Report No. K-TRAN: KU-05-1
FINAL REPORT

DETERMINING MAJOR CAUSES OF HIGHWAY WORK ZONE ACCIDENTS IN KANSAS

Yong Bai, Ph.D., P.E.
Yingfeng Li

The University of Kansas
Lawrence, Kansas

JUNE 2006

K-TRAN

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:
KANSAS DEPARTMENT OF TRANSPORTATION
KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

1 Report No. K-TRAN: KU-05-1	**2 Government Accession No.**	**3 Recipient Catalog No.**

4 Title and Subtitle DETERMINING THE MAJOR CAUSES OF HIGHWAY WORK ZONE ACCIDENTS IN KANSAS	**5 Report Date** June 2006 **6 Performing Organization Code**
7 Author(s) Yong Bai, Ph.D., P.E., and Yingfeng Li	**8 Performing Organization Report No.**
9 Performing Organization Name and Address University of Kansas Civil, Environmental & Architectural Engineering Department 1530 West 15th Street, 2150 Learned Hall Lawrence, Kansas 66045-7609	**10 Work Unit No. (TRAIS)** **11 Contract or Grant No.** C1482
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Materials and Research 700 SW Harrison Street Topeka, Kansas 66603-3754	**13 Type of Report and Period Covered** Final Report July 2004 – March 2006 **14 Sponsoring Agency Code** RE-0375-01

15 Supplementary Notes

For more information write to address in block 9.

16 Abstract

Highway work zones constitute a major safety concern for government agencies, the legislature, the highway industry, and the traveling public. Despite the efforts made by government agencies and the highway industry, there is little indication that work zone crashes are on the decline nationwide. The main reason behind this is that current safety countermeasures are not working effectively in the work zones. Lack of effective countermeasures may be due to the fact that the characteristics of work zone crashes are not well understood. The primary objective of this research was to investigate the characteristics of fatal crashes and risk factors to these crashes in the work zones so that effective countermeasures could be developed and implemented in the near future. The objective was accomplished using a four-step approach. First, literature review on previous work zone crash studies was conducted to establish a solid understanding on this issue. Second, the research team collected the crash data from the KDOT accident database and the original accident reports. A total of 157 fatal crash cases between 1992 and 2004 were examined. Third, based on the collected data, the researchers systematically examined the work zone fatal crashes using statistical analysis methods such as descriptive analyses and regression analyses. At the end of analyses, the unique crash characteristics and risk factors in the work zones were determined. Finally, improvements on work zone safety were recommended.

17 Key Words Accidents, Fatalities, Traffic Safety and Work Zone	**18 Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19 Security Classification (of this report) Unclassified	**20 Security Classification (of this page)** Unclassified	**21 No. of pages** 168	**22 Price**

Form DOT F 1700.7 (8-72)

DETERMINING MAJOR CAUSES OF HIGHWAY WORK ZONE ACCIDENTS IN KANSAS

Final Report

Prepared by

Yong Bai, Ph.D., P.E.
Assistant Professor

And

Yingfeng Li
Research Assistant

A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
LAWRENCE, KANSAS

June 2006

PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

DISCLAIMER

ABSTRACT

Highway work zones constitute a major safety concern for government agencies, the legislature, the highway industry, and the traveling public. Despite the efforts made by government agencies and the highway industry, there is little indication that work zone crashes are on the decline nationwide. The main reason behind this is that current safety countermeasures are not working effectively in the work zones. Lack of effective countermeasures may be due to the fact that the characteristics of work zone crashes are not well understood. The primary objective of this research was to investigate the characteristics of fatal crashes and risk factors to these crashes in the work zones so that effective countermeasures could be developed and implemented in the near future. The objective was accomplished using a four-step approach. First, literature review on previous work zone crash studies was conducted to establish a solid understanding on this issue. Second, the research team collected the crash data from the KDOT accident database and the original accident reports. A total of 157 fatal crash cases between 1992 and 2004 were examined. Third, based on the collected data, the researchers systematically examined the work zone fatal crashes using statistical analysis methods such as descriptive analyses and regression analyses. At the end of analyses, the unique crash characteristics and risk factors in the work zones were determined. Finally, improvements on work zone safety were recommended.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

1.1 Problem Statement

As the American highway system ages, the federal and state government agencies have been shifting their funding focus to maintenance, rehabilitation, and upgrading of the existing highway networks. More and more highway work zones have constituted an inevitable disruption on regular traffic flows, which has resulted in severe traffic safety problems. Providing safety in work zones while keeping maximum utilization of highways has become one of the overwhelming challenges that traffic engineers and researchers have to confront.

Nationally, great efforts have been devoted to improve the safety and mobility of work zone traffic. Congress addressed the work zone safety issue in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and National Highway System Designation Act of 1995 (FHWA, 1998). In addition, Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) have been developing comprehensive highway work zone safety guidelines and programs. Many state Departments of Transportation (DOTs) have funded various projects to improve work zone safety in their states. Other concerned organizations or research communities have also participated in this campaign and devoted their contributions by conducting meaningful researches on various work zone safety issues.

Regardless of these efforts, there is little indication of significant improvements in work zone safety nationwide. Work zone crash rates by work zone travel mileage are not precisely known, but statistics of work zone fatalities have shown a serious traffic safety problem. Annual work zone fatalities rose from 872 in 1999 to 1,028 in 2003 (an average of 1,020 per year), adding another 40,000 work zone related injuries per year (FHWA, 2004). It was estimated that the direct cost of highway work zone crashes was as high as $6.2 billion per year between 1995 and 1997 with an average cost of $3,687 per crash (Mohan and Gautam 2002). The alarming numbers indicate an urgent need for improving every work zone-safety related field including traffic control and information, project management, public education, and regulation/policy making.

Actual crash experience is always the best source for identifying safety deficiencies and developing effective countermeasures. Studying the characteristics of work zone crashes is the first step towards improving work zone safety. Investigating highway work zone fatal crashes enables researchers to identify unique work zone safety problems. Accordingly, effective countermeasures could be developed to save lives of both construction workers and highway users. With this motivation, Kansas Department of Transportation (KDOT) initiated a project (K-TRAN Project # KU-05-01) to study the fatal crashes in Kansas highway work zones between 1992 and 2004. Through this study, the characteristics of the fatal work zone crashes were investigated. Results of the study could be utilized to develop safety countermeasures in the near future.

1.2 Report Organization

This report includes the following chapters:

1. Introduction. The report starts with this introduction chapter which presents a general problem statement of this research and a brief description of the report organization.
2. Literature review. This chapter presents the findings of a comprehensive literature review. The review covers several work zone safety related subjects such as previous analyses on highway work zone crashes, statistic methods and applications in crash data

analysis, highway work zone traffic control, research and development trend, and other highway work zone-safety related researches.

3. Research scope, objective, and methodology. This chapter outlines the scope, objective, and methodology of the fatal work zone crash study presented in this report.

4. Data collection. This chapter describes various data collection issues including the accident report, data organization, and data collection procedure.

5. Data analyses. This chapter addresses the data analysis procedure and results. The data analyses include a frequency analysis, a detailed analysis of the crash factors that are interrelated with each others, and logistic regression analyses on the effectiveness of traffic control devices and the safety impacts of selected crash variables.

6. Discussion and risk determination. This chapter discusses the major findings from the data analyses. Work zone risks are determined based on the results of data analyses and the comparisons between the characteristics of fatal work zone crashes and all other fatal crashes in Kansas.

7. Conclusions and recommendations. Finally, this chapter presents the final conclusions drawn from the study and the reseachers' recommendations on securing the highway work zones in Kansas.

Chapter 2:

Literature Review

2.1 Introduction

A highway work zone refers to a road section where a construction or maintenance project is carried out. Manual on Uniform Traffic Control Devices (MUTCD) divides a work zone into four areas, as shown in Figure 2.1.1: the advance warning area, the transition area, the activity area, and the termination area (FHWA 2003). Road users traveling through a work zone are warned of the upcoming hazardous area in the advanced warning section and then are directed out of their normal path in the transition area. The transition area frequently forms a bottleneck which could dramatically reduce the traffic throughput. The termination area is the section following activity area where road users return to their normal path.

Highway work zone safety has been an important traffic safety research focus for several decades. The California Department of Public Works (1965) published a report on this subject in 1965. Munro and Huang (1968) conducted a research project on work zone safety in 1968. To date, a significant amount of studies on highway work zone safety have been published. Most of these studies were conducted statewide; only a few addressed nationwide work zone safety issues.

At the beginning of this project, a comprehensive literature review was carried out to gather the results of the previous work zone safety studies. The materials covered in this literature review are from various sources including journals, research reports, conference proceedings, and periodicals. A total of 58 articles were reviewed, among which 39 were journal papers, 10 were research reports, and 9 were conference proceedings. Each of them was briefly summarized in one paragraph including important study issues such as research scope, objective, methodology, contributions, limitations, and needs for further research.

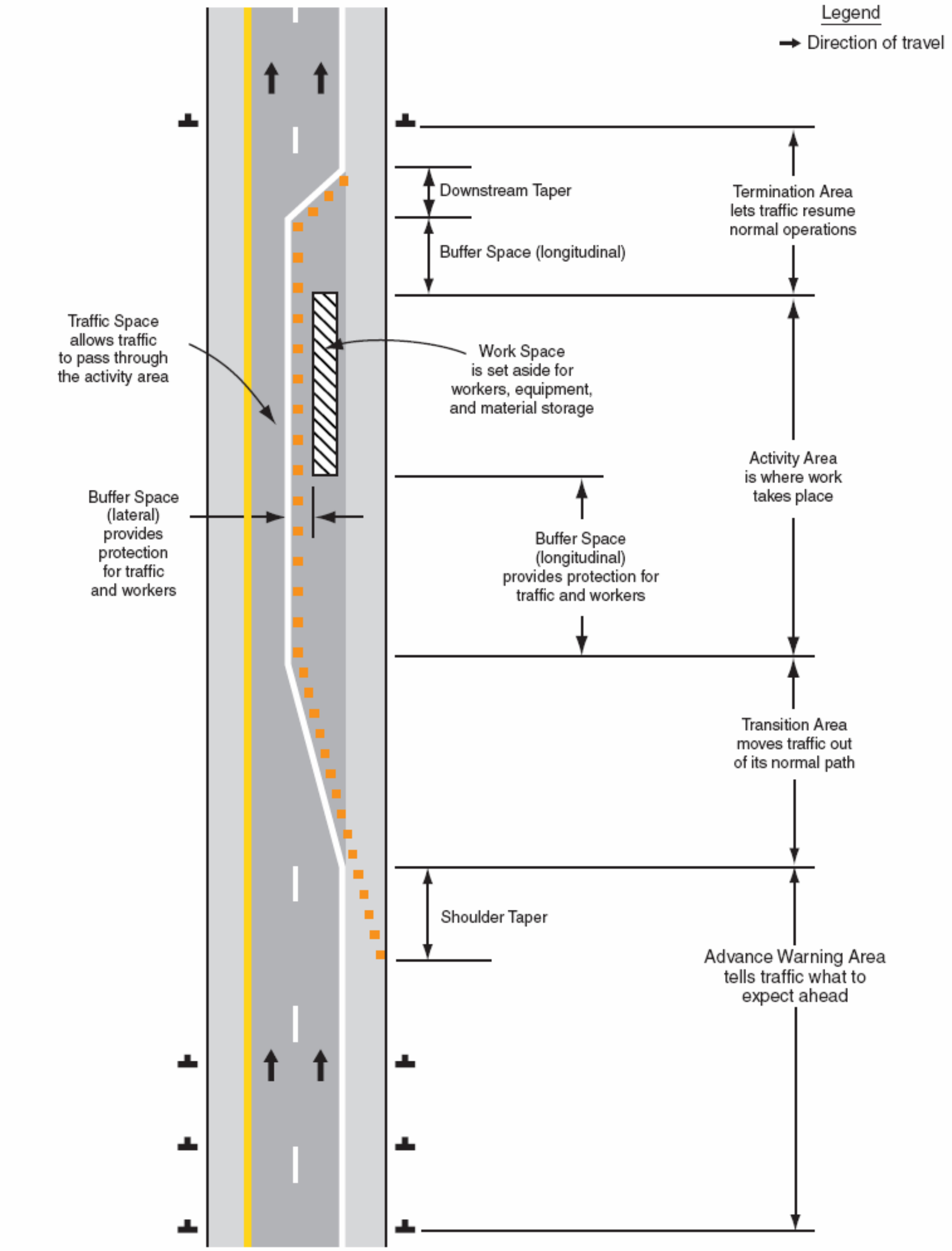


Figure 2.1.1: Component Areas of a Highway Work Zone

*Source: MUTCD (2003 Edition, page 6C-3***)**

The articles annotated in this chapter are categorized into five subjects. Within each category, materials are generally organized chronologically. The five subjects are as follows:

1. Previous analyses on crashes in highway work zones: this section covers the previous studies on work zone crash characteristics. Most of these studies were conducted based on statewide work zone crash data.
2. Statistical methods and applications in traffic data analysis: this part focuses on the research projects which used advanced statistical approaches to analyze massive traffic crash data. The objective of this review is to study the currently available statistical methods for crash analysis.
3. Highway work zone traffic control: this section includes a state-of-the-art review on the previous researches that introduced and/or evaluated various traffic control devices or strategies implemented in work zones. These work zone traffic control devices or strategies include both traditional techniques as introduced in Manual of Uniform Traffic Control Devices (MUTCD) and advanced techniques such as intelligent transportation system (ITS) applications.
4. Research and development trends: newly developed methodologies and technologies for improving highway work zone safety are annotated in this chapter, which include the studies of advanced techniques such as Geographical Information System (GIS) and ITS and the explorations of advanced research tools or approaches used for work zone safety.
5. Other highway work zone safety related researches: this section presents the brief summaries of the research projects related to work zone safety that cannot be categorized explicitly in any of the above chapters but helpful in offering a thorough understanding of highway work zone safety.

2.2 Previous Analyses on Crashes in Highway Work Zones

Many research projects have been conducted to analyze the characteristics of work zone crashes and their detailed distribution within work zones. This section covers recent studies of work zone crash characteristics, most of which were based on statewide research projects. The major findings from work zone crash studies indicate that work zone collisions share some common features in spite of their different spatial distributions across the nation. Ten studies are summarized in this chapter, as shown in Table 1, including seven journal papers, two research reports, and a master degree thesis.

Table 2.2.1: List of the Articles Cited in Section 2.2

No	Researcher(s)	Study Subject	Study Scope	Funding Agency
1	Hill et al.	Work zone fatality characteristics	Texas State	Texas Tech University
2	Garber and Zhao	Work zone crash characteristics	Virginia State	Virginia Transportation Research Council
3	Chambless et al.	Multi-state work zone crash characteristics	Multi-state	N/A
4	Mohan and Gautam	Work zone crash cost	National	N/A
5	Ha and Nemeth	Work zone crash characteristics and traffic controls	Ohio State	N/A
6	Benekohal et al.	Truck drivers' crash experience	Illinois State	Illinois Department of Transportation
7	Pigman and Agent	Work zone crash characteristics in comparison with non-work zone crashes	Kentucky State	N/A
8	Garber and Woo	Urban highway work zone crash characteristics	Virginia State	Virginia Transportation Research Council
9	Hall and Lorenz	Work zone crash characteristics	Mexico State	New Mexico State Highway Department
10	Hargroves	Work zone crash characteristics	Virginia State	N/A

One of the recent studies was conducted by Hill et al. (2003) at Texas Tech University which focused on the analysis of work zone fatal crashes in the State of Texas. The objective of this study was to understand the characteristics of work zone fatalities and then evaluate the effectiveness of existing work zone traffic safety countermeasures. The study was conducted in two steps. The first step is to identify the significant contributing factors of work zone fatalities. An exploratory data analysis was carried out based on three major comparisons including daytime versus nighttime, male driver versus female driver, and commercial-truck-involved versus non-commercial-truck-involved. Then the researcher quantified the effectiveness of work zone traffic control measures such as using an officer/flagman and using a stop/go signal using logistic regression techniques. Results of the study indicated that many variables caused crashes in work zones and there was a significant difference between daytime crashes and nighttime crashes in terms of the types of crashes and types of driver errors. The difference between driver genders also led to differences in crash type and driver error. In addition, commercial truck related crashes were more likely to involve multiple vehicles. According to the logistic regression results, the use of an officer/flagman or a stop/go signal would reduce the chance of having a crash by 68% or 64% respectively. These results provided valuable insights for the highway communities to develop effective safety countermeasures and education programs, and make rational decisions. The Texas Department of Public Safety (TDPS) provided the research team with 376 fatal crashes in Texas highway work zones from January 1, 1997 to December 31, 1999.

The characteristics of highway work zone collisions and their detailed locations within work zones were studied by Garber and Zhao (2002) to enhance the selection of effective countermeasures. The objective was to determine the distribution and characteristics of crashes in specific areas within a work zone and to compare selected characteristics of work zone crashes with those of non-work zone crashes. In their study, the different locations in the work zone were referred to as the advance warning area, transition area (taper), longitudinal buffer area, activity area, and termination area. A total of 1484 work zone related crashes during 1993 and 1999 in Virginia were analyzed; information on each work zone crash was obtained from the original accident reports. The crashes were analyzed in terms of severity, collision type, road type, and time of day. Based on the crash percentages regarding location, severity, and collision type, the researchers concluded several major findings. First, the activity area had the highest number of crashes and the highest number of fatal crashes while the termination area was the safest area in terms of numbers of crashes. Second, property-damage-only (PDO) crashes were the predominant severity type, followed by the injury crashes. Third, rear-end crashes were predominant for all areas and all road types except for the termination area, where all crashes were angle crashes. Fourth, as traffic moved from the transition area to the work area, the proportions of rear-end and same-direction sideswipe crashes decreased and the proportions of fixed-object, off-road, and angle crashes increased, although rear-end crashes were still predominant. Last, most nighttime work zone crashes were in the activity area and the severities of nighttime and daytime work zone crashes were not significantly different. Accordingly, the researchers believed that: 1) the most dangerous area in a work zone was the activity area; 2) rear-end crashes were the predominant crash type; and 3) there was a significant increase in fixed-object crashes during nighttime. Based on the study results, the researchers also offered suggestions such as the careful planning of work zone durations, stricter work zone speed controls, and more effective separations between activity area and traffic. This research was funded by Virginia Transportation Research Council (VTRC) and the Virginia Department of Transportation (VDOT).

Chambless et al. (2002) examined the typical characteristics of highway work zone related crashes. Their research scope was focused on the computerized work zone crash data from three states (Alabama, 1994-1998, 677,049 crash data including 1.8 percent of work zone crashes; Michigan, 1996-1998, 1,244,765 crash data including 1.6 percent of work zone crashes; Tennessee, 1996-1997, 336,862 crash data including 0.76 percent of work zone crashes). In this study, the researchers compared the characteristics of work zone crashes with those of non-work zone crashes to highlight “typical” work zone characteristics. The study used the Information Mining for Producing Accident Countermeasure Technology (IMPACT) module of Critical Analysis Reporting Environment (CARE) software developed by University of Alabama to perform the statistical analysis. Through their analysis, several facts of work zone crashes had been identified in comparison with non-work zone crashes. They were: 1) the severity of the work zone crashes was similar to that of non-work zone crashes; 2) 63 percent of work zone crashes took place on interstate, U.S., and state roads; 3) 48 percent of work zone crashes occurred on 45- and 55-mph speed zones, as opposed to 34 percent of non-work zone crashes; and 4) “misjudging stopping distance/following too close” accounted for 27 percent of the “prime contributing crash circumstances” for work zone crashes as opposed to 15 percent for non-work zone crashes.

To emphasize the severity of highway work zone crashes, Mohan and Gautam (2002) conducted a statistical study on highway work zone crashes which highlighted their monetary costs. Their report presented details of the various injury types of highway work zone crashes and their cost estimates. According to their study, while the highway traffic rate has been declining by approximately 3.3 per year since 1960, work zone fatalities had stayed constant at around 700 deaths per year, without considering the fact that the amount of highway work zones had been increasing. In addition, 30% of highway work zone crashes involve construction workers. Based on the analysis of 3,686 crashes related to highway work zones that occurred during 1990 through 1993 that were reported to the Liberty Mutual Insurance Company, the researchers summarized their findings as: 1) rear-end collision was the most common crash type, followed by the hit-small-object collisions; 2) most crashes occurred when the vehicle was stopping or slowing; 3) the most expensive type of work zone crashes was overturn which had an average cost of $12,627, followed by rear-end collisions which had an average cost of $5,541; 4) the median cost of work zone collisions was $800; and 5) the average direct cost per highway work zone crash was $3,687 and the median direct cost per crash was $687.

Ha and Nemeth (1995) conducted a study in an effort to identify the major cause-and-effect relationships between work zone crashes and traffic controls in order to make the first step towards development of effective work zone traffic control strategies. Their study began with a comprehensive literature review on previous work zone crash studies. Based on the review, they summarized the findings of typical previous researches on work zone crash experience as: 1) the predominant type of crash was rear-end; 2) ineffective attempts were made to reduce speeding problems; 3) improper traffic control was one of the safety problems in construction zones; 4) involvement of trucks in crashes at crossovers was significant. Then, the researchers analyzed the crash data between 1982 and 1986 which were extracted from the accident reports at nine construction sites in Ohio. The analysis focused on the impacts of factors such as inadequate or confusing traffic control, edge drop or soft shoulder, traffic slowdowns, lane changing or merging, guardrails, and alcohol impairment on work zone crashes. Finally, the researchers concluded that: 1) work zone management had been more or less improved; 2) work zone crashes were slightly less severe than other types of crashes; 3) although work zone crashes increased at nights, they actually decreased in proportion to all crashes. The data used in this study were provided by Ohio Department of Transportation (ODOT).

It has been widely agreed that heavy trucks contribute significantly to work zone fatalities. So far, various studies have been conducted to identify the most effective traffic control strategies to prevent trucks from being involved in fatal collisions. Benekohal et al. (1995) conducted a research to study truck drivers' concerns about traffic control in work zones.

The study also attempted to identify risky driving situations and the locations of crashes within a work zone. The study was mainly founded on a statewide opinion survey of 930 semi-trailer drivers which was carried out on several highways in Illinois. The survey contained questions about driver and vehicle characteristics, drivers' assessment of work zones and the traffic control devices, their crash and risky driving experiences, and their suggestions for improving traffic flow and safety in work zones. Based on the analysis on 834 suitable returned surveys, the researchers found that most of the truck drivers (90%) thought that driving through work zones was more hazardous. In addition, approximately half of them wanted to see a warning sign 3 to 5 miles ahead of work zones. According to the survey results, although a significant portion of truck drivers believed the 55 mph speed limit was too high, many others still showed intent to travel in higher speeds. In addition, a portion of drivers surveyed suggested that more signs should be added to work zones and the traditional signs were not clear enough. Regarding the crash locations, there were fewer crashes in the activity area than in the advanced warning area and transition area. It was also identified that crashes were significantly caused by bad driving situations but not other driver/truck characteristics. This study was done in cooperation with the Illinois Department of Transportation (IDOT).

By comparing highway work zone crashes with non-work zone highway crashes, some typical factors which marked the differences of the former from the latter were explored in the study of Pigman and Agent (1990) at the University of Kentucky. The objective of this study was to identify solutions to problems that confronted the personnel involved in traffic control planning for construction and maintenance operations. The research studied the traffic crash data and traffic control devices of 20 highway work zones for a 3-year period (1983 – 1986). Based on the study, they found that: 1) most work zone crashes occur on interstate routes; 2) work zone crashes, especially those during darkness or involving trucks, were more severe than other crashes -- which disagrees with Ha and Hemeth (1995); 3) the percentage of rear-end and same-direction-sideswipe crashes in the work zone crashes was almost three times of the percentage of the same types in the statewide non-work zone crashes; and 4) the greatest contributing factor of work zone crashes was following too close. However, the researchers concluded that, although it was observed in some cases that the number of crashes increased after the installations of work zones, efforts to create safer work zones have been more or less successful in recent years. The data used in this study was obtained from Kentucky Accident Reporting System (KARS) and on-site collection.

In Virginia, another study (Garber and Woo, 1990) was conducted to identify the prevalent characteristics of the crashes in urban work zones and to evaluate traffic control devices commonly used in urban work zones. Their study proceeded in several steps. First, the researchers reviewed the historical crash data and traffic control devices of urban work zones. Then, they studied the crash data collected on several study sites during both before the work zones put in places and during the work zones put in places in Virginia to find significant characteristics. Third, based on the data collected, they established relationships between work zone crash rates and traffic control devices applied in work zones using the regression technique. Finally, guidelines were developed for selecting suitable devices for controlling traffic in urban work zones. According to their study, they found that: 1) crash rates were increased after the installations of urban work zones; 2) angle, rear-end, and side-swipe were the three most prevalent collision types in urban work zones; 3) work zone crashes were more likely to involve multiple vehicles then non-work zone crashes; 4) the adverse environmental conditions and alcohol impairment were not responsible for the increase in crash rates at work zones. In terms of traffic control effectiveness, they found that: 1) the most effective combination of traffic control devices in work zones of multilane highways was the combination of cones, flashing arrows, and flagmen; 2) the use of barricades as part of any combination of control devices in urban multilane highway work zones seemed to reduce the overall effectiveness of the traffic control devices; and 3) the use of flaggers was a very effective means of traffic control in the work zones on urban two-lane highways. According to their study results, the researchers suggested that urban work zone lengths should be limited to 0.6 mile since longer work zones caused much more crashes. This study was based on a project of VTRC in the cooperation of both VDOT and the University of Virginia.

Hall and Lorenz (1989) conducted a study to improve the safety of highway work zones in New Mexico. The immediate objectives of this study were 1) to identify the characteristics of work zone crashes that differ from other crashes of comparable roadways, and 2) to develop effective countermeasures for prevalent work zone safety problems. The researchers examined highway work zone crashes in New Mexico for a 3-year period (1983 – 1985) on a basis of comparing the crashes in several roadway sections during construction with those in previous years with the same road sections. The chi-square statistic (X^2), a statistical method based on the possible values of the categorical data and the desired level of significance, was used to determine whether the difference between crashes of before- and during- construction periods was statistically significant. Through the study, two conditions were found to have significant impacts on work zone crashes: inclement weather conditions and bad roadway surface. In addition, the researchers concluded: 1) the proportion of crashes that were caused mainly by following too close was much higher in during-work zone periods than in before-work zone periods; 2) in comparison with the identical period in the prior year, crashes in construction areas increased 33 percent on the rural interstate system, 17 percent on the rural Federal-Aid-Primary highways, and 27 percent on the rural Federal-Aid-Secondary highways; and 3) improper traffic control was the prevalent problem causing high crash rates in work zones. The researchers suggested that the work zone safety could be improved by devoting more efforts to fields such as education of work zone related personnel, preparation and modification of traffic control plans, safety inspections, and crash record keeping. The study was funded by the New Mexico State Highway Department (NMSHD) and FHWA.

Hargroves (1981) conducted a research which included an examination of both causal factors and characteristics of work zone crashes. The research analyzed 2,127 work zone crashes reported in Virginia in 1977 by first breaking them down according to the variables regularly coded on the Motor Vehicle Accident Report. The variables included time of crash, roadway alignment, weather conditions, etc. Then, the crashes were further analyzed in terms of the following characteristic groups: crash type, causal factors, characteristics of work zones, and crash severity. Based on the study, the most significant facts associated with work zone crashes were identified as: 1) there was a substantial evidence of a rear-end crash problem in highway work zones; and 2) a significant part of highway work zone crashes could be avoided by improving work zone traffic control practices and procedures. The data used in this research were provided by FHWA and Virginia Department of Highways and Transportation.

2.3 Statistic Methods and Applications in Traffic Data Analysis

This section focuses on those researches which used advanced statistical approaches to analyze massive traffic crash data. The objective of this review is to establish a background of the currently available statistical methodologies for crash analysis. Instead of diving into theories of statistical methods, the authors examined the applications of statistical methods that have been used in work zone safety studies and identified those that might have potentials to be utilized for the current KDOT project. The major statistical data analysis methods reviewed in this chapter include: various regression techniques, multinomial logit approach, Empirical Bayes method, general data statistics, and fuzzy-logic technique. An index of statistical methods covered in this chapter is listed in Table 2.3.1, and the studies using these methods are described in the following paragraphs.

The significance of logistic regression technique in the analysis of traffic safety has been recognized for years. Hill et al. (2003) has applied this technique in his analysis of the characteristics of work zone fatal crashes in Texas. A set of sequential binary logistic regression models was developed by Dissanayake and Lu (2002) to analyze the alerting factors and predict the crash severity of single-vehicle fixed-object crashes involving young drivers. Their research scope focused on young drivers because they have been considered to be the age group most likely involved in severe traffic crashes. The researchers utilized the PROC LOGISTIC procedure in the SAS software package to develop the regression models and then organized them from lowest severity level to the highest. Their models took into account several important crash factors such as gender, driver impairment, and geometric conditions of crash locations. Through their modeling of the crash data, they found that factors such as influence of alcohol or drugs, ejection in the crash, rural crash locations, existence of curve or grade at the crash location, and speed of the crash vehicle could significantly increase the probability of having a more severe crash. They also concluded that factors such as restraint device usage and being a male clearly reduced the tendency of high severity, while some other variables, such as weather condition, residence location, and physical condition, were not important at all. However, one limitation to their methodology was that it didn't account for multi-vehicle crashes involving young drivers and the conditions of the crash vehicles. This research used the crash data during the period of 1996 – 1998 extracted from the Florida Traffic Crash Database obtained from the FHWA State Data Program. This project was funded by a grant from the Community Initiative of the University of South Florida.

Table 2.2.1: List of the Articles Cited in Section 2.3

No	Statistical Method	Researcher (s)	Research Scope	Funding Agency
1	Logistic regression	Dissanayake and Lu	Single-vehicle fixed-object crashes involving young drivers	University of South Florida
		Kim et al.	Alcohol-impaired motorcycle crashes in Hawaii	National Highway Traffic Safety Administration and the University of Hawaii
2	Multinomial logit approach	Ouyang et al.	Car-truck collisions	Washington State Department of Transportation
3	Empirical Bayes (EB) Method	Hauer et al.	A tutorial to Empirical Bayes	N/A
		Yuan et al.	Benefits of angle realignment and curve realignment of intersection approach	Connecticut Department of Transportation
		Elvik et al.	Safety effect of bypasses	N/A
4	Negative binomial regression	Donnell et al.	Cross-median collisions	Pennsylvania Department of Transportation
5	General data analysis	Turner and Georggi	Alcohol-related motorcycle crashes in Florida	Florida Department of Highway Safety and Motor Vehicles
		Taylor et al.	Safety impact of replacing bi-directional median crossovers with directional median crossovers	N/A
6	Fuzzy-logic technique	Xiao et al.	Wet-pavement crashes	N/A
7	Nonlinear regression	Garber and Ehrhart	Crashes on two lane highways	Virginia Transportation Research Council
8	Variable-selection procedure	Chen and Jovanis	Bus-involved crashes	N/A

The traditional logit or probit models for traffic crash severity analysis can only model one severity at a time, while many advanced analyses require modeling multiple severities simultaneously. Ouyang et al. (2002) developed a methodology which used a simultaneous binary logit model to account the interrelationships among the injury severity outcomes in multi-vehicle collisions. The model addressed the highway design and environmental issues, along with human factors, in a multivariate context using a simultaneous multinomial logit approach. A random data sample of 2,986 car-truck collisions in the period from 1990 to 1996 was used in the verification and demonstration of their newly developed model. The data contained detailed information regarding weather condition, geometry, pavement surface, and vehicle information. Using their model, the impacts of various factors, such as different vehicle types, collision vehicle conditions, driver and occupant factors, collision locations and their speed limits, and weather related factors, on the severity of multi-vehicle collisions, were examined one by one. Through the examinations, the authors found that three variables including 1) head-on collision, 2) alcohol impairment, and 3) curve-high-speed interaction for truck, could cause high-severity crashes. At last, the authors concluded that, their simultaneous multinomial logit model, which accounted for the joint dependence between crash severities in different vehicles, was more efficient than the traditional ones. Washington State Department of Transportation (WSDOT) supported this research by providing data from their accident database.

Since most of the traditional safety estimation methods are based on crash counts only, they inevitably suffer from the limitations such as imprecision and subjection to common biases. Empirical Bayes (EB) method can overcome these limitations by taking into account the safety experiences of similar highways in the procedure of crash estimation. To introduce the EB method to the traffic safety research, Hauer and his colleagues (2002) published a tutorial paper where the theoretical basis and practical application procedure of EB method were described. According to the authors, the EB method had two significant benefits to safety estimation: 1) it increased the precision of estimation beyond what was possible when one was limited to the use of relatively short-term data; and 2) it corrected the regression-to-mean bias commonly associated with traditional methods. In their report, the application of the EB method in safety study was illustrated by solving 10 numerical examples with gradually increasing complexity. It should be noted that, the relatively higher crash prediction accuracy of the EB method is based on the comparison between the crash counts of one road and the safety experience of other similar roads. This leads to a limitation that the comparable crash data from other similar roadways have to be available. In addition, how to define the similarity between different roadways is also a topic that needs further research.

Although the absolute number of cross-median collisions (CMCs) is small compared to that of all highway collisions, the severity of these collisions is generally high. Statistics has shown that, 15% of CMCs involve fatalities and 72% of them involve injuries. To address this safety concern, Donnell et al. (2002) developed a negative binomial regression methodology to statistically analyze CMCs. The development of the methodology contained three steps. First, the expert knowledge on median safety issues was gathered through a Delphi-type survey. Then, the highway crash data recorded in a period of five years (1994 – 1998) along with the geometric data of the crash locations were analyzed to identify CMCs' typical characteristics. The study in this step indicated that: 1) inside-shoulder width was a critical factor leading to CMCs; and 2) narrow lane widths and cross-slope pavements could increase the likelihood of CMC. Finally, based on the outcomes from the previous steps, two CMC predictive models were developed using negative binomial regression techniques. These models could estimate the likelihood of a CMC by considering three factors: Annual Daily Traffic (ADT), segment length, and median width. The researchers believed that the models they developed were relatively accurate in predicting CMCs and had potential to be applied in practice. The data used in their study were interstate and expressway crashes data extracted from two databases provided by Pennsylvania Department of Transportation (PennDOT).

Yuan et al. (2001) conducted a study through an EB-method-based methodology to evaluate the safety benefits of angle realignment and curve realignment of intersection approach. Their study had several steps. First, the EB method was used to estimate the number of crashes before the realignments. Then crash reduction factors were calculated by comparing the crashes both before and after the realignments. Third, they used a likelihood function to verify the confidence level of the crash reduction factors. At last, an analysis of variance (ANOVA) model was used to analyze the benefit estimates of the realignments. The data used in their study included both geometric information and crash counts collected within 0.1 miles of each approach of the test intersections. Based on their study, they concluded that: 1) the improvements studied reduced the total number of crashes in different levels for different types of crashes; 2) the curve realignment improvement reduced run-off-road crashes and head-on/rear-end crashes significantly, while the run-off-road crashes increased at some sites with angle realignments; and 3) intersection realignment combined with the addition of a left-turn lane did not have extra benefits in reducing the total number of crashes. However, their methodology had several limitations. For instance, in their study, the statistical significances of the effects of site characteristics on safety were not tested and the impacts of driver characteristics were not considered. Further researches on this subject could improve the methodology by overcoming these limitations. This study was conducted at the Connecticut Transportation Institute and sponsored by the Joint Highway Research Advisory Council of the University of Connecticut and the Connecticut Department of Transportation (ConnDOT). ConnDOT provided the data for this study.

Although strict law enforcement has been applied to eliminate drinking and driving, alcohol impairment is still one of the major causes of severe traffic crashes. Recently, Turner and Georggi (2001) studied the characteristics of alcohol-related motorcycle crashes in Florida using general data statistics method to identify potential countermeasures to this safety problem. Their study contained a thorough analysis of 3,012 alcohol-related motorcycle crashes that occurred from 1993 – 1997 across Florida. The researchers investigated the statistical facts of both human-related factors and physical aspects of the crash cases. The human-related factors included age, gender, alcohol use, licensing status, and helmet usage. The physical aspects examined included time of day, day of week, monthly trends, vehicle condition, road condition, environmental condition, and driver factors. Based on the study, they found that: 1) the largest percentage of fatal motorcycle-alcohol crashes happened between 10:00 p.m. and midnight; 2) the highest proportion of alcohol-related crashes happened in March when an annual motorcycle event was held in Florida; 3) human errors caused most of the crashes while the impact of environmental factors was negligible; and 4) drivers without helmets likely had very severe injuries when a crash happened. Finally, the researchers suggested improvements in the following areas: proper licensing, application of message alert systems, and statewide public education and information. Florida Department of Highway Safety and Motor Vehicles (DHSMV) provided the data for this study.

The effectiveness of 20 bypasses in reducing traffic crashes was studied in Norway using EB method (Elvik et al., 2001). Bypass roads are used as a traffic control strategy developed to lead long-distance traffic away from small towns and villages to reduce possible crashes in these areas. The study was an observational before-and-after study which integrated with EB method, an advanced statistical method for analyzing the difference between the number of crashes in. In the study, the researchers analyzed 737 crashes recorded during a period of 12.5 years on the sites of interest, among which 374 crashes happened before the bypass projects and 363 happened in the after period. According to their study, there was a statistically significant reduction of 19 percent in the number of injury crashes on the bypass roads. Also, they had a greater effectiveness in reducing pedestrian crashes compared to other types of crashes. To compare their results with others, the study also conducted a meta-analysis of 9 previous evaluation studies of bypass effects on traffic safety which contained estimates of the effects of 93 bypasses. The comparison indicated that their results were consistent with other researchers' which concluded an overall reduction of 25 percent in the total number of crashes.

Taylor et al. (2001) conducted a study to determine the safety impact of replacing bi-directional median crossovers with directional median crossovers on urban arterials in Michigan. This study examined eight arterial road segments, which varied in length from 0.72mi to 5.52mi and where a total of 54 bi-directional median crossovers were replaced. The crash data of these sections were collected from the Michigan Department of Transportation (MDOT) Statistical Package for the Social Sciences system accident master file in a ten-year period from 1989 to 1998. The crash data contained information including type of crash, crash location, hour, month, weather, surface condition, and injury severity. Their analysis was conducted in four steps. First, a comparison of the average number of total crashes per year before and after the crossover modifications was made to examine the crash frequency change. Then, the locations of the observed crash reductions were determined to investigate whether the crash reduction occurred at the intersections where median crossovers were modified. Third, whether the observed reductions in crash frequency were due to possible changes in volume was determined. Finally, crash frequencies were compared between different types of median crossovers that had different geometries. The analysis showed an average of over 30 percent reduction in both total crashes and injury crashes, which indicated that changing bidirectional crossovers to directional crossovers was an effective safety enhancement.

In the previous traffic crash analyses, logistic regression technique had been used frequently for estimating the probabilities of certain types of crashes. For example, Kim and his colleagues (2000) used logistic regression to facilitate their analysis on motorcycle crash characteristics. The objective of this research was to identify improvements to the safety of motorcyclists through an analysis on the alcohol-impaired motorcycle crashes recorded from 1986 to 1995 in Hawaii. By studying the differences between impaired and non-impaired riders in motorcycle crashes in terms of various demographic characteristics, helmet use, license status, roadway environments, and injury outcomes, a logistic regression model was formulated to explain the likelihood of an alcohol-related motorcycle crash as a function of rider characteristics and environmental and temporal factors. The model developed in their study had the following form: $\mathrm{Log}_e\{P_r(I)/[I - P_r(I)]\} = a_0 + a_1A + a_2A^2 + a_3W + a_4N + a_5O$ (where I = alcohol impaired; a_i = weight parameters; A, W, N, and O are factors associating to alcohol impairment). The researchers used SAS to estimate the parameters of this model and then to calculate various likelihoods. According to their results, they found that: 1) motorcycle safety needed to be improved by focusing both educational and enforcement efforts on specific age groups at specific times and at key locations; and 2) there was a significant safety problem involving unlicensed riders. The researchers also suggested that future researches might entail more detailed surveys of both trip assignment and alcohol consumption. In addition, more efforts to identify impaired riders before they were involved in crashes should be devoted. This research was supported by the Hawaii Crash Outcome Data Evaluation System (CODES) project, a cooperative research agreement between the U.S. DOT, the National Highway Traffic Safety Administration, and the University of Hawaii.

Conventionally, researchers use linear or nonlinear regression models and probabilistic models to predict wet-pavement crashes. Xiao et al. (2000) developed two fuzzy-logic models to predict the risk of crashes that could occur on wet pavements. These models took skid number, posted speed, average daily traffic, percentage of wet time, and driving difficulty as input variables to output the predicted number of wet-pavement crashes. One of the models was based on Mamdani's fuzzy-inference method, and the other one was a Sugeno-type fuzzy-logic model using the fuzzy-clustering method. These models were trained and tested using two data sets collected by PennDOT at 123 sites from 1984 to 1988 and 1987 to 1988. In their research, the developed fuzzy-logic models were compared with two traditional models including a regression model and a probabilistic model. Through the comparison, the researchers found that the regression model would not provide a good basis for evaluating the wet-pavement crash risk, and the probabilistic model lacked reliability and efficiency in describing the relationship between the risk of skidding crashes and the roadway and traffic characteristics. Thus, they concluded that their fuzzy-logic models were superior in accurately predicting the occurrence of wet-pavement crashes. Furthermore, the comparison between their two models showed that the one based on Mamdani's fuzzy-inference method was more effective than the other one which used Sugeno-type fuzzy-logic method.

Previous researches have identified that crash rates for two-lane roads are influenced by many factors including mean speed, standard deviation of speed, flow rate, lane width, and shoulder width. Garber and Ehrhart (2000) conducted a study using nonlinear regression technique to examine the impacts of factors such as traffic characteristics, environmental and road conditions, and road geometry, on crash rates of two-lane highways. In the study, they developed a set of nonlinear regression models to describe the combined effect of these factors on the crash rate for two-lane highways in Virginia. In the development of these regression models, they used Akaike's Information Criterion (AIC) method instead of R^2 method to judge the accuracy of their regression. The former was developed as a relatively accurate approach to predicting the fit of a model based on the expected log likelihood, while the latter was more suitable for linear regression models. Using the function called the "multivariate ratio of polynomials search" in the NCSS program, the authors found four nonlinear regression models that could estimate real crash experience in terms of standard deviation of speed, flow per lane, lane width, and shoulder width. The researchers believed that their models were more advanced in terms of accuracy because they took into account most of the significant crash factors. However, these models were too complicated to be practically used for crash rate prediction. Besides, they could not be applied directly to other roads considering that the database of their study was limited to Virginia two-lane roads. Simplifying these models would be a further research task. The speed data used in their study were collected from speed-monitoring stations established by VDOT and the crash data were extracted from the police accident reports between January 1993 and September 1995.

Since a large number of factors may affect the severity of a traffic collision, how to identify those that are most significant to crash severity would be a challenge. To address this problem, Chen and Jovanis (2000) developed a variable-selection procedure to identify the most significant factors affecting traffic crashes from others. Through a relatively thorough literature review, the authors first studied the current available variable selection methods such as Pearson chi-square, Cochran-Mantel-Haenszel statistics, and likelihood ratio statistics. Then, based on the comparison of these different methods and procedures, the researchers developed a new procedure to optimize their advantages and minimize their disadvantages. The detailed procedure included several steps. First, using Pearson chi-square test, the original variable categories were collapsed and significant individual variables were selected. Second, the interactions between the selected significant variables were tested to identify significant variable combinations. Third, the interactions of the insignificant variables were examined to further detect possible significant combinations omitted by the first step. Fourth, all significant variables were grouped based on their interaction relationships discovered in step 2 and 3. Finally, for each group, associations were investigated by log-linear models and indirect variables were further eliminated. Using this procedure, the research team analyzed a set of 39 possible influential factors, along with their interactions, of the bus-involved crashes on Freeway 1 in Taiwan from 1985 through 1993. The analysis found that the severity of a bus-involved collision was significantly related to the type of the other vehicles involved, collision time, and collision type. Through the application of their procedure to the analysis of real data, the researcher concluded that the new procedure was superior in the following three functions: 1) collapsing categories to reduce their number while conserving the homogeneity in each category, 2) avoiding the influence of sparse cases, and 3) detecting the variables that may or may not have main effects on the response variable.

2.4 Highway Work Zone Traffic Control

Highway work zone traffic control serves as the most direct medium for traffic engineers to improve highway work zone safety. Since excessive travel speed in work zones has been revealed as one of the most significant contributing factors of work zone traffic crashes, controlling the travel speed effectively in work zones has become the predominant challenge for traffic engineers and construction communities. According to the literature review, different traffic control strategies have been implemented in work zones, including both traditional techniques coded in MUTCD and more advanced control techniques developed recently. This chapter summarizes the findings from a thorough review on the previous researches, shown in Table 2.4.1, which introduced and/or evaluated these traffic control devices or strategies.

Table 2.4.1: List of the Articles Cited in Section 2.4

No.	Researchers	Research Subject	Funding Agency
1	Beacher et al.	Evaluation of late-merge traffic control	Virginia Transportation Research Council
2	Bushman and Berthelot	Evaluation of an intelligent traffic information system	North Carolina Department of Transportation
3	Meyer	Evaluation of optical speed bars	Kansas Department of Transportation
4	Yadlapati and Park	Evaluation of Variable Speed Limit System	N/A
5	Huebschman at el.	Study of the possibility of maintaining two lanes open in work zones.	Indiana Department of Transportation
6	Arnold	Evaluation of use of police in work zones	Virginia Transportation Research Council
7,8	Garber and Patel; Garber and Srinivasan	Evaluation of changeable message signs	Virginia Transportation Research Council
9	Richard and Dudek	State-of-the-art examination on highway work zone speed control methodologies	N/A
10	Pain et al.	Evaluation of traditional work zone traffic control devices	American Association of State Highway and Transportation Officials

An innovative work zone traffic control strategy called late-merge traffic control was developed by PennDOT. The rationale behind this strategy was to make more efficient use of the roadway storage space by encouraging drivers stay on all available traffic lanes until the merge point. To provide a comprehensive understanding of its concept and a clear demonstration of its application, Beacher and his colleagues (2005) conducted a study to evaluate the advantages of this work zone traffic control methodology. Their study focused on a field test in a work zone with a 2-to-1 lane closure on a highway section in Virginia in summer 2003. The field study included a comparison between the traffic conditions of with and without late-merge traffic control based on the analysis of the data collected before and after its application. The analyzed data included all kinds of traffic information such as traffic counts, queue length, travel time, and number of crashes. The effectiveness of the late-merge strategy was assessed in three aspects: 1) distribution of traffic across the travel lanes approaching the work zone merge taper, 2) travel time through the queue, and 3) throughput at the lane closure. The researchers found that after the implementation of the late-merge traffic control, both the throughput and the time in queue improved slightly, and more drivers were in the closed lane beyond the merge point, which indicated a positive response to the late merge strategy. The researchers also suggested that additional evaluation with more detailed measures and wider test scope should be conducted to further test the effectiveness of this strategy. The success of this research was made possible by the cooperation between VTRC and VDOT.

Nowadays, ITS has been widely applied in many highway work zones to provide higher safety level in and around work zones. An ITS strategy, which measures current traffic conditions at strategic points to advise drivers of expected delays ahead and direct them to alternative routes using portable changeable message signs, has been developed and implemented in several highway work zones in North Carolina. Bushman and Berthelot (2005) evaluated the effectiveness of this ITS strategy by surveying the motorists who drove through the two work zones on I-95 where this ITS system was applied. The survey was based on a questionnaire to determine characteristics of the motorists and their opinions regarding the traffic information system. Analyses were made to the 333 completed and returned questionnaires. Results of the analyses showed that: 1) most motorists agreed that the work zones with this system were providing more up-to-date information; and 2) most motorists consented that information was accurate or at least accurate in 95% cases. In addition, over 95 percent of motorists supported the future use of these types of systems. The results of this study proved that road users acknowledged the benefits of the ITS in work zones. North Carolina Department of Transportation (NCDOT) provided extensive support for this study.

It is well known that most traffic crashes, including work zone crashes, are either directly or indirectly associated with speeding. To better control work zone speed, a traffic control strategy using optical speed bars modified to meet the requirement of highway work zones has been applied in many countries. Recently, Meyer (2004) conducted a study to evaluate the effectiveness of this strategy in reducing work zone speed in Kansas. Optical speed bars are an innovative speed control technique which uses transverse stripes spaced at gradually decreasing distances on pavement to affect the driver's perception of speed and then to result in a speed reduction. This study examined some of the adaptations that might improve the effectiveness of this device when applied to highway work zones. The tested pattern of optical speed bars consisted of a leading section of uniformly spaced bars, a primary section of bars with graduated spacing, and a work zone section consisting of intermittent groups of six uniformly spaced bars with large gaps between groups. The optical speed bars for the test were installed west of the Spring Creek Road exit ramps and east of the K-185 junction on I-70 in Kansas. Speed data in both before and after periods were collected over a time period of 30 days from June 25, 1999 to July 25, 1999. According to the results of data analyses, the following major conclusions were reached including: 1) reductions in mean and 85th percentile speeds were observed, and the magnitudes of the reductions were small but statistically significant (95% confidence level); 2) the characteristics of the speed changes at different locations within the test site indicated that there were both a warning effect of the bars and a perceptual effect of the bars; 3) the optical speed bars were also effective at reducing the variation in speeds; and 4) the reductions in speeds and speed variations among passenger cars were slightly larger than those among trucks. In addition, the researcher made a recommendation that the transverse pavement markings on the approach to work zones should become a standard practice. This project was funded by the Kansas Transportation Research and New Developments (K-TRAN). Professionals from KDOT, Kansas State University, and the University of Kansas (KU) participated in this research.

Controlling speed is always the primary goal for traffic control strategies in work zones because low travel speed gives a driver more time reacting to unexpected situations and then to avoid crashes. An ITS speed control strategy called variable speed limit (VSL) system was studied by Yadlapati and Park (2004). The purpose of their study was to evaluate the performance of the VSL system at work zones and to develop VSL decision logics for different traffic conditions in a simulation environment. The performance of the speeds in work zones in a postulated highway network was observed in the simulation environment called VISSIM. In order to verify the findings from the test network, the speeds were also simulated using the data collected at a real highway work zone near Covington, Virginia. Based on the simulation results, it was observed that higher speeds performed better (in terms of optimal safety without much reduction in mobility) at all compliance rates (the proportions of drivers following traffic regulations) when the volume levels were low. Higher speeds also performed better at lower compliance rates when the volume levels were moderate. The posted speed limit of 45 mph yielded the best results when the compliance rates were high at moderate volume level. It also gave the best results when there was 100% compliance for all volume levels. The researchers concluded that the application of VSL with proper speed estimation logic in work zones would improve safety in work zones. However, the study assigned safety and mobility in work zones with equal weights in all situations and only took into account rear-end collisions, which could affect the significance of the test results.

Aimed at improving the safety in work zones of rural interstates, a comprehensive highway work zone safety study (Huebschman at el., 2003) was conducted by Purdue University in cooperation with the Indiana Department of Transportation (INDOT). The primary objective of this study was to determine 1) if active warning devices or improved signing could benefit work zone safety, and 2) if it was appropriate to consider temporary roads and bridges during construction activity on interstates in an effort to maintain two lanes open at all times. This study devoted several major contributions to work zone safety research: 1) a thorough review of current work zone traffic control practices applied in several U.S. states, 2) an evaluation of several traffic management technologies that are currently employed in interstate work zones, 3) an analysis to the crash data collected in several interstate work zone projects in Indiana, and 4) an evaluation to determine the feasibility of maintaining two lanes open during work zones on interstates. In this study, the authors studied detailed work zone traffic data such as volume, travel speed, crash location, work zone duration, and traffic control devices used in the studied work zones. The work zone traffic management technologies examined in their study included 1) traffic sensors, 2) proprietary algorithm, 3) communications, and 4) devices used for transmitting information to motorists (Variable Message Signs (VMS), Highway Advisory Radio (HAR), Internet, etc). The major findings of this research project were: 1) the current work zone traffic management technologies, especially traffic information systems, were helpful in informing road users of the ongoing highway projects, but not very effective in improving work zone safety; 2) highway work zones could increase crash rate significantly (27.5% as found by the authors in several Indiana work zones); 3) police presence in work zones was effective in reducing travel speeds and thereby funds for supporting work zone special patrols in the state of Indiana were worthily spent; and 4) variable message signs were no more effective then traditional message panels. The authors suggested that global positioning system (GPS) devices should be equipped to workers and policemen in work zones so to make accurate positioning of crashes possible. Most of the data used in this study were collected on several interstate highways in Indiana.

The presence of policemen in highway work zones has been widely recognized as one of the most effective ways to control drivers' speed in work zones. A study (Arnold, 2003) was carried out in Virginia which evaluated the effectiveness of using policemen as a work zone traffic control strategy. The objectives of this research were to document the current practice of employing police in Virginia work zones and to determine if any enhancements could be made to the current practice. The research was based on an analysis of a survey to the personnel in VDOT, Virginia State Police (VSP), and VMS, Inc. The survey used a questionnaire designed to request a wide range of information on current practices including the use of police in work zones in Virginia. Based on the results of the survey, the researchers concluded: 1) the presence of policemen and police cars with flashing lights in highway work zones was undoubtedly effective in controlling driving speed and alerting inattentive drivers; and 2) VSP had been cooperating well with VDOT in meeting the goal of controlling traffic in work zones. in addition, the researchers suggested that: 1) proper education should be offered to those policemen controlling traffic in work zones; 2) there should be at least two policemen in presence to achieve maximum effectiveness; 3) policemen assigned in work zones should receive additional safety protection; and 4) the current work zone traffic control strategies such as law enforcement and monetary fines should be further improved. This research was done by VTRC in cooperation with the U.S. DOT and FHWA.

Garber and Patel (1994) conducted a research to evaluate the effectiveness of changeable message signs (CMS) in controlling speeds in work zones of Virginia. CMS is an advanced speed control method which can display a real-time warning message to the speeding drivers after their excessive speeds are detected by its actuator (i.e. a radar detector). In their research, the effectiveness of CMS was evaluated by comparing the odds of speeding vehicles when CMS was implemented with the odds of speeding vehicles when using only traditional traffic control devices in seven interstate work zones in Virginia. Speed data were obtained from the traffic counters and videotapes at the beginning, middle, and end sections of the work zones in a seven-day period. Based on the analysis of the data, the researchers concluded that CMS was a more effective means than traditional work zone traffic control devices in reducing the number of speeding vehicles in work zones. According to the study, all of the speed characteristics of speeding vehicles in the test work zones, such as average speeds, 85th percentile speeds, and speed variances, were reduced by 5 mph or more in the seven-day study period. To further observe the long-term effectiveness of CMS in controlling work zone speeds, Garber and Srinivasan (1998) conducted a phase-two research in three work zones for a period of up to seven weeks in Virginia. In the research, the evaluation of the effectiveness of CMS for different types of vehicles and different lengths of work zones was also included. Based on the analysis of the speed data collected using automatic traffic counters at the beginning, middle, and end of each work zone, they found that the duration of exposure of the CMS did not have significant impact on its effectiveness and the CMS was equally effective in reducing the speeds of different types of vehicles. The researchers also found that, in longer work zones, drivers who reduced their speeds in response to the CMS frequently had a tendency to speed back up. Therefore, the use of a second CMS was recommended in very long work zones. These two researches were conducted by VTRC in cooperation with VDOT.

Richard and Dudek (1986) conducted a state-of-the-art examination on highway work zone speed control methodologies, and the applications and effectiveness of these methodologies. The study reviewed each work zone speed control strategy including its application procedure and implementation conditions. In addition, the researchers also discussed the advantages and drawbacks of each strategy. The work zone speed control strategies included speed limit, flagger, law enforcement, changeable message signs, and effective lane width reduction. Finally, recommendations were made in terms of treatment duration, maximum speed reduction, treatment location, and treatment costs. Although these work zone traffic control methods seemed to be traditional approaches for today's traffic engineers, it was a valuable study in 1980's and could still serve as a comprehensive work zone traffic control reference for recent researches.

The MUTCD has introduced a variety of traditional traffic control devices in highway work zones including signs, signals, hand signaling devices, channelization and delineation devices, deflection and attenuation devices, high level warning devices, and lighting devices. These devices have been generally considered effective in alerting drivers of impending conditions, warning them of hazards, and directing them through the proper path. However, Pain et al. (1983) argued that most of these work zone traffic control devices were developed as an evolvement from other devices, rather than as a result of scientific testing on what best stimulated driver awareness of work zone situations. Consequently, they conducted a study to determine the effectiveness of selected types of work zone traffic control devices and to determine how these devices should be designed and used to guide drivers approaching and proceeding through highway work zones. Their research scope was focused on selected traffic control devices including barricades, cones, tubes, drums, panels, and steady-burn lights. The study included three steps: 1) laboratory studies to optimize the design characteristics of barricades and panels, 2) a closed-highway experiment to identify additional optimizations in terms of the best array forms, amount, type, and configuration of reflective material day and night, and 3) final experiments carried out in a real-world situation where the devices with design and layout alterations were tested at three work zone types – a traffic diversion site, a left-lane closure site, and a right-lane closure site. Based on the results of their study, they concluded that: 1) most of the devices tested were effective in alerting and guiding drivers; 2) devices studied only obtained their maximum effectiveness when properly deployed as a system or array of devices; 3) motorists did not respond to a single channelization device, but to the path that was defined by the array. This study was directed by the National Cooperative Highway Research Program and sponsored by the American Association of State Highway and Transportation Officials in cooperation with the FHWA.

2.5 Research and Development Trend

This section presents an overview of the most recent advanced technologies and methodologies that have benefited or could benefit work zone safety practice and research. Based on the results of the review, the general trend of the modern work zone safety research and development has been revealed that is to combine advanced technologies developed from other scientific and engineering fields with traffic engineering to improve safety practices in highway work zones. For instance, the concepts which are previously only found in computer science have been applied in work zone safety research, such as fuzzy logic and artificial intelligence. In addition, the technologies including GIS and ITS have also been widely applied in work zones to improve safety. Some studies included here are not necessarily focused on work zone safety. They are included because the methodologies or technologies used have great potentials in work zone safety practice. A list of the studies included in the section is shown in Table 2.5.1, followed by detailed annotations.

If the tests of newly developed highway work zone traffic control devices can be done in a controlled laboratory environment, considerable time and money could be saved. Triggered by this motivation, Mitchell et al. (2005) conducted a study to assess the validity of using a driving simulator in determining the effectiveness of several speed control techniques in highway work zones. The simulator used was the AMOSII from Doron Precision Systems, Inc., which was operated from one control station (desktop computer) and networked with five individual computers. The simulator ran a variety of driving scenarios and displayed them on the five screens which could produce a realistic 225-degree panoramic field of view for the driver. 15 drivers with different ages, educational levels, and driving experiences participated in the tests. The study simulated a work zone with three different conditions: no speed control, rumble strips placed in advance of the lane closure taper, and narrow traffic lane through the work zone. Through the statistical analysis on the data obtained from the simulations, the researchers found that the narrow-lane scenario was effective in reducing speed through entire work zones. The placement of rumble strips appeared to be effective only in the transition area (where they were placed), but not in the work activity area where construction workers were exposed to traffic. In addition, the researchers discovered that, a driving simulator could be a reasonable evaluation tool for work zone speed control devices when programmed in a sophisticated way. This study had several limitations: 1) it involved only two speed control strategies; 2) it assumed good work zone conditions with daylight and no precipitations for all simulations; 3) the size of the driver sample was small.

Table 2.5.1: List of the Articles Cited in Section 2.5

No.	Researchers	Research Subject	Methodology or Technology	Funding Agency
1	Mitchell et al.	Computational simulation for work zone speed control device in-door testing	Computer visualization and simulation	N/A
2	Adeli and Ghosh-Dastidar	Freeway work zone traffic flow and congestion study	Mesoscopic-wavelet model in traffic flow simulation	N/A
3	Wilson and Lipinski	Application of road safety audit review for work zone safety improvement.	Road safety audit review	N/A
4	Montella and Ciotola	Safety audit in work zone design	Advanced safety audit procedure	N/A
5	Lieberman et al.	Simulation and visualization of Statistical results of crash studies	MATLAB-based graphical simulation	N/A
6	El-Zarif et al.	Computer simulation for evaluation of new work zone ITS application	Computer simulation, advanced rural transportation system	N/A
7	Lord	Crash prediction model and safety risk estimation	Safety risk estimation model and application of EMME/2	Natural Sciences and Engineering Research Council of Canada
8	Jha and McCall	GIS visualization for highway projects	GIS visualization	Maryland State Highway Administration
9	Barton et al.	Improving conspicuity during work zone designs	Computer model for conspicuity analysis	The State of California Business, Transportation, and Housing Agency
10	Krishnan et al.	Rear-end collision prevention	Rear-end-collision warning system	N/A
11	Roche	GIS based crash data analysis	GIS	N/A
12	Misener et al.	Cognitive car-following model	Computer-based decision making system	The State of California Business and Transportation and Housing Agency
13	Carreker and Bachman	Crash location using GIS	GIS	Georgia Department of Transportation
14	Misener et al.	Preventing lead-vehicle-not-moving crashes	cognitive car-following model	State of California Business and Transportation and Housing Agency
15	Jha and Schonfeld	Highway design cost optimization	GIS and generic algorithm	N/A
16	Burnette and Moon	Web-based highway driving simulation	virtual reality modeling language	N/A

Researches have shown that, in a highway work zone project, one lane closure out of three in a single direction reduces capacity by 50%, which is much more than the expected 33.3%. A similar situation on a four-lane highway may cause a capacity loss of up to 60%. Hence, the congestion situations caused by highway work zones could be very severe and understanding the congestion characteristics caused by work zones is important. Adeli and Ghosh-Dastidar (2004) presented a mesoscopic-wavelet model for simulating traffic flow patterns and extracting congestion characteristics in freeways work zones. They argued that both microscopic and macroscopic simulations suffered from various limitations and drawbacks, while mesoscopic models, which were formulated based on concepts from both macroscopic and microscopic models, could practically model individual vehicle behavior. Their research developed a mesoscopic model which incorporated the strong points of both microscopic and macroscopic traffic flow models and minimized their drawbacks. In addition, a multi-resolution filter based on wavelet transformation was used to accurately differentiate congestion characteristics. The model required parameters such as traffic flow, pavement conditions, number of closed lanes, and project durations to be inputted for the proposed work zone simulation. According to the researchers, the model developed in their research could simulate freeway traffic flow patterns and extract congestion characteristics more practically.

Road safety audit is a formal examination of a future road or traffic project, an existing road, or any project which interacts with road users, where an independent, qualified team reports the project's potential crash and safety performance by trying to investigate how the road environment is perceived and ultimately utilized by different road users. Wilson and Lipinski (2003) recognized the importance of road safety audit review (RSAR) as a practical tool that focused on the safety of the existing highways and could identify potential safety problems in design stage. They indicated that the RSAR tool was particularly beneficial to local governments in systematically addressing safety deficiencies on existing rural road networks. In addition, it was a proactive safety tool that had the potential to protect agencies from tort liability because using RSAR would establish a record of an organization’s safety practice. Their study introduced an approach to modify RSAR procedures to enhance the effectiveness of proactive safety programs for rural local agencies. The development of the modified procedure took into account the specific needs of transportation agencies and was based on successful practical cases. The related issues such as training and education to promote RSAR’s implementation were also suggested. This methodology has great potential to be adopted into work zone safety design procedures to improve safety as it has been doing in other highway projects.

Montella and Ciotola (2002) presented a safety audit application to improve work zone safety. They addressed an effective road safety audit procedure for highway work zone designs, which was based on detailed checklists and risk assessment. The objectives of their audit procedure were: 1) to identify potential safety problems for road users traveling through the work zone, and 2) to ensure that the countermeasures to eliminate or reduce the identified problems were fully considered by the client and those involved in work zone activities. Their work zone safety audit procedure was demonstrated to be helpful in 1) minimizing the risk and severity of crashes in work zones, 2) improving awareness of safety practices for all work zone related public, and 3) identifying, primarily from road user’s perspective, those issues and features that gave misleading or confusing messages. In their procedure, several new risk indicators called the global safety index (GSI) were defined for the first time. These indicators were formulated to predict the number and severity of potential crashes in terms of different safety concerns. The GSI took into account various safety evaluation results such as Average Risk Score (ARS), Cumulated Risk Score (CRS), and Weighted Risk Score (WRS) to assess the overall safety level of a highway work zone design. The proposed safety evaluation procedure was strongly related to the safety consequences of the identified problems and thus was beneficial to highway work zone projects for improving their safety levels.

A software tool named MATLAB software toolbox was developed by Lieberman et al. (2002). The software utilized the powerful display capabilities of the MATLAB software package to generate graphical animations of statistical traffic network simulation results. The software's interface allowed users to interactively create animation "movies" displaying the simulation-generated statistics in a visualized format. The display format could be either customized by users or selected from a menu of available formats for their convenience. WATSim micro-simulation model was used to generate the statistical data measuring traffic environmental changes under unexpected interferences such as work zones. The model required several inputs including the geometry data, traffic volumes, patterns of travel, signal control parameters, and traffic operational parameters. The software tool could display the full dimensionality of the data generated by the simulation model and had the capability of representing the two spatial dimensions in combination with the temporal dimension. The approach of animating simulation-based statistics was believed to be superior to static graphical data presentations created by software tools such as MS Excel, because the latter frequently fails to provide the breadth of scope and insight needed by advanced users, particularly when the analysis network was of substantial size and/or the simulation analysis extended over several hours.

A new ITS safety application, designed to detect and warn road users of no-passing zone violations, as part of an advanced rural transportation system (ARTS), was deployed on a two-lane rural road (VA-114) in southwest Virginia to overcome its severe safety problem (El-Zarif et al., 2002). EL-Zarif et al. developed a MATLAB-based simulation method to evaluate the performance of this system. The goals of this development was: 1) to better understand the violation problem on vertical curves of two-lane rural roads by studying the main factors that affect crash occurrences, 2) to estimate how the system would perform under varying conditions, and 3) to perform "what if" tests to assess the sensitivity of the outcome related to some modifications of one or more parameters after system validation. Using the developed method, the researchers simulated the takeover maneuvers of both "without no-passing warning" and "with no-passing warning" cases and then compared the crash rates predicted by the simulations of the two cases to examine the effectiveness of the no-passing warning system on safety improvement. The simulation results of the "without no-passing warning" case showed that over 20% of the vehicles passing at the study highway section could be involved in crashes. In addition, the action of "continuing takeover maneuver with incorrect judgment after seeing the opposing vehicle" was the riskiest action which could cause 69.3% vehicles to be involved in head-on crashes. The results of the "with no-passing warning" case showed that head-on collisions could be virtually eliminated if the human intelligence responded correctly to the early warning of the system and took the appropriate action. The simulation system did not take into account a certain percentage of violators who didn't obey the system suggestion and thus would still likely be involved in crashes, which inevitably lowered its accuracy.

In a recent study, Lord (2002) illustrated the application of Accident Prediction Models (APMs) to estimate crash risk on transportation networks. APMs are tools developed for prediction of crashes on links and nods of computerized transportation networks based on traffic flow information. Crash risk is a safety measurement often used to describe the traffic safety level by incorporating a measure of exposure. This study used a popular transportation planning software package called EMME/2 to create a hypothetical macroscopic highway network and then identified the safest route on the network using APMs. The study introduced an exponential form of crash risk estimation instead of the existing linear form. Using the estimation method, the crash risk was computed based on the traffic flow output of an EMME/2-based computer program. The results of this study suggested that, the individual risk of being involved in a collision decreased as traffic volume increased. After making comparisons between his APMs with the APMs using other forms of risk estimation in terms of accuracy and efficiency, the researcher concluded that his methodology was superior and could have significant impacts on transportation policy and ITS strategies. This research was partly supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada (NSERC). The data used for the calibration of the crash prediction models were provided by the Toronto Transportation Department.

The power of GIS in dealing with geometric and geometrically related data has been fully recognized for years. The development of recent GIS technology even extended the GIS with advanced 3D visualization ability. To utilize the power of GIS, Jha and McCall (2001) explored the applications of GIS-Based computer visualization techniques in highway projects. Based on their study, they concluded that there were two primary benefits of GIS-based computer visualization in highway development. First, it gave a better representation of future enhancement, thereby enhancing public acceptability. Second, it helped in detecting unusual design and location features in early stages. In their study, a framework for cost-effective visualization application was developed. The framework used an algorithm called Projection Option Processor (POP) which was developed in Microstation BASIC language to save multiple design scenarios in a single batch so to save time. The GIS software used for visualization in this framework was primarily ArcGIS 3.x. A complex street rehabilitation project and a highway interchange project were used as two case studies to verify the framework. The two projects were located in Maryland and the required data obtained from the desktop electronic property map called MdProperty View (7) available in Maryland State Highway Administration (MSHA). The visualized final effects of these projects were presented to public and political authorities, and a higher rate of public acceptance to the projects was observed. Based on these two case studies, the researchers concluded that GIS-integrated visualization had significant benefits to highway projects and its prospective popularity could be predicted. This research was supported by the highway design division of MSHA.

A proper level of conspicuity that a highway work zone has can draw more drivers' attentions and thus help avoiding collisions by alerting them earlier. A cost-effective and quantitative methodology to evaluate roadside conspicuity was developed by Barton et al. (2001). The researchers' goal was to develop a tool so that transportation safety practitioners and even the construction crew would be able to utilize it to make work zones more conspicuous for approaching drivers. The research began with an overview of vision modeling from two perspectives – as theorized by vision science researchers, and as applied in safety studies by transportation researchers. Then, the development and validation of an intermediate methodology aimed at combining the two perspectives were described. In their methodology, a computational model was programmed to evaluate the contrast of a scene, which was defined as the light difference between adjacent locations, times, or colors, and then to assess the conspicuity of the scene and quantify it. The researchers concluded that the conspicuity of a work zone could be improved by either applying the developed tool in its design stage or in activity stage. The tool could be further improved in three aspects: 1) modeling of peripheral vision, 2) assessing the background with moving objects, and 3) development of real-time conspicuity equipment. This research was a part of the California PATH Program (CPP) at the University of California in cooperation with the State of California Business, Transportation, and Housing Agency (SCBTHA).

An innovative rear-end-collision warning system was designed and its effectiveness in preventing crashes and reducing crash severity was evaluated through modeling by Krishnan et al. (2001). The scope of this system was narrowed to lead-vehicle-not-moving (LVNM) collisions and its core rationale was to equip vehicles with a rear-facing sensor that measured the range and speed of the approaching vehicle. Before the development of the system, the researchers examined the major operating activities involved in a LVNM collision such as braking and steering, the factors that may affect the warning system such as response time and driving speed, and the design parameters for both light-duty vehicles (LDV) and trucks. The developed warning system used an algorithm designed based on trade-offs among three goals: 1) maximizing the capability of preventing crashes, 2) minimizing the severity of crashes, and 3) reducing the frequency of nuisance alarms. After the system was developed, the researchers evaluated its sensitivity in terms of the approaching vehicle’s speed, mass, and various maneuver times. Based on the evaluation results, they concluded that the rear-end-collision warning system was a good intelligent tool that could prevent crashes without generating excessive nuisance alerts.

As mentioned earlier, GIS has a great power in managing both geographical data and tabular database simultaneously. Roche (2000) explored the existing and potential macroscopic applications of GIS with an emphasis on GIS-based crash data analysis in traffic safety study.

Two specific GIS functions were highlighted: crash location identification and spatial query. The exploration was mainly performed in the following four areas including: 1) engineering, 2) enforcement, 3) education, and 4) emergency response. Through the studies of several cases where GIS was used to identify and analyze traffic safety problems, the researcher reached the following two conclusions: 1) applications of GIS-based crash data analysis had significant impacts on traffic safety engineering; and 2) GIS-based crash data analysis had not been fully utilized despite the fact that using GIS for crash data analysis started over 10 years ago.

Another research project, conducted by Carreker and Bachman (2000), demonstrated that, by applying GIS, the accuracy and efficiency of locating crashes could be improved. The researchers from Georgia Department of Transportation (GDOT) used GIS to enhance the efficiency of crash location. The objectives of this study were to identify potential crash location errors caused by the current crash location procedure and to develop possible technical solutions to strengthen the functionality of crash location systems. To achieve these objectives, the researchers first assessed the existing crash location procedure and identified the potential problems based on analyses of a sample of 43 crashes that occurred in 1997 throughout Georgia using existing crash location procedure. These crashes varied in type from “rear-end”, “angle intersecting”, “struck object”, to “sideswipe”. Then they examined the possible improvements to the procedure by: 1) using new data transcription standards designed to improve geocoding possibilities, 2) conducting data conflation to improve name files or provide alternative names, 3) using alternative road databases, and 4) applying GIS in the procedure of allocation. At last, the authors concluded that the employment of GIS techniques such as batch processing and intersection matching, along with the incorporation of road attributes from multiple sources, significantly increased the identification speed and the percentage of identified and located crashes.

Misener et al. (2000) conducted a research to develop a cognitive car-following model for drivers as they encounter a rear-end crash situation. The cognitive car-following model was a human vision- and cognition- based detection model designed to help drivers in avoiding lead-vehicle-not-moving (LVNM) crashes. In the study, the factors of LVNM crashes were identified based on the analysis of 10,009 LVNM crashes reported from National Accident Sampling System (NASS) General Estimates System (GES) data. The analysis was focused on four groups of LVNM crash variables, which included 1) struck LVNM vehicle information such as the location and reason of stopping, 2) contributing factors such as road and environmental conditions, 3) striking vehicle information such as driver characteristics and crash trajectory, and 4) vehicle descriptive such as types and damages of both vehicles. Based on the analysis, the researchers suggested the possible safety enhancement strategies such as the improvements on roadway, lighting, vehicle, and driver conditions to avoid LVNM crashes. Then, a cognitive car-following model was developed by integrating the countermeasures with computational methods. The researchers believed their cognitive car-following model could help drivers to make accurate decisions in emergent situations before the occurrence of LVNM crashes. In the research, the authors only identified a small number of predominant LVNM crash scenarios (certain combinations of factors) on which they based their driver model development. Further studies could improve the model by considering more LVNM scenarios. Considering the high proportion of rear-end collisions in the work zone crashes, this car-following model might suggest a solution to the problem when specifically modified for work zone environment. This research was in cooperation with SCBTHA.

The design of a new highway involves the pursuit of the route with minimum cost (or maximum benefit) while satisfying a number of design constraints such as curvature, gradient, and sight distance. This design process can be formulated as a mathematical optimization model in which the objective function is represented as a sum of costs sensitive to the highway alignment. An integrated model was developed by linking a GIS with an optimization model employing genetic algorithms to optimize the total cost of a new highway (Jha and Schonfeld, 2000). GIS was selected because it can spatially represent the locations of properties, floodplains, streams, and other geographical characteristics of significance in a highway cost model. The GIS-based model could provide accurate geographical features, compute location-dependent costs, and transmit these costs to an external program to calculate the optimal cost. In the model developed, GIS helped in three aspects: 1) obtaining the land features including areas and costs of properties, 2) accessing environmental features, and 3) computing location-dependent costs through the GIS based algorithm. The developed methodology was applied in a case study using real property maps from Talbot County, Maryland. Results confirmed that optimized alignments could be obtained with little labor or computing time using the integrated model. This study was supported by the Highway Design Division of MSHA.

Burnette and Moon (1999) addressed an approach to simulating interactive highway driving scenes using virtual reality modeling language (VRML). VRML is a relatively simple, cross-platform, and file-interchange-formatted tool for publishing three-dimensional (3D) web pages in a browser that can interact with viewers over an intranet or the internet. The research illustrated the use of VRML script nodes for quickly encapsulating preexisting simulation system software code to drive a VRML model in real time. The most significant feature of VRML was that, it enables the creation of interactive, dynamic, and sensory-rich virtual environments on an intranet or the internet. It could simulate moving objects, sounds, and moving scenes under the control of a user or program. In their research, the researchers simulated driving activities by visualizing driving related features such as highway geometry, dashboard, windshield, terrain, signs, buildings, interactive displays on instrument panel, and other moving vehicles. They concluded that simulation scenes with most of the functional capacities that sophisticated simulation software packages have could be realized with relative ease in VRML. Besides, with adequate network bandwidth connectivity, real-time simulation scenes might be "driven" over networks from remote locations through either signal input from a mouse-like device or a physical driving device. The highway used in their simulation study was generated based on the information extracted from the engineering drawings of Highway I-94 provided by PennDOT.

2.6 Other Highway Work Zone-Safety Related Researches

This section includes brief summaries of the work zone safety studies that cannot be categorized explicitly in any of the above chapters. These studies also made significant contributions to improve work zone safety. They provide comprehensive understanding on the issues of work zone safety. A brief list of the researchers, subject, and funding agency is presented in Table 2.6.1.

Table 2.6.1: List of Articles Included in Section 2.6

No.	Researcher(s)	Research Subject	Funding Agency
1	Kononov and Znamenacek	Evaluation of Lane-closure decision making system	N/A
2	Adeli and Jiang	Work zone capacity estimation using novel adaptive neuro-fuzzy logic model	Ohio Department of Transportation
3	Jiang and Adeli	Freeway work zone traffic delay and cost optimization	Ohio Department of Transportation
4	Chien et al.	work zone scheduling and traffic control optimization	N/A
5	Karim and Adeli	Case-Based Reasoning (CBR) model for freeway work zone traffic management	Ohio Department of Transportation
6	Chien and Schonfeld	Optimization of work zone lengths on four-lane highways	N/A
7	FHWA	A national programmatic review on the effectiveness of the FHWA's and State DOT's policies and procedures for enhancing work zone management	FHWA
8	Fisher and Rajan	Highway constructibility analysis	National Cooperative Highway Research Program
9	Islam et al.	Identification of suitable tools for work zone traffic management	Utah Center for Advanced Transportation Studies and Natural Sciences and Research Council of Canada
10	Shepard and Cottrell	Study of the feasibility of nighttime work zones	N/A

Lane closure is an unavoidable event facing traffic engineers and highway constructors during construction projects on highways. Historically, lane-closure decisions were made primarily on the basis of field observations, previous experience, and engineering judgment. However, improper highway lane closure in peak hours usually leads to severe congestion and safety problem. Recently, a lane closure decision support analysis model was developed and implemented for the Greater Denver Metropolitan Area. A study was conducted by Kononov and Znamenacek (2005) to assess the benefits of such a lane-closure decision strategy by examining risks associated with peak-hour lane closure during construction or maintenance on urban freeways. Based on a framework of a quantitative risk analysis, the study compared savings in the cost of construction when allowing lane closure during peak hours with the cost of potential incident-related delays associated with lane closures. In the framework, crash risk was first assessed using safety performance functions (SPF) for conditions without lane closure. Then appropriate adjustments were made to increase crash frequency for conditions with lane closure in work zones. A dataset containing 14 years of crash data from Colorado Department of Transportation (CDOT) was used to estimate the parameters in SPF. The study showed that it was critical to consider the delay resulting from potential lane-closure related crashes when making decisions on lane closures during peak periods on urban freeways; pure capacity consideration was not sufficient for making an appropriate decision whether a lane closure should be avoided. The study also found that the probability of massive backups and delays occurring at least once during a typical project requiring a lane closure was very high (93.5%), which led to very high cost for road users. Hence, when conditions allowed, an advanced analysis tool such as the introduced lane-closure decision support analysis methodology should be used to assist engineers to make a lane closure decision.

Studying work zone capacity involves a large number of parameters and it is very difficult to analyze them accurately using only mathematical functions. A so-called novel adaptive neuro-fuzzy logic model was developed by Adeli and Jiang (2003) to estimate freeway work zone capacity. The model combined fuzzy logic with neuro-computing concepts and was used for the nonlinear mapping of 17 different factors impacting the freeway work zone capacity. The latter was believed to be an effective approach for representing imprecision and linguistic variables. The testing data for the developed model were collected from the existing literature and augmented by four data sets provided by the ODOT. According to the testing results and their comparison with those of two empirical equations, the researchers concluded that the newly developed model had the following advantages: 1) it included more effective factors to achieve high predicting accuracy; and 2) it had more flexible and straightforward data input structure. The research project was sponsored by ODOT and FHWA.

Jiang and Adeli (2003) developed a freeway work zone traffic delay and cost optimization model considering two variables: the length of the work zone segment and the operation time of the work zone. The model considered the following factors including: 1) the number of lane closures, 2) the length of the work zone segment, 3) the anticipated hourly traffic flow approaching the work zone, 4) the starting time of the work zone, 5) the seasonal variation in travel demand, and 6) the duration of the work zone in hours. In their model, a Boltzmann-simulated annealing neural network was used to solve the formulated cost optimization model for short-term work zones. Using their model, some significant factors such as starting time of the work zone, which influence the total costs, were identified. In addition, the potential benefits of applying this model were also discussed. For example, they argued that, by using their model, traffic engineers would be able to systematically and quickly find the best decisions on the cost-impact factors such as lane closure numbers and project starting times. This study was based on a research project sponsored by ODOT and FHWA. NCDOT provided data for their numerical tests.

The total cost of work zones on two-lane two-way highways includes both direct cost (agency cost) and indirect cost (highway user cost). Chien et al. (2002) developed a numerical method to optimize work zone scheduling and traffic control in order to achieve the goal of minimizing the total cost. In their study, the researchers first formulated a total-cost objective function, and then used it to optimize work zone length, scheduling, and traffic control cycles. However, the model had several limitations. First, the detailed traffic flow information of the work zones used by the model (speeds, volume, etc.) had to be collected in advance. Second, the model assumed that all vehicles traveled through the work zones with a uniform speed and all vehicles were in uniform class (no difference between trucks and passenger cars). Finally, the model could not take into account other work zone related costs such as traffic control costs and indirect cost caused by work zones to their parent highway networks. In addition to the limitations mentioned above, the model could be further improved by considering over-saturated traffic flows, alternative routes for diverting traffic, and more realistic conditions. The data used for model verification were hypothetical.

Karim and Adeli (2002) developed a Case-Based Reasoning (CBR) model for freeway work zone traffic management to minimize work zone total costs. CBR is a methodology for storing and retrieving previous design decisions or cases and adapting them to the solution of new cases. The developed model considered work zone layout, traffic demand, operation characteristics, traffic control measures, and mobility impacts. It utilized the customization function (macro) of MS Excel to manage the case base, which primarily consisted of qualitative information such as work zone classification, traffic control measures, planning goals, and development procedures. By retrieving the data of similar cases stored in the model, users could have a perspective on the traffic status of their cases when their work zones were installed. The operation procedure started with inputting some basic information about the work zone under consideration, such as number of lanes and flow rate. The information was fed into the CBR system through queries made by the system. Then the model provided iterative interfaces where a number of interactive sessions needed to be filled out until a satisfactory solution case was reached for referencing. This CBR system was argued to be the first decision support tool to help traffic engineers to create work zone traffic control plans. ODOT funded this research and provided the data used to create the case base.

Because longer work zones on highway systems likely lead to higher costs and more safety problems, Chien and Schonfeld (2001) developed a relatively simple mathematical model to optimize work zone lengths on four-lane highways where one lane in one direction was closed at a time. The basic rationale of the model was to first formulate a total cost objective function and then minimize it. In their study, the objective function included most of the cost components that had significant impact on the optimal work zone length. The total agency cost and time cost were simplified into two linear functions of work zone lengths. Besides, most of other costs considered in the model were all simplified to linear functions of work zone lengths. The objective function was optimized using a classical optimization approach that was to set its derivative equal to zero and solve it. A numerical example using hypothetical data was used to verify and illustrate the math model. The researchers concluded that the method provided reasonable sensitivity and had a potential to be applied in engineering practice. Further research on this topic could use a more practical approach to measure the speed of traffic passing work zones and to formulate relations between individual cost and total cost using more accurate functions instead of assumed linear functions.

A national programmatic review (FHWA, 1998) was done by the FHWA’s Office of Program Quality Coordination (OPQC) to assess the effectiveness of the FHWA’s and State DOT’s policies and procedures for enhancing the performance of the national highway system (NHS) by reducing traffic congestion/delays due to work zones. The review was conducted in two steps including 1) completion of a Baseline Assessment Data Form by all FHWA field offices, and 2) a scan of the work zone management practices in 26 selected States. The review team interviewed 115 regional transportation agencies, associations, organizations and industries in the selected states and found that, although the severity of delays, the economic impacts, and the safety problems related to highway work zones had been keenly realized by most senior state and local transportation officials, limited effective traffic management techniques and devices were applied. The review team consolidated the information from their investigation into a state-of-the-art statement for each of the work zone traffic management elements, which included policy and procedures, education and outreach, prediction modeling and impact analysis, planning and programming, project development and design, contracting and bidding, construction materials and methods, traveler and traffic information, law enforcement, advanced technologies, and evaluation and feedback. Then the review team identified immediate needs for improvement in various practical fields such as construction project bidding, traditional traffic control, the usage of various work zone traffic prediction models, work zone related public education, applications of ITS, usage of staffed police car with flashing lights, and collection of accurate work zone traffic data. The review team also suggested six fields where FHWA should particularly take a leadership role. They were: research, technology, education, continuous quality improvement, partnership, and standardization. Note that, in this report, a comprehensive background of the recent history of work zone safety including a statistics of fatal crashes was described.

Fisher and Rajan (1996) developed a prototype system to perform highway constructibility analysis in the traffic control planning stage. The system included a database module, an expert system module, and a fuzzy scheduling module. Engineers could use this system to generate generic constructibility recommendations to traffic control planning. According to their report, the system provided advanced means to 1) capture and store constructibility lessons learned from completed projects, 2) query and access these lessons when starting on a new project, 3) provide constructibility recommendations for traffic planning, 4) estimate uncertain construction durations, and 5) schedule the traffic control plan. The system was developed using Microsoft VB 3.0, Microsoft FoxPro 2.5, and Microsoft Project 3.0. This research was a part of the project entitled “Constructibility Review Process for Transportation Facilities” which was funded by the National Cooperative Highway Research Program.

Highway work zone management includes the dealing with traffic problems caused by one or multiple lane closures. Thus, the effectiveness of a traffic management and planning strategy is partly judged by if it can decrease the negative impacts of lane or road closures. A study (Islam et al., 1995) was conducted to identify suitable software packages that could be used to select best traffic management options during the period when the road or its lanes had to be closed for pavement reconstruction or utility upgrade. In the study, the researchers examined the pros and cons of using transportation planning software for evaluating traffic management alternatives under limited data and computer skills. The study began with an evaluation of the principle features of four transportation planning software packages – TRANPLAN, MINUTP, System II, and QRS II. Then the two top-rated packages, QRS II and System II, were used in the case study and further evaluated on the basis of predictive accuracy, modeling deficiency, comprehensiveness, and compatibility with other software. It was found that both packages could be used to evaluate the impact of changes in highway network and zonal characteristics on travel demand. However, both packages were not developed to the extent that was required to generate all the information needed in determining alternative traffic management strategies. The researchers suggested that potential users should specify the primary functions for which it was to be used before investing in these software packages and should find the best trade-off between their costs and versatility. The project was funded by the Utah Center for Advanced Transportation Studies (UCATS) and the Natural Sciences and Research Council of Canada

(NSRCC). The case study in this research was based on the road network in the city of Verdun in Quebec, Canada.

It has been observed that daytime lane closures always entail various traffic impacts such as congestions and delays, while night-time work zones provide highway projects a longer period of light traffic and cause much less traffic delays and congestions. Thus, it is reasonable to consider using a night-time work zone as an alternative to a day-time work zone. Shepard and Cottrell (1986) conducted a research whose objective was to examine the problems inherent to conducting highway projects at night. This research compiled information on previous practices in performing highway maintenance and construction operations at night and then synthesized the information into guidelines for determining when nighttime work zones should be used and what traffic control devices should be employed. According to their research, major advantages of working at night, as compared to working during daytime, could be avoidance of traffic congestion and motorist delay, opportunity to enlarge work areas and to concurrently conduct multiple work functions, and less interruption of traffic. The disadvantages included more safety problems relating driver drowsiness, inattention, intoxication, weakened visibility, and public reactions against noise and light. The researchers developed guidelines for choosing nighttime operations based on multiple considerations such as project evaluation, costs and benefits estimation, feasibility analysis, and advance planning. The study suggested that nighttime traffic control in work zones could use both traditional work zone traffic control and special optical nighttime traffic control devices.

2.7 Literature Review Summary

As the first step of the KDOT work zone project (KTRAN-Project KU-05-01), the researchers from KU conducted a comprehensive review on various literatures including journals, conference proceedings, periodicals, thesis, dissertations, special reports, and other documents. Findings of the literature review were summarized into five categories including 1) previous analyses of crash crashes in highway work zones; 2) statistical methods and applications in safety data analysis; 3) highway work zone traffic control; 4) research and development trend; and 5) other work zone safety related researches. A brief summary of the literature review is presented as follows.

First, the importance of having safe work zones for both construction workers and highway users has been recognized by government agencies, the legislatures, the highway industries, and the traveling public. A significant amount of research projects have been conducted to improve work zone safety. Government agencies including FHWA and state DOTs have financed most of these projects. Researchers have produced many significant results that have been implemented in work zones to improve safety. Despite the efforts made by government agencies and the highway industry, there is little indication that work zone crashes are on the decline nationwide. The main reason behind this might be that current countermeasures are not working effectively enough in the work zones. Further research is needed to continuously improve the work zone safety.

Second, several studies were conducted to investigate the work zone crash characteristics. Although most of these studies were based on analyses of the data from traffic accident reports in different states, common characteristics of work zone crashes were identified, which include: 1) the work zones on interstate highways had the highest crash rate; 2) the most common type of work zone crashes was rear-end; 3) commercial trucks had higher probability involving in work zone fatal crashes; and 4) high speed in work zones was one of the predominant causes of crashes. During the literature search, the KU research team did not find any publications presenting nationwide work zone safety studies. Therefore, it is impossible to know how work zone crash characteristics vary from state to state across the country. Because of this reason, the research team believes that simply adopting the practices of other states may not be the best solution for Kansans.

Third, work zone safety research methodologies and work zone traffic control technologies have been gradually improved. Advanced statistical techniques including Chi-Square test and linear and nonlinear regressions have been utilized in crash data analyses and have produced more accurate and persuasive results. In addition, advanced traffic control techniques have been implemented in work zones and various emerging technologies have been introduced in work zone researches. For example, ITS applications, such as intelligent speed control devices and real-time traffic information systems, have been adopted to create smart work zones. The benefits of using GIS and computer-based simulation systems to facilitate work zone management have been also evaluated. However, the in-depth examinations of the previous researches have showed that there are potentials to make further improvements on work zone safety, which may yield more promising findings.

Last, most of the state DOT's are maintaining relatively detailed work zone accident databases. However, according to the findings in the literature review, most researchers agree that these databases have neither included all information needed for better understanding work zone crashes nor organized the information in a format that readily leads itself to a meaningful analysis. For instance, most crash data are recorded separately from work zone layout information including durations, traffic control settings, and work zone configurations. Thus, connecting a crash with the work zone where the crash happens becomes inconvenient or even impossible. This may be one of the reasons why many factors leading to work zone crashes go unidentified.

Chapter 3:

Research Scope, Objective, and Methodology

3.1 Scope and Objective

The scope of this research is limited to fatal work zone crashes between 1992 and 2004 on the State of Kansas highway system, a total of 157 cases. The primary objective of this research was to investigate the characteristics of fatal crashes and dominant contributing factors to these crashes in the work zones so that effective safety countermeasures could be developed and implemented in the near future.

3.2 Methodology

The research objective is achieved using the following steps:

1. **Literature review**

   A comprehensive literature review was conducted to provide the state-of-the-art of highway work zone safety research. Previous work zone safety studies were reviewed and their findings were summarized. These findings reveal work zone crash characteristics in other states and work zone safety research trends.

2. **Data Collection**

   The fatal work zone accident reports from 1992 to 2004 were recompiled to a spreadsheet format for statistical analyses without missing key information. Some original accident reports were further evaluated in the KDOT office to eliminate possible data errors.

3. **Data Analyses**

   SAS software package was used to analyze the crash data. Various statistical methods such as frequency analysis and chi-square test were utilized to identify the most significant crash factors.

4. **Risk Factor Determination**

   Through this step, highway work zone risk factors will be determined. Geographic Information System (GIS) software will be used to illustrate high-risk locations.

Countermeasures will be suggested accordingly based on the identified work zone safety deficiencies.

5. Conclusions and Recommendations

Conclusions will be given at the end of this research project. The KU research team will assist the Project Monitor and Area Panel Leader to prepare a Research Implementation Plan. In this plan, detailed implementation procedure will be outlined and recommendations for future research, if necessary, will be proposed.

Chapter 4:

DATA COLLECTION

4.1 Data Collection Procedure

This study focuses on the fatal crashes which occurred in the Kansas highway work zones from January 1, 1992 to December 31, 2004. A total of 157 cases were abstracted from the KDOT accident database. In the database, because the information of all parties (responsible driver and non-responsible driver) of each crash was included, a single case frequently occupied multiple rows in the spreadsheet. In addition, factors such as traffic controls or driver errors in a crash also led to multiple rows. In contrast, the data analyses required simply formatted yet comprehensive information that could be readily fed into analysis tools such as SAS software. Thus, compiling each fatal crash case into a single row in the spreadsheet without missing key information of interest became the first critical task. The rationale of accomplishing this task was that, after the responsible driver of a crash was identified, the factors associated with the responsible driver were selected and additional columns were added to the data row to accommodate all the information. For instance, some crash sites had multiple traffic control devices. Three columns were designed under the heading of "Traffic Control" in the spreadsheet to record all possible devices. The most important device was input in column number one under "Traffic Control". A similar strategy was used to record driver factor that often had multiple observations in a crash.

The data collection procedure included two steps. First, based on KDOT's database, the responsible drivers/vehicles for each case were identified. Then, the original accident report for each case including detailed crash descriptions and scene sketches was examined and crash related information was abstracted and recorded numerically to a row in the spreadsheet. Any confusing and/or missing information was clarified with the help from KDOT personnel. The spreadsheet (see Appendix I) was designed to encompass all the information shown on the original accident reports (see Appendix II). Table 4.1.1 presents the accident data categories in the spreadsheet. Six major categories of information were abstracted from accident reports. They are:

1. **Responsible Diver**

   This category included the basic information of a driver who was responsible for a fatal crash. There were two variables, age and gender, in the category. Age was divided into seven groups (see Appendix III, Table 1) and gender had two observations: male and female (see Appendix III, Table 2).

2. **Time Information**

   This category included the temporal variables of the fatal crashes such as the occurrence time and date. The time of the day was divided into four periods: 6:00 a.m. – 10:00 a.m. as the morning peak hours; 10:00 a.m. – 4:00 p.m. as the daytime non-peak hours; 4:00 p.m. – 8:00 p.m. as the afternoon peak hours; and 8:00 p.m. – 6:00 a.m. as the nighttime hours. Other temporal variables such as day of the week and month of year were ordered according to the calendar. Tables 3 – 6 in Appendix III show the four variables in this category with their observations.

3. **Climatic Environment**

   The climatic environmental information reflected the light, weather and road surface conditions of the work zone when a crash occurred. Light conditions included five observations according to the factors affecting visibility such as natural brightness and streetlight. Weather conditions had 14 accounts that might have impacts on traffic safety. Road surface conditions had seven observations reflecting the situations of highway surfaces. The observations of these three variables are listed in Tables 7 – 9 in Appendix III.

4. Crash Information

The crash information gathered from the reports includes vehicle maneuver before crash, crash severity, crash type, vehicle body type, and number of vehicles involved. The before-crash vehicle maneuvers included 16 observations based on the KDOT accident reports. The crash severity had three observations including fatal, injury or near fatal, and property damage only. The focus of this study was only on fatal crashes. For crash type, 16 different observations were included. The vehicle body types were classified into ten categories such as heavy trucks, passenger cars, motorcycles, pedestrians, etc. The number of vehicles involved in a crash was recorded using the actual number. The observations of these variables are listed in Tables 10 – 13 in Appendix III.

5. Road Conditions

The variables in this category described the road conditions where a fatal work zone crash occurred. These variables included road class, road character, number of lanes, speed limit, crash location, surface type, road special feature, area information, and traffic control. Road class included seven road classifications that were defined in the KDOT accident reports. Road character had seven observations that describe the geometric alignments of a crash highway section such as curves and grades. Six observations for crash location were determined according to if the crashes occurred near intersections or crossovers. The surface type variable included six observations such as blacktop (asphalt), brick, concrete, etc. Road special feature had eight observations that were categorized according to the presences of features such as bridges, ramps, and interchanges. Area information had two observations: urban and rural. There were 11 observations for traffic control devices. Other variables including number of lanes and speed limit were recorded using the actual number to the spreadsheet. Tables 14 – 20 in Appendix III show the observations of these variables in detail.

6. Contribution Factors

This category listed the elements that were identified on the accident reports as the contribution factors to the crashes. These elements included driver factor which had 26 human-error observations (Table 21 in Appendix III), pedestrian factor which had nine observations (Table 22 in Appendix III), environment factor which had 11 observations

(Table 23 in Appendix III), and vehicle factor which had 11 observations (Table 24 in Appendix III).

The observations of each variable were assigned with integer values. Therefore, the spreadsheet contains only numerical values. A portion of the spreadsheet is presented in Appendix I. After collecting all the data, the spreadsheet was inputted to the SAS software for data analyses. The results of data analyses are presented in the next chapter.

Table 4.1.1: Crash Data Categories and Variables

No.	Category	Variable	Observations
1	Responsible Driver	Age	See Table 1 in Appendix III
		Gender	See Table 2 in Appendix III
2	Time Information	Time	See Table 3 in Appendix III
		Day	See Table 4 in Appendix III
		Month	See Table 5 in Appendix III
		Year	See Table 6 in Appendix III
3	Climatic Environment	Light Condition	See Table 7 in Appendix III
		Weather Condition	See Table 8 in Appendix III
		Road Surface Condition	See Table 9 in Appendix III
4	Crash Information	Vehicle Maneuver Before Crash	See Table 10 in Appendix III
		Crash Severity	See Table 11 in Appendix III
		Crash Type	See Table 12 in Appendix III
		Vehicle Body Type	See Table 13 in Appendix III
		Number of Vehicles Involved	Using actual numbers
5	Road Condition	Road Class	See Table 14 in Appendix III
		Road Character	See Table 15 in Appendix III
		Number of Lanes	Using actual numbers
		Speed Limit	Using actual numbers
		Crash Location	See Table 16 in Appendix III
		Surface Type	See Table 17 in Appendix III
		Road Special Feature	See Table 18 in Appendix III
		Area Information	See Table 19 in Appendix III
		Traffic Control	See Table 20 in Appendix III
6	Contribution Factor	Driver Factor	See Table 21 in Appendix III
		Pedestrian Factor	See Table 22 in Appendix III
		Environment Factor	See Table 23 in Appendix III
		Vehicle Factor	See Table 24 in Appendix III

Chapter 5:

Data Analyses

5.1 Analyses of Crash Characteristics

5.1.1 Kansas Work Zone Crash Trend

Statewide traffic crash statistics indicate that highway work zone safety in Kansas remains a serious concern. According to the statistics provided by KDOT (Table 5.1.1), in the past 13 years (1992-2004), there were 15,434 work zone crashes reported in Kansas and 30% or 4,600 of them involved injuries or fatalities.

Figure 5.1.1 shows the composition of Kansas work zone crashes and Figure 5.1.2 illustrates the 13-year (1992-2004) trends of work zone fatalities in the State of Kansas. Over the past 13 years, the numbers of annual work zone fatalities showed a non-decreasing trend, although fluctuations were observed in some years including 1994 and 1997.

Table 5.1.1: Kansas Work Zone Crash Statistics (1992-2004)

Year	No. of Fatal Crashes	No. of Deaths	No. of Injury Crashes	No. of Injuries	No. of PDO* Crashes	Total Crashes
1992	15	18	401	667	695	1111
1993	9	12	372	578	755	1136
1994	3	3	344	548	743	1090
1995	14	17	480	750	1049	1543
1996	12	15	509	773	1126	1647
1997	19	22	433	742	942	1394
1998	9	13	326	541	829	1164
1999	11	12	267	466	671	949
2000	9	9	195	329	570	774
2001	13	15	253	408	674	940
2002	14	16	238	368	705	957
2003	11	13	283	425	974	1268
2004	18	24	342	528	1101	1461
Total	157	189	4443	7123	10834	15434

PDO: Property Damage Only.

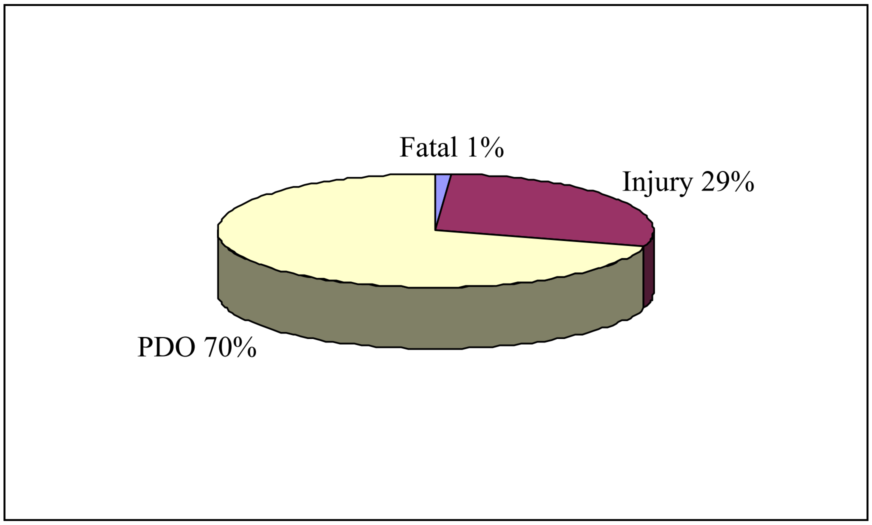


Figure 5.1.1: Overall Work zone Crash Composition (1992-2004)

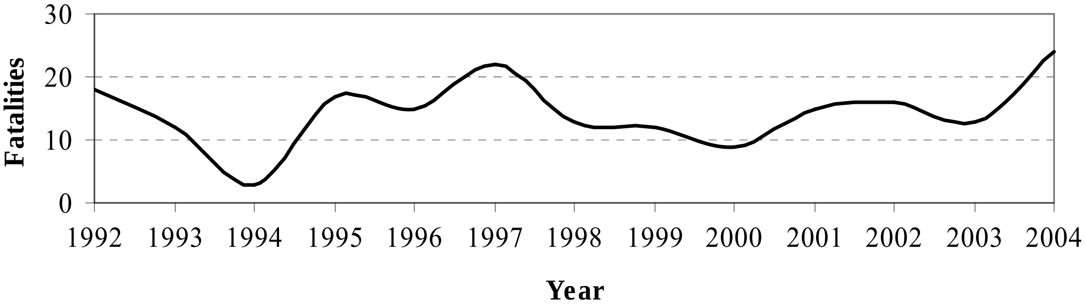


Figure 5.1.2: Kansas Work Zone Fatalities (1992-2004)

The characteristics of the fatal crashes recorded in Kansas highway work zones between 1992 and 2004 were studied in detail. Significant factors that might contribute to these crashes were identified in an effort to direct the development of work zone safety countermeasures in the future.

5.1.2 Kansas Fatal Work zone Crash Characteristics

5.1.2.1 Responsible Driver

A traffic crash is a human-machine interaction event; drivers play a key role in a crash. The driver information, age and gender, was analyzed. The frequency analysis showed that approximately 75% of the responsible work zone fatal crash drivers were males. Table 5.1.2 and Figure 5.1.3 present the frequency analysis results.

Table 5.1.2: Responsible Drivers' Gender Composition

Gender	No. of Crash	Percent (%)
Male	117	75
Female	40	25
Sum	157	100

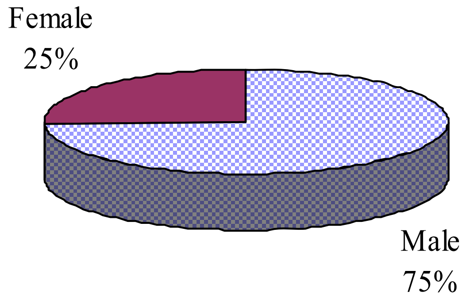


Figure 5.1.3: Male vs. Female Responsible Drivers

Table 5.1.3 and Figures 5.1.4 and 5.1.5 illustrate the age distribution of the responsible drivers for fatal work zone crashes in terms of genders. On average, drivers that were 35-44 years of age caused the highest proportion (24%) of the fatal crashes, while those between 55 and 64 were only responsible for less then 5% of the crashes. The driver group having the second highest fatal work zone crash rate was 65 or older. This driver group caused 18% of the crashes. Note that teenager drivers (15-19 years old) also created a notable safety problem by causing 12% of the total crashes.

When comparing between genders (see Figure 5.1.5), most driver groups had similar distributions except that, for the drivers who were 45 to 54 years old, females (23%) caused a much higher percentage of fatal crashes then males (12%) did.

Table 5.1.3: Responsible Drivers' Age Distribution

Age		15 – 19	20 – 24	25 – 34	35 – 44	45 – 54	55 – 64	≥ 65	Sum
Male	**No. of Crash**	15	13	19	28	14	6	22	117
	Percent (%)	13	11	16	24	12	5	19	100
Female	**No. of Crash**	4	4	5	10	9	1	7	40
	Percent (%)	10	10	13	25	23	3	18	100
Total	**No. of Crash**	19	17	24	38	23	7	29	157
	Percent (%)	12	11	15	24	15	4	18	100

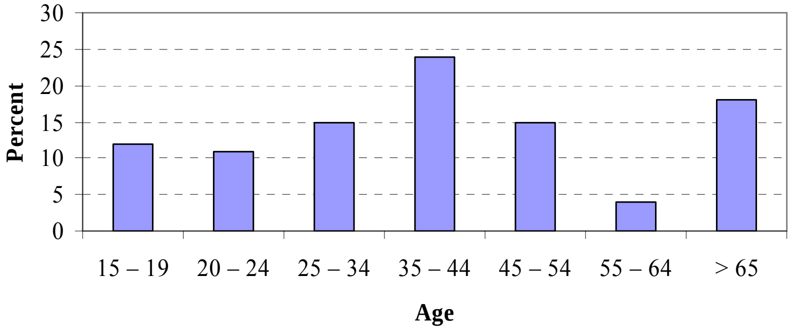


Figure 5.1.4: Responsible Drivers' Age Distribution (Total)

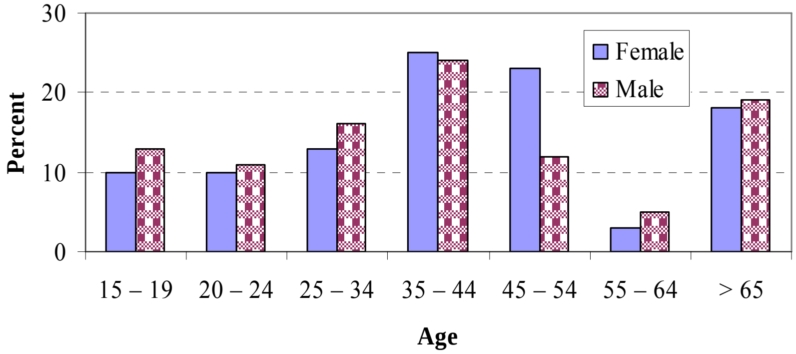


Figure 5.1.5: Responsible Drivers' Age Distribution (Male vs. Female)

5.1.2.2 Time Information

Detailed analyses of the crash occurrence time were conducted and the results are presented herein in terms of time of day, day of week, and month. Table 5.1.4 and Figure 5.1.6 show the fatal crash distributions over the four time periods. The results indicate that most of the crashes occurred during non-peak hours. Significant differences between fatal work zone crashes of each time period were not observed when measured in unit time. It is particularly of interest that in the two peak-hour periods, when the traffic volumes (per hour) were expected to be higher, hourly fatal work zone crash rates were indeed lower than daytime non-peak period rate. Furthermore, given the lower traffic volumes, the nighttime period had a relatively high crash rate.

Table 5.1.4: Fatal Crash Distributions over Different Periods

Time	Length	No. of Crash	Percent (%)	Hourly Rate	30-Day Rate
6:00 a.m. – 10:00 a.m.	4 hours	22	14	1.16/1000hr.	0.84/30d.
10:00 a.m. – 4:00 p.m.	6 hours	51	32	1.79/1000hr.	1.29/30d.
4:00 p.m. – 8:00 p.m.	4 hours	26	17	1.37/1000hr.	0.99/30d.
8:00 p.m. – 6:00 a.m.	10 hours	58	37	1.22/1000hr.	0.88/30d.
Average	-	-	-	1.38/1000hr.	0.99/30d.

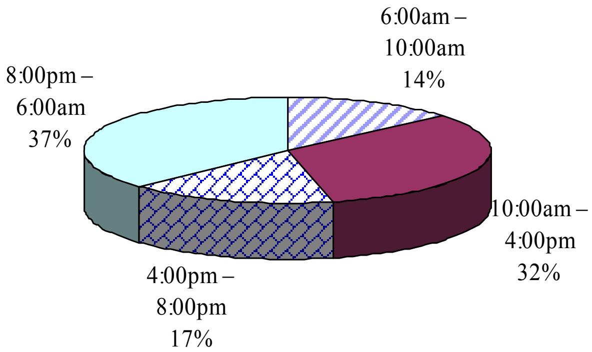


Figure 5.1.6: Fatal Crash Distributions over Different Periods

The crash distributions over different days of week are shown in Table 5.1.5 and Figure 5.1.7. The fatal crashes in Kansas work zones were approximately evenly distributed over the seven days of a week and the most significant difference was found between Saturday and Tuesday which was only about 6%. As seen from Figure 5.1.7, the crash numbers increased gradually from Tuesday, when the lowest crash number was observed, to Saturday, when the highest number was observed.

When the crashes were extended over the twelve month period, a significant proportion of them occurred between May and November, the busiest season for highway construction projects. As shown from Table 5.1.6 and Figure 5.1.8, about 24% of the crashes took place in

January, February, March, April, and December when construction activities are slow during these months.

Table 5.1.5: Crash Distributions over Different Days

Day	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Sum
No. of Crash	22	17	21	23	25	26	23	157
Percent (%)	14	11	13	15	16	17	15	100

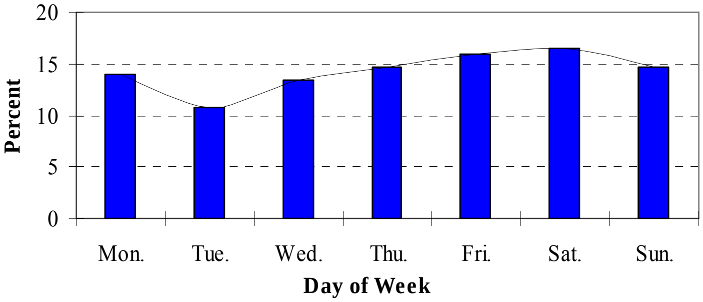


Figure 5.1.7: Crash Distributions over Different Days

Table 5.1.6: Crash Distributions over Twelve Month Period

Month	1	2	3	4	5	6	7	8	9	10	11	12	Sum
No. of Crash	4	6	6	10	17	22	19	19	14	16	13	11	157
Percent (%)	3	4	4	6	11	14	12	12	9	10	8	7	100

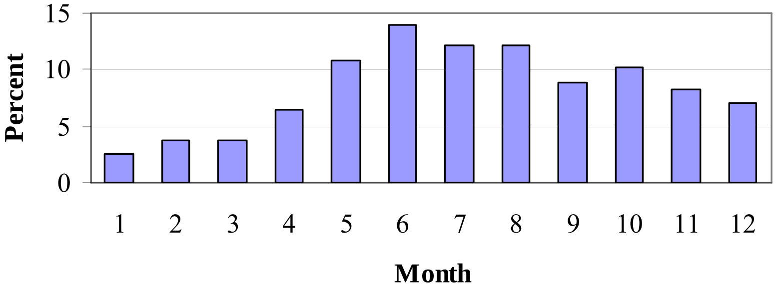


Figure 5.1.8: Crash Distributions over Twelve Month Period

5.1.2.3 Climatic Environmental Characteristics

Climatic environmental factors such as light conditions, weather conditions, and road surface conditions were examined in this study to uncover whether adverse environmental conditions contribute to the fatal crashes in work zones. Table 5.1.7 and Figure 5.1.9 summarize the fatal crashes occurring in various light conditions. Results illustrated that more than half (53%) of the fatal work zone crashes happened when the light condition was good. Among the crashes during adverse light conditions, an overwhelming portion (32% of the total) happened in darkness without street lights. This fact supports the common-sense notion that driving in darkness is more likely to have crashes. Meanwhile, having lights on in the dark highway might reduce the probability of having fatal crashes.

Table 5.1.7: Crash Distributions in Different Light Conditions

Light Condition	**No. of Crash**	**Percent (%)**
Daylight	83	53
Dawn	5	3
Dusk	4	3
Dark: street lights on	14	9
Dark: no street lights	51	32
Sum	157	100

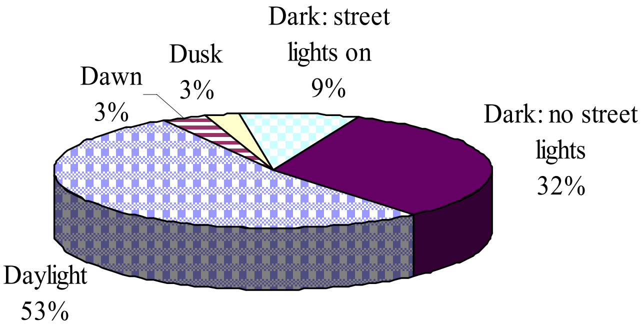


Figure 5.1.9: Crash Distributions in Different Light Conditions

Weather conditions and road surface conditions are two factors commonly considered as contributing factors to traffic crashes. In contrast, this study found that only a very small proportion of fatal work zone crashes occurred in adverse weather and road surface conditions. Results showed only about 9% of the fatal crashes occurred under inclement weather conditions and less than 12% took place when the road surfaces were not dry. Hence, researchers cannot conclude that these two factors were particularly significant in causing fatal work zone crashes. The statistics of the crashes in various weather conditions and road surface conditions are summarized in Tables 5.1.8 and 5.1.9, and Figures 5.1.10 and 5.1.11.

Table 5.1.8: Crashes in Different Weather Conditions

Weather Condition	No. of Crash	Percent (%)
No Adverse Conditions	143	91
Rain, Mist, Drizzle	8	5
Snow	3	2
Fog	2	1
Rain and Wind	1	<1
Sum	157	100

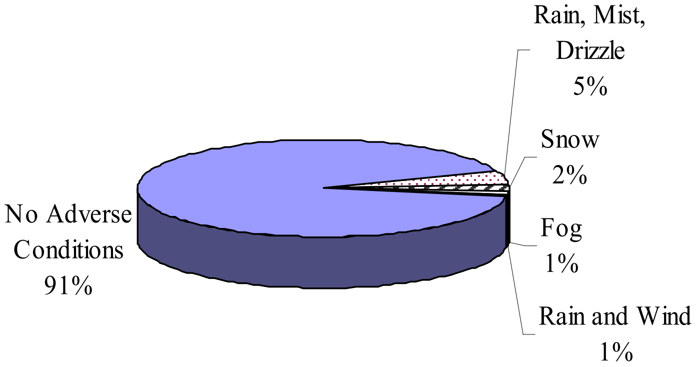


Figure 5.1.10: Crashes in Various Weather Conditions

Table 5.1.9: Crashes in Different Road Surface Conditions

Road Surface Condition	No. of Crash	Percent (%)
Dry	138	88
Wet	12	8
Snow or Slush	1	<1
Ice or Snow Packed	5	3
Mud, Dirt, or Sand	1	<1
Sum	157	100

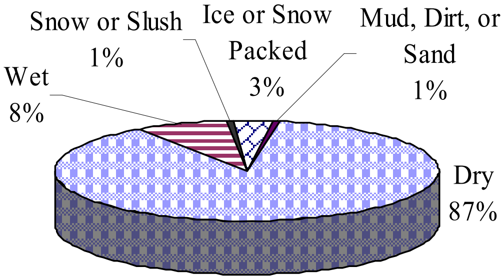


Figure 5.1.11: Crashes in Different Road Surface Conditions

5.1.2.4 Crash Information

Crash information helps researchers to reconstruct the scene of a crash, and then, makes the crash more understandable. The descriptive information of the crashes was studied in detail, which included vehicle maneuver before crash, crash type, vehicle body type, and number of vehicles involved.

Most of the responsible vehicles (74%) were following roadway alignments before they caused fatal crashes. More complicated maneuvers such as turning or stopping movements only coincided with a small proportion (26%) of fatal work zone crashes. Thereby, it is reasonable to conclude that complicated vehicle maneuver is not the dominant cause of the fatal work zone crashes in Kansas. The frequency analysis results are presented in Table 5.1.10 and Figure 5.1.12.

In regard to crash type, head-on was found to be the most frequent work zone crash type (24%), followed by angle-side impact (20%) and rear-end (16%). In addition, overturn and collision-with-fixed-object were the other two frequent crash types which had the same percentages of about 11%. The results of the frequency analysis in terms of crash types are listed in Table 5.1.11 and Figure 5.1.13.

Table 5.1.10: Crash Frequencies by Vehicle Maneuvers

Vehicle Maneuver	No. of Crash	Percent (%)
Following Road	116	74
Left Turn	6	4
Right Turn	1	<1
U-Turn	2	1
Overtaking	10	6
Changing Lanes	6	4
Avoiding	5	3
Slowing/Stopping	1	<1
Other	10	6
Sum	157	100

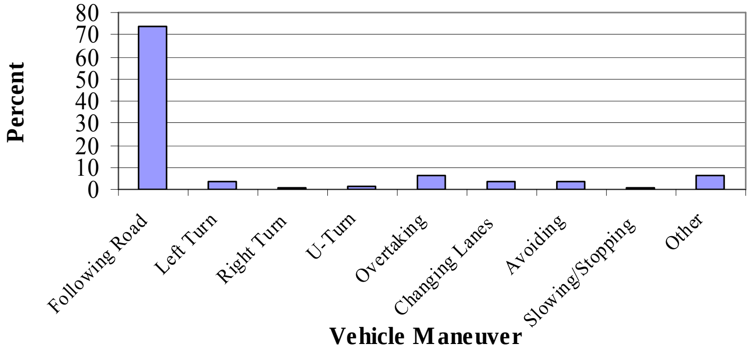


Figure 5.1.12: Crash Frequencies by Vehicle Maneuvers

Table 5.1.11: Crash Frequencies by Crash Types

Crash Type	No. of Crash	Percent (%)
Other Non-Collision	1	<1
Overturned	17	11
CW Pedestrian	11	7
CW Parked Vehicle	9	6
CW Animal	1	<1
CW Fixed Object	17	11
Head-On	37	24
Rear-End	25	16
Angle-Side Impact	32	20
Sideswipe (opposite dir.)	4	3
Sideswipe (same dir.)	2	1
CW Other Object	1	<1
Sum	157	100
CW: Collision With; Dir.: Direction.		

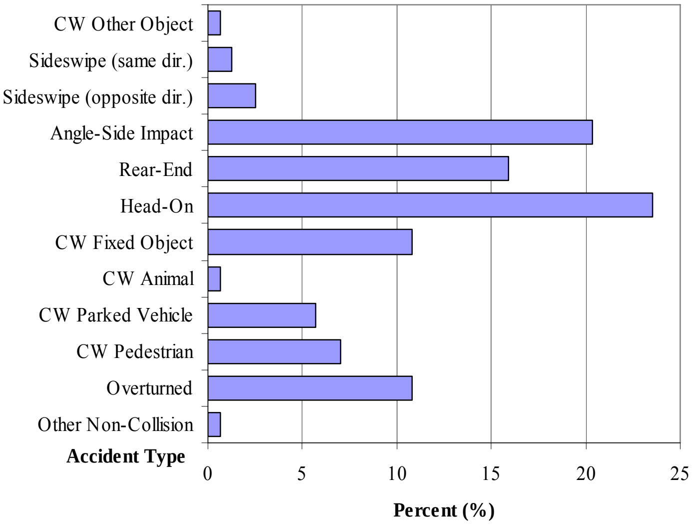


Figure 5.1.13: Crash Frequencies by Crash Types

As mentioned in Chapter 2, significant rates of heavy-truck related fatal work zone crashes were discovered in other states. This phenomenon was also found in Kansas work zones: about 40% of the fatal work zone crashes involved heavy trucks. A heavy truck, defined in the Kansas accident report, is a single large truck, truck and trailer, tractor-trailer, or bus. Truck-vehicle collisions were the dominant collision type among the truck-involved crashes which had a percentage of 34%. The term "vehicle" used in this research project refers to such vehicle types as passenger car, pickup, and all terrain vehicle (AVT). Another dominant collision type was vehicle-vehicle collisions which accounted for 31% of the total crashes. Table 5.1.12 and Figure 5.1.14 show the vehicle types in the Kansas fatal work zone crashes.

Table 5.1.12: Crash Distribution over Vehicle Types

Vehicle Type	No. of Crash	Percent (%)
Truck vs. truck	3	2
Truck vs. vehicle	53	34
Truck vs. Motorcycle	2	1
Truck vs. ped./worker	3	2
Truck vs. object	1	<1
Vehicle vs. vehicle	49	31
Vehicle vs. motorcycle	1	<1
Vehicle vs. ped./worker	6	4
Vehicle vs. object	15	10
Other	24	15
Sum	157	100

Ped.: pedestrian; truck: heavy truck.

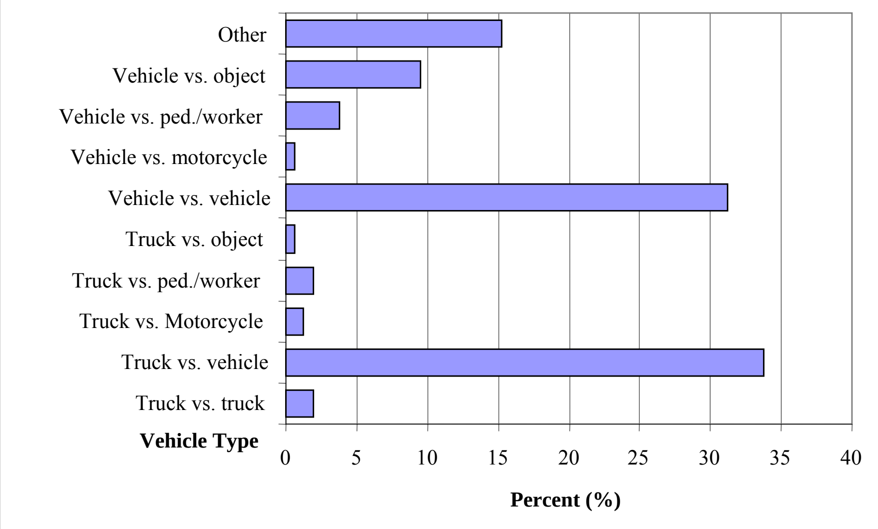


Figure 5.1.14: Crash Distribution over Vehicle Types

When studying the numbers of vehicles involved in the crashes, the results show that 68% of the fatal crashes involved multiple vehicles (Table 5.1.13 and Figure 5.1.15). Among these multi-vehicle collisions, two-vehicle crashes were dominant, which had a total of 53%. Single-vehicle crashes accounted for 32% of the total crashes.

5.1.2.5 Road Conditions

Roadway conditions could directly affect traffic safety and hazardous roadway features may cause crashes. Road conditions examined herein includes road class, road character, number of lanes, speed limit, crash location, surface type, road special feature, area information, and traffic control.

The frequency analyses indicated that most fatal crashes occurred on interstate highways and principle arterials. Table 5.1.14 and Figure 5.1.16 illustrate that, among the five highway classifications, interstate highways and principle arterials had the highest crash frequencies of 27% and 56%, respectively.

Table 5.1.13: Crash Frequencies by No. of Vehicles Involved

No. of Vehicles	1	2	3	4	5	6	**Sum**
No. of Crash	50	83	17	4	1	2	157
Percent (%)	32	53	11	3	<1	1	100

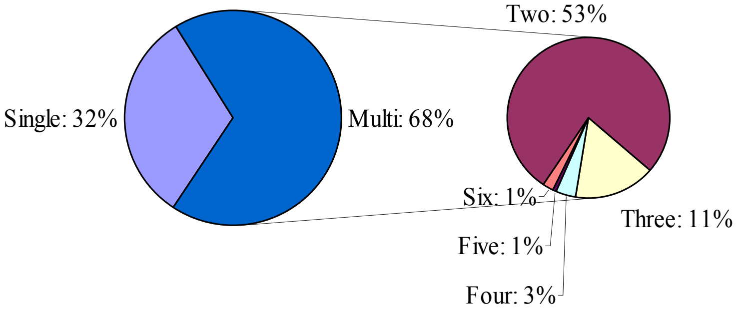


Figure 5.1.15: Crash Frequencies by No. of Vehicles Involved

Table 5.1.14: Crash Distribution over Different Road Classes

Road Class	No. of Crash	Percent (%)
Interstate	42	27
Other Freeway & Expressway	6	4
Other Principle Arterial	88	56
Minor Arterial	14	9
Major Collector	7	4
Sum	157	100

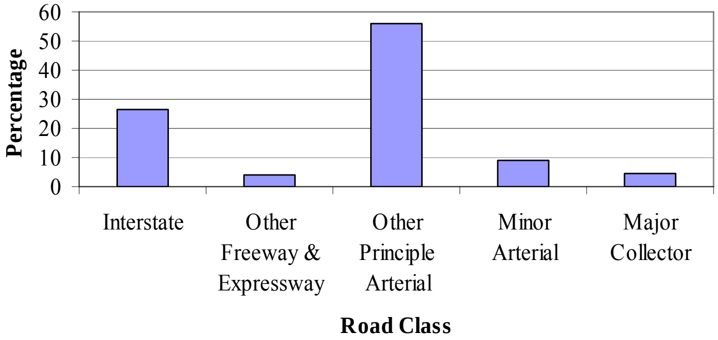


Figure 5.1.16: Crash Distribution over Different Road Classes

A roadway's adverse geometric characteristics could affect drivers, and thus, cause crashes. Frequency analyses were conducted to examine if road geometries contributed to the fatal work zone crashes. As shown in Table 5.1.15 and Figure 5.1.17, 49% of the crashes occurred on complicated highway geometric alignments. In particular, about 25% of the crashes happened within the work zones where the highway section alignments were straight on grade. These results indicate that unfavorable highway geometric alignments in work zone areas may have negative impact on safety.

Table 5.1.15: Crash Frequencies by Different Road Geometries

Road Character	No. of Crash	Percent (%)
Straight & Level	80	51
Straight on Grade	39	25
Straight at Hillcrest	5	3
Curved & Level	19	12
Curved on Grade	13	8
Curved on Hillcrest	1	<1
Sum	157	100

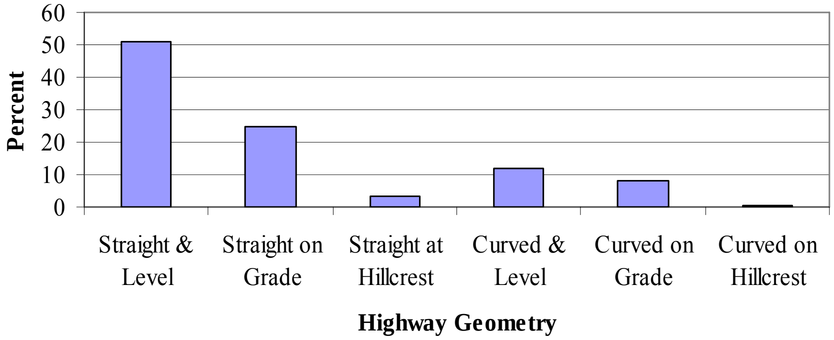


Figure 5.1.17: Crash Frequencies by Different Road Geometries

A significant portion of the work zone crashes (63%) took place on two-lane highways, shown in Table 5.1.16 and Figure 5.1.18. Approximately 92% of the crashes happened on the highways with speed limits between 51 mph and 70 mph. This number strongly suggests that high speed may contribute to the work zone fatal crashes. The proportional differences of crash frequencies in work zones with various speed limits are presented in Table 5.1.17 and Figure 5.1.19.

Table 5.1.16: Crash Frequencies by Number of Lanes

No. of Lanes	2	4	6	Sum
No. of Crash	99	49	9	157
Percent (%)	63	31	6	100

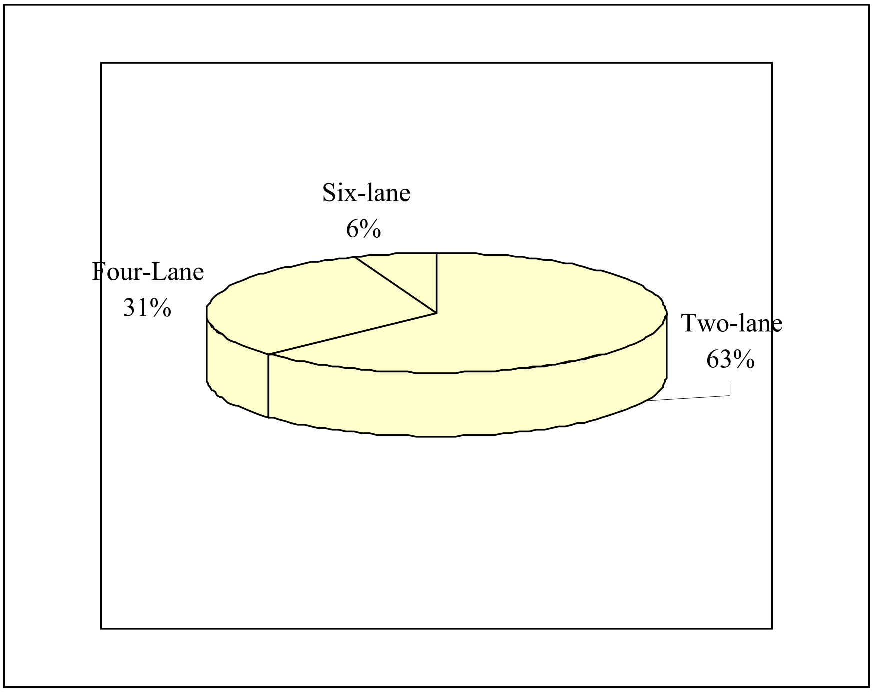


Figure 5.1.18: Crash Frequencies by Number of Lanes

Table 5.1.17: Crashes in Different Speed Zones

Speed Limit (m/hr)	≤ 40	41 – 50	51 – 60	61 – 70	**Sum**
No. of Crash	7	6	74	70	157
Percent (%)	4	4	47	45	100

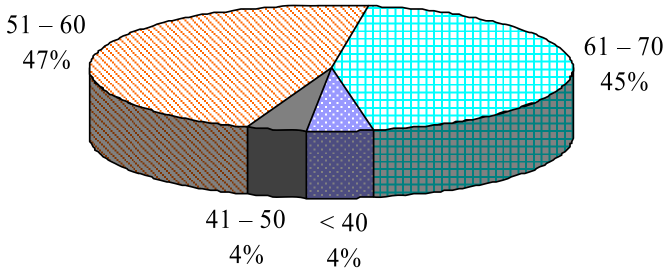


Figure 5.1.19: Crashes in Different Speed Zones

The analysis results with respect to different crash locations are presented in Table 5.1.18 and Figure 5.1.20. According to the analysis, most Kansas fatal work zone crashes (67%) during 1992 and 2004 occurred on non-intersections of the highways.

Highway pavement type and other features such as overhead bridge or on/off ramps could affect drivers in certain situations. Frequency analyses were conducted to examine if these factors were contributing to the fatal work zone crashes. The analysis results indicated that 30% crashes occurred on concrete-paved highways and 70% occurred on blacktop (asphalt) pavements. The results also indicate that highway special features including ramps or bridges didn't have significant impacts on fatal crashes. 85% of the crashes occurred on highway sections where there were not such special features. Tables 5.1.19 and 5.1.20, and Figures 5.1.21 and 5.1.22 present the results of these analyses.

Table 5.1.18: Crash Frequencies by Crash Locations

Crash Location	No. of Crash	Percent (%)
Non-intersection	105	67
Intersection	20	13
Intersection related	4	3
Interchange Area	5	3
Other	23	15
Sum	157	100

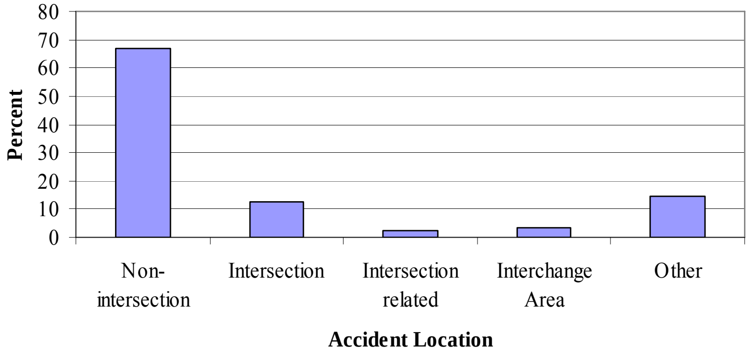


Figure 5.1.20: Crash Frequencies by Crash Locations

Table 5.1.19: Crash Frequencies by Pavement Type

Surface Type	No. of Crash	Percent (%)
Concrete	47	30
Blacktop	109	69
Brick	1	<1
Sum	157	100

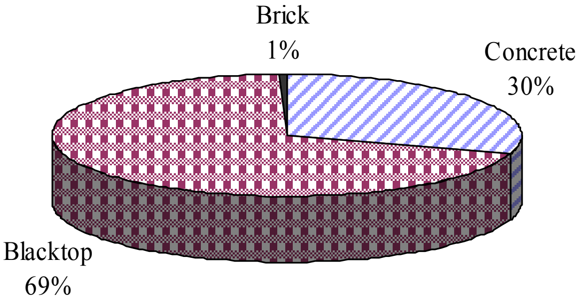


Figure 5.1.21: Crash Frequencies by Pavement Type

Table 5.1.20: Crash Frequencies by Road Special Feature

Road Special Feature	No. of Crash	Percent (%)
None	134	85
Bridge	8	5
Bridge overhead	2	1
Railroad bridge	1	<1
Interchange	6	4
Ramp	3	2
Other	3	2
Sum	157	100

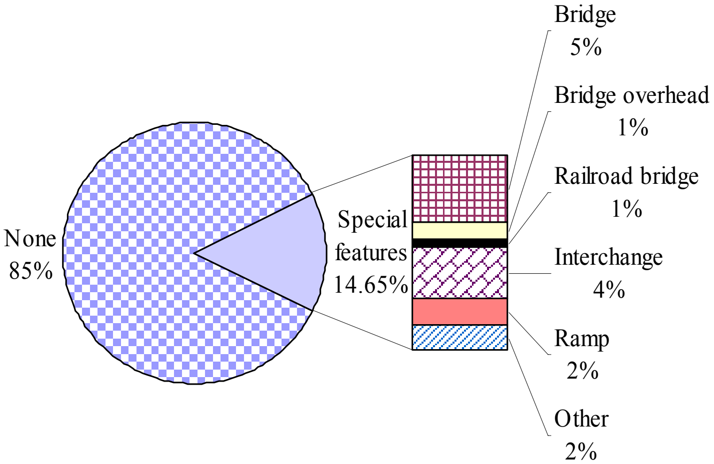


Figure 5.1.22: Crash Frequencies by Road Special Feature

As shown in Table 5.1.21, among the 157 fatal crash cases studied, 84% happened in rural areas. In addition, Table 5.1.22 and Figures 5.1.23 – 5.1.25 indicate that two-lane rural highways with 51 mph – 70 mph speed limits were the places had higher frequencies of fatal crashes. According to the analysis, about 73% of the rural crashes happened on two-lane rural highways and 96% of the rural crashes occurred on the highways with speed limits between 51 mph and 70 mph.

Table 5.1.21: Crash Frequencies by Crash Area (Rural vs. Urban)

Area Information	No. of Crash	Percent (%)
Urban	25	16
Rural	132	84
Sum	157	100

Table 5.1.22: Rural Crash Frequencies by Speed Limit and Lane Number

No. of Lanes / Speed Limit	Two		Four		Six		**Total**	
	#	%	#	%	#	%	#	%
≤ 40	1	<1	0	0	0	0	1	<1
41 – 50	3	2	1	<1	0	0	4	3
51 – 60	46	35	15	11	1	<1	62	47
61 – 70	47	36	18	14	0	0	65	49
Total	97	73	34	26	1	<1	132	100

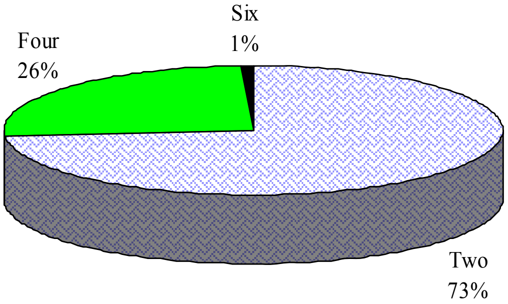


Figure 5.1.23: Crash Distribution on Rural Highways by Number of Lane

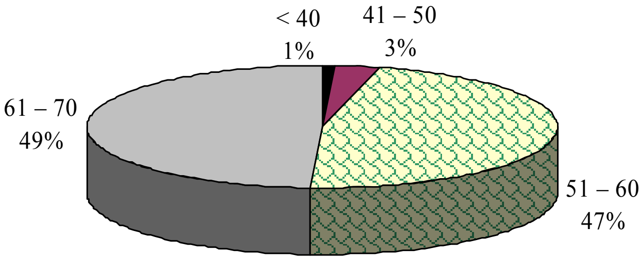


Figure 5.1.24: Crash Frequencies on Rural Highways with Different Speed Limits

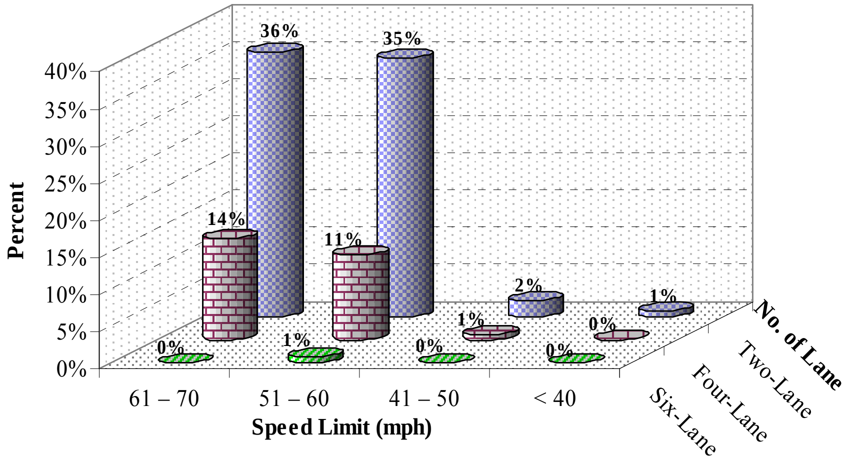


Figure 5.1.25: Rural Crash Frequencies by Lane Number and Speed Limit

Effective work zone traffic control devices regulate traffic flows and minimize hazards in highway work zones. The effectiveness of the work zone traffic control devices were studied and results are presented in Table 5.1.23 and Figure 5.1.26. According to the results, almost half (46%) of the crashes occurred when no traffic control devices were installed or they were inoperative. In addition, 11% of the total cases occurred when there were officers or flaggers guiding the traffic.

Table 5.1.23: Crash Frequencies by Traffic Control Device

Traffic Control	No. of Crash	Percent (%)
None or inoperative	73	46
Officer or flagger	17	11
Traffic signal	12	8
Stop sign/signal	16	10
Flasher	2	1
Yield sign	1	<1
No passing zone	32	20
Other control	29	18

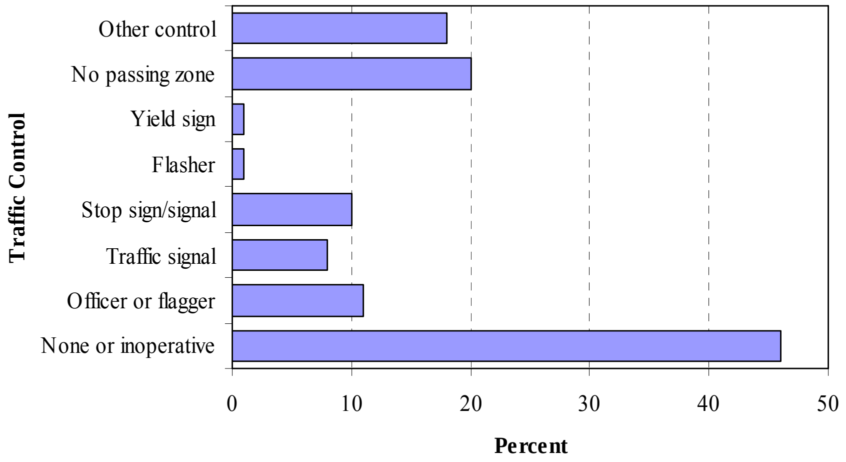


Figure 5.1.26: Crash Frequencies by Traffic Control Device

5.1.2.6 Contribution Factors

As shown in Table 5.1.24 and Figure 5.1.27, 92% of the crashes were associated with human errors. Among the human errors, inattentive driving and too fast for conditions/speeding were the most common contributing factors which were responsible for 53% and 25% of the total crashes, respectively. Disregarded traffic signs/signals, wrong side or wrong way, and alcohol were the other three factors leading to fatal crashes.

Table 5.1.24: Crash Frequencies by Driver Error

Driver Factor	No. of Crash	Percent (%)
Inattention	83	53
Too fast for conditions/speeding	39	25
Disregarded traffic signs/signals	33	21
Wrong side or wrong way	32	20
Under influence of alcohol	21	13
Failed to yield right of way	16	10
Fell asleep	14	9
Followed too closely	7	4
Improper lane change	7	4
Improper passing	6	4
Ill or medical condition	6	4
Avoidance or evasion action	4	3
Not comply-license restrictions	1	<1
Other/unknown	10	6
No human error	12	8

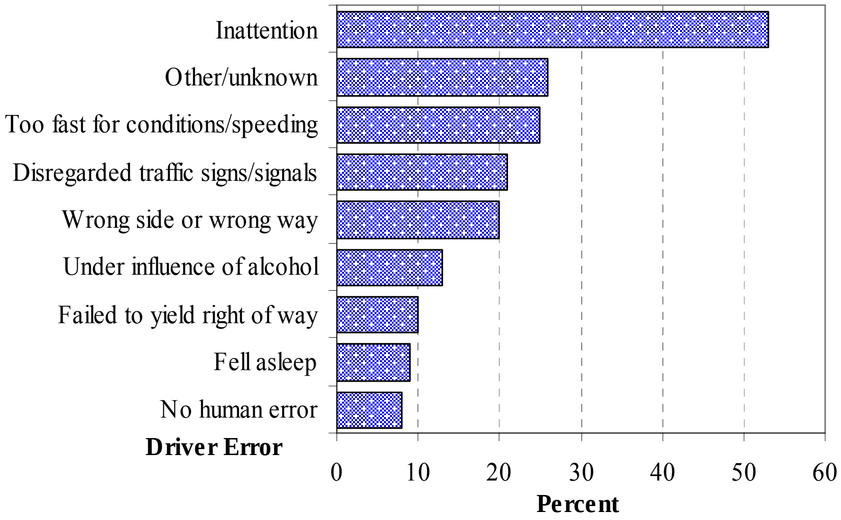


Figure 5.1.27: Crash Frequencies by Driver Error

In addition, among the 157 fatal work zone crashes studied, only 12 cases (8%) were found not to be contributed by driver errors. Table 5.1.25 presents the fatal crashes that were caused by other contributing factors (other than driver errors).

Table 5.1.25: Other Contributing Factors for Kansas Fatal Work zone Crashes

Other Factors	No. of Crash	Percent (%)
Pedestrian Factor		
Failed to yield right of way	1	<1
Illegally in roadway	3	2
Inattention	1	<1
Environmental Factor		
Fog, smoke, or smog	2	1
Rain, mist, or drizzle	3	2
Animal	1	<1
Vision obstruction: glare from sun or headlights	1	<1
Vehicle Factor		
Tires	2	1
Unattended or driverless (in motion)	1	<1

5.1.3 Summary

The most frequent characteristics of the fatal crashes between 1992 and 2004 are listed in Table 5.1.26.

The summary of frequency analysis results is presented as follows.

1. Among the responsible drivers, 75% were males. Drivers between 35-44 and older than 64 were responsible for the largest proportions of the fatal work zone crashes. Teenager drivers (15-19) were also likely to be involved in severe work zone crashes.
2. Fatal crashes in Kansas work zones in the past 13 years were likely to occur during daytime non-peak hours (10:00 a.m. – 4:00 p.m.). The study doesn't find significant crash frequency differences between different days of a week. In addition, 18% of the crashes were reported in slow-construction seasons including December, January, February, and March.
3. The analysis results do not support significant causal relationship between fatal work zone crashes and adverse weather conditions or road surface conditions. A significant percentage (32%) of the crashes occurred during nighttime when there were no street lights, which indicates adverse light condition was a potential contributing factor of fatal work zone crashes.
4. Among the crashes, 85% occurred in road sections without special features such as overhead bridge and ramp; and 67% occurred in non-intersection areas, which indicates that road special features such as intersection and overhead bridge do not significantly contribute to the crashes. The notable 49% of the crashes that occurred on adverse highway geometric alignments implied complex highway geometric alignments may contribute to fatal work zone crashes.

Table 5.1.26: Summary of the Most Frequent Observations

Category	Variable	Observation	No. of Crash	Percent (%)
Driver characteristics	Gender	Male	117	75
	Age	35-44	38	24
Time characteristics	Time*	10:00 a.m. – 4:00 p.m.	51	32
	Day	Saturday	26	17
	Month	June	22	14
Climatic environment factors	Light Condition	Daylight	83	53
	Weather Condition	No Adverse Weather	143	91
	Surface Condition	Dry	138	88
Crash information	Vehicle maneuver	Following road	116	79
	Crash type	Head-on	37	24
	Vehicle body type	Truck-vehicle	53	34
	No. of crash cars	2	83	53
Road conditions	Road Class	Other Principle Arterial	88	56
	Road character	Straight & level	80	51
	Lane Number	2	99	63
	Speed Limit	51 – 60	74	47
	Crash location	Non-intersection	105	67
	Surface Type	Black Top	109	69
	Road special feature	None	134	85
	Area information	Rural	132	84
	Traffic control	None or inoperative	73	46
Con. factors	Driver factor	Inattention	83	53

*: determined according to hourly rate. Con.: Contributing.

5. According to the frequency analyses, most fatal work zone crashes were multi-vehicle collisions in non-intersection areas. Among the multi-vehicle collisions, head-on, angle-side impact, and rear-end were the three most frequent collision types. In addition, truck-vehicle and vehicle-vehicle collisions were the two most common crash types. Before fatal work zone crashes occurred, most of the responsible drivers were driving straightly or following the roads.
6. Most crashes occurred on blacktop (asphalt) pavement highways and two-lane highways. The work zones on the interstate system and other major arterials whose speed limits were between 51 mph and 70 mph had the highest fatal crash frequencies. The analysis results also indicated that fatal work zone crashes were most likely to take place on rural two-lane highways with speed limits from 51 mph to 70 mph.

7. About half of the crashes happened when there were not traffic control devices or those on-site devices were inoperative. Human errors contributed to 92% of the total crashes. Among these human errors, inattention, speeding, and disregarded traffic sign/signal were the three factors causing most crashes.

5.2 Analysis of Interrelated Crash Factors

5.2.1 Introduction

The exploratory analysis of the fatal work zone crashes in Kansas has unmasked the most frequent factors associated with them. However, it is also of great interest to know how multiple factors affect work zone safety interactively and what the relationships between the important factors are. In this section, the meaningful combinations between multiple variables are identified using statistical test methods and their impacts on fatal work zone crashes are studied.

Pearson chi-square test and likelihood ratio chi-square test methods were used to identify all possible combinations between dependant variables. Pearson chi-square test method, originally proposed by Karl Pearson, is known as one of the most popular test methods for independence between two sets of variables. Suppose the results of a random experiment are classified by two attributes ***A*** and ***B*** having a and b values respectively. Let x_{ij} denote the frequency of a result of this random experiment with attribute A_i and attribute B_j, and let $x_i.$ and $x._j$ be $\sum_{j=1}^{b} x_{ij}$ and $\sum_{i=1}^{a} x_{ij}$ respectively. It has been proven that, if the total frequency n is large and the attributes ***A*** and ***B*** are mutually independent, then the random variable

$$Q = \sum_{j=1}^{b} \sum_{i=1}^{a} \frac{[x_{ij} - n(x_i./n)(x._j/n)]^2}{n(x_i./n)(x._j/n)} \tag{5.1}$$

has an approximate chi-square distribution with (a – 1)(b – 1) degrees of freedom (Hogg et al 2005).

The Pearson's chi-square is a more robust test of independence for small samples. On the other hand, the likelihood ratio statistic is more appropriate for use in hierarchical models (The University of Texas at Austin 1999). This test involves the ratios between the observed frequencies x_{ij} and expected frequencies e_{ij}: when the attributes $\boldsymbol{A}$ and $\boldsymbol{B}$ are mutually independent, the random variable

$$G^2 = 2\sum_i \sum_j n_{ij} \ln(\frac{n_{ij}}{e_{ij}}) \tag{5.2}$$

is known to follow an approximate chi-square distribution with (a – 1)(b – 1) degrees of freedom (SAS Institute Inc. 2004).

To test the independence between A and B, the null hypothesis H_0 and the alternative hypothesis H_1 are:

H_0: $P(A_i \cap B_j) = P(A_i)P(B_j)$, or A and B are independent;

H_1: $P(A_i \cap B_j) \neq P(A_i)P(B_j)$, or A and B are not independent.

Where $P(A_i \cap B_j)$is the probability of having A_i and B_j simultaneously, and $P(A_i)$ and $P(B_j)$ are the probabilities of having A_i and B_j, respectively.

It is determined by p-value of a test whether a null hypothesis should be accepted or not. P-value is known as the observed "tail" probability of a statistic being at least as extreme as the particular observed value when H_0 is true. For a particular level of significance such as 5%, when p-value is larger than or equal to 0.05, the null hypothesis H_0 will be accepted and otherwise H_1 should be accepted.

Regardless of the different advantages of the two chi-square test methods, they are both adopted to test for the relationships among the factors of the crashes. This assures the maximized probability of identifying all interrelated factors. A dependant relationship is determined if one or both tests support it. Listed in the following table (Table 5.2.1) are the crash factors that affect each others.

5.2.2 Analysis of Interrelated Crash Factors

5.2.2.1 Driver Characteristics

5.2.2.1A Gender

Test results showed that gender was related to human errors: drivers of different genders tended to make different errors. Table 5.2.2 and Figure 5.2.1 show the crash frequencies with respect to genders and driver errors. They illustrate that the crashes caused by male drivers were much more frequent than female drivers for inattentive driving and misjudgment/disregarded traffic controls. In addition, male drivers caused more crashes due to speeding. It was also noted that males and females caused the same amounts of crashes under drug/alcohol influence.

Table 5.2.1: Independence Test Results at 5% Level of Significance

Interrelated Factor Pairs		Pearson Chi-Square		Likelihood Ratio Chi-Square	
		p-Value	Related?	p-Value	Related?
Gender	Driver error	0.060	No	0.047	Yes
Age	Time	0.061	No	0.034	Yes
	Light condition	0.023	Yes	0.015	Yes
	Driver error	0.005	Yes	0.000	Yes
Light condition	Number of vehicles	0.000	Yes	0.000	Yes
	Number of lanes	0.033	Yes	0.037	Yes
	Speed limit	0.008	Yes	0.002	Yes
	Area information	0.004	Yes	0.011	Yes
	Driver error	0.012	Yes	0.005	Yes
Vehicle type	Light condition	0.002	Yes	0.002	Yes
	Number of vehicles	0.000	Yes	0.000	Yes
	Number of lanes	0.046	Yes	0.044	Yes
	Area information	0.030	Yes	0.024	Yes
	Driver error	0.006	Yes	0.001	Yes
Number of vehicles	Time	0.006	Yes	0.006	Yes
	Number of lanes	0.011	Yes	0.011	Yes
	Driver error	0.000	Yes	0.000	Yes
Speed limit	Time	0.006	Yes	0.008	Yes

Table 5.2.2: Percentage Crash Frequencies by Gender and Driver Error

Driver error/Gender	Male	Female	**Total**
None	4	4	8
Drug/alcohol impairment	4	4	8
Speeding	4	<1	5
Misjudgment/ disregarded traffic controls	27	8	35
Inattentive driving	25	8	33
Ill/medical condition	4	0	4
Other/unknown	6	<1	7
Total	74	26	100

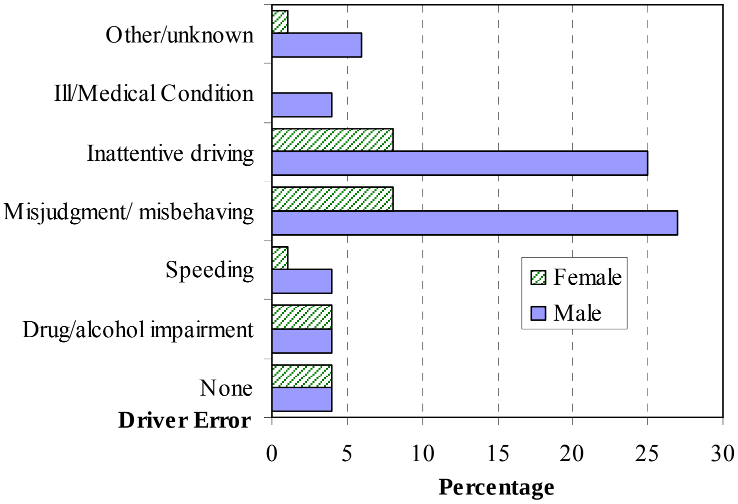


Figure 5.2.1: Crash Frequencies by Gender and Driver Error

5.2.2.1B Age

Drivers at different ages acted differently in different time periods and light conditions; they also made different human errors. Table 5.2.3 and Figure 5.2.2 show the fatal crash distributions over different age groups and time periods. A significant percentage of the crashes during nighttime (8:00 p.m.-6:00 a.m.) was caused by drivers younger than 55-year old. Drivers who were older than 65 caused more crashes than other age groups in the time periods between 10:00 a.m.-4:00 p.m. and 4:00 p.m.-8:00 p.m. Drivers between 35-44 also caused a significant percentage of fatal work zone crashes during 10:00 a.m.-4:00 p.m.

As shown in Table 5.2.4 and Figure 5.2.3, under different light conditions, drivers of various ages responded significantly differently. Crash frequency analysis with respect to different ages and light conditions showed that, although the highest percentages of the total crashes occurred when light conditions were good, a considerable number of crashes occurred under adverse light conditions such as in darkness without streetlights. Drivers between 35 – 54 caused the highest percentages of the crashes in adverse light conditions, although they were considered as the most experienced driver group. Moreover, most of the crashes caused by elderly drivers (≥65) occurred during daytime when light conditions were good.

Table 5.2.3: Crash Frequencies by Age and Time

Time/Age	15 – 19	20 – 24	25 – 34	35 – 44	45 – 54	55 – 64	≥ 65	**Total**
6:00 a.m. – 10:00 a.m.	3	<1	3	3	2	<1	2	14
10:00 a.m. – 4:00 p.m.	4	3	3	8	4	1	9	32
4:00 p.m. – 8:00 p.m.	1	1	2	4	<1	2	6	17
8:00 p.m. – 6:00 a.m.	5	6	8	10	7	<1	<1	37
Total	12	11	15	24	15	4	18	100

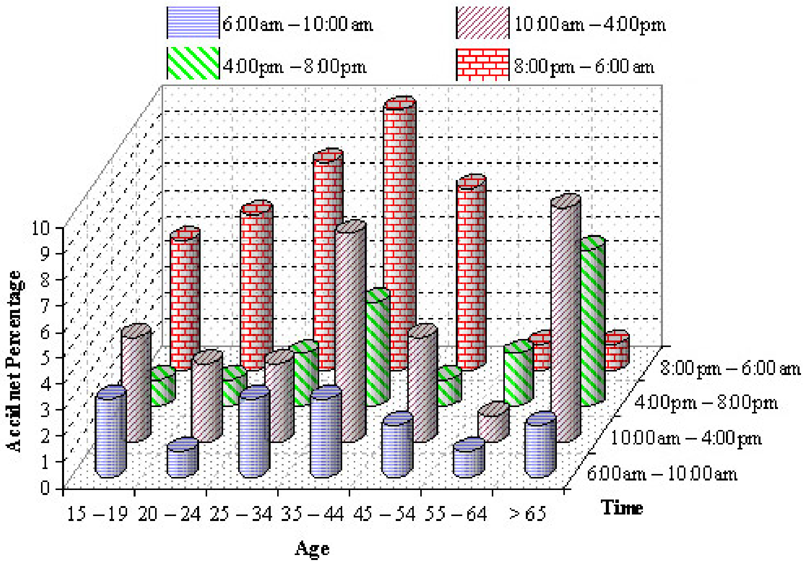


Figure 5.2.2: Crash Frequencies by Age and Time

Table 5.2.4: Crash Frequencies by Age and Light Condition

Light condition/Age	15 – 19	20 – 24	25 – 34	35 – 44	45 – 54	55 – 64	≥ 65	**Total**
Good	4	4	8	14	4	3	15	53
Fair	3	3	2	1	4	0	1	14
Bad	4	3	6	9	6	<1	3	33
Total	12	11	15	24	15	4	18	100

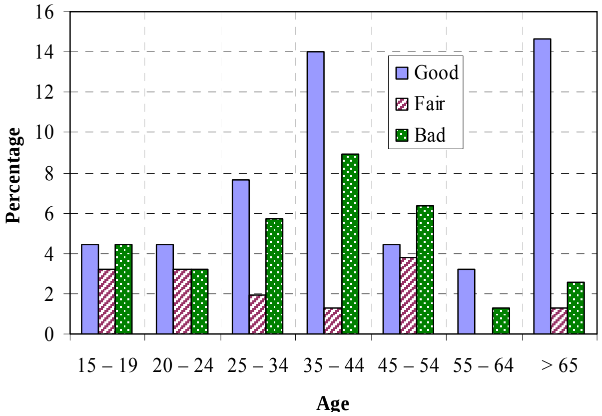


Figure 5.2.3: Crash Frequencies by Age and Light Condition

Statistical tests also showed a strong relationship between age and driver error. As shown in Table 5.2.5 and Figure 5.2.4, the responsible drivers between 35-54 had the error of inattentive driving more frequently than the drivers in other age groups. In addition, drivers between 25-44 or older than 64 caused crashes due to misjudgment/disregarded traffic controls. Drivers aging from 35 to 44 had the highest percentage of crashes caused by drug/alcohol impairment.

Table 5.2.5: Crash Frequencies by Age and Driver Error

Driver error/Age	15 – 19	20 – 24	25 – 34	35 – 44	45 – 54	55 – 64	≥ 65	**Total**
None	0	<1	<1	<1	3	0	3	8
Drug/alcohol impairment	<1	0	3	4	1	0	0	9
Speeding	<1	<1	0	2	2	0	0	6
Misjudgment/ disregarded traffic controls	5	3	9	8	1	3	7	35
Inattentive driving	4	5	2	8	7	2	4	32
Ill/medical condition	0	<1	0	1	0	0	3	4
Other/unknown	<1	<1	<1	0	<1	0	3	6
Total	10	10	16	24	15	5	20	100

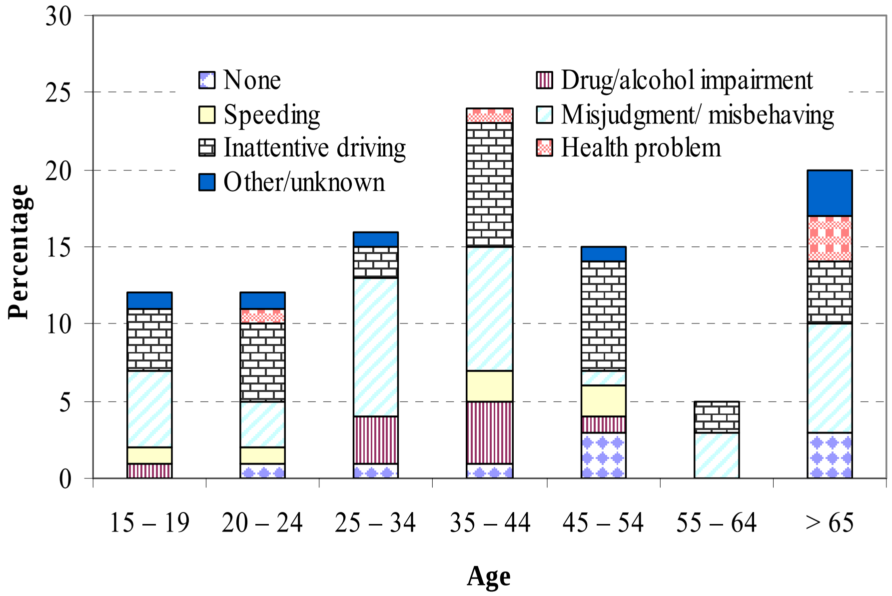


Figure 5.2.4: Crash Frequencies by Age and Driver Error

5.2.2.1C Light Condition

The light conditions in which a fatal work zone crash occurs was related to the number of vehicles involved in the crash. Table 5.2.6 and Figure 5.2.5 present the crash frequencies categorized by number of vehicles and light conditions. To better analyze the impacts of light conditions, they were classified into three groups: good conditions (daylight with good visibility), fair conditions (daylight with adverse visibility, dawn, dusk, and nighttime with streetlights), and poor conditions (nighttime without streetlights). The striking percentage (36%) of the crashes involved two vehicles during good light conditions. This result suggested that good light condition alone was not enough to avoid fatal crashes in the work zones. In addition, a significant proportion (17% of total) of single-vehicle fatal work zone crashes occurred in nighttime, which indicated that adverse light condition had notable impact on work zone drivers.

When analyzing the crashes with light conditions and number of lanes, as shown in Table 5.2.7 and Figure 5.2.6, it was found that a significant amount of crashes (63%) occurred on two-lane highways. 36 percent of the total crashes occurred in two-lane highways with good light conditions. In addition, 21% of the total crashes were reported in adverse light conditions.

Table 5.2.6: Crash Frequencies by Light Condition and Number of Vehicles

No. of vehicles/ Light condition	1	2	≥3	**Total**
Good	7	36	10	53
Fair	8	6	<1	15
Poor	17	11	4	32
Total	32	53	15	100

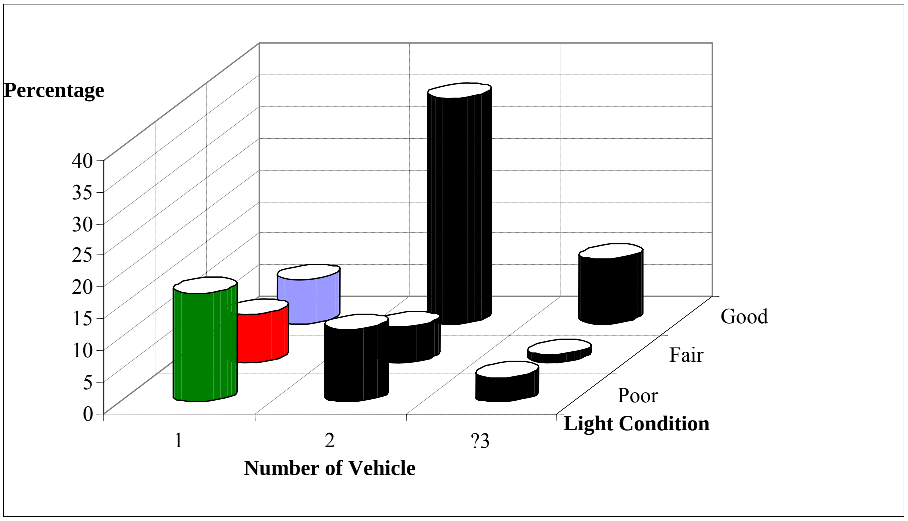


Figure 5.2.5: Crash Frequencies by Number of Vehicles and Light Condition

Table 5.2.7: Crash Frequencies by Light Condition and Number of Lanes

No. of lanes/ Light condition	Two-lane	Multi-lane	**Total**
Good	36	17	53
Fair	6	9	15
Poor	21	11	32
Total	63	37	100

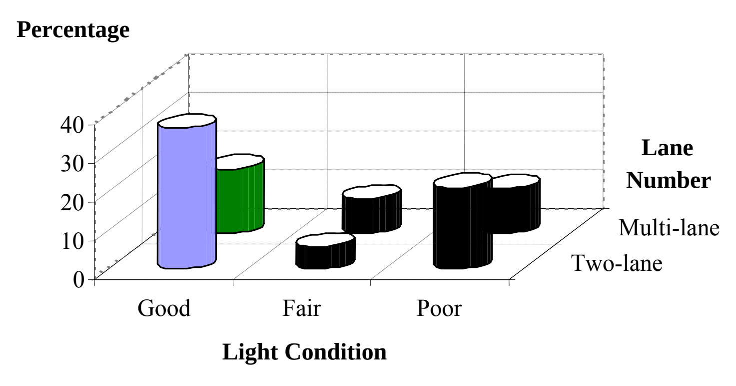


Figure 5.2.6: Crash Frequencies by Light Condition and Number of Lanes

As shown in Table 5.2.8, almost half of the crashes (47%) happened in rural areas when light conditions were good and 28% occurred in rural areas when light conditions were poor. Figure 5.2.7 displays that percentages of fatal work zone crashes in rural areas were larger than the percentages in urban areas for all light conditions.

The light conditions were associated with types of driver errors as well. As shown in Table 5.2.9 and Figure 5.2.8, inattentive driving and misjudgment/disregarded traffic controls were responsible for a majority of fatal work zone crashes in all light conditions. Drug/alcohol impairment, the driver error seldom reported when light conditions were good, caused more fatal crashes in unfavorable light conditions.

Table 5.2.8: Crash Frequencies by Area and Light Condition

Area/ Light condition	Urban	Rural	Total
Good	6	47	53
Fair	6	9	15
Poor	4	28	32
Total	16	84	100

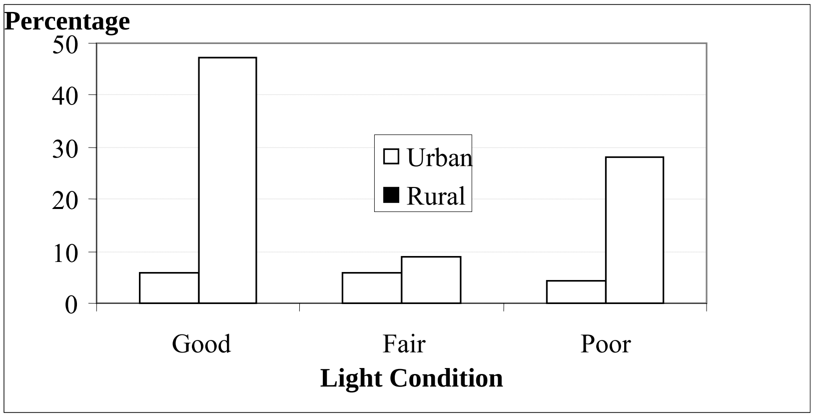


Figure 5.2.7: Crash Frequencies by Area and Light Condition

Table 5.2.9: Crash Frequencies by Light Condition and Driver Error

Light Condition/ Driver error	Good	Fair	Bad	**Total**
None	<1	3	4	8
Drug/alcohol impairment	1	3	5	9
Speeding	3	1	2	6
Misjudgment/ misbehaving	24	3	8	35
Inattentive driving	18	4	10	32
Ill/medical condition	3	1	0	4
Other/unknown	2	<1	3	6
Total	53	15	32	100

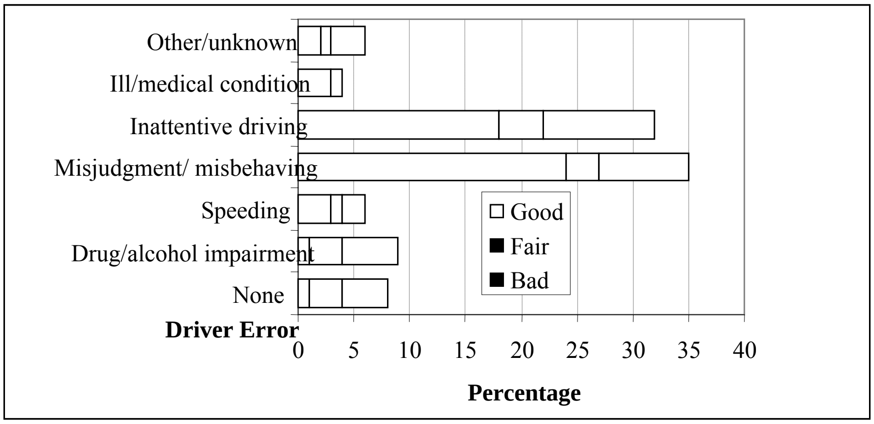


Figure 5.2.8: Crash Frequencies by Light Condition and Driver Error

5.2.2.1D Vehicle Type

The involvement of heavy trucks in a crash could dramatically increase its severity. Statistical tests showed that truck involvement could be related to light condition, number of crash vehicles, number of lanes at the crash location, area type, and driver error. Table 5.2.10 and Figure 5.2.9 show the crash frequencies sorted by light conditions and truck involvement. Truck-involved fatal crashes usually occurred when the light conditions were good. The percentage of truck-involved crashes (27%) under good light conditions was slightly higher than for non-truck-involved crashes (25%). Non-truck-involved crashes were the prevalent crash type when the light conditions were unfavorable. Furthermore, the non-truck-involved crashes in both good light conditions and darkness were roughly equal in proportion (25% vs. 23%).

Truck-involved crashes frequently caused collisions of multiple vehicles. As shown in Table 5.2.11 and Figure 5.2.10, truck-involved crashes were much more prominent (11% vs. 4% of total) for crashes of three or more vehicles. This phenomenon strongly suggests that when heavy trucks were involved, the crashes tended to be more severe.

<u>Table 5.2.10: Crash Frequencies by Light Condition and Vehicle Type</u>

Vehicle type/ Light condition	Good	Fair	Poor	**Total**
Truck-involved	27	3	10	40
Non-truck-involved	25	12	23	60
Total	52	15	33	100

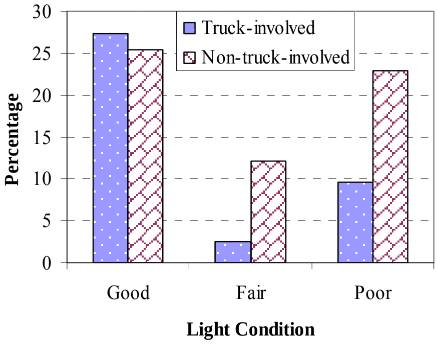


Figure 5.2.9: Crash Frequencies by Light Condition and Vehicle Type

Table 5.2.11: Crash Frequencies by Vehicle Type and Number of Vehicles

Vehicle type/ No. of vehicles	1	2	≥3	**Total**
Truck-involved	3	25	11	39
Non-truck-involved	29	27	4	61
Total	32	52	15	100

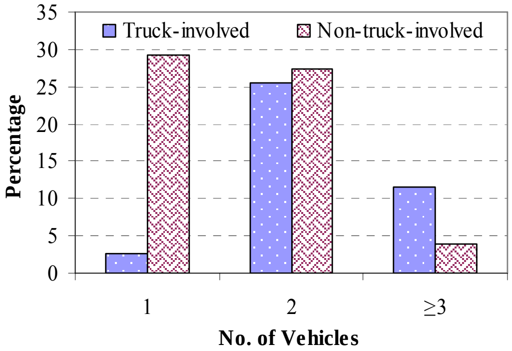


Figure 5.2.10: Crash Frequencies by Vehicle Type and Number of Vehicles

Most heavy-truck-involved work zone collisions (29% of all crashes) occurred on two-lane highways compared to only 11% on multi-lane highways, shown in Table 5.2.12 and Figure 5.2.11. Non-truck-involved crashes on two-lane highways constituted 34% of the total, a comparable proportion (26% of all crashes) occurred on multi-lane highways. In regard to different areas, as shown in Table 5.2.13 and Figure 5.2.12, both truck- and non-truck- involved crashes were most likely to happen in the work zones on rural highways.

Table 5.2.12: Crash Frequencies by Number of Lanes and Vehicle Type

Vehicle type/No. of lanes	Two-lane	Multi-lane	**Total**
Truck-involved	29	11	40
Non-truck-involved	34	26	60
Total	63	37	100

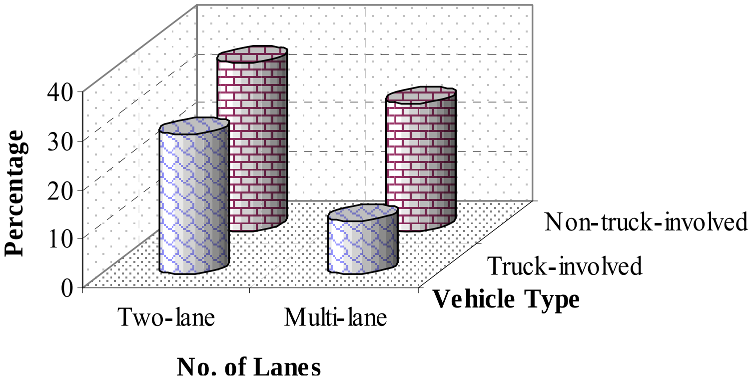


Figure 5.2.11: Crash Frequencies by Number of Lanes and Vehicle Type

Table 5.2.13: Crash Frequencies by Area and Vehicle Type

Vehicle type/Area	Urban	Rural	**Total**
Truck-involved	3	36	39
Non-truck-involved	13	48	61
Total	16	84	100

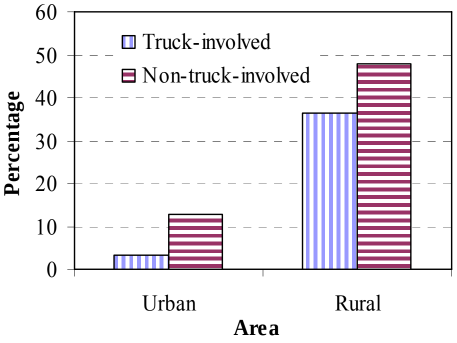


Figure 5.2.12: Crash Frequencies by Area and Vehicle Type

When studying the relationship between driver errors and vehicle types, it was found that inattentive driving and misjudgment/disregarded traffic controls were the two most frequent driver errors for both truck- and non-truck- involved fatal work zone crashes (see Table 5.2.14 and Figure 5.2.13). Speeding and drug/alcohol impairment were not significant contributing factors of truck-involved crashes.

Table 5.2.14: Percent Crash Frequencies by Driver Error and Vehicle Type

Driver error/Vehicle type	Truck-involved	Non-truck-involved	**Total**
None	2	6	8
Drug/alcohol impairment	1	8	9
Speeding	2	4	6
Misjudgment/ misbehaving	17	18	35
Inattentive driving	16	17	32
Ill/Medical Condition	2	2	4
Other/unknown	0	6	6
Total	39	61	100

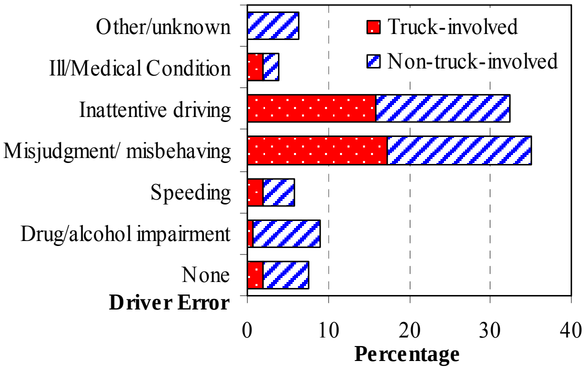


Figure 5.2.13: Truck- vs. Non-Truck- Involved Crashes by Driver Error

5.2.2.1E Number of vehicles

The number of vehicles involved in a fatal work zone crash was related to the time when this crash occurred. As shown in Table 5.2.15 and Figure 5.2.14, multi-vehicle crashes were the dominant type of all daytime crashes, while the numbers of single- and multi-vehicle crashes were roughly equal during nighttime (both were approximately 18%). In addition, a significant proportion of multi-vehicle crashes (26% of total) occurred in daytime non-peak hours (10:00 a.m. – 4:00 p.m.), which indicated that high volume of traffic was not an important factor for the fatal work zone crashes.

Analysis results also showed that most of the multi-vehicle fatal work zone crashes happened on two-lane highways instead of multi-lane highways, as shown in Table 5.2.16 and

Figure 5.2.15. About half of the crashes were multi-vehicle collisions that occurred on two-lane highways where drivers didn't have other lanes to switch when crashes happened.

Research findings showed that different driver errors caused crashes involving varying numbers of vehicles. The frequency analysis results were sorted by driver errors and number of vehicles in Table 5.2.17 and Figure 5.2.16. Most of the multi-vehicle crashes were associated with inattentive driving and misjudgment/disregarded traffic controls. The proportional differences among the single-vehicle crashes for various driver errors were much less than for multi-vehicle crashes.

Table 5.2.15: Crash Frequencies by Time and Number of Vehicles

Time/No. of vehicles	1	2	≥3	**Total**
6:00 a.m. – 10:00 a.m.	3	8	3	14
10:00 a.m. – 4:00 p.m.	6	18	8	32
4:00 p.m. – 8:00 p.m.	4	11	1	17
8:00 p.m. – 6:00 a.m.	18	15	3	37
Total	32	53	15	100

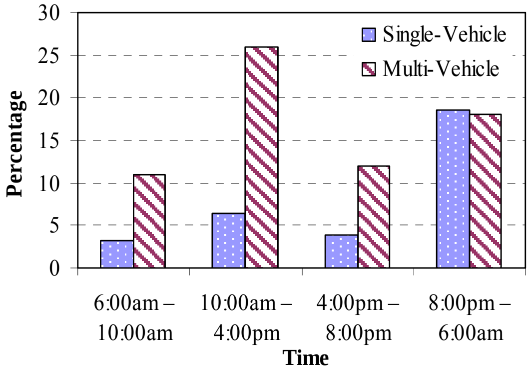


Figure 5.2.14: Crash Frequencies by Time and Number of Vehicles

Table 5.2.16: Crash Frequencies by Number of Lanes and Number of Vehicles

No. of vehicles/ No. of lanes	Two-lane	Multi-lane	**Total**
1	15	17	32
2	39	14	53
≥3	9	6	15
Total	63	37	100

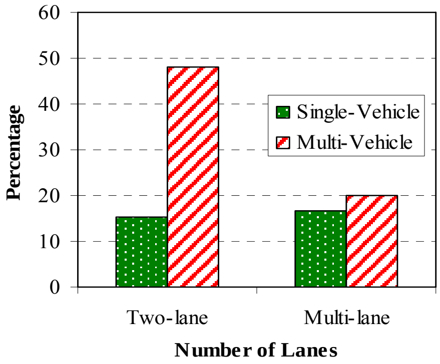


Figure 5.2.15: Crash Frequencies by Number of Lanes and Number of Vehicles

Table 5.2.17: Crash Frequencies by Driver Error and Number of Vehicles

Driver error/No. of vehicles	1	2	≥3	**Total**
None	4	2	1	8
Drug/alcohol impairment	4	4	0	9
Speeding	3	3	<1	6
Misjudgment/ misbehaving	3	25	7	35
Inattentive driving	10	17	6	32
Ill/Medical Condition	1	2	1	4
Other/unknown	6	<1	0	6
Total	31	53	16	100

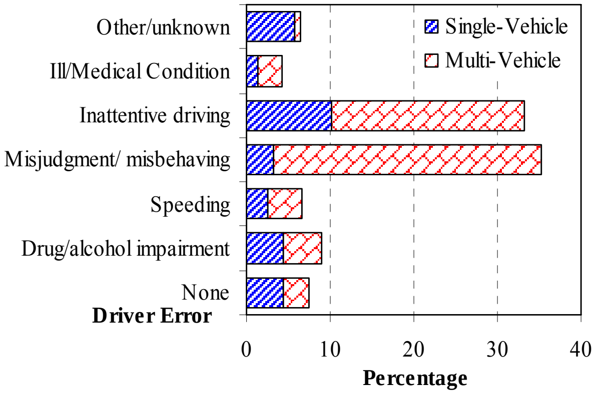


Figure 5.2.16: Crash Frequencies by Driver Error and Number of Vehicles

5.2.2.1F Speed Limit

When categorizing the crashes by time and speed limit, it was observed that a significant percentage of the crashes (24%) occurred during nighttime (8:00 p.m. – 6:00 a.m.) with speed between 51 mph and 60 mph. In contrast, another significant proportion (20%) was reported during daytime non-peak hours (10:00 a.m. – 4:00 p.m.) on highways with speed limits between 61 mph – 70 mph. As shown in Table 5.2.18 and Figure 5.2.17, 92% of the fatal crashes occurred within the speed limits of 51 – 71 mph. This result confirmed that high speed collision caused fatalities in the work zones.

Table 5.2.18: Crash Frequencies by Speed Limit and Time

Time/Speed limit	≤ 40	41 – 50	51 – 60	61 – 70	**Total**
6:00 a.m. – 10:00 a.m.	<1	2	5	6	14
10:00 a.m. – 4:00 p.m.	<1	1	11	20	32
4:00 p.m. – 8:00 p.m.	<1	0	7	9	17
8:00 p.m. – 6:00 a.m.	2	1	24	10	37
Total	4	4	47	45	100

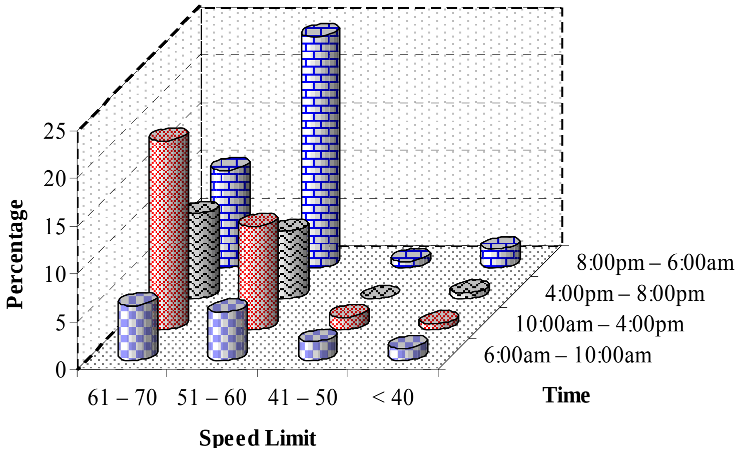


Figure 5.2.17: Crash Frequencies by Speed Limit and Time

5.2.3 Summary

Through chi-square tests, the factors that could cause fatal work zone crashes interactively were identified. The findings are summarized as follows.

1. Inattentive driving and misjudgment/disregarded traffic controls were the two most frequent human errors for all age groups and under all light conditions. Males caused much more fatal work zone crashes than females because of inattentive driving, misjudgment/disregarded traffic controls, and speeding. Males and females caused the same amount of crashes due to drug/alcohol impairment.

Drug/alcohol impairment was observed as a causal factor primarily for drivers aging between 25 – 44.

2. Most nighttime crashes were caused by drivers younger than 55. Drivers between 35 – 44 and older than 65 caused most daytime (6:00 a.m. – 8:00 p.m.) crashes. Most of the crashes caused by senior drivers ($\geq$65) occurred in good light conditions, while drivers between 35 – 54 caused much more crashes in adverse light conditions.
3. Of the studied crashes, 46% were multi-vehicle collisions occurring under good light conditions and 25% were single-vehicle crashes in unfavorable light conditions. In almost all light conditions, work zones on two-lane highways in rural areas had the highest fatal crash frequencies. Drug/alcohol impairment problem was much more serious during the time when light conditions were poor.
4. Truck-caused fatal work zone crashes occurred more frequently during daytime when light conditions were good, while non-truck-involved crashes dominated all other time periods when light conditions were unfavorable. An overwhelming proportion of truck-caused crashes involved multiple vehicles. Non-truck-involved fatal work zone crashes were relatively evenly distributed between two-lane highways and multi-lane highways. Most of the truck-involved crashes (29% of the total) occurred in the work zones on two-lane roads. Inattentive driving and misjudgment/disregarded traffic controls caused most of both non-truck- and truck-involved crashes; speeding and drug/alcohol impairment were frequently found to cause non-truck-involved crashes.
5. Single-vehicle crashes were most likely to occur during nighttime. Most of the multi-vehicle crashes occurred on two-lane highways. In addition, single-vehicle crashes were caused by all types of human errors, while multi-vehicle crashes were primarily caused by inattentive driving and misjudgment/ disregarded traffic controls.
6. Nighttime crashes occurred mostly on highways with speed limits between 51 mph and 60 mph, while daytime non-peak-hour crashes occurred mostly on highways with speed limits between 61 mph and 70 mph. Overall 92% of crashes occurred in the speed limits between 51 and 70 mph.

5.3 Binary Logistic Regression Analysis

5.3.1 Introduction

The development of safe and cost-effective work zone traffic control plans is always the key step towards the ultimate goal of securing work zones. Prioritizing the available work zone traffic control methods in different circumstances would be critical for such a development. In this section, the effectiveness of several commonly used work zone traffic control devices is quantified using binary logistic regression technique. The results of the analyses can be used as references in work zone traffic control plans.

Binary logistic regression analysis is a statistical technique developed specifically for describing the relationships between a set of independent explanatory variables and a dichotomous response variable or outcome. Because traffic crash analyses involve establishing the relationships between the occurrence of a crash and the presences of various contributing factors, this regression technique arises as a suitable method. Its applications in traffic crash analysis can be found in the studies of Hill (2003) and Dissanayake and Lu (2002). Since binary logistic regression model is a direct probability model which has no requirements on the distributions of the explanatory variables or predictors (Harrell 2001), it's more flexible and more likely to yield accurate results in traffic crash analyses where the safety impacts of contributing factors need to be quantified.

Herein briefly described is the basic theory of the logistic regression method. If Y denotes an event (Y = 1 and Y = 0 denote occurrence and nonoccurrence, respectively) and let a vector $\boldsymbol{X}$ be a set of predictors $\{X_1, X_2, \ldots, X_k\}$, then the expected value of Y given $\boldsymbol{X}$ is the probability (P) of the occurrence of Y given $\boldsymbol{X}$, which can be expressed in linear regression form as:

$$E\{Y|\boldsymbol{X}\} = P\{Y = 1|\boldsymbol{X}\} = \boldsymbol{X\beta}, \qquad (5.3)$$

where $\boldsymbol{\beta}$ is the regression parameter vector and $\boldsymbol{X\beta}$ stands for $\beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k$. Because the probability determined in Equation (5.3) can exceed 1, the following binary logistic regression model is generally preferred for the analysis of binary responses:

$$P\{Y = 1|\boldsymbol{X}\} = [1 + exp(-\boldsymbol{X\beta})]^{-1} = exp(\boldsymbol{X\beta})/[1 + exp(\boldsymbol{X\beta})]^{-1} \quad (5.4)$$

The above equation can be expressed in the following logistic form:

$$logit\{Y = 1|\boldsymbol{X}\} = log[P/(1 - P)]$$

$$= \beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k \quad (5.5)$$

For the above model, maximum likelihood method can be used to estimate the parameter combination that maximizes the likelihood of the observed outcomes. Given the estimated β's as $\hat{\beta}_0, \hat{\beta}_1, \cdots, \hat{\beta}_k$, the estimated probability $\hat{P}$ which an event Y happens, can be computed based on Equation (5.4) as:

$$\hat{P}\{Y = 1|\boldsymbol{X}\} = exp(\boldsymbol{X}\hat{\boldsymbol{\beta}})/[1 + exp(\boldsymbol{X}\hat{\boldsymbol{\beta}})]^{-1} \quad (5.6)$$

where $\boldsymbol{X}\hat{\boldsymbol{\beta}}$ stands for $\hat{\beta}_0 + \hat{\beta}_1 X_1 + \cdots + \hat{\beta}_k X_k$.

The significance of a predictor can be tested using Likelihood Ratio (LR) Test Method. This test method compares the deviation of the model with the predictor and that without the predictor. Two other statistically equivalent tests for significance of a predictor are the Wald Test and the Score Test (Hosmer and Lemeshow, 2000). The Wald Test is obtained by comparing the maximum likelihood estimate of the slope parameter, β_1, to an estimate of its standard error. The Score Test is based on the distribution theory of the derivatives of the log likelihood. Studies have shown that Wald Test could fail to reject the null hypothesis (the coefficient is not significant) when the coefficient is actually significant, while the Score Test is a multivariate test requiring matrix calculations which are not available in some statistical software (Hosmer and

Lemeshow, 2000). SAS has been embedded with the logistic regression function and these three test-of-significance methods.

Quantifying the safety impact of an explanatory variable can be treated as a special logistic regression case, where the model (5.5) is written as:

$$logit\{Y = 1|X = 0\} = \beta_0 \quad (5.7.1)$$

$$logit\{Y = 1|X = 1\} = \beta_0 + \beta_1 \quad (5.7.2)$$

Accordingly, the estimated probability that an event (crash) happens ($Y = 1$) when the test factor is present ($X = 1$) is:

$$\hat{P}\{Y = 1|X = 1\} = exp\{\hat{\beta}_0 + \hat{\beta}_1\}/(1 + exp\{\hat{\beta}_0 + \hat{\beta}_1\}) \quad (5.8.1)$$

and the estimated probability that this event happens ($Y = 1$) when the test factor is absent ($X = 0$) is:

$$\hat{P}\{Y = 1|X = 0\} = exp\{\hat{\beta}_0\}/(1 + exp\{\hat{\beta}_0\}) \quad (5.8.2)$$

5.3.2 Quantifying Work Zone Traffic Control Effectiveness

The effectiveness of two widely used work zone traffic control approaches, flagger and stop sign/signal, on some factors of fatal crashes, was quantified using logistic regression technique. Variables included in the analysis were genders of responsible drivers, truck involvement, number of crash vehicles, crash class, and driver errors. At least two of the three different test methods (Likelihood Ratio Test, Wald Test, and Score Test) indicated that these variables could be affected significantly (i.e. at 0.1 level of significance) by the usage of the two traffic control approaches.

5.3.2.1 ***Effects of Flagger Usage***

In estimating the effectiveness of flaggers, the response variable is the occurrence of a fatal crash caused by a male driver ($Y = 0$) and the explanatory variable X is the presence of a flagger (1 for presence and 0 for no presence). The logistic model was estimated as following:

$$logit\{Y = 0|X\} = 1.86 - 0.91X \tag{5.9}$$

According to this model, the conditional probability of a male driver causing a fatal crash with flagger control presence is computed as follows:

$$\hat{P}\{Y = 0|X = 1\} = exp\{\hat{\beta}_0 + \hat{\beta}_1\}/(1+ exp\{\hat{\beta}_0 + \hat{\beta}_1\}) = 0.72, \tag{5.10.1}$$

and the conditional probability without flagger control presence can be calculated as follows:

$$\hat{P}\{Y = 0|X = 0\} = exp\{\hat{\beta}_0\}/(1+ exp\{\hat{\beta}_0\}) = 0.8. \tag{5.10.2}$$

The two modeled probabilities indicate that the presence of flagger control in work zones could reduce the probability of male drivers causing fatal crashes by 15% (or 0.87 to 0.72) given the occurrences of the crashes.

Because crashes involving heavy trucks tended to cause higher fatality rate per crash, reducing such kind of crashes is important. Tests showed that the presence of flaggers in work zones affected the probability of involving trucks in fatal crashes given the occurrences of these crashes. By denoting $Y = 1$ as a fatal work zone crash event that involved heavy trucks and X as the presence of flaggers (1 as presence and 0 as not presence), the logistic regression model between flagger control and truck involvement was constructed as:

$$Logit\{Y = 1|X\} = 0.44 - 1.1X. \tag{5.11}$$

Based on this equation, the conditional probability of heavy trucks being involved in a fatal crash with the presence of a flagger was 0.34, while the probability without a flagger was

0.61. Therefore, having flaggers directing traffic in work zones could reduce the conditional probability of involving heavy trucks in fatal crashes by 27%.

5.3.2.2 Effects of Stop Sign/Signal

Tests showed that in the condition of fatal crashes, the use of stop signs or signals in work zones had effects on such variables as number of crash vehicles, crash class, and causing by misjudgment/disregarding traffic control.

In the case of modeling the effect of stop signs/ signals on the number of vehicles involved in a fatal crash, the response variable Y was assigned with binary values 0 and 1 to denote single-vehicle crashes and multi-vehicle crashes, respectively. Using the SAS software, the following logistic regression model was generated at the 0.05 significance level:

$$logit\{Y = 1|X\} = 1.33 - 0.68X. \tag{5.12}$$

Consequently, the conditional probability of the fatal crash involving multiple vehicles when there were stop signs or signals on site ($X = 1$) was 0.66. In contrast, the same probability without stop signs or signals ($X = 0$) would be 0.79. This implies that the use of stop signs or signals was effective in reducing multi-vehicle fatal crashes and lowered the conditional probability of a fatal crash involving multiple vehicles by 13%.

The above model was estimated in terms of the number of crash vehicles. Another common interest in studying crashes is to find out how to reduce the vehicle-vehicle collisions as they cause more monetary and life loss. In terms of crash type, the vehicle-vehicle collisions quoted here refer to the collision types such as head-on, rear-end, angle-side impact, sideswipes, and backed-into. The logistic regression model for the effectiveness of stop signs or signals in preventing vehicle-vehicle fatal crashes given their occurrences was developed as:

$$logit\{Y = 1|X\} = 1.23 - 0.79X. \tag{5.13}$$

In this model, the response variable $Y = 1$, is the occurrence of a vehicle-vehicle crash (in contrast with Y = 0 for vehicle-other collisions or single vehicle crashes) and the explanatory variable, X, is the presence of stop signs or signals (1 as presence and 0 as not presence). According to this model, the conditional probability of a fatal crash being a vehicle-vehicle crash given its occurrence with work zone stop signs or signals was 0.61 and the probability without stop signs or signals was 0.77. In another words, when a fatal work zone crash occurs, the presence of stop signs or signals reduced the probability of having a vehicle-vehicle collision by 16%.

Tests demonstrated that the relationship between the presence of stop signs or signals and the involvement of the misjudgment/disregarding traffic control driver error in a fatal crash was statistically significant. Let $Y = 1$ be a fatal crash involving driver error of misjudgment/disregarding traffic control and X be the presence of stop signs or signals in work zones (1 as presence and 0 as not presence). The logistic regression model can be expressed as:

$$logit\{Y = 1|X\} = 0.03 - 0.84X. \qquad (5.14)$$

The conditional probability of a fatal crash caused by driver misjudgment/ disregarding traffic control when it occurred in a work zone with stop signs or signals was 0.31; the probability without stop signs or signals was 0.51. This indicated that using stop signs or signals in work zones could reduce 20% of the conditional probability of a fatal crash caused by misjudgment/disregarding traffic control.

5.3.3 Factors Affecting Heavy Truck Involvement

5.3.3.1 Quantifying the Impacts of Individual Variables

Logistic regression models were constructed to estimate the conditional probability of involving heavy trucks in fatal work zone crashes. Variables analyzed included light conditions, number of traffic lanes, area information, and contribution of driver errors such as drug/alcohol impairment, inattentive driving, and misjudgment/ disregarding traffic control.

The following logistic regression model was developed to quantify the effect of light conditions on the probability of involving heavy trucks given the occurrences of fatal work zone crashes:

$$logit\{Y = 1|X\} = -0.50 + 0.57X, \tag{5.15}$$

where $Y = 1$ denotes the involvement of heavy trucks in a fatal crash; X is the explanatory variable light condition. Based on this fitted model, the conditional probability of involving heavy trucks in a fatal crashes under good light condition ($X = 0$) was 0.38. The probability under unfavorable light conditions ($X = 1$) was estimated as 0.52. The comparison of these two probabilities implies that poor light conditions could increase the conditional probability of involving heavy trucks in fatal work zone crashes by 14%.

The effect of the number of traffic lanes on the involvement of trucks in fatal work zone crashes can be estimated according to the following logistic regression model:

$$logit\{Y = 1|X\} = -0.53 - 0.35X. \tag{5.16}$$

In this regression equation, $Y = 1$ was defined as the involvement of heavy trucks. The explanatory variable, X, represented the number of traffic lanes ($X = 0$ as multiple lane and $X = 1$ as two lane) in the crash highway section. For the fatal work zone crashes on two-lane highways, the conditional probability of involving heavy trucks was 0.29 and the probability on multi-lane highways was 0.37. The results show that on multi-lane highways, trucks were 8% more likely to be involved in a fatal work zone crash given this crash occurred.

Because of the different configurations between urban highways and rural highways, trucks traveling in different areas (urban vs. rural) had different probabilities of involving in a fatal work zone crash, given its occurrence. According to the logistic regression analysis, trucks on rural highways were 10% less likely to be involved in fatal work zone crashes than trucks on urban highways, given the occurrences of the crashes. The following is the fitted logistic regression model where the response variable, $Y = 1$, is truck involvement and the explanatory variable, X, is the area information (0 as urban and 1 as rural).

$$logit\{Y = 1|X\} = -0.83 - 0.56X. \qquad (5.17)$$

This model suggests that the conditional probability of involving heavy trucks in a fatal work zone crash was 0.30 in urban areas and 0.20 in rural areas.

Driver errors such as drug/alcohol impairment, inattentive driving, and misjudgment/ disregarding traffic control, had an impact on the probability of truck involvement in a fatal crash. The logistic regression models along with the estimated conditional probabilities and quantified impacts for these three driver errors are listed in the following table (Table 5.3.1). As in the previous models, the involvement of a heavy truck is denoted by $Y = 1$ and a certain driver error was X ($X = 0$ as no presence and $X = 1$ as presence).

As exhibited in Table 5.3.1, the modeling results showed that the drug/alcohol influence could increase the probability of involving heavy trucks in work zone fatal crashes given their occurrences by 24%. The other two driver errors, inattentive driving and misjudgment/disregarding traffic control, could both increase the probability by 7%.

Table 5.3.1: Logistic Regression Models for Three Driver Errors

Driver Error	Logistic Regression Model	PW	PWO	PW - PWO
DE1	$logit\{Y = 1\|X\} = - 1.43 + 1.13X.$	0.43	0.19	24%
DE2	$logit\{Y = 1\|X\} = - 0.33 - 0.29X.$	0.35	0.42	7%
DE3	$logit\{Y = 1\|X\} = - 0.34 - 0.31X.$	0.34	0.41	7%
Note	DE1: drug/alcohol impairment; DE2: inattentive driving; DE3: misjudgment/ disregarding traffic control; PW: estimated probability with the driver error; PWO: estimated probability without the driver error.			

5.3.3.2 Modeling Impacts of Multiple Factors

Through the course of quantifying the impacts of individual variables on the involvement of heavy trucks in fatal crashes, variables that are statistically significant have been identified. Variables such as light conditions, number of traffic lanes, area information, and driver errors were analyzed at the significance level of 0.1. A multiple logistic regression model for the relationship between the probability of involving heavy trucks and these variables was also investigated in this study. During the study, the effect of geometric alignment condition was added to the model because it was tested to be significant at a lower confidence level (0.3) and including it decreased the model's p-value; hence, statistically increasing its accuracy. The model with the estimated coefficients is listed as following:

$$logit\{Y = 1|\mathbf{X}\} = -0.19 + 0.26(LI\_CON) + 0.12(AL\_CON) - 0.20(LA\_NO) - 0.86(FL) - 0.16(AREA) + 0.57(DE1) - 0.49(DE2) - 0.47(DE3). \tag{5.18}$$

In this model, the responsible variable, *Y = 1,* represents a crash involving heavy trucks and the explanatory variables are described in Table 5.3.2. The p-values for this model that estimated by the Likelihood Rato Test, the Wald Test, and the Score Test were all less than 0.01, which indicates that the model was statistically significant at the 0.01 level of confidence.

Given different conditions, the conditional probability $\hat{P}$ of involving heavy trucks in a fatal crash given its occurrence can be estimated by the following equation, using the corresponding binary value of each explanatory variable:

$$\hat{P}\{Y = 1|\mathbf{X}\} = exp(logit\{Y = 1|\mathbf{X}\})/[1 + exp(logit\{Y = 1|\mathbf{X}\})]^{-1}. \tag{5.19}$$

For example as listed in Table 5.3.3, when *LI_CON = DE1 = DE2 = DE3 = 1* and *AL_CON = LA_NO = AREA = FL = 0* (the worst case), the value of *logit{Y = 1|**X**}* is -0.52 and the probability is 0.37. For the best case where *LI_CON = DE1 = DE2 = DE3 = 0* and *AL_CON*

= LA_NO = AREA = FL = 1, the corresponding values are -1.29 and 0.22, respectively, which indicates a decrease in probability of 15%. That is to say, in the latter condition, the conditional probability of a fatal truck-involved crash given its occurrence in work zones was 15% less than the former condition (the worst case).

5.3.4 Summary of Logistic Regression Analysis

Since the logistic regression technique can effectively model the relationships between a dichotomous response variable and a set of independent explanatory variables, it was used to investigate the fatal work zone crash variables and their interrelationships. In this study, the logistic regression modeling was utilized to numerically measure the effectiveness of two work zone traffic control methods, flaggers and stop signs/signals, as well as the impacts of some variables on the probability of heavy truck involved crashes. A multivariate logistic regression model was also developed to estimate the relationship between heavy truck involved crashes and a set of related driving conditions. For a specific combination of these driving conditions, this model can be used to predict the conditional probability of involving heavy trucks in a fatal work zone crash, given its occurrence.

Table 5.3.2: Explanatory Variables in the Truck-Involvement Logistic Regression Model

Variable	Description	Value = 0	Value = 1
LI_CON	Light condition	Good	Poor
AL_CON	Geometric alignment condition	Complicated	Straight & Level
LA_NO	Number of lanes (both directions)	Multiple	Two
AREA	Area information (rural vs. urban)	Urban	Rural
FL	Flagger control	No presence	Presence
DE1	Drug/alcohol impairment	No presence	Presence
DE2	Inattentive driving	No presence	Presence
DE3	Misjudgment/ disregarding traffic control	No presence	Presence

Table 5.3.3: Variable Values in Best Case and Worst Case

Variable	Description	Best Case Value	Worst Case Value
LI_CON	Light condition	Good / 0	Poor / 1
AL_CON	Geometric alignment condition	Straight & Level / 1	Complicated / 0
LA_NO	Number of lanes (both directions)	Two / 1	Multiple / 0
AREA	Area information (rural vs. urban)	Rural / 1	Urban / 0
FL	Flagger control	No presence / 1	No Presence / 0
DE1	Drug/alcohol impairment	No presence / 0	Presence / 1
DE2	Inattentive driving	No presence / 0	Presence / 1
DE3	Misjudgment/ disregarding traffic control	No presence / 0	Presence / 1

The effectiveness of traffic control methods such as flaggers and stop signs/signals is of particular interest to traffic engineers. The logistic regression analysis found that, the usage of flaggers in work zones could reduce the probability of involving heavy trucks in fatal crashes by 27%. Under the conditions of fatal work zone crash occurrence, flaggers could reduce 15% of the probability for male drivers to cause these crashes. In addition, stop signs/signals could reduce the conditional probability of involving multiple vehicles in the crashes by 13%, vehicle-vehicle collisions by 15%, and human error of misjudgment/disregarding traffic control by 20%.

Heavy-truck involved crashes are not desirable since they could yield much higher loss. The analysis results showed that poor light conditions could increase the probability of involving heavy trucks in fatal work zone crashes by 14%. Trucks on multilane highways were 8% more likely to be involved in fatal work zone crashes than trucks on two-lane highways. Trucks on urban highways were 10% more likely to be involved in fatal work zone crashes than those on rural highways. Under the conditions of fatal work zone crash occurrence, it was estimated that the conditional probability of truck involved crashes were increased by 24% for drug/alcohol influence and by 7% for both inattentive driving and misjudgment/disregarding traffic control.

Chapter 6:

Discussion and Risk Determination

The characteristics of the fatal work zone crashes in Kansas have been systematically examined. In this chapter, these characteristics are further discussed and work zone driving risks are determined. The driving risks in Kansas highway work zones are identified primarily based on the comparisons between the characteristics of the work zone crashes and all fatal crashes in Kansas. The information of general fatal crashes in Kansas was obtained from KDOT website (KDOT, 2005). Although some of the crash information from the website is for the past five years (2000-2004) instead of the last 13 years (the analysis time period) for this research, the risk determination should retain reasonable accuracy. The discussions provide insights to facilitate the complete understanding of both the crashes and their reflected unique work zone safety problems. This section includes the discussions and risk determinations regarding dangerous driver groups, work zone hazards, and contributing factors.

6.1 High-Risk Drivers and Hazardous Factors

6.1.1 High-Risk Driver Groups

The study found that male drivers caused most (75%) of the fatal crashes in Kansas highway work zones. This percentage is higher than the average percentage (73%) of male drivers for all fatal crashes in Kansas in the past five years (2000-2004). This indicates that males were the dangerous driver group and they experience higher safety risks in Kansas highway work zones. One of the findings of this study in response to this conclusion is that males caused significantly more crashes because of inattentive driving and misjudgment/ disregarded traffic controls.

In regards to ages, the drivers between 35-44 had the highest percentage (24%) of the crashes among all the age groups. Comparing the corresponding percentage (18%) for all fatal crashes, this driver group caused relatively more work zone fatal crashes in Kansas and thereby had higher driving risks. Although the work zone vehicle miles traveled (VMT) of this driver group might be relatively higher, considering their driving skills and experience, the higher fatal crash rate suggests a need for further safety education. Another driver group drawing particular attention is senior drivers who are over 65 years of age. This group of drivers, who caused 13% of all the fatal traffic crashes in Kansas for the past five years (2000-2004), were responsible for 18% fatal crashes in Kansas highway work zones. One of the reasons could be that the interruption of work zone settings on regular travel condition had more impact on senior drivers, whose driving skills were generally impaired with the increase of their age.

Teenage drivers (ages 15-19), on the other hand, accounted for 12% of the work zone fatal crashes, three percent lower than that for all fatal crashes (15%). The researchers could not conclude that teenagers were not the problematic driver group, but the impacts of work zones on them were less severe comparing to the two groups mentioned earlier. According to the comparisons, there were no significant changes on crash percentages found for other age groups.

Truck drivers, according to the analysis results, were exposed to high risks when they traveled through work zones: 40% of the total crashes involved heavy trucks and most of the truck-involved crashes involved multiple vehicles. In contrast, only 16% of all fatal crashes in Kansas involved heavy trucks during the past 13 years (1992-2004). The striking difference in percentage (24%) demonstrates that highway work zones were high-risk locations particularly for truck drivers. Heavy trucks have bigger bodies and less flexibility which require higher level driving skills when passing through work zones. The high percentage of crashes calls for immediate work zone safety countermeasures and configurations in consideration of heavy trucks.

6.1.2 Hazardous Times and Locations

The percentage of fatal crashes during non-peak hours (10:00 a.m. – 4:00 p.m.) was 32% of total fatal work zone crashes (No. of non-peak hour crashes in work zones divided by total crashes in work zones). The percentage of fatal crashes (work zone plus non-work zone crashes) during the same period was 28% of total fatal crashes (No. of non-peak hour crashes divided by total fatal crashes). The percentage of work zone non-peak hour crashes was 4% higher than the percentage of total fatal crashes during the same period in the past five years (2000-2004). Another significant portion that was 37% of fatal crashes in the work zones occurred during nighttime from 8:00 p.m. to 6:00 a.m. (No. of nighttime work zone fatal crashes divided by total work zone fatal crashes), especially in work zones without illuminations (32%). Analysis also showed that poor light condition increased the probability of heavy truck involvement by 14%. Therefore, illuminating highway work zones during nighttime might be an effective safety countermeasure. In addition, because of the lower traffic volumes at night, travelers may be more likely to drive at higher speeds, which also contributes to more fatal crashes. It is important to note that, the percentage of nighttime work zone fatal crashes was only slightly higher than that for all fatal crashes (work zone plus non-work zone crashes) during the same time period for last 5 years (37% vs. 36%).

In the State of Kansas, approximately 92% of the roadway systems are rural (NACo 2005). This high percentage of rural highway mileage coincided with the high percentage of fatal work zone crashes in rural areas (84%): 8% higher than that (76%) for all fatal crashes in the past five years (2000-2004). In addition, 73% of the fatal work zone crashes occurred on two-lane highways, which was proportionally double of the percentage (35%) for all fatal crashes during 2000 – 2004. Further analyses showed that 59% of the fatal crashes occurred on two-lane rural highways with speed limits between 51 mph and 70 mph. Thereby, work zones on two-lane rural highways with 51 mph – 70 mph speed limits are identified as one of the high-risk locations. The alarming amount of severe crashes may be an interactive outcome of high traveling speeds and limited maneuvering spaces.

Complicated highway geometric alignments in work zone areas could create work zone hazards. The frequency analysis determined that 49% of the fatal work zone crashes occurred on highway sections with complex geometries which include grade, curve, hillcrest, or any of their combinations: 9% higher than that for all fatal crashes (40%) in the past five years (2000-2004). This indicates that complicated road geometries in the work zones may cause more fatal work zone crashes. Therefore, more traffic control efforts should be devoted to secure work zones on the highways with complicated geometries. Among this 49%, the crashes occurred in work zones on highways that were straight on grade were most common which had a percentage of about 25% of the total. Grades, especially downhill grades, can directly affect driving speeds and hence lead to more speed control failures and create hazards for work zone travelers. Thus, work zones on highway segments with steep grades must have adequate traffic controls installed.

The safety impacts of work zones during slow-construction season such as December, January, February, and March is not negligible. Among the crashes, 18% occurred during these four months, and in particular, 7% occurred in December which was only slightly lower than the average (8.3%) of the other months. Traffic control devices in work zones during slow-construction season might be not routinely inspected while construction-related obstructions remain. This could contribute to fatal work zone crashes during slow-construction season.

6.2 Driver Errors and Traffic Controls

Driver errors caused 92% of the fatal work zone crashes in the past thirteen years. The most common driver errors include inattention, disregarded traffic controls, speeding, and alcohol impairment. In particular, the logistic regression modeling estimated that the conditional probability of truck involved in fatal work zone crashes were increased by 24% when under drug/alcohol influence.

According to the crash reports, many crashes were caused by multiple errors interactively. For example, human errors, such as inattention and speeding or inattention and disregarded traffic controls, were frequently reported together. In addition, drunk driving could also be accompanied by inattention and/or speeding. The researchers studied all the contributing driver errors of the crashes in the order that were listed in the crashes reports. Note that the driver errors for some crashes might not be determined precisely or even not be identified in the original reports, which may limit the accuracy of the human error analysis.

In this study, the effectiveness of work zone traffic controls on preventing fatal crashes is not precisely determined due to the insufficient information. However, the analysis showed that the usage of flaggers in work zones could reduce the probability of involving heavy trucks in fatal crashes by 27%. In addition, under the conditions of fatal crash occurrence, stop signs/signals could reduce the probability of involving multiple vehicles in the crashes by 13% and misjudgment/disregarding traffic control by 20%.

Chapter 7

Conclusions and Recommendations

7.1 Conclusions

Highway work zones have constituted a serious safety concern to traffic engineers and researchers. Considerable efforts from both the government agencies and the industries have been devoted to improve the work zone safety. Many studies have been conducted both statewide and nationwide to investigate work zone crash characteristics since the 1960s. However, national statistics have indicated a continuous increase of the work zone death toll.

To improve the highway work zone safety in the State of Kansas, KDOT initiated a project to study the characteristics of the fatal work zone crashes during the past 13 years (1992-2004). The main goal was to identify the unique safety problems in Kansas work zones. The researchers systematically examined a total of 157 fatal cases in that time period. Through this effort, the unique characteristics of work zone crashes were determined and work zone risks were identified.

7.1.1 High-Risk Drivers

Male drivers cause about 75% of the fatal work zone crashes in Kansas. Drivers that are between 35 and 44 years old, and older than 65, are the high-risk driver groups in work zones. In addition, a majority of the nighttime crashes were caused by drivers younger than 55.

7.1.2 High-Risk Time Periods

The daytime non-peak hours (10:00 a.m. – 4:00 p.m.) were the most hazardous time period in work zones by accounting for 32% (highest hourly rate) of the fatal crashes. Nighttime (8:00 p.m. – 6:00 a.m.) had 37% of the crashes. Significant differences are not found among the crashes within seven days of a week. However, the nontrivial proportion of the crashes during slow-construction season (November – March) suggests safety countermeasure or traffic control devices need to be maintained during the entire construction period.

7.1.3 High-Risk Locations

Work zones on rural two-lane highways with speed limits from 51 mph to 70 mph were high risk locations, accounting for 59% of the fatal crashes. Work zones located on complex geometric alignments were more hazardous, with half of the fatal crashes. The work zones on two-lane rural roads had more truck involved crashes. In addition, multilane highways and urban areas may increase the probability of heavy truck involved fatal crashes.

7.1.4 Crash Type

Most (68%) of the crashes are multi-vehicle crashes. Among the multi-vehicle collisions, head-on, angle-side impact, and rear-end are the three most frequent collision types. In addition, analyses show that the most severe crashes frequently involved heavy trucks: 40% of the crashes were caused by heavy trucks and almost all of these crashes involved multiple vehicles.

7.1.5 Contributing Factors

Human errors including inattentive driving and misjudgment/disregarding traffic control were the top killers in work zones. Inclement weather conditions and unfavorable road features (interchange areas, intersections, ramps, etc.) do not significantly contribute to fatal work zone crashes. Light condition and complex highway geometric alignments may increase driving risks in work zones. Inefficient traffic controls and human errors contributed to most fatal work zone crashes.

7.2 Recommendations

Based on the research findings, recommendations are presented below for the future improvement of Kansas work zone safety. These recommendations are proposed in three aspects: traffic control, education, and crash investigation. In addition, a summary of work zone safety risks and their safety improvement recommendations are listed in Table 7.2.1.

7.2.1 Traffic Control

Improved traffic control is the most direct method to reduce highway work zone fatalities. More effective and sufficient work zone traffic controls should be installed. In particular, there is an urgent need to develop speed control methods that can be strictly enforced in the work zone areas. Illumination or retroreflective devices should be installed in the dark work zones. Devices such as transverse markings or temporary raised pavement markers in the advance warning areas can be used to alert inattentive travelers of the upcoming work zones. Special traffic control methods need to be developed for work zones on complex highway geometric alignments. The study results have also indicated a need for traffic control improvements in the work zones during slow-construction season.

7.2.2 Education

Drivers ranging in age from 35 to 44 were the groups having the highest fatal crash rate in Kansas work zones. Truck drivers also create serious safety problems in work zones. Driver-group-oriented education programs need to be developed to raise the awareness of work zone traveling hazards. The fact that most crashes were caused by human errors also indicates the urgency of developing effective education programs to educate the general public who have to travel through the work zones.

7.2.3 Accident Report Improvement

During the data collection of this study, the researchers found that some sections of the State of Kansas Motor Vehicle Accident Report could be modified to make it easier for accident investigation. For instance, the traffic control list on the reports does not include the temporary traffic controls such as barriers and temporary lighting devices that are commonly used in the work zones. As a result, accident investigators (police) usually either classify those temporary work zone traffic control devices as “other” or do not list them. This limited the researchers to perform extensive studies of the effectiveness of work zone traffic controls. Revisions might also be considered for other sections such as pedestrian identification (regular pedestrian or construction worker) and detailed accident locations within work zones (advance warning area, transition area, activity area, or termination area).

Researchers also suggest that KDOT shall conduct work zone crash characteristics study every five years in order to determine the new development trend.

Table 7.2.1: Work Zone Risks and Safety Improvement Recommendations

Risk Category	Risk Description	Safety Improvement Recommendation
High-risk drivers	Male drivers	Safety education
	Drivers between 35-44	Safety education
	Drivers ≥ 65	Safety education
High-risk time periods	Daytime non-peak hours (10:00 a.m. – 4:00 p.m.)	Safety education and traffic control enforcement
	Nighttime (8:00 p.m. – 6:00 a.m.)	Illumination or retro-reflective devices
	Slow-construction season (November – March)	Routine traffic control inspection and public information
High-risk locations	Rural two-lane highways with speed limits from 51 mph to 70 mph	Effective speed control devices and speed limit enforcement
	Complex geometric alignments	Developing special traffic controls for complex geometric alignment
Most common crash types	Multi-vehicle collisions (head-on, angle-side impact, and rear-end)	Effective speed control devices and speed limit enforcement
	Heavy truck involved crashes	Safety education, speed control, and work-zone geometric design with enough space for heavy truck maneuver
Driver errors	Inattentive driving	Devices such as flashing lights or temporary raised pavement markers in the advance warning area
	Misjudgment/disregarded traffic controls	Traffic control enforcement and avoiding confusing traffic control signs/signals

References

Adeli, H. and Ghosh-Dastidar, S. (2004). "Mesoscopic-Wavelet Freeway Work Zone Flow and Congestion Feature Extraction Model". *Journal of Transportation Engineering 130(1)*, ASCE, pp94 – 103.

Adeli, H. and Jiang, X. (2003). "Neuro-Fuzzy Logic Model for Freeway Work Zone Capacity Estimation". *Journal of Transportation Engineering 129(5)*, ASCE, pp484 – 493.

Arnold, E. D. (2003). "Use of Police in Work Zones on Highways in Virginia". Final Report VTRC 04-R9, Virginia Transportation Research Council, Charlottesville, Virginia.

Bai, Y., 2002. Improving Highway Work Zone Safety. In: Proceedings of the Fall Meeting of American Society of Civil Engineering (Texas section), Waco, Texas, CD-ROM.

Bai, Y., Cao, Q., 2003. Reducing Fatalities in Highway Construction Work Zones. In: Proceedings of 33rd Annual meeting of Southeast Decision Sciences Institute, Williamsburg, Virginia, pp.367 – 369.

Barton, J. E., Misener, J. A., and Cohn, T. E. (2001). "A Computational Vision Model-Based Method to Address Work Zone Conspicuity". 80th TRB Annual Meeting CD-ROM, January 7-11, Washington, D.C.

Beacher, A. G., Fontaine, M. D., and Garber, N. J., (2005). "Field Evaluation of the Late Merge Work Zone Traffic Control". 84th Annual Meeting CD-ROM, January 9 – 13, 2005, Transportation Research Board, Washington D. C.

Benekohal, R. F., Shim, E., and Resende, T. V. (1995). "Truck Drivers' Concerns in Work Zones: Travel Characteristics and Accident Experiences". *Transportation Research Record 1509*, Transportation Research Board, Washington D. C., pp55 – 64.

Burnette, C. and Moon, S. (1999). “Developing Highway driving Simulations Using Virtual Reality Modeling Language”. *Transportation Research Record 1525*, Transportation Research Board, Washington D.C., pp40 – 45.

Bushman, R. and Berthelot, C. (2005). “Response of North Carolina Motorists to a Smart Work Zone System”. TRB 84th Annual Meeting CD-ROM, January 9 – 13, 2005. Transportation Research Board, Washington D.C.

Carreker, L. E. and Bachman, W. (2000). “Geographic Information System Procedures to Improve Speed and Accuracy in Locating Crashes”. *Transportation Research Record 1719*, Transportation Research Board, Washington D.C., pp215 – 218.

Chambless, J., Chadiali, A. M., Lindly, J. K, and McFadden, J. (2002). “Multistate Work zone Crash Characteristics”. *ITE Journal*, Institute of Transportation Engineers, pp46 – 50.

Chien, S. and Schonfeld, P. (2001). “Optimal Work Zone Lengths for Four-Lane Highways”. *Journal of Transportation Engineering 127(2)*, ASCE, pp124 – 131.

Chien, S., Tang, Y., and Schonfeld, P (2002). “Optimizing Work Zones for Two-Lane Highway Maintenance Projects”. *Journal of Transportation Engineering 128(2)*, ASCE, pp145 – 154.

Chen, W. and Jovanis, P. P., (2000). “Method for Identifying Factors Contributing to Driver-Injury Severity in Traffic Crashes”. *Transportation Research Record 1707*, Transportation Research Board, Washington D.C., pp1 – 9.

Department of Public Works (1965). *Progress Report on Construction Zones, Detour, and Temporary Connection Crashes*. Department of Public Works, California.

Dissanayake, S. and Lu, J. (2002). “Analysis of Severity of Yong Driver Crashes, Sequential Binary Logistic Regression Modeling”. *Transportation Research Record 1784*, Transportation Research Board, Washington D.C., pp 108 – 114.

Donelson, A. C., Ramachandran, K, Zhao, K., and Kalinowski, A., (2000). "Rates of Occupant Deaths in Vehicle rollover -- Importance of Fatality-Risk Factors". *Transportation Research Record 1665*, Transportation Research Board, Washington D. C., pp109 – 117.

Donnell, E. T., Harwood, D. W., Bauer, K. M., Mason, J. M. Jr., and Pietrucha, M. T. (2002). "Cross-Median Collisions on Pennsylvania Interstates and Expressways". *Transportation Research Record 1784*, Transportation Research Board, Washington D.C., pp91 – 99.

El-Zarif, J., Hobeika, A., and Rakha, H. (2002). "Simulating No-Passing Zone Violations on a Vertical Curve of a Two-Lane Rural Road". *Transportation Research Record 1800*, Transportation Research Board, Washington D.C., pp16 – 26.

Elvik, R., Amundsen, F. H., and Hofset, F. (2001). "Road Safety Effects of Bypasses". *Transportation Research Record 1758*, Transportation Research Board, Washington D.C., pp13 – 20.

FHWA (1998). *Meeting the Consumer's Needs for Mobility and Safety during Construction and Maintenance Operations*. Office of Program Quality Coordination, Federal Highway Administration (FHWA), September 1998.

FHWA (2003). *Manual on Uniform Traffic Control Devices for Streets and Highways*. 2003 Edition, Federal Highway Administration.

FHWA (2004). "Work Zone Safety Facts and Statistics". http://safety.fhwa.dot.gov/wz/wz_facts.htm. Updated on 12/28/2004.

Fisher, D. J. and Rajan, N. (1996). "Automated Constructibility Analysis of Work zone Traffic-Control Planning". *Journal of Construction Engineering and Management 122(1)*, ASCE, pp36 – 43.

Garber, N. J. and Ehrhart, A. A. (2000). “Effect of Speed, Flow, and Geometric Characteristics on Crash Frequency for Two-Lane Highways”. *Transportation Research Record 1717*, Transportation Research Board, Washington D.C., pp76 – 83.

Garber, N. J. and Patel, S. T. (1994). “Effectiveness of Changeable Message Signs in Controlling Vehicles Speeds in Work Zones” Report No. VTRC 95-R4. Virginia Transportation Research Council, Charlottesville, Virginia.

Garber, N. J. and Srinivasan, S. (1998). “Effectiveness of Changeable Message Signs in Work Zones: Phase II”. Report No. VTRC 98-R 10. Virginia Transportation Research Council, Charlottesville, Virginia.

Garber, N. J. and Woo, T. H. (1990). “Accident Characteristics at Construction and Maintenance Zones in Urban Areas”. Research Report VTRC 90 – R12, Virginia Transportation Research Council, Charlottesville, Virginia.

Garber, N. J. and Zhao, M. (2002). “Crash Characteristics at Work Zones”. Research Report VTRC 02-R12, Virginia Transportation Research Council, Charlottesville, Virginia.

Ha, T. and Nemeth, Z. A. (1995). “Detailed Study of Accident Experience in Construction and Maintenance Zones”. *Transportation Research Record 1509*, Transportation Research Board, Washington D.C., pp38 – 45.

Hall, J. W. and Lorenz, V. M. (1989). “Characteristics of Construction Zone Crashes,” *Transportation Research Record 1230*, Transportation Research Board, Washington, D.C., pp20 – 27.

Hargroves, B. T. (1981). “Vehicle Crashes in Highway Work Zones”. *Journal of Transportation Engineering 107(TE5)*, ASCE, pp525 – 539.

Hauer, E., Harwood, D. W., Council, F. M., and Griffith, M. S. (2002). "Estimating Safety by the Empirical Bayes Method". *Transportation Research Record 1784*, Transportation Research Board, Washington D.C., pp126 – 131.

Herrell, F. E. (2001). *Regression Modeling Strategies*, Chapter 10, p217.

Hill, R. W. (2003). "Statistical Analysis of Fatal Traffic Accident Data". Master's Thesis, Texas Tech University.

Hogg, R. V., J. W. McKean, and A. T. Craig (2005). *Introduction to Mathematical Statistics*. Upper Saddle River, New Jersey, pp. 284.

Hosmer, D. W. and Lemeshow, S. (2000). Applied Logistic Regression, 2nd edition, p. 16.

Huebschman, C. R., Garcia, C., Bullock, D. M., and Abraham, D. M. (2003). "Construction Work Zone Safety". Report No. FHWA/IN/JTRP-2002/34, Joint Transportation Research Program, Purdue University, West Lafayette, Indiana.

Islam, M. N., Seneviratne, P. N., and Kalakota, K. R. (1995). "Traffic Management During Road Closure". *Transportation Research Record 1509*, Transportation Research Board, Washington D.C., pp46 – 54.

Jha, M. K. and McCall, C. (2001). "Implementing Visualization and GIS Techniques in Highway Projects". 80th TRB Annual Meeting CD-ROM, January 7-11, Washington, D.C.

Jha, M. K. and Schonfeld, P. (2000). "Integrating Genetic Algorithms and Geographic Inforamtion System to Optimize Highway Alignments". *Transportation Research Record 1719*, Transportation Research Board, Washington D.C., pp233 – 240.

Jiang, X. and Adeli, H. (2003). "Freeway Work Zone Traffic Delay and Cost Optimization Model". *Journal of Transportation Engineering 129(3)*, ASCE, pp230 – 241.

Kansas Department of Transportation (KDOT) (2005). Accident Statistics. http://www.ksdot.org/ burTransPlan/prodinfo/accista.asp. Data as of 9-1-2005.

Karim, A. and Adeli, H. (2002). "CBR Model for Freeway Work Zone Traffic Management". *Journal of Transportation Engineering 129(2)*, ASCE, pp134 – 145.

Kim, K., Kim, S. and Yamashita, E. (2000). "Alcohol-Impaired Motorcycle Crashes in Hawaii, 1986 to 1995". *Transportation Research Record 1704*, Transportation Research Board, Washington D.C., pp77 – 85.

Kononov, J and Znamenacek, Z (2005). "Risk Analysis of Freeway Lane Closure during Peak Hour". TRB 84th Annual Meeting CD-ROM, January 9 – 13, 2005. Transportation Research Board, Washington D.C.

Krishnan, H., Gibb, S., Steinfeld, A. and Shladover, S. (2001). "Rear-End Collision-Warning System, Design and Evaluation via Simulation". *Transportation Research Record 1759*, Transportation Research Board, Washington D.C., pp52 – 60.

Lieberman, D., Lieberman, E., and Yoon, J., (2002). "Animation of Simulation-Based Statistics". TRB 81st Annual Meeting CD-ROM, January 13 – 17, 2002. Transportation Research Board, Washington D.C.

Lord, D. (2002). "Application of Accident Prediction Models for Computation of Accident Risk on Transportation Networks". *Transportation Research Record 1784*, Transportation Research Board, Washington D.C., pp17 – 26.

Meyer, E. (2004). "Evaluation of Data from Test Application of Optical Speed Bars to Highway Work Zones". Final Report No. K-TRAN: KU-00-4. Kansas Department of Transportation.

Misener, J. A., Tsao, H.-S. J., Song, B., and Steinfeld, A. (2001). "Emergence of a Cognitive Car-Following Driver Model – Application to Rear-End Crashes with a Stopped Lead Vehicle". *Transportation Research Record 1724*, Transportation Research Board, Washington D.C., pp29 – 38.

Mitshell, G., Schattler, K. L., and Datta, T. K. (2005). "Use of a Driving Simulator for Evaluation of Safety Measures in Highway Work Zones". TRB 84th Annual Meeting CD-ROM, January 9 – 13, 2005. Transportation Research Board, Washington D.C.

Mohan, S. B. and Gautam, P. (2002). "Cost of Highway Work Zone Injuries". *Practical Periodical on Structural Design and Construction 7(2)*, ASCE, pp68 – 73.

Montella, A. and Ciotola, G. (2002). " Road Safety Audit at Work Zone". TRB 81st Annual Meeting CD-ROM, January 13 – 17, 2002. Transportation Research Board, Washington D.C.

Munro, D. M. and N. W. Huang (1968). *Motor Vehicle Safety at Temporary Construction or Repair Sites on Highways*. Highway Safety Research Institute, Ann Arbor, Michigan.

NACo (2005). "The Rural Context for Transportation Consultations". http://www.ruraltransportation.org/library/ks.shtml, National Association of Counties (NACo), Accessed June 12, 2005.

Ouyang, Y, Shankar, V., and Yamamoto, T. (2002). "Modeling the Simultaneity in Injury Causation in Multi-vehicle Collisions". *Transportation Research Record 1704*, Transportation Research Board, Washington D.C., pp143 – 152.

Pain, R. F., McGee, H. W., and Knapp, B. G. (1983). "Evaluation of Traffic Controls for Highway Work Zones". National Cooperative Highway Research Program Report 236, Transportation Research Board, Washington D. C.

Pigman, J. G. and Agent, K. R. (1990). “Highway Crashes in Construction and Maintenance Work Zones”. *Transportation Research Record 1270*, Transportation Research Board, Washington D.C., pp12 – 21.

Richards. S. H. and Dudek, C. L. (1986). “Implementation of Work zone Speed Control Measures”. *Transportation Research Record 1086*, Transportation Research Board, Washington D.C., pp36 – 42.

Roche, J. (2000). “Geographic Information Systems-Based Crash Data Analysis and the Benefits to Traffic Safety”. *2000 MTC Transportation Scholars Conference*, Ames, Iowa, pp100 – 122.

SAS Institute Inc. (2004). *Base SAS 9.1.3 Procedures Guide*. SAS Institute Inc., Cary, NC, Chapter 2, pp. 105.

Shepard, F. D. and Cottrell, B. H. (1986). “Benefits and Safety Impact of Night Work zone Activities”. *Transportation Research Record 1086*, Transportation Research Board, Washington D.C., pp31 – 36.

Taylor, W. C., Lim, I., and Lighthizer, D. R. (2001). “Effect on Crashes After Construction of Directional Median Crossovers”. *Transportation Research Record 1758*, Transportation Research Board, Washington D.C., pp30 – 35.

Turner, P. A. and Georggi, N. (2001). “ Analysis of Alcohol-Related Motorcycle Crashes in Florida and Recommended Countermeasures”. *Transportation Research Record 1779*, Transportation Research Board, Washington D.C., pp189 – 196.

The University of Texas at Austin (2005). “Tests of Independence Using Two-Way Contingency Tables in SPSS”. http://www.utexas.edu/cc/docs/stat58.html#testing. Accessed June 12, 2005.

Wilson, E. M. and Lipinski, M. E. (2003). "Practical Safety Tool for Local Low-Volume Rural Roads, the Road Safety Audit Review". *Transportation Research Record 1819*, Transportation Research Board, Washington D.C., pp225 – 230.

Xiao, J., Kulakowski, B. T., and El-Gindy, M. (2000). "Prediction of Risk of Wet-Pavement Crashes, Fuzzy Logic Model". *Transportation Research Record 1717*, Transportation Research Board, Washington D.C., pp28 – 36.

Yadlapati, S. S. and Park, B. (2004). "Development and Testing of Variable Speed Limit Control Logics for Work Zones Using Simulation". Research Report No. UVACTS-13-0-43, Center for Transportation Studies, the University of Virginia.

Yuan, F., Ivan, J. N., Qin, X., Garrick, N. W., and Davis, C. F. (2001). "Safety Benefits of Intersection Approach Realignment on Rural Two-Lane Highways". *Transportation Research Record 1785*, Transportation Research Board, Washington D.C., pp21 – 29.

Appendix I

Data Collection Sheet (A PORTION)

Table A1: A Portion of the Datasheet Used for Statistical Analyses

Crash Number (Key #)	Responsible Driver		Time Information				Climatic Environment			Crash Information				
	Age	Gender	Time	Day	Month	Year	Light Condition	Weather Condition	Road Sur Condition	Vehicle Maneuver	Crash Severity	Crash Type	Vehicle Type	No. of Vehicles
199200032160	5	1	4	2	3	1	4	1	1	1	1	9	6	2
199200033190	2	0	4	7	5	1	4	1	1	7	1	10	6	2
199200033250	3	0	4	7	6	1	4	1	1	1	1	11	2	2
199200106070	3	0	4	5	7	1	5	1	1	7	1	8	9	1
19920016161C	5	0	2	1	6	1	1	1	1	7	1	8	6	2
199200161720	7	0	2	4	7	1	1	1	1	1	1	8	9	1
199200161740	3	0	4	7	7	1	5	1	1	1	1	2	10	1
199200161880	3	1	3	2	8	1	1	1	1	1	1	10	2	2
199200201790	1	0	4	3	8	1	4	1	5	1	1	11	6	2
199200201800	4	1	3	6	8	1	1	1	1	1	1	9	6	2
199200201910	2	0	2	4	9	1	1	1	1	1	1	10	2	2
199200306440	6	0	4	2	9	1	5	1	1	1	1	4	3	1
199200415420	4	1	4	3	10	1	1	1	1	1	1	10	2	2
19920064005C	4	0	3	1	6	1	1	1	1	1	1	10	2	6
19920064008C	5	1	4	3	6	1	5	1	1	1	1	12	2	2
199300008200	1	0	1	4	1	2	5	2	4	1	1	10	2	3
199300008430	3	0	4	1	2	2	5	1	1	1	1	8	9	1
199300009080	2	0	2	2	5	2	1	1	1	1	1	3	4	1
199300009110	7	0	1	5	5	2	1	1	1	16	1	9	6	2
199300299140	1	0	2	5	8	2	1	1	1	1	1	8	9	1
199300299150	6	0	1	5	8	2	1	1	1	1	1	11	6	3
199300299530	5	0	4	3	9	2	5	1	1	1	1	8	5	1
199300448090	7	0	2	5	9	2	1	1	1	5	1	9	6	3
199300556110	2	0	4	4	12	2	5	1	1	1	1	8	9	1
199400317990	4	1	2	7	8	3	1	2	2	1	1	12	2	2
199400522470	2	0	4	1	9	3	4	1	1	1	1	10	6	2
199400523280	1	0	4	7	12	3	4	1	1	7	1	1	10	1

Table A1 (Continued): A Portion of the Datasheet Used for Statistical Analyses

Crash Number (Key #)	Road Information											Contribution Factor						
	Road Class	Road Character	No. of Lanes	Speed Limit	Crash Location	Surface Type	Road Sp Feature	Area Info.	TC 1	TC 2	TC 3	DF 1	DF 2	DF 3	DF 4	Pedes. Factor	Envir. Factor	Vehicle Factor
199200032160	1	4	6	55	1	2	1	0	10			4	8	16				
199200033190	3	1	2	55	1	2	1	1	3	10		4	5	16	2			
199200033250	2	2	4	45	2	2	1	0	3	10		2	4					
199200106070	2	4	4	40	6	1	1	0	3	11		26						
19920016161C	1	2	4	65	6	1	1	1	10			15	16	8				
199200161720	3	1	4	55	1	1	1	1	1			4	6	8	16			
199200161740	3	4	4	65	1	2	1	1	10			2	6	16				
199200161880	5	1	2	55	1	2	1	1	9	10		3	4	6				
199200201790	3	1	4	55	2	1	1	1	8			4	3	6				
199200201800	3	5	2	55	1	2	1	1	11			2	6					
199200201910	3	5	2	55	1	2	1	1	11			3	5	16				
199200306440	5	4	2	55	1	2	1	1	10			4	6	16				
199200415420	3	1	2	55	1	2	1	1	2	10		16						
19920064005C	3	2	2	55	1	2	1	1	2	10		4	16	6				
19920064008C	3	2	2	55	1	2	1	1	10			16	8					
199300008200	3	1	2	55	1	2	1	1	10			9	6					
199300008430	3	4	2	55	6	2	1	1	10			15						
199300009080	1	2	4	65	1	2	1	1	2	9		16	6					
199300009110	3	1	2	55	6	2	1	1	10			4	16	8				
199300299140	1	1	4	65	6	1	3	1	11	10		16	6					
199300299150	2	1	4	35	2	1	1	0	3	10		4						
199300299530	1	1	4	65	1	2	2	0	11	10		15	16					
199300448090	3	4	2	55	1	2	8	1	4	10		9	16					
199300556110	3	1	2	55	1	2	1	1	10			26						
199400317990	4	4	2	55	1	2	1	1	10			16	8					
199400522470	4	1	2	55	1	2	1	1	11			5	16	6				
199400523280	3	1	4	55	2	1	1	1	10			16						

TC: traffic control; DF: driver factor.

Appendix II

KDOT Accident Report Sample

☐ FATAL
☐ INJURY
☐ PDO over $500
☐ PDO under $500
☐ PRIVATE PROPERTY

STATE OF KANSAS
MOTOR VEHICLE ACCIDENT REPORT

DOT FORM NO. 850
Rev. 1-2003

☐ Amended Report
☐ Hit & Run Accident
☐ KDOT Property Damage
☐ KDOT Construction Zone

Sample

Milepost	COUNTY	On Road	Speed Limit	CITY	Photos By	Local Case Number	Page of /
Distance	Ft/Mi	Dir.	☐ FROM ☐ AT Road	Speed Limit	Investigating Dept.	Investigating Officer /Badge Number	Reviewed By

COLLISION DIAGRAM (Show Unit Movements, Roads) ↑ N	Describe pre-crash movement or action and direction of vehicles and pedestrians by traffic unit number.	Date of Accident	
		TIME Occurred	DAY
		TIME Notified	DAY
		TIME Arrived	DAY
Object Damaged and nature of damage (Show location in diagram)	Name and Address of object owner		

ON Road	Cntl Sec.	Sec. Milepost	AT Road	Distance	Unit	Dir.	Latitude	Longitude	STATE USE ONLY
County	City Code	Agency Code N	Distance M	Reference Road 1 +	E Distance M		Reference Road 2	Coder	Func. Class

Unit	☐ Driver ☐ Ped NAME (Last, First and Initial)	Phone ☐ Work ☐ Home	Color	YEAR	MAKE	MODEL & BODY STYLE	MC CCs
Driver/Ped ADDRESS (Number, Street, City, State, Zip Code)			STATE	LICENSE PLATE #	EXP YR	Removed By:	
DRIVER'S LICENSE STATE and NUMBER St. No.	CDL?	DATE OF BIRTH	SEX	VEHICLE IDENTIFICATION NUMBER		Odometer	
Registered OWNER FULL NAME ("Same" if Driver)	Phone ☐ Work ☐ Home		TOTAL occupants in this vehicle	Fire?	Insurance Company		
OWNER Address ("Same" if Driver)			Special Data Area	Direction of Travel	Policy Number		

Special Conditions for unit above: ☐ 01 Hit & Run ☐ 02 Non-Contact ☐ 03 Stolen ☐ 04 Legally parked ☐ 05 Police pursuit ☐ 06 Driverless ☐ 07 Towed away

Unit	☐ Driver ☐ Ped NAME (Last, First and Initial)	Phone ☐ Work ☐ Home	Color	YEAR	MAKE	MODEL & BODY STYLE	MC CCs
Driver/Ped ADDRESS (Number, Street, City, State, Zip Code)			STATE	LICENSE PLATE #	EXP YR	Removed By:	
DRIVER'S LICENSE STATE and NUMBER St. No.	CDL?	DATE OF BIRTH	SEX	VEHICLE IDENTIFICATION NUMBER		Odometer	
Registered OWNER FULL NAME ("Same" if Driver)	Phone ☐ Work ☐ Home		TOTAL occupants in this vehicle	Fire?	Insurance Company		
OWNER Address ("Same" if Driver)			Special Data Area	Direction of Travel	Policy Number		

Special Conditions for unit above: ☐ 01 Hit & Run ☐ 02 Non-Contact ☐ 03 Stolen ☐ 04 Legally parked ☐ 05 Police pursuit ☐ 06 Driverless ☐ 07 Towed away

TRAF UNIT	SEAT TYPE	Last NAME First Name Initial	ADDRESS (Number, Street, City, State, Zip)	SEX	AGE	S.E. USED	EJECT TRAP	INJ SEV	EMS UNIT

E M S Unit A	INJURED TAKEN By: INJURED TAKEN To:	E M S Unit B	INJURED TAKEN By: INJURED TAKEN To:	E M S Unit C	INJURED TAKEN By: INJURED TAKEN To:

Dr/Pd	Violation Charged	Citation No.	Dr/Pd	Violation Charged	Citation No.	Dr/Pd	Violation Charged	Citation No.
Dr/Pd	Violation Charged	Citation No.	Dr/Pd	Violation Charged	Citation No.	Dr/Pd	Violation Charged	Citation No.

OFFICER'S OPINIONS OF APPARENT CONTRIBUTING CIRCUMSTANCES (Factor Type-Unit Number/Specific Factor) Enter in order all codes that apply.

LIGHT
01 Daylight
02 Dawn
03 Dusk
04 Dark: street lights on
05 Dark: no street lights

WEATHER
00 No adverse conditions
01 Rain, Mist, Drizzle
02 Sleet
03 Snow
04 Fog
05 Smoke
06 Strong winds
07 Blowing dust, sand, etc.
08 Freezing rain
14 Rain & fog
16 Rain & wind
24 Sleet & fog
36 Snow & winds
88 Other ______

SURFACE TYPE
ON ☐ AT ☐
01 Concrete
02 Blacktop
03 Gravel
04 Dirt
05 Brick
88 Other ______

SURFACE CONDITION
ON ☐ AT ☐
01 Dry
02 Wet
03 Snow or slush
04 Ice or snowpacked
05 Mud, dirt or sand
06 Debris (Oil, etc.)
88 Other ______

VEHICLE MANEUVER BEFORE CRASH
1 ☐ 2 ☐
01 Straight/following road
02 Left turn
03 Right turn
04 U-turn
05 Overtaking (passing)
06 Changing lanes
07 Avoiding maneuver
08 Merging
09 Parking
10 Backing
11 Stopped awaiting turn
12 Stopped in traffic
13 Illegal parked
14 Disabled in roadway
15 Slowing or stopping
88 Other ______

VEHICLE DAMAGE
1 ☐ 2 ☐
00 None/None known
01 Damage (minor)
02 Functional
03 Disabling
04 Destroyed
88 Other ______

DR. LIC. COMPLY (Code each driver)
1 ☐ 2 ☐
00 Not licensed
01 Valid license
02 Invalid license

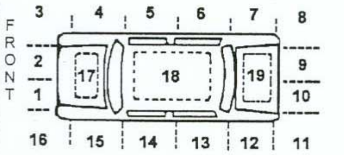
TRAFFIC CONTROLS
O/A (On/At Road)
Type Present
OK/NF(OK/Non-functional)
1 ☐ ☐ ☐
2 ☐ ☐ ☐
3 ☐ ☐ ☐
4 ☐ ☐ ☐
5 ☐ ☐ ☐
00 None
01 Officer, flagger
02 Traffic signal
03 Stop sign
04 Flasher
05 Yield sign
06 RR gates or signal
07 RR crossing signal
08 No passing zone
09 Center/edge lines
88 Other ______

ROAD CHARACTER
ON ☐ AT ☐
01 Straight and level
02 Straight on grade
03 Straight at hillcrest
04 Curved and level
05 Curved on grade
06 Curved at hillcrest
88 Other ______

Sample

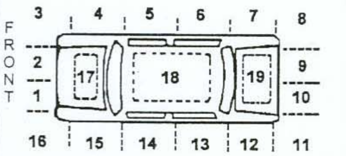
CONST./MAINT. ZONE
ON ☐ AT ☐
00 None apply
01 Construction zone
02 Maintenance zone
03 Utility zone

DAMAGE LOCATION AREA - Vehicle ☐



☐ Top ☐ Windshld ☐ Windows
☐ Under ☐ Overturn ☐ Other
Trailer? ☐ Present ☐ Damaged

DAMAGE LOCATION AREA - Vehicle ☐



☐ Top ☐ Windshld ☐ Windows
☐ Under ☐ Overturn ☐ Other
Trailer? ☐ Present ☐ Damaged

RESTRICT. COMPLY (Code each driver)
1 ☐ 2 ☐
00 No restrictions
01 Complied with
02 Do not comply

ACCIDENT CLASS
00 Other non-collision
01 Overturned
COLLISION WITH:
02 Pedestrian
03 Other motor vehicle *
04 Parked motor vehicle
05 Railway train
06 Pedalcycle
07 Animal (specify) ______
08 Fixed object ** ______
09 Other object ______

ACCIDENT LOCATION
ON ROADWAY:
11 Non-intersection
12 Intersection
13 Intersection-related
14 Parking lot or driveway access
15 Interchange area
16 On crossover
OFF ROADWAY:
21 Roadside (Including shoulder)
22 Median
23 Parking lot, rest area, trafficway
88 Other ______

ROAD SPECIAL FEATURES (IDENTIFY UP TO THREE)
00 None
01 Bridge
02 Bridge overhead
03 Railroad bridge
04 Railroad crossing
05 Interchange
06 Ramp
88 Other ______

VEHICLE BODY TYPE
1 ☐ 2 ☐
01 Automobile
02 Motorcycle
03 Motorscooter or Moped
04 Van
05 Pickup truck
06 Sport Utility Vehicle
07 Camper or RV
08 Farm equipment
09 All terrain vehicle (ATV)

PEDESTRIAN LOCATION BEFORE IMPACT-IN INTERSECTION:
1 ☐ 2 ☐
01 In crosswalk or bikeway
02 Not in crosswalk or bikeway
03 In intersection without crosswalk or bikeway
NOT IN INTERSECTION
11 In available crosswalk or bikeway
12 Not in available crosswalk or bikeway
13 In area without crosswalk or bikeway
25 NOT IN ROADWAY

SUBSTANCE USE
1 ☐ ☐ ☐ 2 ☐ ☐ ☐
AP - Alcohol Present
AC - Alcohol Contributed
DP- Illegal Drug Present
DC- Illegal Drug Contributed
MP - Medication Present
MC - Medication Contributed

*** COLLISION WITH OTHER MOTOR VEH.**
01 Head on
02 Rear end
03 Angle - side impact
04 Sideswipe: opposite direction
05 Sideswipe: same direction
06 Backed into
88 Other ______

**** FIXED OBJECT TYPE**
01 Bridge structure
02 Bridge rail
03 Crash cushion (barrels)
04 Divider, median barrier
05 Overhead sign support
06 Utility devices: pole, meter, etc.
07 Other post or pole
08 Building
09 Guardrail
10 Sign post
11 Culvert
12 Curb
13 Fence / Gate
14 Hydrant
15 Barricade
16 Mailbox
17 Ditch
18 Embankment
19 Wall
20 Tree
21 RR crossing fixtures
88 Other ______

ENTER ANY VISIBLE IDENTIFIER:
refer by code
Code ______ Ident: ______
Code ______ Ident: ______

HEAVY / LARGE VEHICLES
10 Single Large Truck
11 Truck and trailer(s)
12 Tractor-trailer(s)
13 Cross country bus
14 School bus
15 Transit bus
25 Train
77 Emergency Vehicles
88 Other ______

Bus Capacity
1 ☐
2 ☐

PEDESTRIAN ACTION
1 ☐ 2 ☐
01 Entering or crossing road
02 Walking or riding on road
03 Approaching, leaving, or working on vehicle
04 Working (not on vehicle)
05 Playing or standing
06 Approaching or leaving bus
07 In parked vehicle
88 Other ______

PED OBEDIENCE TO TRAF SIG
1 ☐ 2 ☐
00 No pedestrian signal
01 Obeyed pedestrian signal
02 Disobeyed ped signal
03 Ped signal malfunction
04 Not applicable

DRIVER/PED IMPAIRMENT TEST
1 ☐ ☐ 2 ☐ ☐
TR - Alcohol or drug Test Refused
PT - Positive preliminary Test
RP - Test given, Results Pending

1 0.0 ← B.A.C. → 2 0.0

INVESTIGATIVE - FATALITY REPORT

COUNTY	ON Road	CITY	DATE of Accident	☐ Fatal, narrative & diagram on fatal accident (required by State) ☐ Investigative Report	Page / of	
STATE USE ONLY	INVESTIGATIVE DEPT.	TIME Occurred	Day	Invest. OFFICER	BADGE No.	Local Case Number

Sample

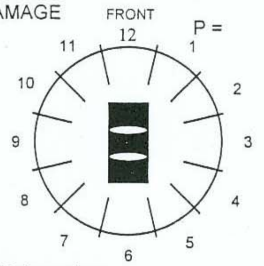
FATALITY DATA

TIME EMS NOTIFIED	EXTRICATION WAS REQUIRED FOR THE FOLLOWING PERSONS	SPECIAL JURISDICTION	
TIME EMS ARRIVED		00 Not Special 01 National Park Service 02 Military 03 Indian Reservation 04 College/University Campus 05 Other Federal properties 88 Other 99 Unknown	
TIME EMS ARRIVED AT HOSPITAL			

VEHICLE DAMAGE

I =

P =



☐ Undercarriage

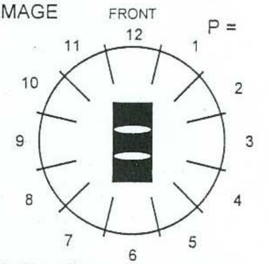
☐ No Damage

Estimated Speed,MPH

VEHICLE DAMAGE

I =

P =



☐ Undercarriage

☐ No Damage

Estimated Speed,MPH

IMPACT POINTS: Show initial impact point by arrow and label "I".
Show principal impact point by arrow and label "P".

Rev. 1-95

D.O.T FORM NO. 851

COLLISION DIAGRAM Draw scene as observed. Refer to vehicles, drivers, and pedestrians by numbers assigned in this report.

SHOW
(1) Outline of street and access points and identify specifically by number.
(2) Paths of units prior to and after impact, skidmarks, and point of impact (POI).
(3) Location of signs, traffic controls, and reference points.
(4) Location of other property hit or damaged (trees, signs, etc.).
(5) Specific features at location (bridge, overpass, culvert, railroad crossing, etc.).
(6) Location of temporary highway conditions.
(7) All measurements to locate the accident relative to specific, fixed, and identifiable points.

↑
NORTH

Sample

TRUCK - BUS SUPPLEMENT

☐ Completed post-crash inspection

Supplement required for accidents involving trucks with at least 2 axles and 6 tires, OR buses with a seat capacity of 15 or more, OR any vehicle transporting hazardous material.

COUNTY	ON Road	CITY	DATE of Accident	TIME Occurred	Day	Traffic Unit No.	Page of /

STATE USE ONLY	Investigating Dept.	Investigating Officer	Badge No.	Local Case Number

CARRIER NAME (CORPORATE BUSINESS NAME)

CARRIER ADDRESS CITY STATE ZIP CODE

U.S. GOVERNMENT PERMITS (Issuer and Number)

USDOT ____________ ICC MC ____________

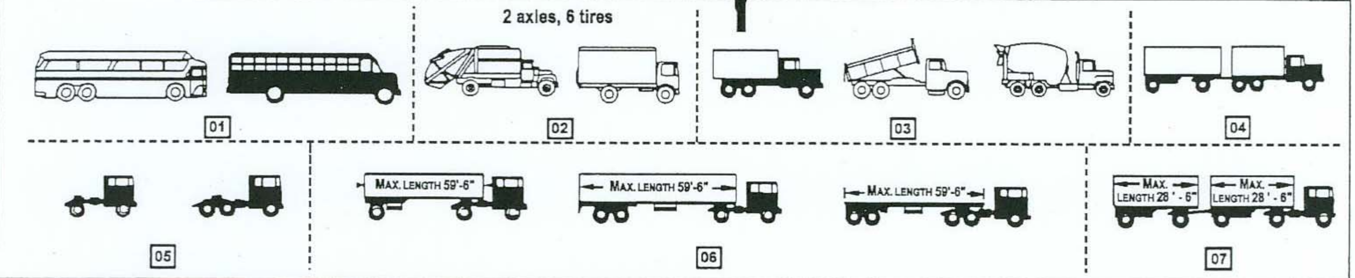
SOURCE OF NAME (Enter one only)

01 Side of vehicle
02 Shipping papers or manifest
03 Driver
04 Logbook

KANSAS PERMITS (Issuer and Permit Number)

1. ____________ ____________
2. ____________ ____________
3. ____________ ____________

Sample



VEHICLE CONFIGURATION

01 Bus ______ (capacity)
02 Single-unit truck (2-axle, 6-tires)
03 Single-unit truck (3 or more axles)
04 Truck and trailer
05 Truck tractor (bobtail)
06 Truck tractor and semi-trailer
07 Truck tractor and double trailer
08 Truck tractor and triple trailer
09 Heavy truck, cannot classify

ON ROAD LANE TYPE

00 Undivided
01 One-way roadway
02 Divided roadway, medianstrip without barrier
03 Divided roadway, medianstrip with barrier

ACCESS CONTROL

00 No control (unlimited access)
01 Full control (entry/exit only by ramp)

88 Other ____________

CAB TYPE

(for single truck or tractor)

01 Cab behind engine
02 Cab over engine

CARGO BODY TYPE

01 Van or enclosed box
02 Hopper
03 Tank
04 Flatbed
05 Dump
06 Concrete mixer
07 Auto transporter
08 Garbage or refuse

88 Other ____________

CARGO TYPE

00 Empty
01 Driveaway or towaway
02 Explosives
03 Farm and other animals
04 Farm products
05 Gases
06 General freight (packages)
07 Heavy machinery, objects
08 Household goods
09 Liquids (bulk)
10 Logs, poles, lumber
11 Metal (coils, sheets, etc.)
12 Mobile / Modular home
13 Motor vehicles
14 Refrigerated foods
15 Solids (bulk)
16 Rock, sand, gravel, salt
17 Food products
18 Plastic products

88 Other ____________

1
2
3
4

SEQUENCE OF EVENTS (list up to 4)

00 Ran off road
11 Jackknife
12 Overturn
13 Downhill runaway
14 Cargo loss or shift
15 Explosion
16 Fire
17 Separation of units
18 Trailer swing

COLLISION WITH:

21 Pedestrian
22 Motor vehicle in transport
23 Parked motor vehicle
24 Train
25 Pedalcycle
26 Animal
27 Fixed object
28 Other object

88 Other event ____________

TRAILERS			TOTALS				HAZARDOUS MATERIALS DATA		
	WIDTH (inches)	LENGTH (feet)	Total Length (feet)	No. of Axles	No. of Trailers	Gross Vehicle Weight	Material ID No.	Weight (pounds)	Spill or Release?
Trailer 1									
Trailer 2									
Trailer 3									

USE CODE "99" FOR UNKNOWN

Placard? Class:

Rev. 1-2003

D.O.T FORM NO. 852

ACCIDENT CODING LIST

Contributing Circumstances -- List in order of significance

(Example: Officer's Opinion ... | D1 | 07 | OR | 02 | interpretation: driver 1 - made imporper turn; On Road - icy or slushy)

D (n) DRIVER (1, 2, etc.)

01 Under influence of drugs
02 Under influence of alcohol
03 Failed to yield right of way
04 Disregarded traffic signs, signals, or markings
05 Exceeded posted speed limit
06 Too fast for conditions
07 Made improper turn
08 Wrong side or wrong way
09 Followed too closely
10 Improper lane change
11 Improper backing
12 Improper passing
13 Improper or no signal
14 Improper parking
15 Fell asleep
16 Inattention
17 Did not comply - license restrictions
18 Other Distraction in or on vehicle
19 Avoidance or evasion action
20 Impeding or too slow for traffic
21 Ill or medical condition
22 Distraction - mobile (cell) phone
23 Distraction - other electronic devices
24 Aggressive / Antagonistic driving
25 Reckless / Careless driving

P (n) - PEDESTRIAN/CYCLIST (1, 2, etc.)

01 Under influence of illegal drugs
02 Under influence of alcohol
03 Failed to yield right of way
04 Disregarded traffic control
05 Illegally in roadway
06 Pedalcycle violation
07 Clothing not visible
08 Inattention
09 Distraction - mobile (cell) phone

E - ENVIRONMENT

01 Fog, smoke, or smog
02 Sleet, hail, or freezing rain
03 Blowing sand, soil, or dirt
04 Strong winds
05 Rain, mist, or drizzle
06 Animal
07 Vision Obstruction: building, vehicles, objects made by humans
08 Vision Obstruction: vegetation
09 Vision Obstruction: glare from sun or headlights
10 Reduced visibility due to cloudy skies
11 Falling Snow

V (n)VEHICLE (1, 2, etc.)

01 Brakes
02 Tires
03 Exhaust
04 Headlights
05 Window or windshield (includes ice on windshield & designer tinting)
06 Wheel(s)
07 Trailer coupling
08 Cargo
09 Unattended or Driverless (in motion)
10 Unattended or Driverless (not in motion)
11 Other lights

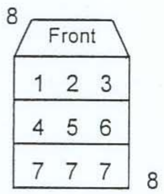
O/A (On/At) R (Road)

01 Wet
02 Icy or slushy
03 Debris or obstruction
04 Ruts, holes, bumps
05 Road construction or maintenance
06 Traffic control device inoperative
07 Shoulders: low, soft, high
08 Snow packed

Miscellaneous Codes:

Occupant Seat Position Codes

01 DRIVER (any vehicle type)
02 Center front
03 Right front
04 Left rear
05 Center rear
06 Right rear
07 Other seat position IN vehicle
08 Any position ON or Outside vehicle
09 Unknown location IN or ON vehicle
10 Motorcycle passengers
11 Extra person on driver's seat or lap
12-17 Extra person on passenger's lap



Ejected / Trapped

N No
E Ejected
P Partially Ejected
T Trapped
U Unknown

Train Occupant Seat Codes

31 Train crew (List all in control whether injured or not)
32 Train passenger (List only if injured)

Pedestrian Type Codes

21 Pedestrian
22 Pedalcyclist
23 Rider of animal
24 In animal-drawn vehicle
25 In vehicle NOT IN TRANSPORT
26 Machine operator or passenger
88 Other

Injury Severity

N Not injured
P Possible injury
I Injury, not incapacitating
D Disabled, incapacitating
F Fatal injury
U Unknown

Hazardous Material Classes

1 Explosives
2 Gases
3 Flammable/Combustible Liquid
4 Flammable/Combustible Solid
5 Oxidizers & organic peroxides
6 Poisonous/Infectious substance
7 Radioactive material
8 Corrosive material
9 Miscellaneous hazardous material

Safety Equipment Use

S Shoulder and Lap belt
X Shoulder only
L Lap belt only
I Infant seat / restraint system
C Child seat / restraint system
T "Booster" seat / restraint system
P Airbag deployed only (Passive System)
R Airbag deployed - Shoulder & Lap belt
J Airbag deployed - Shoulder belt only
W Airbag deployed - Lap belt only
F Airbag deployed - Infant seat
D Airbag deployed - Child seat
K Airbag deployed - "Booster" seat
B Both MC helmet and eye protection
E Motorcyclist eye protection
H Motorcyclist or pedalcycle helmet
N None used
U Unknown

Gender

M Male
F Female
U Unknown

Animal Type Codes

01 Deer
02 Other wild animal: bobcat, coyote, etc.
03 Cow
04 Other domestic animal: cat, dog, etc.
05 Horse

Appendix III

Crash Variable Tables

Index of the Tables Included in Appendix III

Table 1: Observations for Age

Number	Name of Observation
1	15-19
2	20-24
3	25-34
4	35-44
5	45-54
6	55-64
7	65+

Table 2: Observations for Gender

Number	Name of Observation
0	Male
1	Female

Table 3: Observations for Crash Time

Number	Name of Observation
1	6:00 a.m. - 10:00 a.m.
2	10:00 a.m. - 4:00 p.m.
3	4:00 p.m. - 8:00 p.m.
4	8:00 p.m. - 6:00 a.m.

Table 4: Observations for Day of the Week

Number	Name of Observation
1	Monday
2	Tuesday
3	Wednesday
4	Thursday
5	Friday
6	Saturday
7	Sunday

Table 5: Observations for Month of the Year

Number	Name of Observation
1	January
2	February
3	March
4	April
5	May
6	June
7	July
8	August
9	September
10	October
11	November
12	December

Table 6: Observations for Year of Crash

Number	Name of Observation
1	1992
2	1993
3	1994
4	1995
5	1996
6	1997
7	1998
8	1999
9	2000
10	2001
11	2002
12	2003
13	2004

Table 7: Observations for Light Condition

Number	Name of Observation
1	Daylight
2	Dawn
3	Dusk
4	Dark: street lights on
5	Dark: no street lights

Table 8: Observations for Weather Condition

Number	Name of Observation
1	No adverse conditions
2	Rain, Mist, Drizzle
3	Sleet
4	Snow
5	Fog
6	Smoke
7	Strong winds
8	Blowing dust, sand
9	Freezing rain
10	Rain & fog
11	Rain & wind
12	Sleet & fog
13	Snow & winds
14	Other

Table 9: Observations for Road Surface Condition

Number	Name of Observation
1	Dry
2	Wet
3	Snow or slush
4	Ice or snowpacked
5	Mud, dirt or sand
6	Debris
7	Other

Table 10: Observations for Vehicle Maneuver before Crash

Number	Name of Observation
1	Straight/following road
2	Left turn
3	Right turn
4	U-turn
5	Overtaking (passing)
6	Changing lanes
7	Avoiding maneuver
8	Merging
9	Parking
10	Backing
11	Stopped awaiting turn
12	Stopped in traffic
13	Illegal parked
14	Disabled in roadway
15	Slowing or stopping
16	Other

Table 11: Observations for Crash Severity

Number	Name of Observation
1	Fatal
2	Injury or near fatal
3	Property Damage Only

Table 12: Observations for Crash Type

Number	Name of Observation
1	Other non-collision
2	Overturned
3	Collision with pedestrian
4	Collision with parked motor vehicle
5	Collision with railway train
6	Collision with pedalcycle
7	Collision with animal
8	Collision with fixed object
9	Collision with other vehicle: head on
10	Collision with other vehicle: rear end
11	Collision with other vehicle: angle-side impact
12	Collision with other vehicle: sideswipe-opposite direction
13	Collision with other vehicle: sideswipe-same direction
14	Collision with other vehicle: backed into
15	Collision with other vehicle: other
16	Other object

Table 13: Observations for Vehicle Body Type

Number	Name of Observation
1	Commercial Truck with Commercial Truck
2	Commercial Truck with Vehicle
3	Commercial Truck with Motorcycle
4	Commercial Truck with Pedestrian/Worker
5	Commercial Truck with Object
6	Vehicle with Vehicle
7	Vehicle with Motorcycle
8	Vehicle with Pedestrian/Worker
9	Vehicle with Object
10	Other

Note: Vehicle includes sedan, wagon, coupe, convertible, suv, van, rv, small bus, and pickup

Table 14: Observations for Road Class

Number	Name of Observation
1	Interstate highway
2	Other freeways & Expressways
3	Other Principal Arterial
4	Minor Arterial
5	Major collector
6	Minor collector
7	Local roads

Table 15: Observations for Road Character

Number	Name of Observation
1	Straight and level
2	Straight on grade
3	Straight at hillcrest
4	Curved and level
5	Curved on grade
6	Curved at hillcrest
7	Other

Table 16: Observations for Crash Location

Number	Name of Observation
1	Non-intersection
2	Intersection
3	Intersection-related
4	Interchange area
5	On crossover
6	Other

Table 17: Observations for Surface Type

Number	Name of Observation
1	Concrete
2	Blacktop
3	Gravel
4	Dirt
5	Brick
6	Other

Table 18: Observations for Road Special Features

Number	Name of Observation
1	None
2	Bridge
3	Bridge overhead
4	Railroad bridge
5	Railroad crossing
6	Interchange
7	Ramp
8	Other

Table 19: Observations for Area Information

Number	Name of Observation
0	Urban
1	Rural

Table 20: Observations for Traffic Controls

Number	Name of Observation
1	None or inoperative
2	Officer or flagger
3	Traffic signal
4	Stop sign/signal
5	Flasher
6	Yield sign
7	RR gates or signal
8	RR crossing signal
9	No passing zone
10	Center/edge lines
11	Other control

Table 21: Observations for Driver Factor

Number	Name of Observation
0	No human error
1	Under influence of drugs
2	Under influence of alcohol
3	Failed to yield right of way
4	Disregarded traffic signs, signals, or markings
5	Exceeded posted speed limit
6	Too fast for conditions
7	Made improper turn
8	Wrong side or wrong way
9	Followed too closely
10	Improper lane change
11	Improper backing
12	Improper passing
13	Improper or no signal
14	Improper parking
15	Fell asleep
16	Inattention
17	Did not comply-license restrictions
18	Other distraction in or on vehicle
19	Avoidance or evasion action
20	Impeding or too slow for traffic
21	Ill or medical condition
22	Distraction-cell phone
23	Distraction-other electronic devices
24	Aggressive/Antagonistic driving
25	Reckless/Careless driving
26	Other/unknown

Table 22: Observations for Pedestrian Factor

Number	Name of Observation
1	Under influence of illegal drugs
2	Under influence of alcohol
3	Failed to yield right of way
4	Disregarded traffic controls
5	Illegally in roadway
6	Pedalcycle violation
7	Clothing not visible
8	Inattention
9	Distraction-cell phone

Table 23: Observations for Environment Factor

Number	Name of Observation
1	Fog, smoke, or smog
2	Sleet, hail or freezing rain
3	Blowing sand, soil or dirt
4	Strong winds
5	Rain, mist, or drizzle
6	Animal
7	Vision obstruction: building, vehicles, objects made by humans
8	Vision obstruction: vegetation
9	Vision obstruction: glare from sun or headlights
10	Reduced visibility due to cloudy skies
11	Falling Snow

Table 24: Observations for Vehicle Factor

Number	Name of Observation
1	Brakes
2	Tires
3	Exhaust
4	Headlights
5	Window or windshield
6	Wheels
7	Trailer coupling
8	Cargo
9	Unattended or driverless (in motion)
10	Unattended or driverless (not in motion)
11	Other lights

K - TRAN

KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY