Reducing Work Zone Crashes by Using Emergency Flasher Traffic Control Device

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ABSTRACT

Rural two-lane highways compose a large percent of the highway system nationwide. Preserving, expending, and enhancing these highways result in many one-lane, two-way work zones that have caused a safety concern for the traveling public. Aimed at reducing crashes attributed to inattentive driving in these work zones, a new traffic warning sign was proposed, which was assembled using the hazard warning flashers of motor vehicles. This warning sign, named as the Emergency Flasher Traffic Control Device (EFTCD), is flexible and cost-effective and particularly benefits the rural one-lane, two-way work zones that are frequently moved due to construction progress. This research project evaluated the effectiveness of the proposed EFTCD by comparing the speeds with and without the EFTCD and analyzing survey results in three one-lane, two-way work zones in Kansas. Study results showed that the EFTCD effectively reduced the mean speeds in work zones as well as the proportions of high speed vehicles. In addition, the EFTCD successfully captured the attention of most drivers when they were approaching the work zones. A majority of the surveyed drivers recommended the implementation of this warning sign in the work zones. The outcome of this research project benefits both drivers and construction workers in rural work zones by providing an additional traffic control measure that can prevent crashes caused by inattentive drivers.

INTRODUCTION

In the United States, more than half of the major highway miles (principal arterials, minor arterials, and major collectors) were rural and 90% of the rural major roads have two lanes (*1*). Preserving, rehabilitating, expending, and enhancing these highways result in a large number of work zones, which constitutes a severe safety concern for the traveling public and government agencies.

Kansas is one of the states where a large percent of the public roadway-miles are rural. Crash analyses in the state showed that 63% of the work zone fatal crashes and a third of the work zone injury crashes occurred on two-lane highways (*2*). In addition, inattentive driving contributed to more than half of the severe work zone crashes involving fatalities and/or injuries. The crash analyses also highlighted rear-end collisions as a dominant crash type. Preventing inattentive driving in work zones on rural two-lane highways has become a critical challenge for improving highway safety.

Aimed at reducing the work zone crashes, especially rear-end crashes that are contributed by inattentive driving, Kansas Department of Transportation (KDOT) initiated a research project to study the effectiveness of a traffic warning sign that used vehicles' hazard warning flashers in one-way, two-lane work zones. This warning sign, named as the Emergency Flasher Traffic Control Device (EFTCD), was proposed to work in the following manner. When a vehicle approaches a one-lane, two-way work zone, the driver is required to turn on the hazard warning flashers to warn the following vehicle of the work zone stopping condition. Ideally, the vehicles will turn on their flashers one by one to form a flasher array on the road and all vehicles approaching the work zone will be warned of the work zone condition. Advantages of the EFTCD include easy installation/un-installation, high visibility, and low cost. During the research project, the researchers evaluated the effectiveness of the warning sign based on data obtained within three one-lane, two-way rural work zones in Kansas during summer 2007. The evaluation involved two major tasks including a traffic survey and a comparison study of vehicle speeds with and without the EFTCD. This paper documents the procedure and major findings of the research project.

LITERATURE REVIEW

On two-lane highways, in order to carry out road work without complete loss of highway functionality, the construction activities are typically constrained within one lane while the other lane remains open for through traffic. These one-lane, two-way work zones require traffic from one direction to pass through cautiously and the traffic from the other direction has to be stopped until the open lane is cleared. One-lane, two-way work zones typically use flaggers to stop and coordinate traffic from both directions. In addition, a pilot-car is frequently used to guide travelers through work zones at a safe speed. These work zones move as the road projects progress and require frequently installing and moving the Temporary Traffic Control (TTC) devices.

Although the crashes in one-lane, two-way work zones have not been specifically analyzed, previous studies showed that the work zones on rural highways accounted for 69% of the work zone crashes nationwide (*3*). The dominant types of work zone crashes vary with different locations and times, but studies indicated that rear-end collision was one of the most frequent work zone crash types (*4, 5, 6*). Previous studies also pointed at human errors, such as following too close, inattentive driving, and misjudging, as the most common causes for work zone crashes (*2, 4, 6*). Some studies noted that speeding (*5*) and inefficient traffic control (*7*) were two other major factors causing crashes in work zones.

TTC devices that have been frequently used in one-lane, two-way work zones include flaggers, temporary traffic signs/signals, portable arrow panels or changeable message signs, and channelizing devices. Research suggested that flaggers were efficient on two-lane, two-way rural highways and urban arterials and were well suited for short-duration applications (less than one day) and for intermittent use at long-duration work zones (*8*). Static traffic signs could effectively reduce crashes in work zones when used together with flaggers (*9*). In addition, some evaluations indicated that portable changeable message signs were more effective than traditional work zone traffic control devices in reducing the number of speeding vehicles in work zones (*10, 11*), but they could only result in modest speed reductions when used alone and would lose their effectiveness when operated continuously for long periods with the same messages (*8*). An early study of channelizing devices (*12*) showed that they obtained their maximum effectiveness when properly deployed as a system or array of devices.

In summary, various studies have been conducted to evaluate the effectiveness of common traffic control methods. However, the traffic control method that uses vehicles' hazard warning flashers as a warning sign in one-lane, two-way work zones has not been used and evaluated in the United States. Findings of previous studies imply that many severe crashes occur in rural two-lane work zones, many of which are rear-end collisions caused by inattentive driver. Advantages of EFTCD make it a high-potential candidate for temporary work zone traffic warning. If feasible and effective, the proposed traffic warning method would particularly benefit one-lane, two-way work zones that stay set up for short durations and require frequent movement.

EXPERIMENTAL DESIGN AND DATA COLLECTION

The evaluation of the proposed EFTCD included a comparison study of with- and without- EFTCD speeds and a traffic survey regarding the effectiveness of the warning method. With-EFTCD speeds were the speeds collected when the proposed warning method was used, while without-EFTCD speeds were the speeds when the warning method was not used. Assuming the EFTCD was effective, then, drivers who approached a work zone flagger would drive more cautiously, which could be implied by reduced speeds. Therefore, studying the speed reductions was a straightforward approach for assessing the effectiveness of the warning method.

The evaluation of the EFTCD was conducted in the following manner. When a vehicle stopped at the flagger of a work zone, a research assistant required the driver to turn on the hazard warning flashers. The speed of the next vehicle was recorded at a selected location when it approached the work zone. The research assistant would also survey the driver of the second vehicle after he/she stopped the vehicle completely. The speed and survey results were considered valid only when the flashers were turned on before the next vehicle clearly entered the sight of the research assistant.

Three work zones were selected based on factors including availability, traffic volume, speed limit, and road work type. Among the available work zones, the researchers focused on those that had speed limits higher than 50 mph. The highway sections where the selected work zones located had moderate traffic volumes so that large headways were available for deploying the EFTCD. The highway sections had pavement rehabilitation projects and work zones were only required to move up to twice a day. In addition, the researchers did not select work zones close to major intersections that would interrupt traffic flows. The three selected work zone locations were:

- US-36 between K-15 and K-148, with an annual average daily traffic (AADT) between 1,000 and 2,500 vehicles per day and a speed limit of 65 mph.
- K-192 between US-59 and K-17, with an AADT between 750 and 1,500 vehicles per day and a speed limit of 55 mph.
- K-16 between US-59 and US-24, with an AADT between 2,500 and 5,000 vehicles per day and a speed limit of 55 mph.

The vehicle speeds were collected using a SmartSensor HD (Model 125) with microwave radar technology. This device provides relatively accurate speed data and its performance will not be significantly influenced by environmental factors. During the experiments, the speeds of the first vehicles stopped by a flagger were not collected since the warning sign was not applicable to them. In most cases, only the speeds of the second vehicles were collected. Based on a number of trials, it was found that the most evident differences between with- and without- EFTCD speeds were observed at a location that was approximately 400 ft away from the actual stopping point of a second vehicle in 55-mph work zones and approximately 500 ft in the 65-mph work zone. Therefore, these locations were used to install the speed detector. Figure 1 indicates the distance configuration of a typical experiment when the two leading vehicles were passenger cars. When conditions allowed (i.e., the first two vehicles were light-duty vehicles and the spatial gaps between the two vehicles, or distance BC in Figure 1, and between the first stopped vehicle and the flagger, or distance AB in Figure 1, were sufficiently small), the speed of the third vehicle in a platoon was also measured and used in the speed analyses.

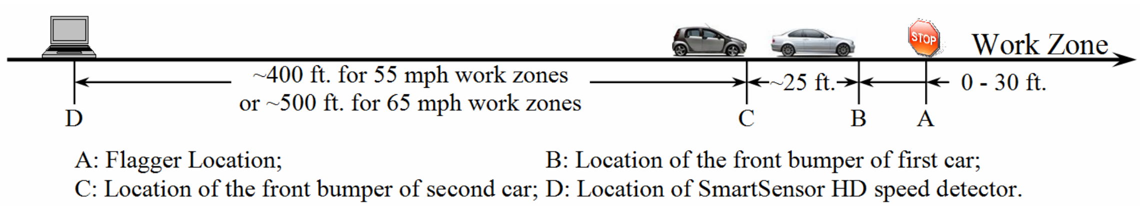


FIGURE 1 Locations of the speed detector and vehicles in work zones.

Researchers designed a simple questionnaire that can be answered within a few minutes to gather the feedback from drivers on the effectiveness of the EFTCD. The drivers were surveyed when waiting for their turn to pass the work zones. The questionnaire contained five questions, each of which was provided by multiple answer options. Additional comments were also collected if they were available from the surveyed drivers. These five questions were:

1. *Did you see the vehicle's flashers when you approach the work zone?*
2. *How do you interpret the flashers?*
3. *What actions did you take after you saw the flashers?*
4. *Do you think that the flashers bring you more attention to the work zone condition?*
5. *Do you prefer to use vehicles' flashers as a warning sign in work zones?*

During the experiments, the research team minimized the impact of their presence in the work zones so that the speeds of the approaching vehicles were not significantly affected. Table 1 shows the numbers of the collected speed and survey data.

TABLE 1 Collected Speed and Survey Data

Work Zone	Speed Limit	No. of With-EFTCD Speeds	No. of Without-EFTCD Speeds	No. of Surveys
K-192	55 mph	18	21	18
K-16		46	57	46
Subtotal		**64**	**78**	**64**
US-36	65 mph	46	40	46
Total		**110**	**118**	**110**
Note: Survey data also included information on driver gender, vehicle type, and weather condition.				

DATA ANALYSIS

Speed Data Analyses

The researchers first thoroughly compared speeds with- and without- EFTCD to study the speed changes after the warning method was used. The speed comparison included three major analyses: 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 vehicle speeds and use of the EFTCD.

Change in Vehicle Speeds when Using EFTCD

The statistical methods including two-sample *t*-test for means and the analysis of variance (ANOVA) were used to evaluate the change in vehicle speeds after the EFTCD was deployed. The two-sample *t*-test is a method frequently used for comparing the means of two sample datasets. In order to correctly interpret the two-sample *t*-test results, ANOVA needs to be performed to determine if the variances are the same between two sample populations. This research used the SAS software package for statistical analyses. SAS uses three ANOVA tests including Bartlett's test, Brown-Forsythe test, and Levene's test (*13*). Bartlett's test is a modification of the normal-theory Likelihood Ratio test. While it has accurate rates on predicting Type I error (the error of rejecting a null hypothesis when it is actually true) when data have a normal distribution, it could be 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 indicated the Brown-Forsythe test was best at providing power to detect variance differences while protecting the Type I error probability.

Figure 2 shows the average speeds observed in the experimental work zones. A reduction in average speed of 5 mph was observed in the 65-mph work zone, a noteworthy reduction of more than 10% comparing to the average speed without the EFTCD sign. In the two work zones with a speed limit of 55 mph, the overall speed reduction was 2.5 mph when the EFTCD sign was turned on, a decrease of 7% comparing to the average speed without warning sign. However, the average with-EFTCD speed was higher than the average without-EFTCD speed in K-192 experimental site. One of the factors for this phenomenon could be that the number of measured speed data on K-192 was relatively small, as shown in Table 1.

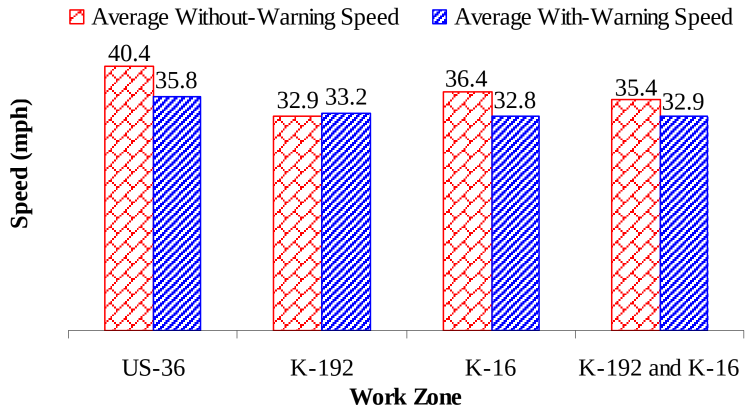


FIGURE 2 Average speed comparisons in experimental work zones.

Table 2 shows the results of *t*-test for the equality between the two means of with-EFTCD speeds and without-EFTCD speeds, and Table 3 shows the results of the ANOVA tests for variance equality. Based on the results of the ANOVA tests, the researchers could not conclude either equality or inequality between the two variances in the 55-mph work zones. However, as shown in Table 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. For the 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 (Table 3). From Table 2, the *t*-test had a *p*-value of 0.002 that suggested the null hypothesis should be rejected at the 0.05 level of significance, indicating that the EFTCD resulted in a significant speed reduction in this work zone.

TABLE 2 Results of Two-Sample t-Test for Means of Speeds

If variances are	*t*-Statistic	Degrees of Freedom	*p*-Value	Reject H_0
Work Zones with 55-mph Speed Limit				
Equal	2.45	140	0.008	Yes
Not Equal	2.432	130.39	0.008	Yes
Work Zone with 65-mph Speed Limit				
Equal	2.95	84	0.002	Yes
Not Equal	3.02	81.28	0.002	Yes

Note: H_0 = the mean value of the without-EFTCD speeds is less then or equal to the mean value of the with-EFTCD speeds; Level of significance = 0.05.

Table 3 ANOVA Tests for Variance Homogeneity

ANOVA Test	*p*-Value	Notation
Work Zones with 55-mph Speed Limit		
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
Work Zone with 65-mph Speed Limit		
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-EFTCD speed data and without-EFTCD speed data do not significantly differ; Level of significance = 0.05.

Researchers further compared the with-EFTCD speeds and without-EFTCD speeds in terms of roadway geometric alignments to better understand the effect of EFTCD at highway locations characterized by different geometric features, as shown in Table 4. The largest speed reduction in the work zones was observed at locations where the roadways were curved but level.

TABLE 4 Average Speeds by Road Geometric Alignments

Geometric Alignment	Without-EFTCD Speeds (mph)		With- EFTCD Speeds (mph)		Speed Reduction (mph)
	Average Speed	**Sample Size**	**Average Speed**	**Sample Size**	
Work Zones with 55-mph Speed Limit					
Curved Level	40.3	7	34.3	4	**6.0**
Straight Level	36.2	38	33.5	30	**2.7**
Straight Uphill	33.5	33	32.2	30	**1.3**
Work Zone with 65-mph Speed Limit					
Curved Level	41.8	31	37.7	31	**4.1**
Straight Level	35.7	9	31.8	15	**3.9**

Change in Proportions of High Speeds

Vehicles approaching work zones with noticeably high speeds carry high risk of rear-end collisions. One aspect of the effectiveness of the EFTCD was to reduce the proportion of vehicles approaching the work zones at recklessly high speeds. Figures 3 and 4 illustrate the frequencies of the observed speeds grouped in 3-mph speed interval. The figures show a general trend of more vehicles approaching at relatively high speeds in all work zones when the EFTCD was not used. In addition, researchers recorded a vehicle with 55-mph speed in the 55-mph work zones and a vehicle with 56-mph speed in the 65-mph work zone. One of these two drivers was unable to safely stop and had to run off the road to avoid colliding into the stopped vehicles. However, because of the small numbers of riskily high speeds observed, researchers could not confidently conclude the effectiveness of the EFTCD sign in reducing the proportion of recklessly high vehicle speeds.

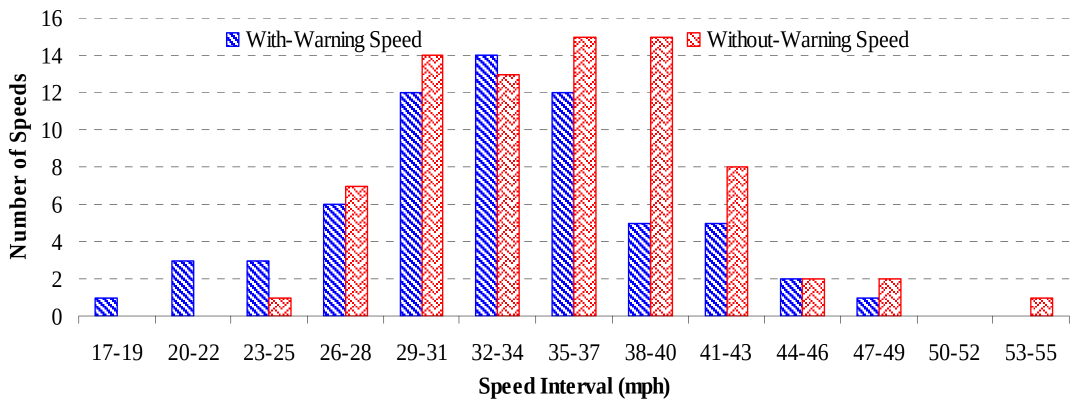


FIGURE 3 Distribution of speeds by 3-mph speed intervals in the 55-mph work zones.

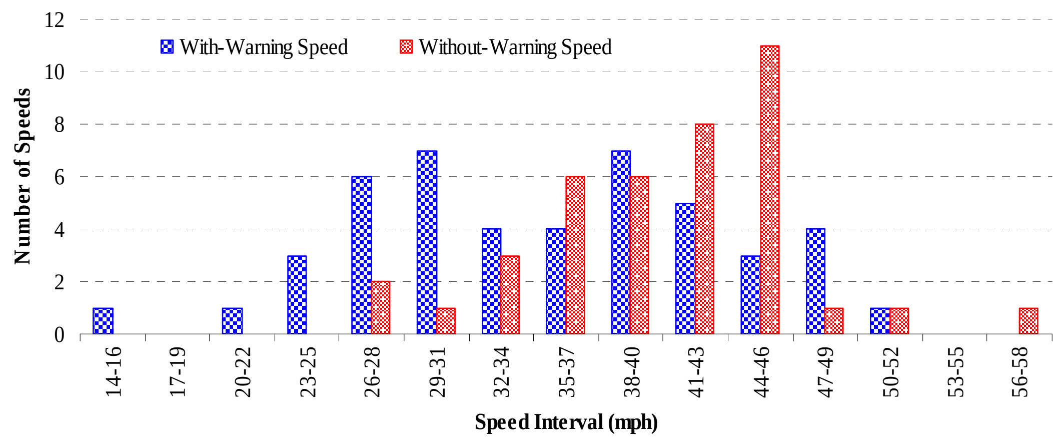


FIGURE 4 Distribution of speeds by 3-mph speed intervals in the 65-mph work zone.

Dependent Relationship between Speed Changes and the EFTCD

The relationship between the vehicle speeds and the EFTCD was tested using Pearson and Likelihood Ratio Chi-square statistics. These statistical analyses were intended to verify the existence of a causal relationship between the EFTCD and speed reductions. The researchers used the two types of Chi-square statistics to increase the probability of capturing the relationship. A dependent relationship was determined if it was supported by at least one test at a 0.05 level of significance.

Results showed that, for the two 55-mph work zones, both tests did not support a significant dependent relationship (i.e., p-values > 0.05). When the speed data from all three work zones were tested together, the Likelihood Ratio test yield a p-value (0.03) that was less than 0.05, which indicated that the use of the EFTCD was a significant cause for the vehicle speed reductions. In addition, for the 65-mph work zone, the Likelihood Ratio Chi-square test showed a p-value of 0.02, indicating a significant dependent relationship between the vehicle speed reduction and the use of EFTCD. These test outcomes suggested that the use of EFTCD resulted in more significant speed reductions in the 65-mph work zone, indicating a higher level of effectiveness in work zones with high speed limits.

Driver Survey Results

To fully understand the feasibility and effectiveness of the EFTCD, the researchers surveyed a sample of drivers in the three work zones. Among 110 participated drivers, 41 were females and 69 were males. In addition, only 14 of the surveyed vehicles were heavy vehicles and therefore the survey results were not analyzed separately for different vehicle types. The collected survey forms were screened to understand the interpretations and suggestions of the surveyed drivers regarding the EFTCD.

The researchers found that the 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 failed to notice the EFTCD when approaching the work zones. Drivers who failed to notice the EFTCD were not asked about the remaining questions. Therefore, the total completed survey was 92 instead of 110. Factors that could have contributed to the nontrivial proportion of drivers not seeing the EFTCD may include bright sunlight during the day that decreased the visibility of the EFTCD, certain vehicles with dusty or dim flashers, and unwillingness of participating survey.

As shown in Figure 5, when asked for interpretations of the EFTCD, 65% of the drivers who saw the EFTCD considered the sign as a need to reduce their speeds. More then a half of the drivers also interpreted the EFTCD as an indication of emergency or dangerous traffic conditions ahead. None of the drivers were confused by the EFTCD in the work zones. In addition, five drivers interpreted the EFTCD as an indication of a breakdown vehicle; four drivers depicted the EFTCD as a requirement of driving cautiously.

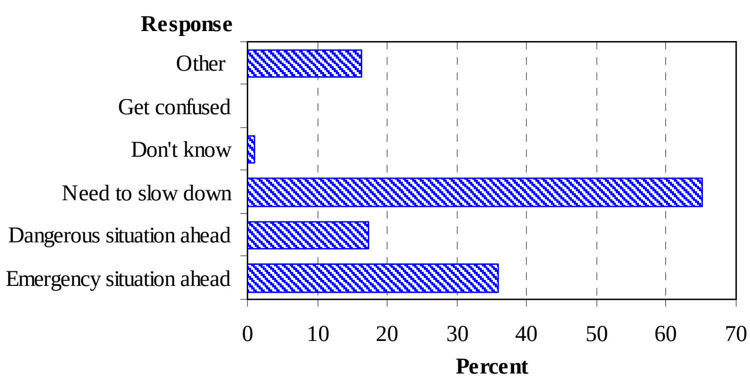
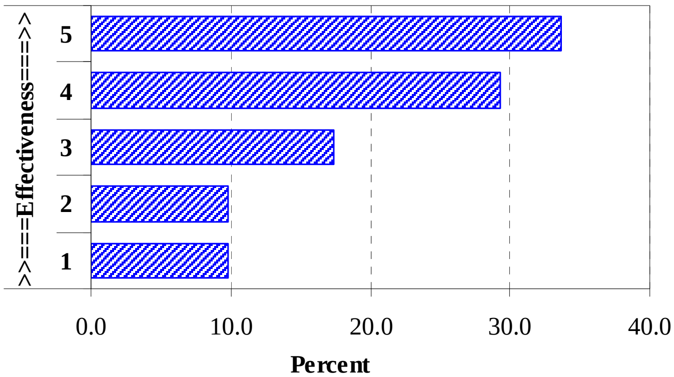


FIGURE 5 Drivers' interpretations to EFTCD.

When asked about the actions taken after they saw the EFTCD, 35 % of the surveyed drivers chose "slowed down" and another 21% chose "slowed down further." In addition, 14 (15%) drivers selected "look for more information" upon seeing the EFTCD, among which a majority (11 out of 14) also selected either "slow down" or "slow down further." However, 37 drivers (40%) indicated that they did nothing when they saw the EFTCD in work zones.

Figure 6 shows the responses to Question 4: *did you think that the EFTCD bring you more attention to the work zone conditions*? Results showed that a majority of the drivers (80%) considered the EFTCD to be effective (very much, somewhat more, and some) in alerting them about the irregular 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." In addition, 82% of the surveyed drivers recommended using the EFTCD in work zones.



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

FIGURE 6 Effectiveness in bringing drivers' attention to work zone condition.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The one-lane, two-way work zones on rural two-lane highways constitute a safety concern nationwide. To prevent crashes, especially rear-end crashes caused by inattentive drivers in these work zones, KDOT initiated a research project to evaluate the effectiveness of the newly proposed EFTCD that was assembled using the hazard warning flashers of motor vehicles. The researchers assessed the EFTCD based on a comparison study of speeds with- and without- EFTCD and a field driver survey. The researchers concluded that the proposed EFTCD was effective in alerting drivers about the irregular traffic conditions in work zones. Major findings of the speed data analyses are:

- The EFTCD coincided with a 5-mph reduction in average speed in the 65-mph work zone and a 2.5-mph reduction in the 55-mph work zones. *t*-tests showed that these speed reductions were statistically significant.
- When the EFTCD was used, larger speed reductions were recorded at curved-and-level work zones (6 mph in the 55-mph work zones and 4.1 mph in the 65-mph work zone) where sight distance was limited.
- Generally, when the EFTCD was used, speed data were more concentrated in a lower speed range (e.g., 29 – 37 mph in the 55-mph work zones and 29 – 40 mph in the 65-mph work zone), and no strikingly high speeds where recorded.

However, when EFTCD was not used, researchers recorded a 55-mph speed and a 56-mph speed in the work zones that were potentially risky.

- Chi-Square tests showed that there was a causal relationship between the EFTCD and the observed speed reductions in the 65-mph work zone. The tests also supported this causal relationship when the speeds in all work zones were tested together.

The results of each survey question were analyzed using the frequency analysis method. Major findings of the survey results are:

- A majority (84%) of the surveyed drivers noticed the warning flashers when the EFTCD was used.
- Most (65%) surveyed drivers interpreted that the EFTCD signalized a need for reducing speed. Many drivers considered the sign as an indication of emergency or dangerous situation ahead.
- Upon seeing the EFTCD, 56% of the drivers claimed that they slowed down or slowed down further; 40% of the drivers stated that they did not take any action specifically because of the EFTCD.
- Most (80%) of the drivers considered the EFTCD to be effective in warning them of the work zone conditions. In particular, 34% considered this traffic warning method very effective in drawing travelers' attention to the work zone stopping condition.
- A dominant percent (82%) of the drivers recommended using the EFTCD in work zones.

Recommendations

The researchers recommend the implementation of the EFTCD in one-lane, two-way work zones. Other than proved effectiveness, the EFTCD has additional advantages including low cost, easy set-up and movement, and minimum requirement for maintenance. These advantages will particularly benefit rural one-lane, two-way work zones that stay set up for short durations and require frequent movement. In regard to the potential implementation, the researchers would like to recommend the following.

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% of the surveyed drivers interpreted the warning flashers as an indication of emergency situation ahead. Field observation showed that, failed noticing the flagger and the stopping condition, some aggressive drivers tried to bypass a leading vehicle immediately after its hazard flashers were turned on, which increased crash risk. Therefore, the EFTCD may be implemented only when proper signing and adequate public education are provided.
2. The long-term effectiveness of the proposed EFTCD is not clear at this time. The EFTCD was evaluated for one week in each of the three work zones, where drivers were not familiar with this traffic warning sign. A consensus regarding the effectiveness of a newly proposed traffic control sign is that it may diminish over time. It is likely that the drivers' responses to this warning sign in terms of speed reductions may decrease over time. However, the EFTCD was mainly intended to bring the attention of drivers to the upcoming work zone conditions. This

effectiveness may remain at an acceptable level regardless of time. Nevertheless, the long-term effectiveness of the EFTCD needs to be further studied in the future.

3. Further studies are recommended for the associated traffic signs and their effectiveness if the EFTCD is to be implemented. Based on the field experience, the researchers recommend that two advanced warning signs showing "Turn on Hazard Warning Flashers" to be installed to instruct drivers to turn on their hazard flashers. The first sign may be located 750 feet away from the flagger's station and the second sign may be located 100 feet away from the flagger's station. In addition, education and enforcement strategies may need to be developed to ensure that drivers comply with the signs.
4. Finally, the researchers recommend further studies on the feasibility and effectiveness of the proposed EFTCD in other types of work zones and traffic conditions. For example, the EFTCD may be extended to all work zones on two-lane highways.

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