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DETERMINING THE MAJOR CAUSES OF HIGHWAY WORK ZONE ACCIDENTS IN KANSAS (PHASE 2)

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16 Abstract

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The primary objectives of this study were to investigate the characteristics of the injury crashes, to identify risk factors that contributed to the injury crashes, and to compare characteristics between fatal and injury crashes in highway work zones. Frequency analysis was utilized to discover the basic characteristics reflected by single-variable frequencies as well as the complicated characteristics based on cross-categorized frequencies. The variable combinations used for analyzing cross-categorized frequencies were identified through independence test methods such as Pearson Chi-Square Test and Likelihood-Ratio Chi-Square Test. The characteristic comparison between fatal and injury crashes further helps to document the general characteristics of both fatal and injury crashes and to discover the unique factors that characterize different severities.

The researchers found significant characteristics of Kansas highway work zone injury crashes and summarized them in six categories. The researchers also discovered noteworthy characteristic differences between work zone fatal and injury crashes and concluded the important factors that could have increased the severity of work zone crashes. Potential safety improvements were recommended accordingly and future research were suggested. The significant insights from this study are valuable for the design of safer highway work zones and for the development of safety countermeasures that have potential not only in reducing the number of crashes but also in mitigating the crash severity.

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Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
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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.

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ABSTRACT

The work zones on the United States highway system have created an inevitable disruption on regular traffic flows and resulted in traffic safety problems. Understanding the characteristics and major causes of highway work zone crashes is a critical step towards developing effective safety countermeasures in highway work zones. In 2004, Kansas Department of Transportation (KDOT) initiated a project (K-TRAN Project No. KU-05-01) to study the fatal crashes in Kansas highway work zones between 1992 and 2004. The study results including crash characteristics and major crash contributing factors were published in Bai and Li (2006). Built on the previous success, KDOT sponsored this research project (K-TRAN Project No. KU-06-01) to further study the injury crashes during the same period in Kansas highway work zones.

The primary objectives of this study were to investigate the characteristics of the injury crashes, to identify risk factors that contributed to the injury crashes, and to compare characteristics between fatal and injury crashes in highway work zones. Frequency analysis was utilized to discover the basic characteristics reflected by single-variable frequencies as well as the complicated characteristics based on cross-categorized frequencies. The variable combinations used for analyzing cross-categorized frequencies were identified through independence test methods such as Pearson Chi-Square Test and Likelihood-Ratio Chi-Square Test. The characteristic comparison between fatal and injury crashes further helps to document the general characteristics of both fatal and injury crashes and to discover the unique factors that characterize different severities.

The researchers found significant characteristics of Kansas highway work zone injury crashes and summarized them in six categories. The researchers also discovered noteworthy characteristic differences between work zone fatal and injury crashes and concluded the important factors that could have increased the severity of work zone crashes. Potential safety improvements were recommended accordingly and future researches were suggested. The significant insights from this study are valuable for the design of safer highway work zones and for the development of safety countermeasures that have potential not only in reducing the number of crashes but also in mitigating the crash severity.

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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 allocating their funding on preserving, expanding, and enhancing the existing highway networks. As a result, the traveling public will encounter more and more work zones on the highways. The highway work zones have created an inevitable disruption on regular traffic flows and have resulted in traffic safety problems. Nationally, great effort has been devoted to improving the safety and mobility of work zone traffic. The recent Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) included a number of provisions emphasizing highway work zone safety and other work zone-related issues (FHWA 2005). The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have played leading roles on this subject and have developed practical highway work zone safety guides and programs. Many state Departments of Transportation (DOTs) have been initiating research projects to improve work zone safety in their states. Other concerned organizations and research individuals have also participated in this campaign by conducting meaningful research on various work zone safety issues.

Despite the effort, work zone safety remains unsatisfactory nationwide. In 2004, 1,068 people were killed in work zones, adding about 49,620 more work zone related injuries (FHWA 2006). The direct cost of highway work zone crashes, estimated based on the crash data from 1995 to 1997, was as high as $6.2 billion per year: an average cost of $3,687 per crash (Mohan and Gautam 2002).

Understanding the characteristics and major causes of highway work zone crashes is a critical step towards developing effective safety countermeasures in highway work zones. In 2005, Kansas Department of Transportation (KDOT) initiated a project (K-TRAN Project No. KU-05-01) to study the fatal crashes in Kansas highway work zones between 1992 and 2004. The results including crash characteristics and major crash contributing factors were published in Bai and Li (2006). Built on the previous success, KDOT sponsored this research project (K-TRAN Project No. KU-06-01) to study the Kansas work zone injury crashes in the same period. The goal of this study was to systematically investigate the characteristics and contributing factors of Kansas work zone injury crashes. The results of injury crashes were compared with those of the fatal crashes to discover the unique characteristics that distinguish different severities. The significant safety insights from this research project are valuable for the development of more effective safety countermeasures in highway work zones.

1.2 Report Organization

This report presents the results from the analyses of Kansas highway work zone crashes, which are organized as the following chapters:

Chapter 1: Introduction. This chapter starts with a general introduction to work zone safety-related issues followed by this brief description of the report organization.

Chapter 2: Literature review. This chapter presents the findings of the literature review on work zone safety-related studies. The literature review included the previous explorations on work zone crash characteristics as well as the typical intelligent transportation system (ITS) applications in highway work zones.

Chapter 3: Research objectives and methodology. This chapter outlines the objectives and methodology of this study on work zone injury crashes.

Chapter 4: Data collection. This chapter describes various data collection issues including the procedure of data collection, the organization of crash data, and the determination of injury crash sample size.

Chapter 5: Data analyses. This chapter presents the data analysis procedures and the results of data analyses such as frequency analyses and interrelated crash factor analyses. The outcomes of the injury crash analyses presented in this chapter include injury crash characteristics and the determined highway work zone risk factors.

Chapter 6: Work Zone Injury and Fatal Crash Characteristic Comparison. This chapter presents the comparison of the major characteristics between work zone fatal and injury crashes. The characteristic comparison helps to thoroughly understand the general characteristics of work zone severe crashes involving fatalities and injuries and the major differences characterizing the crashes of different severities.

Chapter 7: Conclusions and recommendations. This chapter first outlines the conclusions based on the work zone crash analyses. These conclusions include the major crash characteristics and factors potentially contributed to the increase of work zone crash severity. Next, safety countermeasures and future research needs are recommended accordingly in the chapter.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

Nowadays, highway funding has been mostly allocated on existing highway preservation, expansion, and enhancement. Most of these construction activities require the set-up of work zones on highways with active traffic. The interrupted travel conditions in work zones result in safety problems including increased crash frequency and severity. To address these issues, researches on highway work zone safety have been carried out for decades. The early research efforts on this subject can be found in California Department of Public Works (1965) and Munro and Huang (1968). To date, a number of studies on highway work zone safety have been published.

A detailed literature review on work zone safety-related subjects was conducted in the previous project (K-TRAN Project No. KU-05-01) and findings were published in the final report (Bai and Li 2006). The subjects covered in that report included previous analyses on highway work zone crashes, statistical methods and applications in accident data analysis, highway work zone traffic control, research and development trend, and other highway work zone-safety related researches. In this project, the literature review was primarily focused on work zone crash characteristic studies. Moreover, a brief review of the typical ITS applications in work zones were also included since they represent the advanced work zone traffic control technologies. The reviewed materials are from various sources including journals, research reports, conference proceedings, and periodicals.

2.2 Previous Studies on Work Zone Crash Characteristics

2.2.1 Work Zone Crash Characteristics

This section synthesizes the findings of previous studies on work zone crash characteristics. Table 2.1 lists the work zone crash studies after the late 1970s that were included in this literature review. Most of these studies were conducted statewide, although a few addressed nationwide work zone safety issues. Because of the diversity of the data scopes, some findings were inconsistent. The predominant work zone crash characteristics concluded in these studies are summarized in terms of severity, rate, type, time, location, and causal factors.

Crash Severity. When compared with non-work zone crashes, inconsistent conclusions have been reached about whether more severe crashes occur in work zones. Some studies from Virginia (Garber and Zhao 2002), Texas (Ullman and Krammes 1990), Kentucky (Pigman and Agent 1990), and Ohio (Nemeth and Migletz 1978) documented significant increases of severe crashes in work zones. A national study (AASHTO 1987) also discovered that both fatal crash frequency and average fatalities per crash were higher in work zones across the nation. However, several other studies (Chembless et al. 2002; Ha and Nemeth 1995; Hall and Lorenz 1989) did not find significant changes on work zone crash severity. The work zone crashes were even found less severe in a few other studies (Wang et al. 1996; Garber and Woo 1990; Rouphail et al. 1988; Hargroves 1981).

Table 2.1: Previous Work zone Crash Studies

Subject	No.	Study Data	State	Ref.
Crash characteristics	1	Statewide WZ crashes (1996-1999)	Virginia	Garber and Zhao 2002
	2	Alabama crashes (1994 - 1998); Michigan crashes (1996 – 1998); Tennessee crashes (1994–1997)	Alabama, Michigan, Tennessee	Chembless et al. 2002
	3	Crashes of three states (1991-1992)	--	Wang et al. 1996
	4	Crashes of 20 WZ's (1986-1987)	Kentucky	Pigman and Agent 1990
	5	Statewide WZ crashes (1982-1986)	Ohio	Ha and Nemeth 1995
	6	Crashes on Interstate and other primary highway systems (1984-1985)	National (46 states)	AASHTO 1987
	7	Statewide WZ crashes (1983-1985)	New Mexico	Hall and Lorenz 1989
	8	2,127 WZ crashes (1977)	Virginia	Hargroves 1981
	9	151 crashes of 21 WZ's (1973)	Ohio	Nemeth and Migletz 1978
	10	Crashes of 79 long-term WZ's	Multi-state	Graham et al. 1977
Crash characteristic and traffic control study	11	Crashes in long-term and short-term WZ's in Chicago (1980-1985)	Illinois	Rouphail et al. 1988
Crash costs	12	3,686 WZ crashes (1990–1993) from Liberty Mutual Insurance Company Database	--	Mohan and Gautam 2002
Crash rate	13	Crashes before and after 7 interstate WZ's	Indiana	Pal and Sinha 1996
Fatal crash characteristics	14	77 fatal WZ crashes throughout Texas (02/2003– 4/2004)	Texas	Schrock et al. 2004
	15	376 fatal crashes (1997-1999)	Texas	Hill 2003
	16	181 fatal WZ crashes (1995-1997)	Georgia	Daniel et al. 2000
Long-term WZ crashes	17	Crashes at 5 long-term WZ's (1984-1988)	Texas	Ullman and Krammes 1990
Truck drivers' crash experience	18	834 surveys to truck drivers (1993)	Illinois	Benekohal et al. 1995
Urban WZ crashes	19	Crashes of 26 urban WZ's (1982-1985)	--	Garber and Woo 1990

Note: Unless otherwise defined, the crashes here are work zone crashes; WZ: work zone.

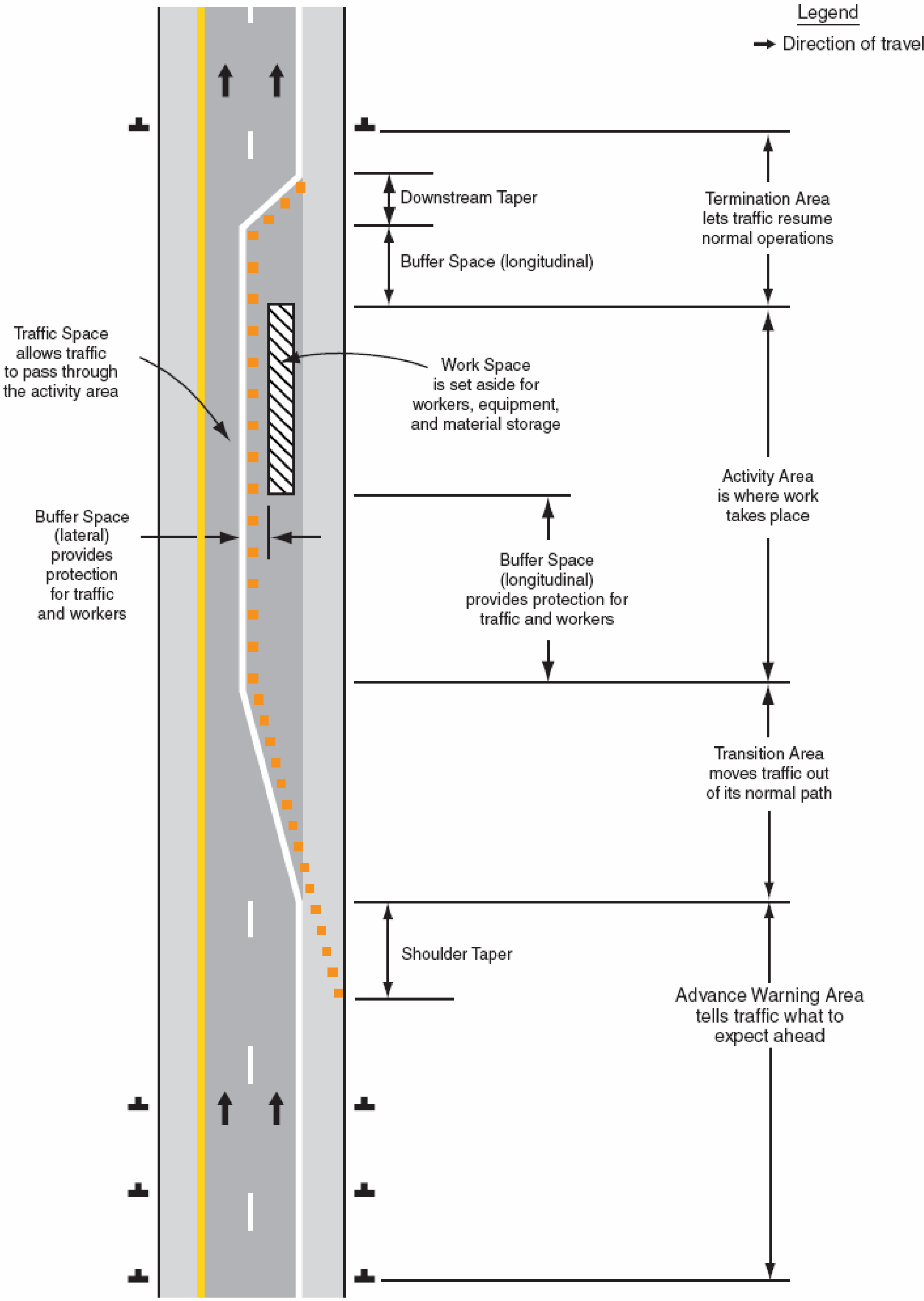
Crash Rate. Since highway work zones disrupt regular traffic flows, higher crash rates would be an anticipated outcome. Many studies (Garber and Zhao 2002; Pigman and Agent 1990; AASHTO 1987; Hall and Lorenz 1989; Pal and Sinha 1996; Graham et al. 1977) agreed on the higher crash rates in highway work zones. In particular, some studies (Ullman and Krammes 1990; Rouphail et al. 1988) suggested that considerably crash-rate increases could be expected in long-term highway work zones.

Crash Type. The prevailing types of work zone crashes vary with different locations and times, but it was agreed by most of the previous studies that rear-end collisions were one of the most frequent work zone crash types (Mohan and Gautam 2002; Garber and Zhao 2002; Pigman and Agent 1990; Nemeth and Migletz 1978; Chembless et al. 2002; Hall and Lorenz 1989; Wang et al. 1996; Garber and Woo 1990; Rouphail et al. 1988; Hargroves 1981). Other major crash types in work zones include same-direction sideswipe collision (Pigman and Agent 1990; Garber and Woo 1990) and angle collision (Pigman and Agent 1990). Some studies ranked hit-fixed-object as another dominant type of work zone crash (Mohan and Gautam 2002; Nemeth and Migletz 1978; Hargroves 1981). A study in Georgia found that single-vehicle crashes, angle, and head-on collisions were the dominant types of fatal work zone crashes (Daniel et al. 2000).

Another major work zone safety concern is the frequent involvement of heavy trucks in work zone crashes. Several studies found that the percentage of truck-involved crashes was much higher in work zones (Pigman and Agent 1990; AASHTO 1987) and heavy truck related crashes were more likely to involve multiple vehicles and hence frequently resulted in fatalities and large monetary loss (Pigman and Agent 1990; Schrock et al. 2004; Hill 2003). Because of the alarming crash numbers, Benekohal et al. (1995) found that 90% of the surveyed truck drivers considered driving through work zones to be more hazardous than in other areas.

Crash Time. Work zone crashes frequently occur in the daytime (Mohan and Gautam 2002; Chembless et al. 2002; Hill 2003; Li and Bai 2006) during the busiest construction season between June and October (Pigman and Agent 1990). Nighttime work zone crashes, however, were found to be much more severe in most cases (Garber and Zhao 2002; Pigman and Agent 1990; AASHTO 1987). Nemeth and Migletz (1978) found that the proportion of tractor-trailer- or bus- caused crashes at darkness was greater than the proportion of other vehicles, which consequently resulted in more severe crashes due to the large sizes of tractor-trailers and buses.

Crash Location. Figure 2.1 illustrates the component areas of a highway work zone as defined in the 2003 Manual on Uniform Traffic Control Devices (MUTCD). According to the literature review, the previous studies agreed on the unbalanced crash distribution along the work zones, but they did not reach consistent conclusions on the most dangerous work zone areas. The activity area (Garber and Zhao 2002; Schrock et al. 2004), the advanced warning area (Pigman and Agent 1990), the transition area, and the termination area (Nemeth and Migletz 1978; Hargroves 1981) were highlighted as the most dangerous areas in terms of severe crash frequency in different literatures. In addition, a national study (AASHTO 1987) found that the work zones on rural highways accounted for 69% of all fatal crashes. In particular, the rural interstate systems (Pigman and Agent 1990; AASHTO 1987; Chembless et al. 2002) or two-lane highways (Rouphail et al. 1988) are the places where work zone crashes most likely happen. However, a Virginia study (Garber and Zhao 2002) argued that, in general, urban highways had much higher percentage of work zone crashes than rural highways.



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

Figure 2.1: Component Areas of a Highway Work Zone

Causal Factors. Most previous studies pointed at human errors, such as following too close, inattentive driving, and misjudging, as the most common causes for work zone crashes (Mohan and Gautam 2002; Pigman and Agent 1990; Chembless et al. 2002; Hargroves 1981; Daniel et al. 2000). Some studies also indicate that speeding (Garber and Zhao 2002) and inefficient traffic control (Ha and Nemeth 1995) are two other factors causing crashes in work zones. Hill (Hill 2003) found that there was a significant difference on types of driver errors between daytime crashes and nighttime crashes. Researchers proved that adverse environmental and road surface conditions did not contribute more to work zone crashes than to crashes at other places(Nemeth and Migletz 1978; Garber and Woo 1990).

2.2.2 Summary of Work Zone Crash Characteristics

The characteristics of work zone crashes studied in the previous researches are summarized as following:

1. Researches on work zone safety have been carried out since 1960s. To date, most work zone crash studies have been conducted statewide and their findings vary in some aspects.
2. There is no consistent conclusion on whether work zone crashes were more severe than other crashes. However, researchers agreed on that truck-involved and nighttime work zone crashes were more severe than non-work zone crashes.
3. Most previous studies showed that it was likelier to have crashes in work zones than in non-work zones. Particularly, higher crash rates were found in rural and long-term highway work zones.

4. Rear-end, same-direction sideswipe, and angle collisions were the most frequent crash types in work zones. Single-vehicle crashes, angle, and head-on collisions were frequently found among fatal work zone crashes. Truck-involved crashes were more frequent and severe in work zones.
5. Most work zone crashes occurred in the daytime. However, work zone crashes during nighttime were more severe than both daytime work zone crashes and non-work zone crashes.
6. No consistent conclusion was reached on the most dangerous area in work zones. However, previous studies indicated that rural interstate highways were most likely to have work zone crashes.
7. Human errors such as speeding and inefficient traffic controls were the major causes of work zone crashes. Adverse environmental factors, in contrast, were not contributing more for work zone crashes than for non-work zone crashes.

2.3 ITS Applications in Highway Work Zones

ITS represents the most advanced traffic controls and management techniques that have been developed and implemented in the transportation industry. Some ITS have been implemented in highway work zones to improve safety and mitigate congestions. These systems usually involve the use of electronics, computers, and communication equipment to collect, process, and share the real-time information. Traffic engineers use the information to decide traffic control actions accordingly. ITS applications in highway work zones may function for one or several of the following purposes (FHWA 2006b):

- Traffic monitoring and management

- Providing traveler information
- Incident management
- Enhancing safety of both the road user and worker
- Increasing capacity
- Enforcement
- Tracking and evaluation of contract incentives/disincentives (performance-based contracting)
- Work zone planning

This section provides the results of reviews on the ITS applications in highway work zones. A review of these applications helps researchers to understand the most recent work zone traffic control techniques. A list of the previous ITS applications are presented in Table 2.2.

Table 2.2: Reviewed ITS Technologies

No.	ITS Technology	Effectiveness	Reference
1	Real-time traffic control systems	Improved work zone traffic flow and safety	FHWA 2002
2	Dynamic lane merge systems	Reduced average delay and number of vehicles stops	FHWA 2004a
3	Temporary traffic management systems	Real-time traffic information for pre-trip route planning	FHWA 2002
4	Work zone traffic and incident management systems	Improved in work zone safety and mobility	FHWA 2004b
5	Work zone travel time systems	Reduced work zone delays	FHWA 2004c
6	Advanced Traveler Information Systems	No significant increase on vehicle diversion, user acknowledgement	Pesti et al. 2004; Bushman and Berthelot 2005

<u>Real-Time Traffic Control System (RTTCS).</u> A RTTCS was deployed in a work zone on I-55 by Illinois Department of Transportation (IDOT) to reduce congestion and improve safety (FHWA 2002). The RTTCS consisted of portable dynamic message

signs (DMS), portable traffic sensors, and portable closed circuit television (CCTV) cameras. The traffic sensors detect types of approaching vehicles and their traveling speeds first, and then based on predefined thresholds, the DMS displayed proper messages to warn the drivers of traveling hazards. The sensors and cameras also sent data to a real-time congestion map displayed on IDOT's website for public information and provided congestion/incident detection alerts to IDOT staff for further traffic management actions. IDOT staff believed that the system effectively improved the work zone traffic flow and safety, and provided important traffic information for trip planning with minimal human intervention.

Dynamic Lane Merge System (DLMS). The Michigan Department of Transportation (MDOT) rebuilt a large section of I-94 near Detroit during the 2002 and 2003 summer construction seasons. In the project, MDOT implemented a DLMS to help smooth traffic flow and reduce aggressive driving prior to transiting to the construction area (FHWA 2004a). The system consisted of microwave radar sensors installed on five trailers to detect traffic volume, vehicle speed, and traffic density. These data were analyzed and results triggered the system to automatically change the messages displayed on DMS to enforce different merging strategies and regulate merging traffic. The evaluation performed by MDOT indicated that the system was effective in reducing average delay and number of vehicles stops. It also considerably decreased aggressive merging maneuvers and consequently resulted in less work zone crashes.

Temporary Traffic Management System (TTMS). A TTMS was deployed by Michigan Department of Transportation (MDOT) during a construction project that involved a total closure of I-496 in downtown Lansing, Michigan (FHWA 2002). The ITS system included traffic detection and surveillance equipment along with changeable message signs and a public information website in an effort to help guiding motorists to alternate routes and alleviate traffic congestion on surrounding roads when the major freeway was closed. The real-time traffic data were collected by the on-site detection and surveillance equipment and sent back to a server at the Construction Traffic Management Center (CTMC) via wireless radio frequency communication equipment. The server processed the data and then informed CTMC operators of problem areas where queues were building and automatically updated DMS and displayed a map with color-coded average roadway speeds on the website for trip planning. The system made possible for daily commuters to make right choices regarding their travel plans and thus mitigated congestions in the work zone.

Work Zone Traffic and Incident Management System (TIMS). An example of work zone TIMS was demonstrated in a large highway project conducted by New Mexico State Highway and Transportation Department (NMSHTD) (FHWA 2004b). The system consisted of a series of DMS, CCTV cameras, and highway advisory radio (HAR) units, which were all linked to a central traffic management center. The CCTV cameras detected the real-time traffic conditions and sent data to the traffic management center, where trained staff identified incidents and other adverse traffic conditions and initiated appropriate responses immediately. Meanwhile, DMS displayed appropriate messages and HAR transmitted them to the motorists. NMSHTD's evaluation showed that the system improved work zone mobility by effectively reducing congestion and incident clearance time. In addition, the system resulted in a 32% reduction in crashes during the first three months of its installation.

Work Zone Travel Time System (TTS). The Arizona Department of Transportation (ADOT) used a TTS to support work zone operations during the reconstruction and widening of State Route 68 (SR 68) in northern Arizona (FHWA 2004c). The system consisted of two monitoring stations and a central processor. Each monitoring station included an inductive loop embedded in the roadway, a control cabinet with a communication system, and two digital cameras (one for each direction of traffic) linked to the cabinet via fiber-optic cable. The system captured images of individual vehicles and calculated their travel times through the work zone. Based on the travel times, ADOT staff estimated the delays and assessed the contractor a disincentive fee when excessive delay occurred. By doing so, the contractor was forced to adjust its construction sequences to mitigate the work zone travel delays so that travel time provision set by ADOT could be met. The system allowed ADOT staff to effectively monitor the construction process and reduced excessive travel delays in the work zone.

Advanced Traveler Information System (ATIS). An ATIS is designed to disseminate real-time traffic information including route and delay conditions to drivers to allow them make reasonable travel decisions. The information is usually communicated through changeable message signs (CMS) or other media. An ATIS was deployed in the advance warning area of a work zone on northbound I-680 by Nebraska Department of Roads (NDOR). The system was utilized to advise drivers the real-time work zone speeds and to encourage them to divert to alternate routes to avoid congestions (Pesti et al. 2004). The system was comprised of a video detection system, two portable CMS, and a central computer to coordinate communications between the detection system and the CMS. NDOR staffs were informed by the detected speeds, which enabled them to display real-time advisory messages accordingly. However, during the evaluation process, NDOR failed to prove that using this system could significantly increase vehicle diversion. Bushman and Berthelot (2005) evaluated a similar system implemented in North Carolina through a public survey and found that most motorists acknowledged the benefits of such kind of a system.

2.4 Literature Review Summary

In the previous project report, Bai and Li (2006) presented a comprehensive literature review on highway work zone safety. Findings of that report were summarized into five categories including 1) previous analyses of highway work zone crashes; 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. In this project, the literature review was only focused on the work zone crash characteristic studies and ITS applications in highway work zones. A brief summary of the findings is presented as follows.

According to the literature, the importance of having safe work zones for both construction workers and highway users has been widely recognized. Despite the effort devoted in this subject, there is little indication that work zone crashes are on the decline nationwide. An important 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. The literature review also showed that work zone crash characteristics vary from state to state across the country. Thus, simply adopting the practices of other states may not be the best solution for Kansans.

Work zone crash characteristics have been explored in a number of studies with a variety of data sources. Some of the sources included urban work zone crashes, crashes in long-term work zones, and work zone crashes on interstates and other primary highways. Some of the studies analyzed the general characteristics of work zone crashes of all severities and others only focused on crashes of a certain severity such as fatal crashes. Most of the previous studies were based on statewide crash data; only a few used multi-state data. The researchers found no studies comparing the characteristics between the work zone crashes of different severities such as fatal vs. injury crashes.

ITS technologies have been implemented in highway work zones to improve safety and mitigate congestions. Their major functions include traffic control, public information, and project monitoring. These systems usually collect, process, and share the real-time traffic information for traffic engineers to decide appropriate traffic control actions and to inform the traveling public. Results of evaluations showed that most of the applications were effective in improving work zone safety and reducing traffic delay.

CHAPTER 3 - RESEARCH OBJECTIVES AND METHODOLOGY

3.1 Research Objectives

The primary objectives of this research were to investigate the characteristics of injury crashes, to identify risk factors that contributed to injury crashes, and to compare characteristics between fatal and injury crashes. The data collection scope of this research was limited to injury crashes between 1992 and 2004 in the work zones on the State of Kansas highway system. Fatal crash data was collected in the previous project (K-TRAN Project No. KU-05-01) in the same time period and will be used for comparison.

3.2 Methodology

The research objectives are achieved in five steps:

1. Literature review. The previous work zone crash analyses and the recent work zone ITS applications were reviewed first. The review findings are presented in chapter two of this report. These findings included a synthesis of work zone crash characteristics from the past studies and an introduction to the state-of-the-practice on work zone ITS applications.

2. Data collection. A sample data of 460 work zone injury crashes from KDOT accident database between 1992 and 2004 were recompiled to a spreadsheet for statistical analyses. The sample size was determined based on sampling theories. Using this size, the analysis results could reflect the true characteristics of the total injury crashes at 5% level of confidence. Instead of the analyzing the entire crash population, studying the sample crashes reduced excessive time spent on data

collection while maintained relatively high accuracy. The original crash reports for the cases with unclear information were screened to maximize the data accuracy.

3. Work zone injury crash 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 achieve the research objectives. The results of analyses were classified into two categories: 1) work zone injury crash characteristics and 2) risk factors (that contribute to the injury crashes in the work zones).

4. Characteristic comparison between fatal and injury crashes. In this step, the characteristics of work zone fatal and injury crashes were compared. Through the comparison, the factors that had impacts on the increase of work zone crash severity were determined. The determination of these factors may help traffic engineers to design safety countermeasures that reduce the severity of crashes.

5. Conclusions and recommendations. The major research findings including injury crash characteristics, significant risk factors, and comparison between fatal and injury crashes were concluded. The research team also recommended work zone safety improvements and potential future researches.

CHAPTER 4 - DATA COLLECTION

4.1 Data Collection Procedure and Crash Variables

This study focused on the injury crashes that occurred in the Kansas highway work zones from January 1, 1992 to December 31, 2004. The crash data were extracted from KDOT accident database. Some of the crashes contained multiple data rows because each of these crashes involved multiple drivers, had multiple traffic controls in work zones, or drivers made multiple errors leading to the crash. In contrast, one data row for each crash was required for data analyses in the SAS software. Thus, compiling the crash data into one-data-row format without missing useful information became a critical task.

The data collection procedure included two steps. First, based on KDOT's database, the at-fault 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 using the one-data-row format in the spreadsheet. Any confusing and/or missing information was clarified with the help from KDOT personnel. The spreadsheet was designed to encompass all the information shown on the original accident reports (see Appendix I for a sample accident report).

Six major categories of crash information were collected. Each category included several crash variables and each variable had a number of observations. The observations were selected based on the KDOT accident report. For example, the crash variable "gender" belongs to the category of "at-fault driver" and it has two observations known as "male" and "female". For some crash variables, the detailed observations were reorganized into broader groups. Without losing necessary information, this regrouping was intended to maximize the accuracy in statistical analyses such as Chi-square tests by increasing the frequencies of cross-categorized data points. The six categories and their variables are listed in Table 4.1 and described in the following paragraphs.

At-fault driver. This category included basic information about the drivers responsible for the work zone crashes. Two variables, age and gender, fell in this category. Age was divided into seven observations (see Appendix B, Table B.1) and gender had two observations: male and female (see Appendix B, Table B.2). Each observation was assigned a numerical value so that statistical analyses could be performed.

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 morning peak hours; 10:00 a.m. – 4:00 p.m. as daytime non-peak hours; 4:00 p.m. – 8:00 p.m. as afternoon peak hours; and 8:00 p.m. – 6:00 a.m. as nighttime hours. Other temporal variables included day of week and month. Tables B.3 – B.6 in Appendix B show the four variables in this category and their observations.

Climatic environment. The climatic environmental information recorded the work zone light, weather and road surface conditions when a crash occurred. Light conditions included five observations according to factors affecting visibility such as daylight and darkness. Weather conditions had 14 observations that might have impacts on traffic conditions. Road surface conditions had seven observations reflecting different characteristics of highway surfaces. In addition, the observations of these three variables were further regrouped as good conditions or poor conditions. Good conditions refer to the conditions that are favorable to drivers; while poor conditions were unfavorable to drivers and may impair their driving. The observations of these variables are listed in Tables B.7 – B.9 in Appendix B.

Table 4.1: Crash Data Categories and Variables

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

Crash information. The crash variables included 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, and property-damage-only (PDO); but "injury" was the only observation for this study. For crash type, 16 different observations were included which were further regrouped as "vehicle-vehicle" and "vehicle-other" crashes. The vehicle body types were classified into ten observations reflecting vehicle classes such as heavy trucks, light-duty vehicles, motorcycles, pedestrians, etc. The term "vehicle" or "light-duty vehicle" refers to such vehicle types as passenger cars, minivans, pickups, campers or RVs, sport utility vehicles (SUVs), and all-terrain vehicles (ATVs); while "truck" includes such heavy vehicle types as single large trucks, truck and trailers, tractor-trailers, and buses. The observations of vehicle body type were also regrouped into three general observations such as "truck-involved", "vehicle-only", and "other" as listed in Table B.13 in Appendix B. The number of vehicles involved in a crash was recorded using the actual number. The observations of the crash information variables are listed in Tables B.10 – B.13 in Appendix B.

Road conditions. The variables in this category described the road conditions where an injury crash occurred in the work zones. 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 had seven classifications that were defined in the KDOT accident reports. Road character had seven observations describing the geometric alignments of a 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 according to the presence of features such as bridges, ramps, and interchanges. Area information had two observations: urban and rural. There were 11 observations for traffic control devices. Many crashes had multiple traffic control devices on site. Multiple columns were added under the heading of "Traffic Control" in the spreadsheet to accommodate all major traffic control devices at the crash sites. A similar strategy was used to record driver factor variable that frequently had multiple observations for single crash. Other variables, including number of lanes and speed limit, were recorded using the actual number in the spreadsheets. In this data category, the observations of variables such as road character and road special feature were regrouped according to if the observations are favorable to drivers. Tables B.14 – b.20 in Appendix B show the observations and observation groups of these variables.

Contributing factors. This category listed the elements that were identified on the accident reports as the contributing factors to the crashes. These elements included driver factor which had 26 observations (Table B.21 in Appendix B), pedestrian factor which had nine observations (Table B.22 in Appendix B), environment factor which had 11 observations (Table B.23 in Appendix B), and vehicle factor which had 11 observations (Table B.24 in Appendix B).

The observations of each variable were assigned integer values and the final spreadsheets contained only numbers. A portion of the spreadsheets is presented in Appendix C.

4.2 Determine the Number of Injury Crashes for Analyses

There were 4,443 injury crashes in Kansas highway work zones from January 1, 1992 to December 31, 2004. It would be extremely time-consuming yet not statistically meaningful to compile and analyze this entire injury dataset. Instead, 460 injury crashes were randomly sampled from the KDOT database to save data collection time while maintain reasonable accuracy of analysis results.

The sample size was determined based on the method of Thompson (2002). Considering that the data would be used for frequency analysis of characteristics reflected through the proportions of the different crashes marked by different variable observations, the sample size was determined such that the proportions can be estimated accurately. Based on normal approximation, to obtain a proportion estimator $\hat{p}$ with a probability of at least 1- α of being no farther than *d* (error) from the true population proportion *p*, one would choose a corresponding sample size such that

$$P(|\hat{p} - p| > d) < \alpha .$$

When $\hat{p}$ is an unbiased, normally distributed estimator of *p*, the variable

$$\frac{\hat{p} - p}{\sqrt{\mathrm{var}(\hat{p})}}$$

has a standard normal distribution *N(0, 1)*. For estimating a proportion, an unbiased estimator of the variance var($\hat{p}$) can be estimated by:

$$\mathrm{var}(\hat{p}) = \left(\frac{N-n}{N}\right)\frac{\hat{p}(1-\hat{p})}{n-1},$$

where *N* is the population size.

Given the above theoretical basis, to obtain an estimator $\hat{p}$ of the true proportion *p* with *1- α* confidence of having an error less then *d*, the minimum sample size n_{min} required could be computed using the following equation:

$$n_{\min} = \frac{Np(1-p)}{(N-1)(d^2/z_{\alpha/2}^2) + p(1-p)},$$

where $z_{\alpha/2}$ is the upper α/2 point of the standard normal distribution.

When there is no estimate of *p* available and *N* is large, a worst-case value of *p = 0.5* can be used in determining the minimum sample size:

$$n_{\min} = \frac{1}{(N-1)/Nn_0 + 1/N} \approx \frac{1}{1/n_0 + 1/N},$$

where:

$$n_0 = \frac{z_{\alpha/2}^2\, p(1-p)}{d^2} = \frac{0.25 z_{\alpha/2}^2}{d^2}.$$

Note that the minimum sample size determined using this equation is theoretically appropriate to estimate the proportion of the crashes with only binary variables. In fact, variables frequently have several values and multiple proportions need to be estimated simultaneously. For example, the “age” variable is usually divided into several groups (i.e. 15-19, 20-24, 25-29…) and the crash proportions of all these groups need to be estimated simultaneously. In this situation, the sample size should be adjusted accordingly. Based on the same rationale, Thompson (2002) provided a table (Table 4.2) of adjusted n_0 when the population size *N* is large.

Based on Equation *[4.2.1]* and Table 4.2, given the 4,443 injury crashes from 1992 to 2004, the minimum sample size needed for frequency analysis at 95% confidence level (an error *d* less than 5%) was determined as:

$$n_{\min} \approx \frac{1}{1/n_0 + 1/N} = \frac{1}{1/510 + 1/4443} = 457$$

and rounded to 460.

Table 4.2: Sample Size n_0 for Simultaneously Estimating Several Proportions within Distance d of the True Values at Confidence Level (1- α)

α	$d^2 n_0$	n_0 **with** d **= 0.05**	m
0.5	0.44129	177	4
0.4	0.50729	203	4
0.3	0.60123	241	3
0.2	0.74739	299	3
0.1	1.00635	403	3
0.05	1.27359	510	3
0.025	1.55963	624	2
0.02	1.65872	664	2
0.01	1.96986	788	2
0.005	2.28514	915	2
0.001	3.02892	1212	2
0.0005	3.33530	1342	2
0.0001	4.11209	1645	2
Note:	The worst-case minimum sample size occurs when some *m* of the proportions in the population are equal and the rest are zero.		

(Source: *Sampling*. Thompson, S. K., John Willy & Sons Inc. 2002. p16)

4.3 Summary

As a key step towards data analyses, the original crash data were colleted and compiled into a spreadsheet that was suitable for statistical analyses using SAS software without missing critical crash information. The final spreadsheets contained only crash variables whose observations were all represented by numerical values. A sample of 460 injury crashes between January 1, 1992 and December 31, 2004 was examined. The sample size was determined using statistical theory to provide a 5% level of significance.

CHAPTER 5 - DATA ANALYSIS

5.1 Injury Work Zone Crash Characteristics

5.1.1 Introduction

Annually, a noteworthy proportion of traffic crashes in Kansas occur in highway work zones. As shown in Table 5.1 and Figure 5.1, in the past 13 years (1992 – 2004), Kansas had 15,434 work zone crashes and about 29% or 4,443 of them involved injuries. Figure 5.2 illustrates the 13-year (1992-2004) trends of the total work zone injuries in Kansas. This figure shows a continuous increasing in the number of annual work zone injuries since 2000. However, researchers do not know precisely the number of work zone crashes per vehicle miles traveled (VMT) each year during this period. The crash increase could be partly due to the increasing VMT in Kansas work zones.

Table 5.1: 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.

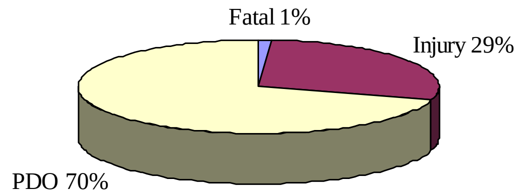


Figure 5.1: Overall Work Zone Crash Composition (1992-2004)

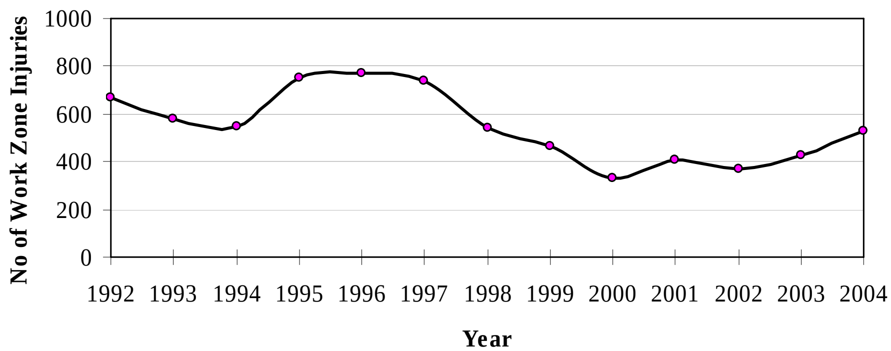


Figure 5.2: Kansas Highway Work zone Injuries between 1992-2004

To identify the characteristics of injury crashes, 460 sample injury crashes in the work zones between 1992 and 2004 were studied in detail. The injury crashes were first examined based on single crash variables, then the crash frequencies were examined based on interrelated variable pairs. Finally, the risk factors that contributed to injury crashes were also analyzed.

5.1.2 Basic Injury Work Zone Crash Characteristics

5.1.2.1 Driver Characteristics

The 460 sample injury crashes in Kansas highway work zones between 1992 and 2004 were first analyzed based on the gender of the at-fault drivers. As shown in Table 5.2 and Figure 5.3, it was found that male drivers caused 66% of the crashes. In contrast, the 2004 Kansas statistics on the gender composition of licensed driver population showed that only 50% were males (FHWA 2004d).

Table 5.2: Injury Crash Frequencies by Gender

Gender	No. of Crashes	Percent (%)
Male	303	66
Female	157	34
Total	460	100

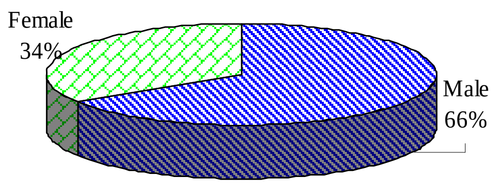


Figure 5.3: Injury Crash Frequencies by Gender

Next, analyses on drivers' age were conducted. The results showed that drivers younger than 35 caused the highest proportions of the injury crashes. Drivers aged between 15 and 19 caused 16% of the crashes, which was much higher than the percentage of the licensed drivers in this age group in the total Kansas driver population (FHWA 2004d). In addition, compared to their 10% distribution in the total Kansas driver population (FHWA 2004d), the drivers between 20 and 24 years of age caused 17% of the injury crashes. Drivers between 55 and 64 and drivers older than 64 years of age were responsible for only 7% and 8% of the crashes, respectively. The detailed crash frequencies and the distribution of Kansas licensed drivers by driver age are exhibited in Table 5.3 and Figure 5.4.

Table 5.3: Injury Crash Frequencies by Age

Age	Licensed Drivers in each Age Group* (%)	No. of Crashes	Percent of Crashes (%)
15 – 19	7	73	16
20 – 24	9	77	17
25 – 34	18	94	20
35 – 44	18	70	15
45 – 54	19	66	14
55 – 64	13	34	7
65+	16	36	8
Other/Unknown	--	10	3
Total	100	460	100

*This is the percentage of the licensed drivers in each age group out of the Kansas driver population.

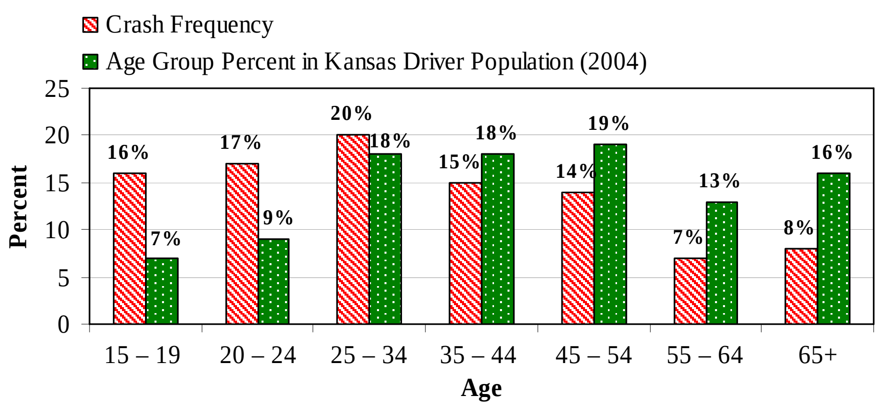


Figure 5.4: Injury Crash Frequencies and Nationwide Driver Distribution by Age

5.1.2.2 Time Information

As shown in Table 5.4 and Figure 5.5, daytime non-peak hours (10:00 a.m. - 4:00 p.m.) had the most injury crashes in Kansas highway work zones, followed by afternoon peak hours (4:00 p.m. - 8:00 p.m.) and morning peak hours (6:00 a.m. - 10:00 a.m.). Nighttime (8:00 p.m. - 6:00 a.m.) had the lowest proportion of the crashes with an hourly percent of only 1.8%.

When analyzing the crash frequency by day of week, Friday and Wednesday had the highest percentages of 18% and 17%, respectively. In contrast, Sunday had only 9% of the crashes. A majority (85%) of the injury crashes occurred in the construction season from April to November, while January, February, March, and December had only 15%. The crash frequencies by day of week were illustrated in Table 5.5 and Figure 5.6. Table 5.6 and Figure 5.7 show the crash frequencies by month.

Table 5.4: Injury Crash Frequencies by Crash Time

Accident Time	No. of Crashes	Percent (%)	Hourly Percent* (%)
6:00 a.m. - 10:00 a.m.	72	16	4.0
10:00 a.m. - 4:00 p.m.	194	42	7.0
4:00 p.m. - 8:00 p.m.	109	24	6.0
8:00 p.m. - 6:00 a.m.	83	18	1.8
Unknown	2	0	0
Total	460	100	--

*Hourly percent is calculated by dividing the percent of a time period by the number of hours in that period.

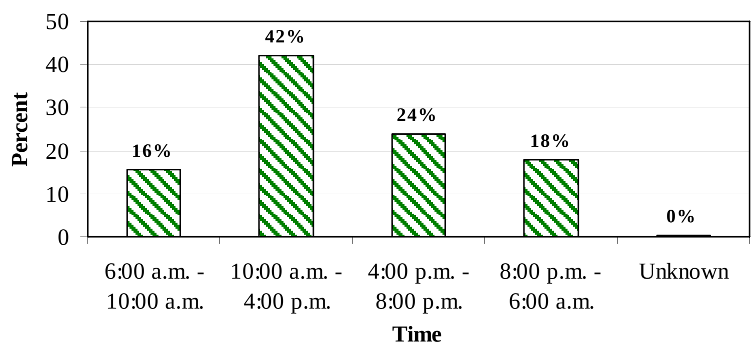


Figure 5.5: Injury Crash Frequencies by Crash Time

Table 5.5: Injury Crash Frequencies by Day of Week

Day	No. of Crashes	Percent (%)
Monday	67	15
Tuesday	71	15
Wednesday	80	17
Thursday	51	11
Friday	83	18
Saturday	68	15
Sunday	40	9
Total	460	100

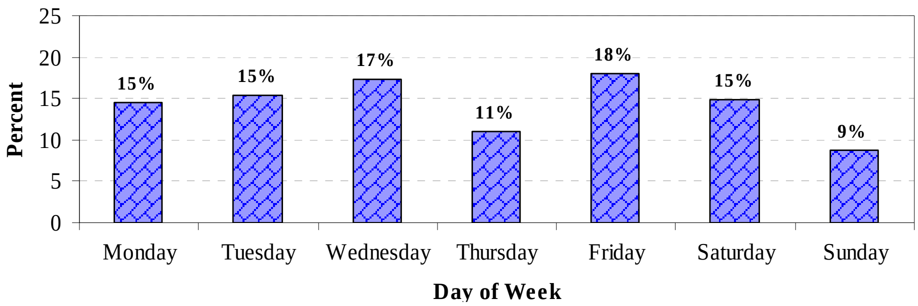


Figure 5.6: Injury Crash Frequencies by Day of Week

Table 5.6: Injury Crash Frequencies by Month

Month	No. of Crashes	Percent (%)
January	17	<4
February	13	3
March	20	4
April	33	7
May	42	9
June	55	12
July	49	11
August	68	15
September	55	12
October	45	10
November	41	9
December	22	5
Total	460	100

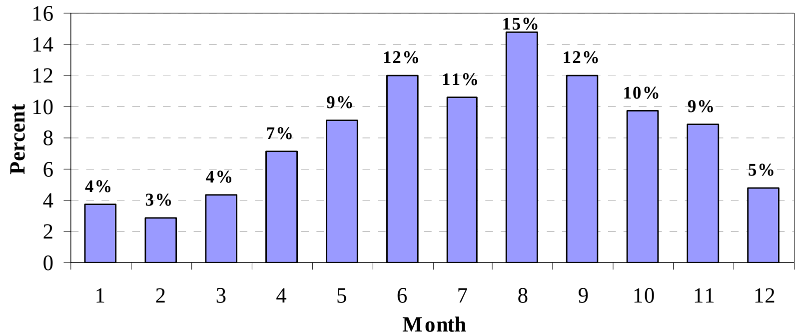


Figure 5.7: Injury Crash Frequencies by Month

5.1.2.3 Climatic Environment Characteristics

The injury crash frequencies in different light conditions are shown in Table 5.7 and Figure 5.8. The analysis results indicated that 75% of the work zone injury crashes occurred during daytime with favorable light conditions. Among poor light conditions, "dark with no street lights on" had the highest crash percent of 13%.

Table 5.7: Injury Crash Frequencies by Light Condition

Light Condition	No. of Crashes	Percent (%)
Daylight	343	75
Dawn	7	2
Dusk	7	2
Dark: street lights on	39	8
Dark: no street lights	62	13
Other/Unknown	2	0
Total	460	100

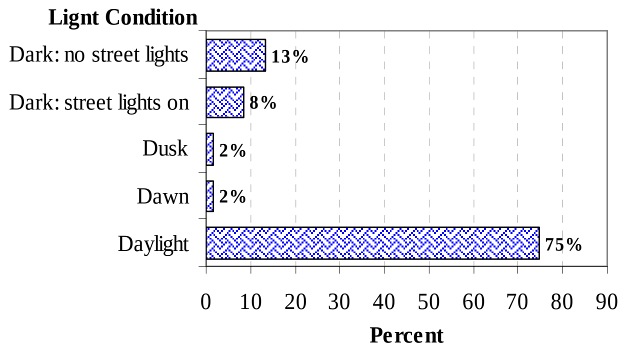
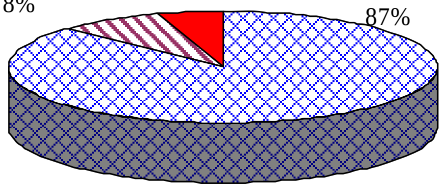


Figure 5.8: Injury Crash Frequencies by Light Condition

In terms of weather condition, a majority (87%) of the crashes occurred when no adverse weather conditions were observed. This fact indicates that inclement weather conditions were not a significant contributing factor for the injury crashes. Correspondingly, the analysis found that 84% of the injury crashes occurred on dry pavements and only 16% were affected by unfavorable pavement conditions such as pavement with rain, snow, or ice. The Kansas work zone injury crash frequencies by weather condition and road surface condition are shown in Table 5.8 and Figure 5.9, and Table 5.9 and Figure 5.10, respectively.

Table 5.8: Injury Crash Frequencies by Weather Condition

Weather Condition	**No. of Crashes**	**Percent (%)**
No adverse conditions	401	87
Rain, mist, drizzle	36	8
Sleet	2	0
Snow	6	2
Fog	4	1
Strong winds	3	1
Blowing dust, sand	2	0
Freezing rain	3	1
Snow & winds	1	0
Other	2	0
Total	460	100

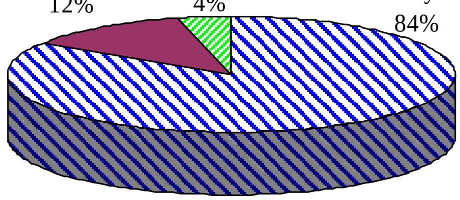


Note: "Other adverse conditions" include sleet, snow, fog, strong winds, blowing dust or sand, freezing rain, snow & winds, and other.

Figure 5.9: Injury Crash Frequencies by Weather Condition

Table 5.9: Injury Crash Frequencies by Road Surface Condition

Road Surface Condition	No. of Crashes	Percent (%)
Dry	388	84
Wet	54	12
Snow or slush	5	1
Ice or snow-packed	10	3
Mud, dirt or sand	1	0
Debris	1	0
Other	1	0
Total	460	100



Note: "Other conditions" include snow or slush, ice or snow-packed, mud, dirt or sand, debris, and other.

Figure 5.10: Injury Crash Frequencies by Road Surface Condition

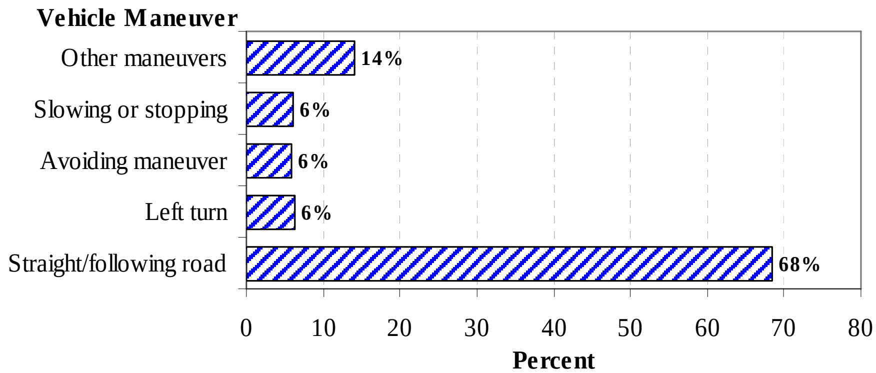
5.1.2.4 Crash Information

To thoroughly understand the occurrence of work zone injury crashes, the maneuver of a vehicle before it caused an injury crash was studied. According to data analysis, most of the at-fault vehicles for the crashes (68%) were traveling straight or following the roads before they caused collisions. As shown in Table 5.10 and Figure

5.11, the complicated maneuvers including left turn, slowing or stopping, and avoiding maneuver only coincided with 18% of the crashes (6% each). Lane changing and overtaking contributed to 3% and 2%, respectively.

Table 5.10: Injury Crash Frequencies by Vehicle Pre-Crash Maneuver

Vehicle Maneuver	No. of Crashes	Percent (%)
Straight/following road	315	68
Left turn	29	6
Right turn	4	1
U-turn	4	1
Overtaking (passing)	11	3
Changing lanes	14	3
Avoiding maneuver	27	6
Merging	6	1
Backing	1	0
Stopped awaiting turn	2	1
Stopped in traffic	6	1
Disabled in roadway	2	0
Slowing or stopping	28	6
Other	11	3
Total	460	100



Note: "Other maneuvers" include right turn, U-turn, overtaking (passing), changing lanes, merging, backing, stopped awaiting turn, stopped in traffic, disabled in roadway, and other.

Figure 5.11: Injury Crash Frequencies by Vehicle Pre-Crash Maneuver

The study of the number of crash vehicles showed that 50% of the crashes involved two vehicles and 20% of the crashes involved more than two vehicles. These results are illustrated in Table 5.11 and Figure 5.12. In addition, Table 5.12 and Figure 5.13 show the injury crash frequencies by crash type. In the study period (1992 – 2004), the dominant type of injury crash was rear-end collision which constituted roughly half (46%) of the total crashes. Other common injury crash types included angle-side impact collisions (18%), fixed-object collisions (13%), and overturned crashes (10%).

Table 5.11: Injury Crash Frequencies by Number of Crash Vehicles

No. of Crash Vehicles	No. of Crashes	Percent (%)
1	138	30
2	231	50
3	62	13
4	23	5
5	3	1
6	2	1
8	1	0
Total	460	100

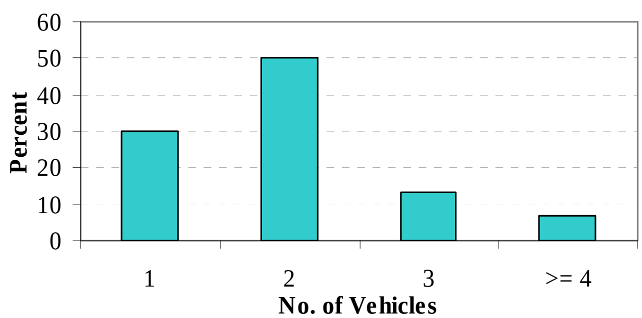
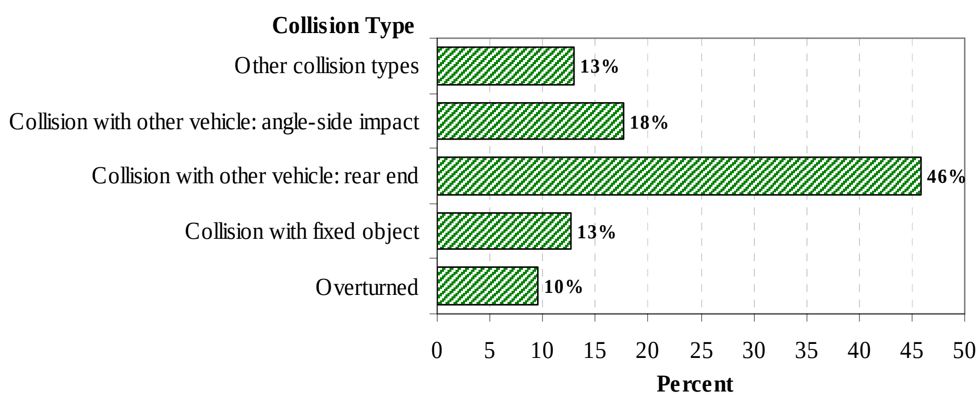


Figure 5.12: Injury Crash Frequencies by Number of Crash Vehicles

Table 5.12: Injury Crash Frequencies by Crash Type

Crash Type	No. of Crashes	Percent (%)
Other non-collision	13	3
Overturned	44	10
Collision with pedestrian	6	1
Collision with parked motor vehicle	4	1
Collision with pedalcycle	1	0
Collision with animal	7	1
Collision with fixed object	58	13
CWOV: head on	9	2
CWOV: rear end	211	46
CWOV: angle-side impact	81	18
CWOV: sideswipe-opposite direction	4	1
CWOV: sideswipe-same direction	6	1
CWOV: backed into	2	0
CWOV: other	4	1
Other object	10	2
Total	460	100

CWOV: Collision with other vehicle.



Note: "Other collision types" include other non-collision, collision with pedestrian, collision with parked motor vehicle, collision with pedalcycle, with-other-vehicle collisions such as head on, sidewipe-opposite direction, sidewipe-same direction, backed into, and other, and collision with other object.

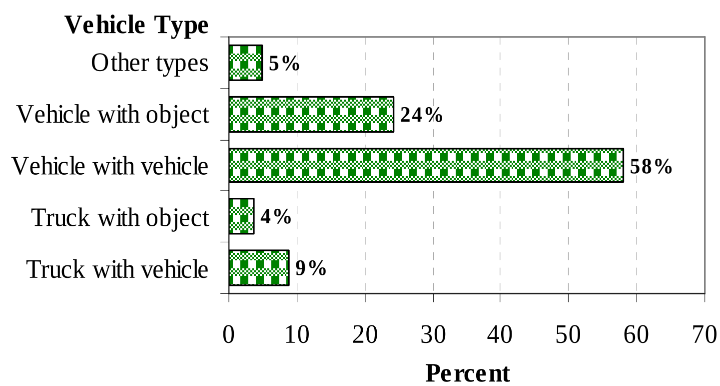
Figure 5.13: Injury Crash Frequencies by Crash Type

The most common crash type by crash vehicle type was vehicle-vehicle crashes (58%), followed by vehicle-object collisions (24%), and truck-vehicle collisions (9%). Truck-truck collisions only accounted for 1% of the total crashes. Here "truck" refers to the heavy vehicle types such as single unit large trucks, trucks and trailers, tractor-trailers, and buses. Passenger cars, minivans, pickups, SUVs, ATVs, and campers or

RVs are categorized as "vehicle" as opposed to trucks. The detailed crash frequencies are presented in Table 5.13 and Figure 5.14.

Table 5.13: Injury Crash Frequencies by Crash Vehicle Body Type

Vehicle Body Type	No. of Crashes	Percent (%)
Truck with Truck	5	1
Truck with Vehicle	41	9
Truck with Motorcycle	2	0
Truck with Object	17	4
Vehicle with Vehicle	267	58
Vehicle with Motorcycle	3	1
Vehicle with Pedestrian/Worker	1	0
Vehicle with Object	112	24
Other	12	3
Total	460	100



Note: "Other types" include truck with truck, truck with motorcycle, vehicle with motorcycle, vehicle with pedestrian/worker, and other collisions.

Figure 5.14: Injury Crash Frequencies by Crash Vehicle Body Type

5.1.2.5 Road Information

Among the injury crashes in the work zones, interstate highways had 33% of the crashes, other freeways and expressways had 15% of the crashes, and other principal roads had 45% of the crashes. Table 5.14 and Figure 5.15 show details on the relationships between crash frequencies and road class.

Table 5.14: Injury Crash Frequencies by Road Class

Road Class	No. of Crashes	Percent (%)
Interstate highway	151	33
Other freeways & Expressways	68	15
Other Principal Arterial	205	45
Minor Arterial	32	7
Major collector	4	0
Total	460	100

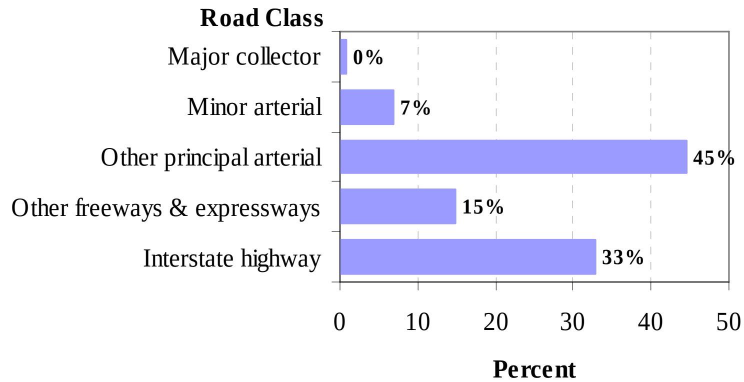


Figure 5.15: Injury Crash Frequencies by Road Class

Table 5.15 and Figure 5.16 exhibit that 66% of the injury crashes occurred in the work zones on straight and level highway sections. Complicated highway alignments contributed to some percentages of the crashes: 18% on straight on grade highway sections; 9% on curved and level highway sections; and 7% on the rest of alignments.

Table 5.15: Injury Crash Frequencies by Road Character

Road Character	No. of Crashes	Percent (%)
Straight and level	302	66
Straight on grade	84	18
Straight at hillcrest	10	2
Curved and level	40	9
Curved on grade	22	5
Curved at hillcrest	0	0
Other	2	0
Total	460	100

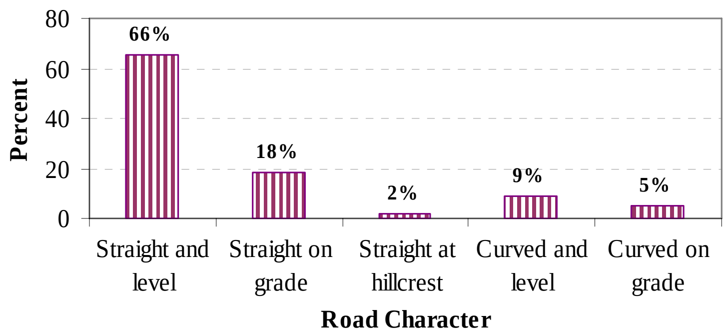


Figure 5.16: Injury Crash Frequencies by Road Character

When studying the crashes by number of lanes (two direction), 33% occurred on two-lane highways and 67% on multi-lane highways. For the latter, 49% occurred on four-lane highways while six-lane highways and eight-lane highways had 16% and 2%, respectively. These results are shown in Table 5.16 and Figure 5.17.

Table 5.16: Injury Crash Frequencies by Number of Lanes

No. of Lanes (Two Direction)	No. of Crashes	Percent (%)
2	150	33
4	224	49
6	75	16
8	11	2
Total	460	100

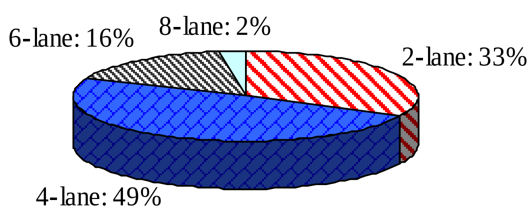


Figure 5.17: Injury Crash Frequencies by Number of Lanes

It was found that 47% of the injury crashes occurred on highway sections with speed limits between 51 mph and 60 mph, and 21% occurred in 61 mph – 70 mph speed zones. As a result, a total of 68% of the injury crashes occurred in highway sections with speed limits higher than 50 mph. This fact indicates that injury crashes were related to relatively high vehicle speeds. Table 5.17 and Figure 5.18 show the crash frequencies by speed limit.

Table 5.17: Injury Crash Frequencies by Speed Limit

Speed Limit (mph)	No. of Crashes	Percent (%)
≤30	22	5
31-40	66	14
41-50	46	10
51-60	216	47
61-70	98	21
Unknown	12	3
Total	460	100

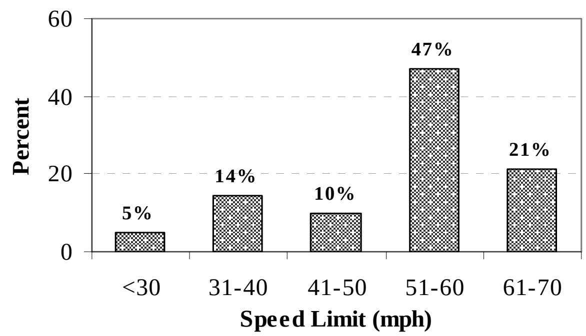


Figure 5.18: Injury Crash Frequencies by Speed Limit

The crash frequencies were studied in terms of crash locations in an effort to discover the impacts of the complex highway features such as intersections and interchanges on safety. It was found that 58% of the injury crashes were located in non-intersection areas and 24% occurred in intersections or intersection-related areas. As seen from Table 5.18 and Figure 5.19, another 8% of the crashes occurred in work zones that overlapped with interchange areas.

Table 5.18: Injury Crash Frequencies by Crash Location

Crash Location	No. of Crashes	Percent (%)
Non-intersection	266	58
Intersection	70	15
Intersection-related	39	9
Interchange area	37	8
On crossover	1	0
Other	47	10
Total	460	100

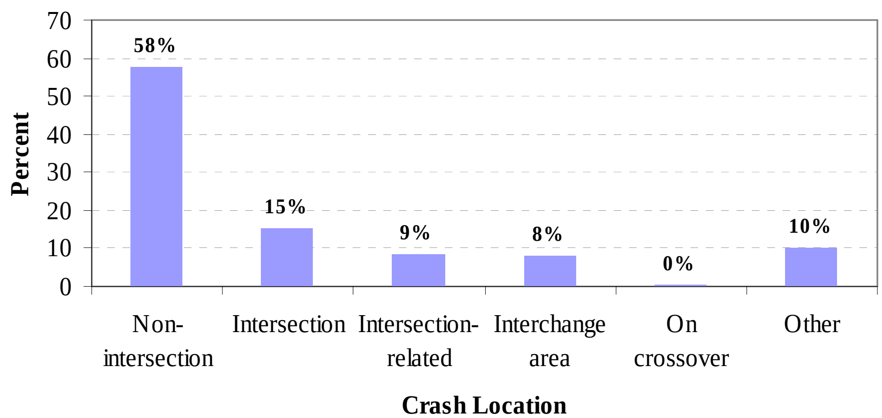


Figure 5.19: Injury Crash Frequencies by Crash Location

As seen from Table 5.19 and Figure 5.20, among the crashes, 61% occurred on asphalt pavements (blacktop); only 39% were found on concrete pavements. A majority (85%) of the crashes was in the work zones where no road special features were present. Only 6% coincided with bridges, 5% with interchanges, and 3% with ramps. Table 5.20 and Figure 5.21 illustrate the crash frequencies in work zones with various special features.

Table 5.19: Injury Crash Frequencies by Pavement Type

Pavement Type	No. of Crashes	Percent (%)
Concrete	178	39
Blacktop	279	61
Gravel	1	0
Dirt	1	0
Other	1	0
Total	460	100

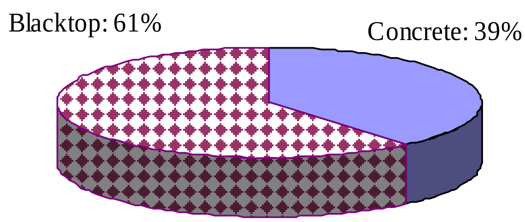


Figure 5.20: Injury Crash Frequencies by Pavement Type

Table 5.20: Injury Crash Frequencies by Road Special Feature

Road Special Feature	No. of Crashes	Percent (%)
None	389	85
Bridge	27	6
Bridge overhead	4	0
Interchange	23	5
Ramp	12	3
Other	5	1
Total	460	100

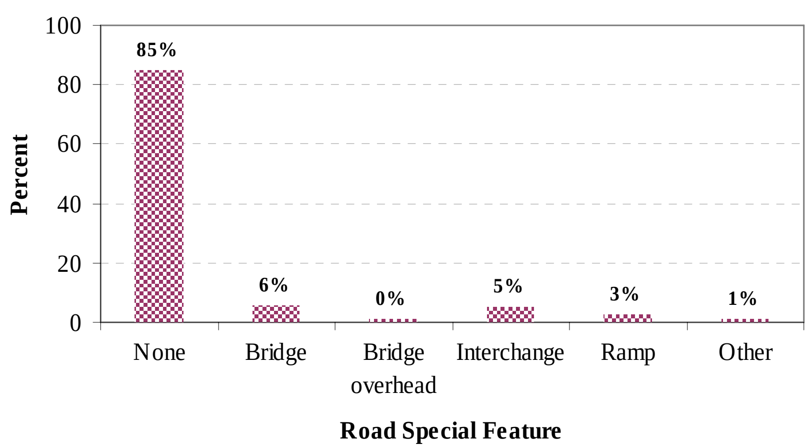


Figure 5.21: Injury Crash Frequencies by Road Special Feature

The 2004 highway statistics (FHWA 2004e) showed that 92% of the public roadway miles in Kansas were rural. Correspondingly, the study found that most (85%) of the crashes occurred in rural highway work zones. As shown in Table 5.21 and Figure 5.22, 43% of the crashes occurred in rural areas with 51 mph – 60 mph speed zones and 20% in rural areas with 61 mph – 70 mph speed zones. The facts indicate that rural highways with speed limits higher than 51 mph were more hazardous for public travelers.

The effectiveness of work zone traffic controls is directly related to work zone safety. In data analysis, crash frequencies were also categorized under different traffic control devices. Table 5.22 and Figure 5.23 show the frequency analysis results on traffic control devices installed at the crash locations. It was found that 72% of the crashes occurred on the pavements marked with center/edge lines. Other traffic control devices present in crash work zones included: traffic signal (15%), no passing zone (14%), and stop sign/signal (7%). 11% of the crashes occurred in work zones with no or inoperative traffic control and 15% occurred with presence of other traffic control devices.

Table 5.21: Injury Crash Frequencies by Area and Speed Limit

Speed Limit (mph)	Rural		Urban	
	No. of Crashes	Percent (%)	No. of Crashes	Percent (%)
≤30	21	5	1	0
31-40	40	9	26	6
41-50	28	6	18	4
51-60	199	43	17	4
61-70	94	20	4	1
Unknown	10	2	2	0
Total	392	85	68	15

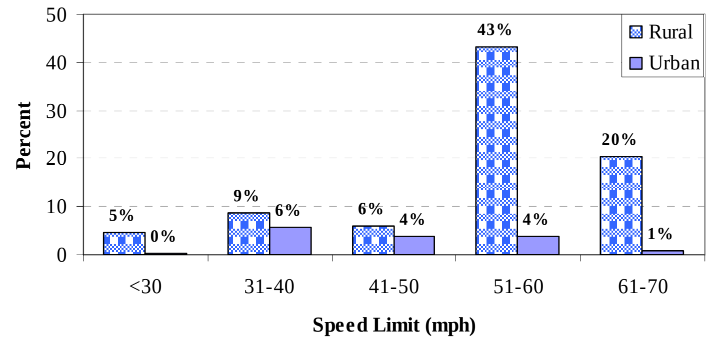


Figure 5.22: Injury Crash Frequencies by Area and Speed Limit

Table 5.22: Injury Crash Frequencies by Traffic Control

Traffic Control	No. of Crashes	Percent (%)
None or inoperative	49	11
Officer or flagger	25	5
Traffic signal	68	15
Stop sign/signal	33	7
Flasher	12	3
Yield sign	3	1
No passing zone	65	14
Center/edge lines	331	72
Other control	70	15

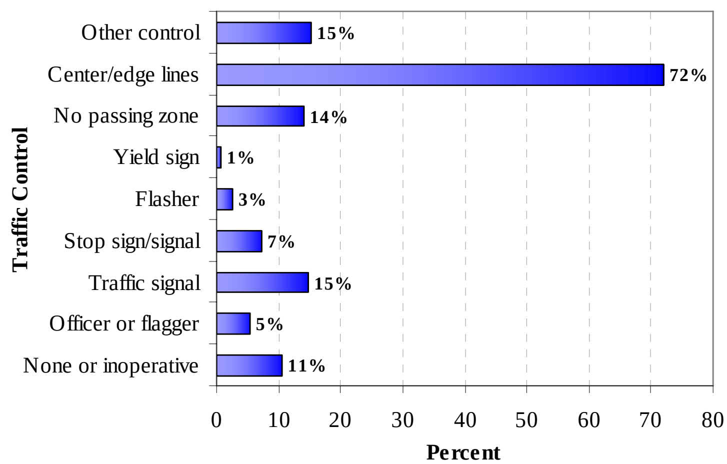


Figure 5.23: Injury Crash Frequencies by Traffic Control

5.1.2.6 Contributing Factors

The study found that 82% of the injury crashes were contributed by driver errors. As shown in Table 5.23 and Figure 5.24, among the observed driver errors, inattention contributed to 51% of the crashes, followed by followed too closely (18%), too fast for conditions (16%), and disregarded traffic signs, signals, or markings (10%). In addition, among the crashes without driver errors, 4% were caused by environment factors such as inclement weather conditions and animal interfering and another 4% were caused by vehicle factors. Less than 1% of the crashes were caused by pedestrians.

Table 5.23: Injury Crash Frequencies by Driver Error

Driver Error	No. of Crashes	Percent (%)
No human error	82	18
Inattention	236	51
Followed too closely	85	18
Too fast for conditions	72	16
Disregarded traffic signs, signals, or markings	47	10
Failed to yield right of way	38	8
Under influence of alcohol	23	5
Made improper turn	13	3
Avoidance or evasion action	13	3
Fell asleep	12	3
Exceeded posted speed limit	10	2
Wrong side or wrong way	7	2
Improper lane change	7	2
Other distraction in or on vehicle	7	2
Improper passing	6	1
Did not comply-license restrictions	5	1
Ill or medical condition	3	1
Under influence of drugs	2	0
Improper backing	1	0
Impeding or too slow for traffic	1	0
Distraction-other electronic devices	1	0

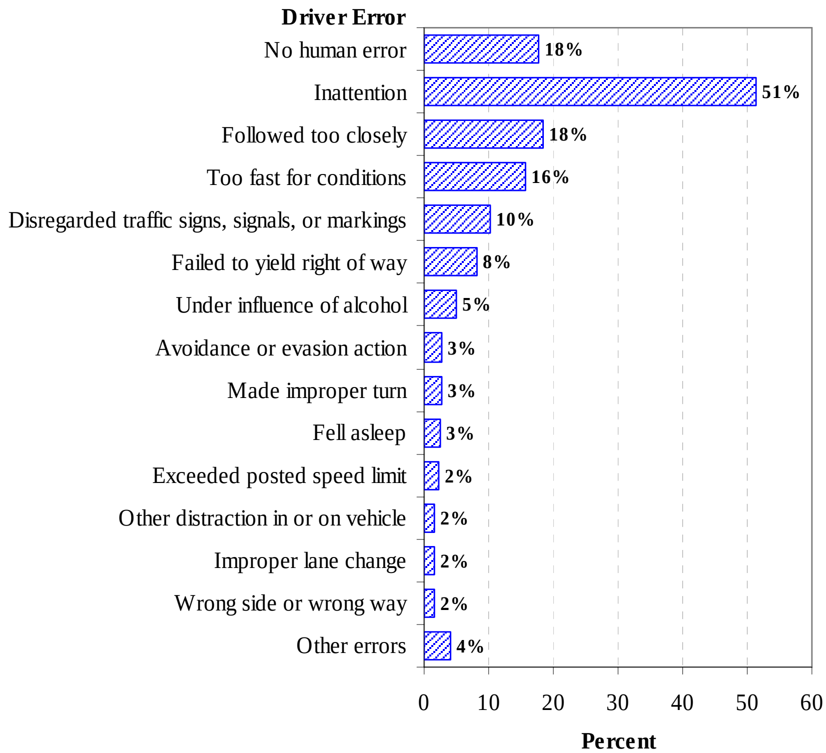


Figure 5.24: Injury Crash Frequencies by Driver Error

5.1.3 Crash Characteristics by Interrelated Factors

The basic characteristics of the injury work zone crashes were first explored based on the frequencies of single crash variable. Then, the researchers studied injury crash characteristics that were illustrated by the crash frequencies based on the combinations of interrelated crash variables. The interrelated variable combinations were determined based on Pearson Chi-Square Test and Likelihood Ratio Chi-Square Test methods. 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). Regardless of the different advantages of the two chi-square test methods, they are both adopted in the tests for the crash variable relationships to avoid missing potential interrelated variable pairs. The theories of these two test methods were described in the work zone fatal crash project report (Bai and Li 2006) and similar applications can be found in Li and Bai (2006).

In the tests, the detailed observations for some variables were further categorized into fewer observation groups (see Tables B.7 – B.9, B.12, B.13, B.15 and B.18 in Appendix B). In doing so, similar-in-nature observations of each variable could be analyzed together. It also increased the frequencies of cross-categorized observations for chi-square tests and therefore resulted in higher accuracy. For example, as shown in Table 15 in Appendix II, the original seven road character observations were classified into two groups including simple alignment and complex alignment. In addition, the variables such as driver error and traffic control were not included in these tests since most crashes had multiple observations for these variables which could not be easily manipulated in the tests.

An interrelationship or dependency was determined when at least one of the two tests supported it at 5% significance level. Table 5.24 shows the interrelated variables according to test results from SAS software. The researchers did not include those statistically interrelated but practically meaningless variable pairs such as weather condition and road surface condition (inclement weather conditions are usually accompanied by poor road surface conditions) and accident time and light conditions (nighttime commonly have poor light conditions) in the tests.

Table 5.24: Interrelated Injury Crash Variables at 5% Level of Significance

Interrelated Factor Pairs		Pearson Chi-Square		Likelihood Ratio Chi-Square	
		p-Value	Related?	p-Value	Related?
Age	Vehicle type	0.03	Yes	0.02	Yes
Gender	Surface condition	0.02	Yes	0.02	Yes
Gender	Vehicle type	<0.01	Yes	<0.01	Yes
Gender	Number of vehicles	0.08	No	0.04	Yes
Crash time	Number of vehicles	<0.01	Yes	<0.01	Yes
Light condition	Number of vehicles	<0.01	Yes	<0.01	Yes
Vehicle type	Number of vehicles	<0.01	Yes	<0.01	Yes
Number of vehicles	Road character	0.05	Yes	0.05	Yes
Number of vehicles	Speed limit	<0.01	Yes	<0.01	Yes
Number of vehicles	Crash location	<0.01	Yes	<0.01	Yes
Number of vehicles	Road class	<0.01	Yes	<0.01	Yes
Road class	Area information	<0.01	Yes	<0.01	Yes
Number of lanes	Speed limit	<0.01	Yes	<0.01	Yes

5.1.3.1 Responsible Driver Information

The frequency analysis showed that most (83%) of the injury crashes involved only light-duty vehicles as opposed to heavy trucks. Among these light-duty-vehicle-only crashes, as shown in Table 5.25 and Figure 5.25, young drivers between 15 and 24 years of age caused 29% of the total crashes, followed by the driver group between 25 and 34 years of age who were responsible for 17% of the total crashes.

Table 5.25: Injury Crash Percent Frequencies by Age and Vehicle Body Type

Vehicle type	Age							
	Other/ Unknown	15 - 19	20 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 +
Truck-involved	0	1	2	3	2	3	2	1
Vehicle only	2	15	14	17	13	10	5	7
Other	0	0	0	0	1	1	0	0

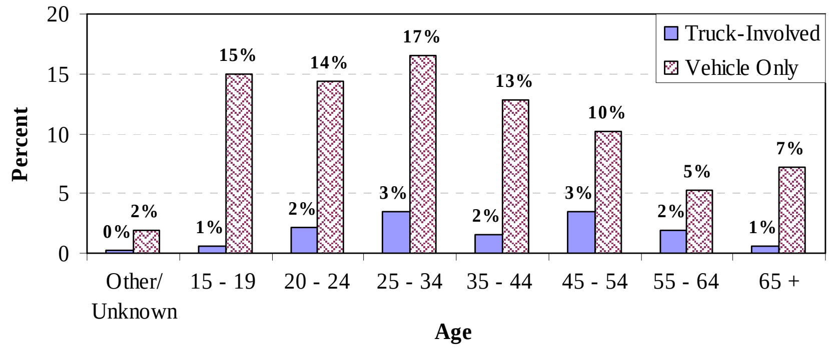


Figure 5.25: Injury Crash Percent Frequencies by Age and Vehicle Body Type

When studying the crash frequencies by gender and road surface condition, 54% of the injury crashes were caused by male drivers on dry road surface. For the same surface condition, females caused about 31% of the total crashes. In addition, most (88%) of the truck-involved crashes (12% of the total crashes) were caused by male drivers, which is probably due to the high composition of males in the truck driver population. Compared with the 64% (45% out of 70%) of the multi-vehicle crashes caused by males, the study found that 70% (21% out of 30%) of the single-vehicle crashes were caused by male drivers. Table 5.1.26 and Figure 5.1.26 illustrate the crash frequencies by gender and road surface condition; Table 5.27 and Figure 5.27 show the crash frequencies by gender and number of vehicles.

Table 5.26: Injury Crash Percent Frequencies by Gender and Road Surface Condition

Gender	**Road Surface Condition**	
	Good	Poor
Male	54	12
Female	31	3

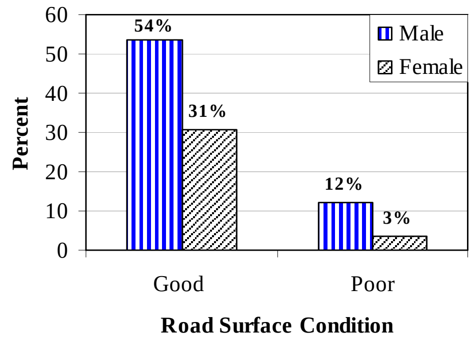


Figure 5.26: Injury Crash Percent Frequencies by Gender and Road Surface Condition

Table 5.27: Injury Crash Percent Frequencies by Gender and Number of Vehicles

Gender	Number of Vehicles	
	single	Multiple
Male	21	45
Female	9	25
Total	30	70

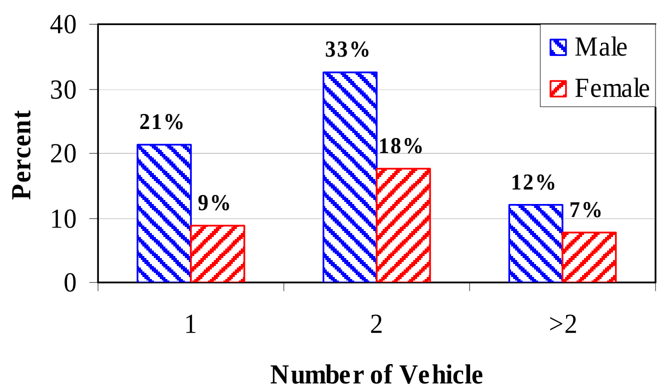


Figure 5.27: Injury Crash Percent Frequencies by Gender and Number of Vehicles

5.1.3.2 Crash Time

The results of statistical tests showed that crash time was interrelated with number of vehicles. It was found that one third of the crashes (33%) were multi-vehicle crashes that occurred during daytime non-peak hours (10:00 a.m. – 4:00 p.m.). Detailed percent frequencies by crash time and number of vehicles are presented in Table 5.28 and Figure 5.28.

Table 5.28: Injury Crash Percent Frequencies by Crash Time and Number of Vehicles

Number of Vehicles	Time			
	6:00 a.m. - 10:00 a.m.	10:00 a.m. - 4:00 p.m.	4:00 p.m. - 8:00 p.m.	8:00 p.m. - 6:00 a.m.
Single vehicle	6	10	4	10
Multiple vehicle	10	33	19	8

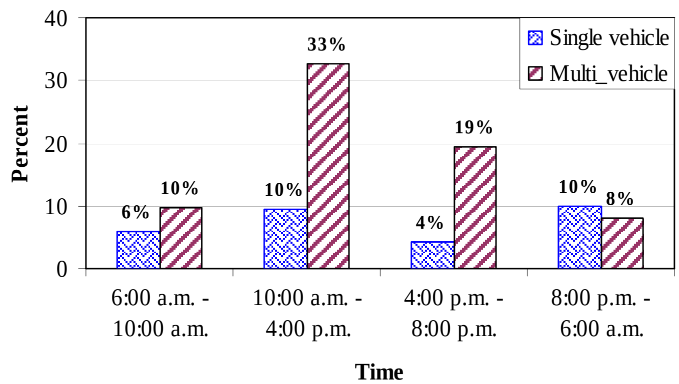


Figure 5.28: Injury Crash Percent Frequencies by Crash Time and Number of Vehicles

5.1.3.3 Light Condition

The study showed that light condition was interrelated with number of vehicles. Compared to the 18% (13% out of 70%) of multi-vehicle crashes in poor light conditions, 43% (13% out of 30%) of the single-vehicle crashes occurred in poor light conditions. As opposed to good light condition (daylight), poor light conditions refer to the conditions such as “dawn”, “dusk”, “dark with street lights”, and “dark without street lights”. Table 5.29 and Figure 5.29 show the detailed injury crash frequencies by light condition and number of vehicles.

Table 5.29: Crash Percent Frequencies by Light Condition and Number of Vehicles

Light Condition	Number of Vehicles	
	Single	Multiple
Good	17	57
Poor	13	13
Total	30	70

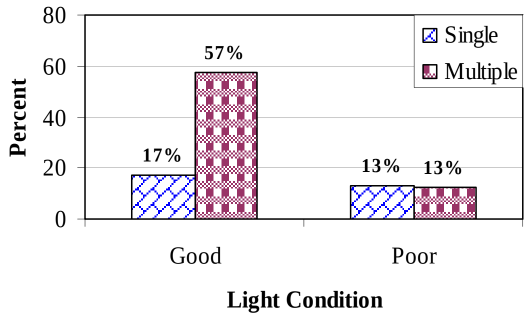


Figure 5.29: Crash Percent Frequencies by Light Condition and Number of Vehicles

5.1.3.4 Vehicle Type and Number of Vehicles

The study found that, although only 14% of the crashes involved heavy trucks, 79% (11% out of 14%) of these truck-involved crashes were multi-vehicle crashes. In contrast, 71% (59% out of 83%) of the crashes involving only light-duty vehicles were multi-vehicle crashes. Table 5.30 and Figure 5.30 show the crash frequencies by vehicle body type and number of vehicles.

Table 5.30: Percent Frequencies by Vehicle Body Type and Number of Vehicles

Number of Vehicles	Vehicle Body Type		
	Truck-involved	Vehicle- only	Other
Single-vehicle	3	24	2
Multi-vehicle	11	59	1
Total	14	83	3

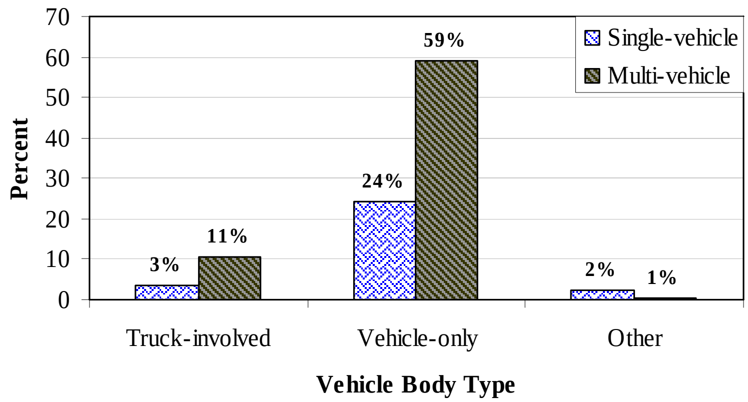


Figure 5.30: Percent Frequencies by Vehicle Body Type and Number of Vehicles

Almost half (14% out of 30%) of the single-vehicle crashes occurred in work zones on highway sections with complicated alignments including straight on grade, straight at hillcrest, curved and level, and curved on grade. In addition, a noteworthy proportion of the multi-vehicle crashes were located on highway sections with these features. The facts indicate that complicated highway geometric alignments were a contributing factor for work zone crashes especially single-vehicle crashes. Table 5.31 and Figure 5.31 illustrate the work zone injury crash distribution over number of vehicles and road character.

Table 5.32 and Figure 5.32 show the crash frequencies by number of vehicles and speed limits. Analysis results showed that the percentages of multi-vehicle crashes occurred in 51 – 60 mph speed zones was 32% and in 31 – 40 mph speed zones was 14%. Multi-vehicle crashes were the dominant in all speed zones except the highways with speed limits between 61 mph and 70 mph where both single- and multi- vehicle injury crashes were 11% of the total. In addition, the researchers found that one third of multi-vehicle crashes occurred in intersection or intersection-related areas.

Table 5.31: Crash Percent Frequencies by Number of Vehicles and Road Character

Road Character	No. of Vehicles		
	1	2	>2
Simple alignment	16	35	14
Complicated alignments	14	15	6
Total	30	50	20

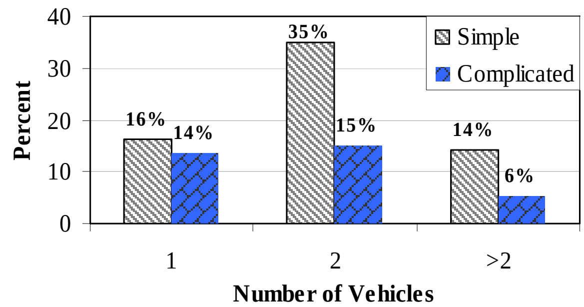


Figure 5.31: Crash Percent Frequencies by Number of Vehicles and Road Character

Table 5.32: Crash Percent Frequencies by Number of Vehicles and Speed Limit

No. of Vehicles	Speed Limit (mph)					
	<31	31-40	41-50	51-60	61-70	Total
Single-vehicle	1	1	2	15	11	30
Multi-vehicle	5	14	8	32	11	70

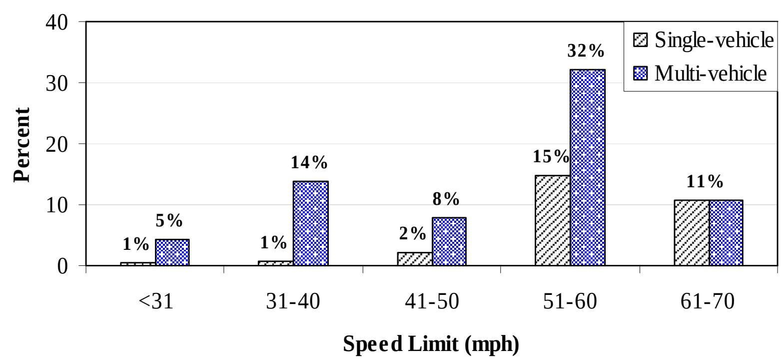


Figure 5.32: Crash Percent Frequencies by Number of Vehicles and Speed Limit

In terms of number of vehicles and highway class, half (15% out of 30%) of the single-vehicle crashes occurred on interstate highways. Instead, about half (34% out of 70%) of the multi-vehicle crashes occurred on “other principal arterials”. The detailed frequencies are showed in Table 5.33 and Figure 5.33.

Table 5.33: Crash Percent Frequencies by Number of Vehicles and Road Class

Road class	**Number of vehicles**	
	Single-vehicle	Multi-vehicle
Interstate highway	15	18
Other freeways & expressways	2	13
Other principal arterial	10	34
Minor arterial	2	5
Major collector	1	0
Total	30	70

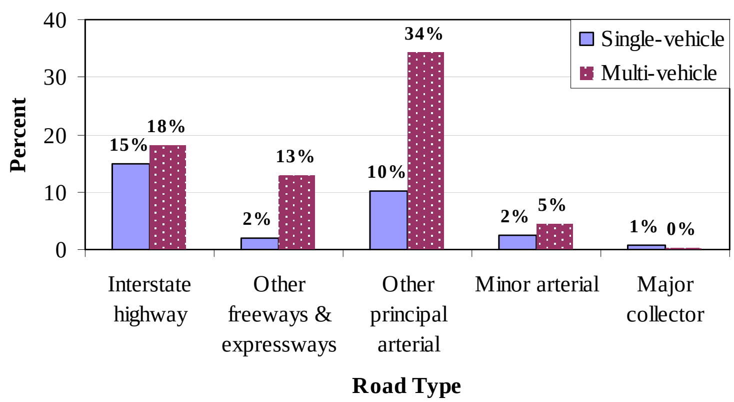


Figure 5.33: Crash Percent Frequencies by Number of Vehicles and Road Class

5.1.3.5 Road Class

The statistical tests showed that there was an interrelationship between road class and area information. The results indicated that most of the crashes occurred on rural Interstate Highways (31%) and “Other Principal Arterials” (41%). Table 5.34 and Figure 5.34 illustrate the crash frequencies by road class and area type.

Table 5.34: Crash Percent Frequencies by Road Class and Area Information

Road Class	Area Information	
	Urban	Rural
Interstate highway	2	31
Other freeways & expressways	8	7
Other principal arterial	3	41
Minor arterial	0	7
Major collector	0	1
Total	13	87

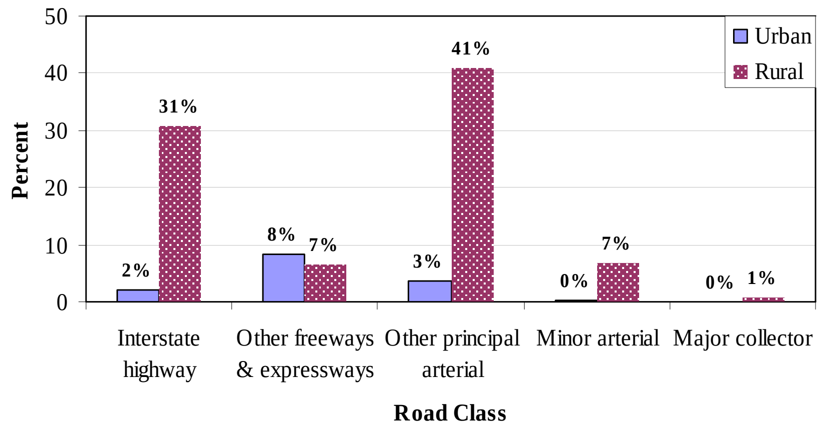


Figure 5.34: Crash Percent Frequencies by Road Class and Area Information

5.1.3.6 Number of Lanes

As shown in Table 5.35 and Figure 5.35, work zones on multi-lane highways with speed limits between 51 – 60 mph were the locations that accounted for the highest percentage (29%) of the injury crashes. Other locations such as two-lane highways with speed limits between 51 – 60 mph and multi-lane highways with speed limits between 61 – 70 mph were also common places to have injury crashes.

Table 5.35: Crash Percent Frequencies by Speed Limit and Number of Lanes

Number of Lanes	Speed Limit					
	<31	31-40	41-50	51-60	61-70	Total
Two-lane	2	1	4	18	8	33
Multi-lane	3	14	7	29	14	67

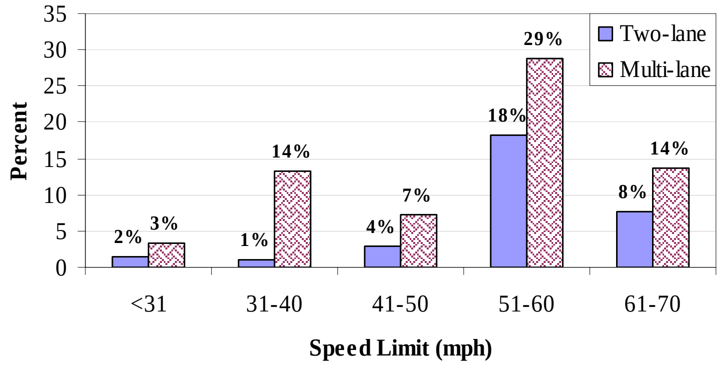


Figure 5.35: Crash Percent Frequencies by Speed Limit and Number of Lanes

5.1.4 Summary of Work Zone Injury Crash Characteristics

The characteristics of 460 sample injury crashes that occurred in Kansas work zones between 1992 and 2004 were explored in this study. The basic characteristics were first investigated by analyzing the crash frequencies based on single crash variable. Then, statistical tests were utilized to explore the characteristics based on the interrelated variable combinations. Listed in Table 5.36 are the most frequent observations for work zone injury crash variables. The characteristics of the injury crashes are summarized in terms of at-fault driver, time, location, type, driver error, and causal factors.

5.1.4.1 Responsible Driver

Male drivers caused two thirds (66%) of the work zone injury crashes in Kansas. Young drivers between 15 – 24 years of age were the driver group frequently involved in injury crashes in Kansas work zones. In particular, teenage drivers between 15 – 19 years of age caused 16% of the work zone injury crashes, a percentage that was more than double of the percentage of this driver group in the Kansas driver population. Among the crashes caused by teenage drivers, males were responsible for 94%. Proportionally, male drivers caused more single-vehicle crashes than multi-vehicle crashes. The researchers also found that 55% of the light-duty vehicle crashes were caused by drivers younger than 34.

Table 5.36: Most Frequent Observations for Injury Crash Variables

Category	Variable	Observation	Percent
Responsible Driver	Age	15-24	33
	Gender	Male	66
Time Information	Time	10:00 a.m. - 4:00 p.m.	42
	Day	Friday	18
	Month	August	15
Climatic Environment	Light condition	Daylight	75
	Weather condition	No adverse conditions	87
	Road surface condition	Dry	84
Crash Information	Vehicle maneuver before crash	Straight/following road	68
	Crash type	Rear-end	46
	Vehicle body type	Vehicle with vehicle	58
	Number of vehicles involved	Two	50
Road Condition	Road class	Other principal arterial	45
	Road character	Straight and level	66
	Number of lanes	four	49
	Speed limit	51-60 mph	47
	Crash location	Non-intersection	58
	Surface type	Blacktop	61
	Road special feature	None	85
	Area information	Rural	85
	Traffic control	Center/edge lines	72
Contributing Factor	Driver factor	Inattention	51

5.1.4.2 Crash Time

Daytime non-peak hours (10:00 a.m. - 4:00 p.m.) had the highest injury crash frequency (42%). The afternoon peak hours (4:00 p.m. - 8:00 p.m.) had a higher injury crash rate (24% vs. 16%) than the morning peak hours (6:00 a.m. - 10:00 a.m.). Among all crashes, the most frequent type was multi-vehicle crash during daytime non-peak hours (33% of total). When comparing days, the lowest crash frequency was observed on Sundays. A majority (84%) of the crashes occurred in the busy construction season from April to November.

5.1.4.3 Crash Location

A third of the injury crashes occurred on interstate highways and 45% occurred on the principal arterial roads (other than interstate highways and other expressways or freeways). Almost half of the single-vehicle crashes occurred on interstate highways and one third of the multi-vehicle crashes occurred in intersection or intersection-related areas. Two thirds of the crashes were found on multi-lane highways especially on four-lane highways. Work zones on highways with speed limits higher than 50 mph accounted for most (68%) of the crashes. Particularly, 51 – 60 mph speed zones had 47% of the total crashes. In addition, a majority of the crashes (85%) occurred in rural work zones. Rural areas with 51 – 70 mph speed limit ranges had 63% of the crashes.

5.1.4.4 Crash Type

The study found that 50% of the injury crashes involved two vehicles and 20% of the crashes involved more than two vehicles. Rear-end collisions were the dominant crash type, accounting for 46% of the total crashes, followed by angle-side impact collisions (18%), and fixed-object collisions (13%). Most (83%) of the crashes involved only light-duty vehicles.

5.1.4.5 Driver Error

According to the injury crash data, 82% of the crashes were attributed to driver errors. Among the driver errors, inattentive driving was the most common error (51%), followed by followed too close (18%) and too fast for conditions (16%).

5.1.4.6 Causal factors

Driver errors were the most common causal factor for work zone injury crashes. Data analysis results did not support that factors such as inclement weather conditions and unfavorable pavement conditions had significant contributions to injury crashes. Poor light conditions were most likely to contribute to single-vehicle crashes. Road special features such as bridges, interchanges, or ramps did not significantly contribute to the injury crashes. Complex geometric alignment features such as grades and curves had some impact on the occurrences of the injury crashes: 34% of the crashes occurred on complicated alignments and 46% of the single-vehicle crashes occurred on complex alignments. The fact that 24% of the total crashes or 33% of the multi-vehicle crashes occurred in intersections or intersection-related areas indicates that the presence of an intersection in highway work zones was a contributing factor to injury crashes.

5.2 Determination of Risk Factors

To determine risk factors in work zones, the important characteristics of work zone injury crashes were further discussed. The term “risk” in this report refers to a relatively high probability of contributing to or being associated with injury or fatal crashes in work zones. The discussions involved comparisons between the characteristics of the studied injury crashes and the available information of other Kansas crashes and national traffic-related statistics. These discussions provide insights that facilitate the complete understanding of both crashes themselves and their reflected work zone safety deficiencies.

5.2.1 High-Risk Drivers

According to the 2004 highway statistics (FHWA 2004d), roughly half of the Kansas driving population were males. In addition, KDOT traffic crash statistics (KDOT 2006) showed that an average percent of 54% of the drivers injured in all traffic crashes during 2001 – 2004 were males. However, the study showed that male drivers caused two thirds (66%) of the work zone injury crashes in Kansas. The comparison of these percentages arguably indicates the high risk of male drivers in Kansas work zones. Note that the researchers did not find statistics showing the percentage of vehicle-miles traveled (VMT) by male drivers and the percent composition of at-fault male drivers in total at-fault drivers who caused non-work zone crashes in Kansas.

The injury crash analyses suggested that young drivers aged from 15 to 34 were the high-risk driver group in work zones. Particularly, drivers aged between 15 and 19 caused 16% of the crashes, which was considerably higher than the percentage (7%) of the licensed drivers younger than 20 in the total Kansas driver population (FHWA 2004d). In addition, among these crashes caused by teenage drivers, males were responsible for 94%. Comparing to their 9% distribution in the total nationwide driver population (FHWA 2004d), the drivers between 20 and 24 years of age caused 17% of the injury crashes. However, the study of all injury crashes including non-work zone crashes in Kansas indicated that these two driver groups were involved in similarly large percentages of the total injury crashes in Kansas as well. The statistics of KDOT (2006) showed that 18% of the drivers involved in the total injury crashes in Kansas between

2000 and 2004 were aged from 15 to 19 years of age and 15% were between 20 and 24 years of age. These facts imply that young drivers under 24 years of age carried high risk in work zones, even though this risk may not actually be higher than in non-work zone areas.

5.2.2 High-Risk Times and Locations

Data analysis results showed that daytime non-peak hours (10:00 a.m. - 4:00 p.m.) had the highest injury crash frequency (42%). The hourly percent during this period was as high as 7% per hour. Figure 5.36 shows the comparisons of hourly crash percentages in the four periods among work zone injury crashes, the total traffic crashes in Kansas during 2000 – 2004, and the total deaths in Kansas traffic crashes during 2000 – 2004. The comparison exhibits that the hourly percentage of Kansas work zone injury crashes during the daytime non-peak hours were higher than both the percentages for total crashes and for total traffic-crash deaths in the same period. Therefore, daytime non-peak hours may be the risk time period for work zone traffic. In addition, the second highest hourly percent was observed in the afternoon peak hours (4:00 p.m. – 8:00 p.m.) which was 6% per hour. However, the comparison did not show that this hourly rate was particularly higher than the total traffic crashes.

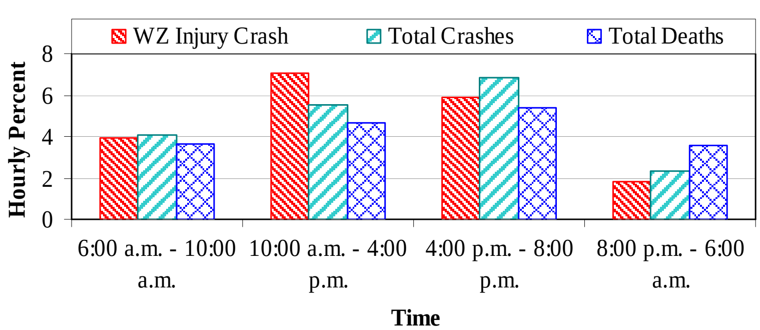


Figure 5.36: Hourly Percent Comparison among Work Zone Injury Crashes, Total Kansas Crashes, and Total Kansas Traffic-Crash Deaths (WZ: work zone)

Analysis results also indicated that injury crashes frequently occurred in the work zones on rural major multi-lane arterials. For instance, a majority (85%) of the injury crashes occurred in rural work zones. Work zones in 51 – 60 mph speed zones had 47% of the crashes and those in 61 – 70 mph speed zones had 21%. Two thirds of the crashes were found on multi-lane highways and most of which were on four-lane highways. The fact that 24% of the total crashes or 33% of the multi-vehicle crashes occurred in intersections or intersection-related areas indicates that the presence of intersections in highway work zones may increase the risk of having an injury crash. In addition, the noteworthy percentage (34%) of the crashes especially the high percentage of the single-vehicle crashes on complicated alignments suggest that complex road geometries may also increase the work zone risk.

5.2.3 Driver Errors

Driver errors were the most common causal factor for work zone injury crashes. The study found that 82% of the injury crashes were contributed by driver errors. Among the observed driver errors, inattention contributed to 51% of the crashes, followed by followed too closely (18%), too fast for conditions (16%), and disregarded traffic signs, signals, or markings (10%). Thereby, driver errors, inattentive driving in particular, increased work zone risks. The authors could not find driver error information of non-work zone injury crashes and hence could not reach conclusions on if the dominant driver errors in work zones were different from those contributing to general traffic crashes.

CHAPTER 6 - WORK ZONE INJURY AND FATAL CRASH CHARACTERISTIC COMPARISON

6.1 Introoduction

The characteristics of the injury crashes in Kansas work zones have been investigated and results were presented in the previous chapters. In addition, a previous project (Bai and Li 2006) had investigated the characteristics of the fatal crashes in Kansas work zones in the same period. In this section, the characteristics of both fatal and injury crashes were further compared and significant differences were highlighted. The purpose of the comparison was to unveil the factors leading to severity increase during the crashes. The comparison also helps in thoroughly understanding the general characteristics of work zone fatal and injury crashes as well as the unique ones distinguishing crashes of different severities. Note that the comparisons were based on percent frequencies because the injury crash characteristics were studied based on a random sample of 460 cases instead of the total crashes. In addition, comparing on a percentage basis rather than absolute numbers would avoid the important characteristics of fatal crashes being overwhelmed by those of the injury crashes that had much larger numbers of cases.

6.2 Comparing Major Characteristics between Injury Crash and Fatal Crash

6.2.1 At-Fault Driver

For both work zone fatal and injury crashes, male drivers caused a much higher percentage than female drivers did. The percentage of at-fault male drivers for the fatal crashes was higher than that for the injury crashes by 9% (75% vs. 66%). In addition, drivers between 15 and 34 years of age caused a higher percentage of injury crashes than fatal crashes. However, the drivers aged 35 to 44, the most reliable driver group as commonly believed, caused the highest percentage (24%) of the fatal crashes among all the age groups, which was 9% higher than the injury crashes caused by the same age group. Senior drivers (65 or older) were found to be responsible for a larger proportion of fatal crashes than for injury crashes. Table 6.1 and Figure 6.2.1 exhibit the fatal and injury crash distributions by at-fault driver age. Table 6.2 summarizes the percent frequencies of the top two observations for each variable describing the drivers responsible for the crashes.

Table 6.1: Fatal and Injury Crash Percent Frequencies by Age

Age	Injury (%)	Fatal (%)
15 - 19	16	12
20 - 24	17	11
25 - 34	20	15
35 - 44	15	24
45 - 54	14	15
55 - 64	7	4
65 +	8	18
Other/unknown	3	1
Total	100	100

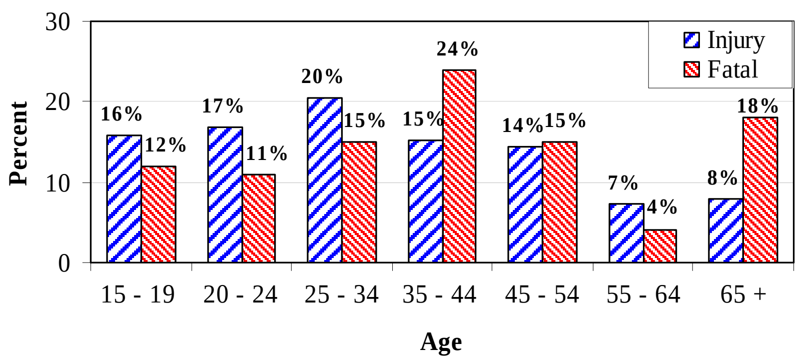


Figure 6.1: Fatal and Injury Crash Percent Frequencies by Age

Table 6.2: Most Frequent Observations for At-Fault Driver Variables

Variable	Top Two Observations			
	Fatal Crash		**Injury Crash**	
Gender	Male (75%)	Female (25%)	Male (66%)	(Female 34%)
Age	35 – 44 (24%)	15 – 24 (23%)	15 – 24 (33%)	25 – 34 (20%)

6.2.2 Time Information

The researchers found that daytime non-peak hours between 10:00 a.m. – 4:00 p.m. accounted for the highest hourly percentages for both fatal crashes and injury crashes. Compared with injury crashes, a larger proportion of work zone fatal crashes occurred at nighttime (8:00 p.m. – 6:00 a.m.). Table 6.3 and Figure 6.2 show the percent frequencies of both fatal and injury crashes by crash time. Regarding the seven days of week, no significant proportional differences were found. In addition, most of the fatal and injury crashes occurred in the construction season from April to November. The two most frequent observations of the crash temporal variables such as time, day, and month for both fatal and injury work zone crashes are listed in Table 6.4.

Table 6.3: Fatal and Injury Crash Percent Frequencies by Crash Time

Crash Time	Injury (%)	Fatal (%)
6:00 a.m. - 10:00 a.m.	16	14
10:00 a.m. - 4:00 p.m.	42	32
4:00 p.m. - 8:00 p.m.	24	17
8:00 p.m. - 6:00 a.m.	18	37
Total	100	100

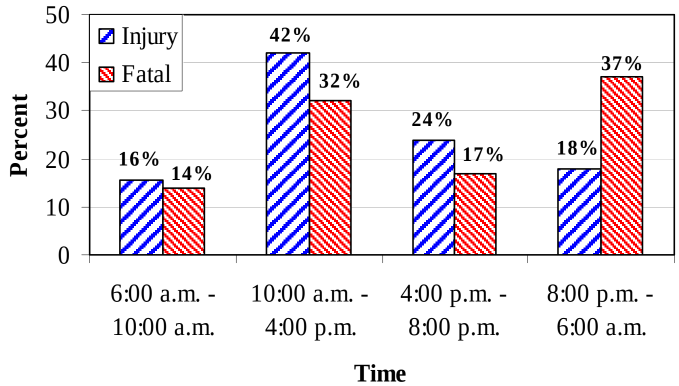


Figure 6.2: Fatal and Injury Crash Percent Frequencies by Crash Time

Table 6.4: Most Frequent Observations for Time Information Variables

Variable	**Top Two Observations**			
	Fatal Crash		**Injury Crash**	
Time	8:00pm – 6:00am (37%)	10:00am – 4:00pm (32%)	10:00am – 4:00pm (42%)	4:00pm – 8:00pm (24%)
Day	Saturday (17%)	Friday (16%)	Friday (18%)	Wednesday (17%)
Month	June (14%)	July/August (12%)	August (15%)	June/Sept. (12%)

6.2.3 Climatic Environment Information

Generally, comparison showed that poor light conditions contributed to a larger proportion of fatal crashes than for injury crashes. As seen in Table 6.5 and Figure 6.3, 32% of the fatal crashes occurred in darkness without streetlights, while this unfavorable light condition only contributed to 13% of the injury crashes. Correspondingly, 22% more injury crashes than fatal crashes (75% vs. 53%) occurred in daylight condition. The considerable differences indicate that poor light conditions could result in high-severity work zone crashes. Regarding the other environmental variables such as weather condition and road surface condition, the comparison showed no notable differences between fatal and injury crashes. Table 6.6 lists the most frequent observations for climatic environmental variables such as light condition, weather condition, and road surface condition.

Table 6.5: Fatal and Injury Crash Percent Frequencies by Light Condition

Light Condition	Injury (%)	Fatal (%)
Daylight	75	53
Dawn	2	3
Dusk	2	3
Dark: street lights on	8	9
Dark: no street lights	13	32
Total	100	100

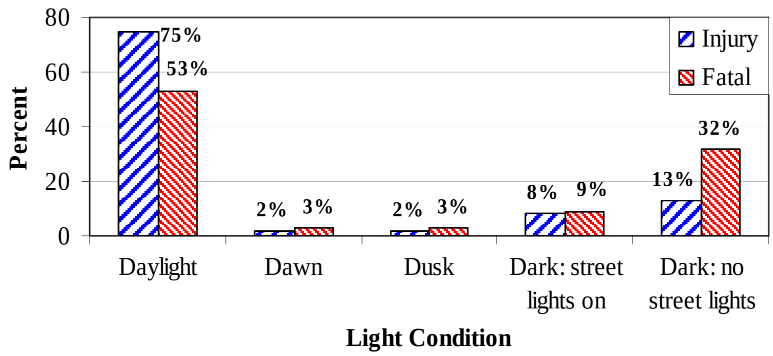


Figure 6.3: Fatal and Injury Crash Percent Frequencies by Light Condition

Table 6.6: Most Frequent Observations for Climatic Environment Variables

Variable	**Top Two Observations**			
	Fatal Crash		**Injury Crash**	
Light condition	Daylight (53%)	Dark: no street lights (32%)	Daylight (75%)	Dark: no street lights (13%)
Weather condition	Good (91%)	Rain, mist, or drizzle (5%)	Good (87%)	Rain, mist, or drizzle (8%)
Road surface condition	Dry (88%)	Wet (8%)	Dry (84%)	Wet (12%)

6.2.4 Crash Information

Crash information was described by several variables such as vehicle maneuver before crash, crash type, vehicle body type, and number of vehicles. The comparisons for vehicle maneuver before crash and number of vehicles did not show any significant differences. Instead, the comparisons in terms of crash type and vehicle body type showed practical results which are discussed in detail hereafter.

Table 6.7 and Figure 6.4 show the injury and fatal crash frequencies by crash type. The dominant type for injury crashes were “collision with other vehicles: rear-end” which accounted for 46% of the total injury crashes, 30% higher than for fatal crashes. Head-on crashes were the most common type for work zone fatal crashes and attributed to 24% of the total fatal crashes, while this crash type only characterized 2% of the injury crashes. This pronounced percent difference indicates that head-on collisions could significantly increase the crash severity and cause fatalities. In addition, fatal and injury crashes had comparable proportions of angle-side impact, fixed object, and overturned crashes.

Table 6.7: Fatal and Injury Crash Percent Frequencies by Crash Type

Crash Type	Injury (%)	Fatal (%)
Overturned	10	11
Collision with fixed object	13	11
CWOV: rear end	46	16
CWOV: angle-side impact	18	20
CWOV: head-on	2	24
Other collision types	11	18
Total	100	100

CWOV: collision with other vehicle.

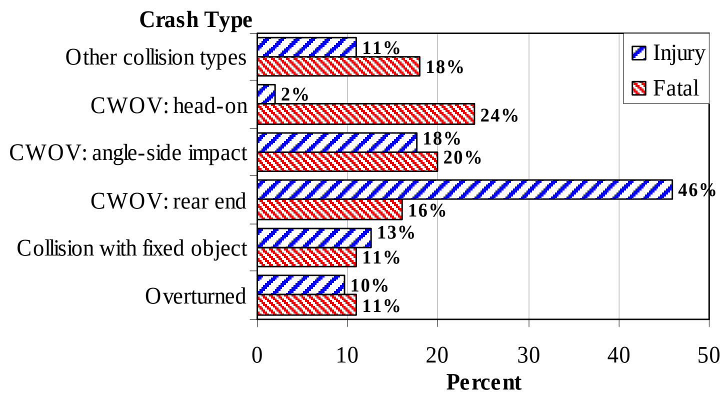


Figure 6.4: Fatal and Injury Crash Percent Frequencies by Crash Type (CWOV: collision with other vehicles)

The comparison by vehicle body type indicated that truck-involved work zone crashes had a higher probability of causing fatalities. As seen from Table 6.8 and Figure 6.5, the most common fatal crashes were truck-vehicle crashes that comprised 34% of the total, 25% more than for injury crashes. The term “truck” here refers to the heavy vehicle types such as single large truck, truck and trailer, tractor-trailer, and buses. The term “vehicle”, when used as opposed to trucks, includes such light-duty vehicle types as passenger car, van, pickup truck, SUV, ATV, and camper or RV. Vehicle-vehicle crashes were found most frequent for the injury crashes by accounting for 58%. These facts imply that truck involvement was a catalyzing factor for work zone traffic fatalities. The most frequent observations of the crash information variables for both fatal and injury crashes are listed in Table 6.9.

Table 6.8: Fatal and Injury Crash Percent Frequencies by Vehicle Body Type

Vehicle Body Type	Injury (%)	Fatal (%)
Truck with truck	1	2
Truck with vehicle	9	34
Truck with motorcycle	0	1
Truck with pedestrian/worker	0	2
Truck with object	4	1
Vehicle with vehicle	58	31
Vehicle with motorcycle	1	1
Vehicle with pedestrian/worker	0	3
Vehicle with object	24	10
Other	3	15
Total	100	100

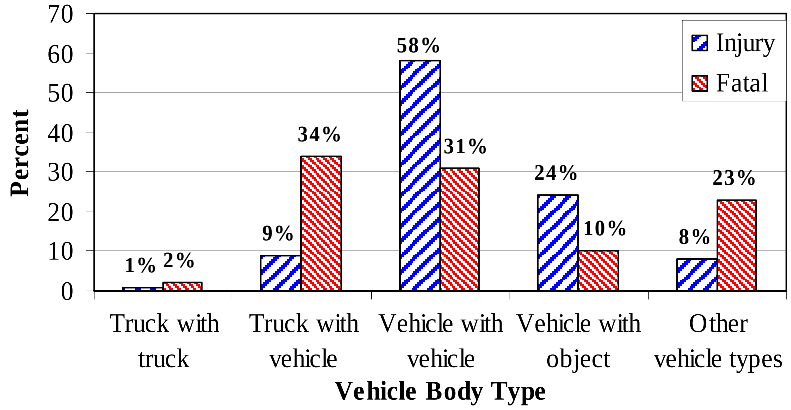


Figure 6.5: Fatal and Injury Crash Percent Frequencies by Vehicle Body Type

Table 6.9: Most Frequent Observations for Crash Information Variables

Variable	Top Two Observations			
	Fatal Crash		Injury Crash	
Vehicle maneuver before crash	Following road (74%)	Overtaking (6%)	Following road (68%)	Left turn (6%)
Crash type	Head-on (24%)	Angle-side (20%)	Rear-end (46%)	Angle-side (18%)
Vehicle body type	Truck-vehicle (34%)	Vehicle- vehicle (31%)	Vehicle-vehicle (58%)	Vehicle-object (24%)
No. of vehicles involved	Two-vehicle (53%)	Single-vehicle (32%)	Two-vehicle (50%)	Single-vehicle (30%)

6.2.5 Road Condition

The characteristics of fatal and injury crashes were first compared by road class. As seen in Table 6.10 and Figure 6.6, most of the fatal and injury crashes occurred on interstates and other principal arterials. Specifically, 11% more fatal crashes (56% vs. 45%) than injury crashes were found in the work zones on the principal arterials other than interstates and other freeways or expressways. On the contrary, interstate highways and other freeways or expressways totally had 17% more injury crashes than fatal crashes.

Table 6.10: Fatal and Injury Crash Percent Frequencies by Road Class

Road Class	Injury (%)	Fatal (%)
Interstate highway	33	27
Other freeways & expressways	15	4
Other principal arterial	45	56
Minor arterial	7	9
Major collector	<1	4
Total	100	100

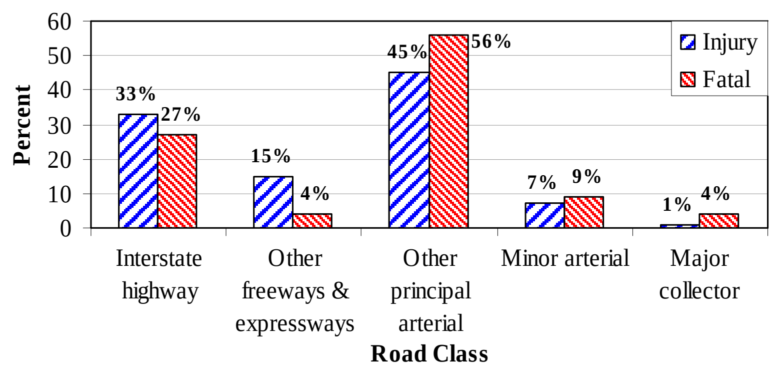


Figure 6.6: Fatal and Injury Crash Percent Frequencies by Road Class

Table 6.11 and Figure 6.7 exhibit the percent frequencies of both work zone fatal and injury crashes by road character. It was found that most (66%) injury crashes occurred in work zones on straight and level highway sections and only 34% of the injury crashes were on highway sections with complicated geometric alignments. The fatal crashes, however, had almost half (49%) in the work zones on highway sections with complex alignment characters such as grades and curves. In particular, among the complex alignment conditions, straight on grade contributed to the highest proportion of both injury crashes (18%) and fatal crashes (25%). These differences in percentage indicate that the presence of complicated highway alignment combinations, especially straight on grade, could potentially increase the severity of a work zone crash.

Table 6.11: Fatal and Injury Crash Percent Frequencies by Road Character

Road Character	Injury (%)	Fatal (%)
Straight and level	66	51
Straight on grade	18	25
Straight at hillcrest	2	3
Curved and level	9	12
Curved on grade	5	8
Other	0	1
Total	100	100

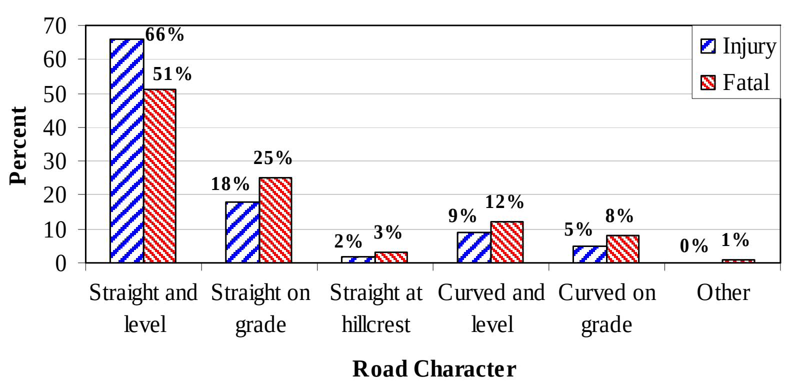


Figure 6.7: Fatal and Injury Crash Percent Frequencies by Road Character

The analyses of fatal crashes in Kansas highway work zones showed that most (63%) of the fatal crashes occurred on two-lane highways. On the contrary, the study of the injury crashes found that only one third (33%) were on two-lane highways while the rest were on multilane highways. Table 6.12 and Figure 6.8 illustrate that, comparing with fatal crashes, work zone injury crashes were more likely to occurred on multi-lane highways especially on four-lane highways. Combining the facts that the most common crash type for the injury crashes was rear-end while head-on was the most common for fatal crashes, the different proportional distributions of fatal and injury crashes over number of traffic lanes suggested that injury crashes were more attributed to high volumes of traffic than fatal crashes.

Table 6.12: Fatal and Injury Crash Percent Frequencies by Number of Lanes

No. of Lanes (Two Direction)	Injury (%)	Fatal (%)
2	33	63
4	49	31
≥ 6	18	6
Total	100	100

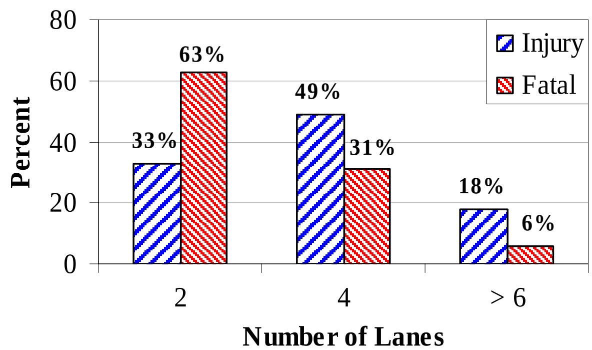


Figure 6.8: Fatal and Injury Crash Percent Frequencies by Number of Lanes

The fatal and injury crash distributions over speed limits are shown in Table 6.13 and Figure 6.9. As seen from these illustrations, 51 – 60 mph speed zones had the highest proportion (47%) of both fatal and injury crashes. A much larger proportion of fatal crashes than injury crashes (45% vs. 21%) occurred on highways with high speed limits between 61 – 70 mph. With speed limits decreasing, highways tended to have proportionally more injury crashes than fatal crashes. For instance, a much larger proportion of injury crashes were found in highways with speed limits lower than 51 mph. This tendency confirmed that high speeds increased the severity of work zone crashes.

Table 6.13: Fatal and Injury Crash Percent Frequencies by Speed Limit

Speed Limit (mph)	Injury (%)	Fatal (%)
≤ 40	19	4
41-50	10	4
51-60	47	47
61-70	21	45
Unknown	3	0
Total	100	100

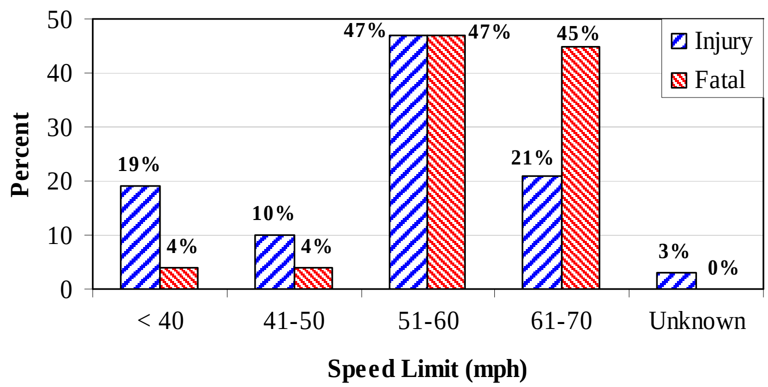


Figure 6.9: Fatal and Injury Crash Percent Frequencies by Speed Limit

When comparing the fatal and injury crash distributions by crash location, it was found that slightly higher percentages of injury crashes occurred in intersections, intersection-related areas, and interchange areas. As shown in Table 6.14 and Figure 6.10, a majority (67%) of fatal crashes occurred in non-intersection areas while 58% of injury crashes were in the same areas.

Table 6.14: Fatal and Injury Crash Percent Frequencies by Crash Location

Crash Location	Injury (%)	Fatal (%)
Non-intersection	58	67
Intersection	15	13
Intersection-related	9	3
Interchange area	8	3
Other	11	15
Total	100	100

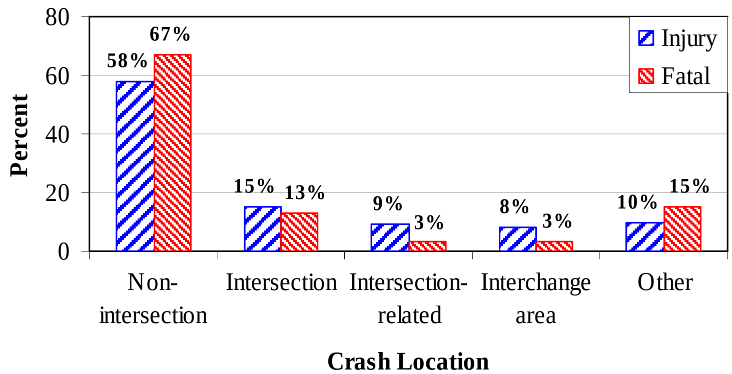


Figure 6.10: Fatal and Injury Crash Percent Frequencies by Crash Location

The comparisons based on other road condition variables including surface type, road special feature, and area information showed no significant differences between fatal and injury crash distributions. Generally, most fatal and injury crashes occurred on blacktop (asphalt-paved) highways, highways without special features such as bridges, railroad crossings, interchanges/ramps, and highways in rural areas. When comparing the crash distributions by traffic control devices, slight proportional differences were found for most of the devices. As shown in Table 6.15 and Figure 6.11, center/edge line was the most common traffic control present at crash sites. It was noticed that "none or inoperative traffic control" coincided with 8% more injury crashes than fatal crashes (11% vs. 3%). The most frequent observations for the variables reflecting the crash-site road conditions are listed in Table 6.16.

Table 6.15: Fatal and Injury Crash Percent Frequencies by Traffic Control

Traffic Control	Injury (%)	Fatal (%)
None or inoperative	11	3
Officer or flagger	5	11
Traffic signal	15	8
Stop sign/signal	7	10
Flasher	3	1
Yield sign	1	1
No passing zone	14	20
Center/edge lines	72	80
Other control	15	18

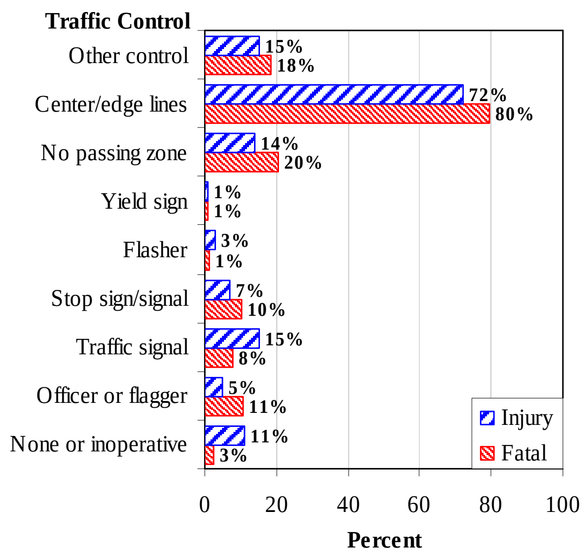


Figure 6.11: Fatal and Injury Crash Percent Frequencies by Traffic Control

Table 6.16: Most Frequent Observations for Road Condition Variables

Variable	Top Two Observations			
	Fatal Crash		Injury Crash	
Road class	Other principle arterials (56%)	Interstate (27%)	Other principal arterials (40%)	Interstate (33%)
Road character	Straight & level (51%)	Straight on grade (25%)	Straight & level (66%)	Straight on grade (18%)
Number of lanes	Two-lane (63%)	Four-lane (31%)	Four-lane (49%)	Two-lane (33%)
Speed limit (mph)	51 – 60 (47%)	61 – 70 (45%)	51 – 60 (47%)	61 – 70 (21%)
Crash location	Non-intersection (67%)	Intersection (13%)	Non-intersection (58%)	Intersection (15%)
Surface type	Blacktop (69%)	Concrete (30%)	Blacktop (61%)	Concrete (39%)
Road special feature	None (85%)	Bridge (5%)	None (85%)	Bridge (6%)
Area information	Rural (84%)	Urban (16%)	Rural (86%)	Urban (14%)
Traffic control	Center/edge lines (80%)	No passing zone (20%)	Center/edge lines (72%)	Traffic signal (15%)

6.2.6 Contributing Factor

As discovered in the separate analyses of fatal and injury crash characteristics, pedestrian factor, environmental factor, and vehicle factor contributed only a trivial percent for both types of work zone crashes. The comparison discussed hereafter was only based on driver errors, which have been proved as the major cause for most crashes. It was found that inattentive driving contributed to more than half of both the fatal and injury crashes. Followed too closely caused 14% more injury crashes than fatal crashes (18% vs. 4%). On the other hand, some other driver errors such as “disregarded traffic signs, signals, or markings” and “under influence of alcohol” resulted in notably higher percentages of fatal crashes than injury crashes. The detailed crash distributions over driver errors are shown in Table 6.17 and the crash frequencies by major errors are highlighted in Figure 6.12. The most frequent observations for the contribution factor variables are listed in Table 6.18.

Table 6.17: Fatal and Injury Crash Percent Frequencies by Driver Error

Driver Factor	Injury (%)	Fatal (%)
Inattention	51	53
Too fast for conditions/speeding	18	25
Disregarded traffic signs, signals or markings	10	21
Wrong side or wrong way	2	20
Under influence of alcohol	5	13
Failed to yield right of way	8	10
Fell asleep	3	9
Followed too closely	18	4
Improper lane change	2	4
Improper passing	1	4
Ill or medical condition	1	4
Avoidance or evasion action	3	3
Not comply-license restrictions	1	1
Other/unknown	5	6
No human error	18	8

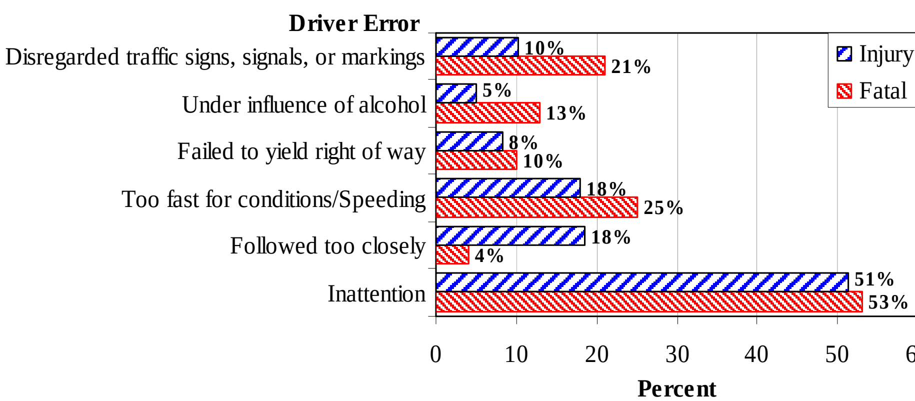


Figure 6.12: Fatal and Injury Crash Percent Frequencies by Driver Error

Table 6.18: Most Frequent Observations for Contribution Factor Variables

Variable	Top Two Observations			
	Fatal Crash		Injury Crash	
Driver factor	Inattention (53%)	Too fast/ Speeding (25%)	Inattention (51%)	Followed too close (25%)
Pedestrian factor	Illegal in road (2%)	--	--	--
Environment factor	Rain, mist, or drizzle (2%)	--	Rain, mist, or drizzle (2%)	--
Vehicle factor	Tires (1%)	--	Brakes/tires (1%)	--

6.3 Summary

In this chapter, the crash characteristics were further studied based on a comparison between fatal crashes and injury crashes. The comparison helps in thoroughly understanding the general characteristics of the work zone crashes as well as the unique ones distinguishing the crashes of different severities. The results also provide practical insights to facilitate the development of work zone traffic control strategies that could not only reduce the number of accidents but also mitigate the accident severity. The comparison results are summarized in terms of at-fault driver, crash time characteristics, crash location, crash type, causal factors, and crash severity increasing factors.

At-fault driver. Most of the work zone crashes, including both fatal and injury crashes, were caused by male drivers. The percentage of at-fault male drivers for the fatal crashes was higher than that for the injury crashes (75% vs. 66%). Male drivers were much more likely to have truck-involved and single-vehicle fatal and injury crashes than females. Young drivers between 15 and 24 years of age caused a high percentage of the work zone crashes especially injury crashes. However, the drivers aged 35 to 44, the most reliable driver group as commonly believed, caused the highest percentage (24%) of the fatal crashes among all the age groups, which was 9% higher than the injury crashes caused by the same age group. Senior drivers who were older than 64 years of age caused a higher percentage of fatal crashes than injury crashes (18% vs. 8%).

Crash time characteristics. Both fatal crashes and injury crashes more frequently occurred in daytime non-peak hours between 10:00 a.m. – 4:00 p.m. Compared with injury crashes, work zone fatal crashes were much more likely to be at nighttime (8:00 p.m. – 6:00 a.m.). In addition, most of the fatal and injury crashes occurred in the construction season from April to November. Regarding to day of week, Fridays and Sundays had the respective highest and lowest percents of injury crashes (18% vs. 9%). The distribution of fatal crashes had no significant differences over the seven days. However, Sundays accounted for 6% more (15% vs. 9%) fatal crashes than injury crashes.

Crash location. A majority of the crashes, including both fatal and injury crashes, occurred on rural highways. In particular, "other principal highways" and interstates with 51 – 70 mph speed limits had most of the crashes. Generally, the work zones on two-lane and four-lane highways were the locations where most of the crashes occurred. Specifically, two-lane highways were more likely to have work zone fatal crashes than injury crashes while four-lane highways had a much higher proportion of injury crashes. Although the study showed that most of the fatal and injury crashes occurred in non-intersection areas, it was found that the percentage of the injury crashes in intersection and intersection-related areas was higher than that for fatal crashes (24% vs. 16%). For both fatal and injury work zone crashes, low percentages were observed in highway sections with special features such as highway bridges, railroad bridges, interchanges, or ramps. Comparing with the 34% of injury crashes on highway sections with complicated geometric alignment features such as grades, curves, and hillcrests, almost half of the fatal crashes took place in work zones with complex highway alignment features.

Crash type. Among both fatal and injury work zone crashes, multi-vehicle crashes were the most frequent crashes. Among multi-vehicle crashes, two-vehicle crash was the most frequent one. Head-on crashes were the dominant work zone fatal crash type while rear-end crashes were the most common for the work zone injury crashes. Angle-side-impact crashes were another major crash type for both the injury and fatal crashes. It was found that most injury crashes involved only light-duty vehicles. However, truck-involved crashes constituted a relatively high percentage (40%) of the fatal crashes. For both fatal and injury crashes, most of the truck-involved crashes were multi-vehicle crashes. These results indicate that truck-involved crashes were more likely to cause severe crashes with considerable property losses and high fatality rates.

Causal factors. Human errors such as inattentive driving were found to be the primary causal factors for both fatal and injury crashes. In particular, too fast for condition/speeding was one of the primary causal factors for fatal work zone crashes while followed too close was a primary causal factor for the injury crashes. Although alcohol impairment was not one of the primary contributing factors for fatal and injury crashes, it resulted in a much higher percentage of fatal crashes than injury crashes (13% vs. 5%). Adverse weather condition, poor road surface conditions, pedestrian factors, and vehicle problems caused a trivial percentage of the crashes. Unfavorable light conditions, especially darkness, were an important contributing factor for both fatal and injury crashes in work zones and were more attributed to the former. Complicated geometric alignments were a contributing factor especially for fatal crashes. Intersections, on the other hand, contributed to a noteworthy percentage of injury crashes.

Factors increasing crash severity. The researchers found that complicated geometric highway alignments (especially grades), unfavorable light conditions, involvement of trucks, alcohol impairment, and disregarding traffic control, were potential factors that contributed to the increase of accident severity in work zones. Comparison results also suggested that the fatal accidents were more related to high speeds while the injury accidents were more related to high traffic volumes.

CHAPTER 7 - CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Highway work zone safety has been a public concern for years and considerable research effort has been devoted to mitigate work zone traffic crashes. In 2004, a research project was initiated by KDOT (K-TRAN Project No. KU-05-01) to study the Kansas highway work zone fatal crashes between 1992 and 2004 and the outcomes have been published in (Bai and Li 2006). Following the previous success, KDOT funded this research (K-TRAN Project No. KU-06-01) to further study the injury crashes during the same period in Kansas highway work zones. The research was focused on investigating the characteristics of the injury crashes and identifying risk factors that contributed to these crashes. The results of injury crash study were compared with those of the fatal crashes to better understand the characteristics of both fatal and injury crashes as well as the significant factors that could increase work zone crash severity. The outcomes from this study are valuable for the development of effective safety countermeasures that could not only reduce the number of severe crashes but also mitigate the crash severity in highway work zones. The following are the conclusions drawn based on the study results.

7.1.1 Work Zone Injury Crash Characteristics and Driving Risks

High-risk driver and time. Male drivers caused two thirds of the work zone injury crashes in Kansas. Young drivers between 15 and 24 years of age, especially males in the teenage driver population, were the high-risk drivers who caused more injury crashes in Kansas work zones. Daytime non-peak hours (10:00 a.m. - 4:00 p.m.) had the highest hourly injury crash frequency (7% per hour) and afternoon peak hours (4:00 p.m. - 8:00 p.m.) had the second highest hourly injury crash rate (6% per hour).

High-risk locations. Rural work zones had 85% of the total injury crashes. The principal arterial roads other than interstate highways and other expressways or freeways had the highest proportion (45%) of the injury crashes. Work zones on multilane highways, especially those with 51 – 60 mph speed limits, were the high-risk locations where injury crashes occurred more frequently. In addition, 24% of the injury crashes took place in intersection or intersection-related areas and 34% of total injury crashes or 46% of the single-vehicle crashes occurred on complicated highway alignments.

Crash type and crash vehicle. The study found that 50% of the injury crashes involved two vehicles and 30% involved only one vehicle. Rear-end collisions were the dominant crash type, accounting for 46% of the total crashes, followed by angle-side impact collisions (18%), and fixed-object collisions (13%). In addition, most (82%) of the crashes involved only light-duty vehicles.

Causal factors. Driver errors, especially inattentive driving, followed too closely, and too fast for conditions, were the most common causal factors for work zone injury crashes. Poor light conditions were most likely to contribute to single-vehicle crashes. Complex geometric alignment features, especially grades, had contributed to the occurrences of work zone injury crashes. The presence of an intersection in or near highway work zones more or less contributed to the occurrences of injury crashes.

7.1.2 Major Differences between Fatal and Injury Crashes

The authors discovered a number of noteworthy differences in characteristics between fatal and injury crashes through the comparison study. The major characteristic differences are summarized in Table 7.1. These characteristic differences were discovered in the aspects including at-fault drivers, crash time, crash location, crash type, and causal factors. The comparison showed that complicated highway geometric alignments (especially grades), unfavorable light conditions, involvement of heavy vehicles, alcohol impairment, and disregarding traffic control, were factors that could potentially increase the crash severity in work zones. Comparison results also illustrated that the fatal crashes were more related to high speeds while the injury crashes were more related to high traffic volumes.

Table 7.1: Major Characteristic Differences between Fatal and Injury Crashes

Category	Fatal Crash Characteristics	Injury Crash Characteristics
Drivers at fault	Drivers between 35-44 and older than 64 frequently caused more fatal crashes.	Drivers younger than 35, especially those between 15-24, frequently caused injury crashes.
Accident time	A much larger proportion occurred during nighttime.	Daytime non-peak hours had the highest crash frequency.
Accident location	Most crashes took place in 51-60 mph and 61-70 mph speed zones.	51-60 mph speed zones had almost half of the crashes; the rest were relatively evenly distributed over other speed zones.
Accident type	Head-on was the dominant type.	Rear-end was the dominant type.
	A large percent of crashes involved trucks.	A majority of crashes involved only light-duty vehicles.
Causal factors	Disregarded traffic control, alcohol impairment, and speeding caused a much larger proportion.	Followed too close caused a much higher percent.
	Unfavorable light conditions, especially nighttime darkness, contributed to a larger proportion.	A majority of the crashes occurred when light conditions were favorable.
	Complicated road geometries contributed to a larger proportion.	A majority of the crashes occurred on straight and level highways.
Note	The comparison is based on percentage distributions.	

7.2 Recommendations

The study has revealed the major injury and fatal crash characteristics and risks in Kansas highway work zones. Based on these results, some potential safety improvements were recommended. These improvements were categorized in three aspects: traffic control, safety education, and crash investigation. A summary of the major work zone risk factors and corresponding safety countermeasure recommendations are listed in Table 7.1.

Table 7.2: Work Zone Risks and Safety Improvement Recommendations

Risk* Category	Risk Description	Safety Improvement Recommendation
High-risk drivers	Male drivers	Safety education
	Drivers between 15 – 24 (who caused a large proportion of injury crashes)	Safety education
	Drivers between 35 – 44 and older than 65 (who caused large proportions of fatal crashes)	Safety education
High-risk time periods	Daytime non-peak hours (10:00 a.m. – 4:00 p.m.)	Safety education, traffic control enforcement
	Nighttime between 8:00 p.m. – 6:00 a.m. (when a large proportion of fatal crashes occurred)	Illumination or retroreflective devices, speed control
High-risk locations	Rural highway work zones with speed limits between 51 – 70 mph	Speed limit enforcement, more effective speed control devices
	Work zones on highway sections with complex geometric features especially grades	Driver information, special traffic control devices or settings, lower speed limit
	Work zones with or close to intersections	Speed control, sufficient driver information and warning.
Most common crash types	Rear-end (the dominant type of injury crashes)	Effective speed control and headway control strategies
	Head-on (the dominant type of fatal crashes)	Median separation, speed control
	Heavy-truck involved crashes (a large proportion of fatal crashes)	Driver education, work zone design with more consideration of heavy truck characteristics
Driver errors	Inattentive driving	Temporary rumble strips, highly visible warning signs
	Followed too closely	Effective speed control, headway control strategies
*Risk refers to a relatively high probability of contributing to or being associated with injury and/or fatal crashes in work zones.		

Improvement of traffic control is the most direct method to reduce highway work zone crashes. More effective and sufficient work zone traffic controls should be installed. In particular, based on the characteristics of highway work zone crashes, the following traffic control improvements are recommended.

- More effective speed control strategies. The high composition of crashes in high-speed zones and the dominance of rear-end collisions in injury crashes indicate a strong association between high speeds and work zone injury and fatal crashes. Therefore, controlling speeds is a key step towards improving work zone safety. The crash analyses results suggest a need of more effective and more strictly enforced speed control strategies in highway work zones to prevent high-severity crashes causing injuries and fatalities. In particular, more strictly enforced speed limits should be considered in work zones with complex highway geometric alignments. However, the question that remains is how to set up speed limits properly in work zones. A previous study indicated that a sharp reduction of speed (e.g., a reduction of more than 10 mph) might cause more crashes in highway work zones. There is a need to conduct further research in this area.
- Effective headway control strategies. The study found that the most common type for injury crashes was rear-end and a majority of the truck-involved crashes were multi-vehicle collisions. In addition, in many work zones, the remaining travel lanes are usually separated from construction areas by chanalization devices and it is often impossible to escape from a following high-speed vehicle in the travel lane. Therefore, it would be practically promising to develop

strategies of effectively controlling and enforcing safe headways between consecutive vehicles especially when the platoon has heavy vehicles. Such a device could be a headway detector controlled by intelligent algorithms to send instant warning messages to changeable message signs. Work zone driving regulations can be also developed to enforce safe headways.

- More effective warning devices. The fact that inattentive driving contributed most of the fatal and injury crashes in work zones suggests an immediate need for effective approaches to warn the inattentive drivers of the upcoming work zone conditions. When construction workers and/or other personnel are present in traffic lanes, such devices that can effectively alert inattentive drivers become extremely important. The researchers hence recommend the use of more effective warning devices such as temporary rumble strips or other raised pavement markings in highway work zones. These devices may have both physical vibration and visual impacts which might be effective in alerting drivers to drive more cautiously. Some highly visible warning devices such as flashing lights may also be effective in warning inattentive drivers and consequently enhance the work zone safety level.
- Other traffic control improvements. The study of both injury and fatal work zone crashes also suggested needs for other traffic control improvements. For instance, the high percent of nighttime fatal crashes might be reduced by installing illumination or highly retroreflective devices in the work zones at nighttime. Installation of median separators should be considered in some work zones to eliminate head-on crashes, one of the major collision types for fatal

crashes. In addition, special traffic control strategies such as warning signs that have a particularly impact on truck drivers need to be developed to help drivers pass the work zones safely.

In addition to the improvements on work zone traffic controls, education will be a promising supplement for maximized safety improvement in highway work zones. The crash investigation showed that male drivers caused most of both fatal and injury crashes in Kansas highway work zones. Drivers younger than 25 years of age, especially males in the teenage driver population, were responsible for a large proportion of the injury crashes. Drivers aged 35 to 44 and older than 64 were the groups with the highest fatal crash rate in Kansas work zones. Truck drivers also create safety problems in work zones especially by contributing to a large percent of work zone fatal crashes. The researchers suggest launching a risk-driver-oriented education program in order to raise awareness of highway work zone hazards. The fact that a major cause of most crashes was human errors also indicates the urgency for developing effective education programs for the traveling public.

Regarding accident reporting, some sections of the State of Kansas Motor Vehicle Accident Report need to be modified to better facilitate work zone accident investigation. For instance, the traffic control devices listed on the report do not include temporary traffic control devices such as channelization devices and temporary lighting devices that are commonly used in work zones. As a result, accident investigators (police) usually either classify those temporary work zone traffic control devices as "other" or do not record them. Revisions might also be considered for other sections such as pedestrian identification (regular pedestrian or construction worker), and crash locations within work zones (advance warning area, transition area, activity area, or termination area). Descriptions of the work zone including the construction work types, basic construction zone configurations, and the status of construction work at the crash time should be also included in the accident reports.

The research findings once again raised the attention on the safety concern created by heavy trucks which frequently caused high-severity and multi-vehicle crashes in work zones. The researchers recommend an in-depth study to further analyze truck-related crashes in work zones. Such a study may unveil the reasons of truck-related crashes. Thus, it might be possible to develop safety countermeasures that can effectively prevent trucks from causing crashes and to improve the safety in highway work zones.

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APPENDIX A: KDOT ACCIDENT REPORT SAMPLE (2004 EDITION)

☐ 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

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.

Sample

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 | Distance N 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

EMS Unit A | INJURED TAKEN By: | INJURED TAKEN To:
EMS Unit B | INJURED TAKEN By: | INJURED TAKEN To:
EMS 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

TRAFFIC CONTROLS
O/A (On/At Road)
Type Present
OK/NF(OK/Non-functional)
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

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

*** 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

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

**** 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

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 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

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

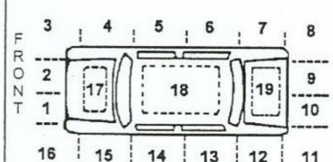
CONST./MAINT. ZONE
ON / AT
00 None apply
01 Construction zone
02 Maintenance zone
03 Utility zone

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

ENTER ANY VISIBLE IDENTIFIER:
refer by code
Code Ident:

VEHICLE MANEUVER BEFORE CRASH
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

DAMAGE LOCATION AREA - Vehicle



Top Windshld Windows
Under Overturn Other
Trailer? Present Damaged

VEHICLE BODY TYPE
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)

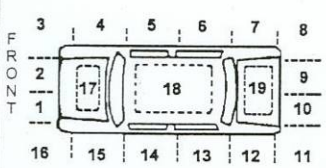
HEAVY / LARGE VEHICLES
10 Single Large Truck
11 Truck and trailer(s)
12 Tractor-trailer(s)
13 Cross country bus
14 School bus
15 Transit bus
25 Train
77 Emergency Vehicles
88 Other

Bus Capacity

PEDESTRIAN LOCATION BEFORE IMPACT-IN INTERSECTION:
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

PEDESTRIAN ACTION
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

DAMAGE LOCATION AREA - Vehicle



Top Windshld Windows
Under Overturn Other
Trailer? Present Damaged

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

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

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

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

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

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

0.0 ← B.A.C. → 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

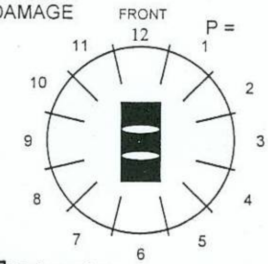
FATALITY DATA

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

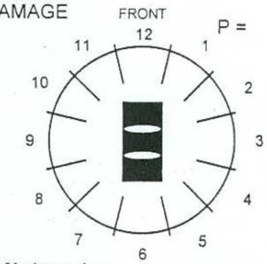
☐ No Damage

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)

KANSAS PERMITS (Issuer and Permit Number)

1. ____________ ____________

2. ____________ ____________

3. ____________ ____________

CARRIER ADDRESS CITY STATE ZIP CODE

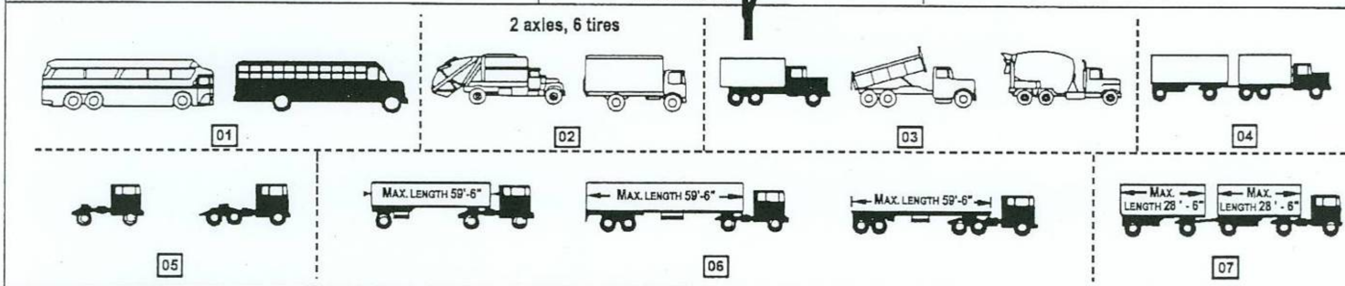
U.S. GOVERNMENT PERMITS (Issuer and Number)

USDOT ____________ ICC MC ____________

SOURCE OF NAME (enter one only)

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

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 ____________

SEQUENCE OF EVENTS (list up to 4)

1 ___
2 ___
3 ___
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

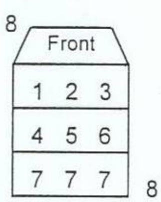
O/A (On/At) R (Road)

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 Snowpacked

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 B: OBSERVATIONS OF CRASH VARIABLES

Table B.1: Observations for Age

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

Table B.2: Observations for Gender

Name of Observation	Number Assigned
Male	0
Female	1

Table B.3: Observations for Crash Time

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

Table B.4: Observations for Day of the Week

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

Table B.5: Observations for Month of the Year

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

Table B.6: Observations for Year of Crash

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

Table B.7: Observations for Light Condition

Name of Observation	Number Assigned	Observation Group
Daylight	1	Good Condition
Dawn	2	Poor Condition
Dusk	3	Poor Condition
Dark: street lights on	4	Poor Condition
Dark: no street lights	5	Poor Condition

Table B.8: Observations for Weather Condition

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

Table B.9: Observations for Road Surface Condition

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

Table B.10: Observations for Vehicle Maneuver before Crash

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

Table B.11: Observations for Crash Severity

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

Table B.12: Observations for Crash Type

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

Table B.13: Observations for Vehicle Body Type

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

Note: Vehicle includes passenger cars, SUV, minivan, ATV, camper or RV, and pickup

Table B.14: Observations for Road Class

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

Table B.15: Observations for Road Character

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

Table B.16: Observations for Crash Location

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

Table B.17: Observations for Surface Type

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

Table B.18: Observations for Road Special Features

Name of Observation	Number Assigned	Observation Group
None	1	No feature impact
Bridge	2	Feature impact
Bridge overhead	3	Feature impact
Railroad bridge	4	Feature impact
Railroad crossing	5	Feature impact
Interchange	6	Feature impact
Ramp	7	Feature impact
Other	8	Feature impact

Table B.19: Observations for Area Information

Name of Observation	Number Assigned
Urban	0
Rural	1

Table B.20: Observations for Traffic Controls

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

Table B.21: Observations for Driver Factor

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

Table B.22: Observations for Pedestrian Factor

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

Table B.23: Observations for Environment Factor

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

Table B.24: Observations for Vehicle Factor

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

APPENDIX C: A PORTION OF COLLECTED DATASHEET

Table 1: 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 1 (Continued): A Portion of the Datasheet Used for Statistical Analyses

Crash Number (Key #)	Road Information											Contributing 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.

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