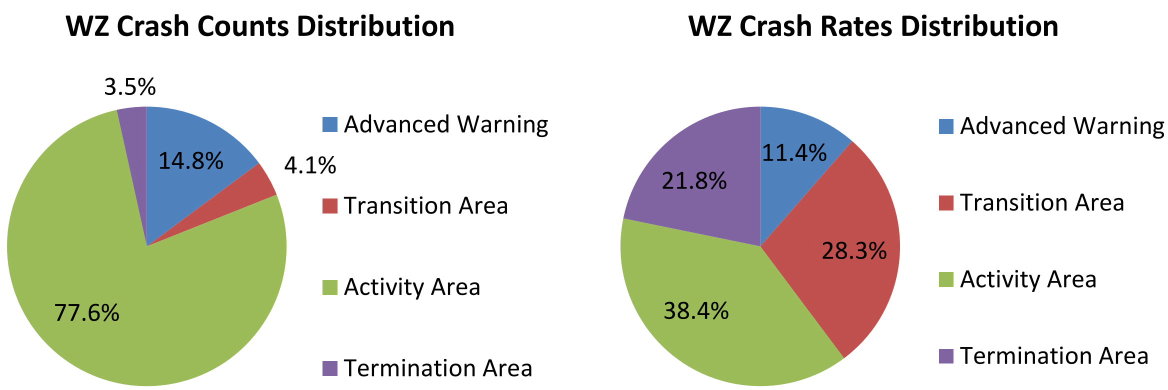
The crash counts and crash rates are estimated for each specific work zone component. Considering crash counts, risk priority is defined in the following order:

1. Activity area (77.6 percent)
2. Advanced warning area (14.8 percent)
3. Transition area (4.1 percent)
4. Termination area (3.5 percent)

The segment length for transition and termination areas is small compared to activity area and advanced warning area. Hence, a crash count comparison is biased for these areas according to the risk priority. When crash rates are estimated for these specific locations, the risk priority order must be changed. Crash rate is defined by the following formula, which has a unit of mvm:

$$R = \frac{A \times 10^6}{V \times D \times L} \quad (9)$$

where, *A* = the average number of crashes at the study location, *V* = volume (AADT) in the study location, *D* = duration (the number of days in the study period), and *L* = length of work zone (in miles).



(a) (b)

Figure 38. Work Zone Components (a) Crash Counts and (b) Crash Rates

Crash rate distribution shows that transition and termination areas are also risky places in terms of crash occurrence probability. New risk priority levels can be written in the following order:

1. Activity area (38.4 percent)
2. Advanced warning area (11.4 percent)
3. Transition area (28.3 percent)
4. Termination area (21.8 percent)

Crash counts for each component are plotted with intersection and ramp information. Intersection and ramp milepost information is gathered from New Jersey straight-line diagrams. Figure 39 offers a sample for three same-direction work zones. Crash distribution histograms are plotted for all work zones and provided in Appendix B.

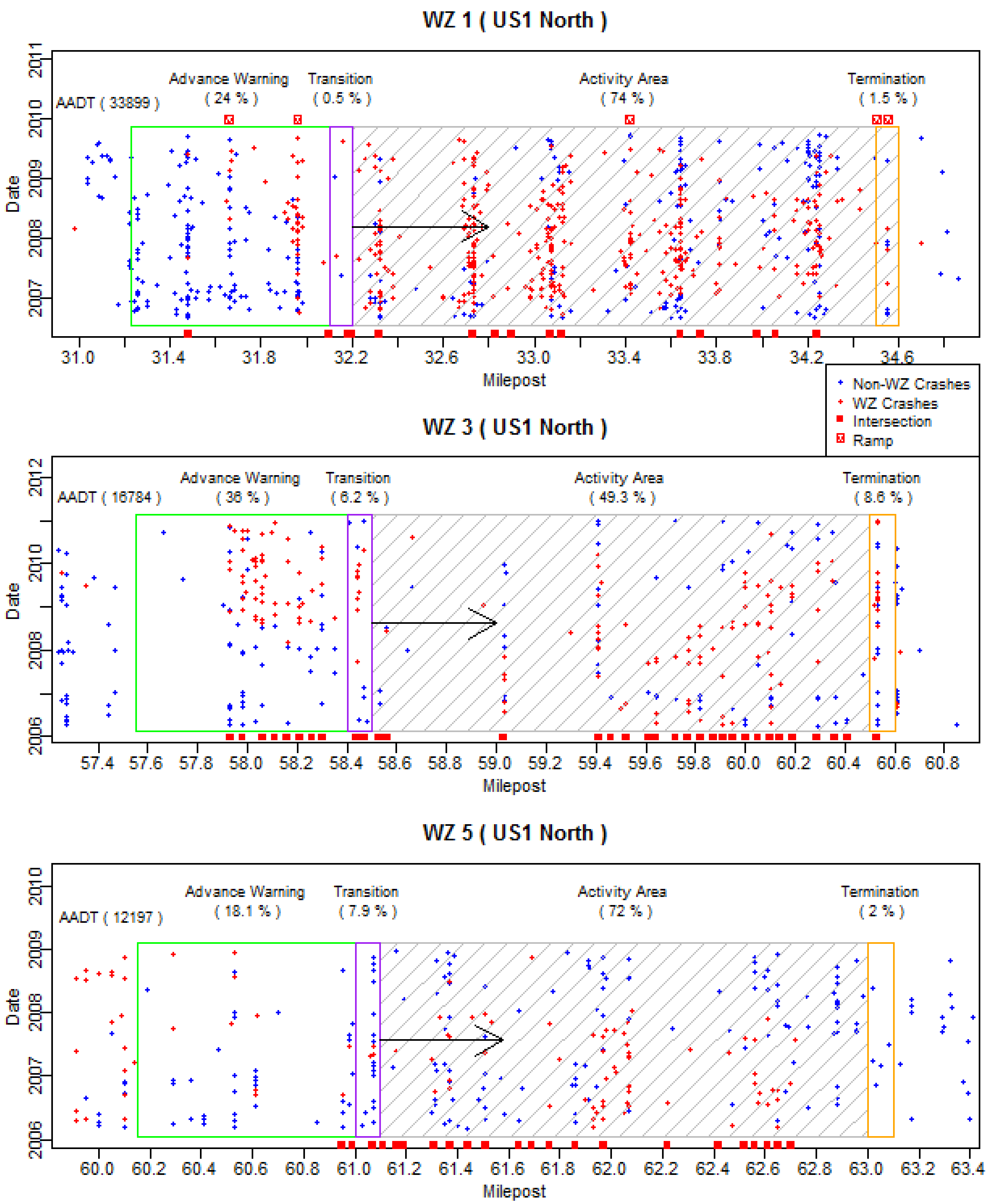


Figure 39. Intersection and Ramp vs. Crash Relationship Within the Work Zone

WORK ZONE CRASH FREQUENCY MODELING

We used the New Jersey crash database (2004–2010) to construct the statistical models of crashes in the work zones. The objective of statistical modeling is to identify the factors that contribute to work zone crash frequency in New Jersey.

Crash Frequency Modeling

Accident occurrences are considered non-negative count data, the outcome of several contributing factors. To model such count data, the Poisson regression model was frequently used in crash data analysis.[42,43] However, the Poisson model cannot address potential overdispersion issues of the data. To deal with the problem, many researchers have suggested extensions of simple Poisson models.[44,45] Among the extensions, the NB model has become one of the extensively used alternatives to model crashes.[46,47]

In this study, we made an attempt to estimate the NB models in which the dependent variable is the number of accidents that occurred every three months in a work zone. Because there is no actual information about the duration of work zones, 60 work zones are identified using the spatial–temporal method described in the previous section. Further information on the work zones was obtained through work zone project files and straight-line diagrams and incorporated into the statistical models.

We built three statistical models to analyze the contributing factors. The general model was used to investigate the duration effect of work zones by using all counts for the full period. Property damage and injury crash models were also developed to examine the seasonal crash counts.

Model Specification

Y_i denotes the number of crashes at the i^{th} work zone in a given time period. Assuming that Y_i follows the Poisson distribution with the mean λ_i, the probability of observing y_i crashes in the work zone can be described by the basic Poisson regression model:

$$P(Y_i = y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!} \quad (1)$$

Location-specific work zone explanatory variables are incorporated into the model to specify the parameter λ_i:

$$\lambda_i = \exp(\beta' x_i) \quad (2)$$

where β is the vector of estimated coefficients of the model and x_i is the explanatory variable vector for the i^{th} work zone (duration, length, traffic volume, and so on).

To deal with unobserved heterogeneity and to allow for unexplained randomness, a noisy measurement ε_i is introduced into equation (2):

$$\lambda_i = \exp(\beta' x_i + \varepsilon_i) \tag{3}$$

where ε_i is an error term, which represents a random effect of omitted explanatory variables and unmeasured heterogeneity. In the NB regression model, we assume that $\exp(\varepsilon_i)$ is gamma distributed:

$$\exp(\varepsilon_i) \sim \mathrm{Gamma}(k, k) \tag{4}$$

where k is an inverse dispersion parameter.

Compared to the Poisson regression model, the NB model has the additional parameter k to be estimated, and the model has the following properties:

$$P(Y_i = y_i | \lambda_i, \kappa) = \frac{\Gamma(y_i+\kappa)}{y_i!\Gamma(\kappa)} (\frac{\kappa}{\kappa+\lambda_i})^{\kappa} (\frac{\lambda_i}{\kappa+\lambda_i})^{y_i} \tag{5}$$

$$E(Y_i) = \lambda_i; \;\; \mathrm{Var}(Y_i) = \lambda_i + \frac{\lambda_i^2}{\kappa} \tag{6}$$

The variance $\mathrm{Var}(Y_i)$ shown in Equation 6 is always larger than the mean $E(Y_i)$. Thus, the NB model is more appropriate for modeling the overdispersed crash data.

The safety performance function (SPF) for predicting the number of accidents in an interval of given length can be specified as follows:

$$\ln(\lambda_i) = \alpha_0 + \alpha_1 \ln(L_i) + \alpha_2 \ln(Q_i) + \sum_{j=1}^{m} \beta_j X_{ji}, \quad i = 1, \dots, n \tag{7}$$

where λ_i is the expected number of accidents in a given time period; L_i is the work zone length; Q_i is the traffic volume during the period of study; X_{ij} represents the j^{th} explanatory variable at the i^{th} work zone; and α_0, α_1, α_2 and β_j are the model parameters.

Three monthly crash counts are used to build the SPF. Because work zones represent temporary conditions on the roadway and each work zone has its own construction schedule, it is not possible to aggregate the accidents over a longer period. Thus, the shortest appropriate duration for dealing with work zone crashes is three months.

Considering the crash information available from the NJDOT crash database, work zone project files, straight-line diagrams, and the variables used in previous CF models,[9,10,11] seven categories of variables are selected: length, light conditions, annual average daily traffic, posted speed, number of lanes, road type, and three-month occurrence. The NB model becomes the following, with the variables described in Table 18.

The general model considers work zone duration, PDO, and Injury crash models using three-month data:

$$\begin{aligned}\mathrm{crash\_count} = \exp(&\beta_0 + \ln(\mathrm{length})^{\beta_1} + \beta_2\mathrm{night} + \ln(\mathrm{adt})^{\beta_3} + \beta_4\mathrm{wzspeed} + \\ &\beta_5\mathrm{operatedlane} + \beta_6\mathrm{lanedrop} + \beta_7\mathrm{speedreduction} + \\ &\beta_8\mathrm{roadtype} + \beta_9\mathrm{ramp} + \beta_{10}\mathrm{intersection} + \ln(\mathrm{duration})^{\beta_{11}})\end{aligned} \tag{8}$$

$$\begin{aligned}crash\_count = \exp(&\beta_0 + \ln(length)^{\beta_1} + \beta_2 night + \ln(adt)^{\beta_3} + \beta_4 wzspeed + \\ &\beta_5 operatedlane + \beta_6 lanedrop + \beta_7 speedreduction + \\ &\beta_8 roadtype + \beta_9 intersection + \beta_{10}\mathrm{ramp})\end{aligned} \tag{9}$$

Although the number of accidents is classified for three months, we prefer to incorporate work zone length as an independent variable, because locations within the work zone may be subject to different crash rates. NJDOT records provide seven different light conditions, but for the sake of simplicity, these conditions are categorized in two levels: daytime and nighttime. Duration is implemented in the general model as the number of days during the work zone. Average annual daily traffic volume values are adjusted for three months by seasonal adjustment factors as well as for day and nighttime with respect to hourly distribution of traffic. Work zone speeds are gathered from the accident database according to the distribution of posted speed values within work zones. Operated number of lanes information is obtained through work zone project drawing lane closure plans and decided by represented values during daytime and nighttime. Work zone speed reduction and lane drop parameters are generated by estimating the difference between work zone and normal conditions. Road types are categorized in two levels: interstate and state. The number of ramps and intersections for each work zone is obtained from New Jersey straight-line diagrams.

Table 18 - Variables Considered in the NB Model

Category	Variable	Type	Description
Length	length	Continuous	Length of the work zone
Light Conditions	night	Indicator	daytime = 0, nighttime = 1
ADT	adt	Continuous	Adjusted AADT per lane (by direction, seasonal factor, time factor)
WZ Speed	wzspeed	Continuous	Reduced posted speed limit (mph)
Operated Lane	operatedlane	Indicator	Number of operating lanes
Lane Drop	lanedrop	Continuous	Number of closed lanes
Speed Reduction	speedreduction	Continuous	Reduction in posted speed limit (mph)
Road System	roadsystem	Indicator	interstate = 0, state = 1
Ramp Number	ramp	Continuous	Number of ramps within the work zone
Intersection	intersection	Continuous	Number of intersections within the work zone
Duration	duration	Continuous	Duration of the work zone (days)

<u>Modeling Results</u>

The estimated parameters shown in Table 19, Table 20, and Table 21 were used to determine the relationship between independent variables and the frequency of work zone accidents. Interpretation of the results explained the model parameters according to a 95% level of significance.

Interpretation of the NB Model for Total Number of Crashes

- Duration of the work zone is the most significant parameter related to total number of crashes for the general model.
- Length of the work zone is also a significant factor for crash occurrence.
- The frequency of work zone crashes is higher for daytime traffic than for nighttime traffic; nighttime produces fewer crashes.
- As expected, crash frequency increases by an increment of AADT values. Because AADT represents daily traffic for each lane, the number of operated lanes is significant for reflecting exposure to traffic.
- Speed reduction affects work zone crash occurrence positively. An increase in the variance of speed change results in more crashes.
- Work zone speed limit is not within the significance level of 0.05 but it is still within the acceptable range for the model.
- Road type, the number of lane drops, and the summation of intersection and ramp number parameters are not significant for this model.

- The alpha number is not close to zero, which means that overdispersion occurred. The NB regression is more appropriate for this dataset than the Poisson regression.
- The intercept value is significant for the general model.

Table 19. Estimated Parameters for the CF Model

Variable	Coefficient	Standard Error	*Z*	*P* > |z|	Significant
ln(length)	0.477	0.133	3.580	0.000	***
night	−0.080	0.227	−0.350	0.725	–
ln(aadt)	0.512	0.158	3.230	0.001	***
wzspeed	−0.023	0.014	−1.600	0.110	–
operatedlane	0.642	0.141	4.540	0.000	***
lanedrop	0.158	0.129	1.230	0.220	–
speedreduction	0.025	0.013	2.000	0.045	*
roadsystem	0.203	0.193	1.050	0.292	–
ramp	0.011	0.028	0.410	0.680	–
intersection	0.014	0.010	1.380	0.167	–
ln(duration)	0.710	0.084	8.500	0.000	***
intercept	−6.731	1.097	−6.140	0.000	***
alpha	0.190	0.030	–	–	–
chibar2 =	614.89	Prob ≥ chibar2 = 0.000			

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Interpretation of the NB Model for Property Damage Accidents

- AADT per-lane values are significantly related to non-injury CF. The number of lanes with AADT shows exposure to traffic, which are effective parameters for PDO crash occurrence.
- Length of the work zone is strongly associated with the number of crashes. A longer work zone results in more accidents.
- Daytime traffic is closely related to property damage work zone crashes; in other words, night conditions in work zones decrease the frequency of PDO crashes.
- Speed reduction is also a significant parameter for the frequency of non-injury crashes. The larger variance in speed limits causes more PDO crashes.
- The number of lane drops increasingly affects PDO crash occurrence.
- Interstate highways tend to have fewer property damage crashes than state highways.
- The number of ramps and intersections increases non-injury CF.
- Work zone speed limit is not significant for the PDO model.

- The alpha value shows that overdispersion occurred, because the values is different than 0. The NB model is appropriate for modeling PDO crashes.
- The intercept value is significant for the PDO CF model.

Table 20. Estimated Parameters of the PDO CF Model

Variable	Coefficient	Standard Error	*Z*	*P* > |z|	Significant
ln(length)	0.476	0.118	4.04	0.000	***
night	-0.314	0.152	-2.07	0.039	*
ln(aadt)	0.446	0.110	4.06	0.000	***
wzspeed	-0.011	0.009	-1.22	0.223	
operatedlane	0.581	0.099	5.87	0.000	***
lanedrop	0.253	0.084	3.00	0.003	**
speedreduction	0.036	0.010	3.46	0.001	***
roadsystem	0.473	0.138	3.42	0.001	***
ramp	0.042	0.020	2.15	0.032	*
intersection	0.013	0.007	1.84	0.066	.
intercept	-4.648	0.876	-5.30	0.000	***
alpha	0.501	0.040			
chibar2 =	896.1	Prob>=chibar2 = 0.000			
*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*					

Interpretation of NB Model for Injury Accidents

- The number of operated lanes and AADT, which reflect traffic density per lane, are the most effective parameters on injury CF.
- Length of the work zone is strongly associated with the number of injury crashes during the work zone.
- Injury CF is lower at nighttime than in daytime.
- Lane drop is also an effective parameter for injury crash occurrence within work zones.
- Speed reduction has a slight effect on injury crashes.
- Interstate highways tend to have fewer injury crashes than state highways.
- The number of intersections, number of ramps, and work zone speed limit parameters are not significant for the injury crash model.
- The intercept value is significant for the model.

Table 21. Estimated Parameters of Injury CF Model

Variable	**Coefficient**	**Standard Error**	***Z***	***P* > |z|**	**Significant**
ln(length)	0.642	0.153	4.20	0.000	***
night	−0.381	0.189	−2.02	0.043	*
ln(aadt)	0.325	0.137	2.36	0.018	*
wzspeed	−0.016	0.011	−1.46	0.143	–
operatedlane	0.590	0.126	4.69	0.000	***
lanedrop	0.393	0.102	3.84	0.000	***
speedreduction	0.024	0.014	1.81	0.071	.
roadsystem	0.959	0.184	5.21	0.000	***
ramp	0.023	0.024	0.96	0.337	–
intersection	−0.001	0.009	−0.16	0.873	–
intercept	−4.752	1.138	−4.18	0.000	***
alpha	0.489	0.061	–	–	–
chibar2 =	172.1	Prob ≥ chibar2 = 0.000			
*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*					

Comparison of Model Results with Previous Studies

Common independent variables to be compared include length, duration, and *AADT*. As mentioned in the section, Review of Work Zone Crash Frequency incorporation of logarithmic transformations of work zone length, duration, and roadway demand into the NB model gives us the opportunity to test the proportionality of them to the CF. In other words, when the independent variables enter the NB model logarithmically, their parameters signify elasticity, giving the percentage change in crash counts in response to 1 percent change in the corresponding variable. Duration is only investigated for the total number of crashes, and the coefficient for duration is 0.709, which was found to be 1.11 by Khattak et al. (2002).[10] Khattak et al. (2002)[10] found the AADT coefficient to be 1.239; Venugopal and Tarko (2000)[9] found it to be 1.050. In this study, we found it to be 0.513. Unlike other studies directly using AADT in their models, daily traffic was transformed to traffic volume per lane. Only 4–6 parameters were used in the mentioned studies above. In this study, we used 10 parameters to determine effective factors for CF. Obviously, when the number of parameters increases, some of the estimated coefficients will change as a result of the incorporation of new variables.

Addressing Measurement Errors in Work Zone Length

Considering the potential errors in modeled variables, we extended the use of the NB model by incorporating measurement errors. The following sections described the development of the models.

Modeling Measurement Errors in Work Zone Length

The work zone length can be determined in two ways: (1) by using the length from the work zone project file and (2) by employing spatial–temporal diagrams of work zone crash data. Figure 35 shows examples of the spatial–temporal distributions of the observed work zone crashes for a specific work zone site. The solid-line box indicates the proposed work zone length obtained from the project file; the dashed-line box shows the adjusted work zone length based on the reported work zone crashes.

Using the aforementioned methods, the length measurement of each work zone has important accuracy issues. First, the length extracted from the project plans provided by the NJDOT engineering document unit is likely to be inaccurate. These project plans may not reflect the final work zone layouts, which may be slightly changed in the field. Moreover, work zone projects generally have multiple stages of tasks, and the length of a work zone can vary according to the progress of the project. The length information for each stage was not clearly described in most of the project plans. Second, the length of a work zone identified using the spatial–temporal diagrams of work zone crashes could have estimation errors. As shown in Figure 35, the length of the work zone is estimated as the difference between the lowest and highest mileposts in which work zone crashes are observed. The estimation relies on the locations of the observed crashes. Obviously, this brings a major bias into work zone length measurement, mainly because of the randomness of accident locations. If the observed crashes are not uniformly distributed along the entire work zone, the estimated work zone length is biased. In addition, the reported milepost of an observed crash might not be accurate. Therefore, these imperfect data sources imply that either the length based on spatial–temporal diagrams or the length obtained from project plans are likely to have measurement errors.

To consider the measurement errors in the work zone length, a classical measurement-error model has been proposed. Specifically, we assume that the length on the log-scale is measured as the true value on the log-scale plus an additive error. The model structure can be expressed as:

$$\ln(L_{it}) = \ln(F_i) + \tau_{it}, \quad i = 1, \ldots, n; \ t = 1, \ldots, T_i \tag{10}$$

where L_{it} denotes the measured work zone length in each time period (in terms of season), F_i denotes the true length, and τ_{it} is the measurement error term. T_i is the total number of periods for the work zone i.

If we assume that error term τ_{it} and F_i are independent and τ_{it} follows a normal distribution $N(0, \sigma_\varepsilon^2)$, then the measured work zone length follows the log-normal distribution shows here:

$$\ln(L_{it}) \sim N(\ln(F_i), \sigma_\varepsilon^2), \quad i = 1, \ldots, n; \ t = 1, \ldots, T_i \tag{11}$$

Equation 11 is a classical measurement error model that captures the relationship between measured work zone length L_{it} in a given season t and the (unknown) actual length F_i.

As F_i is unknown, it can be assumed to be a latent variable that follows a log-normal distribution:

$$\ln(F_i) \sim N(\ln(\mu_{iF}), \sigma_F^2), \quad i = 1, \ldots, n \tag{12}$$

Equation 12 represents the seasonal variation model describing the distribution of the unknown work zone length over the work zone duration. Because the dataset is not homogeneous, each work zone has its own expected length μ_{iF}. A common seasonal variation parameter, σ_F^2, is assumed.

Instead of using the measured work zone length, the true (unknown) length obtained from Equation 12 is incorporated into Equation 7, and the mean function can be rewritten as follows:

$$\ln(\lambda_i) = \alpha_0 + \alpha_1 \ln(F_i) + \alpha_2 \ln(Q_i) + \sum_{j=1}^{m} \beta_j X_{ji}, \quad i = 1, \ldots, n \tag{13}$$

Equations 10–13 represent the fundamental NB model, with a measurement error (MENB) in work zone length. The adjust work length based on spatial–temporal diagrams of work zone crashes was assumed to be the measured length L_{it}. The work zone length determined from the individual work zone project files was assumed to be the expected length μ_{iF}.

Model Estimation

Full Bayesian Estimation

All model parameters are estimated using the Full Bayesian method, which uses Monte Carlo Markov Chain (MCMC) sampling. The WinBUGS statistical software package was used. This estimation methodology has been widely used in road safety studies.[48,49,50] MCMC repeatedly samples from the posterior distribution and generates chains of random points. Once the distribution of the chains converges to the target posterior distribution, full Bayesian estimates of the parameters can be obtained from the remaining iterations. Convergence can be monitored through trace plots of the chains and the Brooks-Gelman-Rubin (BGR) statistic. The BGR diagnostic was suggested by Brooks and Gelman (1998).[51] BGR in WinBUGS examines average widths of 80 percent intervals of the pooled sample and each individual sample. The average width of the individual samples should approach the average width of the pooled sample so that BGR statistic approaches 1. In other words, if chains have converged, the ratio should be close to 1 (less than 1.2 is often sufficient to indicate convergence). The iterations up to the convergence point are excluded as burn-in samples, and the rest is used for parameter estimation. Monte Carlo error relative to the standard deviation of the estimated parameter is suggested to be less than 0.05 for a reliable inference.(52)

Prior Distributions

Full Bayesian estimates of the parameters can be obtained by specifying prior distributions. Prior distribution reflects some known information about the parameter distributions. If such information is available, it can be used to predict informative priors. In the absence of strong prior information, uninformative priors can be used to obtain the Full Bayesian estimates. A frequently used diffuse prior distribution for the regression parameters is the normal distribution, with zero mean and a relatively large variance.(53) In this study, we assumed that the prior distributions were a normal distribution $\beta_j \sim N(0, 1000)$. Noninformative prior distribution Gamma(0.001, 0.001) was imposed on the inverse dispersion parameter (κ) of NB distribution, parameters σ_ε^{-2} and σ_F^{-2}.

Model Selection

Two criteria are used to compare alternative models and determine which model outperforms the others. The first criterion is the Deviance Information Criterion (DIC), which is calculated as follows:

$$\mathrm{DIC} = \overline{\mathrm{D}} + \mathrm{p_D} \tag{14}$$

where $\overline{\mathrm{D}} = \mathrm{E}[\mathrm{D}(\beta)] = -2\log\big(\mathrm{L}(\mathrm{Y}|\beta)\big)$ and $\mathrm{p_D} = \overline{\mathrm{D}} - \mathrm{D}(\bar{\beta})$. $\overline{\mathrm{D}}$ is the posterior mean; $\mathrm{D}(\bar{\beta})$ is the point estimate, which measures how well the model fits the data via a log-likelihood function and unknown parameters of the model β; Y is the data; $\mathrm{L}(\mathrm{Y}|\beta)$ is the likelihood function; $\mathrm{p_D}$ is a measure of model complexity, which defines the effective number of parameters; and $\bar{\beta}$ is the posterior mean of β.

As a rule of thumb, the model with the lowest DIC value is the **best estimated** model. A difference in DIC larger than 10 suggests in favor of the model with a smaller DIC. However, if the difference in DIC is less than 5, it might be misleading to report the model with the lower DIC as the best model.(54,55)

In addition to DIC, another goodness-of-fit criterion used to aid in model selection is the posterior predictive loss in terms of the mean square predictive error (MSPE) on the log-scale.(56) The MSPE measures the discrepancy between the observed number of work zone crashes and the data predicted from the posterior predictive distribution. The model that results in predicted values closest to the actual observations will yield the lowest MSPE. Statistically, this criterion is defined as follows:

$$MSPE = \frac{1}{n}\sum_{\forall i,t}\left[\log\left(y_{it}^{obs} + 0.5\right) - \log\left(y_{it}^{pred} + 0.5\right)\right] \tag{15}$$

where n is the total number of data points; y_{it}^{obs} is the observation for the i^{th} work zone in period t; and y_{it}^{pred} is the sample from the posterior predictive distribution for the i^{th}

work zone in period t. A stabilizing factor of 0.5 is used to avoid log(0) when observed, or a predictive number of crashes is zero.

Results and Discussion

The posterior estimates of model parameters were obtained via WinBUGS using two independent Markov chains of 40,000 iterations each. The first 20,000 iterations in each chain were discarded as burn-in runs. The convergence of each model's parameters was monitored using the BGR statistic (below 1.2) and also using visual approaches such as observing trace plots. In addition, the ratio of the Monte Carlo error relative to the standard deviation of each parameter is about 0.008 to 0.071. Table 22 and Table 23 present the parameter estimations and the 95 percent Bayesian credible intervals (C.I.) for modeling PDO crashes and injury crashes, respectively.

Results of a conventional NB model and the alternative model proposed by this study (MENB) are summarized in Table 22 and Table 23. For PDO crashes, most of the parameters are identified as having a statistically significant effect on the PDO crash risk, as their 95 percent Bayesian CI did not cover zero for both the NB and MENB models. Specifically, longer work zone length and larger number of ADT per lane are associated with a higher PDO crash rate. Moreover, if the work zone speed was sharply dropped, it will increase the PDO crash rate. In addition, state highways have higher PDO crash rates. Work zones at sites that have more lanes will have higher PDO crash rates compared to locations with fewer lanes. This might be attributed to the complexity of the site and more interactions (for example, lane change) among vehicles in different lanes. Notably, if the number of lanes under normal conditions was sharply reduced, the PDO crash rate will increase. Many vehicles are forced to merge, and some of late merge attempts might be a possible reason for the higher crash rate. If the work zone contains many ramps or intersection, they will create more complicated traffic conditions at work zones, which in turn may increase the crash rate. For instance, the ramps on highways involve a lot of unsafe merging or diverging events. If they were combined in a work zone, the situation might be worse. Similarly, these parameters were found to significantly affect the injury crash rate in work zones regardless of which model is used. Both PDO and injury crash rates were found to be lower during nighttime, which may be attributed to the lower traffic volume and fewer vehicle interactions in the work zones in the evening.

Comparing the NB and MENB models, the inverse dispersion parameter κ of the NB model is less than that of MENB model. This validates the assumption that the observations are overdispersed with respect to Poisson distribution. In addition, the larger value of $1/\kappa$ in the NB model implies that apparent overdispersion can be partially caused by measurement error in the work zone length. The magnitude of the measurement error relative to the variation in work zone length is assessed using the reliability ratio $\sigma_{\varepsilon}^2/(\sigma_{\varepsilon}^2 + \sigma_{F}^2)$. The reliability ratios for PDO and injury crash models are 0.222 and 0.223, respectively, which indicate the presence of a relative high magnitude of measurement error in the observed work zone length. The estimated coefficient of work zone length in the NB model is almost double the MENB model. Without addressing the measurement error, the larger coefficient of work zone length in the NB model thus can lead to a downward bias on some other coefficients in the model.

The comparisons of the model diagnostic criteria estimated from each model are also shown in Table 22 and Table 23. For POD crash modeling, the DIC for the NB model is 4309.63 and 4284.69 for the MENB model. For injury crash modeling, the DICs are 2737.50 and 2714.49 for NB and MENB models, respectively. For both PDO and injury crash modeling, allowing for measurement error in work zone length produces smaller DIC values (DIC values were reduced by more than 20 using MENB). Thus, model selection based on DIC suggests that MENB leads to a better model fit. Similarly, MSPE rankings were consistent with the previous finding that the MENB model provides a better model fitting for the work zone crash data than the NB model. The results indicate that the MENB model improved the fitting performance by about 2.5 percent for PDO crashes (MSPE from 1.506 to 1.468) and 1.8 percent for injury crashes (MSPE from 1.142 to 1.122). Therefore, we concluded that the MENB model is preferred in modeling work zone crashes given the measurement errors in work zone lengths.

Table 22. Model Results for Work Zone PDO Crashes

Variables	**NB**		**MENB**	
	Estimate ± SE	**95% CI**	**Estimate ± SE**	**95% CI**
constant	−4.037 ± 0.647	−5.443, −3.008	−3.644 ± 0.575	−4.578, −2.060
ln(length)	0.490 ± 0.119	0.257, 0.725	0.246 ± 0.099	0.066, 0.450
ln(adt)	0.367 ± 0.084	0.233, 0.533	0.403 ± 0.070	0.238, 0.521
night	−0.349 ± 0.156	−0.649, −0.035	−0.403 ± 0.142	−0.689, −0.120
work zone speed limit	−0.010 ± 0.010	−0.029, 0.010	−0.012 ± 0.008	−0.026, 0.004
speed reduction	0.034 ± 0.011	0.013, 0.055	0.045 ± 0.011	0.024, 0.065
road system	0.501 ± 0.133	0.236, 0.761	0.310 ± 0.110	0.091, 0.521
number of lanes	0.599 ± 0.096	0.421, 0.795	0.529 ± 0.087	0.356, 0.711
dropped lanes	0.277 ± 0.081	0.117, 0.434	0.254 ± 0.082	0.100, 0.421
number of ramps	0.044 ± 0.020	0.004, 0.084	0.067 ± 0.019	0.029, 0.103
number of intersections	0.012 ± 0.007	−0.002, 0.027	0.018 ± 0.007	0.003, 0.031
κ	1.926 ± 0.150	1.652, 2.239	1.994 ± 0.181	1.675, 2.386
σ_ε	–	–	0.402 ± 0.014	0.375, 0.430
σ_F	–	–	0.752 ± 0.020	0.714, 0.792
MSPE	1.506 ± 0.066	1.383, 1.637	1.468 ± 0.073	1.324, 1.612

Table 23. Model results for work zone injury crashes

Variables	NB		MENB	
	Estimate ± SE	**95% CI**	**Estimate ± SE**	**95% CI**
constant	−5.756 ± 0.994	−8.116, −4.182	−3.109 ± 1.091	−4.883, −1.049
ln(length)	0.628 ± 0.167	0.251, 0.935	0.355 ± 0.167	0.024, 0.668
ln(adt)	0.421 ± 0.094	0.262, 0.605	0.236 ± 0.095	0.054, 0.396
night	−0.322 ± 0.192	−0.680, 0.075	−0.523 ± 0.181	−0.888, −0.157
work zone speed limit	−0.015 ± 0.011	−0.036, 0.007	−0.017 ± 0.011	−0.040, 0.004
speed reduction	0.028 ± 0.015	−0.001, 0.060	0.035 ± 0.018	0.003, 0.067
road system	0.975 ± 0.169	0.647, 1.319	0.736 ± 0.170	0.415, 1.076
number of lanes	0.594 ± 0.131	0.328, 0.856	0.520 ± 0.119	0.292, 0.772
dropped lanes	0.376 ± 0.093	0.190, 0.554	0.410 ± 0.094	0.227, 0.591
number of ramps	0.023 ± 0.026	−0.025, 0.079	0.053 ± 0.025	0.004, 0.102
number of intersections	0.001 ± 0.010	−0.017, 0.023	0.004 ± 0.012	−0.019, 0.027
κ	2.264 ± 0.330	1.710, 3.007	2.329 ± 0.407	1.692, 3.274
σ_ε	–	–	0.403 ± 0.014	0.376, 0.432
σ_F	–	–	0.751 ± 0.020	0.714, 0.791
MSPE	1.142 ± 0.046	1.053, 1.235	1.122 ± 0.057	1.008, 1.233
DIC	2737.50	–	2714.49	–

To better understand the marginal effects of the variables, elasticity of each variable is examined. In general, elasticity is calculated as:

$$E_{x_{ij}}^{\lambda_i} = \frac{\partial \lambda_i}{\partial x_{ij}} \frac{x_{ij}}{\lambda_i} \tag{16}$$

where E represents the elasticity; λ_i is the accident frequency of the work zone i; and x_{ij} is the j^{th} explanatory variable associated with work zone i. We applied Equation 16) to Equation 3:

$$E_{x_{ij}}^{\lambda_i} = \beta_j x_{ij} \tag{17}$$

where β_j is the coefficient of the corresponding variable j.

Inclusion of a logarithmic transformation of variables in the NB model gives us the opportunity to test the proportionalities between the variables and the crash counts. The estimated log-transformed model parameters directly indicate the elasticity of the corresponding variables.

Equation 17 is valid only for the continuous explanatory variables, not for dummy variables. For them, pseudo-elasticity can be used to approximate the elasticity of these variables.(57) In cases where the covariates are dummy variables, pseudo-elasticity indicates the incremental change in the CF produced by change in the corresponding dummy variables. Pseudo-elasticity can be calculated as:

$$E_{x_{ij}}^{\lambda_i} = \frac{\exp(\beta_j)-1}{\exp(\beta_j)} \tag{18}$$

The elasticity for each explanatory variable is shown Table 24. The elasticity of the MENB model implicates that a 1 percent increase in the work zone length on the log-scale resulted in about a 0.2 percent increase in PDO and a 0.3 percent increase in injury CF. Similarly, a 1 percent increase in ADT on the log-scale resulted in about a 3.7 percent and 2.2 percent increase in PDO and injury CF, respectively. When the work zone speed limit increased 1 percent, the PDO and injury CF were reduced by about 0.5 percent and 0.7 percent, respectively. If the difference between the posted speed limit under normal traffic conditions and the speed limit in working conditions increased 1 percent, the PDO crash count increased by about 0.3 percent, and the injury crash counts increased by about 2.5 percent. These two findings about work zone speed reflect the practices that if the presence of a work zone does not seriously affect traffic conditions (in terms of both operation and safety), a relatively higher speed limit or the normal speed limit generally will be posted in the work zone. Despite the different magnitude, other variables, including operated lanes, closed lanes, number of ramps, and intersections within the work zone, collectively affect work zone crash occurrence.

For indicator variables such as light condition and road system type, the interpretation of elasticity is different. The estimated elasticity indicates the change in CF given the existence of a condition (indicator = 1). For example, during nighttime, PDO and injury crashes in MENB models will be reduced by about 50 percent and 69 percent, respectively. Similarly, if the road system is a state highway or other lower-level road, the expected number of injury crashes will increase by about 52 percent in the MENB model, and the PDO crash counts will increase by about 26.6 percent.

Table 24. Elasticity Estimates for Explanatory Variables

Variables	**PDO CF Model**		**Injury CF Model**	
	NB	**MENB**	**Estimate ± SE**	**95% CI**
ln(length)	0.433	0.217	0.555	0.314
ln(adt)	3.368	3.698	3.857	2.164
night	−0.417	−0.496	−0.380	−0.687
work zone speed limit	−0.413	−0.511	−0.626	−0.716
speed reduction	0.246	0.322	0.200	0.249
road system	0.394	0.266	0.623	0.521
number of lanes	0.451	0.411	0.448	0.406
dropped lanes	0.242	0.225	0.313	0.336
number of ramps	0.043	0.064	0.023	0.052
number of intersections	0.012	0.018	0.001	0.004

As shown in Table 24, the elasticity of work zone length in the NB model is almost twice as much as that in the MENB model. The impact of work zone length on work zone crash occurrence will thus be overemphasized. Such an exaggerated impact of work zone length on safety can lead to biased selection of optimal work zone length,[58] which in turn may result in unreliable decisions for estimation of work zone user (accident) costs, design of work zone project contracting strategies, and impact management strategies.

Summary

In this section, statistical relationships between a set of explanatory variables and work zone CF were examined using extensive and detailed work zone data collected in New Jersey. We extended the traditional NB model by incorporating the effects that arise from measurement errors related to work zone length. A new model to estimate the work zone CF—namely, the MENB—has been developed.

The modeling results suggest that both work zone length and traffic volume are positively associated with crash occurrence in work zones. Such finding confirmed outcomes in previous studies.[7,9,10] The crash occurrence during nighttime was less than that of daytime. The elasticity of the coefficient in the MENB model suggested that nighttime can result in a more than 50 percent reduction in CF. The detailed information obtained through work zone project files provided us with opportunities to examine more relevant factors than previous studies did. First, two parameters related to work zone speed were specially considered in the models, and the results suggest that more changes in the speed in work zones can result in more crashes. In addition, parameters that represent the type of road and the complexity of the work zone (in terms of number of operated lanes, closed lanes, number of intersections, and ramps within work zones) were investigated. The results imply that work zones on state highways tend to cause more crashes than interstate highways. Increasing the complexity of work zones was also attributable to more work zone crashes.

Because work zone length or configuration may change as the construction schedule progresses, using a fixed-length measurement throughout the work zone duration in the NB model was found to lead to an upward bias on the coefficient of work zone length. It also affects the estimation of other explanatory variables. By considering the measurement errors, the MENB model provides a better fit to the data than the traditional NB model, as indicated by DIC and the MSPE. However, the proposed model is not meant to provide an excuse for collecting low-quality data. If the work zones were not subject to such uncertainty in length measurement, it is obvious that both models would provide comparable findings.

The model proposed in this study can be enhanced in several ways. The proposed CF model can be improved to account for measurement errors related to other explanatory variables such as traffic volume. Other distributions can be tested to identify better representations of the measurement errors in variables.

WORK ZONE CRASH SEVERITY MODELING

Data Source

Crash data used in subsequent model estimations were obtained from the crash database of NJDOT. Crash-related attributes, including roadway characteristics, environmental conditions, crash characteristics, driver information, vehicle information, and occupant information, are collected for each crash in the database. The original data are kept in four separate tables: an accident table (crash summary), a driver table (driver information), a vehicle table (vehicle information), and an occupant table (occupant information). In the accident table, each crash is described by a single data row regardless of the number of vehicles involved. The other three tables provide information about each individual (vehicle or person) in a row, as multiple vehicles, drivers, or occupants can be involved in the same crash. A unique case number is shared among these tables to link essential information about the crash, drivers, vehicles, and occupants involved in the same crash. Crash severity is coded using three categories: property damage only (noninjury), injury, and fatality.

Work zone crash data between 2006 and 2010 were extracted. After removing about 8.9 percent of data with missing values, 26,602 work zone crashes involving about 48,318 drivers and 17,126 occupants were selected for analysis. Three units of analysis are of interest in this study. The first is the injury severity of the crash level, considering driver faults. The second unit is the injury severity of drivers; the third is the injury severity of occupants. For crash-level analysis, crash severity is defined according to the highest level of severity occurring to the victims involved in the crash. Of 26,602 work zone crashes, only 42 (0.16 percent) are classified as fatal. To simplify analysis, the number of injury and fatal crashes were combined and denoted as injury crashes in this study. Table 25 summarizes the observed injury severity according to the unit of analysis.

Table 25. Observed Work Zone Crash Severity for Different Units of Analysis

Unit of Analysis	Noninjury	Injury	Total
Crash level	20,180 (75.86%)	6,422 (24.14%)	26,602 (100%)
Driver level	42,157 (87.25%)	6,161 (12.75%)	48,318 (100%)
Occupant level	14,864 (86.79%)	2,262 (13.21%)	17,126 (100%)

Contributory Attributes

To develop injury severity models for different units of analysis, it is necessary to preselect contributory attributes. In this study, we determined the contributory attributes based on two steps. The first step was to review all possible attributes available in the NJDOT crash records and refer to key attributes that are frequently used in the literature in Table 13. The second step is to select attributes that are thought to have influence on crash severity in New Jersey conditions and are available in the crash records. Following these two steps, 30 attributes of seven groups were initially hypothesized to have some association with severity levels. These attributes were grouped in terms of timeline (time of day, day of the week), environmental conditions (light, weather, road surface condition), road user–dependent variables (age, gender, license state, driver under the influence, seat position), vehicle characteristics (vehicle type, vehicle age), roadway characteristic variables (road class, alignment, median type, surface type, speed limit), crash-dependent variables (number of vehicles and people involved, cell phone use, truck involved, light vehicle involved, hazardous material involved, crash type, contributing circumstances, vehicle precrash action), and work zone information (work zone type, traffic control type). Some attributes are further classified into different dummy variables to indicate the existence of a specific condition. The definition together with the code for each variable is presented in Table 26. The majority of these variables are binary or dummy indicators representing the existence of a given condition.

Chi-square statistics are used to screen the potential correlation between the attributes and the severity. A variable is considered a risk factor if the Pearson chi-square test provides a *p* value less than the level of significance (0.1). Several factors were excluded, as they were found to be statistically insignificant. Eventually, the 58 variables listed in Table 26 were considered potential risk factors and were incorporated into the following model analysis.

Table 26. Description of Variables Used in the Model

Variable	Symbol	Type	Description
Time of day	Time	Binary	= 0 if daytime (06:00–20:00); = 1 otherwise
Day of week	Day	Binary	= 0 if weekday; = 1 if weekend
Light condition	Light	Dummy	= 0 if good condition (daylight); = 1 if poor condition (dawn, dusk, dark)
Weather condition	Weather	Dummy	= 0 if good condition (clear); = 1 if unfavorable condition (rain, snow, and so on)
Surface condition	Surf_Cond	Dummy	= 0 if good condition (dry); = 1 if poor condition (wet, snowy, icy, and so on)
Driver age	Drv_age	Continuous	Driver's age
Driver gender	Drv_gender	Binary	= 0 if male; = 1 if female
Occupant age	Occ_age	Continuous	Occupant's age
Occupant gender	Occ_gender	Binary	= 0 if male; = 1 if female
Driver license state	License	Dummy	= 0 if New Jersey issued; = 1 if other state issued
Driver under influence	DUI	Dummy	= 0 if apparently normal; = 1 if under influence (alcohol, drug, sleep, and so on)
Seat position	Seat	Dummy	= 0 if front row; = 1 if other position (second row, third row, and so on)
Vehicle type	Pass_car	Dummy	= 1 if passenger car (car, van, SUV, pickup); = 0 otherwise
	Light_veh	Dummy	= 1 if light vehicle (motorcycle, scooter, and so on); = 0 otherwise
	Heavey_veh	Dummy	= 1 if truck or bus; = 0 otherwise
Vehicle age	Veh_age	Continuous	Number of years since vehicle was built
Road class	Rd_classhigh	Dummy	= 1 if interstate, state/interstate authority; = 0 otherwise
	Rd_classmedium	Dummy	= 1 if state highway; = 0 otherwise
	Rd_classlow	Dummy	= 1 if other highway; = 0 otherwise
Road alignment	Align	Dummy	= 0 if straight; = 1 curved
Road median	Nomedian	Dummy	= 1 if no median; = 0 otherwise
	Curbmedian	Dummy	= 1 if curbed, grass, painted median; = 0 otherwise
	Barriermedian	Dummy	= 1 if barrier median; = 0 otherwise
Road surface type	Surf_typ	Dummy	= 1 if blacktop; = 0 otherwise (concrete, gravel steel grid, dirt)
Posted speed limit	Speedlow	Dummy	= 1 if speed limit ≤40 mph; = 0 otherwise
	Speedincrease	Dummy	= 1 if speed limit is 41–50 mph; = 0 otherwise
	Speedmedium	Dummy	= 1 if speed limit is 51–60 mph; = 0 otherwise
	Speedhigh	Dummy	= 1 if speed limit ≥61 mph; = 0 otherwise
Work zone type	Construction	Dummy	= 1 if construction zone; = 0 otherwise
	Maintenance	Dummy	= 1 if maintenance zone; = 0 otherwise
	Utility	Dummy	= 1 if utility zone; = 0 otherwise
Traffic control type	Nocontrol	Dummy	= 1 if no control; = 0 otherwise

	Humancontrol	Dummy	= 1 if human control (police, flagman); = 0 otherwise
	Signalsign	Dummy	= 1 if signal, sign, flashing, and so on; = 0 otherwise
	Lanemark	Dummy	= 1 if lane markings; = 0 otherwise
	Channelization	Dummy	= 1 if channelization; = 0 otherwise
Number of vehicles	Veh_num	Continuous	Total number of vehicles involved in crash
Number of victims	Person_num	Continuous	Total number of victims involved in crash
Cell phone use	Cellphone	Binary	= 1 if yes; = 0 no
Truck involved	Truck_involved	Binary	= 1 if yes; = 0 no
Light vehicle involved	Lightveh_involved	Binary	= 1 if yes; = 0 no
Hazardous material	Hazmat	Binary	= 1 if yes; = 0 no
Crash type	C_samedirection	Dummy	= 1 if same direction (rear end, side swipe); = 0 otherwise
	C_angle	Dummy	= 1 if with angle (right angle, left turn/U turn); = 0 otherwise
	C_opposite	Dummy	= 1 if opposite direction (head on, angular, side swipe); = 0 otherwise
	C_overturn	Dummy	= 1 if overturned; = 0 otherwise
	C_fixedobj	Dummy	= 1 if fixed objected; = 0 otherwise
	C_nonfixed	Dummy	= 1 if nonfixed object (animal, pedestrian, and so on); = 0 otherwise
Contributing circumstances	Unsafespeed	Dummy	= 1 if unsafe speed; = 0 otherwise
	Inattention	Dummy	= 1 if driver inattention; = 0 otherwise
	Improper	Dummy	= 1 if improper action or failed to follow regulations; = 0 otherwise
	Close	Dummy	= 1 if following too closely; = 0 otherwise
	Other_error	Dummy	= 1 if other driver errors (vehicle, road, and so on); = 0 otherwise
Precrash action	Gostraight	Dummy	= 1 if going straight ahead; = 0 otherwise
	Maketurn	Dummy	= 1 if making turn; = 0 otherwise
	Slowmove	Dummy	= 1 if low-speed manipulation (slow moving, parking, and so on); = 0 otherwise
	Interaction	Dummy	= 1 if vehicle interaction (changing lanes, merging, and so on); = 0 otherwise
	Other_action	Dummy	= 1 if other actions; = 0 otherwise

Methodology

In this study, we aimed to examine the factors that contribute to the severity of work zone crashes. Each work zone crash in the crash dataset was categorized as either injury or noninjury. Thus, crash severity can be denoted as a dichotomous outcome (injury vs. noninjury) of a work zone crash, where $y = 1$ for the injury crash and $y = 0$ for the noninjury crash. Naturally, such a dichotomous nature facilitates the use of a binomial/binary logistic regression model to examine the influence of various factors on the probability of a crash being an injury crash, where $\pi(x)$ is the probability of a work zone crash being categorized as an injury crash and $1 - \pi(x)$ is the probability of a work zone crash being noninjury. The binary logistic regression model identifies the relationship between the log odds of the dichotomous outcome and various risk factors. Mathematically, it can be formulated as in Equation 19:

$$\mathrm{logit}[\pi(x)] = \log\left[\frac{\pi(x)}{1-\pi(x)}\right] = \alpha + \mathrm{X}'\beta \qquad (19)$$

Based on Equation 19, the probability that an injury work zone crash will occur can be described by the logistic distribution shown in Equation 20:

$$\mathrm{P}(\mathrm{y} = 1|\mathrm{X}) = \pi(x) = \frac{exp(\alpha+\mathrm{X}'\beta)}{1+exp(\alpha+\mathrm{X}'\beta)} \qquad (20)$$

where $\pi(x)$ is the conditional probability of the form $\mathrm{P}(\mathrm{y} = 1|\mathrm{X})$; X is the vector of explanatory variables (risk factors) that could be continuous or dichotomous; β is the corresponding vector of the coefficients; and α is the intercept parameter. A maximum-likelihood estimation technique was used to determine these parameters in the regression model. A chi-square test was used to test the overall significance of the logistic regression model. The significance of individual risk factors within the model was evaluated using the Wald chi-square statistic. Moreover, the unique contribution of the $\mathrm{j^{th}}$ risk factor on crash severity can be expressed by the odds ratio (OR), which is defined as:

$$\mathrm{OR} = \exp(\beta_\mathrm{j}) \qquad (21)$$

with the 95% CI of $\left[\exp\left(\beta_\mathrm{j} - 1.96\mathrm{SD}_{\beta_\mathrm{j}}\right), \exp(\beta_\mathrm{j} + 1.96\mathrm{SD}_{\beta_\mathrm{j}})\right]$, where $\mathrm{SD}_{\beta_\mathrm{j}}$ is the standard error of the coefficient β_j. OR measures the ratio of the predicted odds for a one-unit increase in the predictor variable $\mathrm{x_j}$ when other variables in the model are held fixed.

Results and Discussion

The binary logistic regressions were fitted using the Generalized Linear Model in the statistical software R. The estimated parameters for the severity models for crash-level, driver-level, and occupant-level analysis are presented in Table 27, Table 28, and Table 29, respectively. The overall model fit was tested by examining whether the full model with those independent variables fit significantly better than a null model with just an intercept. The chi-squared test was performed. The test statistic was the difference between the residual deviance for the model with independent variables and the null model with degrees of freedom (df) equal to the number of predictor variables in the full model. For the crash-level analysis, the chi-squared statistic χ^2 =1983.222 with 46 degrees of freedom and an associated *p* value less than 0.001indicates that the overall explanatory variables of the model have significant influence on the crash risk given a significance level of 0.05. Similarly, the model for driver-level (χ^2 =3201.171, df = 45) as well as occupant-level (χ^2 =997.659, df = 48) analysis also fits significantly better than an empty model.

The significance of individual variables within each model was tested using the Wald chi-squared statistic. Of the variables used for the crash-level severity analysis, 27 were found to be statistically significant. Of the variables entered into the driver-level severity model, 29 were identified as statistically significant. Similarly, 27 variables were found to be statistically significant in the occupant-level severity model. The corresponding estimated coefficients, standard error, Wald chi-squared statistics, and *p* values for each variable for different units of analysis are listed in Table 27, Table 28, and Table 29, accordingly. It should be noted that the estimated coefficients are not directly interpretable; therefore, the ORs were derived. The OR in the table is interpreted as a comparison of the injury risk associated with each level of a variable with the selected reference. It helps us determine the variables that significantly affect the probability of a crash being an injury crash. The interpretations of these results are presented in the following subsections.

Crash-level Analysis

For crash-level analysis, factors associated with the driver at fault were considered in the model. It should be noted that the original dataset was limited by the unavailability of at-fault driver information. To address this problem, a new dataset was created based on the following assumptions:

- *Driver at fault* is defined as the driver under the influence (DUI) or who has apparent contributing circumstances.
- For single-vehicle crashes, the driver of the vehicle is automatically considered the driver at fault.
- For multiple-vehicle crashes, if only one driver is involved in the crash who has a driver error, that person is considered the driver at fault.
- For multiple-vehicle crashes, if multiple drivers are involved in the crash, drivers who do not have any error (“none” in the driver error column) are excluded from the dataset. If more than one driver is left in the dataset for a particular crash after the above step, a random selection is made among them.

According to Table 27, following findings were identified:

Time and Environmental Characteristics

The OR associated with the time of day in Table 27 is 1.147, which implies that the likelihood of injury for a work zone crash occurring at nighttime is 1.147 times that of daytime. This result is consistent with the observations in the section, "Severity Description," that about 27 percent of crashes occurring between 20:00 and 06:00 resulted in injury or fatality, while only about 23 percent of crashes occurring during daytime were injury or fatal crashes. Nighttime work zones creating injury risk may be attributed to their visibility, lighting glare, and reduced driver alertness.[11,35,39] As many researchers have shown,[34,35] this study found that day of the week, weather condition, and road surface condition do not have a significant impact on injury risk in a work zone crash. Generally, poor light conditions were expected to increase the severity of work zone crashes.[see references 32,34,35, and 59] However, this study found that light condition did not significantly affect injury risk in New Jersey.

Road User and Vehicle Characteristics

Based on model results, Li and Bai (2008)[34] showed that the age of the driver at fault had a significant impact on crash severity, although gender did not. Moreover, it is said that the risk of fatalities in a severe crash caused by a male driver was about 1.7 times higher than that caused by a female driver.[35] In contrast, our modeling results show that the age of the driver at fault did not significantly contribute to the injury risk of work zone crashes. However, if the driver at fault were female, the outcome of the crash was more likely to be an injury crash compared to a crash caused by a male driver (OR: 1.209). As shown by Wang (2009),[59], if the driver's physical status were apparently under the influence of alcohol, drugs, or fatigue, he or she was also more likely to cause a more severe crash (OR: 2.198). In addition, the at-fault driver driving a light-duty vehicle such as a motorcycle or scooter leads to greater injury risk (OR: 1.627). This outcome was expected, as these vulnerable users are less protected than car users, and if a crash occurred, they were more likely to be injured. The results about driver gender, physical condition, and vehicle type were also consistent with findings by Khattak et al. (2003)[31] when analyzing total harm of multivehicle collisions. Similarly, the at-fault driver driving an old vehicle may raise the injury risk compared with new vehicles (OR: 1.012). It is expected that these old-vehicle users suffered more injury risk, as their safety equipment may not be as good as those in new vehicles. Interestingly, out-of-state drivers are less likely to cause severe crashes (OR: 0.924), which can be explained by people driving more carefully on roads with which they are unfamiliar.

Road and Work Zone Characteristics

State highways are found to be associated with increased injury risk compared to lower-level roads (OR: 1.221). A high speed limit in work zones also increases the injury risk, as is consistent with many existing studies.[see references 31,32,34,39, and 59] Barrier medians are also associated with increased injury risk (OR: 1.068). Maintenance zones are associated with greater injury risk than utility work zones (OR: 1.172). As shown in other studies,[31,32], however, the presence of a construction zone did not significantly change the injury risk compared to utility zones.

It is intuitively expected that traffic controls in work zones would decrease crash severity to a certain level. However, the modeling results suggested that the presence of traffic-control devices did not significantly reduce injury risk. Indeed, most such controls are found to be associated with greater injury risk (OR: >1). In fact, there are still no common findings on the effects of these countermeasures. For instance, Qi et al. (2005)[11] showed that flaggers can reduce work zone crash severity, while Li and Bai (2009)[35] found no significant effect when flaggers are used. Interestingly, traffic signs and signals were frequently found to have no effect or even increase injury risk.[32,35] Possibly, these control devices are deployed in larger work zones that have higher levels of hazardous activity.[31] The intervention of traffic-control devices may cause more severe vehicle conflicts; thus, their use in work zones needs to be further examined.

Crash Characteristics

As research has shown,[11,31,32] an increase in the number of vehicles and people involved in a crash increases the likelihood of injury crashes, as their ORs are significantly greater than 1. The OR associated with the variable “light-duty vehicle involved in crash” is 1.688, implying that the injury propensity of a crash involving light vehicles is about 69 percent higher. Inconsistent with a previous study,[35] crashes involving trucks are found to decrease the likelihood of severe crashes. Such findings are not the same as we commonly think. Wang (2009)[59] suggested that the reason may be attributed to people driving carefully when a truck is near them.

Compared to rear-end or side-swipe crashes, crash types such as right-angle, head-on, or fixed-object collisions are prone to cause severe crashes. In particular, the OR associated with overturn crashes is 13.716, implying that the injury risk of an overturn crash is about 13 times higher than crashes in the same direction. Previous research[31,32] has identified many of these dangerous crash types. Driver errors, such as unsafe speed, inattention, and following too close, are found to contribute to crash severity level. Unsafe speed is associated with the largest OR (1.616), which indicates the significant relationship between driving speed and crash severity. Inattentive driving or following too close may increase the injury risk of work zone crashes by about 20 percent. Compared to vehicles going straight ahead, vehicles making turns, interacting with others, or moving slowly lead to less severe crashes. This finding might be explained by the lower speed or greater caution when interacting with surrounding vehicles and infrastructures.

Driver-level Analysis

The previous section gave an overview of the explanatory variables that may influence work zone crash severity. This section further examines the factors that contribute to driver injury risk in work zone crashes.

Time and Environmental Characteristics

The OR associated with time of day in the driver-level model is 1.201 in Table 28. Model estimation for driver-level severity analysis (*n* = 48318)
, which suggests that a crash occurring at nighttime tends to increase the likelihood of driver injury risk. Day of the week and weather conditions are found to have no obvious impact on driver injury risk. In addition, as shown by Akepati and Dissanayake (2011)[38] other variables such as road surface condition and light conditions are found not to significantly affect the injury risk of drivers.

Road User and Vehicle Characteristics

Elderly drivers are likely to be involved in severe crashes, as the OR of age is 1.003. This finding might be partially attributed to limitations in the physical, visual, and cognitive ability of elderly drivers.[59] Similarly, female drivers are more likely to be injured than male drivers in work zone crashes. This finding is consistent with a recent finding by Weng and Meng (2011) [41] that female drivers have greater injury risk in work zone crashes, especially in crashes occurring in construction and utility work zones. Out-of-state drivers are less likely to be involved in severe crashes, as they may pay more attention to unfamiliar roads and regulations in New Jersey. Compared to normal drivers, those who drive under the influence of alcohol, drugs, fatigue, and the like are associated with significantly higher risk (OR: 3.331) of being injured in a work zone crash.

As shown by Akepati and Dissanayake (2011),[38] vehicle configurations also have an impact on driver injury risk. If a driver rides a light-duty vehicle such as a motorcycle or scooter, his or her risk of being injured is more than five times higher than passenger car drivers, because a light-duty vehicle driver is less protected than those in cars. In contrast, driving a heavy vehicle, such as a truck or tractor, tends to dramatically decrease drivers' injury risk, as the OR is 0.288. This is understandable, as other vehicles are vulnerable compared to these heavy vehicles. When hitting other vehicles, these heavy vehicles may cause severe injury to others rather than their own drivers. As shown by Weng and Meng (2011),[41] drivers of older vehicles may be less protected because of the unavailability of safety equipment. Therefore, these drivers are associated with a greater risk of injury in a crash (OR: 1.024).

Road and Work Zone Characteristics

Driving on state highways (arterials) poses a greater injury risk than driving on lower-level roads such as municipal or county roads (OR: 1.216). This may be because of the complicated driving conditions, such as traffic light interventions, high volume, relatively high speed, and frequent lane changes on these state highways. Similarly, the presence of a barrier median is likely to result in a severe crash for drivers (OR: 1.059). As many studies have shown,(35,38,41) the ORs associated with speed variables confirmed that a high speed limit increases driver injury risk in a work zone crash. In particular, if the speed limit is greater than 60 mph, drivers' risk of being injured is about 40 percent greater than those driving in low-speed-limit work zones. However, road alignment was found to have no significant impact on driver injury risk, which is inconsistent with Weng and Meng (2011),(41) who found that work zones located on curved sections were associated with higher driver casualty risk.

The ORs associated with work zone types indicated that driver injury risk is statistically different depending on the work zone type. Driver injury risk in maintenance work zones is statistically higher (OR: 1.205), although there is no significant difference between construction and utility zones. This result is slight different from the findings of Weng and Meng (2011),(41) which suggested that construction work zones had the greatest driver casualty risk, followed by maintenance and utility work zones. Deployment of traffic signals or signs is shown to increase driver injury risk (OR: 1.244). Again, such a finding is inconsistent with previous studies.(41,38)

Crash Characteristics

The OR of the number of vehicles involved is 1.264, implying that if multiple vehicles were involved in a crash, the driver is likely to be injured, as there were multiple collisions (hits) among vehicles. As shown by Weng and Meng (2011),(41) if the crash involved a truck, driver injury risk is about 24 percent higher. However, if a driver hit a light vehicle, he or she was less likely to suffer physical harm or damage than his or her counterparts. Such a driver’s injury risk is about 30 percent lower compared to hitting larger vehicles.

Different crash types have different effects on driver injury risk. For instance, the nonfixed-object crash has the lowest impact on driver injury risk compared to other crash types, such as rear-end or side-swipe crashes (OR: 0.704). In contrast, four major crash types, including angle, opposite direction, overturn, and fixed-object collisions, are found to statistically increase driver injury risk. In particular, the OR for overturn crash is 22.306, which implies that such crashes significantly contribute to drivers’ physical harm. In fact, these crashes were widely recognized as the most harmful events.(41)

The small ORs of driver errors suggest that driving at unsafe speeds, being inattentive, using improper actions, and following too closely may not contribute directly to drivers hurting themselves. When turning or interacting with other vehicles, drivers pay more attention to their surroundings. If a crash occurs in these situations, drivers are less likely to be injured than unprepared drivers going straight ahead. In contrast, drivers in vehicles moving slowly (that is, stopping or stopped) are prone to suffering greater injury risk (OR: 1.190).

Occupant-level Analysis

This section investigates the potential factors that may contribute to the crash severity of occupants involved in work zone crashes.

Time and Environmental Characteristics

Similar to drivers, occupants are prone to have more severe crashes at nighttime. Specifically, their injury risk is about 24 percent higher than in daytime crashes. Unlike driver severity, the likelihood of injury risk for occupants is about 15 percent less during the weekend. As shown by Meng and Weng (2011),[(41)] environmental factors such as weather conditions, surface condition, and light conditions are found to have no significant impact on occupant injury risk.

Road User and Vehicle Characteristics

The OR associated with the occupants' age is 1.012, as shown in Table 29. It suggests that elderly occupants tend to incur a higher injury risk. In addition, female occupants have about a 57 percent greater injury risk than male occupants, which is consistent with previous reports.[(41)] The OR of driver age is 0.995, which suggests an interesting finding: The injury risk of seating in a vehicle driven by an adult driver is slight lower than seating in a vehicle driven by a young driver, possibly because adult drivers have more driving experience and can avoid dangerous situations. Notably, drivers under the influence may cause severe crashes that lead to relatively high injury risk not only for themselves but also for occupants (OR: >3). Compared to passengers in cars, occupants in light vehicles are less protected; thus, their injury risk is almost doubled (OR: 1.833) when involved in a work zone crash. In contrast, occupants in heavy vehicles have about a 56 percent lower injury risk. Moreover, as shown by Meng and Weng (2011),[(41)] occupants of newer vehicles have lower injury risk. As explained in driver-level analysis, this outcome can be attributed to the enhanced safety equipment and performance of newer vehicles.

Road and Work Zone Characteristics

As with drivers, occupants incur a statistically higher injury risk in work zones on state highways (OR: 1.184). Roads with curb medians and barrier medians increase the injury risk for occupants. However, increasing the posted speed limit in a work zone does not necessary increase occupants’ injury risk. In contrast to drivers, a medium speed limit is found to reduce about 10 percent of the injury risk for occupants. The occupant injury risk is not statistically different depending on the work zone type and their corresponding traffic control type. This outcome is consistent with findings by Meng and Weng (2011),[(41)] which showed that traffic control with signals or signs did not significantly change occupant injury risk.

Crash Characteristics

Occupant injury risk increases if the number of vehicles in a crash increases (OR: 1.202). As with drivers, this is because occupants may incur more impacts from multiple-vehicle inter-collisions. The impact of different crash types on driver injury risk is also found to have a similar effect on occupant injury risk. Specifically, overturn crashes overwhelmingly contribute to occupant injury risk (OR: 30.812), followed by opposite-direction (that is, head-on) crashes (OR: 2.789), fixed-object crashes (OR: 2.476), and left- or U-turn crashes (OR: 1.819). However, occupants have about a 30 percent lower injury risk when a nonfixed-object work zone crash occurs compared to a rear-end or side-swipe crash in the same direction. Driver errors and vehicle precrash actions lead to a similar impact on occupant injury risk as for drivers. As with findings by Meng and Weng (2011),[(41)] if the vehicle moves slowly or stops on the roadway, occupants in the vehicle suffer greater injury risk when other vehicles hit it.

Summary

This section modeled the severity of work zone crashes. Specifically, three different units of analysis—crash level, driver level, and occupant level—were performed. Three separate logistic regression models were built to examine the contributory factors that may influence overall severity, driver injury risk, and occupant injury risk in work zone crashes, respectively. Important factors belonging to different categories were identified.

Table 27. Model estimation for crash-level severity analysis (*n* = 26602)

Variable	Symbol	Description	Estimate	Standard Error	Wald χ2	OR	Significance
Constant	Intercept	Constant in model	−3.078	0.088	1215.303	–	***
Time of day	Time	= 0 if daytime (06:00–20:00); = 1 otherwise	0.137	0.047	8.619	1.147	**
Light condition	Light	= 0 if good condition (daylight); = 1 if poor condition (dawn, dusk, dark)	−0.069	0.043	2.602	0.933	–
Surface condition	Surf_Cond	= 0 if good condition (dry); = 1 if poor condition (wet, water, sand, snowy, icy, slush, oil)	−0.059	0.041	2.029	0.943	–
Driver gender	Drv_gender	= 0 if male; = 1 if female	0.190	0.032	36.086	1.209	***
Driver license state	License	= 0 if New Jersey issued; = 1 if other state issued	−0.079	0.041	3.716	0.924	.
Driver under the influence	DUI	= 0 if apparently normal; = 1 if under the influence (alcohol, drug, medication, fell asleep, and so on)	0.788	0.071	124.314	2.198	***
Vehicle type	Light_veh	= 1 if light vehicle (motorcycle, scooter, and so on); = 0 otherwise	0.487	0.210	5.380	1.627	*
Vehicle age	Veh_age	Number of years since vehicle was built	0.011	0.003	16.326	1.012	***
Road class	Rd_classhigh	= 1 if interstate, state/interstate authority; = 0 otherwise	−0.093	0.059	2.476	0.911	–
	Rd_classmedium	= 1 if state highway; = 0 otherwise	0.200	0.044	20.424	1.221	***
Road divided by median	Barriermedian	= 1 if barrier median; = 0 otherwise	0.066	0.038	3.045	1.068	.
Posted speed limit	Speedhigh	= 1 if speed limit is ≥61 mph; = 0 otherwise	0.206	0.072	8.248	1.229	**
	Speedmedium	= 1 if speed limit is 41–60 mph; = 0 otherwise	0.067	0.040	2.831	1.069	.
Work zone type	Maintenance	= 1 if maintenance zone; = 0 otherwise	0.159	0.077	4.251	1.172	*
Traffic control type	Humancontrol	= 1 if human control (police, flagman, and so on); = 0 otherwise	0.387	0.096	16.334	1.473	***
	Signalsign	= 1 if signal, sign, flashing, and so on; = 0 otherwise	0.334	0.053	40.245	1.396	***
	Lanemark	= 1 if lane markings; = 0 otherwise	0.159	0.050	9.871	1.172	**
	Channelization	= 1 if channelization; = 0 otherwise	0.096	0.067	2.052	1.101	–
Number of vehicles involved	Veh_num	Total number of vehicles involved in crash	0.446	0.034	174.270	1.562	***
Number of persons involved	Person_num	Total number of occupants involved in crash	0.156	0.012	161.880	1.169	***
Truck involved in crash	Truck_involved	= 1 if yes; = 0 no	−0.398	0.045	76.871	0.672	***
Light vehicle involved in crash	Lightveh_involved	= 1 if yes; = 0 no	0.524	0.163	10.292	1.688	**
Crash type	C_angle	= 1 if with angle (right angle, left turn or U turn); = 0 otherwise	0.620	0.061	103.439	1.859	***
	C_opposite	= 1 if opposite direction (head on, angular, side swipe); = 0 otherwise	0.787	0.113	48.655	2.196	***
	C_overturn	= 1 if overturned; = 0 otherwise	2.619	0.180	212.172	13.716	***
	C_fixedobj	= 1 if fixed objected; = 0 otherwise	0.638	0.060	114.021	1.892	***
Contributing circumstances	Unsafespeed	= 1 if unsafe speed; = 0 otherwise	0.480	0.071	46.181	1.616	***
	Inattention	= 1 if driver inattention; = 0 otherwise	0.208	0.035	34.522	1.231	***
	Close	= 1 if following too closely; = 0 otherwise	0.199	0.051	15.337	1.220	***
Vehicle precrash action	Maketurn	= 1 if making turn; = 0 otherwise	−0.493	0.064	60.224	0.611	***
	Slowmove	= 1 if low-speed manipulation (slow moving, parking, backing, and so on); = 0 otherwise	−0.108	0.038	8.245	0.898	**
	Interaction	= 1 if driving interaction (changing lanes, merging, passing, and so on); = 0 otherwise	−0.534	0.048	121.597	0.586	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 28. Model estimation for driver-level severity analysis (n = 48318)

Variable	Symbol	Description	Estimate	Standard Error	Wald χ2	OR	Significance
Constant	Intercept	Constant in model	−3.237	0.081	1599.814	–	***
Time of day	Time	= 0 if daytime (06:00–20:00); = 1 otherwise	0.184	0.038	23.225	1.201	***
Surface condition	Surf_Cond	= 0 if good condition (dry); = 1 if poor condition (wet, water, sand, snowy, icy, slush, oil)	−0.106	0.040	7.061	0.900	**
Driver age	Drv_age	Driver's age	0.003	0.001	11.513	1.003	***
Driver gender	Drv_gender	= 0 if male; = 1 if female	0.607	0.029	423.755	1.835	***
Driver license state	License	= 0 if New Jersey issued; = 1 if other state issued	−0.157	0.042	14.270	0.855	***
Driver under the influence	DUI	= 0 if apparently normal; = 1 if under the influence (alcohol, drug, medication, fell asleep, and so on)	1.203	0.078	239.643	3.331	***
Vehicle type	Light_veh	= 1 if light vehicle (motorcycle, scooter, and so on); = 0 otherwise	1.689	0.221	58.452	5.412	***
	Heavey_veh	= 1 if truck or bus; = 0 otherwise	−1.246	0.091	185.908	0.288	***
Vehicle age	Veh_age	Number of years since vehicle was built	0.024	0.003	78.783	1.024	***
Road class	Rd_classmedium	= 1 if state highway; = 0 otherwise	0.196	0.030	42.179	1.216	***
Road alignment	Align	= 0 if straight; = 1 curve	0.073	0.045	2.627	1.076	–
Road divided by median	Barriermedian	= 1 if barrier median; = 0 otherwise	0.058	0.034	2.912	1.059	.
Posted speed limit	Speedhigh	= 1 if speed limit is ≥61 mph; = 0 otherwise	0.337	0.062	29.976	1.401	***
	Speedmedium	= 1 if speed limit is 41–60 mph; = 0 otherwise	0.129	0.035	13.712	1.138	***
Work zone type	Maintenance	= 1 if maintenance zone; = 0 otherwise	0.187	0.072	6.643	1.205	**
Traffic control type	Humancontrol	= 1 if human control (police, flagman, and so on); = 0 otherwise	0.171	0.094	3.309	1.187	.
	Signalsign	= 1 if signal, sign, flashing, and so on; = 0 otherwise	0.219	0.044	25.152	1.244	***
	Lanemark	= 1 if lane markings; = 0 otherwise	0.096	0.039	6.002	1.101	*
Number of vehicles involved	Veh_num	Total number of vehicles involved in crash	0.234	0.018	162.992	1.264	***
Cell phone use	Cellphone	= 1 if yes; = 0 no	0.256	0.150	2.901	1.291	.
Truck involved in crash	Truck_involved	= 1 if yes; = 0 no	0.218	0.051	18.574	1.244	***
Light vehicle involved in crash	Lightveh_involved	= 1 if yes; = 0 no	−0.343	0.189	3.279	0.710	.
Crash type	C_angle	= 1 if with angle (right angle, left turn or U turn); = 0 otherwise	0.661	0.054	149.915	1.937	***
	C_opposite	= 1 if opposite direction (head on, angular, side swipe); = 0 otherwise	1.112	0.094	138.458	3.040	***
	C_overturn	= 1 if overturned; = 0 otherwise	3.105	0.178	303.742	22.306	***
	C_fixedobj	= 1 if fixed object; = 0 otherwise	1.136	0.061	351.681	3.113	***
	C_nonfixed	= 1 if nonfixed object (animal, pedestrian, railcar-vehicle, and so on); = 0 otherwise	−0.350	0.073	22.858	0.704	***
Contributing circumstances	Unsafespeed	= 1 if unsafe speed; = 0 otherwise	−0.131	0.083	2.504	0.877	–
	Inattention	= 1 if driver inattention; = 0 otherwise	−0.703	0.041	297.208	0.495	***
	Improper	= 1 if improper action or failed to follow regulations; = 0 otherwise	−0.601	0.065	84.763	0.548	***
	Close	= 1 if following too closely; = 0 otherwise	−0.780	0.065	144.355	0.459	***
	Other_circumstance	= 1 if other factors (vehicle, road, and so on); = 0 otherwise	−0.407	0.063	41.713	0.665	***
Vehicle precrash action	Maketurn	= 1 if making turn; = 0 otherwise	−0.349	0.072	23.839	0.705	***
	Slowmove	= 1 if low-speed manipulation (slow moving, parking, backing, and so on); = 0 otherwise	0.174	0.035	24.814	1.190	***
	Interaction	= 1 if driving interaction (changing lanes, merging, passing, etc.); = 0 otherwise	−0.365	0.061	35.715	0.694	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 29. Model estimation for occupant-level severity analysis (n = 17126)

Variable	Symbol	Description	Estimate	Standard Error	Wald χ2	OR	Significance
Constant	Intercept	Constant in model	−2.961	0.172	297.364	–	***
Time of day	Time	= 0 if daytime (06:00–20:00); = 1 otherwise	0.219	0.059	13.938	1.245	***
Day of week	Day	= 0 if weekday; = 1 if weekend	−0.161	0.051	9.912	0.851	**
Driver age	Drv_age	Driver's age	−0.005	0.002	7.160	0.995	**
Driver gender	Drv_gender	= 0 if male; = 1 if female	0.082	0.049	2.829	1.086	.
Occupant age	Occ_age	Occupant's age	0.012	0.001	87.010	1.012	***
Occupant gender	Occ_gender	= 0 if male; = 1 if female	0.455	0.049	84.975	1.577	***
Driver under the influence	DUI	= 0 if apparently normal; = 1 if under the influence (alcohol, drug, medication, fell asleep, and so on)	1.240	0.143	75.633	3.457	***
Vehicle type	Light_veh	= 1 if light vehicle (motorcycle, scooter, and so on); = 0 otherwise	0.606	0.212	8.156	1.833	**
	Heavey_veh	= 1 if truck or bus; = 0 otherwise	−0.813	0.166	24.017	0.444	***
Vehicle age	Veh_age	Number of years since vehicle was built	0.039	0.004	79.870	1.040	***
Road class	Rd_classmedium	= 1 if state highway; = 0 otherwise	0.169	0.049	12.124	1.184	***
Road divided by median	Curbmedian	= 1 if curbed, grass, painted median; = 0 otherwise	0.201	0.070	8.329	1.223	**
	Barriermedian	= 1 if barrier median; = 0 otherwise	0.266	0.067	15.644	1.304	***
Road surface type	Surf_typ	= 1 if blacktop; = 0 otherwise (concrete, gravel steel grid, dirt)	−0.163	0.088	3.407	0.850	.
Posted speed limit	Speedmedium	= 1 if speed limit is 41–60 mph; = 0 otherwise	−0.109	0.052	4.403	0.896	*
Work zone type	Construction	= 1 if construction zone; = 0 otherwise	−0.149	0.097	2.337	0.862	–
Traffic control type	Signalsign	= 1 if signal, sign, flashing, and so on; = 0 otherwise	0.094	0.058	2.577	1.098	–
Number of vehicles involved	Veh_num	Total number of vehicles involved in crash	0.184	0.026	51.513	1.202	***
Crash type	C_angle	= 1 if with angle (right angle, left turn or U turn); = 0 otherwise	0.598	0.088	46.398	1.819	***
	C_opposite	= 1 if opposite direction (head on, angular, side swipe); = 0 otherwise	1.026	0.152	45.400	2.789	***
	C_overturn	= 1 if overturned; = 0 otherwise	3.428	0.296	133.795	30.812	***
	C_fixedobj	= 1 if fixed object; = 0 otherwise	0.907	0.097	87.638	2.476	***
	C_nonfixed	= 1 if nonfixed object (animal, pedestrian, railcar-vehicle, and so on); = 0 otherwise	−0.363	0.135	7.196	0.696	**
Contributing circumstances	Inattention	= 1 if driver inattention; = 0 otherwise	−0.663	0.069	92.116	0.515	***
	Improper	= 1 if improper action or failed to follow regulations; = 0 otherwise	−0.455	0.105	18.704	0.635	***
	Close	= 1 if following too closely; = 0 otherwise	−0.723	0.115	39.715	0.485	***
	Other_circumstance	= 1 if other factors (vehicle, road, and so on); = 0 otherwise	−0.315	0.102	9.555	0.730	**
Vehicle precrash action	Maketurn	= 1 if making turn; = 0 otherwise	−0.252	0.117	4.615	0.777	*
	Slowmove	= 1 if low-speed manipulation (slow moving, parking, backing, and so on); = 0 otherwise	0.139	0.058	5.703	1.149	*
	Interaction	= 1 if driving interaction (changing lanes, merging, passing, and so on); = 0 otherwise	−0.314	0.098	10.273	0.731	**
	Other_action	= 1 if other actions; = 0 otherwise	0.688	0.421	2.671	1.990	–

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

FIELD DATA COLLECTION

New Jersey drivers have particular driving characteristics and New Jersey has distinct traffic and geometric conditions that may impact the contributing factors associated with work zone crashes in New Jersey. Historical crash data is limited in capturing driver behavior in construction work zones. For this reason, field data were collected in a number of work zones for the purpose of better understanding driver behavior and identifying factors that may lead to unsafe driving behavior in New Jersey work zones. The data collection also serves to provide preliminary data that could be used to identify the types of countermeasures that should be considered for New Jersey conditions.

The data collected include speed and flow data in the four areas of the work zone including: the advance warning area, the transition area, the activity area and the termination area. The objective of the data collection was to determine existing driver compliance, or the extent of driver non-compliance, to work zone speed limits and to determine lane change behavior prior to and within the work zone where lane closures are warranted.

Work Zone Selection Criteria

The initial thinking in identifying work zones for data collection was to select work zones identified as having a high frequency of work zone crashes, long-term stationary work zones and work zones with lane closures. The initial thinking was also to collect data using two methodologies: Autoscope and Nu-metrics Classifiers. Autoscope uses video data of traffic conditions to detect, calculate, and collect traffic data including: vehicle presence and passage; speed; density; time occupancy; incident detection; vehicle length; space occupancy; flow rate; volume; time headway; and level of service. One of the limitations of Autoscope is the need to be at a high vantage point, such as at an overpass, to collect video data for all lanes of the roadway. Where overpasses did not exist, data would be collected using Numetrics Classifiers. Numetrics classifiers are devices which are installed in the middle of the travel lane and provide a count and speed of each vehicle that passes over the device.

Working with the Research Project Selection and Implementation Panel (RPSIP) it was determined that due to liability and insurance issues, it would not be feasible to collect data using the numetrics classifiers. For this reason an additional criteria used in identifying work zones for data collection was the presence of an overpass suitable for collecting video data.

Using the State's www.511nj.org website, information on long and short-term construction projects was reviewed to identify work zones for data collection. The review showed that although several construction events involved lane closures, many of these lane closures were short-term or occurred at night. Short-term work zones proved problematic as the time limitations made it difficult to have sufficient time to set-up the equipment and for getting multiple days of data. Night construction also posed concern as the quality of the video and ultimately the data may be impacted with low light conditions.

Work Zone Configurations

Despite the restrictions in the work zones where data were to be collected, 40 hours of data were collected in four work zones in New Jersey. Table 30 shows the locations and time period where data were collected.

I-78

Data were collected in New Jersey on I-78 in the westbound local lanes from milepost 55.13 to 55.46. At this location, I-78 is a three lane freeway with the left lane closed during construction. Figure 40 shows the work zone layout where the data collection was performed. The figure also shows the signage placed upstream of the work zone. Video data were collected at the Nye Avenue and Bragaw Avenue overpasses. The video data collected at Nye Avenue captured conditions upstream of the work and the data collected at Bragaw Avenue captured conditions within the work zone. Figure 41 shows photos upstream of the work zone at the Nye Avenue overpass. Figure 42 shows photos within the work zone at the Bragaw Avenue overpass. For the upstream work zone, all lanes were open, while within the work zone, the left lane was closed with only the middle lane and shoulder lane in use. The work zone during non-construction periods has a posted speed limit of 55 mph, with a small portion posted at 65 mph. During the construction period the work zone had a speed limit of 45 mph.

Table 30. Work Zone Data Collection Sites

Route	Milepost	City (County)	Work Zone Location	Date	Time
I-78 WB	55.13 – 55.46	Newark (Essex)	Upstream	9/29/10	10 AM–12 PM
			Within	9/29/10	1 PM–3 PM
NJ 21 SB	9.0 – 9.7	Clifton (Passaic)	Upstream	11/09/10	1 PM–3 PM
			Within	11/09/10	10 AM–12 PM
I-295 NB	27.71 – 33.22	Haddon Heights (Camden)	Upstream	11/12/10	11:30AM–1:30PM
			Entering	11/23/10	11:30 AM – 1:30 PM
			Within	11/23/10	12 PM–2 PM
			Exiting	11/12/10	12 PM–2 PM
I-80 EB	42.80 – 44.20	Parsippany-Troy (Morris)	Upstream	06/05/11 06/11/11 06/13/11	10:20AM– 12:20AM
			Entering	06/05/11 06/11/11 06/13/11	10 AM–12 PM
			Within	06/08/11 06/12/11 06/14/11	10 AM–12 PM
			Exiting	06/08/11 06/12/11 06/14/11	10:20AM– 12:20AM

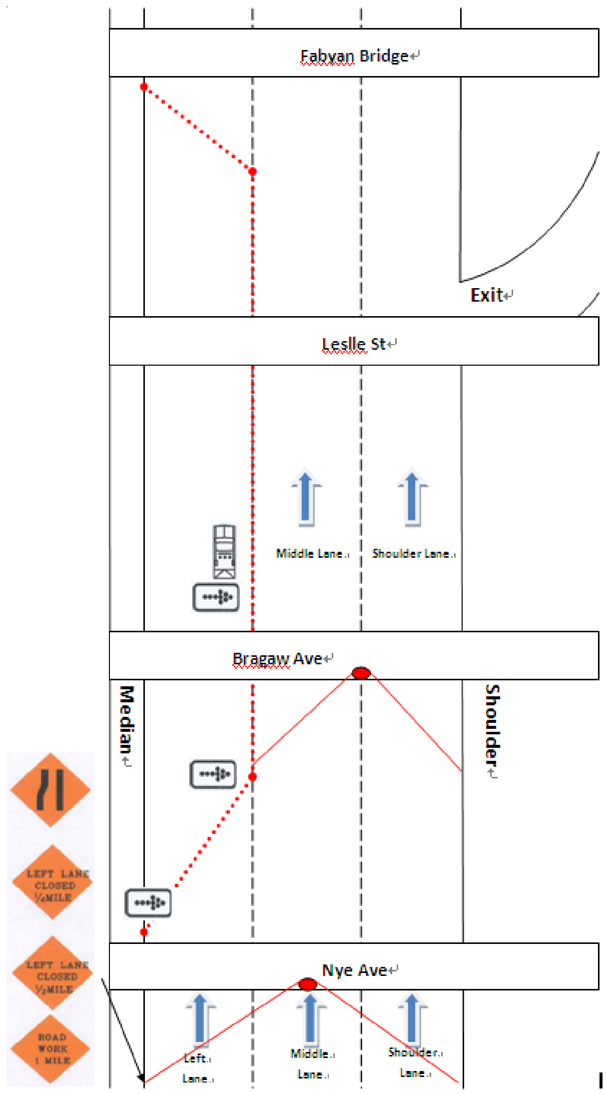


Figure 40. I-78 Work Zone Layout

Figure 41. I-78 Westbound, Nye Ave Overpass Upstream of Work Zone

Figure 42. I-78 Westbound, Bragaw Avenue Overpass Within Work zone

The data were collected from 10:00AM to 12:00PM for the location upstream of the work zone and from 1:00PM to 3:00PM for the location within the work zone. Overall statistics for the operating conditions at the work zone are shown in Table 31. Traffic volume and speed data are given by lane in Table 32 for locations upstream and within the work zone. Upstream of the work zone, the volume in the shoulder lane and middle lane are relatively the same carrying 42% and 43% of the volume, respectively. The left lane volume is much lower than the remaining lanes with this lane carrying 15% of the volume. The lower volume in the left lane is due to left lane closure occurring downstream which causes drivers to change lanes before the buffer area. Within the work zone area, a higher percent of vehicles use the middle lane with 54% of vehicles using this lane with 46% of vehicles using the shoulder lane.

Table 31. Overall Operating Conditions at I-78 Work Zone

Location in Work Zone	Speed (mi/hr)	Density (veh/mi/ln)	Flow (veh/hr/ln)	Headway (sec)
Upstream	56.17	12.56	667	8.18
Within	46.28	34.99	1515	2.54

Table 32. I-78 Average Volumes and Speeds by Lane at Work Zone

	Upstream Work Zone				Within Work Zone		
	Shoulder Lane	**Middle Lane**	**Left Lane**	**Total**	**Shoulder Lane**	**Middle Lane**	**Total**
Volume (vph)	838	866	305	2008	1411	1644	3055
Vol. Distrib.	41.70%	43.11%	15.19%	-	46.17%	53.83%	-
Speed (mph)	52.34	56.08	59.92	56.11	45.01	46.97	45.99

The average speed of vehicles by lane upstream and within the work zone is also provided in Table 32. Upstream of the work zone, speeds are highest in the left lane with an average speed of 60 mph. This is due to the fact that the left lane has lower volumes compared to the shoulder and middle lanes. The higher speeds in the left lane is also attributable to the lack of heavy vehicles in the left lanes as heavy vehicles are prohibited from using the left lane on freeways in New Jersey. Although the middle lane has higher volumes than the shoulder lanes, the middle lane has a higher speed of 56 mph compared to the shoulder lane which has a speed of 52 mph. Shoulder lane vehicles have slower speeds as some vehicles in this lane are preparing to exit the highway and so travel at a lower speed. Within the work zone, speeds are uniform between the shoulder and middle lanes.

NJ 21

Data were collected southbound on NJ-21 in the westbound local lanes from milepost 9.0 to 9.7. At this location, NJ-21 is a three lane freeway with a left lane closure and traffic shift during construction. Figure 43 shows the work zone layout where the data collection was performed. The figure also shows the signage placed upstream of the work zone. Video data were collected at the River Drive and Route 3 overpasses. The video data collected at River Drive captured conditions upstream of the work and the data collected at Route 3 captured conditions within the work zone. Figure 44 shows photos upstream of the work zone at the River Drive overpass. Figure 45 shows photos within the work zone at the Route 3 overpass. For the upstream work zone, all lanes were open, while within the work zone the left lane was closed with only the middle lane and shoulder lane in use. The work zone during non-construction periods has a posted speed limit of 55 mph. During the construction period the work zone had a speed limit of 45 mph.

The data were collected from 1:00PM to 3:00PM for the location upstream of the work zone and from 10:00AM to 12:00PM for the location within the work zone. Overall statistics for the traffic data collected at the work zone are shown in Table 33. Traffic volume and speed data are given by lane in Table 34 for locations upstream and within the work zone. Upstream of the work zone, the volume in the shoulder lane and middle lane are relatively the same carrying 38% and 40% of the volume, respectively. The left lane volume is much lower than the remaining lanes with this lane carrying 22% of the volume. The lower volume in the left lane is due to left lane closure occurring downstream. Although no lane changes are required, few vehicles stay in the left lane. Within the work zone area, a higher percent of vehicles use the middle lane with 64% of vehicles using this lane with 37% of vehicles using the left lane.

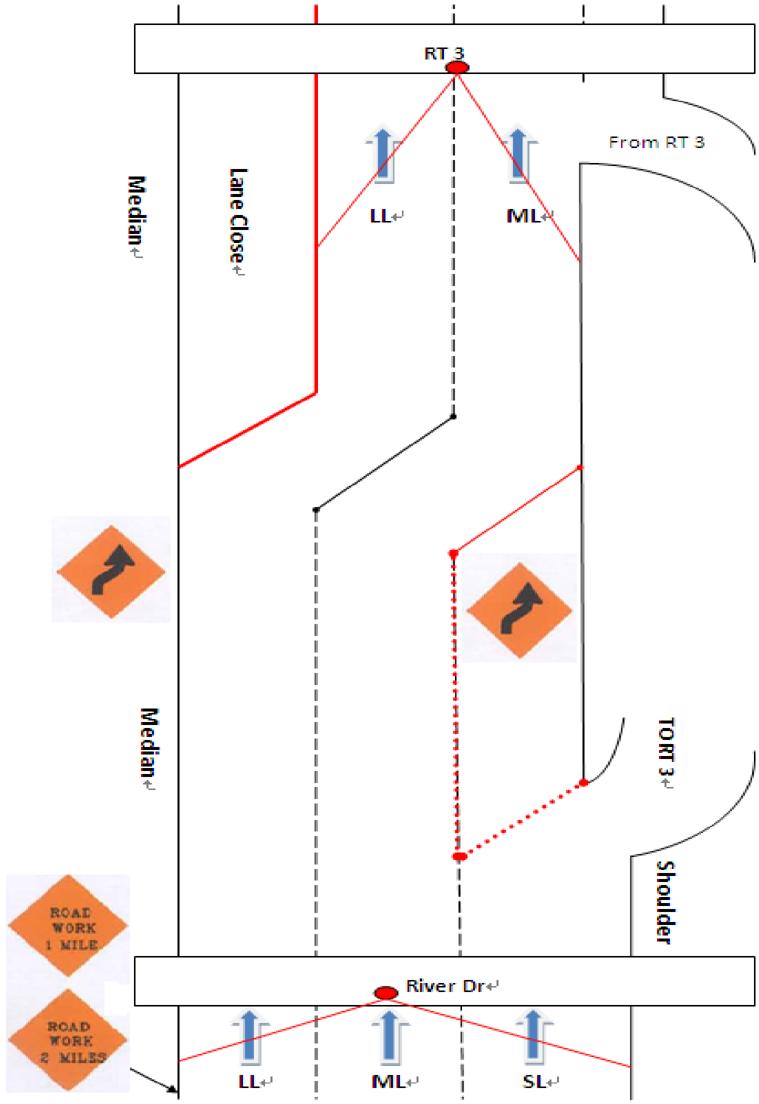


Figure 43. NJ-21 Work Zone Layout

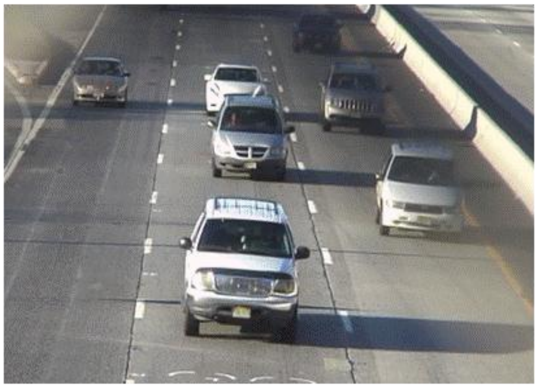


Figure 44. NJ-21 Southbound, River Drive Overpass Upstream of Work Zone

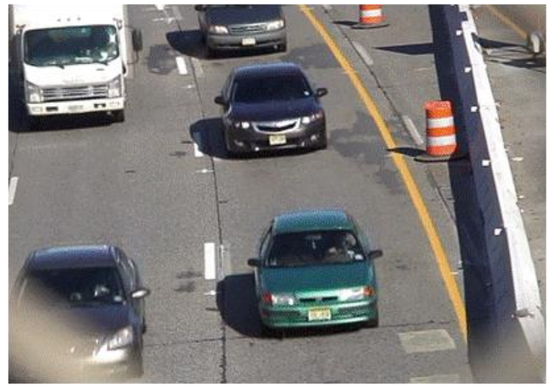


Figure 45. NJ-21 Southbound, Route 3 Overpass Within Work Zone

Table 33. Overall Operating Conditions at NJ-21 Work Zone

Location in Work Zone	Speed (mi/hr)	Density (veh/mi/ln)	Flow (veh/hr/ln)	Headway (sec)
Upstream	61.89	14.02	825	5.85
Within	57.06	9.88	549	9.15

Table 34. NJ-21 Average Volumes and Speeds at Work Zone

	Upstream Work Zone				Within Work Zone		
	Shoulder Lane	**Middle Lane**	**Left Lane**	**Total**	**Middle[1] Lane**	**Left[2] Lane**	**Total**
Volume (vph)	943	980	553	2475	706	392	1097
Vol. Distrib.	38.10%	39.59%	22.32%	-	64.31%	35.69%	-
Speed (mph)	59.55	62.80	63.31	56.11	54.22	59.91	45.99

[1] Lane is the continuation of the upstream middle lane
[2] Lane is the continuation of the upstream left lane

The average speed of vehicles upstream and within the work zone is also provided in Table 34. Upstream of the work zone, speeds are highest in the left lane with an average speed of 63 mph. This is due to the fact that the left lane has lower volumes compared to the shoulder and middle lanes. Although the middle lane has slightly higher volumes than the shoulder lanes, the middle lane has a higher speed of 63 mph compared to the shoulder lane which has a speed of 60 mph. Shoulder lane vehicles have slower speeds as some vehicles in this lane are preparing to exit the highway and so travel at a lower speed. Within the work zone, the left lane has a higher speed of 60 mph compared to speeds in the middle lane of 54 mph.

I-295

Data were collected in New Jersey on I-295 in the northbound local lanes from milepost 27.71 to 33.22. At this location, I-295 is a three lane freeway with the left lane closed during construction. Figure 46 shows the work zone layout where the data collection was performed. The figure also shows the signage placed upstream of the work zone. Video data were collected at four overpasses: Kresson Road (Upstream WZ), Berlin Road (Entering WZ), Devon Avenue (Within WZ) and Bell Road (Exiting WZ). Figure 47, Figure 48, Figure 49 and Figure 50 show photos upstream, within, entering and exiting the work zone, respectively. For the upstream work zone, all lanes were open, while within the work zone there was a crossover from the local lane to the express lane with a left shift of the middle and shoulder lanes. The work zone during non-construction periods has a posted speed limit of 55 mph.

The data were collected from 11:30AM to 1:30PM for the upstream and entering locations of the work zone and from 12:00PM to 2:00PM for locations within and exiting the work zone. Overall statistics for the traffic data collected at the work zone are shown in Table 35. Traffic volume and speed data are given by lane in Table 36 for locations upstream, entering, within and exiting the work zone. Upstream of the work zone, the volume in the shoulder and middle lanes are relatively the same carrying 40% and 38% of the volume, respectively. The left lane volume is much lower with this lane carrying 15% of the volume. The lower volume in the left lane may be due to the downstream conditions within the work zone where vehicles in the left lane are forced to enter the express lanes. By the time vehicles are entering there are significant shifts in the distribution of volume between the lanes. The left lane which previous had the lowest volumes, now has the highest percentage of vehicles with 39 percent of the volume. The middle lane has the next highest volume of 37% and the shoulder has 23 percent. Within the work zone the lane previously designated as the shoulder lane is shifted to the middle lane and the lane previously designated as the middle lane is shifted to the left lane. The middle lane now carries 53 percent of the volume and the shoulder lane carries 47 percent. Exiting the work zone the volume distribution is similar to the upstream work zone conditions with the shoulder and middle lanes carrying 37% and 40% of the volume, respectively and the left lane carrying 23%.

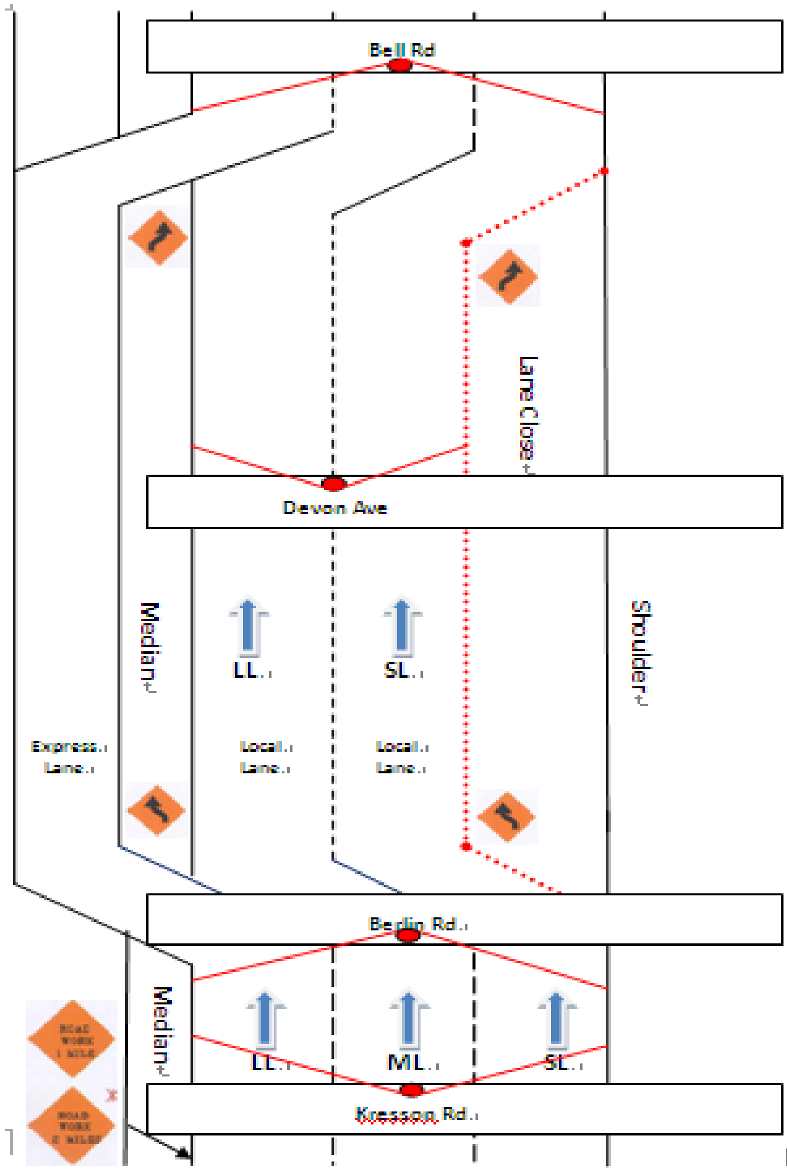


Figure 46. I-295 Work Zone Layout

Figure 47. I-295 Northbound, Kresson Road Overpass Upstream of Work Zone

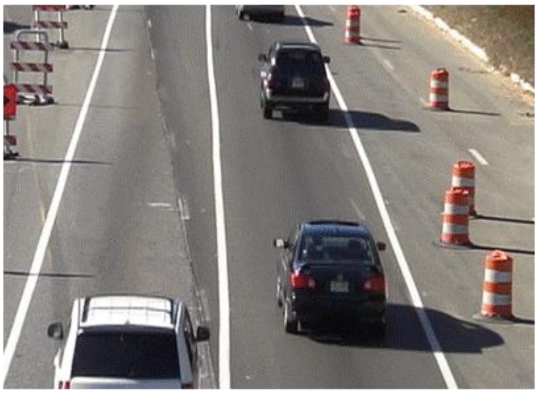


Figure 48. I-295 Northbound, Devon Avenue Overpass Within the Work Zone

Figure 49. I-295 Northbound, Berlin Road Overpass Entering Work Zone

Figure 50. I-295 Northbound, Bell Road Overpass Exiting Work Zone

Table 35. Overall Operating Conditions at I-295 Work Zone

Location in Work Zone	Speed (mi/hr)	Density (veh/mi/ln)	Flow (veh/hr/ln)	Headway (sec)
Upstream	61.85	22.62	1295	3.56
Entering	52.10	19.33	992	4.07
Within	54.59	23.54	1217	3.18
Exiting	58.08	21.66	1207	3.39

Table 36. I-295 Average Volumes and Speeds at Work Zone

	Upstream Work Zone			
	Shoulder Lane	**Middle Lane**	**Left Lane**	**Total**
Volume (vph)	1542	1488	598	3627
Vol. Distrib.	39.72%	38.33%	15.40%	-
Speed (mph)	60.26	63.29	64.78	62.78
	Entering Work Zone			
	Shoulder Lane	**Middle Lane**	**Left Lane**	**Total**
Volume (vph)	1053	1688	1771	4512
Vol. Distrib.	23.34%	37.42%	39.24%	-
Speed (mph)	48.11	52.06	54.84	51.67
	Within Work Zone			
	Shoulder Lane[1]	**Middle Lane**[2]	**Left Lane**	**Total**
Volume (vph)	1722	1969	-	3691
Vol. Distrib.	46.65%	53.35%	-	-
Speed (mph)	52.75	56.52	-	54.64
	Exiting Work Zone			
	Shoulder Lane	**Middle Lane**	**Left Lane**	**Total**
Volume (vph)	2053	2187	1231	5452
Vol. Distrib.	37.32%	40.11%	22.57%	-
Speed (mph)	56.66	58.56	59.14	58.12

[1]Shoulder lane shifted to middle lane [2]Middle lane shifted to left lane

The average speed of vehicles upstream and within the work zone is also provided in Table 36. Upstream of the work zone, speeds are similar across all lanes with the highest speed in the left lane with an average speed of 65 mph. This is due to the fact that the left lane has lower volumes compared to the shoulder and middle lanes. As vehicles enter the work zone speeds decrease to an average speed of 52 mph compared to an average speed of 63 mph upstream of the work zone. There is also larger variation in the speed by lane with a 6 mph difference in speeds between the shoulder and left lane. Within the work zone speeds are similar in the two lanes with an average speed of 53 mph in the shoulder lane and 57 mph in the middle lane. Although speeds increase at the exit of the work zone, the average speed of 58 mph is lower than the average speed entering the work zone which was 63 mph.

I-80

Data were collected in New Jersey on I-80 in the northbound local lanes from milepost 42.8 to 44.20. At this location, I-80 is a four lane freeway with the left lane closed and traffic shift during construction. Figure 51 shows the work zone layout where the data collection was performed. The figure also shows the signage placed upstream of the work zone. Video data were collected at four overpasses: Cherry Hill Road (Upstream WZ), Parsippany Road (Entering WZ), Parsippany Road (Within WZ) and Troy Road (Downstream WZ). Figure 52, Figure 53, Figure 54 and Figure 55 show photos upstream, within, entering and downstream the work zone, respectively. Upstream of the work zone, all lanes were open, while within the work zone there was a traffic shift. The work zone during non-construction periods has a posted speed limit of 65 mph.

The data were collected from 10:00AM to 12:00PM for the entering and within locations of the work zone and from 10:20AM to 12:20PM for locations upstream and exiting the work zone. Overall statistics for the traffic data collected at the work zone are shown in Table 37. Traffic volume and speed data are given by lane in Table 38 for locations upstream, entering, within and exiting the work zone. Upstream of the work zone, the volume in the shoulder and middle lane1 are relatively the same carrying 23% and 25 of the volume, respectively. The second middle lane carries the highest percent of volume with 32% of the volume in this lane and the left lane carries the lowest percent of volume with 19 percent of the volume.

The percent of volume in the shoulder lane and middle lane 1 entering the work zone is similar to conditions upstream of the work zone. Twenty-percent of the volume entering the work zone use the shoulder lane and 28% use middle lane 1. The second middle lane has the remainder of the freeway volume and carries 51% of the volume with the left lane closed at this section of the freeway. The middle 1 lane in the work zone continues to carry the highest percent of vehicles with the shoulder lane carrying a smaller percentage of the volume when compared to entering the work zone and middle lane 1 carrying a larger percentage of the volume when compared to entering the work zone.

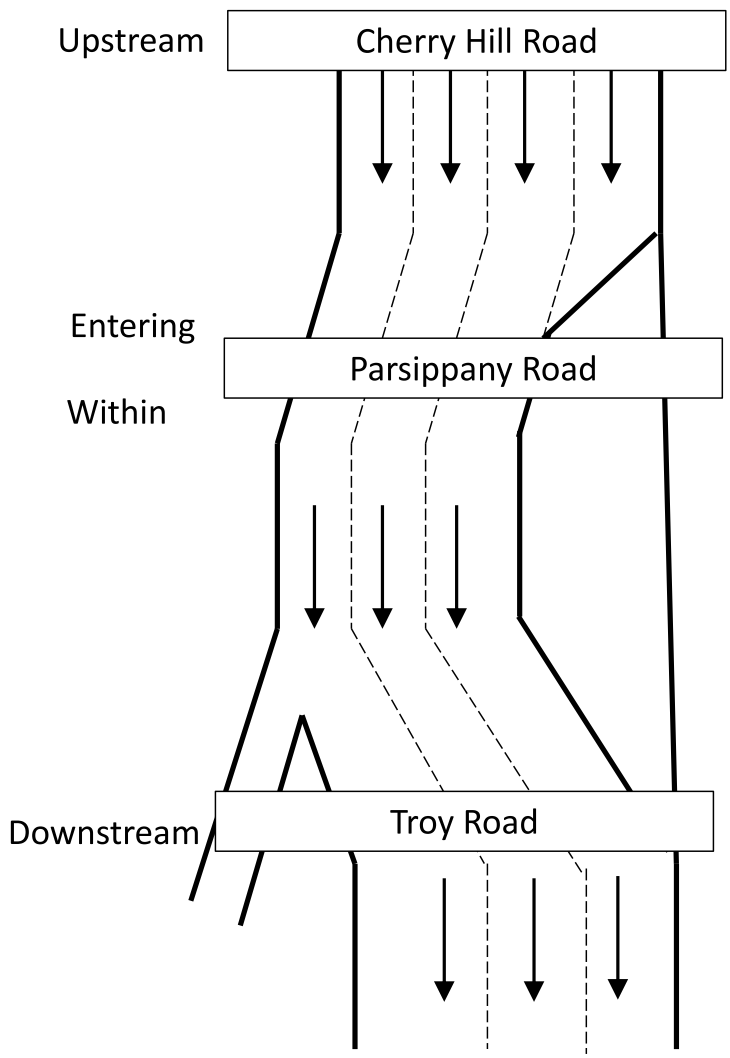


Figure 51. I-80 Work Zone Layout

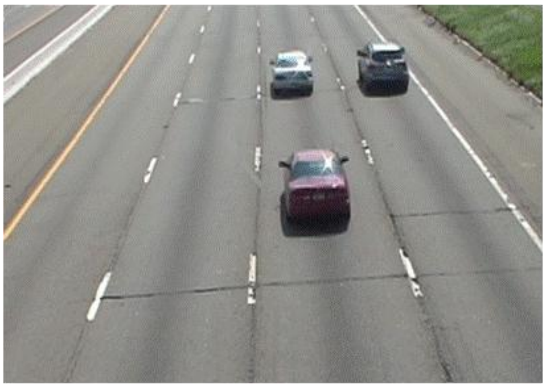


Figure 52. I-80 Eastbound, Cherry Hill Road Overpass Upstream of Work Zone

Figure 54. I-80 Eastbound, Parsippany Road Overpass Entering Work Zone

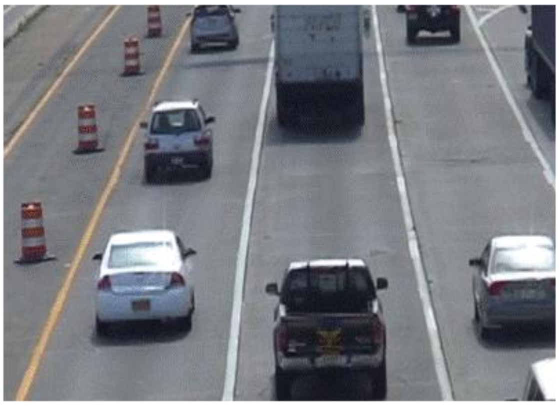


Figure 53. I-80 Eastbound, Parsippany Road Overpass Within the Work Zone

Figure 55. I-80 Eastbound, Troy Road Overpass Downstream Work Zone

Table 37. Overall Operating Conditions at I-80 Work Zone

Location in Work Zone	Speed (mi/hr)	Density (veh/mi/ln)	Flow (veh/hr/ln)	Headway (sec)
Upstream	67.29	16.50	1982	3.94
Entering	56.56	21.58	2453	3.45
Within	63.75	18.31	2281	4.38
Exiting	71.04	15.73	2081	4.44

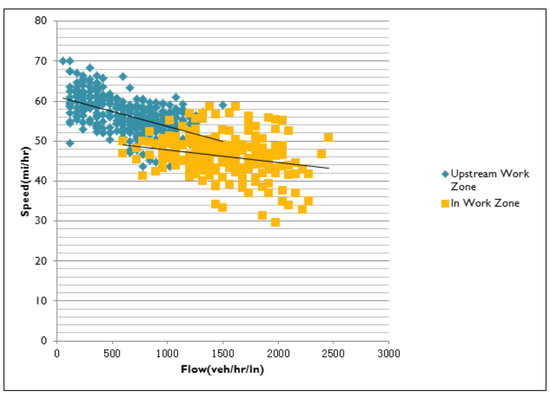
Table 38. I-80 Average Volumes and Speeds at Work Zone

	Upstream Work Zone				
	Shoulder Lane	**Middle Lane 1**	**Middle Lane 2**	**Left Lane**	**Total**
Volume (vph)	1841	2017	2550	1521	7929
Vol. Distrib.	23.22%	25.44%	32.16%	19.18%	-
Speed (mph)	63.85	67.81	68.50	69.01	67.29
	Entering Work Zone				
	Shoulder Lane	**Middle Lane 1**	**Middle Lane 2**	**Left Lane**	**Total**
Volume (vph)	1575	2064	3720	-	7359
Vol. Distrib.	21.40%	28.05%	50.55%	-	-
Speed (mph)	53.16	57.76	58.78	-	56.56
	Within Work Zone				
	Shoulder Lane	**Middle Lane 1**	**Middle Lane 2**	**Left Lane**	**Total**
Volume (vph)	1083	2222	3537	-	6842
Vol. Distrib.	15.83%	32.48%	51.70%	-	-
Speed (mph)	61.77	64.34	65.16	-	63.75
	Exiting Work Zone				
	Shoulder Lane	**Middle Lane 1**	**Middle Lane 2**	**Left Lane**	**Total**
Volume (vph)	1082	2748	2113	-	5943
Vol. Distrib.	18.21%	46.24%	35.56%	-	-
Speed (mph)	68.80	71.17	73.14	-	71.04

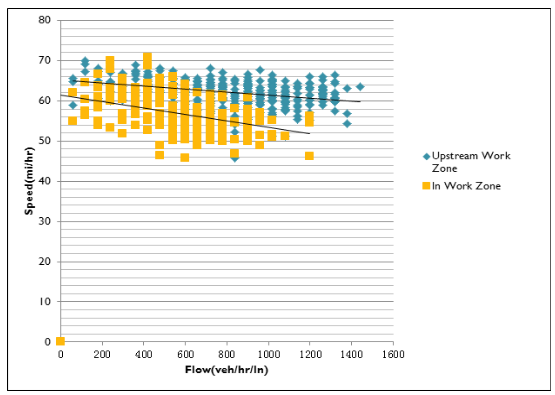
The average speed of vehicles upstream and within the work zone is also provided in Table 38. Upstream of the work zone, speeds are similar across all lanes with the highest speed in the left lane with an average speed of 69 mph. As vehicles enter the work zone speeds decrease from an average speed of 56 mph compared to an average speed of 67 mph upstream of the work zone. Within the work zone, the average speed is 64 mph across the lanes with the highest speed in middle lane 2. Downstream the work zone speeds increase to 71 mph across all lanes with the highest speed in the left lane.

Summary of Work Zone Field Conditions

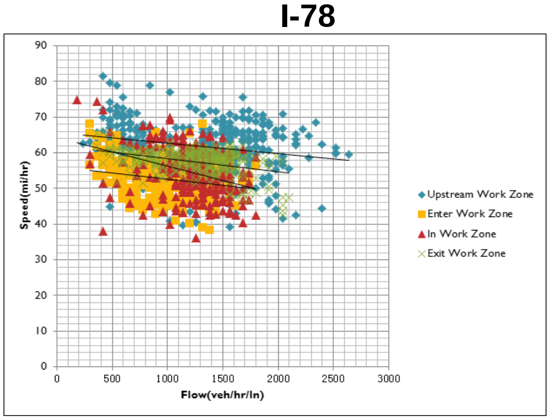
Each work zone is unique and driver behavior is significantly impacted by the work zone configuration and roadway operation. This is evidenced in Figure 56 which shows the speed-flow relationship for each work zone. The figure illustrates differences in the



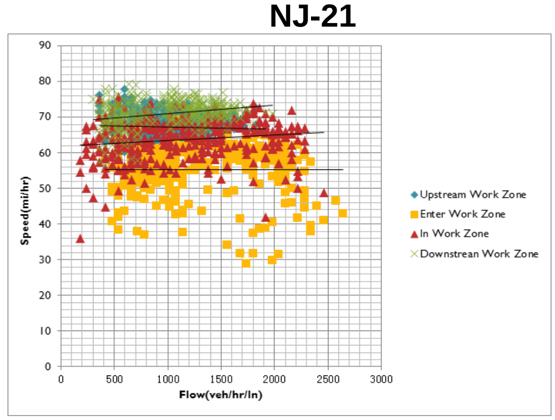
I-78



NJ-21



I-295



I-80

Figure 56. Speed-Flow Relationship for Each Work Zone

speed-flow relationship between each segment of the work zone. The speed-flow shows that the location of the work zone with the lowest speeds and greatest variability in speeds is entering the work zone. This larger variation in speeds as vehicles enter the work zone results in a larger potential for vehicle-vehicle crashes.

Lane Change Maneuvers Within Work Zone

In addition to determining existing driver compliance to speed limits, a second objective of the field data study was to better understand driver behavior with regard to lane changes within the work zone. Lane change behavior at locations upstream, entering, within and downstream of the work zone was studied at each of the work zones studied.

I-78

Table 39 provides additional information about the volume and average speed by lane under which the lane changes occur. The number of lane changes was determined manually through observing the video data gathered from the work zone location. Lane changes were counted upstream of the work zone for four maneuvers including vehicles moving: (1) from the shoulder lane to the middle lane (SL to ML); (2) from the middle lane to the shoulder lane (ML to SL); (3) from the middle lane to the left lane (ML to LL); and (4) from the left lane to the middle lane (LL to ML). For the location upstream of the work zone, there are slight differences in the number of lane changes between the maneuvers. A number of vehicles continue to change lanes from the middle lane to the left lane despite warnings of a left lane closure.

At the I-78 work zone, lane change behavior was studied prior to and within the work zone. Figure 57 show the number of lane changes occurring upstream of the work zone during 30-minute time

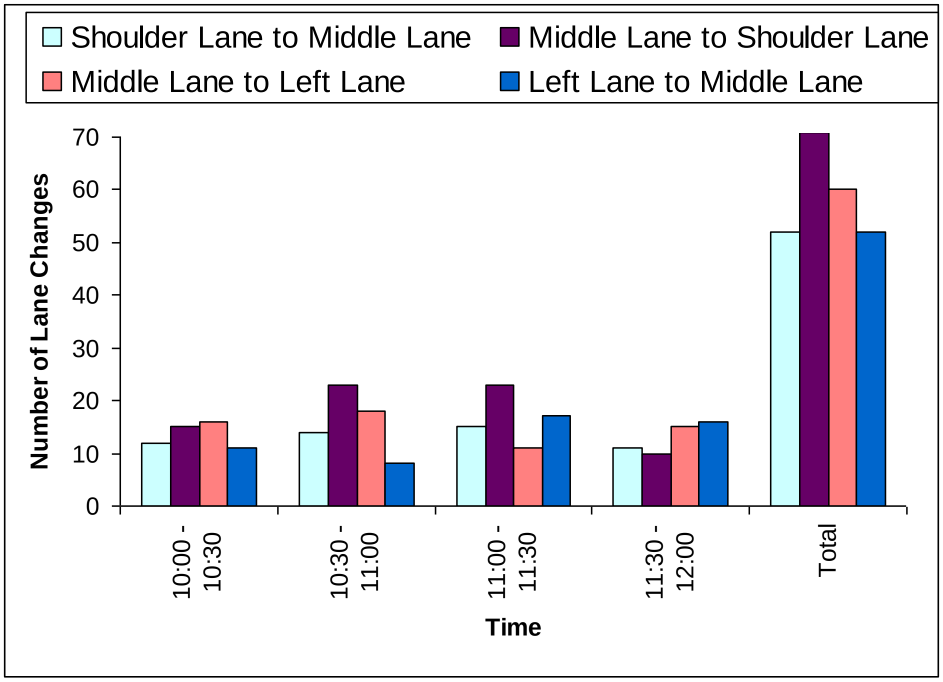


Figure 57. Lane Changes Upstream of the Work Zone

Table 39. Number of Lane changes Upstream of the Work Zone (I-78)

Time		**10:00 - 10:30 AM**			**10:30 – 11:00 AM**			**11:00 – 11:30 AM**			**11:30 - 12:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		432	436	166	387	421	131	430	450	140	426	424	173
Speed (mph)		52.72	55.97	60.19	51.65	55.92	58.42	52.99	56.78	60.57	51.99	55.67	60.50
No. of Lane Changes	**SL to ML**	12			15			16			11		
	ML to SL	15			23			18			8		
	ML to LL	16			23			11			17		
	LL to ML	11			10			15			16		

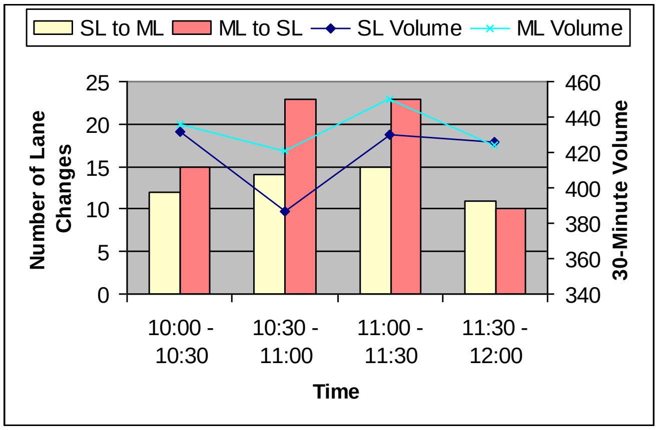


Figure 58. Lane Changes by Volume for Shoulder Lane (SL) and Middle Lane (ML)

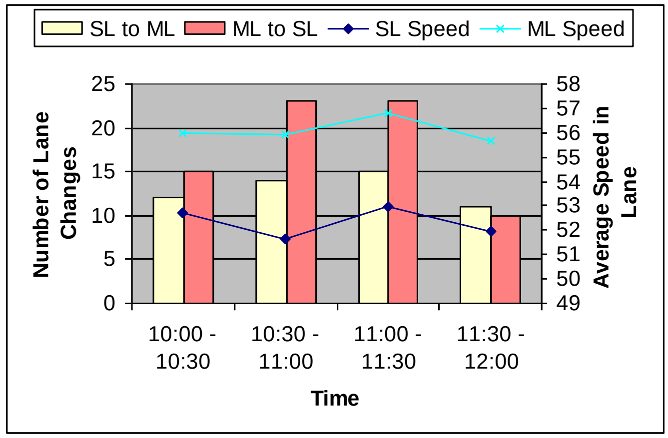


Figure 59. Lane Changes by Speed for Shoulder Lane (SL) and Middle Lane (ML)

Figure 58 shows the number of lane changes from the shoulder lane to the middle lane and from the middle lane to the shoulder lane. Included in the figure is the 30-minute volume for the middle and shoulder lanes. The figure shows that, in general, the number of lane changes is higher from the middle lane to the shoulder lane compared to the number of lane changes from the shoulder lane to the middle lane. For a left lane closure, it is expected that there would be more vehicles moving from the middle lane to the shoulder lane. The number of lane changes from the shoulder lane to the middle lane is slightly higher, though, than the lane changes from the middle lane to the shoulder lane during the 11:30 to 12:00 pm time period. During this time period there is little difference in the volumes in the shoulder and middle lanes. For the 10:00 to 10:30 am time period, the volume in the two lanes are also very close resulting in a small difference between the number of lane changes between the middle and should lanes.

Figure 59 shows the number of lane changes and includes the average speed by lane. There is about a 3 to 4-mph difference in speeds between the middle and the shoulder lane. The number of lane changes does not appear to be impacted by the average speed by lane.

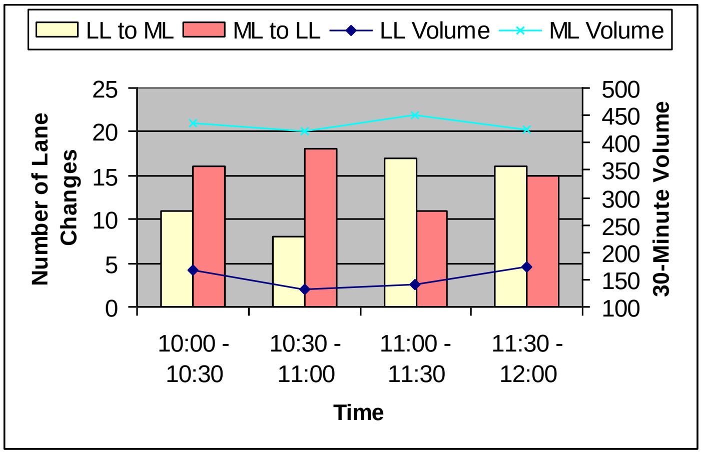


Figure 60. Lane Change by Volume for Left Lane (LL) and Middle Lane (ML)

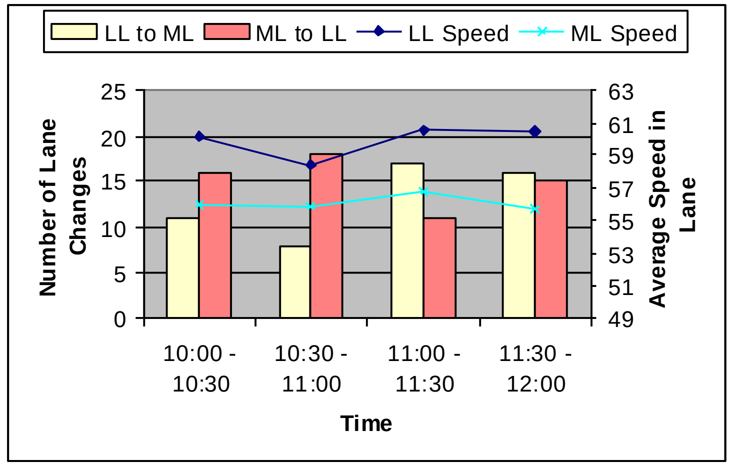


Figure 61. Lane Change by Speed for Left Lane (LL) and Middle Lane (ML)

Figure 60 shows the number of lane changes from the left lane to the middle lane and from the middle lane to the left lane. It is to be expected that because of the left lane closure in the construction work zone vehicles would change lanes from the left lane to the middle lane. What is not expected, however, is that although the left lane is closed in the construction area, the figure indicates more lane changes occurring from the middle lane to the left lane compared to lane changes from the left lane to the middle lane for the 10:00 to 10:30 AM period and for the 10:30 to 11:00 AM period. The middle lane has significantly higher volumes than compared to the left lane throughout the time period which may account for the higher number of lane changes. The higher volumes in the middle lane during the 11:00 to 11:30 AM and the 11:30 to 12:00 PM period, however, did not result in a large number of lane changes from this lane compared to lane changes from the left lane to the middle lane.

Figure 61 shows the number of lane changes and includes the average speed by lane. Speeds in the left lane are higher than those in the middle lane. There is about a 2 to 4-mph difference in speeds between the middle and the left lane.

NJ-21

At the NJ-21 work zone, lane change behavior was studied prior to and within the work zone. Figure 62 and Figure 63 show the number of lane changes occurring upstream and within the work zone during 30-minute time periods, respectively. Table 40 provides additional information about the volume and average speed by lane under which the lane changes occur.

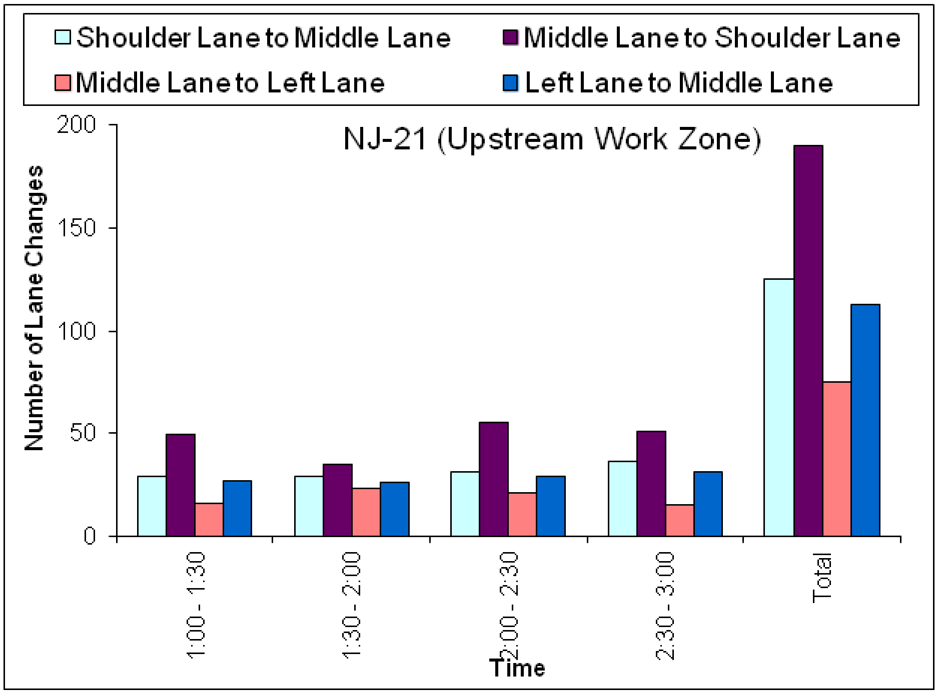


Figure 62. Lane Changes Upstream of the Work Zone (NJ-21)

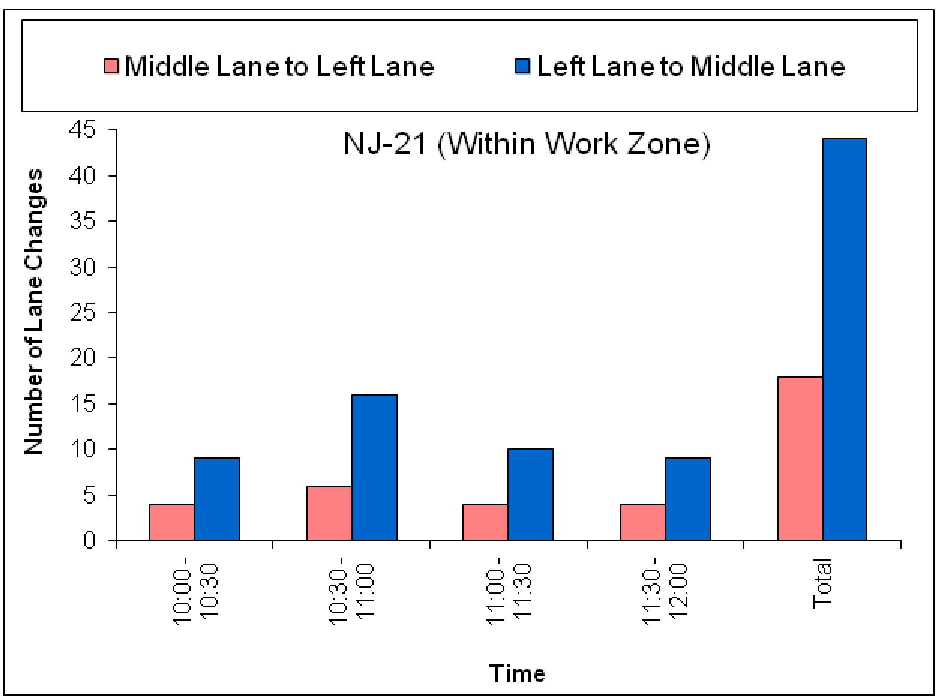


Figure 63. Lane Changes Within Work Zone (NJ-21)

Table 40. Number of Lane changes at Work Zone (NJ-21)

Upstream Work Zone													
Time		**1:00 - 1:30 PM**			**1:30 – 2:00 PM**			**2:00 – 2:30 PM**			**2:30 - 3:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		461	456	196	453	400	172	485	524	349	487	579	388
Speed (mph)		59.63	62.76	64.31	60.06	63.03	64.88	59.05	63.06	64.28	59.46	62.35	59.79
No. of Lane Changes	**SL to ML**	29			29			31			36		
	ML to SL	49			35			55			51		
	ML to LL	16			23			21			15		
	LL to ML	27			26			29			31		
Within Work Zone													
Time		**10:00 - 10:30 AM**			**10:30 - 11:00 AM**			**11:00 - 11:30 AM**			**11:30 - 12:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane			350	182		348	209		366	190		347	202
Speed (mph)			54.81	62.22		54.56	60.46		53.79	58.72		53.72	58.26
No. of Lane Changes	**ML to LL**	4			6			4			4		
	LL to ML	9			16			10			9		

For the location upstream of the work zone, there are differences in the number of lane changes between the maneuvers. The largest number of lane changes are vehicles going from the middle lane to the shoulder lane and the second largest are vehicles going from the shoulder to the middle lane. Much of these lane changes are associated with a downstream exit ramp, located just upstream of the lane closure. The smallest number of lane changes are vehicles moving from the middle lane to left lane. Although the left lane is closed downstream, there is a lane shift that shifts the left lane to the middle lane. Despite the continuation of the left lane, vehicles continue to shift from the left lane to the middle lane at a greater rate than vehicles shifting from the middle lane to the left lane.

Within the work zone, the largest lane change occurs for vehicles in the left lane moving to the middle lane.

I-295

At the I-295 work zone, lane change behavior was studied upstream, entering, within and exiting the work zone. Figure 64, Figure 65, Figure 66 and Figure 67 show the number of lane changes occurring upstream, within, entering and exiting the work zone during 30-minute time periods, respectively. Table 41 provide additional information about the volume and average speed by lane under which the lane changes occur for the upstream and entering work zone conditions. Similar information is also provided for the within and exiting conditions in Table 42.

Upstream of the work zone the largest number of lane changes occurs for vehicles moving from the left lane to the middle lane. At this work zone, the left lane cross over from the local lanes to the express lanes. Vehicles that need to exit the roadway remain in the local lanes. The large number of left lane vehicles changing lanes can be attributed to the configuration in the work zone. The next largest number of lane changes are vehicles moving from the shoulder lane to the middle lane. This may also be attributed to the work zone configuration that includes a traffic shift and may cause vehicles in the shoulder lane to change lanes.

Although upstream of the work zone the largest number of lane changes are vehicles moving from the left lane to the middle lane, at the location entering the work zone the largest number of lane changes are vehicles moving from the middle lane to the left lane with 436 vehicles making this lane change in two hours of observation. Within the work zone there is little lane changes occurring with the number of lane changes similar between the two lanes. Exiting the work zone the largest number of lane changes occur between the middle and left lanes.

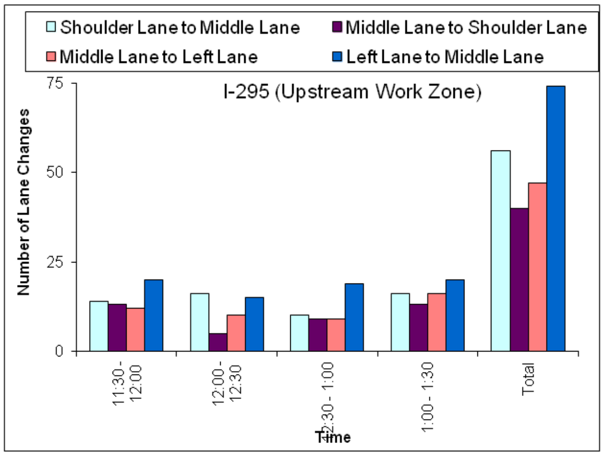


Figure 64. Lane Changing Upstream Work Zone (I-295)

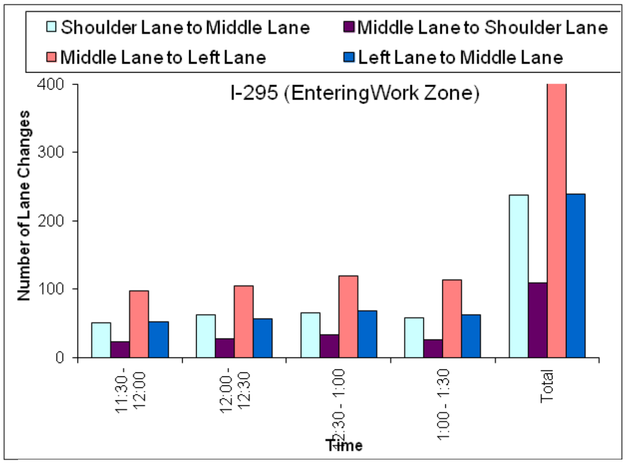


Figure 66. Lane Changing Entering Work Zone (I-295)

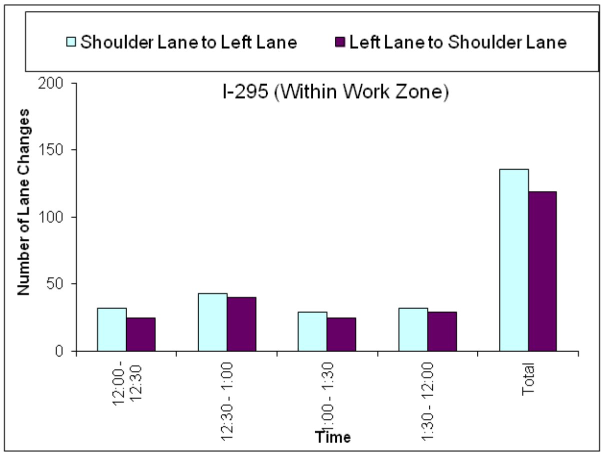


Figure 65. Lane Changing Within Work Zone (I-295)

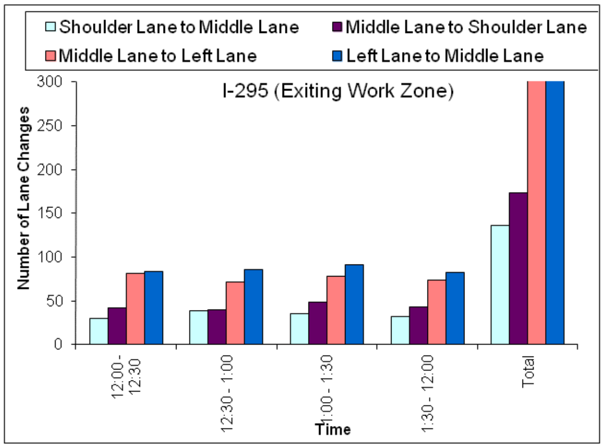


Figure 67. Lane Changing Exiting Work Zone (I-295)

Table 41. Number of Lane changes Upstream and Entering Work Zone (I-295)

Upstream Work Zone													
Time		**11:30 – 12:00 PM**			**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		862	763	311	719	737	287	735	733	282	767	742	315
Speed (mph)		55.58	59.95	63.48	58.73	58.57	63.77	57.71	63.40	65.82	64.88	65.89	64.51
No. of Lane Changes	**SL to ML**	14			16			10			16		
	ML to SL	13			5			9			13		
	ML to LL	12			10			9			16		
	LL to ML	20			15			19			20		
Entering Work Zone													
Time		**11:30 – 12:00 PM**			**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		353	542	564	327	554	541	347	554	594	366	586	624
Speed (mph)		48.78	53.64	56.55	49.33	53.20	56.33	48.60	53.29	56.04	47.00	49.93	52.57
No. of Lane Changes	**SL to ML**	14			16			10			16		
	ML to SL	13			5			9			13		
	ML to LL	12			10			9			16		
	LL to ML	20			15			19			20		

Table 42. Number of Lane changes Within and Exiting Work Zone (I-295)

Within Work Zone													
Time		**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**			**1:30 – 2:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		527	616		581	632		560	664		608	681	
Speed (mph)		54.07	56.64		51.20	56.08		52.75	56.17		52.83	56.98	
No. of Lane Changes	**SL to ML**	32			43			29			32		
	ML to SL	25			40			25			29		
Exiting Work Zone													
Time		**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**			**1:30 – 2:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		669	687	386	710	730	403	672	727	401	673	751	435
Speed (mph)		56.78	58.55	59.48	55.62	58.55	59.04	56.58	58.82	59.00	57.05	58.32	59.20
No. of Lane Changes	**SL to ML**	30			39			35			32		
	ML to SL	42			40			48			43		
	ML to LL	81			71			78			74		
	LL to ML	83			86			91			82		

I-80

At the I-80 work zone, lane change behavior was studied upstream, entering, within and downstream of the work zone. Figure 68, Figure 69, Figure 70 and Figure 71 show the number of lane changes occurring upstream, entering, within and exiting the work zone during 30-minute time periods, respectively. Table 43 provide additional information about the volume and average speed by lane under which the lane changes occur for the upstream and entering work zone conditions. Similar information is also provided for the within and exiting conditions in Table 44 and Table 45, respectively.

Upstream of the work zone the largest number of lane changes occurs for vehicles moving from the left lane to the middle lane. At this work zone, the left lane cross over from the local lanes to the express lanes. Vehicles that need to exit the roadway remain in the local lanes. The large number of left lane vehicles changing lanes can be attributed to the configuration in the work zone. The next largest number of lane changes are vehicles moving from the shoulder lane to the middle lane. This may also be attributed to the work zone configuration that includes a traffic shift and may cause vehicles in the shoulder lane to change lanes.

Although upstream of the work zone the largest number of lane changes are vehicles moving from the left lane to the middle lane, at the location entering the work zone the largest number of lane changes are vehicles moving from the middle lane to the left lane with 436 vehicles making this lane change in two hours of observation. Within the work zone there is little lane changes occurring with the number of lane changes similar between the two lanes. Exiting the work zone the largest number of lane changes occurs between the middle and left lanes.

Summary of Lane Change Behavior

The previous section provided an overview of driver behavior in the work zone, indicating that improper lane changing entering the work zone may impact safety. Behavior where drivers merge into the lane that is signed to be closed, can have negative consequences on the work zone safety. This behavior suggests that countermeasures aimed at improving safety at work zone areas in New Jersey should include strategies to impact lane changing entering the work zone.

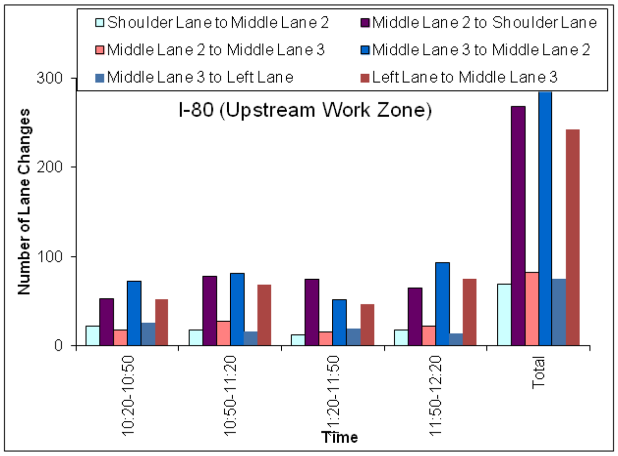


Figure 68. Lane Changing Upstream the Work Zone (I-80)

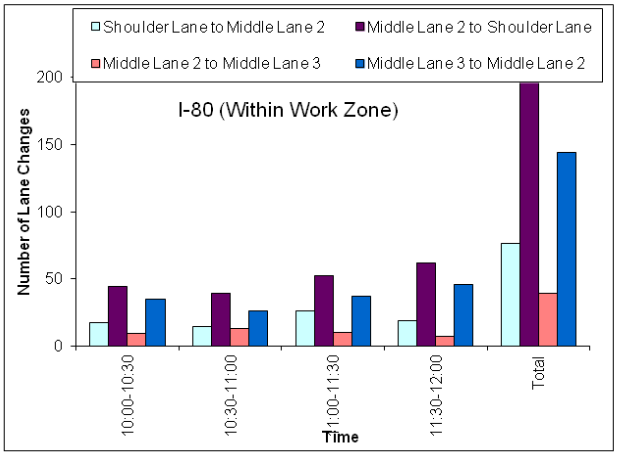


Figure 70. Lane Changing Within the Work Zone (I-80)

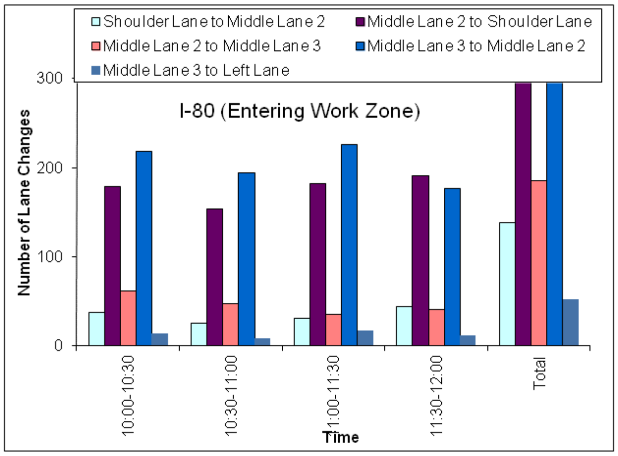


Figure 69. Lane Changing Entering the Work Zone (I-80)

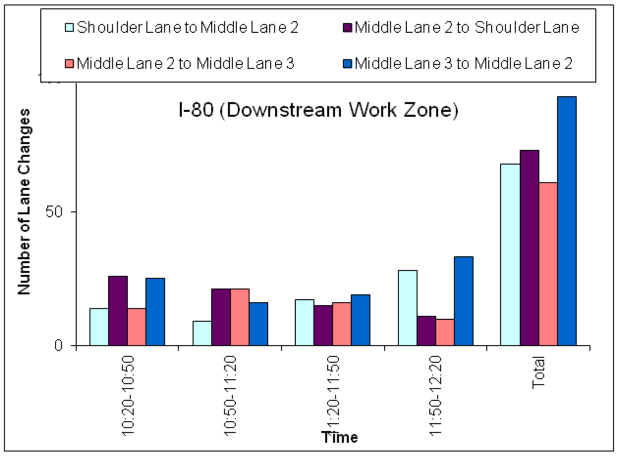


Figure 71. Lane Changing Downstream the Work Zone (I-80)

Table 43. Number of Lane changes Upstream Work Zone (I-80)

Time		**10:20 - 10:50 AM**				**10:50 - 11:20 AM**			
		Shoulder Lane	**Middle Lane 2**	**Middle Lane 3**	**Left Lane**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Left Lane**
Vehicles per Lane		480	516	630	402	419	502	610	374
Speed (mph)		63.33	67.89	67.69	68.05	64.02	68.66	67.88	68.19
No. of Lane Changes	**SL to ML2**	22				17			
	ML2 to SL	52				78			
	ML2 toML3	18				27			
	ML3 toML2	72				81			
	ML3 to LL	26				16			
	LL to ML3	52				68			
Time		**11:20 – 11:50 AM**				**11:50 AM – 12:20 PM**			
		Shoulder Lane	**Middle Lane 2**	**Middle Lane 3**	**Left Lane**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Left Lane**
Vehicles per Lane		455	500	672	370	487	499	636	375
Speed (mph)		64.61	67.10	68.99	69.57	63.43	67.58	69.44	70.20
No. of Lane Changes	**SL to ML2**	12				18			
	ML2 to SL	74				64			
	ML2 toML3	15				22			
	ML3 toML2	51				93			
	ML3 to LL	19				14			
	LL to ML3	47				75			

Table 44. Number of Lane changes Entering and Within Work Zone (I-80)

Time		**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**			**1:30 – 2:00 PM**		
		Shldr. Lane	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**
Speed (mph)		53.93	58.94	59.99	52.19	55.75	56.71	54.43	58.87	59.50	52.09	57.48	58.90
No. of Lane Changes	**SL to ML2**	37			26			31			44		
	ML2 to SL	179			154			182			191		
	ML2 toML3	62			47			35			41		
	ML3 toML2	218			194			226			176		
	ML3 to LL	14			9			17			12		
Within Work Zone													
Time		**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**			**1:30 – 2:00 PM**		
		Shldr. Lane	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**	**Shoulder Lane**	**Middle Lane 2**	**Middle Lane 3**
Vehicles per Lane		265	583	907	261	521	864	290	561	852	265	583	907
Speed (mph)		64.59	65.28	66.59	60.90	64.61	66.24	62.04	66.37	67.49	64.59	65.28	66.59
No. of Lane Changes	**SL to ML2**	17			14			26			19		
	ML2 to SL	44			39			52			62		
	ML2 toML3	9			13			10			7		
	ML3 toML2	35			26			37			46		

Table 45. Number of Lane changes Downstream in Work Zone (I-80)

Downstream in Work Zone													
Time		**12:00 – 12:30 PM**			**12:30 - 1:00 PM**			**1:00 - 1:30 PM**			**1:30 – 2:00 PM**		
		Shoulder Lane	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**	**Shoulder Lane**	**Middle Lane**	**Left Lane**
Vehicles per Lane		279	734	577	264	660	544	274	655	531	265	699	461
Speed (mph)		68.87	71.13	73.08	69.03	71.58	73.96	67.89	70.87	72.55	69.40	71.12	72.96
No. of Lane Changes	**SL to ML2**	14			9			17			28		
	ML2 to SL	26			21			15			11		
	ML2 toML3	14			21			16			10		
	ML3 toML2	25			16			19			33		

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Temporary traffic-control measures have been developed and used in work zones. However, the effectiveness of traffic-control methods in work zones has not been clearly identified. To further improve safety and to identify effective control measures, there is a need to determine the factors that lead to accidents in work zone. This study specifically examined the characteristics of work zone crashes in New Jersey. Potential contributory factors that affect the CF and injury severity levels have been investigated. To achieve the goals of this study, three major tasks have been undertaken. The first was to provide a state-of-the-art review of work zone safety. The second was to conduct a descriptive statistical analysis that provided an overview of the potential causal relationship between work zone crashes and various factors. The third task was to statistically model how those factors influence crash occurrences as well as injury severity levels. As a result, various statistical models have been developed.

Our literature review indicated that most of the previous research that focused on descriptive statistics of work zone crash data was interested in crash severity, crash rate, location, time, type, and data-collection issues. These approaches provided a direction to explore similar factors as well as other, specific factors of work zone crashes in New Jersey.

In our descriptive analysis, CF and crash injury severity were investigated separately. For work zone CF, particular interest was given to crash distributions under different temporal features, crash types, road characteristics, and other environmental conditions. Similarly, we studied severity distributions of work zone crashes by examining work zone types, environmental conditions, road characteristics, number of vehicles involved, occupants involved, types of vehicles involved, alcohol use, accident time, and accident type. Between 2004 and 2010, 2010 had the highest number of work zone crashes. For monthly crashes, October had the highest frequency. Similarly, more crashes occurred on Friday between 15:00 and 16:00. Rear-end, side-swipe (same direction), and fixed-object crashes are the most common crash type within work zones among all crash types. State highways have the largest number of work zone crashes by road class. Most of the work zone accidents happened during daylight, on dry surfaces, and in clear weather conditions. Activity areas are the most likely places for accidents to occur among all work zone components. Maintenance work zones have the greatest risk of injury crash percentages compared to other zone types. For light condition, the nighttime severe crash ratio is higher than the daytime severe crash ratio. Severity ratios are almost the same for different weather conditions and different road surface conditions. A greater proportion of severe crashes occurred on state highways than on other road types. Crashes related to alcohol use are significantly more severe than non-alcohol-involved crashes. Driving a light vehicle has higher severity ratio, as well.

Statistical relationships between a set of explanatory variables and work zone CF were examined using extensive and detailed work zone data collected in New Jersey. Separate NB models for all crashes, PDO, and injury crashes were developed. In addition, we extended traditional NB models by incorporating the effects that arise from measurement errors related to work zone length. New models to estimate work zone CF—namely, the MENB—have been developed. The modeling results suggested that the duration of the work zone, daily traffic exposure, length of the work zone, speed variance, and number of lane closures are some of the parameters positively associated with the crash occurrence. Crash occurrence at nighttime was less than that of daytime. In addition, state highways were more likely to have a higher CF compared to interstate highways. Comparisons between the traditional NB model and the MENB models showed that the MENB models outperformed the traditional model by addressing the potential errors in work zone length. However, the proposed models are not meant to provide an excuse for collecting low-quality data. To better understand the work crash safety issues, high-quality data should be collected in the future.

Based on the findings in our descriptive analysis, we have developed statistical models to capture the causal relationship between crash severity and various factors such as driver characteristics, vehicle characteristics, environmental features, and road characteristics. To fully understand the impacts of these factors, we developed logistic regression models for crash-level analysis, driver-level analysis, and occupant-level analysis, respectively, which is beneficial for selecting different countermeasures to reduce both driver and occupant injury severity. Based on the modeling results, factors such as driver gender, DUI, vehicle type and age, road class, work zone speed limit, work zone type, traffic control type, number of vehicles involved in the crash, and type of crash are among the major elements affecting injury severity in work zone crashes. Some of the specific issues have been addressed in the following recommendations.

Recommendations

Work Zone Crash Data Collection

The crash report form should be modified to reflect work zone–specific characteristics, including the following information:

- Accurate crash location within the work zone (that is, advanced warning, buffer, termination)
- Number of closed lanes and number of operating lanes
- Left-, middle-, or right-lane closure; shoulder closure
- Operating hours
- Presence of workers or equipment
- Work zone speed limit

- Detour or full-road closure information, including duration
- Channelization details of the work zone (concrete barrier)
- Workers or equipment involved in an accident

Other necessary information for work zone crash analysis is available in the crash database, but these entries need to be filled out carefully, or officers should be instructed about the specific aspects of detailed information for work zone–related accidents to reduce the number of unclear records within the crash database (for example, temporary traffic control zone, speed limit, alcohol, severity).

Crash Frequency

- The duration of the work zone project should be minimized to reduce work zone crash occurrence. Many researchers agree on the increasing effect duration has in work zones.[10, 60] The results of the general model show that duration increases the number of work zone accidents. A contracting strategy that encourages contractors through financial incentives or disincentives could be a solution for keeping project durations shorter.[61] The New York State Department of Transportation used this bidding strategy for 120 construction sites, and 103 contractors finished earlier than the standard duration of the project. In addition, full-lane closure can be an effective solution for reducing project durations when alternative routes are available.

- The length of the work zone is also a significant parameter for both work zone property damage and injury CF. Keeping project lengths shorter reduces the number of work zone crashes. Also, when deciding working sections, if possible, the number of "active" intersections and ramps within each section should be minimized. Intersections and ramps cause an increase in PDO CF (Figure 39).

- Model results for injury and PDO crashes show that AADT has a big role in CF. To avoid exposure resulting from heavy traffic (AADT), traffic should be diverted to alternate routes when appropriate conditions exist. Road user cost analysis should be used to decide the most effective detour strategy. Weekends instead of weekdays as an operating time is also another alternative for reducing exposure.[60]

- State highways in our models have significantly more work zone crashes than interstate highways. Hence, work zone safety strategies should be compared among different road systems. Possibly, different work zone designs should be considered for state highways to minimize injury and PDO crashes.

- Nighttime coefficients are negative for all models, which means that operating work zones during nighttime keeps the number of injury and PDO crashes lower. Nighttime AADT is about a quarter of the daily AADT; therefore, the likelihood of crashes will be reduced for nighttime work zones because of the low exposure of traffic.

- Speed reduction should only be applied for necessary operating conditions. From the model results, speed reduction has a positive effect on CF. Hence, the variance between the posted speed limit and the work zone speed limit should be optimized to prevent increasing crash occurrence. A sharp reduction in speed limits may cause more accidents within work zones.[62] Drivers should be warned with signs to ensure safe transition between changing speed limits.

- Lane reduction is another parameter that increases the number of crashes in frequency models. Therefore, lane closing strategies should be revised to minimize the number of lane drops for necessary conditions. If closures are necessary, smart lane merging strategies should be implemented to allow a smooth transition and termination at work zones to reduce crashes at these areas.

Crash Severity

- Nighttime crashes were found to be more severe than daytime crashes in our severity models. Therefore, visibility, alertness, and awareness of both drivers and workers should be improved in the vicinity of work zones. When increasing visibility, warning lights should not be overpowering, and work vehicles should not point toward incoming traffic, which affects motorists' vision.[60]

- Our crash severity model results show that higher speed limits cause more injury risk crashes. To reduce injury risk, a lower speed limit should be posted, but special attention should be paid to transitioning from normal speed to reduced speed. High-level (speed limit greater than 60 mph) and medium-level (60 mph to a speed limit greater than 41 mph) speed limits increase crash severity 22.9 percent and 6.9 percent, respectively.

- Young drivers and female drivers are more likely to be involved in injury crashes. Severity model results show that they have a greater risk of being involved in severe crashes. Safety education or training programs should be provided for these specific groups. Drivers license testing that includes more information about work zone safety is suggested.

- If the site has higher truck traffic flow, their interaction with other road users should be monitored and controlled. From the model results, truck-involved crashes have a 25 percent greater risk of severe crashes than all other crashes.

- Opposite crashes (that is, head-on, angular, and side swipe) are likely to be injury crashes. Model results show that these crashes are three times more severe than others. Therefore, when median crossover is needed in some work zones, traffic-control strategies should be carefully studied to prevent opposite-direction crashes.

- Special enforcement should be used for all traffic violations within the work zone to keep drivers' level of attention high. For example, strict regulations and the law should be enforced to prevent DUI violations within work zones. DUI drivers are the cause of significantly greater injury risk (OR: >2) according to the severity model results.

- Safety strategies for maintenance work zones should be improved, because model results show that maintenance work zones have higher injury risk than construction and utility work zones (17.2 percent more than construction zones).

- Driving light-duty vehicles carries a greater risk of being involved in an injury work zone accident. Operators of light-duty vehicle such as scooters and motorcycles should drive more carefully in work zone sites. Again, driver education programs should be designed to address this issue.

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APPENDIX A: INCLUDED FIELDS IN NJDOT CRASH DATABASES

Accident Database

Field	Length	Field	Length
Year	4	Route Suffix	1
County Code	2	SRI (Std Rte Identifier)	16
Municipality Code	2	MilePost	7
Department Case Number	23	Road System	2
County Name	12	Road Character	2
Municipality Name	24	Road Surface Type	2
Crash Date	10	Surface Condition	2
Crash Day Of Week	2	Light Condition	2
Crash Time	4	Environmental Condition	2
Police Dept Code	2	Road Divided By	2
Police Department	25	Temporary Traffic Control Zone	2
Police Station	15	Distance To Cross Street	4
Total Killed	2	Unit Of Measurement	2
Total Injured	2	Directn From Cross Street	1
Pedestrians Killed	2	Cross Street Name	35
Pedestrians Injured	2	Is Ramp	1
Severity	1	Ramp To/From Route Name	25
Intersection	1	Ramp To/From Route Direction	2
Alcohol Involved	1	Posted Speed	2
HazMat Involved	1	Posted Speed Cross Street	2
Crash Type Code	2	Latitude	8
Total Vehicles Involved	2	Longitude	8
Crash Location	50	Cell Phone In Use Flag	1
Location Direction	1	Other Property Damage	80
Route	4	Reporting Badge No.	5

(Source: http://www.state.nj.us/transportation/refdata/accident/master.shtm)

Driver Database

Field	**Length**
Year	4
County Code	2
Municipality Code	2
Department Case Number	23
Vehicle Number	2
Driver City	25
Driver State	2
Driver Zip Code	5
Driver License State	2
Driver DOB	10
Driver Sex	1
Alcohol Test Given	1
Alcohol Test Type	2
Alcohol Test Results	3
Charge	30
Summons	30
Multi Charge Flag	1
Driver Physical Status	2

(Source: http://www.state.nj.us/transportation/refdata/accident/drivers.shtm)

Vehicle Database

Field	Length
Year	4
County Code	2
Municipality Code	2
Department Case Number	23
Vehicle Number	2
Insurance Company Code	4
Owner State	2
Make of Vehicle	30
Model of Vehicle	20
Color of Vehicle	3
Year of Vehicle	4
License Plate State	2
Vehicle Weight Rating	1
Towed	1
Removed By	2
Initial Impact Location	2
Principal Damage Location	2
Traffic Controls Present	2
Vehicle Type	2
Vehicle Use	2
Special Function Vehicles	2
Cargo Body Type	2
Contributing Circumstances 1	2
Contributing Circumstances 2	2
Direction of Travel	2
Pre- Crash Action	2
First Sequence of Events	2
Second Sequence of Events	2
Third Sequence of Events	2
Fourth Sequence of Events	2
Oversize/Overweight Permit	2
HazMat Status	1
HazMat Placard	10
USDOT/Other Flag	1
USDOT/OTHER Number	10
Carrier Name	50
Hit & Run Driver Flag	1

(Source: http://www.state.nj.us/transportation/refdata/accident/vehicles.shtm)

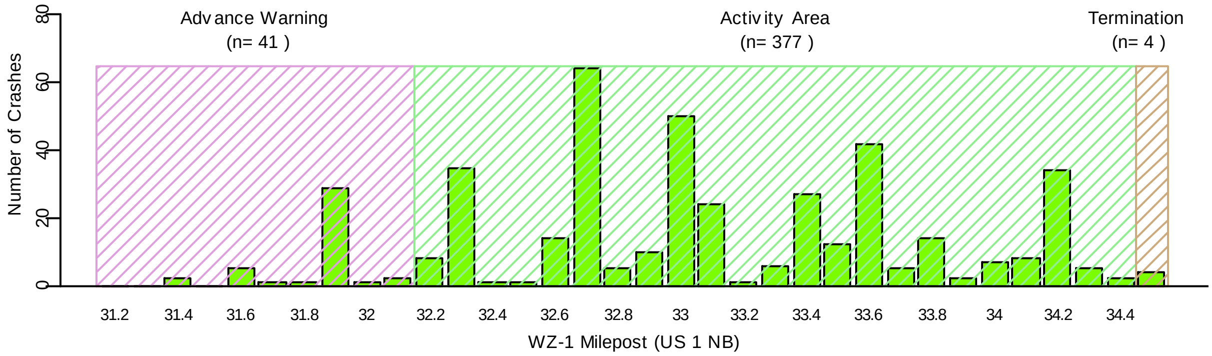
Occupant Database

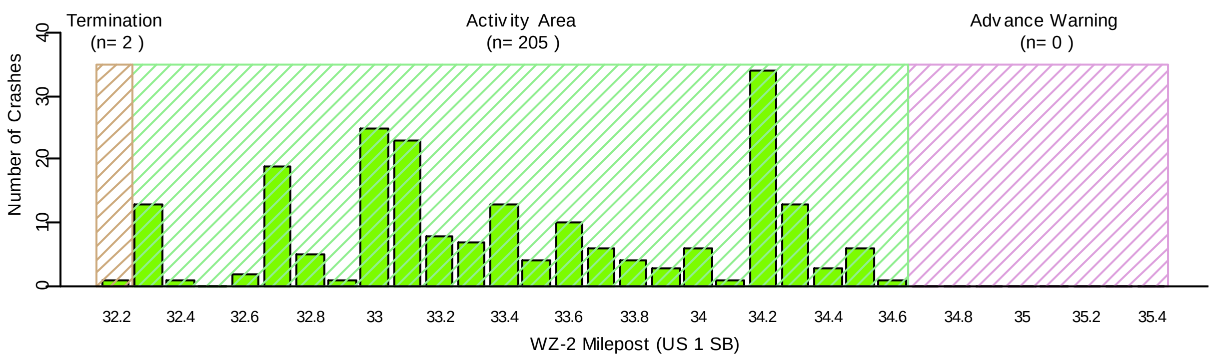
Field	Length
Year	4
County Code	2
Municipality Code	2
Department Case Number	23
Vehicle Number	2
Occupant Number	2
Physical Condition	2
Position In/On Vehicle	2
Ejection Code	2
Age	3
Sex	1
Location of Most Severe Injury	2
Type of Most Severe Phys Injury	2
Refused Medical Attention	1
Safety Equipment Available	2
Safety Equipment Used	2
Airbag Deployment	2
Hospital Code	4

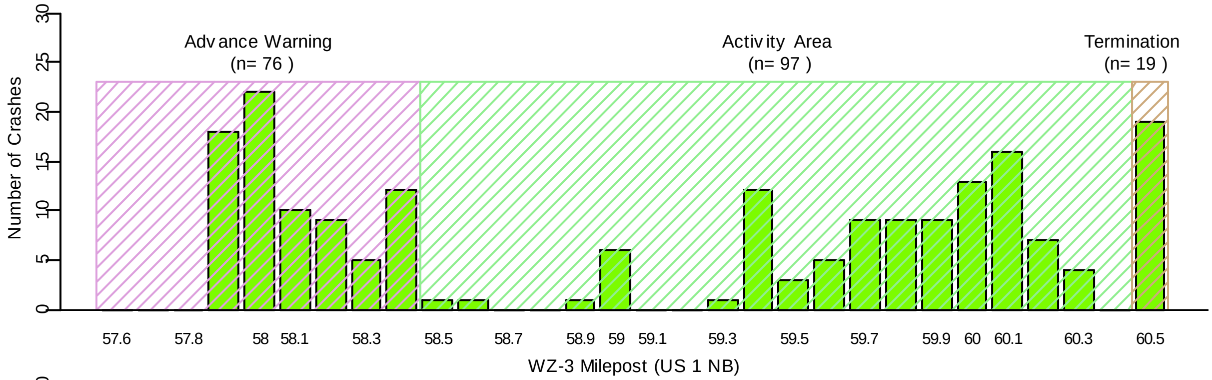
(Source: http://www.state.nj.us/transportation/refdata/accident/occupants.shtm)

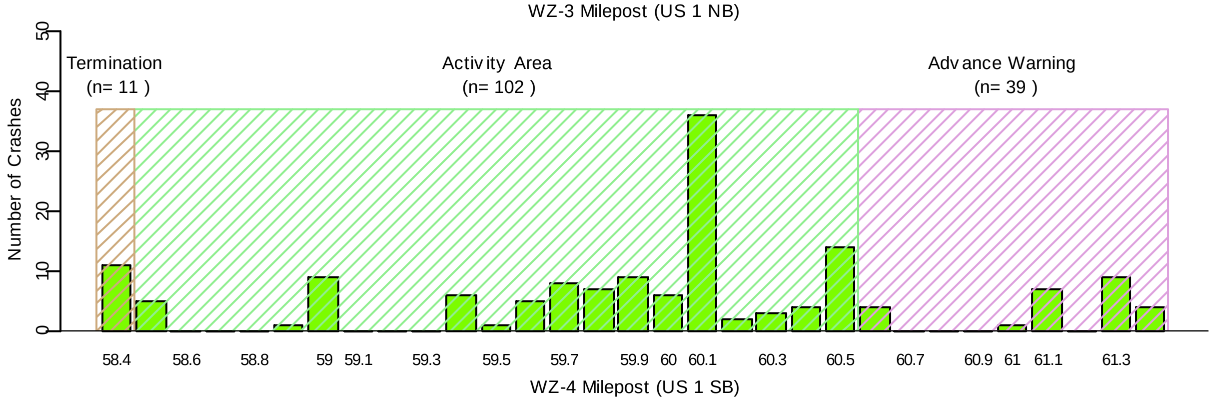
APPENDIX B: WORK ZONE COMPONENTS PLOTS

Work Zones 1–4 Plots

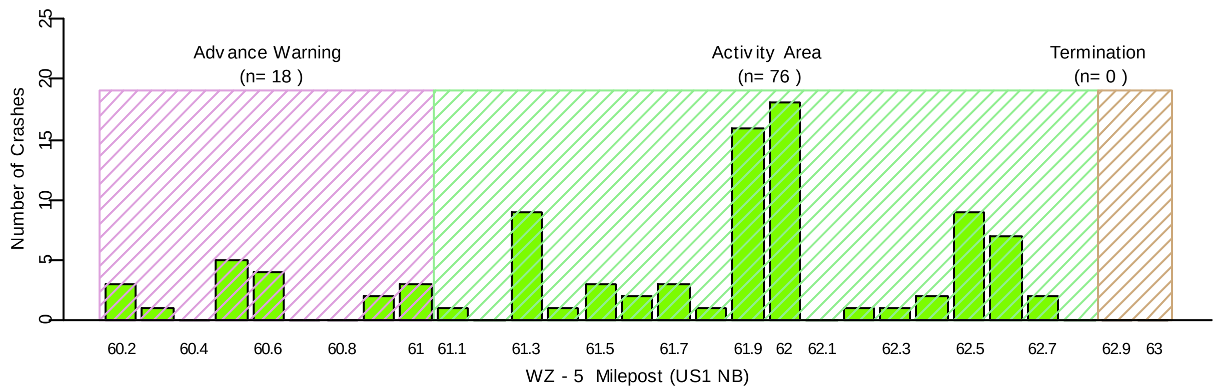


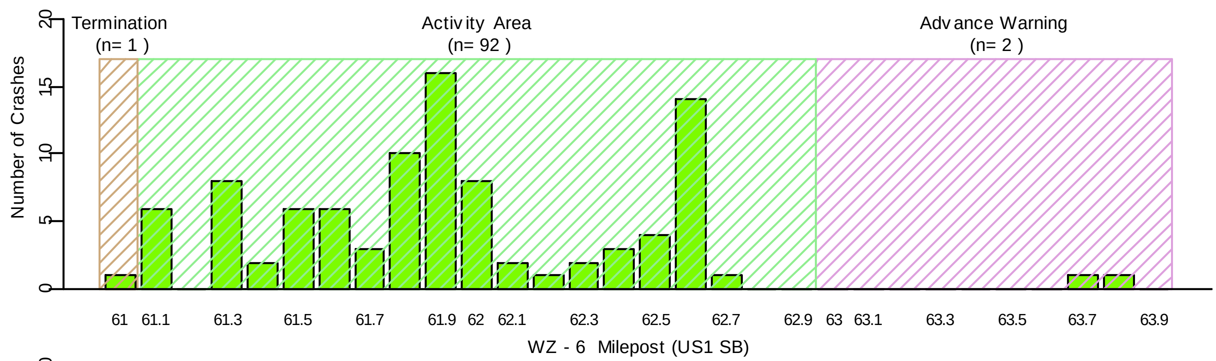


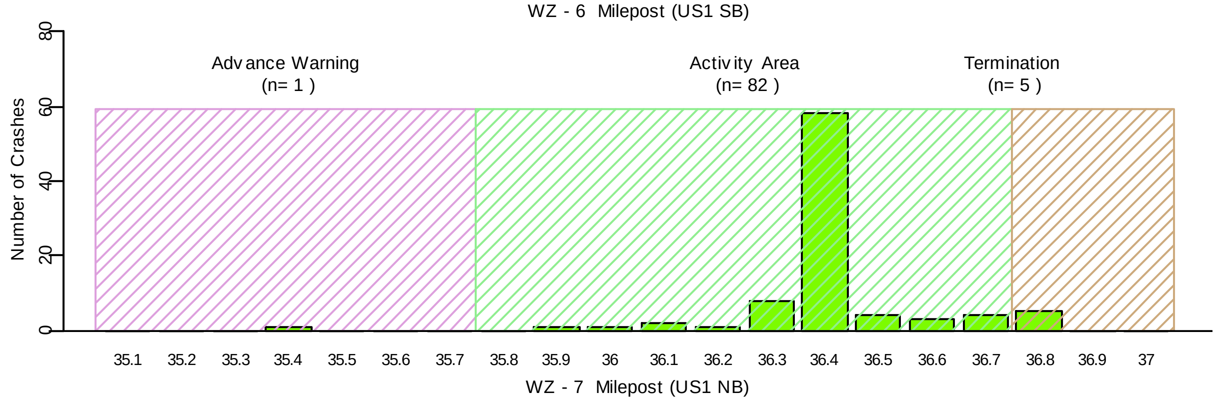


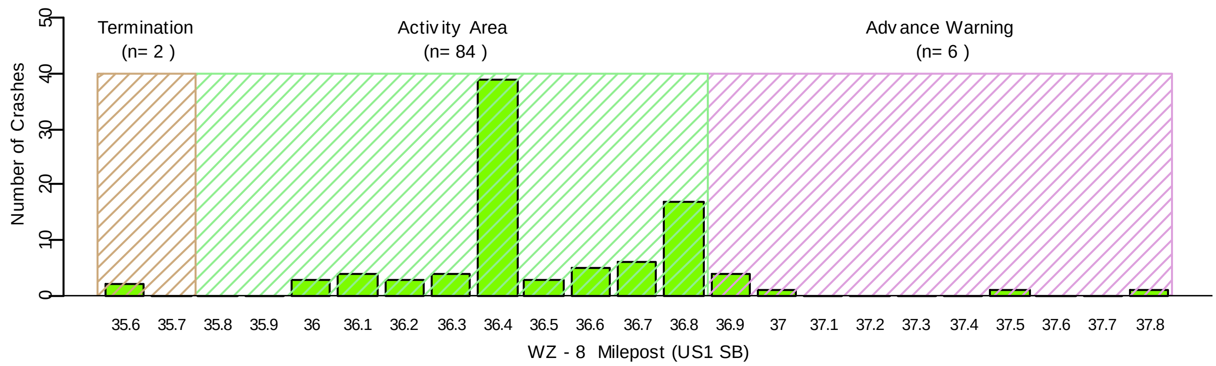


Work Zones 5–8 Plots

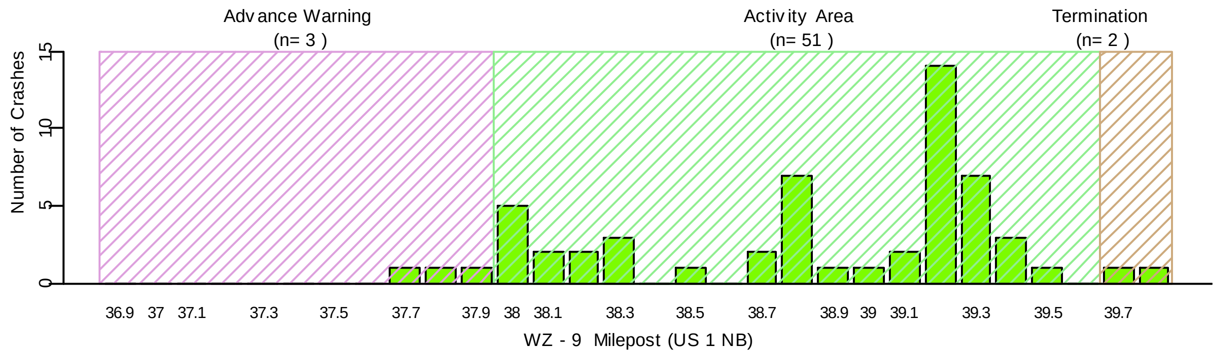


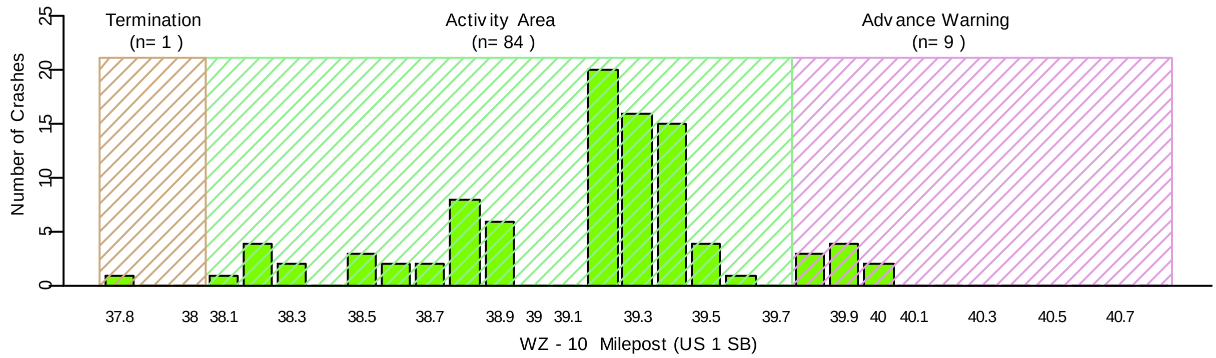


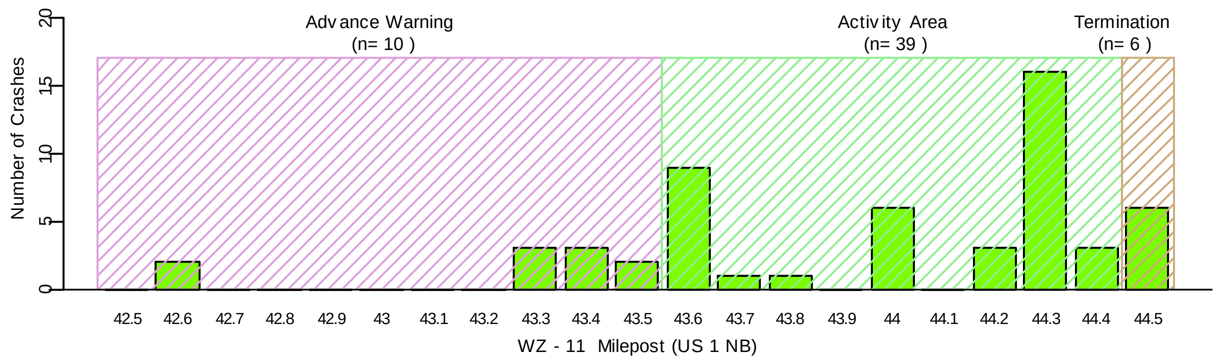


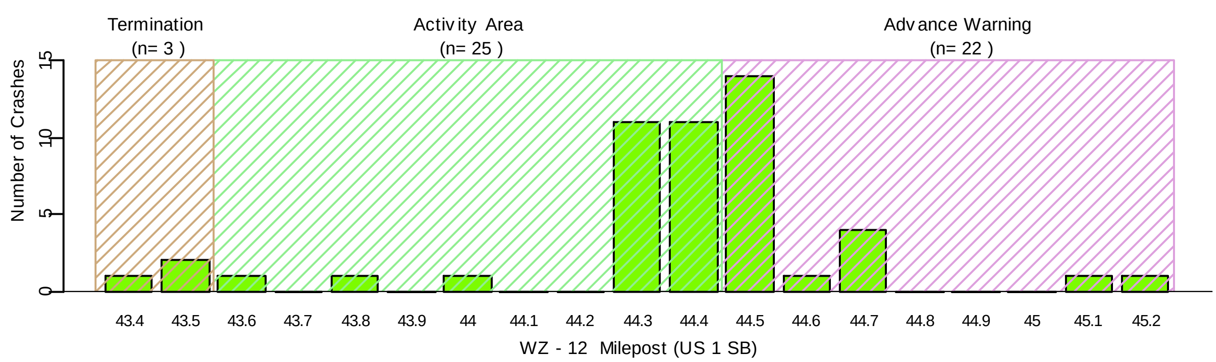


Work Zones 9–12 Plots

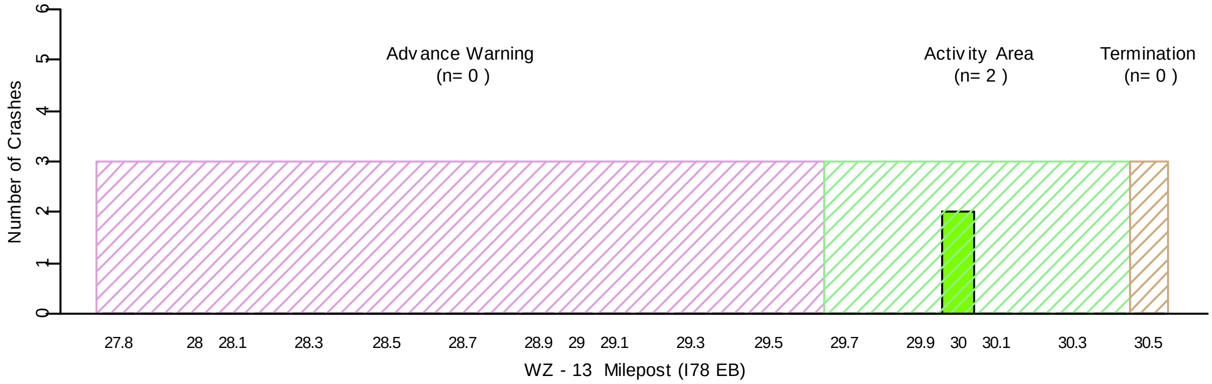


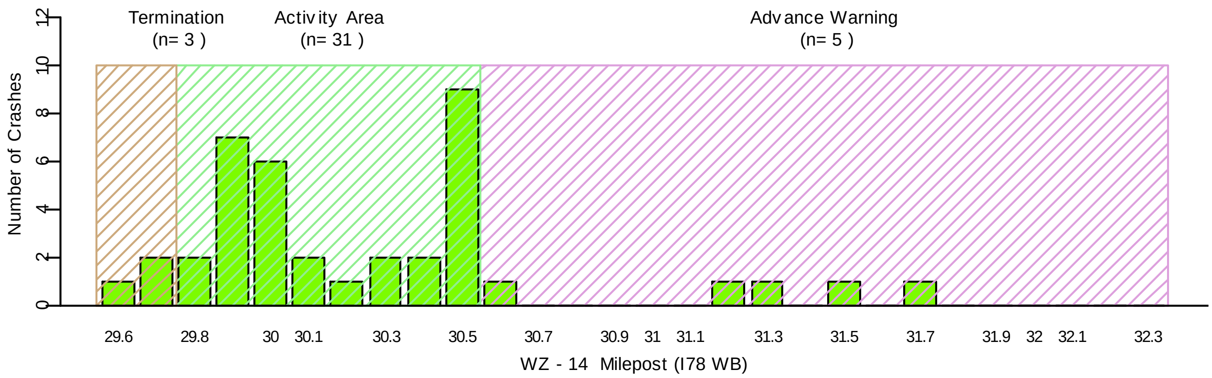


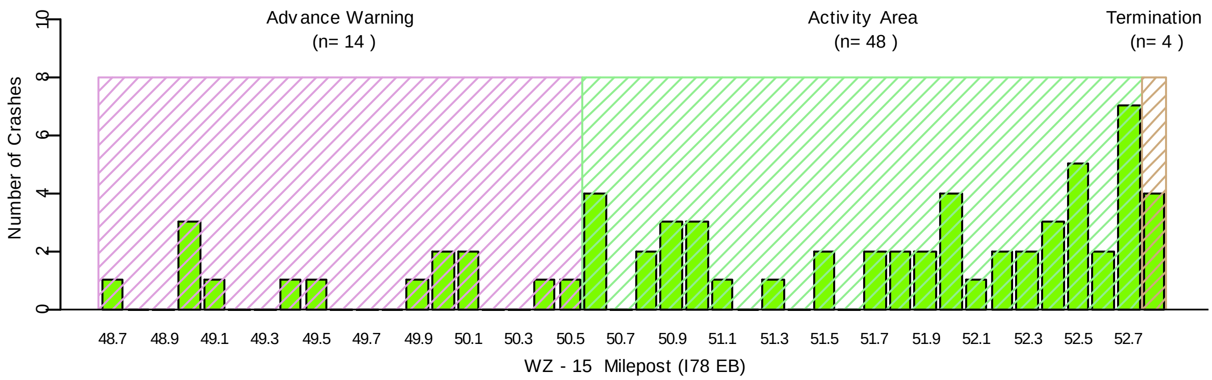


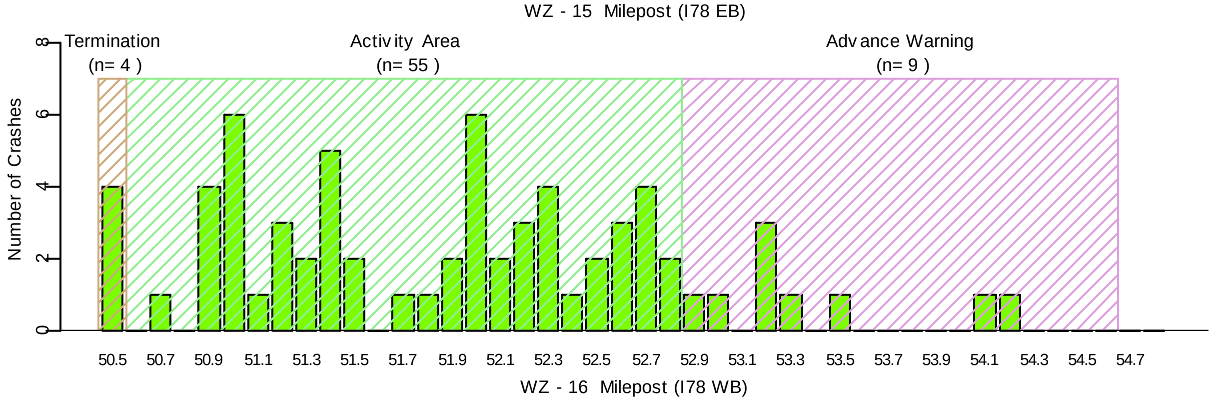


Work Zones 13–16 Plots

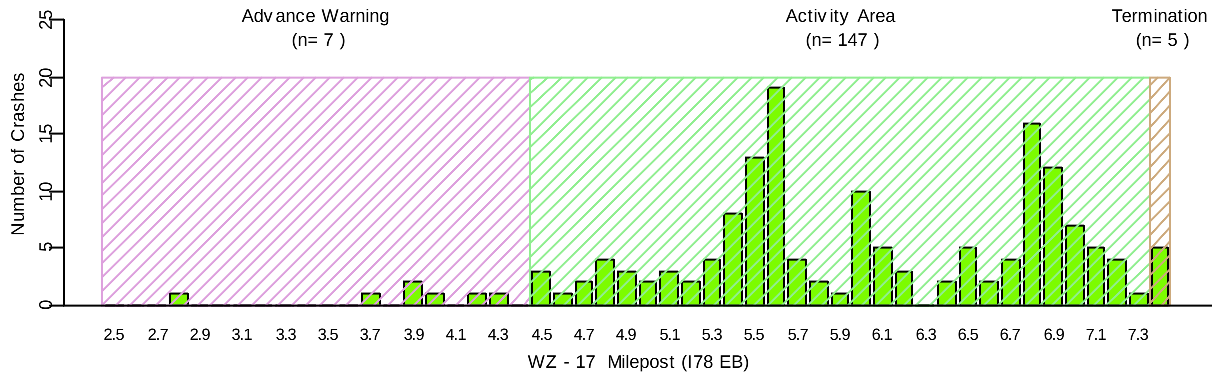


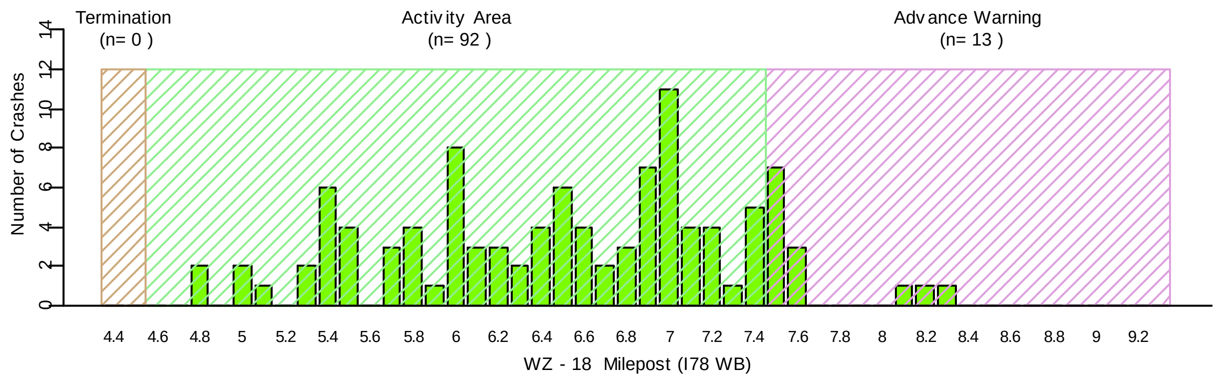


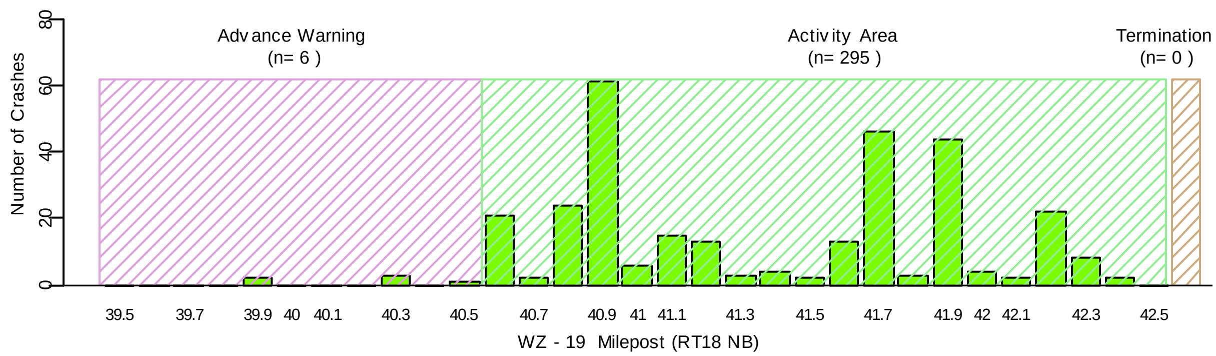


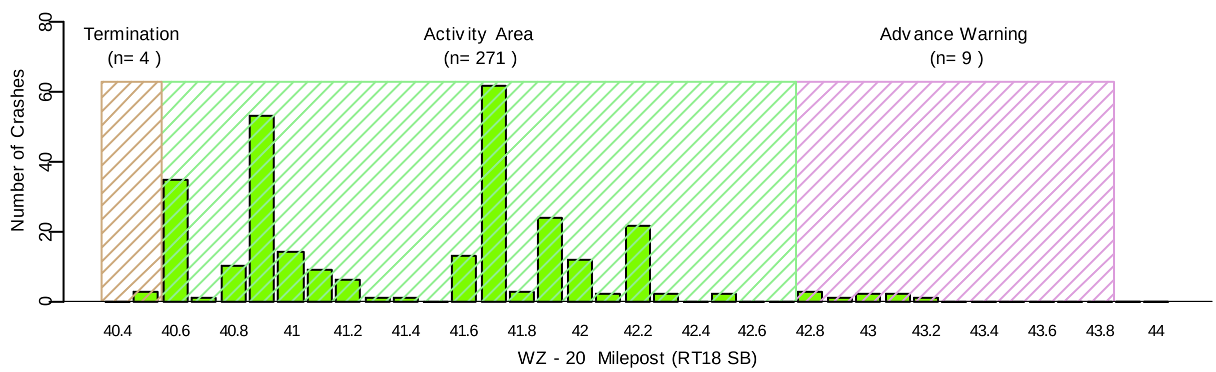


Work Zones 17–20 Plots

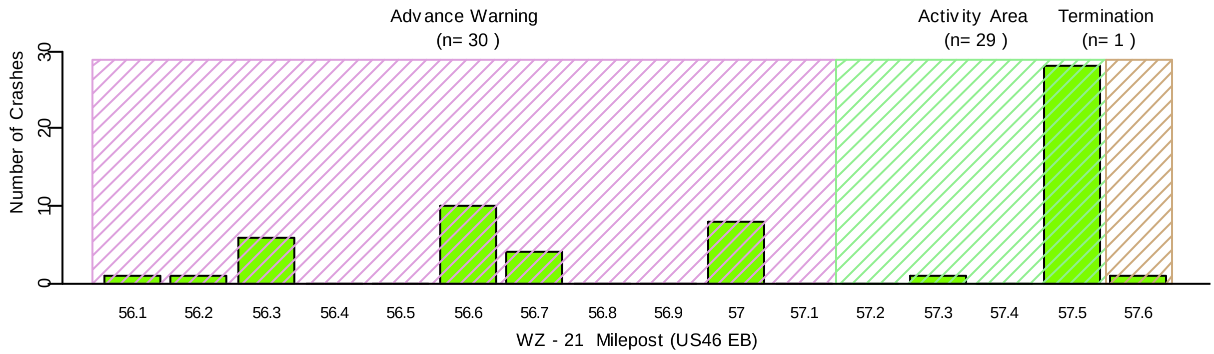


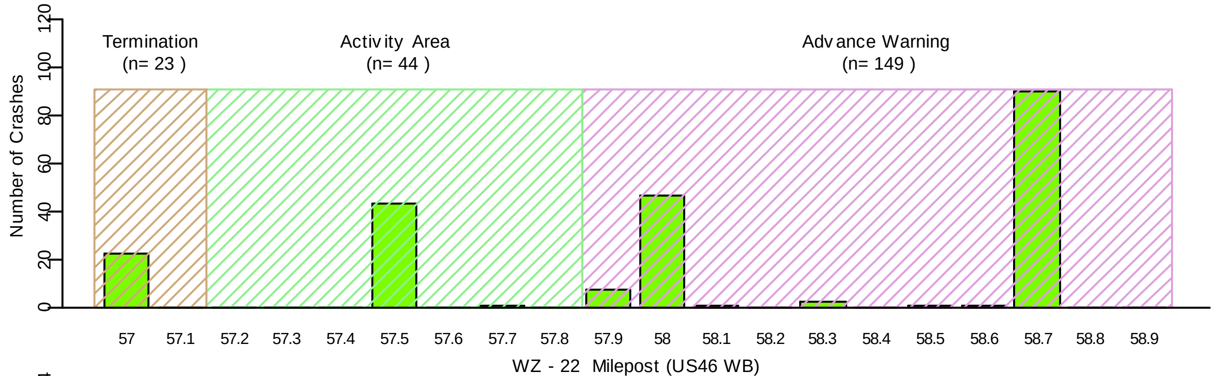


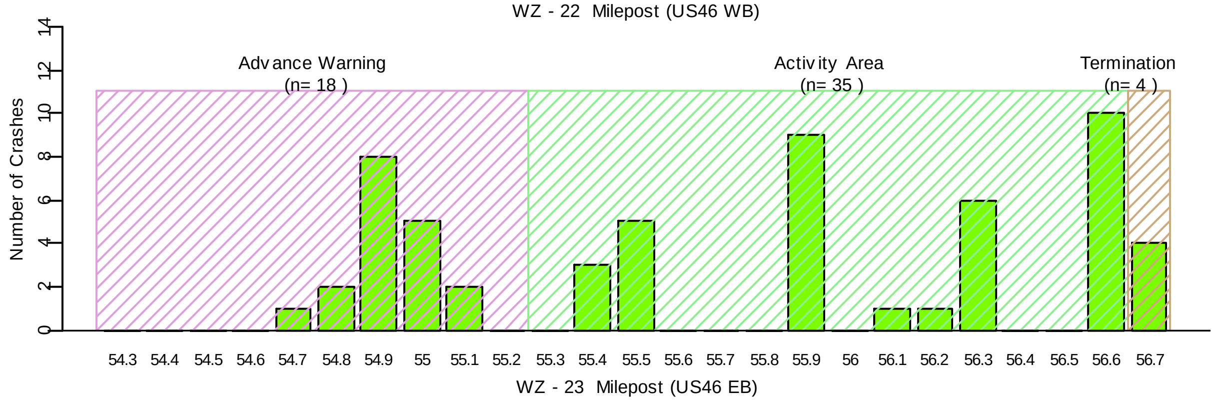


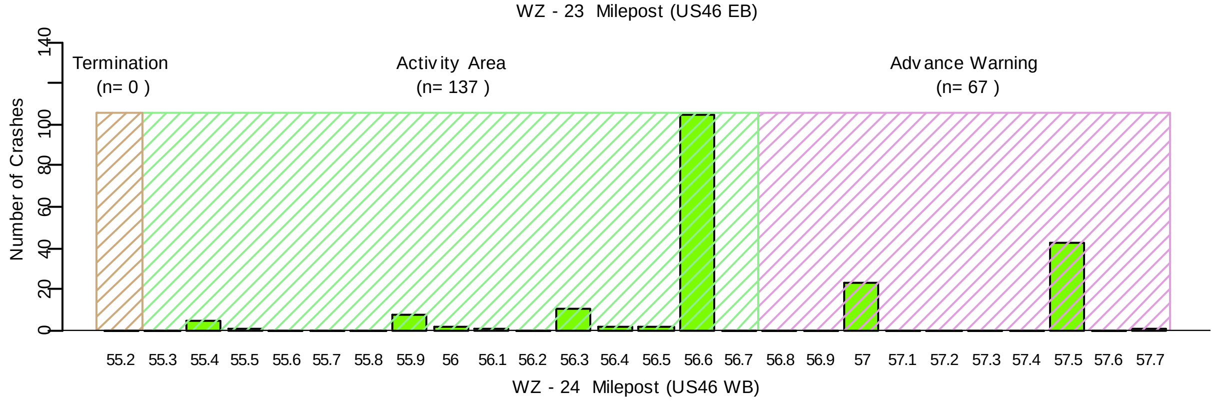


Work Zones 21–24 Plots

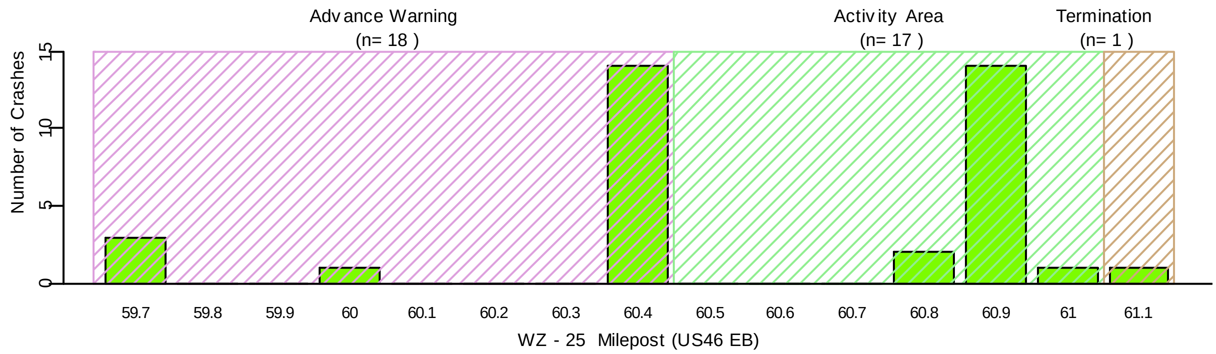


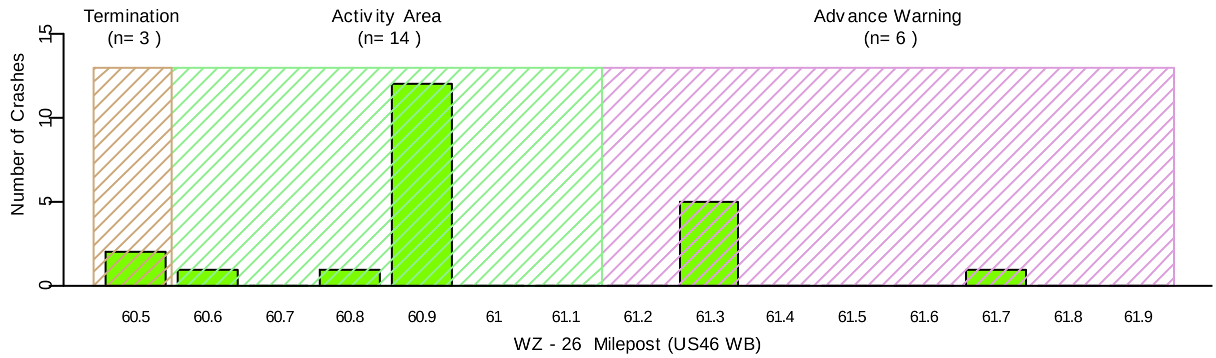


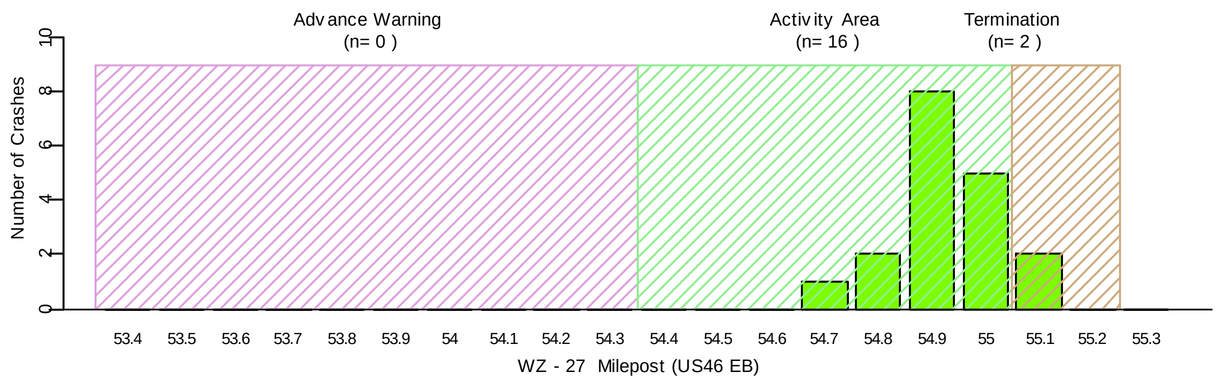


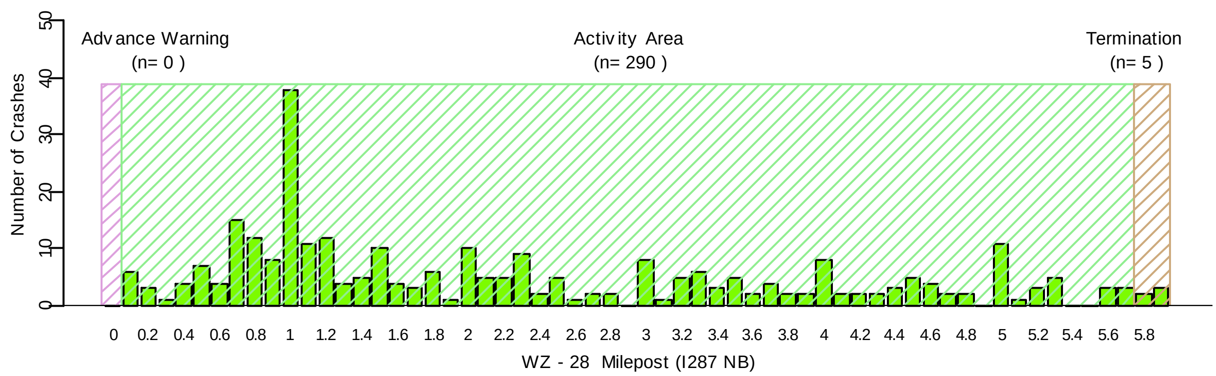


Work Zones 25–28 Plots

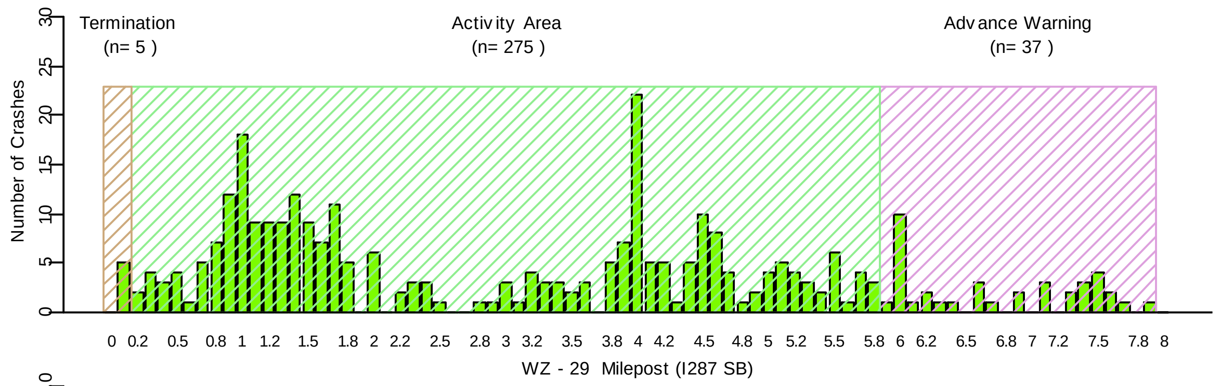


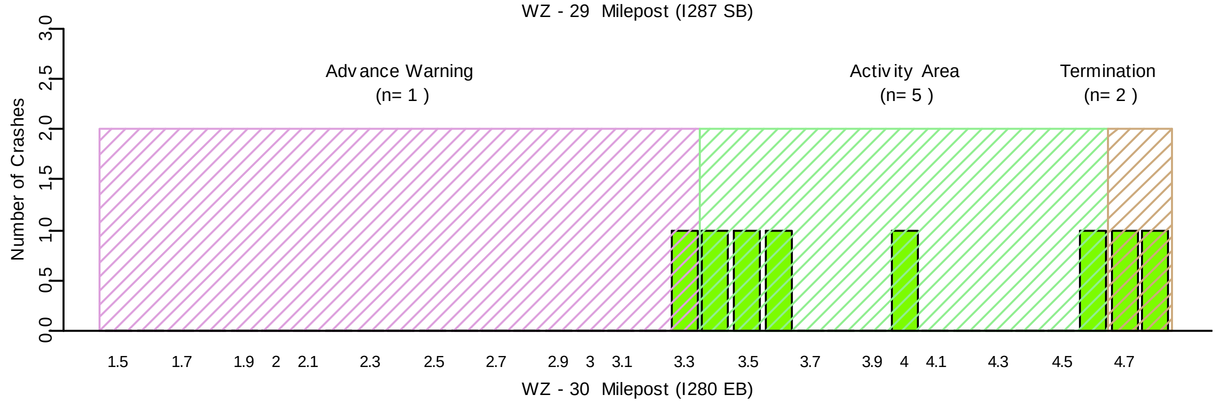


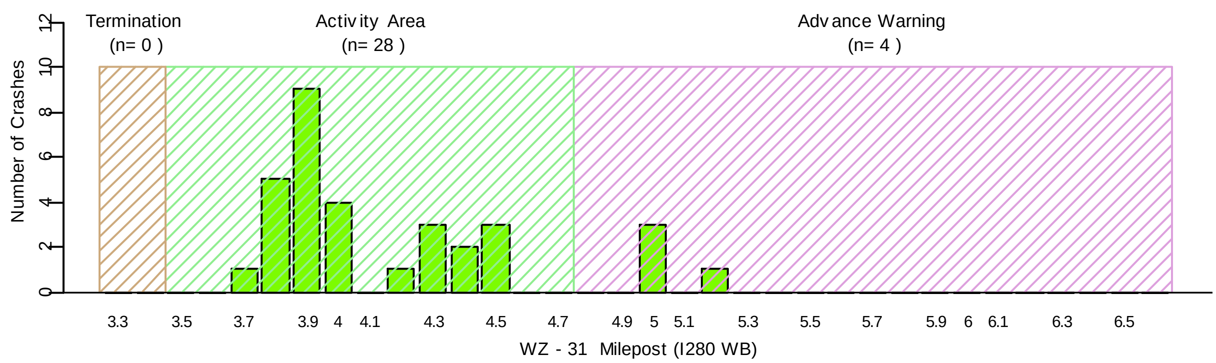


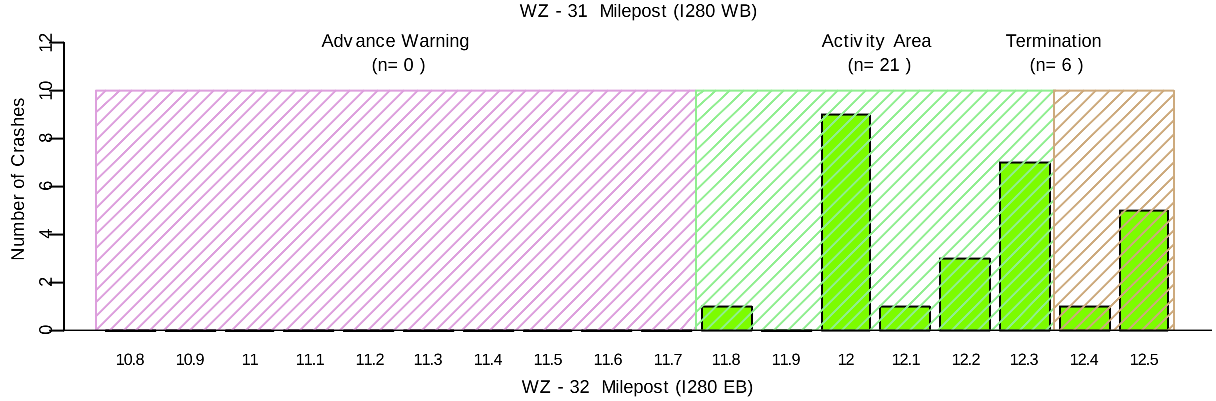


Work Zones 29–32 Plots

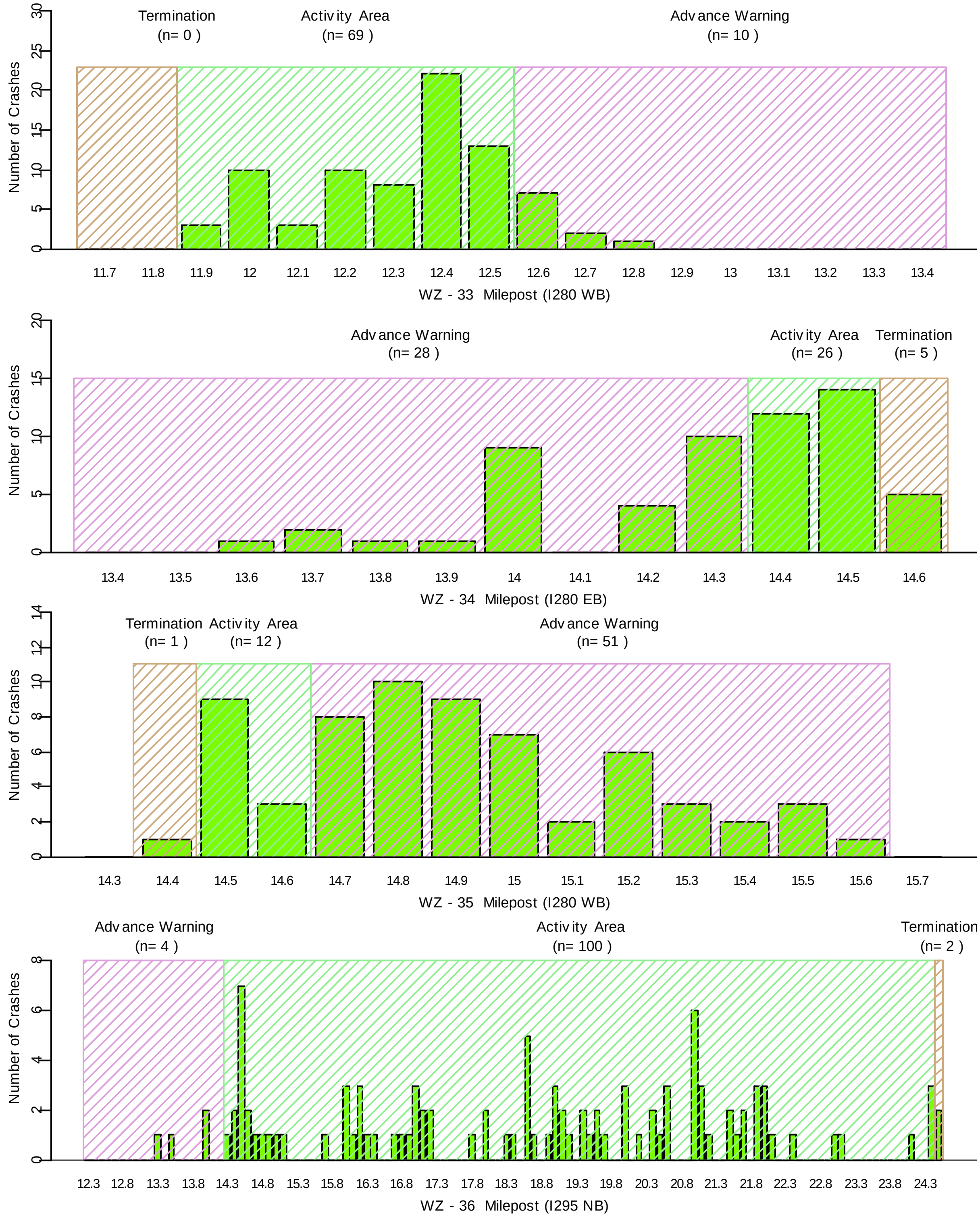




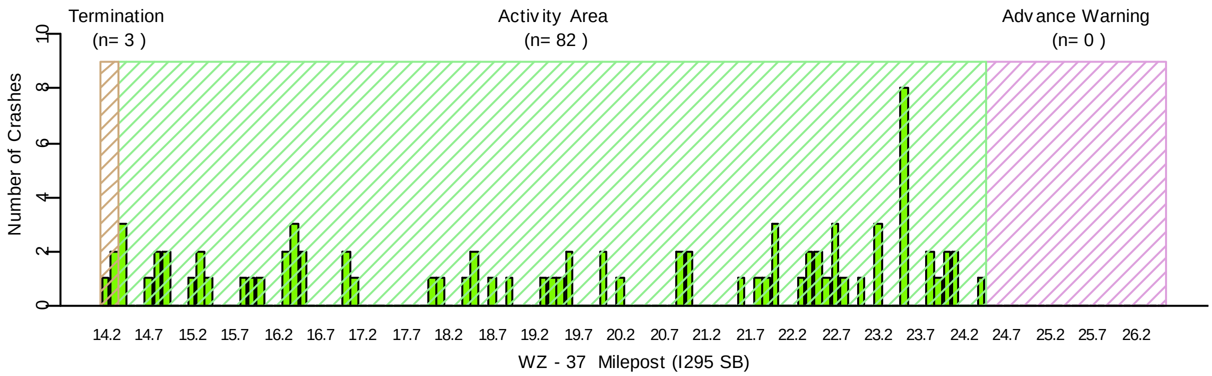


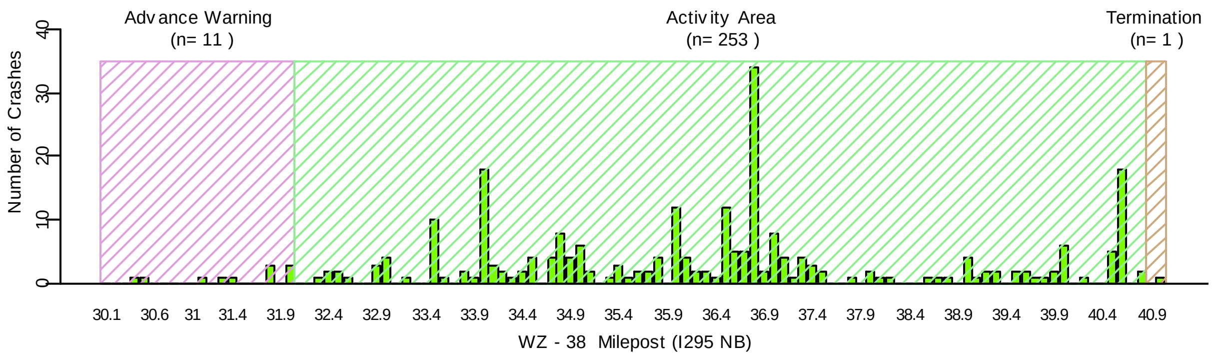


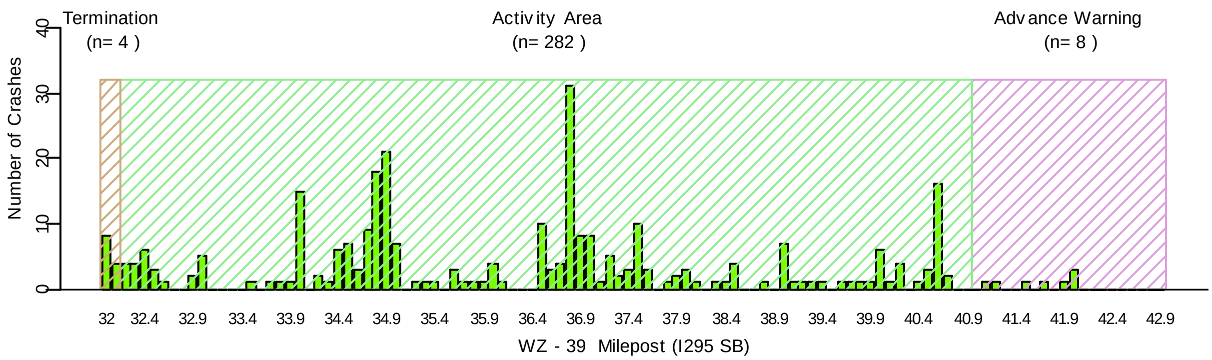
Work Zones 33–36 Plots

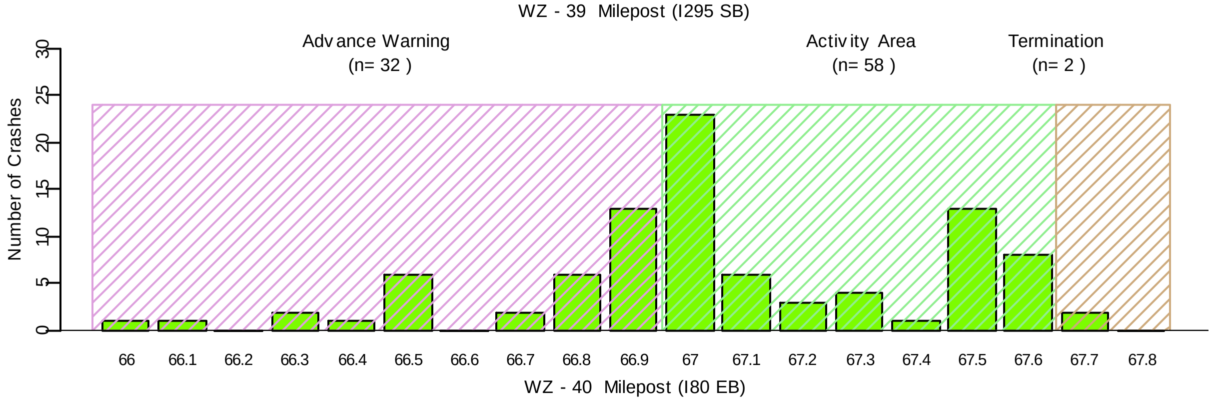


Work Zones 37–40 Plots

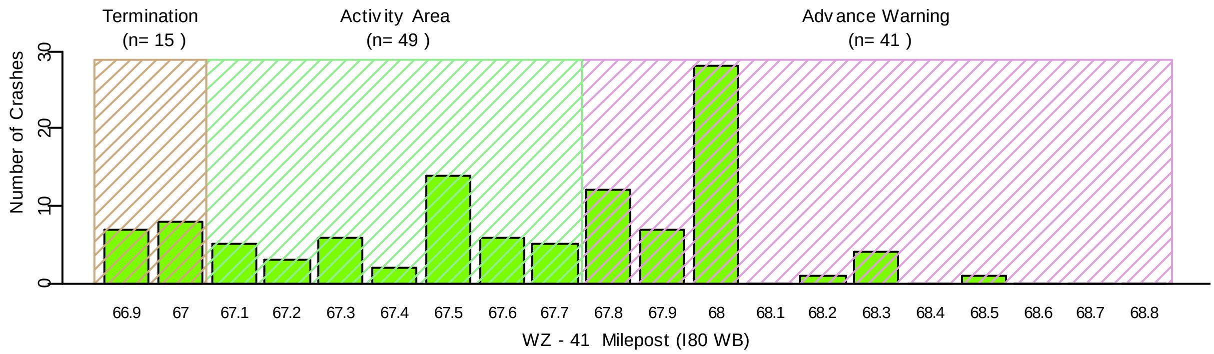


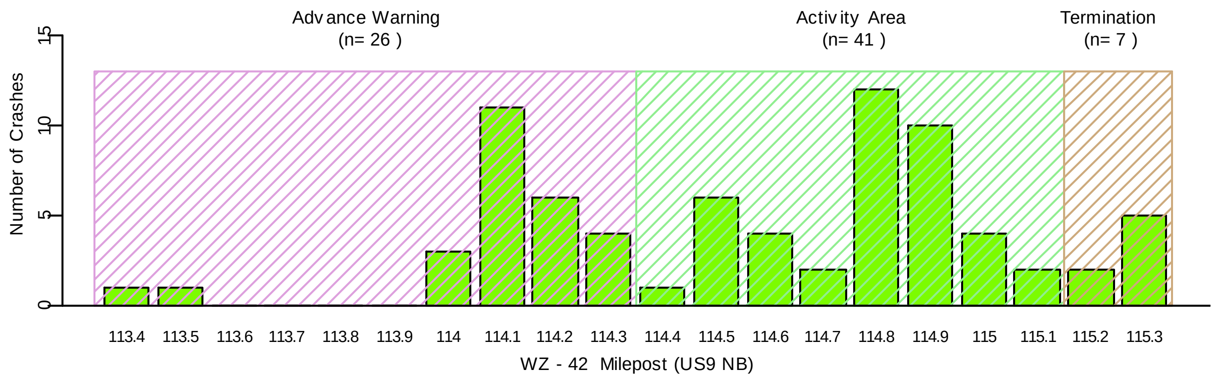


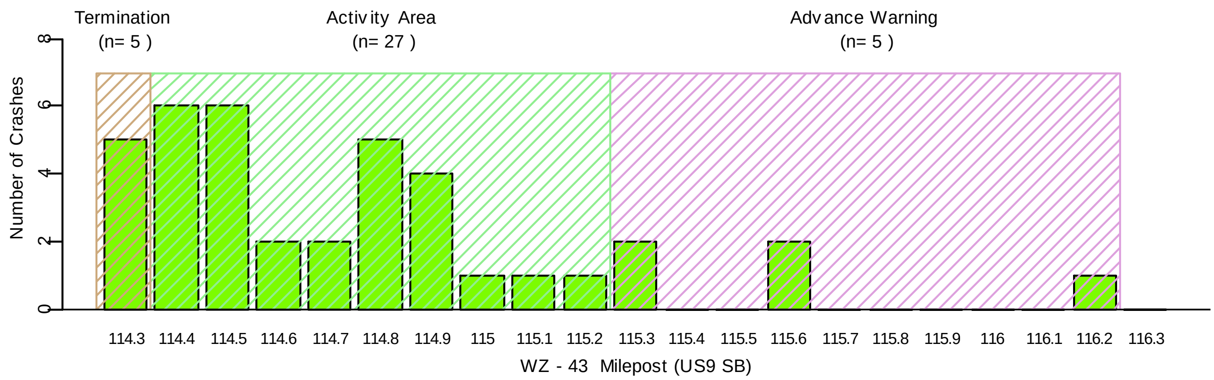


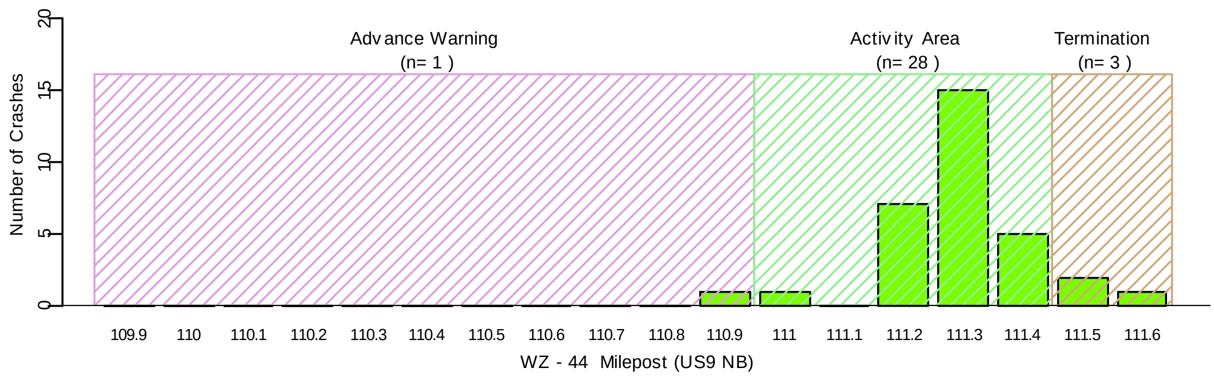


Work Zones 41–44 Plots

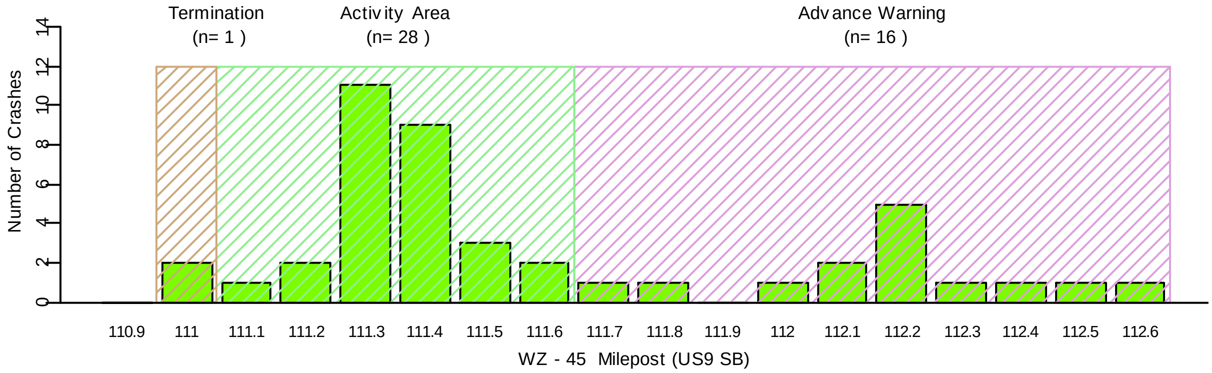


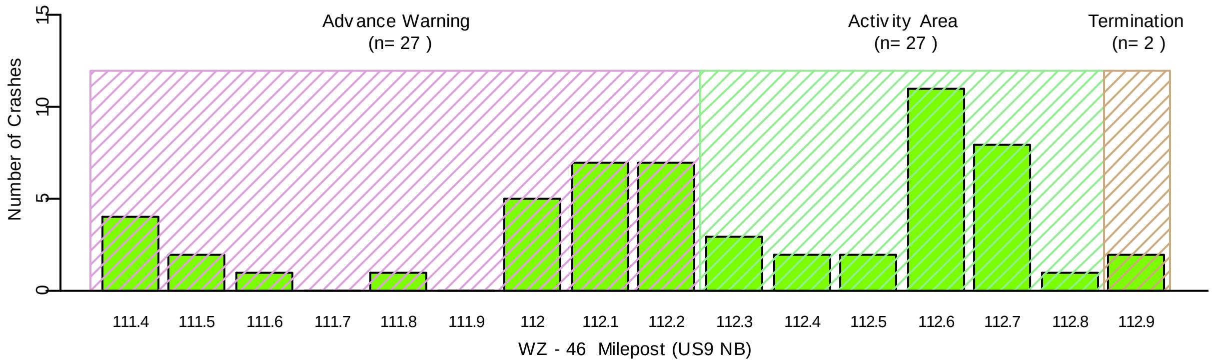


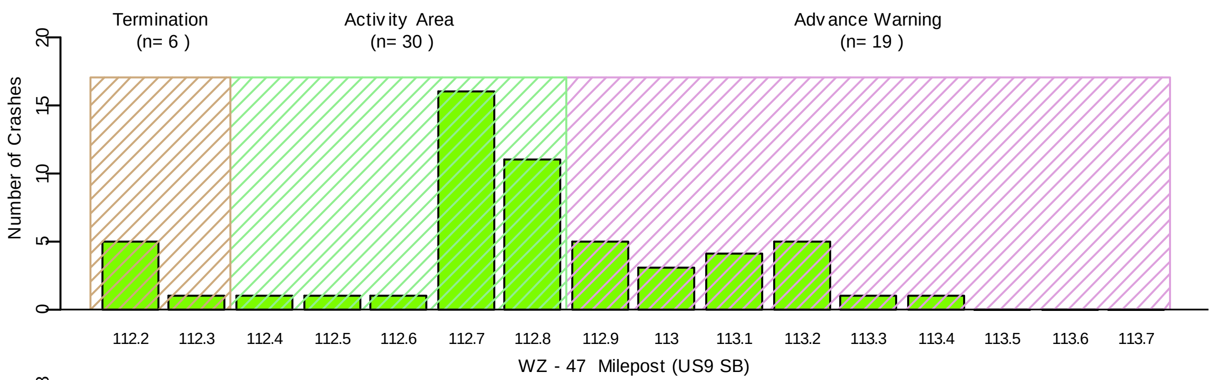


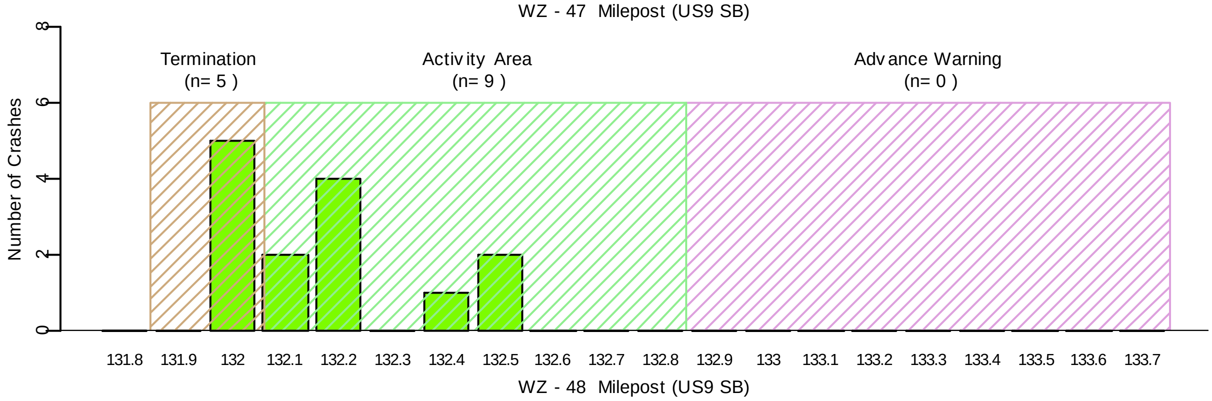


Work Zones 45–48 Plots

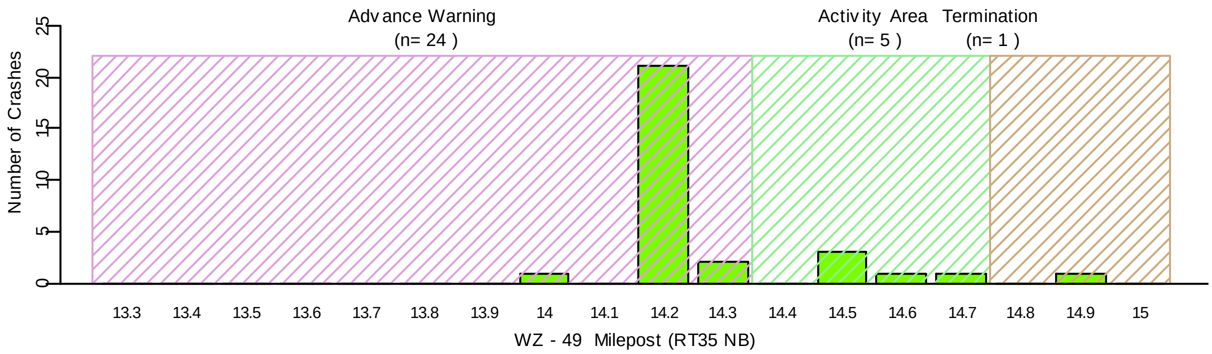


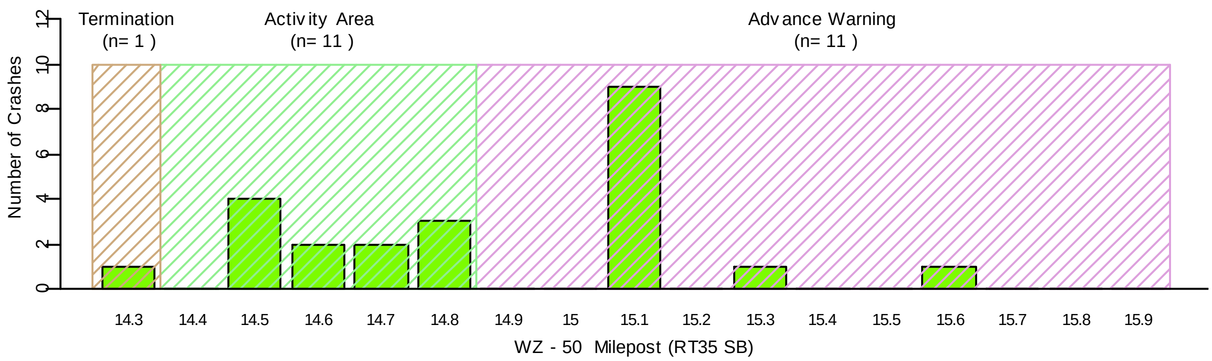


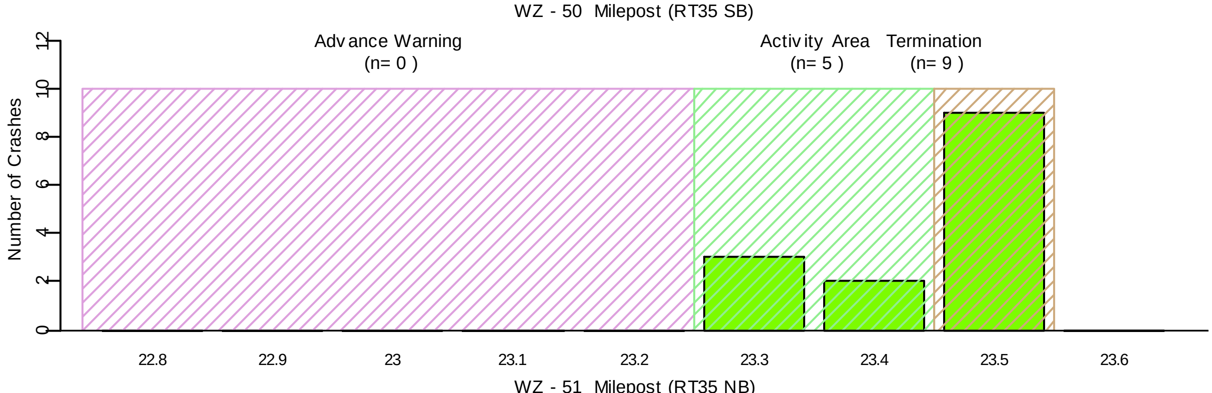


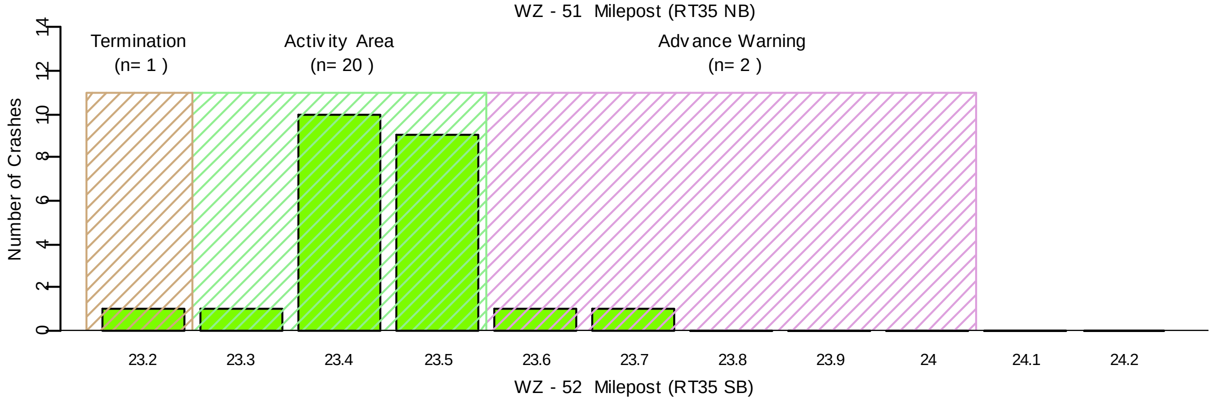


Work Zones 49–52 Plots

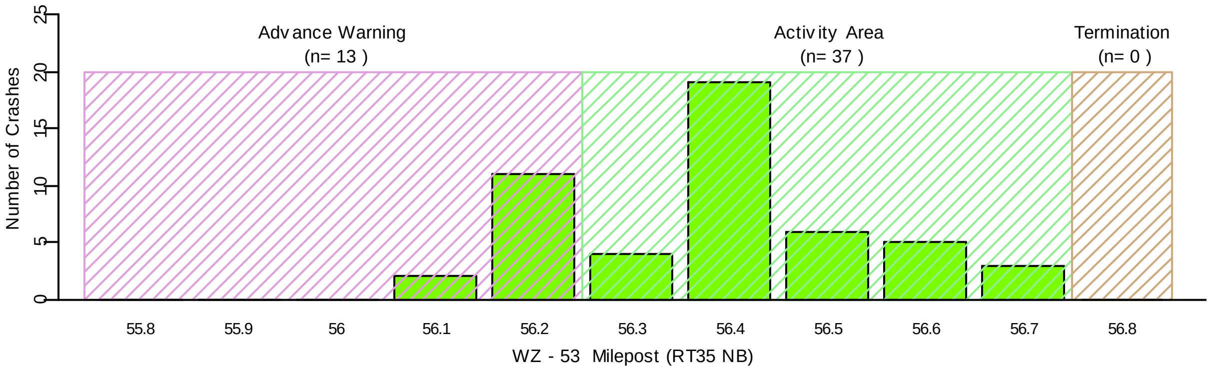


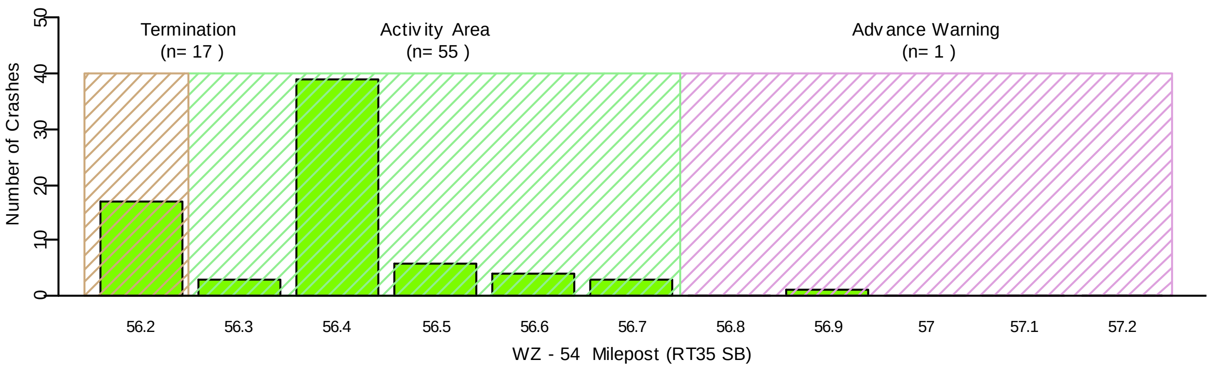


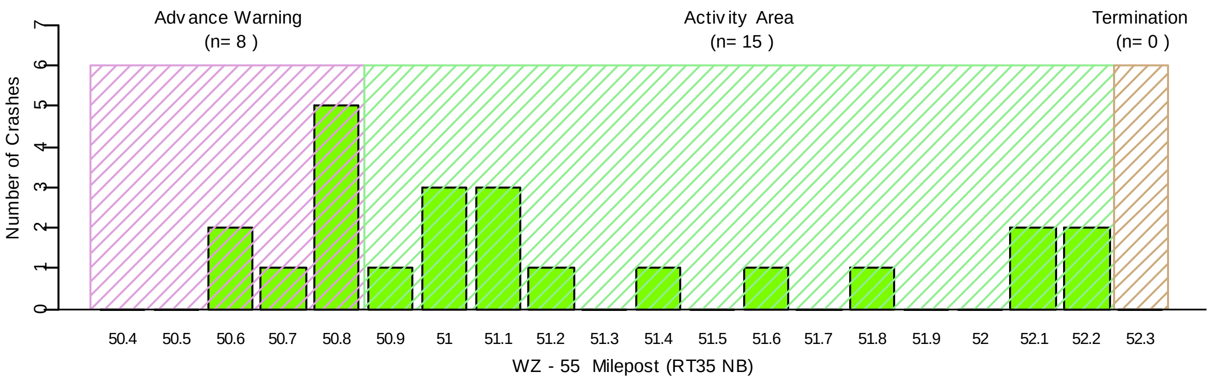


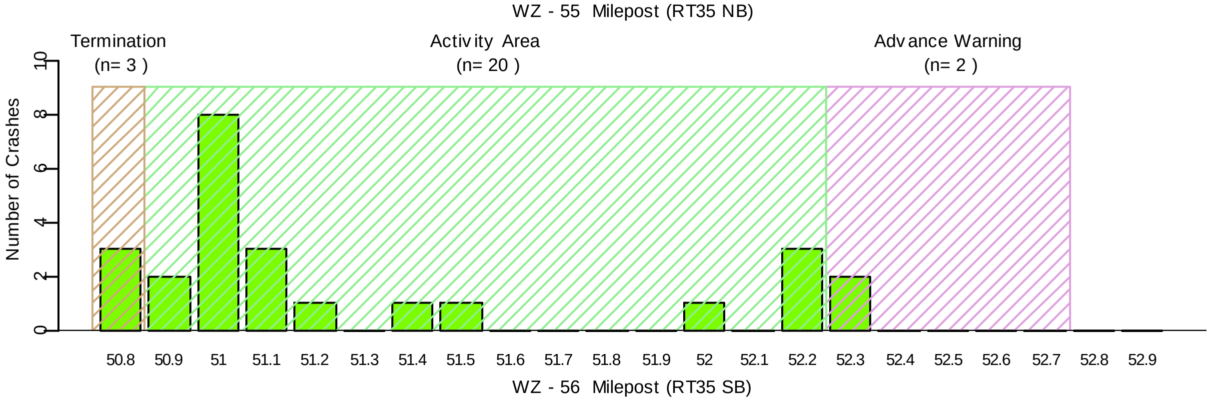


Work Zones 53–56 Plots









Work Zones 57–60 Plots