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REDUCING WORK ZONE CRASHES BY USING VEHICLE'S WARNING FLASHERS AS A WARNING SIGN

Yong Bai, Ph.D., P.E.
Yingfeng Li, Ph.D.
The University of Kansas
Lawrence, Kansas

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16 Abstract

Rural two-lane highways constitute a large percentage of the highway system in Kansas. Preserving, expending, and enhancing these highways require the set-up of a large number of one-lane, two-way work zones where traffic safety has been a severe concern. Aimed at reducing the work zone crashes attributable to inattentive driving, the Kansas Department of Transportation (KDOT) initiated a research project to evaluate the effectiveness of a traffic warning sign that is assembled by using the emergency warning flashers of the vehicles in one-lane, two-way work zones. This warning sign was named as the Emergency Flasher Traffic Control Device (EFTCD). It works in the following fashion. When a vehicle entering a one-lane, two-way work zone where stopping is required for waiting to pass the work zone, the driver is required to turn on its emergency warning flashers to warn the following vehicles of the work zone stopping condition. The EFTCD is flexible and cost-effective and may particularly benefit those work zones that are frequently moved due to the construction progress.

To accurately evaluate the effectiveness of the proposed EFTCD, researchers conducted experiments in three one-lane, two-way work zones in Kansas including two with a 55-mph speed limit and one with a 65-mph speed limit. During experimental period, researchers collected vehicle speed data with and without the EFTCD and surveyed drivers for their interpretation of this warning sign and recommendation on its potential implementation. Analyses results showed that the EFTCD effectively reduced the mean speeds in work zones as well as the proportions of notably high speeds. In addition, survey results indicated that the EFTCD successfully captured the attention of most drivers when they approached the work zones. A majority of drivers recommended the implementation of this warning sign in the work zones. Therefore, researchers concluded that the EFTCD was effective in one-lane, two-way work zones. Recommendations on future research were also presented based on the results of this study. The outcomes of this research project benefit not only Kansas, but also other States where rural two-lane highways constitute a high percentage of their highway systems.

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Final Report

Prepared by

Yong Bai, Ph.D., P.E.
Yingfeng Li, Ph.D.*
The University of Kansas
Lawrence, Kansas

*Currently Affiliated with the Texas Transportation Institute
Texas A&M University

The University of Kansas
Lawrence, Kansas

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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

Rural two-lane highways constitute a large percentage of the highway system in Kansas. Preserving, expending, and enhancing these highways require the set-up of a large number of one-lane, two-way work zones where traffic safety has been a severe concern. Aimed at reducing the work zone crashes attributable to inattentive driving, the Kansas Department of Transportation (KDOT) initiated a research project to evaluate the effectiveness of a traffic warning sign that is assembled by using the emergency warning flashers of the vehicles in one-lane, two-way work zones. This warning sign was named as the Emergency Flasher Traffic Control Device (EFTCD). It works in the following fashion. When a vehicle entering a one-lane, two-way work zone where stopping is required for waiting to pass the work zone, the driver is required to turn on its emergency warning flashers to warn the following vehicles of the work zone stopping condition. The EFTCD is flexible and cost-effective and may particularly benefit those work zones that are frequently moved due to the construction progress.

To accurately evaluate the effectiveness of the proposed EFTCD, researchers conducted experiments in three one-lane, two-way work zones in Kansas including two with a 55-mph speed limit and one with a 65-mph speed limit. During experimental period, researchers collected vehicle speed data with and without the EFTCD and surveyed drivers for their interpretation of this warning sign and recommendation on its potential implementation. Analyses results showed that the EFTCD effectively reduced the mean speeds in work

zones as well as the proportions of notably high speeds. In addition, survey results indicated that the EFTCD successfully captured the attention of most drivers when they approached the work zones. A majority of drivers recommended the implementation of this warning sign in the work zones. Therefore, researchers concluded that the EFTCD was effective in one-lane, two-way work zones. Recommendations on future research were also presented based on the results of this study. The outcomes of this research project benefit not only Kansas, but also other States where rural two-lane highways constitute a high percentage of their highway systems.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - INTRODUCTION

1.1 Problem Statement

The aging highway system in the United States has led to an increasing funding allocation on existing highway preserving, rehabilitating, expanding, and enhancing. As a result, the traveling public has to encounter more and more work zones on the highways. Work zones create an inevitable disruption on regular traffic flows and result in severe traffic delays and safety concerns. Nationally, great effort has been devoted to improve 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). Many State Departments of Transportation (DOTs) are 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 practical researches on various work zone safety issues.

Despite the effort, work zone safety remains unsatisfactory nationwide. In 2005, 1,074 people were killed in work zones in the United States, an increase of 4% compared to 2004 (FHWA 2007). The direct cost of highway work zone crashes, 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). In Kansas, 466 severe crashes were reported in work zones in 2006, leaving 15 killed and 659 injured: an overall increase of 43% compared to 2005 in the total number of fatalities and injuries (KDOT 2007).

Highway statistics data indicate that 91% of the Kansas public roadway-miles are rural and approximately 97% of the major rural roadways (interstates, principal and minor arterials, and major collectors) are two-lane highways. Preserving, rehabilitating, expending, and enhancing these highways require the set-up of a large number of work zones. In Kansas, 63% of the fatal crashes and a third of the injury crashes were taken place in two-lane highway work zones (Bai and Li 2007). Inattentive driving was the reason that contributed to more than half of the severe crashes involving fatalities and/or injuries in Kansas highway work zones and rear-end collisions were found to be the dominant crash type (Bai and Li 2007). It has become a critical challenge for traffic engineers to maintain a satisfactory safety level without sacrificing highway functions in work zones.

On two-lane highways, in order to carry out construction or maintenance projects without completely closing the highway, the construction activities have to be constrained within one lane while another lane remains open for through traffic. These one-lane, two-way work zones require traffic from one direction to pass through with caution and the traffic from another direction has to be stopped until the open lane is cleared. Flaggers were typically employed to stop and coordinate traffic from both directions, and a pilot-car was used to guide travelers through work zones safely. Aimed at reducing the work zone crashes, especially rear-end collisions that are attributable to inattentive driving, Kansas Department of Transportation (KDOT) initiated a research project to evaluate the effectiveness of a traffic warning sign that was assembled using vehicles' emergency warning flashers in one-way, two-lane work zones. This warning sign was named as the Emergency Flasher Traffic Control Device (EFTCD). It works in the following fashion. When a vehicle stops at an entrance of a work zone, the driver is required to turn on the emergency warning flashers to warn the following vehicle driver that he/she is approaching to the work zone. The warning flashers may effectively alert the following vehicles and consequently reduce crashes (especially rear-end collisions) caused by inattentive drivers. Advantages of the EFTCD include easy setup, easy operation, high visibility, and low cost.

In cooperation with KDOT, the research team from the University of Kansas systematically assessed the proposed EFTCD in one-lane, two-way work zones in Kansas. To achieve project objectives, researchers compared the speeds of the approaching vehicles with and without the warning flashers, and conducted random surveys at the work zones. This report documents the execution of the project along with the research findings and recommendations.

1.2 Report Organization

This report includes the following chapters:

1. Introduction. The report starts with this introduction chapter which presents a general problem statement of this research and a brief description of the report organization.
2. Literature review. This chapter synthesizes the findings from a comprehensive review of the literature that is relevant to this study. The topics included in the review are: work zone crash characteristics, work zone traffic control methods and effectiveness,

and research and development trend on work zone safety. The knowledge summarized in this chapter provides a necessary background for this research project.

3. Research objective, scope, and methodology. The primary objective, the scope, and the methodology of this research project are defined in this chapter.
4. Field experimental design. This chapter describes the field experiments conducted in this research project and the devices used for data collection. In addition, the description of the survey questionnaire is also included in this chapter.
5. Data collection. This chapter describes the data collection procedures as well as the collected vehicle speed data and survey data.
6. Data analysis. This chapter includes the analyses of the collected speed data and survey data. The chapter starts with the methodology of data analyses and then proceeds with the detailed analysis results of both speed data and the survey feedbacks collected from the field experiments.
7. Conclusion and recommendation. Based on the results of this research project, conclusions and recommendations on the effectiveness of the EFTCD, the feasibility of utilizing this traffic control, and the implementation of this traffic control in work zones, were provided in this chapter.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

Highway work zones interrupt regular traffic flows and create a safety concern for the traveling public. According to highway statistics, 91% of the Kansas public roadway-miles are in rural areas and approximately 97% of Kansas major rural roadways (interstates, principal and minor arterials, and major collectors) are two-lane highways. Preserving, rehabilitating, expending, and enhancing these highways require the set-up of a large number of one-lane, two-way work zones. Studies showed that 63% of the fatal crashes and a third of the injury crashes in Kansas were taken place in work zones on two-lane highways (Bai and Li 2007). Improving safety in these work zones becomes a critical task for traffic engineers.

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

A typical work zone on a two-lane highway occupies one lane for road work and the other remains open for traffic from both directions. This type of work zone is setup for a short duration (a few hours to several days) and is required frequent movement and re-setup due to the progress of road work. Thus, properly coordinating and safely guiding the traffic from both directions through the work zone become crucial. These one-lane, two-way work zones typically utilize traffic control devices such as flaggers and pilot-cars to control traffic flows and provide safety for both through travelers and highway workers. According to MUTCD, such work zones may require the proper implementation of following traffic control methods (FHWA 2003):

Configuration of flagger control. When a one-lane, two-way work zone is short enough to allow a flagger to see from one end of the zone to the other, a single flagger may be used to control traffic. For relatively long work zones, traffic needs to be controlled by a flagger at each end of the work zone. These flaggers should be able to communicate with each other orally, electronically, or with manual signals. In addition, flaggers should coordinate the traffic so that the vehicles stopping on the other end do not proceed until the platoon from the opposite direction travel through.

Proper use of pilot vehicle. A pilot car may be used in a one-way, two-lane work zone to guide a queue of vehicles. The operation of a pilot vehicle should be coordinated with flagging operations or other controls at each end of the work zone. A PILOT CAR FOLLOW ME sign should be mounted on a pilot vehicle at a conspicuous location. The vehicle may also turn on its emergency lights and additional flashers to improve its visibility.

Other traffic signs and signals. In addition to flaggers and pilot vehicles, other supplemental traffic control methods that could be used in one-lane, two-way work zones include traffic control signals and STOP or YIELD traffic signs. When conditions allow (e.g., drivers are able to see the other end of the work zone and are also sufficiently visible to approaching vehicles), these methods may also be used independently for traffic control.

To gather the background information for this research project, a comprehensive literature review was conducted. This review synthesized the previous research findings that were relevant to this research project. These findings are summarized in this chapter under the following titles: work zone crash characteristics, work zone traffic control, and research and development trend in work zone safety.

2.2 Work Zone Crash Characteristics

Knowledge of highway work zone crash characteristics helps traffic engineers and researchers to better understand the needs of work zone traffic control. This section summarizes the findings of previous studies on work zone crash characteristics. The summary starts with the nationwide work zone crash characteristics studies (not include State of Kansas) followed by the characteristics studies conducted by the State of Kansas.

2.2.1 Nationwide Work Zone Crash Characteristics

Work zone safety has been a research focus for many years and a number of studies were conducted on crash characteristic investigation. Most of these studies were statewide, although a few were based on multi-state work zone crash data. The major characteristics identified from these studies vary with different data scope. Nevertheless, the predominant crash characteristics were reviewed 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).

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 collision was 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. Researchers of 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.

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 Kansas Work Zone Crash Characteristics

The characteristics of severe crashes involving fatalities and/or injuries in Kansas highway work zones were investigated and results were published (Bai and Li 2006; Bai and Li 2007; Li and Bai 2008a). Some characteristics were different from those found in other states due to different highway structures and traffic patterns. This section summarizes the major characteristics of the severe crashes reported in Kansas highway work zones based on the previous studies funded by KDOT.

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. 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 from 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 65 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 occurred more frequently 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 while four-lane highways had a much higher proportion of injury crashes. Although results of 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 crash was the most frequent crash type. Among multi-vehicle crashes, two-vehicle crash was the most frequent one. Head-on crash was the dominant work zone fatal crash type while rear-end crash was the most common type for the work zone injury crashes. Angle-side-impact crash was another major crash type for both 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%) for 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 rate for fatal crashes than for 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 crash severity in work zones. Comparison results also suggested that the fatal crashes were more related to high speeds while the injury crashes were more related to high traffic volumes.

2.3 Work Zone Traffic Control

2.3.1 Traditional Work Zone Traffic Control Methods and Effectiveness

Highway work zones use temporary traffic control (TTC) devices to provide continuity of reasonably safe and efficient traffic flows during road work. As indicated in the MUTCD (FHWA 2003), TTC devices that are commonly used in work zones include flaggers, traffic signs, arrow panels and portable changeable message signs, channelizing devices, pavement markings, lighting devices, temporary traffic control signals, and rumble strips. A review of these traffic control methods and their related studies is presented herein.

Flagger Control. Flaggers are qualified personnel wearing high-visibility safety apparel and equipped with hand-held devices such as STOP/SLOW paddles, lights, and red flags to control road users through work zones. The MUTCD suggests that flaggers should be located such that approaching road users have sufficient distance to stop at an intended stopping point. Flaggers should be preceded by an advance warning sign or signs and be illuminated at night.

A study (Richards and Dudek 1986) showed that flaggers were most efficient on two-lane, two-way rural highways and urban arterials, where they had the least competition for drivers' attention; flaggers were also well suited for short-duration applications (less than one day) and for intermittent use at long-duration work zones. Garber and Woo (1990) concluded that the most effective combinations of traffic control devices for work zones on multilane highways were cones, flashing arrows and flaggers, and the effective combinations of traffic control devices for work zones on urban two-lane highways were cones and flaggers, and static signs and flaggers. Hill (2003) proved that flaggers were effective in reducing fatal work zone crashes. However, the study by Benekohal et al. (1995) indicated there was a need for improving flagging for heavy-truck traffic. Their survey showed that one third of the surveyed truck drivers responded that flaggers were hard to see and half of them thought the directions of flaggers were confusing. Recent evaluations (Li and Bai 2008b) showed that the presence of flaggers in work zones could lower the odds of causing fatalities when a severe crash occurred by 56%.

Traffic Signs. As listed in the MUTCD, traffic signs in work zones include regulatory signs, warning signs, and guide signs. Regulatory signs inform road users of traffic laws or regulations and indicate the applicability of legal requirements that would not otherwise be apparent. Most regulatory signs are rectangular with a black legend and border on a white background. Warning signs notify road users of specific situations or conditions on or adjacent to a roadway that might not otherwise be apparent. Common warning signs are diamond-shaped with a black legend and border on a yellow background and are placed in advance of work zones. Guide signs along highways provide road users with information to help them through work zones.

Traffic signs in work zones are important in informing travelers about interrupted traffic conditions. A survey indicated that 50% of the surveyed truck drivers wanted to see warning signs 3-5 miles in advance (Benekohal et al. 1995). Garber and Woo (1990) found that static traffic signs could effectively reduce crashes in work zones on urban two-lane highways when used with flaggers. However, Li and Bai (2008b) found that having stop signs in work zones could triple the odds of having crashes caused by “following too closely.”

Arrow Panels and Portable Changeable Message Signs. An arrow panel is a sign with a matrix of elements capable of either flashing or sequential display.

A portable changeable message sign is a message sign with the flexibility to display a variety of messages. Arrow panels and portable changeable message signs usually contain luminous panels with high visibility that makes them an ideal traffic control supplement in both daytime and nighttime.

A number of studies (Garber and Patel 1994, Garber and Srinivasan 1998, and Brewer et al. 2007) showed that a changeable message sign was a more effective means than traditional work zone traffic control devices in reducing the number of speeding vehicles in work zones. Another evaluation (Dixon and Wang 2002) showed that changeable message signs with radar effectively reduced vehicle speeds in the immediate vicinity of the sign. However, vehicles tended to return back to their original speeds later. Richards and Dudek (1986) commented that changeable message signs could result in only modest speed reductions (less than 10 mph) when used alone and they would lose their effectiveness when operated continuously for long periods with the same messages. Huebschman et al. (2003) argued that changeable message signs were actually no more effective than traditional message panels.

Channelizing Devices. Channelizing devices are used to warn road users of changed traffic conditions in work zones and to guide travelers to drive safely and smoothly through work zones. Channelizing devices include cones, tubular markers, vertical panels, drums, barricades, and temporary raised islands. Results of a study (Pain et al. 1983) showed that most of the channelizing devices were effective in alerting and guiding drivers, but the devices only obtained their maximum effectiveness when properly deployed as a system or array of devices. Garber and Woo (1990) however, found that the use of barricades in any combination of traffic control devices on urban multilane highways seemed to reduce the effectiveness of other traffic control devices.

Temporary Pavement Markings. Temporary pavement markings are maintained along paved streets and highways in all long- and intermediate- term stationary work zones. In addition, temporary raised pavement markers and delineators are used sometimes to supplement pavement markings to highlight the travel paths. Pavement markings can be used to control speeds. A traffic control strategy using modified optical speed bars to meet the conditions of highway work zones has been applied to control speeds in work zones. Utilizing optical speed bars is an innovative speed control technique that uses transverse stripes spaced at gradually decreasing distances on pavement to affect the driver's perception of speed. Meyer (2004) conducted a study to evaluate the effectiveness of this strategy in reducing work-zone speed in Kansas. Results of the study showed that the speed bars had both warning effect and perceptual effect and were effective in controlling speeds and reducing speed variations.

Lighting Devices. Lighting devices are used based on engineering judgment to supplement retroreflectorized signs, barriers, and channelizing devices. The four types of lighting devices commonly used in work zones are floodlights, flashing warning beacons, warning lights, and steady-burn electric lamps. These devices attract drivers' attentions and can illuminate work zones or warn drivers of the complicated travel conditions at both daytime and nighttime. It was recommended that properly aiming and alining lighting to avoid glare was important for nighttime work zone setup (Cottrell 1999). Some studies (Huebschman et al. 2003; Arnold 2003) found that using flashing warning lights, especially police vehicles with flashing lights, was one of the most effective approaches for reducing speeds in work zones.

Temporary Traffic Control Signals. Temporary traffic control signals are typically used for conditions such as temporary one-way operations in work zones with one lane open and work zones involving intersections. The MUTCD suggests that temporary traffic control signals should be used with other traffic control devices, such as warning and regulatory signs, pavement markings, and channelizing devices. In addition, the design and placement of temporary traffic control signals should include interconnection to other traffic control signals along the subject roadway and those not in uses should be covered or removed. Some analyses of work zone fatal crashes showed that certain temporary traffic control signals, such as STOP/GO signals, were very effective in reducing fatal crashes in work zones (Hill 2003).

Rumble Strips. Rumble strips consist of intermittent narrow, transverse areas of rough-textured or slightly raised or depressed road surface that extend across the travel lanes to alert drivers of unusual traffic conditions through noise and vibration. Longitudinal rumble strips are rough-textured road surfaces located along the shoulder to alert road users that they are leaving the travel lanes. Two types of temporary transverse rumble strips were tested by Horowitz and Notbohm (2005). Test results showed that the rumble strips with a depth of 0.25 inches were as effective as cut-in-pavement rumble strips when vehicles traveled at 55mph and the rumble strips with a depth of 0.75 inches were effective for vehicles speed between 10 and 40 mph. Another evaluation (Meyer 2006) of temporary rumble strips showed that properly designed strips could be easily installed and reinstalled. The un-installation of these rumble strips was not extremely difficult and could be done by individual workers.

2.3.2 ITS Applications in Highway Work Zones

Intelligent Transportation Systems (ITS) represent a modern traffic control and management trend in highway work zones. Currently, various ITS have been implemented in highway work zones to improve safety and mitigate congestion. These systems usually involve the use of electronics, computers, and communication equipment to collect real-time information, process it, and send it to engineers for making traffic control decisions accordingly. ITS applications in highway work zones may function for one or several of the following purposes (FHWA 2006):

- 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); and
- Work zone planning.

This section presents a review of the typical ITS applications in highway work zones.

Real-Time Traffic Control Systems (RTTCS). A RTTCS was deployed in a work zone on I-55 by the 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 detected types and traveling speeds of the approaching vehicles 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 Web site 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 or downtime.

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

Temporary Traffic Management Systems (TTMS). A TTMS was employed by the 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 Web site. These features were used to help guide motorists to alternate routes and alleviate traffic congestion on surrounding roads when the major freeway was closed. 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 up and automatically updated the DMS to display a map with color-coded average roadway speeds on the Web site for trip planning. The system allowed daily commuters to make informed choices regarding their travel plans and thus mitigated congestion in the work zone.

Traffic and Incident Management Systems (TIMS). An example of work-zone TIMS was demonstrated in a large highway project conducted by the 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, all linked to a central traffic management center. The CCTV cameras detected the real-time traffic conditions and sent them to the traffic management center, where trained staff identified incidents and other adverse traffic conditions and initiated appropriate responses immediately. Meanwhile, the DMS displayed appropriate messages and the HAR units transmitted them to the motorists. NMSHTD's evaluation showed that the system improved work zone mobility by effectively reducing congestion and incident response and 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 Systems (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 cables. 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 flexibly adjust their construction operations to mitigate the work zone travel delays to meet the travel time provision set by ADOT. The system allowed ADOT staff to effectively monitor the construction process and reduced excessive travel delays in the work zone.

Advanced Traveler Information Systems (ATIS). ATIS are 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 serving as work zone speed advisory system was deployed in advance for a work zone on northbound I-680 by the Nebraska Department of Roads (NDOR) to advise drivers on the real-time work zone speeds and encourage them to divert to alternate routes to avoid congestion (Pesti et al. 2004). The system was composed of a video detection system, two portable CMSs, and a central computer that coordinated communications between the detection system and the CMS. NDOR engineers were informed about detected speeds, which enabled them to display real-time advisory messages accordingly. The evaluation of this system, however, suggested that it did not significantly increase vehicle diversion during the study period. Bushman and Berthelot (2005) and Chu et al. (2005) evaluated similar systems implemented in North Carolina and California and found that most motorists acknowledged the benefits of the system.

2.4 Research and Development Trends in Work Zone Safety

This section presents an overview of some relatively new technologies and methodologies that have benefited or could benefit work zone safety practice and research. Based on the results of the review, the general trend of the modern work zone safety research and development is to combine advanced technologies developed from other scientific and engineering fields with traffic engineering to improve safety practices in highway work zones. For instance, the concepts which are previously only found in computer science have been applied in work zone safety research, such as fuzzy logic and artificial intelligence. In addition, the technologies including GIS and ITS have also been applied in work zones to improve safety. Some studies included here are not necessarily focused on work zone safety. They are included because the methodologies or technologies used have potentials in work zone safety practice. A list of the studies reviewed in this project is shown in Table 2.1, followed by brief annotations.

Table 2.1: List of the Articles Reviewed in Section 2.3

No.	Researchers	Research Subject	Methodology or Technology	Funding Agency
1	Mitchell et al.	Computational simulation for work zone speed control device in-door testing	Computer visualization and simulation	N/A
2	Adeli and Ghosh-Dastidar	Freeway work zone traffic flow and congestion study	Mesoscopic-wavelet model in traffic flow simulation	N/A
3	El-Zarif et al.	Computer simulation for evaluation of new work zone ITS application	Computer simulation, advanced rural transportation system	N/A
4	Lord	Crash prediction model and safety risk estimation	Safety risk estimation model and application of EMME/2	Natural Sciences and Engineering Research Council of Canada
5	Jha and McCall	GIS visualization for highway projects	GIS visualization	Maryland State Highway Administration
6	Barton et al.	Improving conspicuity during work zone designs	Computer model for conspicuity analysis	The State of California Business, Transportation, and Housing Agency
7	Krishnan et al.	Rear-end collision prevention	Rear-end-collision warning system	N/A
8	Roche	GIS based crash data analysis	GIS	N/A
9	Misener et al.	Preventing lead-vehicle-not-moving crashes	cognitive car-following model	State of California Business and Transportation and Housing Agency
10	Burnette and Moon	Web-based highway driving simulation	virtual reality modeling language	N/A

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

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

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

In a recent study, Lord (2002) illustrated the application of Accident Prediction Models (APMs) to estimate crash risk on transportation networks. APMs are tools developed for prediction of crashes on links and nods of computerized transportation networks based on traffic flow information. Crash risk is a safety measurement often used to describe the traffic safety level by incorporating a measure of exposure. This study used a popular transportation planning software package called EMME/2 to create a hypothetical macroscopic highway network and then identified the safest route on the network using APMs.

The study introduced an exponential form of crash risk estimation instead of the existing linear form. Using the estimation method, the crash risk was computed based on the traffic flow output of an EMME/2-based computer program. The results of this study suggested that, the individual risk of being involved in a collision decreased as traffic volume increased. After making comparisons between his APMs with the APMs using other forms of risk estimation in terms of accuracy and efficiency, the researcher concluded that his methodology was superior and could have significant impacts on transportation policy and ITS strategies. This research was partly supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada (NSERC). The data used for the calibration of the crash prediction models were provided by the Toronto Transportation Department.

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

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

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

As mentioned earlier, GIS has a great power in managing both geographical data and tabular database simultaneously. Roche (2000) explored the existing and potential macroscopic applications of GIS with an emphasis on GIS-based crash data analysis in traffic safety study. Two specific GIS functions were highlighted: crash location identification and spatial query. The exploration was mainly performed in the following four areas including: 1) engineering, 2) enforcement, 3) education, and 4) emergency response. Through the studies of several cases where GIS was used to identify and analyze traffic safety problems, the researcher reached the following two conclusions: 1) applications of GIS-based crash data analysis had significant impacts on traffic safety engineering; and 2) GIS-based crash data analysis had not been fully utilized despite the fact that using GIS for crash data analysis started over 10 years ago.

Misener et al. (2000) conducted a research to develop a cognitive car-following model for drivers as they encounter a rear-end crash situation. The cognitive car-following model was a human vision- and cognition- based detection model designed to help drivers in avoiding lead-vehicle-not-moving (LVNM) crashes. In the study, the factors of LVNM crashes were identified based on the analysis of 10,009 LVNM crashes reported from National Accident

Sampling System (NASS) General Estimates System (GES) data. The analysis was focused on four groups of LVNM crash variables, which included 1) struck LVNM vehicle information such as the location and reason of stopping, 2) contributing factors such as road and environmental conditions, 3) striking vehicle information such as driver characteristics and crash trajectory, and 4) vehicle descriptive such as types and damages of both vehicles. Based on the analysis, the researchers suggested the possible safety enhancement strategies such as the improvements on roadway, lighting, vehicle, and driver conditions to avoid LVNM crashes. Then, a cognitive car-following model was developed by integrating the countermeasures with computational methods. The researchers believed their cognitive car-following model could help drivers to make accurate decisions in emergent situations before the occurrence of LVNM crashes. In the research, the authors only identified a small number of predominant LVNM crash scenarios (certain combinations of factors) on which they based their driver model development. Further studies could improve the model by considering more LVNM scenarios. Considering the high proportion of rear-end collisions in the work zone crashes, this car-following model might suggest a solution to the problem when specifically modified for work zone environment. This research was in cooperation with SCBTHA.

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

2.5 Summary

To gather the background information, a comprehensive literature review was conducted as the first step of this research. The review synthesized the previous research findings that were relevant to this research project. In this chapter, these findings are organized into three topics including work zone crash characteristics, work zone traffic control, and research and development trend in work zone safety.

To date, many research efforts have been devoted to investigating work zone crash characteristics. Most of the previous work zone crash studies were based on statewide crash data; only a few studies used multi-state data. Many studies agreed that crashes in highway work zones were more severe and more frequent. Some studies attributed the unsatisfactory work zone safety level to insufficient work zone traffic controls. In addition, results of research showed that work zones on two-lane highways were responsible for 63% of the fatal crashes and a third of the injury crashes in Kansas. Inattentive driving was found to be the most common driver error causing severe work zone crashes in Kansas and rear-end collisions were the predominant type of these crashes. Improving traffic control in work zones on two-lane highways has been a significant challenge for traffic engineers and researchers.

MUTCD has provided detailed traffic control guides for highway work zones. Various studies have been conducted to evaluate the effectiveness of common traffic control methods. However, the traffic control method that uses the emergency warning flashers of a vehicle as a warning sign in one-lane, two-way work zones has not been used and evaluated previously in the United States. This traffic control method may particularly benefit one-lane, two-way work zones that are setup for short durations and are required frequent movement.

Results of the literature review also show that ITS technologies have been applied in highway work zones to mitigate congestion and improve traffic safety. Typical work zone ITS applications collect, analyze, and distribute real-time traffic information for various purposes such as incident management, public information, traffic controlling, and project monitoring. Follow-up evaluations showed that most of the applications were effective in achieving the design goals.

The general trend of the modern work zone safety research and development was to combine advanced technologies developed from other scientific and engineering fields with traffic engineering to improve safety practices in highway work zones. The researchers found that some technologies available in computer engineering have been applied in work zone safety research, such as fuzzy logic and artificial intelligence. In addition, technologies such as GIS and computer-based simulations have also been applied in work zone to improve safety.

CHAPTER 3 - RESEARCH OBJECTIVE, SCOPE, AND METHODOLOGY

3.1 Objective and Scope

As indicated in the literature review, a large proportion of work zone crashes is rear-end collision due to inattentive driving. In addition, the presence of stop signs/signals could increase the likelihood of severe rear-end crashes between adjacent vehicles (Bai and Li 2007). These crashes are frequently observed in two-lane highway work zones with relatively high speed limits. To reduce and/or mitigate rear-end crashes, an innovative work zone warning sign was developed that was assembled by using vehicles' emergency warning flashers.

The primary objective of this research project was to investigate the effectiveness of a warning sign that is assembled by using vehicles' emergency flashers in one-lane, two-way highway work zones. This warning sign was named as the Emergency Flasher Traffic Control Device (EFTCD). To achieve the research objective, experiments and survey were conducted in the following three work zones in Kansas.

1. The work zone on US-36 between K-15 and K-148. This is a two-lane highway section located in north Kansas between Marysville, Kansas and Washington, Kansas.
2. The work zone on K-192 between US-59 and K-17. This is a two-lane highway section in northeast Kansas between Winchester, Kansas and Easton, Kansas.

3. The work zone on K-16 between US-59 and US-24. This is a two-lane highway section in northeast Kansas from the intersection of US-59 and K-16 to Tonganoxie, Kansas.

3.2 Methodology

The objective of this research was achieved through the following steps.

Step 1: Literature Review. The research team first conducted a comprehensive literature review to gather the background information. As presented in Chapter 2 of this report, researchers synthesized findings from previous studies on topics including work zone crash characteristics, work zone traffic control methods and effectiveness, ITS applications in work zones, and research and development trend on work zone safety.

Step 2: Assessing the Effectiveness of EFTCD. The effectiveness of using the EFTCD in work zones was measured by two methods employed in the field experiments. One method was to compare changes of vehicle speeds in the work zones with and without the EFTCD. Vehicle speeds were measured by an advanced sensor, called Wavetronix Smart Sensor HD Model 125. If speeds of vehicles decrease when the device is turned on, then, a conclusion can be reached, which is that the EFTCD does impact on drivers' behaviors. A slow speed is more likely to reduce the probability of having a crash or the severity of a crash. Another method was to survey the drivers who simply pass the work zones with or without the EFTCD. The research team developed a questionnaire and surveyed drivers to determine if the EFTCD has any impacts on their driving behaviors.

Step 3: Data analysis. The collected speed data and returned surveys were carefully analyzed using statistics methods such as ANOVA test, *t*-test, Chi-square test, and frequency analysis. In addition, drivers' responses to the survey questions were analyzed to determine the positive and negative implications regarding the potential implementation of the EFTCD.

Step 4: Conclusion and recommendation. Based on the data analysis outcomes, conclusion on the effectiveness of EFTCD was reached. Recommendations for the potential implementation of this device and future research needs were also outlined.

The rest of the report is organized as follows. First, authors will described the field experimental design (Chapter 4), followed by data collection (Chapter 5) and data analysis (Chapter 6). Then, conclusions and recommendations will be presented in Chapter 7.

CHAPTER 4 - FIELD EXPERIMENTAL DESIGN

To achieve the objective of this research, field experiments were conducted in three work zones in Kansas. This chapter describes the field experimental design including experimental device and installation, speed data collection, development of survey questionnaire, and experimental site selection.

4.1 Experimental Device and Installation

Evaluating the effectiveness of the EFTCD required accurate measurement of traffic speeds at specified work zone locations. After a careful review of the exiting speed detection technologies, the Wavetronix SmartSensor HD Model 125 was selected to measure the speeds of vehicles for this research project. SmartSensor HD uses microwave radar technology and can accurately detect the speeds of vehicles passing through its detection range. Results of previous research indicate that SmartSensor HD has several advantages such as no interference with traffic, less influence by weather or lighting conditions, easy installation and configuration, and high data accuracy (TxDOT 2007). Table 4.1 summarizes the major technical data of SmartSensor HD Model 125.

Table 4.1: Fact Sheet of SmartSensor HD Model 125

Category	Description
Installation	Relatively easy installation procedure. It can be mounted on an existing pole that provides proper height and distance.
Configuration	Auto configuration, low requirement for human adjustments.
Detection Range	Up to 10 traffic lanes, 6 to 250 ft.
Data Storage	Flash memory-based data storage.
Data Downloading	Wireless or cable downloading.
Operating Environment	Temperature: -40^{o}C to 75^{o}C; Humidity: up to 95% RH.
Maintenance	Minimum maintenance required.

Source: Wavetronix LLC. (2007). "SmartSensor 125 Cut Sheet." http://www.wavetronix.com/support/smartsensor/125/documents/SS125_CutSheet.pdf. (Oct. 20, 2007).

The SmartSensor HD speed detection device used in this research project, shown in Figure 4.1, includes the following components:

- One SmartSensor HD (model 125) unit including power and data cables;
- One set of solar panels that charges two 12-volt batteries;
- One equipment/battery cabinet. This cabinet homes the central control panel for the SmartSensor and the solar battery set;
- One laptop computer for data collection, monitoring, and downloading; and
- One set of 12-foot temporary mounting post which was assembled by a seven-foot top, a six-foot base, and three supporting anchors.

Figure 4.1: SmartSensor HD Speed Detection Device

As illustrated in Figure 4.1, the SmartSensor HD was mounted on the mounting post approximately 12 feet above the ground. A 40-foot cable connected the sensor with the central control panel located in the cabinet. This cable also delivered the speed data to the data ports in the control panel. Two 12-volt batteries were stored in the cabinet which could provide the required power to the sensor for eight consecutive days. To monitor real-time data collection and data processing, a laptop computer was connected to the central control panel in the cabinet through a RS232 9-pin straight-through cable. In addition, to function properly, the sensor was required to have horizontal and vertical orientations and lane setup (direction, lane width, and lane location) for each installation.

Although the sensor has functions such as data storage and wireless data downloading, a laptop computer and a person had to be employed in a real-time basis during the data collection procedure as determined by the nature of this research project. The speed comparison analyses must differentiate between vehicle speeds with and without the EFTCD. Thus, each speed datum collected by the sensor had to be clearly labeled with the proper speed type (i.e., with EFTCD or without EFTCD) when it was collected. Furthermore, to ensure accurate speed analyses, it was necessary to annotate the collected speeds with the information of respective vehicles (e.g., vehicle type and position in a queue). As a result, a laptop computer and real-time human supervision were needed so that the measured speeds could be identified and then properly characterized. These tasks were accomplished in the following fashion. The sensor measured the speeds of vehicles first. Then, speed data were transferred to the laptop computer, which were displayed on computer screen in real time. A research assistant recorded the usable data from the computer screen to a datasheet with proper labels indicating the speed type and vehicle information.

4.2 Speed Data Collection and Experimental Site Selection

4.2.1 Speed Data Collection Strategy

A key element for an accurate speed measurement was the proper location of the speed detection equipment. The location of the sensor was determined based on the understanding of drivers' deceleration behaviors and field trials. Assuming the EFTCD was effective, then, drivers who approached to a stop location controlled by a work zone flagger would drive more cautiously. Presumably, drivers would 1) start reducing their speeds earlier, 2) reduce their vehicle speeds more rapidly, or 3) decelerate vehicle both earlier and rapidly. Any of the three situations would result in a lower speed at a certain stage during the deceleration process.

The success of the experiments would depend greatly on the capture of vehicle speeds at a location where pronounced speed differences would occur given the proposed warning sign is effective. For this research, the SmartSensor HD was set up at a highway location where vehicles would decelerate to a speed between 30 mph and 45 mph when they were required to stop by a flagger.

4.2.2 Experimental Site Selection

Three one-lane, two-way work zones on rural two-lane highways with speed limits between 55 mph and 65 mph were selected for this study. Other than availability, the three work zones were selected based on the following two major reasons.

Roadway type and work zone configurations. The traffic flows on urban two-lane roadways are usually affected considerably by factors such as high traffic volume and traffic signals, and the speed limits for these highways are typically low (i.e., lower then 55 mph). Rural highways, on the other hand, do not have these limitations and are suitable for this study. Work zones with multiple open lanes do not require traffic stop and consequently may not suffer from rear-end collision problems as severely as one-lane, two-way work zones where complete stop is required for through traffic. In addition, one-lane, two-way work zones that require traffic stops give researchers an ideal opportunity to conduct driver surveys.

Traffic characteristics. Traffic characteristics including traffic volume and typical traffic headways were critical factors for the success of this study. During experiments, the first driver approaching a flagger-controlled work zone was asked to turn on his/her vehicle’s emergency flashers as a warning sign for the following vehicles. There must be enough distance between the first vehicle and the second vehicle so that the second vehicle driver will be able to see the flash sign and have time to react. If traffic volume of the study work zones was extremely low such as only one vehicle at a time, researchers would not be able to collect enough data for analysis. Therefore, traffic volume in the study work zone must be moderate and traffic headways between adjacent vehicles should be fairly large.

The first selected work zone was located on highway US-36 between K-15 and K-148, as shown in Figure 4.2. This highway section was a two-lane highway section with a speed limit of 65 mph in north Kansas between Marysville and Washington. According to the 2000 KDOT traffic count map, the annual average daily traffic (AADT) along the highway section was between 1,000 and 2,500 vehicles per day and a majority of the traffic on this highway section was through traffic. A pavement project (hot-mixed asphalt overlay) was carried out on this highway section in late June in 2007. The project required the close of one traffic lane so that the pavement on the closed lane could be overlaid while the another lane was kept in service. A flagger was used at each end of the work zone for traffic control and a pilot vehicle was employed to guide the through traffic, as shown in Figure 4.3. Two stop locations at both ends were moved approximately once per day due to the project progress. Experiments were conducted at this work zone during June 18, 2007 and June 22, 2007.

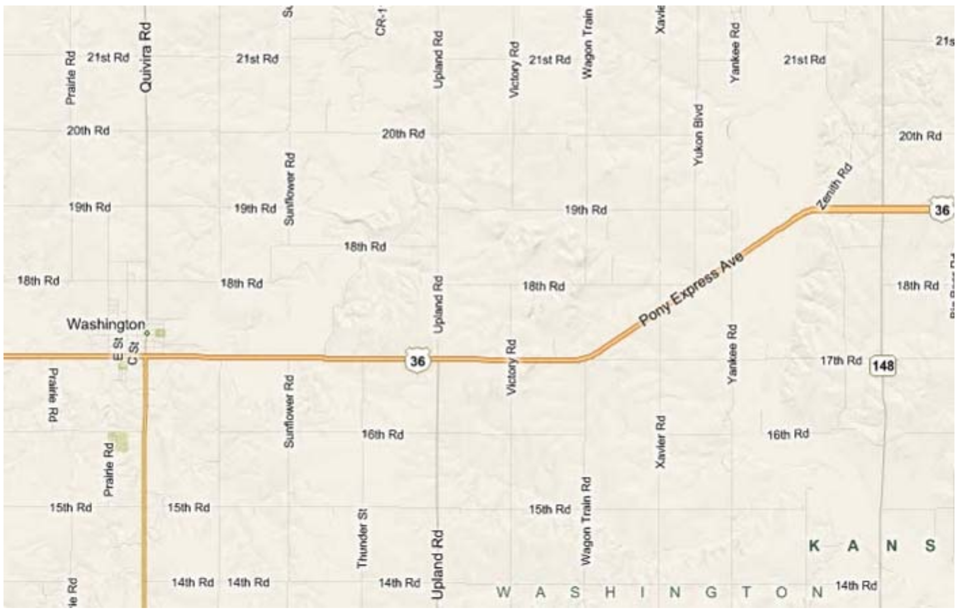


Figure 4.2: Work zone on US-36 between K-15 and K-148

Figure 4.3: A pilot car at the US-36 work zone

The second selected work zone was located on K-192 between US-59 and K-17, as shown in Figure 4.4. It was a two-lane highway section in northeast Kansas between Winchester and Easton. The highway section has a speed limit of 55 mph. According to the 2000 KDOT traffic count map, the AADT along this highway section was between 750 and 1,500 vehicles per day. This work zone enclosed major intersections and traffic might come from roads inside the work zone or might enter the work zone from one end without exiting from another end. The work zone was set up for a hot-in-place pavement recycle project. During the project, one lane of the highway section had to be closed for pavement recycle and another was left open for trough traffic. The work zone used a flagger to control traffic at each end and every major highway entrance. Two stop locations at both ends were moved once or occasionally twice per day depend on the project progress. A pilot car was utilized to guide traffic safely through the work zone. Experiments were conducted at this work zone during July 9, 2007 and July 13, 2007.

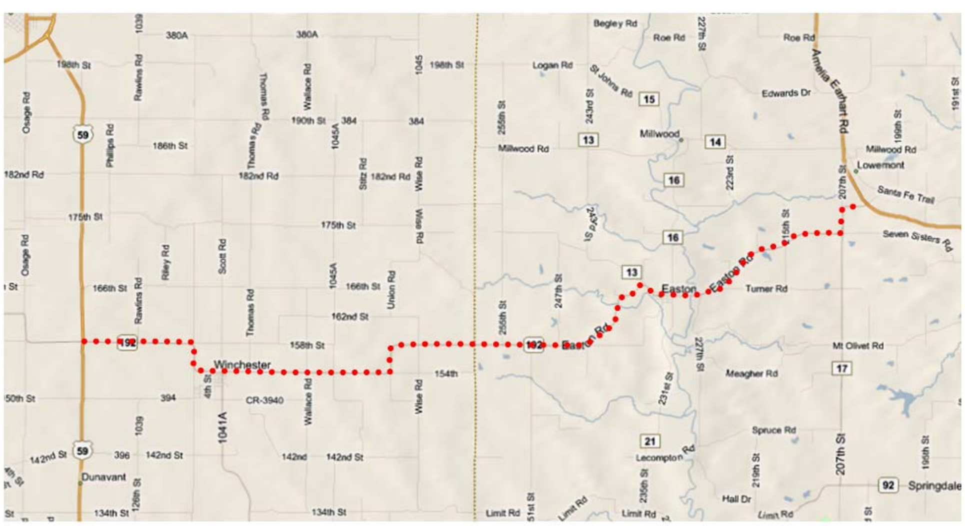


Figure 4.4: Work zone on K-192 between US-59 and K-17

The third selected work zone was located on highway K-16 between US-59 and US-24, as shown in Figure 4.5. It was a two-lane highway section in northeast Kansas from the intersection of US-59 and K-16 to Tonganoxie. The highway section has a speed limit of 55 mph. A pavement recycle project was carried out on this highway section during late July 2007. This project required one traffic lane to be closed to carrying out the highway work and another to remain open for through traffic. According to 2000 KDOT traffic count map, the AADT along this highway section was between 2,500 and 5,000 vehicles per day. A noteworthy percentage of the traffic on this highway section was local traffic entering or leaving the work zone from the entrances within the work zone. Therefore, a flagger was used for traffic control at each end of work zone and every major enclosed entrance within the work zone. A pilot car was also deployed to guide traffic safely through the work zone. Work zone ends were moved once or twice every day depending on the progress of road work.

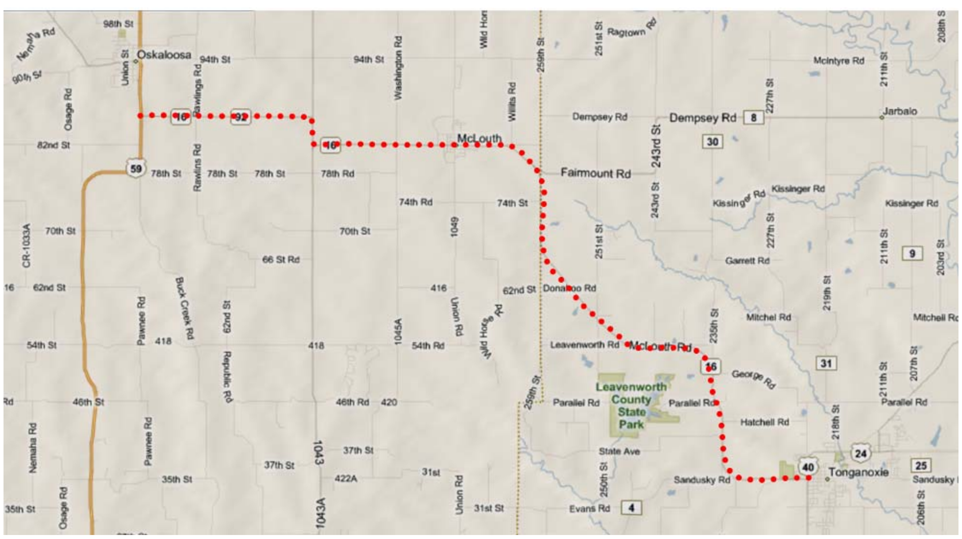


Figure 4.5: Work zone on K-16 between U-59 and U-24

4.3 Development of Survey Questionnaire

Driver survey was conducted at the location where flaggers stopped vehicles. One of the major advantages of surveying work zone drivers at this location was that the drivers had to stop and wait for their turn to pass work zones (the typical waiting time was approximately 10 minutes). Thus, surveys could be conducted during their waiting time without interrupting traffic. This resulted in a higher percentage of success surveys and more thoughtful and thorough feedbacks to the survey questions.

Based on the research objectives, the researchers only surveyed drivers that followed a previous vehicle with emergency warning flashers on before they came to a complete stop. Before survey, researchers made sure that the speeds of the vehicles were successfully captured by the detection sensor. This method guaranteed that each collected speed of a vehicle, when the EFTCD was employed, would have a corresponding driver survey. Therefore, the speed data and survey results could be analyzed together so that in-depth understanding of drivers' behaviors and their comprehensions of the EFTCD could be achieved.

Researchers designed an efficient questionnaire to gather the feedbacks from drivers on the effectiveness of the EFTCD. The questionnaire was designed in an effort to thoroughly gather the drivers' interpretation to the warning sign and their opinions on its potential implementation through short questions that could be finished within several minutes. Example of the survey form was included in Appendix I of this report and questions included in the survey are described as follows.

Question 1: Did you see the vehicle's flashers when you approach the work zone?

This was a simple yes-no question. If the surveyed driver provided "No" as the answer, the survey would be terminated. Otherwise, the research assistant would proceed with the rest of the survey.

Question 2: How do you interpret the flashers?

This question was designed to gather the drivers' interpretation of the warning sign. Several possible responses were included: 1) Emergency situation ahead, 2) Dangerous situation ahead, 3) Need to slow down, 4) Don't know, and 5) Get confused. In addition to these standard answers, the question also included another answer option as "Other." Drivers chosen this response could further explain their interpretations in their own words. For this question, an "emergency situation" referred to the situation when there was an emergency on road and a "dangerous situation" referred to the situation when the road condition was hazardous for through vehicles. Both answers indicate a need for additional driving cautions.

Question 3: What actions did you take after you saw the flashers?

This question was included so that the drivers' actions in response to the warning sign could be collected for comparison with their interpretations to the EFTCD. The available answers for this question included: 1) slow down (press the break), 2) slow down further (if they had started slowing down before they saw the flash signal), 3) look for more information, and 4) do nothing. In addition to these specific answers, an “Other” answer option was also included in case other responses might exist.

Question 4: Do you think that the flashers bring you more attention to the work zone condition?

This question was designed to verify if the EFTCD could more effectively alert drivers who approach to the work zones and how effective the method could be. Answers for this question included: 1) very much, 2) somewhat more, 3) some, 4) little, 5) none, and 6) do not know. In another word, this question was asking the drivers to rank the effectiveness of the EFTCD on a scale. A response of “none” indicated that the driver considered the proposed warning sign to have minimum effectiveness in drawing drivers’ attention for the work zone conditions. In this case, a score of 1 would be assigned to answer “none.” On the other hand, a response of “very much” was equivalent to a score of 5 that indicated the EFTCD were a very effective work zone warning sign.

Question 5: Do you prefer to use vehicles’ flashers as a warning sign in work zones?

This was a simple yes-no question designed to obtain the drivers’ recommendation on the potential implementation of the proposed EFTCD. The answers to this question would indicate if the surveyed drivers would like to see this warning method implemented in work zones.

Other than the above questions, the survey form also included fields for recording other related information such as survey time and date, weather condition, type of the surveyed vehicle, and gender of the surveyed driver. This study used the method of KDOT Motor Vehicle Accident Report (DOT FORM No. 850 Rev. 1-2003) for vehicle type classification. The light-duty vehicle types such as passenger cars, minivans, pickups, campers or RVs, sport utility vehicles (SUVs), and all-terrain vehicles (ATVs) were classified as vehicles. The heavy vehicle types such as single large trucks, truck and trailers, tractor-trailers, and buses were classified as trucks.

CHAPTER 5 - DATA COLLECTION

5.1 Data Collection Procedure

5.1.1 Vehicle Speed Measurement

The vehicle speeds for this research project were collected by a SmartSensor HD (Model 125) manufactured by Wavetronix LLC. As introduced in Chapter 4, the SmartSensor HD uses microwave radar technology and detects speeds with minimum influence from environmental conditions. The sensor was mounted on a 12-foot tall tripod which was installed 8-12 feet away from the travel lane, as exhibited in Figure 5.1. This distance provided a relatively safe lateral clearance for passing traffic from the equipment and the researchers. In addition, this distance also complied with the manufacturer recommended installation requirements. Field tests showed that this installation configuration enabled accurate speed collection especially when the speeds of the passing vehicles were greater than 20 mph.

As discussed earlier, the speed detection device should be installed at a location where passing vehicles had decelerated to a speed between 30 mph and 45 mph. After a number of field trials, the researchers decided to install the device approximately 550 feet from the flagger in work zones with a 65 mph speed limit and approximately 450 feet from the flagger in work zones with a 55 mph speed limit. On-site observations showed that the first vehicle in a platoon would typically stop in a distance less than 30 feet from the flagger who was directing the traffic. The distance between the front bumper of the second vehicle and the flagger was typically less than 60 feet if the leading vehicle was a light-duty vehicle such as a passenger car, a minivan, a pickup, or a sport utility vehicle (SUV). However, the distance would be significantly larger (e.g., greater than 100 feet) if the leading vehicle was a heavy vehicle such as a tractor-trailer or a large single-unit truck.

Figure 5.1: Installation of the speed detection device

During the experiments, the speeds of the first vehicles stopped by a flagger were not collected since the warning sign was not applicable to first vehicles. Thus, their speeds were useless in the data analyses. In most cases, only the speeds of the second vehicles in traffic platoons were collected by the speed detector. Based on the distance configurations described above, the actual stopping point of a second vehicle was approximately 400 feet from the speed detector in work zones with a 55 mph speed limit and 500 feet from the speed detector in work zones with a 65 mph speed limit. Figure 5.2 further illustrates the distance configurations used for the experiments where the two leading vehicles are passenger cars. When conditions allowed (i.e., the first two vehicles are light-duty vehicles and the spatial gaps between the two vehicles, or distance BC in Figure 5.2, and between the first stopped vehicle and the flagger, or distance AB in Figure 5.2, were sufficiently small), the speed of the third vehicle in a platoon was also measured and used in the speed analyses.

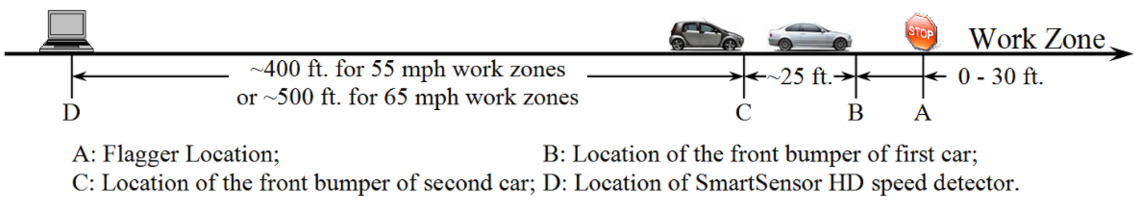


Figure 5.2: Locations of the speed detector and vehicles in work zones

When the speed of a passing vehicle was captured, the speed detector sent the speed datum to the connected notebook computer in real time and the computer displayed the speed on a graphic interface that simulated the passing vehicle labeled with its speed. A research assistant examined each speed datum displayed on the computer and then recorded the ones that were correctly detected and abandoned those of the vehicles that were evidently interfered by factors other than the considered work zone conditions. These factors could include the inferences of pedestrians, low-speed farm vehicles, or construction related vehicles that either had very low speed or had been well aware of the upcoming conditions. In addition, a speed was considered as a valid speed (a speed of a vehicle collected when the evaluated warning sign was employed) only when the flashers of the preceding vehicle were turned on before the vehicle could discern it and the upcoming stopping condition.

5.1.2 Driver Survey

There were two research assistants, named A and B, working in the work zones to collect data. Driver surveys were done by the assistant B in coordination with the assistant A, who was collecting vehicle speed data. The survey procedure is outlined as follows. First, when the first vehicle stopped at a flagger, assistant B required the driver to turn on the emergency warning flashers so that the next vehicle could be warned by the flashers. Second, assistant A notified assistant B if the speed of the second vehicle was recorded successfully. If yes, assistant B would conduct the survey with the second vehicle driver. If no, this experiment trial was considered to be a failure and no survey would be conducted. Figure 5.3 shows that the assistant B was conducting a survey.

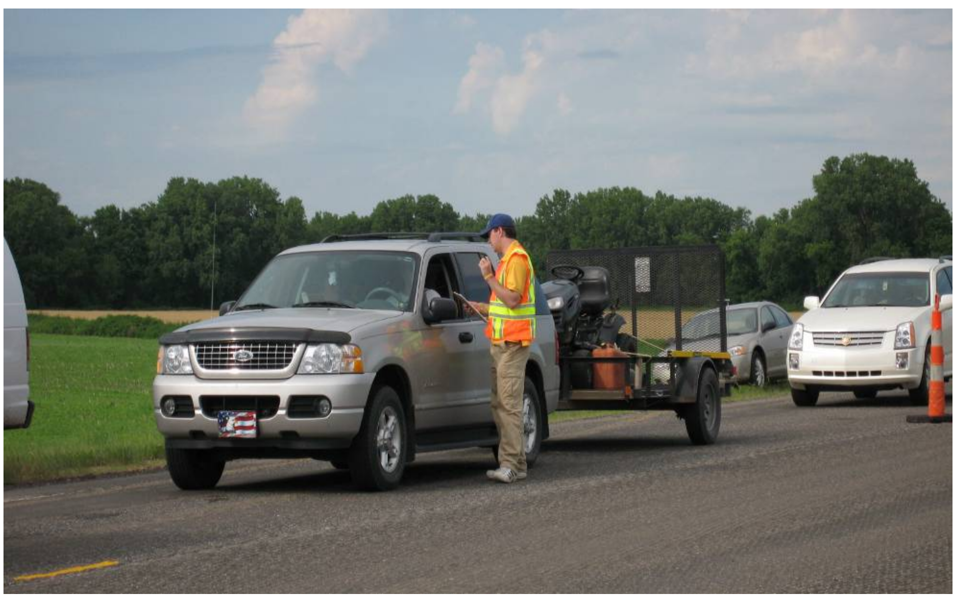


Figure 5.3: A research assistant conducting a driver survey

According to the on-site trials, a driver survey could be finished typically within five minutes. At the same time, vehicles typically had to wait for approximately ten minutes in each stopping cycle. Thus, there was enough time for the research assistant B to conduct the surveys in an efficient manner without causing further traffic delay that could cause drivers' resistance.

A successful experimental trial would depend on a chain of factors that at least include: 1) the compliance of the first vehicle driver upon request of turning on its emergency flashers, 2) the headway between the first two vehicles, 3) the successful record of second vehicle speed, and 4) the cooperation of the second vehicle driver on the survey. When any component of this action chain failed, the experiment trial would fail.

5.2 Collected Datasets

5.2.1 Vehicle Speed data

As presented in Chapter 4, researchers conducted experiments in three work zones for three weeks between June and July in 2007. A total of 228 speed data was collected including 118 speeds without warning sign (without-warning speed) and 110 speeds with warning sign (with-warning speed). Among the with-warning speed data, 64 were collected in work zones with a speed limit of 55 mph and 46 were collected in the work zone with a speed limit of 65 mph. Among the without-warning speeds, 78 were collected in work zones with a speed limit of 55 mph and 40 were collected in the work zone with a speed limit of 65 mph. Table 5.1 presents the numbers of speed data by work zones.

Table 5.1: Speed Data by Work Zones

Work Zone	Speed Limit	Data Collection Period	No. of With-Warning Speeds	No. of Without-Warning Speeds
K-192	55 mph	July 9 – 13, 2007	18	21
K-16		July 16 – 20, 2007	46	57
Subtotal			**64**	**78**
US-36	65 mph	June 18 – 22, 2007	46	40
Total			**110**	**118**

Table 5.2 shows a portion of the speed datasheet and Appendix II presents the entire speed data. Other then the vehicle speeds, the datasheet also included the following relevant traffic and environmental variables:

1. Flashing Light On: This is a binary variable indicating the speed type. Where Y indicates a with-warning speed (speed was collected when the warning sign was used) and N indicates a without-warning speed (speed was collected when the warning sign was not used).
2. Date and Time: These two variables record the date and time when the speed was collected.
3. Weather: This variable indicates the weather condition when the speed was collected. It had two observations for this research including sunny and overcast (o/c).
4. Distance: This is the distance between the speed detector location and the flagger location. As discussed earlier, the distance was 450 feet in work zones with a speed limit of 55 mph and 550 feet in the work zone with a speed limit of 65 mph.

5. Speed Limit: This is the speed limit in the work zone where the vehicle speed was collected. For this research, two work zones had 55 mph speed limit and one work zone had 65 mph speed limit.
6. Road Geometry: This is the roadway geometric alignment conditions at the location where the vehicle speeds were collected. The observations for this research included straight and level, curved and level, and straight on uphill.
7. Vehicle Type: This is the type of the vehicles whose speeds were collected. Two vehicle types are used for this study: light-duty vehicles (as denoted by "C") and heavy-duty vehicles (as denoted by "T"). The former includes such vehicles as passenger cars, minivans, pickups, campers or RVs, and sport utility vehicles (SUVs). The latter includes single-unit large trucks, truck and trailers, tractor-trailers, and large buses. Note that, the data showed that only a minor fraction of the collected speeds belonged to heavy-duty vehicles while a majority of speed data was for light-duty vehicles. Thus, the speed data were not analyzed in terms of vehicle type.
8. Vehicle Sequence: This variable describes the position of a vehicle in a platoon whose speed is collected. A value of 2 indicates that the vehicle is the second vehicle in a platoon (occasionally the third vehicle) and a value of 1 indicates that the vehicle is the first vehicle in the platoon.

Table 5.2: A Portion of the Speed Datasheet

NO	Date	Time	Speed (mph)	Dist. (ft.)	Speed Limit	Roadway Geometry	Vehicle Type	Flashing Light On	Seq.
100006	06192007	1120	29	500	65	Straight Level	C	Y	2
100007	06192007	1129	30	500	65	Straight Level	C	Y	2
100011	06192007	1340	35	500	65	Straight Level	C	Y	2
100013	06192007	1350	14	500	65	Straight Level	C	Y	2
100016	06192007	1408	37	500	65	Straight Level	C	Y	2
100017	06192007	1420	38	500	65	Straight Level	C	Y	2
100020	06192007	1423	28	500	65	Straight Level	C	Y	2
100022	06192007	1445	32	500	65	Straight Level	T	Y	2
100024	06192007	1500	35	500	65	Straight Level	C	Y	2
100025	06192007	1642	28	500	65	Straight Level	T	Y	2
100030	06192007	1722	51	500	65	Straight Level	C	Y	2
100031	06192007	1730	40	500	65	Straight Level	C	Y	2
100033	06192007	1743	27	500	65	Straight Level	C	Y	2

5.2.2 Driver Survey Data

As described in Chapters 4 and 5, the with-warning speeds were paired with the survey feedbacks: every vehicle speed collected when the warning sign was used would have a corresponding survey. Thus, 110 survey forms were completed and information was compiled in a datasheet (Appendix III). In the datasheet, questions with multiple answers were represented in multiple columns to accommodate all responses. A detailed description of the survey questionnaire and answer options was presented in Section 4.3. Table 5.3 presents a portion of the datasheet containing the survey responses.

Table 5.3: A Portion of the Survey Datasheet

Driver Gender	Q1	Q2	Q2	Q2	Q3	Q3	Q3	Q4	Q5
M	2								
M	1	3			2			3	1
M	1	1			1			2	1
M	1	3			2			2	1
M	1	1			4			1	1
M	1	Other (caution, hazards)			4			5	2
M	1	3			3			3	1
F	1	Other (caution)			4			4	1
M	1	3			4			5	1
M	1	1	3		4			5	1
M	1	1	2	3	4			3	1
F	1	2	3	4	2	3		1	3

CHAPTER 6 - DATA ANALYSIS

6.1 Data Analysis Methodology

The primary objective of this research project was to evaluate the effectiveness of the EFTCD that is assembled using the emergency warning flashers of the vehicles in one-lane, two-way work zones. The field experiments were conducted in three work zones, two of which had a speed limit of 55 mph and the other had a speed limit of 65 mph. Researchers collected speed data and conducted surveys in these three work zones. The effectiveness of the EFTCD was first assessed based on the comparison between the with-warning speeds and without-warning speeds. If the vehicle speeds evidently changed in favor of safety at the speed collection locations after the warning sign was turned on, researchers could conclude that the EFTCD was an effective warning sign in one-lane, two-way work zones. In addition, the effectiveness of the EFTCD was further evaluated based on the responses of drivers' surveys in these work zones. The frequency analysis method was used for the analyses of the drivers' surveys.

The major tasks that needed to be accomplished in the analyses of speed data (both with and without the warning sign) include 1) evaluation of the change in vehicle speeds, 2) evaluation of the change in the proportion of high speeds, and 3) evaluation of the interrelationship between speeds and the EFTCD. The major methods used for these data analysis tasks are briefly introduced as follows.

6.1.1 Change in Vehicle Speeds

The two-sample *t*-test for means was used to evaluate the change in vehicle speeds after the EFTCD was deployed. The two-sample *t*-test was developed to statistically compare two population means based on hypothesis tests. The *t*-statistic is defined as:

$$T = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{s_1^2 / N_1 + s_2^2 / N_2}} \qquad \text{Equation 6.1}$$

Where N_1 and N_2 are the sample sizes, $\bar{Y}_1$ and $\bar{Y}_2$ are the sample means, and s_1^2 and s_2^2 are the sample variances.

When the variances of the two samples are equal, the above formula is equivalent to:

$$T = \frac{\bar{Y}_1 - \bar{Y}_2}{s_p \sqrt{1/N_1 + 1/N_2}} \qquad \text{Equation 6.2}$$

Where s_p is the pooled estimation of the standard deviation that can be obtained through the pooled variance defined as:

$$s_p^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2} \qquad \text{Equation 6.3}$$

The degrees of freedom (*df*) for the statistic are:

$$df = N_1 + N_2 - 2 \qquad \text{Equation 6.4}$$

When the variances of the two samples differ significantly, the degrees of freedom are calculated through the effective number of degrees of freedom (*f*) as (Taylor and Cihon 2004):

$$f = \frac{(s_1^2 / N_1 + s_2^2 / N_2)^2}{\frac{(s_1^2 / N_1)^2}{N_1 - 1} + \frac{(s_2^2 / N_2)^2}{N_2 - 1}}$$ Equation 6.5

To test if the variances of the two sample populations are equal, the analysis of variance (ANOVA) method can be used. SAS uses three ANOVA tests to determine if the variances are the same between two sample populations. These three tests include Bartlett's test, Brown-Forsythe test, and Levene's test (SAS 2007). Bartlett's test is a modification of the normal-theory Likelihood Ratio test. While it has accurate rates on Type I error (the error of rejecting a null hypothesis when it is actually true) and optimal power when the underlying distribution of the data is normal, it can be very inaccurate if the distribution is even slightly non-normal, and thus, it is not recommended for routine use. The Brown-Forsythe test and Levene's test are reasonably robust to the underlying distribution, but simulation results indicate the Brown-Forsythe test is best at providing power to detect variance differences while protecting the Type I error probability.

6.1.2 Change in Proportions of High Speeds

Notably high speeds observed at the speed data collection location may be an indication of speeding drivers who may have a high likelihood of causing rear-end collisions with the stopped vehicles at the flagger location in the one-lane, two-way work zones. It will be beneficial if the proposed EFTCD could reduce the proportion of high vehicle speeds when drivers are approaching the work zones. The frequency analysis method was used for this analysis and the distributions of with-warning and without-warning speeds were plotted and compared. If a reduction is observed, researchers will conclude that the EFTCD can more effectively prevent speeding driving in work zones and thus may reduce the rear-end collisions.

6.1.3 Interrelationship between Speeds and the EFTCD

The interrelationship between the vehicle speeds and the employment of the EFTCD was tested using Pearson and Likelihood Ratio Chi-square statistics. The Pearson Chi-square test method, originally proposed by Karl Pearson, is known as one of the most common test methods for independence between two sets of variables. Suppose that results of a random experiment are classified by two attributes A and B having *a* and *b* values, respectively. Let x_{ij} denote the frequency of this random experiment with attributes A_i and B_j, and let $x_{i.}$ and $x_{.j}$ be $\sum_{j=1}^{b} x_{ij}$ and $\sum_{i=1}^{a} x_{ij}$ respectively. It has been proved that, if the total frequency *n* is large and the attributes A and B are mutually independent, then the random variable,

$$Q = \sum_{j=1}^{b}\sum_{i=1}^{a}\frac{[x_{ij} - n(x_{i}. / n)(x._{j} / n)]^2}{n(x_{i}. / n)(x._{j} / n)} \qquad \text{Equation 6.6}$$

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

The Pearson's Chi-square test 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 (University of Texas at Austin 2005). This test involves the ratios between the observed frequencies x_{ij} and expected frequencies e_{ij}: when the attributes A and B are mutually independent, the random variable,

$$G^2 = 2\sum_i \sum_j x_{ij} \ln(\frac{x_{ij}}{e_{ij}}) \qquad \text{Equation 6.7}$$

is known to have an approximate Chi-square distribution with (a – 1)(b – 1) degrees of freedom (SAS 2004). Regardless of the different advantages of the two Chi-square test methods, they were both adopted to test the dependence between the vehicle speeds and the deployment of the EFTCD. A dependant relationship was determined if one or both tests supported it at a 5% level of significance.

6.2 Comparison Analyses of With- and Without- Warning Speeds

6.2.1 Change in Vehicle Speeds

The effectiveness of the EFTCD was first evaluated based on the comparison between the with-warning speeds and the without-warning speeds. With-warning speeds are the speeds collected when the proposed warning sign was turned on, while without-warning speeds were the speeds when the warning sign was turned off. If the vehicle speeds were evidently reduced at the speed collection location after the warning sign was turned on, an implication would be that, because of the warning sign, vehicles decelerated more rapidly, started deceleration earlier, or both. This would be an indication of the effectiveness of the EFTCD in one-lane, two-way work zones. A slow speed is more likely to reduce the probability of having a crash or the severity of a crash.

Table 6.1 and Figure 6.1 show the average speeds observed in each experimental work zone and the overall average speeds by work zone speed limits. As illustrated, the vehicle speeds collected at two of the three work zones decreased when the warning sign was turned on. The reduction in average speed in the work zone with a speed limit of 65 mph was about 5 mph, a noteworthy reduction of more than 10% comparing to the average speed without the warning sign. In the two work zones with a speed limit of 55 mph, the overall speed reduction was 2.5 mph when the warning sign was turned on, a decrease of 7% comparing to the average speed without warning sign.

Table 6.1: Average Speeds and Speed Reduction by Work Zones

Work Zone	Speed Limit	Average Without-Warning Speed	Average With-Warning Speed	Speed Reduction	Reduction Percent
US-36	65 mph	40.4 mph	35.8 mph	4.6 mph	11.4%
K-192	55 mph	32.9 mph	33.2 mph	- 0.3 mph	-0.9%
K-16	55 mph	36.4 mph	32.8 mph	3.6 mph	9.9%
K-192 and K-16	55 mph	35.4 mph	32.9 mph	2.5 mph	7.1%

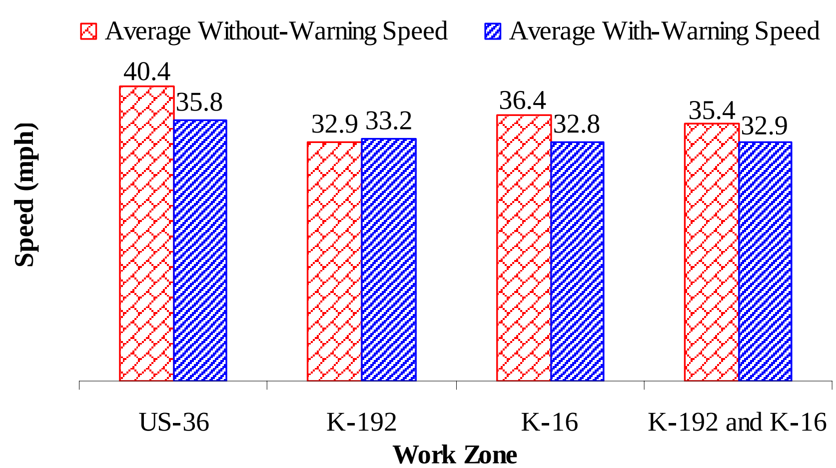


Figure 6.1: Average Speed Comparison in Experimental Work Zones

Among the three work zones, the average speed reduction in the work zone with a speed limit of 65 mph (US-36) was considerably higher than the speed reduction in the two work zones with a speed limit of 55 mph. Two factors may be attributable to this reduction difference. First, the vehicles approaching the US-36 work zone might travel at higher initial speeds, which provided room for a relatively larger speed reduction upon being warned by the emergency warning flashers. This is an implication of a greater effectiveness of the EFTCD in work zones with relatively high speed limits. Second, as discussed in the experimental design section in Chapter 4, the choice of speed detection locations in work zones will directly affect the observed speed changes. Therefore, the larger speed reduction might be partly due to a better location of the speed detecting sensor in the US-36 work zone.

Data analyses showed a slight increase on average speed (0.3 mph) after the implementation of the warning sign in the work zone on K-192 that has a speed limit of 55 mph. This observation is not consistent with the other two work zones where pronounced speed reductions were observed. Due to factors such as low traffic volume, environmental conditions, and construction progress, the researchers could only collect 39 vehicle speeds in the K-192 including 18 with-warning speeds and 21 without-warning speeds. These sample sizes might be not large enough to represent the correct trend of speed change in the work zone. As a result, researchers could not explain this inconsistency using statistics theories.

Researchers utilized the Student's *t*-test to statistically verify the difference of means between the with-warning speeds and the without-warning speeds. The test was conducted on each type of the collected vehicle speeds that were classified by the work zone speed limit. A benefit of testing the speeds based on the speed limit rather than an individual work zone was that the sample size was increased and thus higher test accuracy may be achieved.

In testing the difference between the means of with-warning speed and without-warning speed, the null hypothesis (H_0) and the alternative hypothesis (H_1) were defined as:

$$H_0\text{: Mean 1} - \text{Mean 2} \leq 0$$

$$H_1\text{: Mean 1} - \text{Mean 2} > 0$$

where Mean 1 is the statistical mean of the without-warning speeds and Mean 2 is the mean speed of the with-warning speeds. Equivalently, the null hypothesis is interpreted that the mean of the without-warning speeds is no larger then that of the with-warning speeds. The alternative hypothesis, on the other hand, is interpreted that the mean of the without-warning speed data is larger than that of the with-warning speed data. A level of significance of 0.05 was used in the tests and a *p*-value no greater than 0.05 would indicate that the null hypothesis can be confidently rejected.

Table 6.2 shows the results of *t*-test for the equality between the two means of with-warning speeds and without-warning speeds. Table 6.3 shows the results of the ANOVA tests for variance equality between the with-warning speeds and the without-warning speeds. Based on the results of the ANOVA tests, the researchers could not conclude either equality or inequality between the two variances. However, as shown in Table 6.2, both *p*-values are less than 0.05 no matter if the variances are equal or not, which indicates that the null hypothesis should be rejected at both circumstances at the 0.05 level of significance. In another word, the statistical analyses proved that the average with-warning speed was lower than the average without-warning speed.

Table 6.2: Results of Two-Sample *t*-Test for Means of Speeds at 55-mph Work Zones

If variances are	*t*-Statistic	Degrees of Freedom	*p*-Value	Reject H_0
Equal	2.45	140	0.008	Yes
Not Equal	2.432	130.39	0.008	Yes

Table 6.3: ANOVA Tests for Variance Homogeneity at 55-mph Work Zones

ANOVA Test	*p*-Value	Notation
Levene's Test	0.565	Can not reject the null hypothesis
Brown and Forsythe's Test	0.799	Can not reject the null hypothesis
Bartlett's Test	0.545	Can not reject the null hypothesis

Note: the null hypothesis in this test is that the variances of the with-warning speed data and without-warning speed data do not significantly differ.

Table 6.4 shows the results of the two-sample *t*-test for the relationship between the means of the with-warning speeds and without-warning speeds collected in the 65-mph work zone. Table 6.5 lists the ANOVA test results regarding the difference between the variances of the two types of speeds collected in the 65-mph work zone. The three ANOVA tests all indicated that the variances did differ significantly at the 0.05 level of significance. From Table 6.4, the *t*-test had a *p*-value of 0.002 that indicated the null hypothesis should be rejected at the 0.05 level of significance. In another word, the test statistically confirmed that the use of the EFTCD resulted in an overall speed reduction in the work zone with a 65 mph speed limit.

Table 6.4: Results of Two-Sample *t*-Test for Means of Speeds at 65-mph Work Zone

If variances are	*t*-Statistic	Degrees of Freedom	*p*-Value	Reject H_0?
Equal	2.95	84	0.002	Yes
Not Equal	3.02	81.28	0.002	Yes

Table 6.5: ANOVA Tests for Variance Homogeneity at 65-mph Work Zone

ANOVA Test	*p*-Value	Notation
Levene's Test	0.046	Reject the null hypothesis
Brown and Forsythe's Test	0.013	Reject the null hypothesis
Bartlett's Test	0.037	Reject the null hypothesis

Note: the null hypothesis in this test is that the variances of the with-warning speed data and without-warning speed data do not significantly differ.

Researchers further compared the with-warning speeds and without-warning speeds in terms of roadway geometric alignments. Based on this comparison, researchers could understand the effectiveness levels of the EFTCD at highway locations characterized by different geometric features. Tables 6.6 and 6.7, and Figures 6.2 and 6.3 illustrate the average with-warning speeds and without-warning speeds for various geometric alignments observed in the experimental work zones.

Table 6.6: Average Speeds by Road Geometric Alignments in 55-mph Work Zones

Geometric Alignment	Without-Warning Speeds		With-Warning Speeds	
	Average Speed (mph)	# of Observations	Average Speed (mph)	# of Observations
Curved Level	40.3	7	34.3	4
Straight Level	36.2	38	33.5	30
Straight Uphill	33.5	33	32.2	30

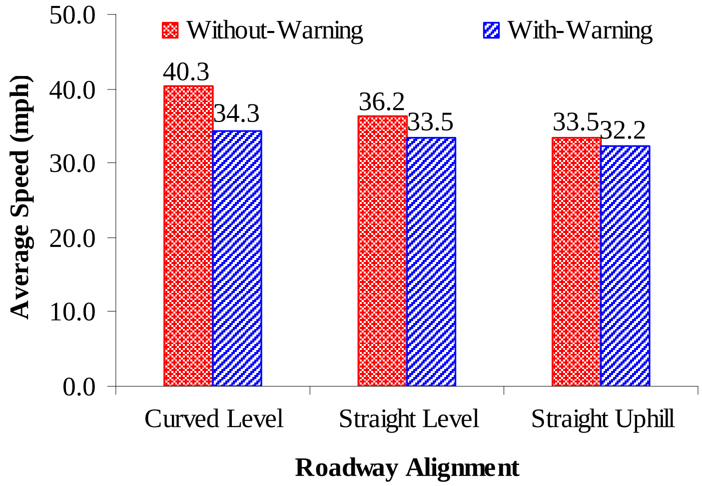


Figure 6.2: Average Speeds by Road Geometric Alignments in 55-mph Work Zones

Table 6.7: Average Speeds by Road Geometric Alignments in the 65-mph Work Zone

Geometric Alignment	Without-Warning Speeds		With-Warning Speeds	
	Average Speed (mph)	# of Observations	Average Speed (mph)	# of Observations
Curved Level	41.8	31	37.7	31
Straight Level	35.7	9	31.8	15

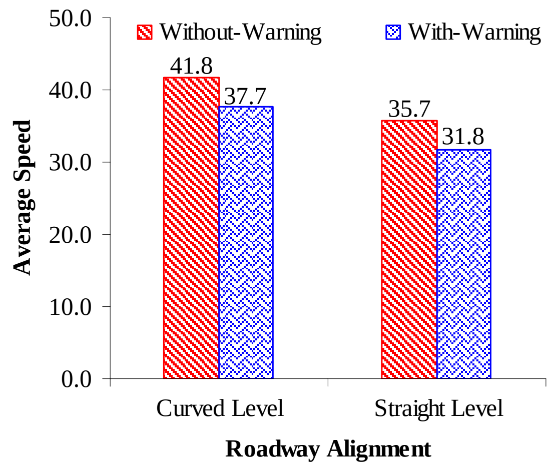


Figure 6.3: Average Speeds by Road Geometric Alignments in the 65-mph Work Zone

As shown in Table 6.6 and Figure 6.2 for the two work zones with the 55-mph speed limit, the largest reduction between the without- and with- warning speeds was observed when the warning sign was turned on in locations where the roadways were curved but level. In addition, both the average with- and without- warning speeds at curved and level roadway locations were higher than the corresponding speeds observed at other highway locations. For instance, the average speed reduction at curved and level roadway locations in the 55-mph work zones was as high as 6 mph, while the reductions for straight and level roadways and straight and uphill roadways were 2.7 mph and 1.3 mph, respectively. A plausible explanation might be that the drivers' sight distances on curved highway sections were limited and the drivers approaching the flagger locations would not start deceleration until they identified the flagger or emergency warning flashers. Thus, the vehicles on curved highway sections might start deceleration relatively later but would decelerate more abruptly. Notice that the numbers of the collected speeds on curved and level sections in the 55-mph work zones were relatively small and thereby the above analysis might be biased.

As illustrated by Table 6.7 and Figure 6.3, for the work zone with the 65-mph speed limit, both average with- and without- warning speeds observed on highway sections that were curved and level were higher than those on straight and level highway sections by approximately 6 mph. However, the obviously larger speed reduction, between with and without warning sign observed in the

55-mph work zones where the experimental highway sections were curved and level, was not found in the 65-mph work zone.

6.2.2 Change in Proportion of High Speeds

Analyses of the distributions of the with-warning speeds and without-warning speeds were another approach to demonstrate the effectiveness of the proposed EFTCD. The basic assumption is that, if the warning sign was effective, it would reduce the number of speeding drivers approaching the work zones, who were commonly characterized as the inattentive or reckless drivers. If the distribution of the with-warning speeds illustrates a pronounced reduction in the number of notably high speeds, then, researchers can reach the conclusion that the proposed EFTCD is able to more effectively reduce the speeding behavior in work zones.

Figures 6.4 and 6.6, and Figures 6.5 and 6.7 illustrate the frequencies of the observed speeds grouped in 3-mph and 5-mph speed intervals, respectively. The figures show a general trend of relatively high speeds in all work zones when the warning sign was not turned on. In addition, researchers noticed a 55-mph speed in the 55-mph work zones (see Fig. 6.5) and a 56-mph speed in the 65-mph work zone (see Fig. 6.7). Such high speeds observed at the speed collection locations were risky of causing rear-end collisions. In fact, one of these two drivers was unable to safely stop in front of the flagger and had to run off the road to avoid colliding into the stopped vehicles in front. However, because of the small numbers of high speeds observed, researchers could not confidently conclude the effectiveness of the warning sign in reducing vehicle speeds purely based on this analysis.

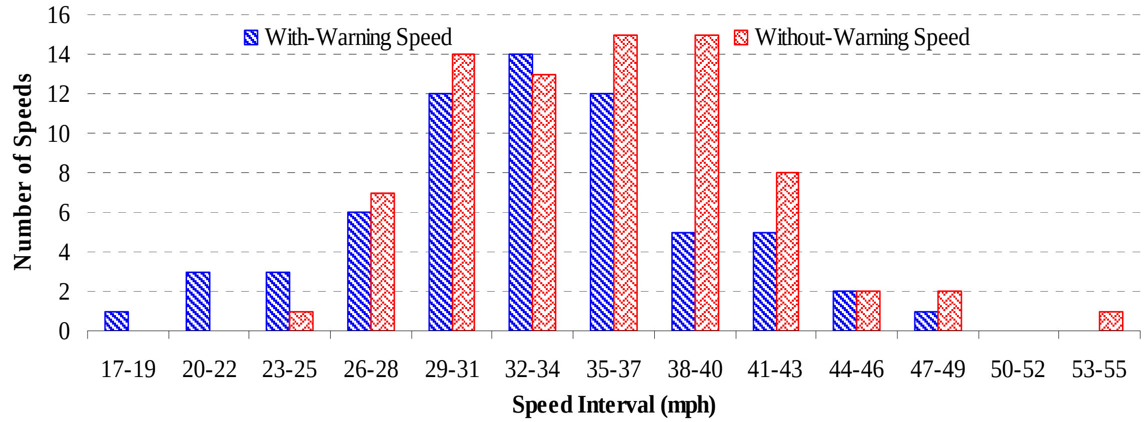


Figure 6.4: Distribution of Speeds by 3-mph Speed Intervals in the 55-mph Work Zones

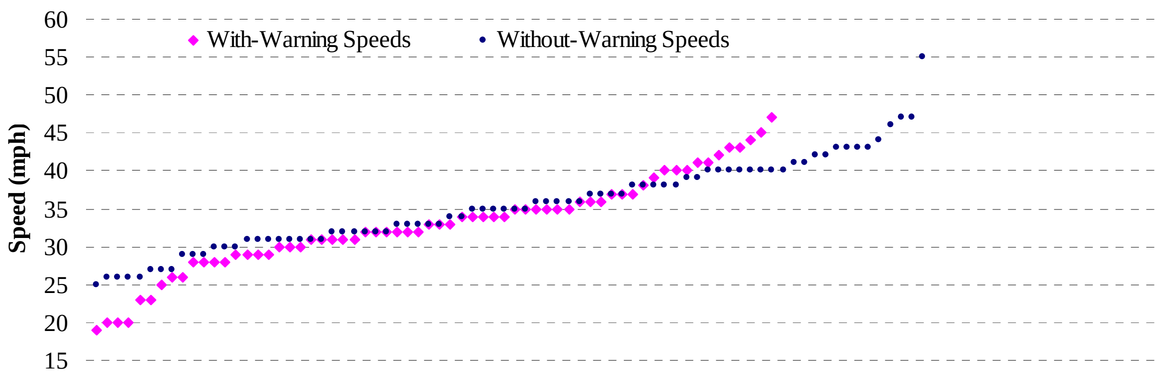


Figure 6.5: Distribution of Speeds by 5-mph Speed Intervals in the 55-mph Work Zones

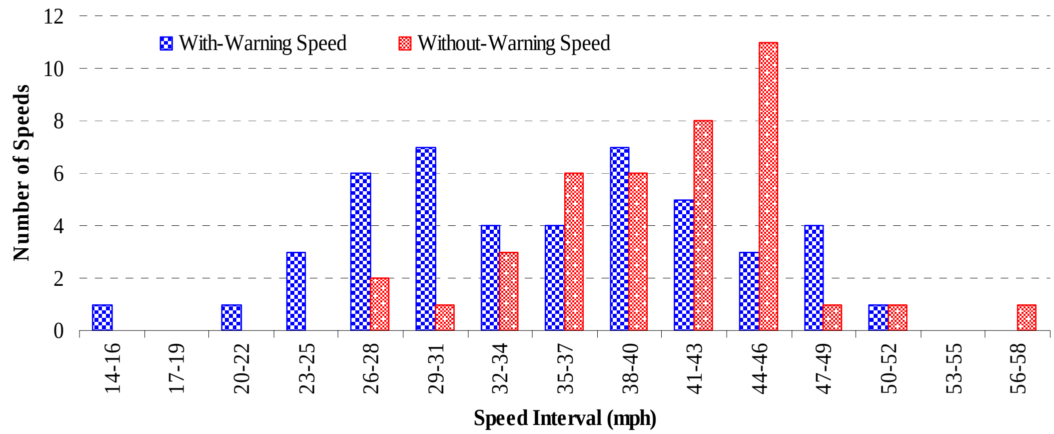


Figure 6.6: Distribution of Speeds by 3-mph Speed Intervals in the 65-mph Work Zone

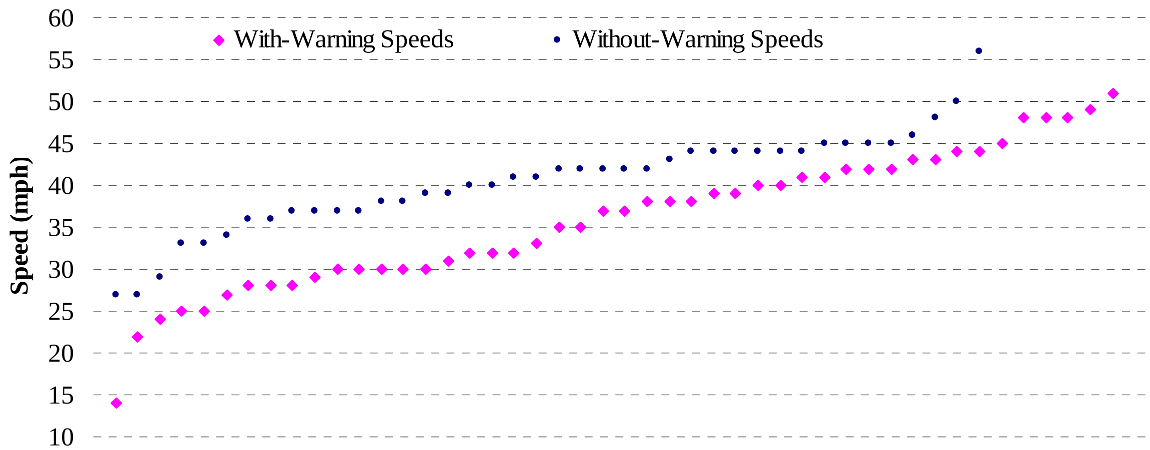


Figure 6.7: Distribution of Speeds by 5-mph Speed Intervals in the 65-mph Work Zone

6.2.3 Interrelationship between Speeds and the EFTCD

The dependent relationship between the vehicle speeds and the employment of the EFTCD was tested using Pearson and Likelihood Ratio Chi-square statistics. These tests were conducted in an effort to seek further statistical evidence to the causal relationship between the proposed EFTCD and the observed speed reductions. Tables 6.8 – 6.10 are the Chi-square test results for the dependant relationship between the observed vehicle speeds and the presence of the warning sign in all three experimental work zones, two 55-mph work zones, and 65-mph work zone, respectively. Note that the accuracy of these Chi-square tests may be limited because of the relatively small sample sizes when the speed data were broken down by speed and the presence of the warning sign.

Table 6.8: Chi-Square Tests for the Relationship between Vehicle Speeds and the Warning Sign in All Work Zones

Test	Degrees of Freedom	Value	*p*-Value	Related
Pearson χ^2	34	41.42	0.18	No
Likelihood Ratio χ^2	34	50.89	0.03	Yes

Note: The level of significance for this test was 0.05.

Table 6.9: Chi-Square Tests for the Relationship between Vehicle Speeds and the Warning Sign in the 55-mph Work Zones

Test	Degrees of Freedom	Value	*p*-Value	Related
Pearson χ^2	26	25.40	0.50	No
Likelihood Ratio χ^2	26	31.77	0.20	No

Note: The level of significance for this test was 0.05.

Table 6.10: Chi-Square Tests for the Relationship between Vehicle Speeds and the Warning Sign in the 65-mph Work Zone

Test	Degrees of Freedom	Value	*p*-Value	Related
Pearson χ^2	28	33.91	0.20	No
Likelihood Ratio χ^2	28	44.48	0.02	Yes

Note: The level of significance for this test was 0.05.

When the speed data collected from all three work zones were tested together, the Pearson Chi-square test did not support the dependent relationship between the vehicle speed reduction and the presence of the proposed EFTCD at the 0.05 level of significance. However, the Likelihood Ratio test yield a *p*-value less than 0.05, which indicated that the presence of the proposed EFTCD had an impact on the vehicle speed reduction.

The relationship between vehicle speeds and the presence of the proposed EFTCD was also tested separately for the two types of work zones. For the two work zones with the 55-mph speed limit, both the Pearson Chi-square test and the Likelihood Ratio Chi-square test indicated that a dependent relationship did not existed at the 0.05 level of significance. For the 65-mph work zone, the Likelihood Ratio Chi-square test showed a *p*-value of 0.02, which indicated a significant dependency between the vehicle speed reduction and the presence of the proposed EFTCD.

6.3 Driver Survey Results

6.3.1 Overview

One of the critical indicators for the effectiveness of the EFTCD is the reaction from drivers when they are encountering it in a work zone. As a key component of this research, a driver survey was carried out in the experimental work zones. As described in the survey design section in Chapter 4, the questionnaire was designed in an efficient way to gather the drivers' feedbacks. The survey form contained five questions and other fields for pertinent information such as driver gender and vehicle type.

The collected survey forms were analyzed to understand the interpretations and suggestions of the surveyed drivers regarding the EFTCD and its potential implementation in the work zones. In this section, an overview of each survey question was first presented, followed by the analysis results.

For this project, 110 completed survey forms were collected from the three experimental work zones. Among the surveyed drivers, 41 were females and 69 were males. In addition, only 14 of the surveyed vehicles were heavy trucks while the rest were light-duty vehicles. Note that, because the limited number of the heavy-vehicle data, the vehicle type was not analyzed separately.

6.3.2 Survey Feedbacks

Question 1: Did you see the vehicle's flashers when you approached the work zone?

The analysis of the responses to the first question showed that the proposed EFTCD successfully captured the attention of 84% (92 out of 110) of the surveyed drivers. However, 16% (18 out of 110) of the surveyed drivers didn't see the EFTCD when they were approaching the work zones, as shown in Figure 6.8. Factors which were observed in the experimental sites and might cause a nontrivial proportion of drivers who claimed not seeing the EFTCD include:

1. Sun glare. Researchers noticed that, during the time periods when the experiments were carried out, the sunlight could be very bright especially in early afternoons on sunny days. If the rear end of a vehicle was against the sunlight direction, the emergency warning flashers could be hard to discernible to an approaching vehicle unless the distance became close enough. In addition, during early mornings or late afternoons when bright sunlight was directly against the driving direction, a driver could not easily recognize the vehicles' flashers because of the sun glares.
2. Vehicles with unclear warning flashers. Some of the vehicles in the experimental work zones were either aged or stained, which caused their

emergency warning flashers to be invisible. Some of the vehicles even had emergency warning flashers that were not functioning.

3. Unwillingness to participation. Some drivers might not want to participate in the survey and thus simply responded “no” to discontinue the survey.

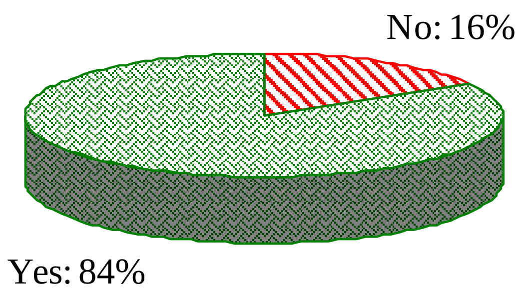


Figure 6.8: Responses for the first question

Question 2: How do you interpret the flashers?

As mentioned before, 18 drivers claimed not seeing the EFTCD when they were entering the work zones. They were not surveyed with the rest of questions. Thus, the following analyses of the survey feedbacks were based on the 92 drivers who responded “yes” to the first question.

The second question had six answer options for a surveyed driver to select. These answers included: 1) Emergency situation ahead, 2) Dangerous situation ahead, 3) Need to slow down, 4) Don’t know, 5) Get confused, and 6) Other. As shown in Table 6.11 and Figure 6.9, survey results indicated that 65% of the drivers realized that they needed to reduce their speeds upon seeing the emergency warning flashers in front. More then a half of these drivers interpreted the emergency warning flashers in the experimental work zones as an indication of emergency or dangerous traffic conditions ahead. None of the drivers considered themselves confused by the EFTCD in the work zones. Among the answer provided by those drivers who chose “other”, 5 drivers described their interpretation to the warning flashers as an indication of a breakdown vehicle; another 4 drivers described the flashers as a requirement of driving cautiously. Notice that a majority of the surveyed drivers selected multiple answers and thus the frequency percentages in Table 6.11 and Figure 6.9 do not add up to 100%.

Table 6.11: Response Frequencies of the Second Question

Response	Frequency	Percent (%)
Emergency situation ahead	33	36
Dangerous situation ahead	16	17
Need to slow down	60	65
Don’t know	1	1
Get confused	0	0
Other	15	16

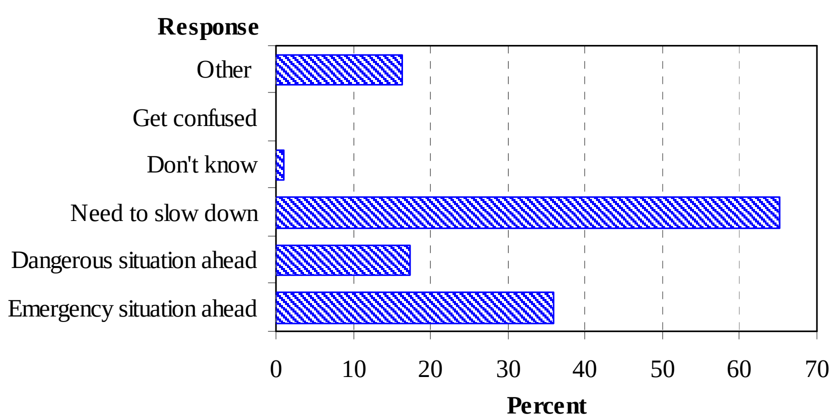


Figure 6.9: Response frequencies of the second question

Question 3: What actions do you take after you see the flashers?

This question had the following five answers: 1) slow down, 2) slow down further (if they had started slowing down before they saw the EFTCD), 3) look for more information, 4) do nothing, and 5) other. The question was designed to understand what reactions drivers would take after they saw the EFTCD in the work zones.

Table 6.12 and Figure 6.9 show the response frequencies, in which 56 % (35 % + 21 %) of the surveyed drivers slowed down or slowed down further when they saw the emergency warning flashers in work zones. In addition, 15% of the drivers were looking for more information upon seeing the warning flashers. It is worthy of discussion that a majority of the drivers (11 out of 14) who chose “look for more information” also selected either “slow down” or “slow down further.” However, there were 37 drivers (40%) indicated that they did nothing when they saw the warning flashers in work zones.

Table 6.12: Response Frequencies of the Third Question

Response	Frequency	Percent (%)
Slow down	32	35
Slow down further	19	21
Look for more information	14	15
Do nothing	37	40
Other	0	0

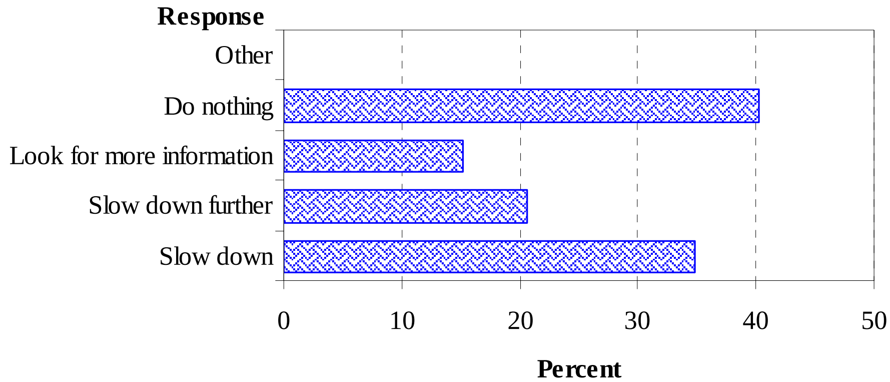


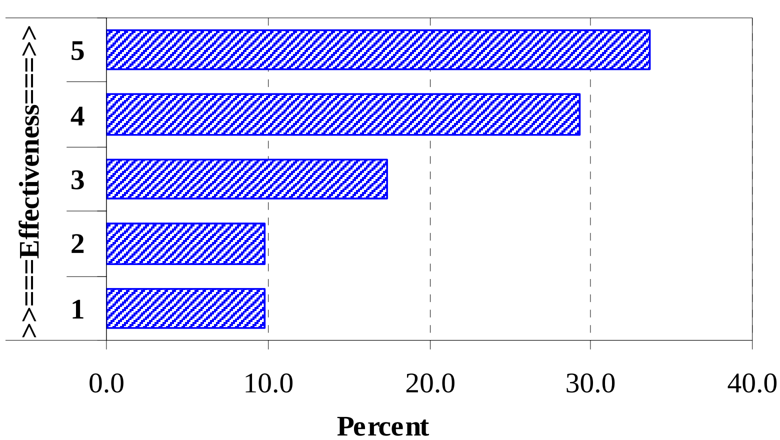
Figure 6.10: Response frequencies of the third question

Question 4: Do you think that the flashers bring you more attention to the work zone traffic condition?

This question was designed to measure the effectiveness of the proposed EFTCD in alerting drivers of the irregular traffic conditions in the work zones. The answers included: 1) very much, 2) somewhat more, 3) some, 4) little, 5) none, and 6) do not know. When answering this question, the surveyed drivers had to assess the effectiveness of the EFTCD from their perspective on a scale (one to five where one and five represented "none" and "very much," respectively). Table 6.13 and Figure 6.10 summarize the response frequencies of this question based on the analysis results.

Table 6.13: Response Frequencies of the Fourth Question

Response	Effectiveness Score	Frequency	Percent (%)
Very much	5	31	34
Somewhat more	4	27	29
Some	3	16	17
Little	2	9	10
None	1	9	10
Total	--	92	100



Where:
5 = Very much; 4 = Somewhat more; 3 = Some; 2 = Little; 1= None

Figure 6.11: Response frequencies of the fourth question

Results of the analyses show that a majority of drivers (80 %) considered the EFTCD effective (very much, somewhat more, and some) in alerting them about the work zone traffic conditions. Specifically, 34 % of the drivers believed that the EFTCD was very effective in bringing the work zone traffic conditions to their attention and 29 % of the drivers indicated that the EFTCD had relatively high effectiveness (an effectiveness score of four). On the other hand, about 20 % of the surveyed drivers rated the effectiveness of the EFTCD as “little” or “none.”

Question 5: Do you prefer to use the vehicle’s flashers as a warning sign in the work zones?

The survey questionnaire included this question to directly obtain the drivers’ recommendation on the implementation of the proposed EFTCD in the work zones. The survey results on this question would be a meaningful indication of the acceptance of the proposed EFTCD by work zone travelers. As shown in Table 6.14 and Figure 6.11, 82 % of the drivers recommended to use this warning sing in work zones; only 12% did not recommend the implementation.

Table 6.14: Response Frequencies of the Fifth Question

Response	Frequency	Percent (%)
Yes	75	82
No	11	12
Don’t know	6	6
Total	92	100

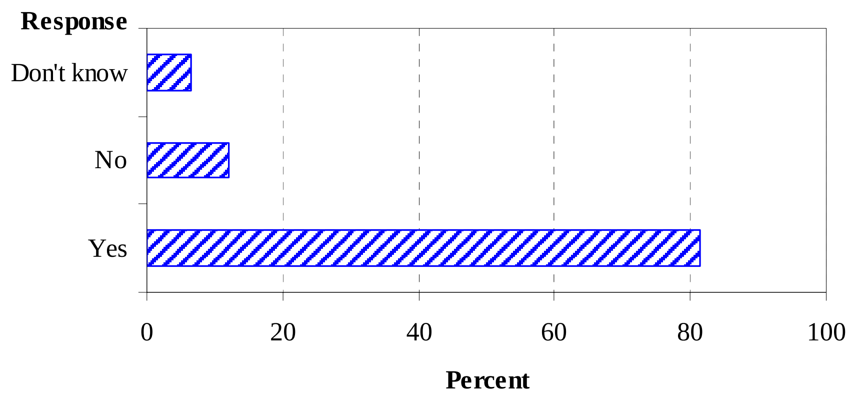


Figure 6.12: Response frequencies of the fifth question

6.4 Summary

In this study, researchers evaluated the effectiveness of the EFTCD that was assembled by the emergency warning flashers of vehicles at the entrance of the one-lane, two-way work zones. Evaluations were conducted in three work zones in Kansas. Two of which had a speed limit of 55 mph and another had a speed limit of 65 mph. Two key components in the evaluations were the analyses of vehicle speed data and driver survey data. The speed analyses included the evaluation of the changes in vehicle speeds, the evaluation of the changes in the proportions of high speeds, and the evaluation of the interrelationship between speeds and the employment of the EFTCD. In speed analyses, researchers utilized statistical methods such as Chi-square tests and ANOVA tests. In the driver survey analyses, the frequency analysis method was used primarily. The results of these analyses are summarized and discussed as follows.

Compared to the average speed without the warning sign, the average speed with warning sign was reduced by more than 10 % or about 5 mph in the work zone with a speed limit of 65 mph. In work zones with a speed limit of 55 mph, a 7 % or 2.5 mph reduction in average speed was observed. Further statistical analyses showed that for both types of work zones where the experiments were conducted, the mean speeds with the warning sign were lower than those without the warning sign. Speed analyses in terms of roadway geometric alignments showed that the speed deductions on curved highway sections were larger than the reductions on non-curved roadways, especially in the two 55-mph work zones.

Regarding the change in proportions of high speeds, researchers found that, in general, reductions on high speeds were observed in the work zones with the warning sign. Researchers collected two notably high speeds in the work zones when the warning sign was not in use. These speeds might be produced by drivers who failed to pay attention to the upcoming stopping condition in the work zones. However, when the warning sign was present, researchers did not found comparably high speeds.

Another speed analysis task was to test the causal relationship between the use of the warning sign and the speed reductions in work zones. Researchers used both Pearson and Likelihood Ratio Chi-square statistics for this analysis. The Likelihood Ratio test supported the close relationship between the speed reduction and the implementation of the warning sign in the work zone with the 65-mph speed limit and all three work zones when data were tested together. On the other hand, the Pearson Chi-square test did not support the relationship for either type of the work zones (55-mph speed limit and 65-mph speed limit), nor did it support the relationship when data of all three work zones were tested together. Thus, researchers could not determine if there was a causal relationship between the EFTCD and the speed reductions purely based on statistical tests.

Analyses of the survey results showed that a majority of drivers were able to recognize the warning sign in the work zones. More than a half of the surveyed drivers considered the warning flashers as an indication of either dangerous situation or emergency situation ahead; 60% of the drivers thought that the warning flashers signified a need for speed reduction. In addition, survey results indicated that about 56% of the drivers slowed down or slowed down further when they saw the warning flashers in work zones. However, survey results showed that 40% of the drivers claimed that they did nothing upon seeing the warning flashers in the work zones.

When asked the question about the effectiveness of the warning sign in capturing drivers' attentions, more than 80% of the drivers expressed positive feedback. In particular, a third of the drivers considered the EFTCD in one-lane, two-way work zones as a very effective warning sign in drawing drivers' attentions to the complicated traffic conditions. Consequently, a majority of the drivers (82 %) would recommend the implementation of this warning sing in work zones.

CHAPTER 7 – CONCLUSION AND RECOMMENDATION

7.1 Conclusions

Rural two-lane highways constitute a large percentage of the Kansas highway system. Preserving, rehabilitating, expending, and enhancing these highways require the set-up of a large number of one-lane, two-way work zones. Results of previous studies have showed that work zones on two-lane highways accounted for 63% of the fatal crashes and a third of the injury crashes in Kansas (Bai and Li 2007). Maintaining safety without sacrificing highway functions in the work zones has been a critical challenge for traffic engineers and researchers.

Crash investigations (Bai and Li 2007) showed that inattentive driving was a causal reason for more than half of the severe crashes involving fatalities or injuries in Kansas highway work zones. In addition, rear-end collisions were the dominant type of injury crashes in the Kansas work zones. Aimed at reducing the work zone crashes (especially rear-end collisions) attributable to inattentive driving, KDOT initiated a research project to evaluate the effectiveness of a newly developed warning sign that is assembled by using vehicles' emergency flashers in one-lane, two-way highway work zones. This warning sign was named as the Emergency Flasher Traffic Control Device (EFTCD). The EFTCD works in the following fashion. When a vehicle stops at an entrance of a work zone for its turn to pass the work zone, the driver is required to turn on vehicle's emergency warning flashers to send a signal to a following vehicle and reminder its driver that he/she approaches the work zone. Ideally, drivers of all vehicles stop at a work zone will turn on their emergency flashers one by one until they safely pass through the work zone. Thus, drivers entering a one-lane, two-way work zone would receive additional warning (besides the signs and signals already exist in the work zone) from the vehicle ahead of them in the queue.

To accurately evaluate the effectiveness of the EFTCD in work zones, researchers first conducted a comprehensive literature review on pertinent topics including nationwide and Kansas work zone crash characteristics, work zone traffic control, and research and development trend on work zone safety. Findings are synthesized and presented in Chapter 2 of this report to provide the background knowledge for this research. Second, researchers carefully planed the field experiments including the selection of the speed collection device, the development of the driver survey, and the determination of speed collection and driver survey strategies. Third, researchers conducted field experiments in three one-lane, two-way work zones in 2007. One work zone has a speed limit of 65 mph and other two have a speed limit of 55 mph. Finally, the collected speed data and survey feedbacks were analyzed using statistical methods such as the Student's *t*-test, Chi-square tests, ANOVA statistics, and the frequency analyses. Results of data analysis are presented as follows.

1. When the EFTCD was in use, the mean speeds of vehicles were evidently lower than the mean speeds of vehicles when the EFTCD was not in use. When the EFTCD was present in the 65-mph work zone, the average vehicle speed was reduced by more than 10 % or by 5 mph. In the work zones with the speed limit of 55 mph, a 7% or 2.5 mph reduction in average vehicle speed was observed.

2. When the EFTCD was present, researchers found that the proportions of high speeds were evidently reduced. Results of Chi-square tests showed a causal relationship between the speed reduction and the presence of the EFTCD in the 65-mph work zone and in all three experimental work zones when speed data were tested together. This was an indication that the EFTCD was effective in preventing speeding.
3. A majority of surveyed drivers were able to recognize the EFTCD in the work zones. More than a half of surveyed drivers considered the EFTCD as an indication of either dangerous situation or emergency situation ahead. 60 percent of the surveyed drivers interpreted that the EFTCD signified a need for speed reduction. As a result, about 56 percent of the surveyed drivers slowed down or slowed down further when they saw the EFTCD in work zones.
4. More than 80 percent of surveyed drivers responded positively when they were asked about the effectiveness of the EFTCD in drawing their attention. Overall, 82 percent of the surveyed drivers recommended the implementation of the EFTCD in work zones.

Based on the data analysis results, researchers were able to conclude that the proposed EFTCD was effective in alerting drivers about the irregular traffic conditions in the work zones. The evidences leading to this conclusion were that the EFTCD reduced the speeds of vehicles approaching to the work zones and prevented speeding which was a major contributing factor of causing the rear-end collisions. Survey results also supported this conclusion with high percentages of feedbacks that acknowledged the effectiveness of the EFTCD and recommended its implementation in the work zones.

7.2 Recommendations

The researchers recommend the implementation of the EFTCD that is assembled by the vehicles' emergency flashers in one-lane, two-way work zones. Other than the vehicle speed and survey analysis results that acknowledged the effectiveness of the EFTCD, the proposed warning sign is cost-effective and easy to be set up and removed. Statewide, a large percentage of rural two-lane highways are low-volume roads where there is an urgent need for low-cost yet highly effective traffic control method. One-lane, two-way work zones on these highways typically stay set up for relatively short durations and require frequent movement. For instance, three experimental work zones where pavement projects were carried out required work zones to be moved and reset-up at least once per day. Therefore, high visibility, high flexibility, and low cost become critical qualifications for an effective warning sign in these work zones.

If the EFTCD is implemented, researchers would recommend that two advanced warning signs, shown "Turn on Vehicle Emergency Flashers When Stopped," should be installed to instruct drivers to turn on the vehicle emergency flashers. Based on the researchers' field observation, the first sign should be located at 750 feet away from the flagger's station and the second sign should be located at 100 feet away from the flagger's station. Too many signs would be excessive considering that one-lane, two-way work zones typically need to be moved and reset up frequently as road projects progress. In addition, when the traffic volume is relatively high, the vehicle queue waiting for passing a work zone may reach several hundreds of feet. Therefore, there must be an adequate clearance distance between the first sign and the flagger so that the sign is not obstructed by vehicles that were stopped. On the other hand, the second sign should be installed close to the flagger so that the drivers of leading vehicles are informed again regarding the requirement of turning on the warning flashers in case drivers miss the sign in the first time. The compliance of leading vehicles is important because they set up an example for the following drivers. Thus, occasional reminding to the non-complying drivers by the flaggers may be required. Notice that this recommendation on signing configuration is primarily based on field experience. Further evaluations and explorations on the signing configuration are needed in the future.

Before implementing the EFTCD in one-lane, two-way work zones, the following challenges need to be fully addressed.

1. Vehicle emergency warning flashers have been widely accepted as an indication of a vehicle emergency such as a mechanical breakdown or a functional failure. As shown by the survey results, 36 percent of the surveyed drivers interpreted the warning flashers as an indication of emergency situation ahead. Field observation showed that, unless the drivers were able to see the flagger and stopping condition at the entrance of a work zone, some aggressive drivers might try to bypass a leading vehicle with emergency flashers on either from the opposite lane or the shoulder. This observed driving behavior may be explained as these

drivers considered emergency warning flashers as an indication of vehicle emergency but not irregular traffic conditions in a work zone. The reckless bypassing maneuvers by some drivers might cause additional crashes such as head-on collisions or rollover accidents. Therefore, the EFTCD should not be implemented unless proper signing and adequate public education are provided.

2. Based on field observations, researchers found that the emergency flashers of some aged and/or muddy vehicles were not evident, especially when the flashers were against the sunlight. This may lead to a certain degree of confusion for following drivers. Therefore, before the implementation of the EFTCD in one-lane, two-way work zones, regulations on the visibility of vehicle emergency warning flashers may need to be imposed.
3. The long-term effectiveness of the proposed EFTCD is not clear at this time. This research project was conducted in a short period of time. Drivers had not seen this type of warning sign so their reactions might be cautious. A consensus regarding the effectiveness of a newly proposed traffic control is that it may diminish over time. It is possible that drivers' responses to the warning sign in terms of speed reductions might decrease over time. However, researchers believe that the EFTCD will be effective in certain ways because it raises the drivers' attention on the traffic conditions in work zones. This effectiveness may remain at an

acceptable level over a long period of time, although further research is necessary to determine and evaluate the lone-term effectiveness.

4. Finally, the setup of two advanced signs (one at 750 feet and another at 100 feet) and prompt maintenance need to be enforced at work zones so that the credibility of the temporary traffic signs is reputed. It has been frequently experienced in work zones when traffic signs are not timely updated to reflect the work zone conditions. For example, a “Work Zone Ahead” sign was set up while the work zone was no longer in place. This would lower the credibility of the temporary traffic signs significantly, which could raise a compliance issue for the EFTCD application in particular.

In addition to this research project, researchers recommend further efforts on evaluating the EFTCD in one-lane, two-way work zones to better understand its long-term effectiveness and to explore implementation strategies. If the EFTCD is further evaluated, researchers recommend the use of additional speed collection sensors in multiple locations in a work zone. Multiple speed detectors would enable researchers to collect speed data at multiple locations. Thus, the speed profiles in work zones can be created. Comparisons between the speed profiles with the warning sign and without the warning sign will allow researchers to better understand the vehicle deceleration behaviors and thus better evaluate the long-term effectiveness of the EFTCD. If possible, more speed data need to be collected and a larger scale of driver survey need to be conducted, both of which would help in achieving more accurate and convincing outcomes. Actual crash data in work zones with and without the EFTCD should be compared when they are available to further verify the evaluation results. The researchers also recommend evaluating the scenarios for setting up the advanced signs that could maximize the effectiveness of EFTCD.

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APPENDIX A - SAMPLE SURVEY FORM

Date: _______________ Time: ______________ Weather: _______________

SURVEY FORM

Project Title: Reducing Work Zone Crashes by Using Vehicle's Flashers as a Warning Sign

1. Do you see the vehicle's flashers when you approach the work zone?

   Yes ____ No ____

<u>If the answer is YES, then continue the survey. If the answer is NO, stop the survey.</u>

2. How do you interpret the flashers?

   Emergency situation ahead ____
   Dangerous situation ahead ____
   Need to slow down ____
   Don't know ____
   Get confused ____
   Other (describe it)
   ____

3. What actions do you take after you see the flashers?

   Slow down (press the break) ____
   Slow down further ____
   Look for more information ____
   Do nothing ____
   Take other actions (describe it)
   ____

4. Do you think that the flashers bring you more attention to the work zone traffic condition?

   Very Much ____
   Somewhat more ____
   Some ____
   Little ____
   None ____
   Don't know ____

5. Do you prefer to use the vehicle's flashers as a warning sign in the work zones?

Date: _______________ Time: _______________ Weather: _______________

Yes ____ No ____ Don't know ____

Vehicle Type: ______________________ Driver Gender: M F

APPENDIX B - VEHICLE SPEED DATA

Table B.1: Vehicle Speed Data

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100001	06192007	Sunny	36	500	65	Straight Level	C	N	2
100002	06192007	Sunny	38	500	65	Straight Level	C	N	2
100003	06192007	Sunny	55	500	65	Straight Level	T	N	1
100004	06192007	Sunny	37	500	65	Straight Level	C	N	2
100005	06192007	Sunny	35	500	65	Straight Level	T	N	1
100006	06192007	Sunny	29	500	65	Straight Level	C	Y	2
100007	06192007	Sunny	30	500	65	Straight Level	C	Y	2
100008	06192007	Sunny	38	500	65	Straight Level	C	N	1
100009	06192007	Sunny	37	500	65	Straight Level	C	N	2
100010	06192007	Sunny	44	500	65	Straight Level	C	N	1
100011	06192007	Sunny	35	500	65	Straight Level	C	Y	2
100012	06192007	Sunny	35	500	65	Straight Level	T	N	1
100013	06192007	Sunny	14	500	65	Straight Level	C	Y	2
100014	06192007	Sunny	36	500	65	Straight Level	T	N	1
100015	06192007	Sunny	40	500	65	Straight Level	C	N	2
100016	06192007	Sunny	37	500	65	Straight Level	C	Y	2
100017	06192007	Sunny	38	500	65	Straight Level	C	Y	2
100018	06192007	Sunny	38	500	65	Straight Level	C	N	1
100019	06192007	Sunny	33	500	65	Straight Level	T	N	2
100020	06192007	Sunny	28	500	65	Straight Level	C	Y	2
100021	06192007	Sunny	36	500	65	Straight Level	C	N	1
100022	06192007	Sunny	32	500	65	Straight Level	T	Y	2
100023	06192007	Sunny	32	500	65	Straight Level	C	N	1
100024	06192007	Sunny	35	500	65	Straight Level	C	Y	2
100025	06192007	Sunny	28	500	65	Straight Level	T	Y	2
100026	06192007	Sunny	37	500	65	Straight Level	T	N	1
100027	06192007	Sunny	27	500	65	Straight Level	C	N	1
100028	06192007	Sunny	27	500	65	Straight Level	C	N	2
100029	06192007	Sunny	29	500	65	Straight Level	C	N	1
100030	06192007	Sunny	51	500	65	Straight Level	C	Y	2
100031	06192007	Sunny	40	500	65	Straight Level	C	Y	2
100032	06192007	Sunny	37	500	65	Straight Level	C	N	2
100033	06192007	Sunny	27	500	65	Straight Level	C	Y	2

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100034	06192007	Sunny	25	500	65	Straight Level	C	Y	2
100035	06192007	Sunny	43	500	65	Straight Level	C	N	1
100036	06192007	Sunny	28	500	65	Straight Level	T	Y	2
100037	06192007	Sunny	36	500	65	Straight Level	C	N	2
100038	06202007	Sunny	33	500	65	Curved Level	C	N	2
100039	06202007	Sunny	54	500	65	Curved Level	C	N	1
100040	06202007	Sunny	38	500	65	Curved Level	C	Y	2
100041	06202007	Sunny	43	500	65	Curved Level	C	Y	2
100042	06202007	Sunny	42	500	65	Curved Level	C	N	2
100043	06202007	Sunny	51	500	65	Curved Level	C	N	1
100044	06202007	Sunny	43	500	65	Curved Level	C	Y	2
100045	06202007	Sunny	36	500	65	Curved Level	C	N	1
100046	06202007	Sunny	59	500	65	Curved Level	C	N	1
100047	06202007	Sunny	41	500	65	Curved Level	C	Y	2
100048	06202007	Sunny	42	500	65	Curved Level	C	N	2
100049	06202007	Sunny	46	500	65	Curved Level	C	N	1
100050	06202007	Sunny	42	500	65	Curved Level	C	N	2
100051	06202007	Sunny	42	500	65	Curved Level	C	N	2
100052	06202007	Sunny	29	500	65	Curved Level	C	N	1
100053	06202007	Sunny	45	500	65	Curved Level	C	N	2
100054	06202007	Sunny	33	500	65	Curved Level	C	Y	2
100055	06202007	Sunny	35	500	65	Curved Level	T	N	1
100056	06202007	Sunny	53	500	65	Curved Level	C	N	1
100057	06202007	Sunny	30	500	65	Curved Level	C	Y	2
100058	06202007	Sunny	37	500	65	Curved Level	C	N	2
100059	06202007	Sunny	35	500	65	Curved Level	T	N	1
100060	06202007	Sunny	39	500	65	Curved Level	C	Y	2
100061	06202007	Sunny	44	500	65	Curved Level	C	N	1
100062	06202007	Sunny	45	500	65	Curved Level	C	Y	2
100063	06202007	Sunny	32	500	65	Curved Level	C	Y	2
100064	06202007	Sunny	44	500	65	Curved Level	C	N	2
100065	06202007	Sunny	22	500	65	Curved Level	T	Y	2
100066	06202007	Sunny	47	500	65	Curved Level	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100034	06192007	Sunny	25	500	65	Straight Level	C	Y	2
100035	06192007	Sunny	43	500	65	Straight Level	C	N	1
100036	06192007	Sunny	28	500	65	Straight Level	T	Y	2
100037	06192007	Sunny	36	500	65	Straight Level	C	N	2
100038	06202007	Sunny	33	500	65	Curved Level	C	N	2
100039	06202007	Sunny	54	500	65	Curved Level	C	N	1
100040	06202007	Sunny	38	500	65	Curved Level	C	Y	2
100041	06202007	Sunny	43	500	65	Curved Level	C	Y	2
100042	06202007	Sunny	42	500	65	Curved Level	C	N	2
100043	06202007	Sunny	51	500	65	Curved Level	C	N	1
100044	06202007	Sunny	43	500	65	Curved Level	C	Y	2
100045	06202007	Sunny	36	500	65	Curved Level	C	N	1
100046	06202007	Sunny	59	500	65	Curved Level	C	N	1
100047	06202007	Sunny	41	500	65	Curved Level	C	Y	2
100048	06202007	Sunny	42	500	65	Curved Level	C	N	2
100049	06202007	Sunny	46	500	65	Curved Level	C	N	1
100050	06202007	Sunny	42	500	65	Curved Level	C	N	2
100051	06202007	Sunny	42	500	65	Curved Level	C	N	2
100052	06202007	Sunny	29	500	65	Curved Level	C	N	1
100053	06202007	Sunny	45	500	65	Curved Level	C	N	2
100054	06202007	Sunny	33	500	65	Curved Level	C	Y	2
100055	06202007	Sunny	35	500	65	Curved Level	T	N	1
100056	06202007	Sunny	53	500	65	Curved Level	C	N	1
100057	06202007	Sunny	30	500	65	Curved Level	C	Y	2
100058	06202007	Sunny	37	500	65	Curved Level	C	N	2
100059	06202007	Sunny	35	500	65	Curved Level	T	N	1
100060	06202007	Sunny	39	500	65	Curved Level	C	Y	2
100061	06202007	Sunny	44	500	65	Curved Level	C	N	1
100062	06202007	Sunny	45	500	65	Curved Level	C	Y	2
100063	06202007	Sunny	32	500	65	Curved Level	C	Y	2
100064	06202007	Sunny	44	500	65	Curved Level	C	N	2
100065	06202007	Sunny	22	500	65	Curved Level	T	Y	2
100066	06202007	Sunny	47	500	65	Curved Level	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100067	06202007	Sunny	48	500	65	Curved Level	C	N	2
100068	06202007	Sunny	39	500	65	Curved Level	C	Y	2
100069	06202007	Sunny	42	500	65	Curved Level	C	Y	2
100070	06202007	Sunny	42	500	65	Curved Level	C	N	1
100071	06202007	Sunny	50	500	65	Curved Level	C	N	2
100072	06202007	Sunny	38	500	65	Curved Level	C	N	2
100073	06202007	Sunny	43	500	65	Curved Level	T	N	1
100074	06202007	Sunny	48	500	65	Curved Level	C	Y	2
100075	06202007	Sunny	45	500	65	Curved Level	C	N	2
100076	06202007	Sunny	38	500	65	Curved Level	C	N	1
100077	06202007	Sunny	60	500	65	Curved Level	C	N	1
100078	06202007	Sunny	42	500	65	Curved Level	C	Y	2
100079	06202007	Sunny	45	500	65	Curved Level	C	N	2
100080	06202007	Sunny	53	500	65	Curved Level	C	N	1
100081	06202007	Sunny	31	500	65	Curved Level	C	Y	2
100082	06212007	Sunny	44	500	65	Curved Level	C	N	2
100083	06212007	Sunny	44	500	65	Curved Level	C	N	2
100084	06212007	Sunny	42	500	65	Curved Level	C	N	1
100085	06212007	Sunny	40	500	65	Curved Level	C	N	1
100086	06212007	Sunny	30	500	65	Curved Level	C	Y	2
100087	06212007	Sunny	39	500	65	Curved Level	C	N	2
100088	06212007	Sunny	29	500	65	Curved Level	T	N	1
100089	06212007	Sunny	44	500	65	Curved Level	C	Y	2
100090	06212007	Sunny	44	500	65	Curved Level	C	N	1
100091	06212007	Sunny	40	500	65	Curved Level	C	Y	2
100092	06212007	Sunny	27	500	65	Curved Level	T	N	2
100093	06212007	Sunny	43	500	65	Curved Level	C	N	1
100094	06212007	Sunny	41	500	65	Curved Level	T	N	1
100095	06212007	Sunny	30	500	65	Curved Level	C	Y	2
100096	06212007	Sunny	41	500	65	Curved Level	C	N	2
100097	06212007	Sunny	46	500	65	Curved Level	C	N	1
100098	06212007	Sunny	48	500	65	Curved Level	C	Y	2
100099	06212007	Sunny	31	500	65	Curved Level	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100100	06212007	Sunny	32	500	65	Curved Level	T	Y	2
100101	06212007	Sunny	34	500	65	Curved Level	C	N	2
100102	06212007	Sunny	37	500	65	Curved Level	C	Y	2
100103	06212007	Sunny	29	500	65	Curved Level	C	N	2
100104	06212007	Sunny	24	500	65	Curved Level	T	Y	2
100105	06212007	Sunny	57	500	65	Curved Level	C	N	1
100106	06212007	Sunny	42	500	65	Curved Level	C	Y	2
100107	06212007	Sunny	35	500	65	Curved Level	T	N	1
100108	06212007	Sunny	44	500	65	Curved Level	C	N	2
100109	06212007	Sunny	36	500	65	Curved Level	T	N	1
100110	06212007	Sunny	41	500	65	Curved Level	C	N	2
100111	06212007	Sunny	33	500	65	Curved Level	C	N	1
100112	06212007	Sunny	44	500	65	Curved Level	C	N	2
100113	06212007	Sunny	44	500	65	Curved Level	C	Y	2
100114	06212007	Sunny	44	500	65	Curved Level	C	N	2
100115	06212007	Sunny	46	500	65	Curved Level	C	N	2
100116	06212007	Sunny	51	500	65	Curved Level	C	N	1
100117	06212007	Sunny	30	500	65	Curved Level	T	Y	2
100118	06212007	Sunny	40	500	65	Curved Level	C	N	2
100119	06212007	Sunny	28	500	65	Curved Level	T	N	1
100120	06212007	Sunny	39	500	65	Curved Level	C	N	2
100121	06212007	Sunny	42	500	65	Curved Level	C	N	2
100122	06212007	Sunny	56	500	65	Curved Level	C	N	2
100123	06212007	Sunny	25	500	65	Curved Level	T	Y	2
100124	06212007	Sunny	37	500	65	Curved Level	T	N	1
100125	06212007	Sunny	38	500	65	Curved Level	C	Y	2
100126	06212007	Sunny	49	500	65	Curved Level	T	Y	2
100127	06212007	Sunny	43	500	65	Curved Level	C	N	2
100128	06212007	Sunny	41	500	65	Curved Level	C	N	1
100129	06212007	Sunny	41	500	65	Curved Level	T	Y	2
100130	06212007	Sunny	45	500	65	Curved Level	C	N	2
100131	06212007	Sunny	31	500	65	Curved Level	T	N	1
100132	06212007	Sunny	44	500	65	Curved Level	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100133	06212007	Sunny	48	500	65	Curved Level	C	Y	2
100134	07092007	O/C	35	400	55	Straight Uphill	C	N	2
100135	07092007	O/C	43	400	55	Straight Uphill	C	N	1
100136	07092007	O/C	26	400	55	Straight Uphill	C	N	2
100137	07092007	O/C	31	400	55	Straight Uphill	C	N	1
100138	07092007	O/C	44	400	55	Straight Uphill	C	Y	2
100139	07092007	O/C	40	400	55	Straight Uphill	C	N	1
100140	07092007	O/C	38	400	55	Straight Uphill	C	N	1
100141	07092007	O/C	31	400	55	Straight Uphill	C	N	2
100142	07092007	O/C	37	400	55	Straight Uphill	C	N	1
100143	07092007	O/C	43	400	55	Straight Uphill	C	N	1
100144	07092007	O/C	40	400	55	Straight Uphill	C	N	2
100145	07092007	O/C	34	400	55	Straight Uphill	C	N	2
100146	07102007	O/C	35	400	55	Straight Uphill	C	N	1
100147	07102007	O/C	27	400	55	Straight Uphill	C	N	2
100148	07102007	O/C	35	400	55	Straight Uphill	C	N	1
100149	07102007	O/C	33	400	55	Straight Uphill	C	N	2
100150	07102007	O/C	37	400	55	Straight Uphill	C	N	1
100151	07102007	O/C	38	400	55	Straight Uphill	C	N	1
100152	07102007	O/C	34	400	55	Straight Uphill	C	N	1
100153	07102007	O/C	36	400	55	Straight Uphill	C	N	1
100154	07102007	O/C	26	400	55	Straight Uphill	C	N	2
100155	07102007	O/C	33	400	55	Straight Uphill	C	Y	2
100156	07102007	O/C	32	400	55	Straight Uphill	C	N	1
100157	07102007	O/C	28	400	55	Straight Uphill	C	N	1
100158	07102007	O/C	32	400	55	Straight Uphill	C	N	2
100159	07102007	O/C	30	400	55	Straight Uphill	C	N	1
100160	07102007	O/C	32	400	55	Straight Uphill	C	Y	2
100161	07102007	O/C	40	400	55	Straight Uphill	C	N	1
100162	07102007	O/C	38	400	55	Straight Uphill	C	N	1
100163	07102007	O/C	38	400	55	Straight Uphill	C	N	1
100164	07102007	O/C	39	400	55	Straight Uphill	C	N	1
100165	07102007	O/C	30	400	55	Straight Uphill	C	Y	2

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100166	07102007	O/C	43	400	55	Straight Uphill	C	N	1
100167	07102007	O/C	34	400	55	Straight Uphill	C	N	1
100168	07102007	O/C	40	400	55	Straight Uphill	C	N	2
100169	07102007	O/C	47	400	55	Straight Uphill	C	N	1
100170	07102007	O/C	26	400	55	Straight Uphill	T	N	1
100171	07102007	O/C	32	400	55	Straight Uphill	C	Y	2
100172	07102007	O/C	31	400	55	Straight Uphill	C	N	1
100173	07102007	O/C	30	400	55	Straight Uphill	C	N	1
100174	07102007	O/C	29	400	55	Straight Uphill	C	N	1
100175	07102007	O/C	39	400	55	Straight Uphill	C	N	1
100176	07102007	O/C	40	400	55	Straight Uphill	C	N	1
100177	07112007	O/C	29	400	55	Straight Uphill	C	N	1
100178	07112007	O/C	36	400	55	Straight Uphill	C	Y	2
100179	07112007	O/C	40	400	55	Straight Uphill	C	N	1
100180	07112007	O/C	36	400	55	Straight Uphill	C	Y	2
100181	07112007	O/C	28	400	55	Straight Uphill	C	Y	2
100182	07112007	O/C	31	400	55	Straight Uphill	C	N	2
100183	07112007	O/C	27	400	55	Straight Uphill	C	N	1
100184	07112007	O/C	31	400	55	Straight Uphill	C	Y	2
100185	07112007	O/C	40	400	55	Straight Uphill	C	N	2
100186	07112007	O/C	23	400	55	Straight Uphill	C	Y	2
100187	07112007	O/C	42	400	55	Straight Uphill	C	Y	2
100188	07112007	O/C	35	400	55	Straight Uphill	C	N	2
100189	07112007	O/C	37	400	55	Straight Uphill	C	N	1
100190	07112007	O/C	42	400	55	Straight Uphill	C	N	1
100191	07112007	O/C	35	400	55	Straight Uphill	C	N	1
100192	07112007	O/C	25	400	55	Straight Uphill	C	Y	2
100193	07112007	O/C	32	400	55	Straight Uphill	C	N	2
100194	07112007	O/C	31	400	55	Straight Uphill	C	N	1
100195	07112007	O/C	26	400	55	Straight Uphill	C	N	2
100196	07112007	O/C	30	400	55	Straight Uphill	C	Y	2
100197	07112007	O/C	39	400	55	Straight Uphill	C	N	1
100198	07112007	O/C	44	400	55	Straight Uphill	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100199	07112007	O/C	27	400	55	Straight Uphill	T	N	1
100200	07112007	O/C	29	400	55	Straight Uphill	C	Y	2
100201	07112007	O/C	32	400	55	Straight Uphill	C	Y	2
100202	07112007	O/C	32	400	55	Straight Uphill	C	N	1
100203	07112007	O/C	40	400	55	Straight Uphill	C	N	1
100204	07112007	O/C	31	400	55	Straight Uphill	C	N	2
100205	07112007	O/C	34	400	55	Straight Uphill	C	N	2
100206	07112007	O/C	32	400	55	Straight Uphill	C	N	1
100207	07112007	O/C	36	400	55	Straight Uphill	C	N	1
100208	07112007	O/C	32	400	55	Straight Uphill	C	N	1
100209	07112007	O/C	33	400	55	Straight Uphill	C	N	2
100210	07112007	O/C	35	400	55	Straight Uphill	C	Y	2
100211	07112007	O/C	43	400	55	Straight Uphill	C	Y	2
100212	07112007	O/C	37	400	55	Straight Uphill	C	N	2
100213	07112007	O/C	33	400	55	Straight Uphill	C	N	1
100214	07112007	O/C	37	400	55	Straight Uphill	C	Y	2
100215	07112007	O/C	29	400	55	Straight Uphill	C	N	2
100216	07112007	O/C	38	400	55	Straight Uphill	C	N	2
100217	07162007	SUNNY	39	400	55	Straight Uphill	C	N	1
100218	07162007	SUNNY	20	400	55	Straight Uphill	C	Y	2
100219	07162007	SUNNY	32	400	55	Straight Uphill	C	Y	2
100220	07162007	SUNNY	41	400	55	Straight Uphill	C	N	1
100221	07162007	SUNNY	31	400	55	Straight Uphill	C	N	2
100222	07162007	SUNNY	30	400	55	Straight Uphill	C	N	2
100223	07162007	SUNNY	50	400	55	Straight Uphill	C	N	1
100224	07162007	SUNNY	38	400	55	Straight Uphill	C	N	2
100225	07162007	SUNNY	32	400	55	Straight Uphill	C	N	2
100226	07162007	SUNNY	36	400	55	Straight Uphill	C	N	1
100227	07162007	SUNNY	39	400	55	Straight Uphill	C	Y	2
100228	07162007	SUNNY	37	400	55	Straight Uphill	C	N	2
100229	07162007	SUNNY	41	400	55	Straight Uphill	C	N	2
100230	07162007	SUNNY	27	400	55	Straight Uphill	C	N	1
100231	07162007	SUNNY	26	400	55	Straight Uphill	C	N	2

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100232	07172007	SUNNY	39	400	55	Straight Level	C	N	2
100233	07172007	SUNNY	43	400	55	Straight Level	C	N	2
100234	07172007	SUNNY	40	400	55	Straight Level	C	Y	2
100235	07172007	SUNNY	43	400	55	Straight Level	C	Y	2
100236	07172007	SUNNY	36	400	55	Straight Level	C	N	2
100237	07172007	SUNNY	40	400	55	Straight Level	C	N	2
100238	07172007	SUNNY	38	400	55	Straight Level	C	N	2
100239	07172007	SUNNY	32	400	55	Straight Level	C	N	2
100240	07172007	SUNNY	41	400	55	Straight Level	C	Y	2
100241	07172007	SUNNY	40	400	55	Straight Level	C	N	2
100242	07172007	SUNNY	42	400	55	Straight Level	C	N	1
100243	07172007	SUNNY	40	400	55	Straight Level	C	Y	2
100244	07172007	SUNNY	35	400	55	Straight Level	C	N	2
100245	07172007	SUNNY	47	400	55	Straight Level	C	N	2
100246	07172007	SUNNY	55	400	55	Straight Level	C	N	2
100247	07172007	SUNNY	59	400	55	Straight Level	C	N	1
100248	07172007	SUNNY	40	400	55	Straight Level	C	Y	2
100249	07172007	SUNNY	28	400	55	Straight Level	C	Y	2
100250	07172007	SUNNY	43	400	55	Straight Level	C	N	1
100251	07172007	SUNNY	34	400	55	Straight Level	C	Y	2
100252	07172007	SUNNY	35	400	55	Straight Level	T	Y	2
100253	07172007	SUNNY	49	400	55	Straight Level	C	N	1
100254	07172007	SUNNY	45	400	55	Straight Level	C	Y	2
100255	07172007	SUNNY	41	400	55	Straight Level	C	Y	2
100256	07172007	SUNNY	38	400	55	Straight Level	C	N	2
100257	07172007	SUNNY	43	400	55	Straight Level	C	N	2
100258	07172007	SUNNY	41	400	55	Straight Level	C	N	1
100259	07172007	SUNNY	43	400	55	Straight Level	C	N	2
100260	07172007	SUNNY	35	400	55	Straight Level	C	N	2
100261	07172007	SUNNY	32	400	55	Straight Level	C	Y	2
100262	07172007	SUNNY	46	400	55	Curved Level	C	N	2
100263	07172007	SUNNY	33	400	55	Curved Level	C	N	2
100264	07172007	SUNNY	39	400	55	Curved Level	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100265	07172007	SUNNY	36	400	55	Curved Level	C	N	2
100266	07172007	SUNNY	44	400	55	Curved Level	C	N	1
100267	07172007	SUNNY	35	400	55	Curved Level	C	Y	2
100268	07172007	SUNNY	41	400	55	Curved Level	C	N	1
100269	07172007	SUNNY	36	400	55	Curved Level	C	N	2
100270	07172007	SUNNY	39	400	55	Curved Level	C	N	1
100271	07172007	SUNNY	42	400	55	Curved Level	C	N	2
100272	07172007	SUNNY	32	400	55	Curved Level	C	Y	2
100273	07172007	SUNNY	49	400	55	Curved Level	C	N	1
100274	07172007	SUNNY	44	400	55	Curved Level	C	N	1
100275	07172007	SUNNY	47	400	55	Curved Level	C	N	2
100276	07172007	SUNNY	32	400	55	Curved Level	T	N	1
100277	07172007	SUNNY	33	400	55	Curved Level	C	Y	2
100278	07172007	SUNNY	37	400	55	Curved Level	C	Y	2
100279	07172007	SUNNY	42	400	55	Curved Level	C	N	2
100280	07182007	SUNNY	38	400	55	Straight Level	C	Y	2
100281	07182007	SUNNY	45	400	55	Straight Level	C	N	1
100282	07182007	SUNNY	30	400	55	Straight Level	C	N	2
100283	07182007	SUNNY	34	400	55	Straight Level	C	Y	2
100284	07182007	SUNNY	37	400	55	Straight Level	C	N	2
100285	07182007	SUNNY	19	400	55	Straight Level	T	Y	2
100286	07182007	SUNNY	42	400	55	Straight Level	C	N	1
100287	07182007	SUNNY	47	400	55	Straight Level	C	Y	2
100288	07182007	SUNNY	35	400	55	Straight Level	C	Y	2
100289	07182007	SUNNY	45	400	55	Straight Level	C	N	1
100290	07182007	SUNNY	38	400	55	Straight Level	C	N	2
100291	07182007	SUNNY	40	400	55	Straight Level	C	N	2
100292	07182007	SUNNY	40	400	55	Straight Level	C	N	2
100293	07182007	SUNNY	45	400	55	Straight Level	C	N	1
100294	07182007	SUNNY	35	400	55	Straight Level	C	N	2
100295	07182007	SUNNY	37	400	55	Straight Level	C	Y	2
100296	07182007	SUNNY	40	400	55	Straight Level	C	N	1
100297	07182007	SUNNY	41	400	55	Straight Level	C	N	2

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100298	07182007	SUNNY	51	400	55	Straight Level	C	N	1
100299	07182007	SUNNY	36	400	55	Straight Level	C	Y	2
100300	07182007	SUNNY	48	400	55	Straight Level	C	N	1
100301	07182007	SUNNY	36	400	55	Straight Level	C	N	2
100302	07182007	SUNNY	34	400	55	Straight Level	C	Y	2
100303	07182007	SUNNY	39	400	55	Straight Level	C	N	1
100304	07182007	SUNNY	35	400	55	Straight Level	C	N	2
100305	07182007	SUNNY	32	400	55	Straight Level	C	N	2
100306	07182007	SUNNY	45	400	55	Straight Level	C	N	1
100307	07182007	SUNNY	31	400	55	Straight Level	C	N	2
100308	07182007	SUNNY	37	400	55	Straight Level	C	N	2
100309	07192007	O/C	25	400	55	Straight Level	T	N	1
100310	07192007	O/C	25	400	55	Straight Level	C	N	1
100311	07192007	O/C	30	400	55	Straight Level	C	Y	2
100312	07192007	O/C	20	400	55	Straight Level	T	Y	2
100313	07192007	O/C	28	400	55	Straight Level	T	N	1
100314	07192007	O/C	27	400	55	Straight Level	C	N	2
100315	07192007	O/C	43	400	55	Straight Level	C	N	1
100316	07192007	O/C	20	400	55	Straight Level	C	Y	2
100317	07192007	O/C	32	400	55	Straight Level	C	N	2
100318	07192007	O/C	33	400	55	Straight Level	C	N	1
100319	07192007	O/C	29	400	55	Straight Level	C	N	2
100320	07192007	O/C	28	400	55	Straight Level	C	Y	2
100321	07192007	O/C	41	400	55	Straight Level	T	N	1
100322	07192007	O/C	40	400	55	Straight Level	C	N	2
100323	07192007	O/C	31	400	55	Straight Level	C	Y	2
100324	07192007	O/C	28	400	55	Straight Level	C	N	1
100325	07192007	O/C	31	400	55	Straight Level	C	Y	2
100326	07192007	O/C	45	400	55	Straight Level	C	N	1
100327	07192007	O/C	30	400	55	Straight Level	C	N	2
100328	07192007	O/C	33	400	55	Straight Level	C	N	1
100329	07192007	O/C	29	400	55	Straight Level	T	Y	2
100330	07192007	O/C	25	400	55	Straight Level	T	N	2

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100331	07192007	O/C	31	400	55	Straight Level	C	N	2
100332	07192007	O/C	23	400	55	Straight Level	C	Y	2
100333	07192007	O/C	34	400	55	Straight Level	C	Y	2
100334	07192007	O/C	33	400	55	Straight Level	C	Y	2
100335	07192007	O/C	37	400	55	Straight Level	C	N	1
100336	07192007	O/C	39	400	55	Straight Level	C	N	2
100337	07192007	O/C	33	400	55	Straight Level	C	N	2
100338	07192007	O/C	26	400	55	Straight Level	C	Y	2
100339	07192007	O/C	31	400	55	Straight Level	C	N	1
100340	07192007	O/C	33	400	55	Straight Level	C	N	2
100341	07192007	O/C	41	400	55	Straight Level	C	N	1
100342	07192007	O/C	31	400	55	Straight Level	C	N	2
100343	07192007	O/C	31	400	55	Straight Level	C	N	2
100344	07202007	O/C	43	400	55	Straight Uphill	C	N	2
100345	07202007	O/C	35	400	55	Straight Uphill	C	Y	2
100346	07202007	O/C	37	400	55	Straight Uphill	C	N	1
100347	07202007	O/C	26	400	55	Straight Uphill	C	Y	2
100348	07202007	O/C	35	400	55	Straight Uphill	C	Y	2
100349	07202007	O/C	27	400	55	Straight Uphill	C	N	1
100350	07202007	O/C	33	400	55	Straight Uphill	C	N	1
100351	07202007	O/C	27	400	55	Straight Uphill	C	N	2
100352	07202007	O/C	29	400	55	Straight Uphill	C	N	2
100353	07202007	O/C	27	400	55	Straight Uphill	C	N	1
100354	07202007	O/C	44	400	55	Straight Uphill	C	N	2
100355	07202007	O/C	28	400	55	Straight Uphill	C	Y	2
100356	07202007	O/C	29	400	55	Straight Uphill	C	N	1
100357	07202007	O/C	34	400	55	Straight Uphill	C	N	1
100358	07202007	O/C	31	400	55	Straight Uphill	C	Y	2
100359	07202007	O/C	36	400	55	Straight Uphill	C	N	1
100360	07202007	O/C	36	400	55	Straight Uphill	C	N	2
100361	07202007	O/C	53	400	55	Straight Uphill	C	N	1
100362	07202007	O/C	29	400	55	Straight Uphill	C	Y	2
100363	07202007	O/C	35	400	55	Straight Uphill	C	N	1

Table B.1: Vehicle Speed Data (continued)

NO	Date	Weather	Speed (mph)	Distance (ft.)	Speed Limit (mph)	Roadway Geometry	Vehicle Type	Flashing Light On	Sequence
100364	07202007	O/C	29	400	55	Straight Uphill	C	Y	2
100365	07202007	O/C	31	400	55	Straight Uphill	C	Y	2
100366	07202007	O/C	21	400	55	Straight Uphill	C	N	1
100367	07202007	O/C	34	400	55	Straight Uphill	C	Y	2

APPENDIX C: DRIVER SURVEY RESULTS

Table C.1: Driver Survey Results

NO	Time	Driver Gender	Q1	Q2	Q2	Q2	Q3	Q3	Q3	Q4	Q5
100006	1120	M	2								
100007	1129	M	1	3			2			3	1
100011	1340	M	1	1			1			2	1
100013	1350	M	1	3			2			2	1
100016	1408	M	1	1			4			1	1
100017	1420	M	1	Other (cautionary area, hazards)			4			5	2
100020	1423	M	1	3			3			3	1
100022	1445	F	1	Other (caution)			4			4	1
100024	1500	M	1	3			4			5	1
100025	1642	M	1	1	3		4			5	1
100030	1722	M	1	1	2	3	4			3	1
100031	1730	F	1	2	3	4	2	3		1	3
100033	1743	M	1	3			4			5	2
100034	1757	F	2								
100036	1810	M	1	Other (work zone)			4			1	1
100040	0945	M	2								
100041	1005	F	1	1	2	3	1	3		1	1
100044	1022	M	1	3			4			4	1
100047	1057	M	1	Other (problem with vehicle, moving slowly)			Other (move to other lane)			1	1
100054	1329	M	1	3			2			1	1
100057	1350	M	1	3			4			3	1
100060	1506	F	1	3			4			1	2
100062	1517	F	2								
100063	1519	M	1	3			4			3	1
100065	1530	M	1	Other (caution)			4			3	3
100068	1538	M	1	3			2			1	1
100069	1553	M	1	2			4			3	3
100074	1620	M	1	1	2		1			1	1
100078	1730	F	1	1			1			3	2
100081	1744	F	1	1			1			2	1
100086	0905	M	1	1			2			2	1

Table C.1: Driver Survey Results (continued)

NO	Time	Driver Gender	Q1	Q2	Q2	Q2	Q3	Q3	Q3	Q4	Q5
100089	0907	F	1	1	2	3	2	3		1	1
100091	0925	F	1	Other (warning: something going on)			1			1	1
100095	0942	M	1	3			4			2	1
100098	1000	M	1	3			1			2	1
100100	1005	M	1	3	Other (caution)		1	3		1	1
100102	1110	F	1	3	Other (change lane)		4			5	2
100104	1120	M	1	3			4			2	2
100106	1127	F	1	3			3			1	1
100113	1155	M	1	3			4			2	1
100117	1220	M	1	1	Other (road blocked)		1			2	1
100123	1433	M	2								
100125	1440	M	1	Other (disabled vehicle)			4			2	3
100126	1450	M	1	3			3			2	1
100129	1501	M	1	2			4			2	1
100133	1525	F	2								
100138	1547	F	1	1	2	3	1	3		1	1
100155	1050	M	1	3			2			1	1
100160	1137	M	1	3			Watch for cones and single lane			2	1
100165	1447	M	1	Broke down, pilot car			1			2	1
100171	1547	M	1	1	2	3	2			1	1
100178	0953	F	1	1	3		2			2	1
100180	1005	F	1	1			1			1	1
100181	1008	M	2								
100184	1022	M	1	1			4			1	1
100186	1027	M	1	3			1			4	1
100187	1042	F	1	3			2			1	3
100192	1409	M	1	1	3		4			1	1
100196	1437	F	1	3			1			4	1

Table C.1: Driver Survey Results (continued)

NO	Time	Driver Gender	Q1	Q2	Q2	Q2	Q3	Q3	Q3	Q4	Q5
100200	1515	F	2								
100201	1517	M	1	3			4			2	1
100210	1610	F	1	Something going on			4			4	1
100211	1615	F	1	1			4			2	1
100214	1623	M	1	Having trouble			4			5	2
100218	1347	M	1	3			4			5	2
100219	1349	F	1	3			2			1	1
100227	1434	M	2								
100234	0927	M	1	2			1			2	1
100235	0930	F	1	2			1			4	1
100240	0955	M	1	3			2	3		1	1
100243	1006	F	1	3			1			1	1
100248	1017	M	1	3			4			3	1
100249	1020	F	1	1	2	3	4			2	1
100251	1030	F	2								
100252	1034	M	1	1	2	3	2			1	1
100254	1047	F	1	3			2	3		1	1
100255	1050	F	1	1			1			2	1
100261	1102	M	1	1			1			1	1
100267	1403	F	2								
100272	1424	M	2								
100277	1445	M	1	1			2			3	1
100278	1508	F	1	Accident			4			2	1
100280	0952	F	1	1	2	3	2	3		1	1
100283	1007	F	2								
100285	1015	M	1	1	3		4			4	1
100287	1021	M	1	3			1			4	2
100288	1026	M	1	1			1			2	1
100295	1052	M	2								
100299	1119	F	2								
100302	1132	M	1	3			4			5	2
100311	1000	F	2								

Table C.1: Driver Survey Results (continued)

NO	Time	Driver Gender	Q1	Q2	Q2	Q2	Q3	Q3	Q3	Q4	Q5
100312	1005	M	1	3			4			4	1
100316	1025	M	1	1	2	3	1	3		2	1
100320	1037	M	1	1	3		1			3	1
100323	1050	F	1	1	3		4			2	1
100325	1111	F	1	3			4			3	1
100329	1131	M	1	3			2			5	2
100332	1141	M	1	1	2	3	1	2	3	2	1
100333	1151	F	1	3			4			3	1
100334	1155	F	1	1			1			2	1
100338	1218	M	1	3			1			2	3
100345	1010	F	1	1	3		1			1	1
100347	1027	M	1	3			1			1	1
100348	1040	F	1	3			1			3	1
100355	1111	M	1	3			1			1	1
100358	1135	M	2								
100362	1200	M	1	1			4			1	1
100364	1459	M	1	Trouble			1			3	1
100365	1454	M	1	3			1	3		3	1
100367	1512	F	2								

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KANSAS TRANSPORTATION RESEARCH
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