

Determining the Effectiveness of Temporary Traffic Control Measures in Highway Work Zones

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ABSTRACT

Highway work zones constitute a major safety concern for government agencies, legislatures, the highway industry, and the traveling public. Each year, hundreds of people lose their lives and many more are injured due to vehicle crashes in work zones on the national highway system. Over the years, temporary traffic control (TTC) measures have been developed to improve the safety in work zones. To improve the safety countermeasures and to identify the traffic control deficiencies in work zones, evaluating the effectiveness of existing TTC measures based on the real crash experience is necessary. In the present study, researchers evaluated the effectiveness of several commonly used TTC methods using logistic regression technique and various chi-square statistics. The assessed TTC methods included flagger/officer, stop sign/signal, flasher, no passing zone control, and pavement center/edge lines. A total of 655 severe crashes in Kansas highway work zones between January 2003 and December 2004 were used for the evaluation, which included 29 fatal crashes and 626 injury crashes. The results indicated that flagger, flasher, and pavement center/edge lines were effective in reducing the probability that work zone crashes would involve fatalities. In addition, the effectiveness of these devices in preventing some common human errors, such as “disregarded traffic control,” “inattentive driving,” “followed too closely,” and “exceeded speed limit or too fast for condition,” from causing severe crashes was also determined.

Key words: Kansas—logistic regression—safety—traffic control effectiveness—work zone

INTRODUCTION

Highway work zones constitute a major safety concern for government agencies, the legislature, the highway industry, and the traveling public. The number of people killed in motor vehicle crashes in work zones rose from 872 in 1999 to 1,028 in 2003 in the United States. In addition, approximately 40,000 people are injured each year as a result of motor vehicle crashes in work zones. Today, the majority of highway funds are being allocated to road and bridge preservation and enhancement, which means the traveling public is encountering more and more highway work zones.

Over the years, many temporary traffic control (TTC) measures have been developed and deployed in highway work zones. The primary function of these TTC measures in work zones is to provide highway users reasonably safe and efficient movement through work zones while protecting construction workers and equipment. There is a consensus that the use of TTC measures improves safety in the work zones if they are designed, installed, and maintained properly. However, it is not clear the extent to which safety has been improved by using these measures. To determine the effectiveness of the safety countermeasures in work zones, there is a need to quantify the effectiveness of existing TTC measures.

RESEARCH OBJECTIVES AND METHODOLOGY

Among all possible work zone crashes, crashes involving injuries or fatalities are the most severe and calamitous. Reducing these crashes will yield the most benefit to society. The objective of this research project was to quantify the effectiveness of several popular TTC measures, including flagger/officer, stop sign/signal, flasher, no passing zone, and pavement center/edge lines, in reducing fatalities when a severe crash occurs and in preventing common human errors from causing work zone severe crashes.

The project was conducted using a four-step approach. First, an extensive literature search was performed to review the previous investigations in this area. Second, fatal and injury crash data were extracted from the Kansas Department of Transportation (KDOT) accident database. A total of 655 severe crashes, including 29 fatal crashes and 626 injury crashes, in Kansas highway work zones between January 2003 and December 2004 were collected for the evaluation. Third, logistic regression analysis was used to evaluate the effectiveness of the safety measures in these work zones. Finally, conclusions and recommendations for future research were formulated based on the results of data analyses.

LITERATURE REVIEW

A highway work zone refers to a road section undergoing a construction or maintenance project. When the normal function of the highway is suspended around a work zone, a TTC plan must be developed to provide continuity of movement for motor vehicles. As included in the Manual of Uniform Traffic Control Devices (MUTCD), some TTC methods that are commonly used in work zones include flaggers, traffic signs, arrow panels and portable changeable message signs, channelizing devices, pavement markings, lighting devices, and temporary traffic control signals (FHWA 2003). To provide the background knowledge on work zone traffic control, a review of these traffic control devices and their related studies is presented in this section.

Flagger Control

Flaggers are qualified personnel with high-visibility safety apparel who are equipped with handheld devices such as STOP/SLOW paddles, lights, and red flags to control road users through work zones. Richards and Dudek (1986) suggested that flaggers have been 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 combination of traffic control devices for work zones on multilane highways was cones, flashing arrows, and flaggers, and the effective combinations of traffic control devices for work zones on urban two-lane highways were both cones and flaggers as well as static signs and flaggers. Hill (2003) proved that flaggers were effective in reducing fatal work zone crashes. However, a study by Benekohal et al. (1995) indicated that 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.

Traffic Signs

As listed in the MUTCD, traffic signs in work zones include regulatory signs, warning signs, and guide signs. Traffic signs in work zones are important for informing travelers about interrupted traffic conditions. A survey indicated that half of truck drivers wanted to see warning signs 3–5 miles in advance (Benekohal, Shim, and Resende 1995). Garber and Woo (1990) found that static traffic signs could effectively reduce crashes in work zones on urban two-lane highways when used together with flaggers.

Arrow Panels and Portable Changeable Message Signs

Arrow panels and portable changeable message signs usually contain luminous panels with high visibility, which makes them an ideal traffic control supplement in both daytime and nighttime. Garber and Patel (1994) and Garber and Srinivasan (1998) conducted a two-phase research project to evaluate the effectiveness of changeable message signs for controlling speeds in work zones in Virginia. The changeable message signs displayed a real-time warning message to the speeding drivers after their excessive speeds were detected by its actuator. The researchers concluded that changeable message signs were a more effective means than traditional work zone traffic control devices in reducing the number of speeding vehicles in work zones. Richards and Dudek (1986) commented that changeable message signs could result in only modest speed reductions (less than 10 mph) when used alone and 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. The 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 used along paved highways in long- and intermediate-term stationary work zones to outline the travel paths. Pavement markings can be used to control speeds. For instance, a

traffic control strategy using optical speed bars modified to meet the conditions of highway work zones has been applied to control speeds in work zones. Optical speed bars are 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. The study showed that the speed bars had both a warning effect and a 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. Four lighting devices commonly used in work zones are floodlights, flashing warning beacons, warning lights, and steady burn electric lamps. These devices raise drivers' attention, warn drivers of complicated travel conditions, and/or illuminate work zones at night. Some studies (Huebschman et al. 2003; Arnold 2003) found that flashing warning lights, especially police vehicles with flashing lights, were 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. Some analyses of work zone fatal crashes have shown that certain temporary traffic control signals, such as STOP/GO signals, have been very effective in reducing fatal crashes in work zones (Hill 2003).

DATA COLLECTION

A total of 655 severe work zone crashes, including 29 fatal cases and 626 injury cases, were extracted from the KDOT accident database. Table 1 shows the variables and their observations. Because the observations in the database were in text format, a numerical value was assigned to each observation to facilitate the regression analyses. At the end of data collection, crash information represented by numerical values was compiled into a spreadsheet where a crash was described in one data row. Then, the spreadsheet was inputted into the SAS software for analyses.

Table 1. Crash data and assigned numerical numbers

Variable	Observation	Assigned Numerical Value
Crash Severity	Fatal	1
	Injury	2
Traffic Control	Flagger/officer	1
	Stop sign/signal	2
	Flasher	3
	No passing zone control	4
	Center/edge lines	5
Driver Error	Inattentive driving	1
	Disregarded traffic signs, signals, or markings	2
	Followed too closely	3
	Exceeded speed limit or too fast for conditions	4

BINARY LOGISTIC REGRESSION METHOD

Binary logistic regression technique was used to evaluate the effectiveness of the TTC methods commonly used in work zones. Binary logistic regression is a statistical method developed specifically for describing the relationships between a set of independent explanatory variables and a dichotomous response variable or outcome. Because the analysis of the effectiveness of TTC measures involves establishing the relationships between the occurrence of a crash and the presence of a TTC measure, this regression technique has been applied in previous traffic crash studies (Hill 2003; Dissanayake and Lu 2002). A binary logistic regression model is a direct probability model that has no requirements on the distributions of the explanatory variables or predictors (Harrell 2001). It is flexible and is likely to yield accurate results when applied to traffic crash analysis in which the safety effectiveness of TTC measures needs to be quantified.

The following briefly describes the theoretical basis of the binary logistic regression method. Let Y be an event ($Y = 1$ and $Y = 0$ denote occurrence and nonoccurrence, respectively) and let a vector \mathbf{X} be a set of predictors $\{X_1, X_2, \dots, X_k\}$. The expected value of Y given \mathbf{X} is the probability (P) of the occurrence of Y given \mathbf{X} , which can be expressed in linear regression form as follows:

$$E\{Y|\mathbf{X}\} = P\{Y = 1|\mathbf{X}\} = \mathbf{X}\boldsymbol{\beta} \quad (1)$$

where $\boldsymbol{\beta}$ is the regression parameter vector and $\mathbf{X}\boldsymbol{\beta}$ stands for $\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k$. Because the probability determined by this equation can exceed one, the following binary logistic regression model is generally preferred for the analysis of binary responses:

$$P\{Y = 1|\mathbf{X}\} = [1 + \exp(-\mathbf{X}\boldsymbol{\beta})]^{-1} = \exp(\mathbf{X}\boldsymbol{\beta})/[1 + \exp(\mathbf{X}\boldsymbol{\beta})] \quad (2)$$

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

$$\text{logit}\{Y = 1|\mathbf{X}\} = \log[P/(1 - P)] = \beta_0 + \beta_1 X_1 + \dots + \beta_k X_k \quad (3)$$

For the above model, given the estimated β 's as $\hat{\beta}_0, \hat{\beta}_1, \dots, \hat{\beta}_k$, the estimated probability \hat{P} that an event Y happens, can be computed as follows:

$$\hat{P}\{Y = 1|\mathbf{X}\} = \exp(\mathbf{X}\hat{\boldsymbol{\beta}})/[1 + \exp(\mathbf{X}\hat{\boldsymbol{\beta}})] \quad (4)$$

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

The significance of a predictor can be tested using the methods of the likelihood ratio test, the Wald test, and the score test (Hosmer and Lemeshow 2000). The likelihood ratio test compares the deviation of the model with the predictor to that without the predictor. The Wald test is obtained by comparing the maximum likelihood estimate of the slope parameter, β_i , to an estimate of its standard error. The score test is based on the distribution theory of the derivatives of the log likelihood. Quantifying the safety impact of an explanatory variable can be treated as a special logistic regression case:

$$\text{logit}\{Y = 1|X = 0\} = \beta_0 \quad (5)$$

$$\text{logit}\{Y = 1|X = 1\} = \beta_0 + \beta_1 \quad (6)$$

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

$$\hat{P}\{Y = 1|X = 1\} = \exp\{\hat{\beta}_0 + \hat{\beta}_1\} / (1 + \exp\{\hat{\beta}_0 + \hat{\beta}_1\}) \quad (7)$$

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

$$\hat{P}\{Y = 1|X = 0\} = \exp\{\hat{\beta}_0\} / (1 + \exp\{\hat{\beta}_0\}) \quad (8)$$

In this study, odds ratio was used to measure the difference between the univariate logistic regression model pairs. Odds ratio is defined as the ratio of the two odds given the two values of the test variable. Given the estimated odds of an event $\{Y = 1|X\}$ as

$$\text{Odds}\{Y = 1|X\} = \hat{P}\{Y = 1|X\} / (1 - \hat{P}\{Y = 1|X\}) \quad (9)$$

the odds ratio for the single-variable case is

$$\text{Odds ratio}(X = x_1 : X = x_2) = \exp[\hat{\beta}_1(x_1 - x_2)] \quad (10)$$

EVALUATING THE EFFECTIVENESS OF WORK ZONE TTC METHODS

Based on the available crash information, the effectiveness of several commonly used work zone TTC methods was evaluated. The effectiveness was evaluated in terms of reducing the severity of work zone crashes and preventing major human errors from causing severe work zone crashes. The crash data used for the evaluation included the fatal and injury work zone crashes in Kansas highway work zones between January 2003 and December 2004. The evaluated TTC methods included flagger/officer, stop sign/signal, flasher, no passing zone, and center/edge lines; the major human errors that were included in the evaluation were “inattentive driving,” “disregarded traffic control,” “followed too closely,” and “exceeded speed limit or too fast for condition.”

Effectiveness of Flagger/Officer Control

For estimating the effectiveness of flagger/officer control in reducing the severity of work zone crashes, the response variable Y represented a severe crash ($Y = 1$ for fatal crashes and $Y = 2$ for injury crashes) and the explanatory variable X represented the presence of a flagger ($X = 1$ for presence and $X = 0$ for absence). The logistic regression model was estimated as follows:

$$\text{logit}\{Y = 1|X\} = -2.42 - 0.81X. \quad (11)$$

The three test-of-significance statistics (likelihood ratio, score, and Wald) all indicated a high level of significance (i.e., 0.01) for the flagger variable.

According to this model, the conditional probability of having fatalities, given the occurrence of a severe crash (either fatal or injury), when flagger control was present was estimated as follows:

$$\hat{P}\{Y = 1|X = 1\} = \exp\{\hat{\beta}_0 + \hat{\beta}_1\}/(1 + \exp\{\hat{\beta}_0 + \hat{\beta}_1\}) = 0.04 \quad (12)$$

The corresponding probability without a flagger control was as follows:

$$\hat{P}\{Y = 1|X = 0\} = \exp\{\hat{\beta}_0\}/(1 + \exp\{\hat{\beta}_0\}) = 0.08 \quad (13)$$

The estimated odds ratio between the occurrence of a fatal crash with flagger control and without flagger control was:

$$\text{Odds ratio } (X = 1 : X = 0) = \exp[\hat{\beta}_1 (x_1 - x_2)] = \exp[-0.81 \times (1 - 0)] = 0.44. \quad (14)$$

Hence, statistically, using a flagger in a work zone could reduce the odds of a severe crash resulting in fatality by 56%. In terms of probability, the presence of a flagger in a work zone could lower the probability of causing fatalities by 4% (or from 0.08 to 0.04) when a severe crash occurred.

Previous work zone crash studies (Bai and Li 2006; 2007) have shown that human errors contribute to a significant proportion of work zone severe crashes. Reducing risky driver errors would be an important objective for work zone TTC methods to accomplish. The effectiveness of the flagger/officer control in work zones in preventing major human errors from causing severe (fatal and injury) crashes was also evaluated in this study. In the evaluations, the response variable Y represented a severe crash that was either caused by a studied human error ($Y = 1$) or not caused by this human error ($Y = 0$). For example, to evaluate the effectiveness of a flagger in preventing “disregarded traffic control” from causing fatal or injury crashes, the logistic regression model was fitted as follows:

$$\text{logit}\{Y = 1|X\} = -1.78 - 0.77X. \quad (15)$$

According to this model, the conditional probability of the crash caused by “disregarded traffic control,” given the occurrence of this severe crash, when flagger control was present was estimated as follows:

$$\hat{P}\{Y = 1|X = 1\} = \exp\{\hat{\beta}_0 + \hat{\beta}_1\}/(1 + \exp\{\hat{\beta}_0 + \hat{\beta}_1\}) = 0.07 \quad (16)$$

The corresponding probability without a flagger control was as follows:

$$\hat{P}\{Y = 1|X = 0\} = \exp\{\hat{\beta}_0\}/(1 + \exp\{\hat{\beta}_0\}) = 0.14 \quad (17)$$

The estimated odds ratio between the severe crash being caused by “disregarded traffic control” human error with flagger control and without flagger control was as follows:

$$\text{Odds ratio } (X = 1 : X = 0) = \exp[\hat{\beta}_1 (x_1 - x_2)] = \exp[-0.77 \times (1 - 0)] = 0.46. \quad (18)$$

These results indicate that using a flagger in a work zone could reduce the odds of a severe crash being caused by “disregarded traffic control” human error by 54%. In terms of conditional probability, the presence of a flagger in a work zone could lower the probability of causing a severe crash due to “disregarded traffic control” by 7% (or from 0.14 to 0.07) when a severe crash occurred. Table 2 lists the parameters and the estimated probabilities and odds ratio of the fitted logistic regression models for the

effectiveness of the flagger/officer control in reducing crash severity and preventing human errors, such as “disregarded traffic control,” “inattentive driving,” and “exceeded speed limit or too fast for condition,” from causing severe crashes. As illustrated in the table, using a flagger/officer in a highway work zone could lower the odds of having a severe crash caused by “inattentive driving” or “exceeded speed limit or too fast for condition” by about 40%. The effectiveness of a flagger/officer in preventing the impact of “followed too closely” was not determined because none of the statistical tests supported the significant relationship between the traffic control and the driver error.

Table 2. Model parameters and evaluation results for flagger control

Parameter	Coefficient		p-Value of Significance Test*			Probability		Odds Ratio ($X = 1 : X = 0$)**
	$\hat{\beta}_0$	$\hat{\beta}_1$	LR***	Score	Wald	$X = 1$	$X = 0$	
Effectiveness in reducing crash severity	-2.42	-0.81	<u>0.01</u>	<u><0.01</u>	<u><0.01</u>	0.04	0.08	0.44
Effectiveness in preventing “disregarded traffic control”	-1.78	-0.77	<u><0.01</u>	<u><0.01</u>	<u><0.01</u>	0.07	0.14	0.46
Effectiveness in preventing “inattentive driving”	0.34	-0.51	<u>0.01</u>	<u>0.01</u>	<u>0.01</u>	0.46	0.58	0.60
Effectiveness in preventing “exceeded speed limit or too fast for condition”	-1.01	-0.46	<u>0.03</u>	<u>0.02</u>	<u>0.02</u>	0.19	0.27	0.63

*: p-Value is the output value of the statistical tests of significance. A p-value less than 0.1 indicates that the test variable is significant at 0.1 level of significance, and is underlined in the table.

**: $X = 1$ when the traffic control was present and $X = 0$ when it was absent.

***: Likelihood Ratio.

Effectiveness of Stop Sign/Signal

The stop sign/signal control was tested for its effectiveness in reducing crash severity and preventing the major human errors from causing severe crashes. The tests of significance showed that the presence of a stop sign/signal control device in a work zone was not significantly related to the involvement of fatalities in severe crashes. In addition, the tests showed that this TTC method could actually catalyze the “followed too closely” human error to cause severe crashes. As listed in Table 3, when a stop sign/signal was used, the odds of having crashes caused by “following too closely” was roughly two and a half times higher than the odds without such a device.

Table 3. Model parameters and evaluation results for stop sign/signal control

Parameter	Coefficient		p-Value of Significance Test*			Probability		Odds Ratio ($X = 1 : X = 0$)**
	$\hat{\beta}_0$	$\hat{\beta}_1$	LR***	Score	Wald	$X = 1$	$X = 0$	
Effectiveness in preventing “followed too closely”	-2.38	1.26	<u><0.01</u>	<u><0.01</u>	<u>0.01</u>	0.25	0.08	3.53

*: p-Value is the output value of the statistical tests of significance. A p-value less than 0.1 indicates that the test variable is significant at 0.1 level of significance, and is underlined in the table.

**: $X = 1$ when the traffic control was present and $X = 0$ when it was absent.

***: Likelihood Ratio.

Effectiveness of Flasher Device

Statistical tests showed that the use of flashers in work zones was not directly related to the involvement of the four major human errors in the severe work zone crashes. However, the effectiveness of flashers in mitigating the severity of work zone crashes was supported by statistical tests and thus was determined. Using the SAS software, the following logistic regression model was generated:

$$\text{logit}\{Y = 1/X\} = -2.24 - 0.86X. \quad (19)$$

Listed in Table 4 are the results of the three tests of significance and the respective probabilities of a severe crash resulting in fatalities with and without a flasher control device. The odds ratio of having a fatal crash with and without a flasher control device is also included in the table. The results indicated that using a flasher device in a work zone could reduce the odds of a severe crash resulting in fatalities by 58%.

Table 4. Model parameters and evaluation results for flasher control

Parameter	Coefficient		p-Value of Significance Test*			Probability		Odds Ratio ($X = 1 : X = 0$)**
	$\hat{\beta}_0$	$\hat{\beta}_1$	LR***	Score	Wald	$X = 1$	$X = 0$	
Effectiveness in reducing crash severity	-2.24	-0.86	0.20	<u>0.09</u>	0.13	0.04	0.10	0.42

*: p-Value is the output value of the statistical tests of significance. A p-value less than 0.1 indicates that the test variable is significant at 0.1 level of significance, and is underlined in the table.

**: $X = 1$ when the traffic control was present and $X = 0$ when it was absent.

***: Likelihood Ratio.

Effectiveness of “No Passing Zone” Control

The results of the three tests of significance, including likelihood ratio test, score test, and Wald test, all suggested that the use of work zone no passing zone controls was significantly related to the odds of a severe crash caused by “disregarded traffic control” human error. Table 5 lists the evaluation results for work zone no passing zone controls. The results indicated that, in a work zone no passing zone, the odds of a severe crash caused by “disregarded traffic control” human error would be 29% less than that in work zones without no passing zones.

Table 5. Model parameters and evaluation results for no passing zone control

Parameter	Coefficient		p-Value of Significance Test*			Probability		Odds Ratio ($X = 1 : X = 0$)**
	$\hat{\beta}_0$	$\hat{\beta}_1$	LR***	Score	Wald	$X = 1$	$X = 0$	
Disregarded traffic control	-2.20	-0.35	<u>0.06</u>	<u>0.04</u>	<u>0.05</u>	0.07	0.10	0.71

*: p-Value is the output value of the statistical tests of significance. A p-value less than 0.1 indicates that the test variable is significant at 0.1 level of significance, and is underlined in the table.

**: $X = 1$ when the traffic control was present and $X = 0$ when it was absent.

***: Likelihood Ratio.

Effectiveness of Pavement Center/Edge Lines

Statistical study showed that the use of center/edge lines in work zones was effective not only for reducing crash severity, but also in preventing human errors such as “exceeded speed limit or too fast for

condition” and “followed too closely” from causing severe crashes. Table 6 shows the results in terms of the estimated probabilities and the odds ratio. The regression analyses’ results suggested that the use of center/edge lines in work zones may reduce the odds of causing fatalities when severe crashes occurred by 55%. In addition, having center/edge lines in work zones may also lower the odds of a severe crash caused by speeding by 29%, and the odds of a severe crash caused by “followed too closely” by 19%.

Table 6. Model parameters and evaluation results for center/edge lines

Parameter	Coefficient		p-Value of Significance Test*			Probability		Odds Ratio ($X = 1 : X = 0$)**
	$\hat{\beta}_0$	$\hat{\beta}_1$	LR***	Score	Wald	$X = 1$	$X = 0$	
Effectiveness in reducing crash severity	-3.63	-0.80	<u>0.01</u>	<u>0.02</u>	<u>0.03</u>	0.01	0.03	0.45
Effectiveness in preventing “exceeded speed limit or too fast for condition”	-1.61	-0.35	<u><0.01</u>	<u>0.01</u>	<u>0.01</u>	0.12	0.17	0.71
Effectiveness in preventing “followed too closely”	-1.30	-0.20	<u>0.06</u>	<u>0.07</u>	<u>0.07</u>	0.18	0.21	0.81

*: p-Value is the output value of the statistical tests of significance. A p-value less than 0.1 indicates that the test variable is significant at 0.1 level of significance, and is underlined in the table.

**: $X = 1$ when the traffic control was present and $X = 0$ when it was absent.

***: Likelihood Ratio.

CONCLUSIONS

Work zone safety has been a research focus for many years, and improving the safety in highway work zones is a high-priority task for traffic engineers. Evaluating the effectiveness of the TTC methods used in highway work zones is a practical approach to safety improvement. In this study, the effectiveness of several TTC methods in mitigating work zone crash severity and preventing common human errors from causing severe work zone crashes was quantified using a logistic regression technique. These TTC methods included flagger/officer, stop sign/signal, flasher, no passing zone, and center/edge lines. The evaluation was intended to provide valuable knowledge for developing more effective traffic control strategies. The results may also provide useful indications regarding safety levels in certain types of work zones where the evaluated TTC methods are regularly installed.

In this research, the TTC methods were evaluated to quantify their effectiveness in both reducing crash severity and preventing common human errors. According to the logistic regression analyses, the presence of a flagger or officer directing traffic could reduce the odds of having fatalities in a severe crash by 56%; having flashers or center/edge lines in work zones could reduce the odds by more than 50% as well. However, based on the available crash data, the statistics could not establish close associations between the usages of stop signs/signals and no passing zones in work zones and the involvement of fatalities in severe crashes.

Regarding the effectiveness TTC methods in preventing common human errors from causing severe crashes in work zones, the evaluation showed that flaggers/officers could considerably lower the odds of severe work zone crashes caused by human errors such as “disregarded traffic control,” “inattentive driving,” and “exceeded speed limit or too fast for condition.” No passing zones in work zones were effective in reducing the odds of “disregarded traffic control” causing severe crashes. In addition, having center/edge lines in work zones could lower the odds of human errors, including “exceeded speed limit or too fast for condition” and “followed too closely,” causing severe work zone crashes. However, having

stop signs/signals in work zones would dramatically increase the odds of severe crashes caused by “followed too closely” human error.

This research project can be extended in several ways, and recommendations for future research include four items. First, fatal crash data from other sources could be added to increase the total number of fatal cases in order to improve the reliability of the analysis. In this project, researchers only examined data from the state of Kansas due to limited resource availability. In the future, researchers could collect data from the work zones in other states to improve the accuracy of the analysis. Second, evaluating the effectiveness of the TTC methods may be extended to property damage-only crashes. When possible, the evaluation should also consider the data such as traffic volume and vehicle-miles traveled so that the TTC measures’ effectiveness in reducing the total number of crashes can be determined. Third, there is a need to evaluate the effectiveness of certain combinations of TTC devices that are commonly used in work zones. The results of such studies will provide a comprehensive understanding on how these TTC measures interactively improve safety in work zones. Finally, there is a need to continuously develop new safety countermeasures and deploy them in the work zones.

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REFERENCES

- Arnold, E.D. 2003. *Use of Police in Work Zones on Highways in Virginia*. Final Report VTRC 04-R9. Charlottesville, VA: Virginia Transportation Research Council.
- Benekohal, R.F., E. Shim, and P.T.V. Resende. 1995. Truck Drivers' Concerns in Work Zones: Travel Characteristics and Accident Experiences. *Transportation Research Record*, 1509, 55–64.
- Dissanayake, S. and J. Lu. 2002. Analysis of Severity of Young Driver Crashes, Sequential Binary Logistic Regression Modeling. *Transportation Research Record*, 1784, 108–114.
- FHWA. 2003. *Manual on Uniform Traffic Control Devices for Streets and Highways (2003 Edition)*. Washington DC: Federal Highway Administration.
- Garber, N.J. and S.T. Patel. 1994. *Effectiveness of Changeable Message Signs in Controlling Vehicles Speeds in Work Zones*. Report No. VTRC 95-R4. Charlottesville, VA: Virginia Transportation Research Council.
- Garber, N.J. and S. Srinivasan. 1998. *Effectiveness of Changeable Message Signs in Work Zones: Phase II*. Report No. VTRC 98-R 10. Virginia: Virginia Transportation Research Council.
- Garber, N. J., and T. H. Woo. 1990. *Accident Characteristics at Construction and Maintenance Zones in Urban Areas*. Report No. VTRC 90-R12. Charlottesville, VA: Virginia Transportation Research Council.
- Harrell, Jr., F.E. 2001. *Regression Modeling Strategies – with Application to Linear Models, Logistic Regression, and Survival Analysis*. New York: Springer-Verlag New York, Inc.
- Hill, R.W. 2003. *Statistical Analysis of Fatal Traffic Accident Data*. Master's Thesis, Texas Tech University.
- Hosmer, D.W. and S. Lemeshow. 2000. *Applied Logistic Regression (2ndEd.)*. New York: John Wiley & Sons, Inc.
- Huebschman, C.R., C. Garcia, D.M. Bullock, and D.M. Abraham. 2003. *Construction Work Zone Safety*. Report No. FHWA/IN/JTRP-2002/34. Lafayette, IN: Joint Transportation Research Program, Purdue University.
- Meyer, E. 2004. *Evaluation of Data from Test Application of Optical Speed Bars to Highway Work Zones*. Final Report No. K-TRAN: KU-00-4. Topeka, KS: Kansas Department of Transportation.
- Pain, R.F., H.W. McGee, and B. G. Knapp. 1983. *Evaluation of Traffic Controls for Highway Work Zones*. NCHRP Report 236. Washington DC: Transportation Research Board, National Research Council.
- Richards. S.H. and C.L. Dudek. 1986. Implementation of Work-Zone Speed Control Measures. *Transportation Research Record*, 1086, 36–42.