Evaluation of Three Supplementary Traffic Control Measures for Freeway Work Zones

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Controlling traffic in work zones to improve safety has long been a major concern for highway agencies. Three traffic control devices—white lane drop arrows, orange rumble strips, and the CB wizard alert system—were tested for their effectiveness in improving merging and reducing speed and speed variance at an interstate highway work zone in Missouri. Results of implementing the white lane drop arrows and the CB wizard alert system indicate decreases in the percentage of vehicles in the closed lane, mean speed, and speed variance. It also appears that the CB wizard alert system may be more effective than the white lane drop arrows. The CB wizard alert system in conjunction with the orange rumble strips did show similar reductions, but they were much smaller in comparison to the CB wizard alert system alone.

INTRODUCTION

Safety in work zones has been recognized as a significant problem for many years. The subject has received additional attention at times when improvement or rehabilitation of existing facilities is more prevalent than new construction. This shift in approach makes maintenance of traffic on highway facilities during repair or reconstruction critical. The closure of a lane on a four-lane high-speed facility during construction or maintenance activity creates many potential safety problems. Lane closures require the driver to make behavior adjustments, such as reducing speed and/or changing lanes. On high-volume facilities, problems often occur when two or more lanes of traffic must be warned sufficiently in advance so that motorists may travel safely through the one lane passing through the work zone.

Past studies of accidents in work zones have found a higher accident rate for work zones than for other sections of the road (*1,2,3,4*). The predominant factors contributing to work zone crashes appear to be failure to drive within the designated lane, failure to reduce speed, and failure to yield right of way, and the occurrence and severity of accidents has been related to both vehicle speed and speed variation (*5*).

The Manual on Uniform Traffic Control Devices (MUTCD) describes use of signs, signals, hand-signaling devices, channelizing devices, and deflection and attenuation devices along the approach to and within a work zone (*6*). In order to further reduce the number of crashes that occur in work zones, consideration should be given to additional traffic control devices. In an effort to improve the flow conditions approaching work zones, four states—Missouri, Kansas, Iowa, and Nebraska—joined together in a study of various additional traffic control devices. Three traffic control devices—white lane drop arrows, orange rumble strips, and the CB wizard alert system—were tested in Missouri and are described here. The hypotheses tested examined whether the devices alone or in combination reduced the mean speed of the traffic, reduced speed variance, and improved advance merging of the two lanes. This research also provided information about lane distributions, 85th percentile speeds, 15th percentile speed, 10 mph pace, percentage of vehicles in the 10 mph pace, and the percentage of vehicles below the speed limit.

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OBJECTIVE

The primary objective of the study was to determine the effectiveness of the three traffic control devices located in the approach to a highway work zone. The devices are intended for use with stationary long-term work zones and with short-term moving projects. This research will help departments of transportation develop guidelines for selecting alternative traffic control devices for use in a work zone. The specific research tasks were:

1. To test and evaluate the effectiveness of the devices in reducing the average speeds and speed variance approaching the work zone;
2. To test the effectiveness of the devices in merging the traffic into one lane before the work zone starts;
3. To determine the opinion of drivers driving through the work zone about the CB wizard alert system;
4. To determine if these devices change the accident rate; and
5. To determine the ease of installation and removal and durability of the arrows and orange rumble strips.

This paper describes the devices, data collection procedures, results, and conclusions.

TRAFFIC CONTROL DEVICES

Orange Rumble Strips

A vehicle passing over the orange rumble strips experiences a bump, which alerts a driver to hazards ahead. The strips, which can be cut to length, are 4" wide and 0.15" thick. The orange color designates the construction site. Six sets of removable orange rumble strips were installed at locations approaching the work zone (Figure 1). Each set of strips contained six strips, which were placed on 10' centers at the site farthest from the lane drop, 5' centers at the next site, and 2' centers at the 4 remaining sites. It was expected that the rumble strips

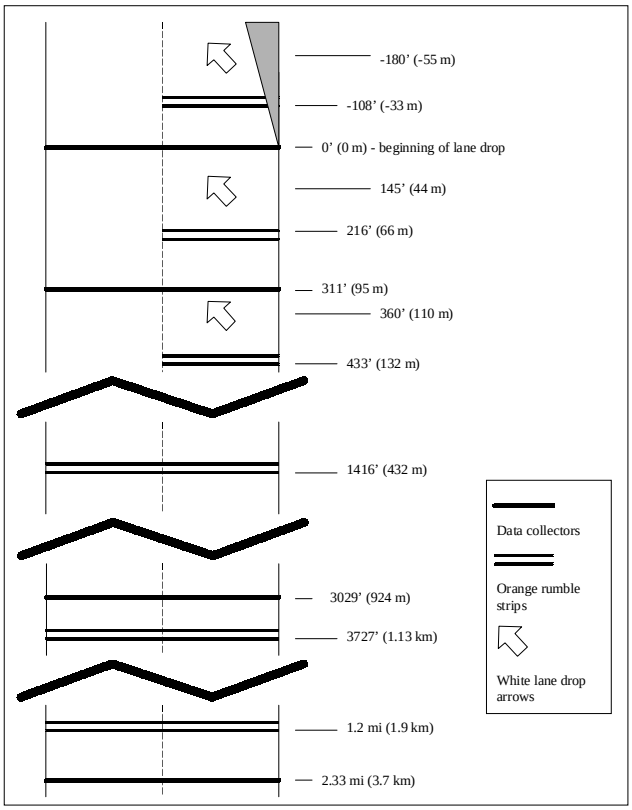

FIGURE 1 Schematic location of detectors and devices on work zone approach

would alert drivers still in the closed lane and approaching the lane closure to change lanes and reduce speed.

White Lane Drop Arrows

The white lane drop arrows were placed at a 45° angle to the travel direction. The arrows are approximately 7' long and slightly thinner than the rumble strips. The large size of the arrows and their white color provide a visual and aural feedback to the driver who passes over them. Three removable white lane drop arrows were installed near the beginning of the lane taper for the lane closure, as shown in Figure 1. It was expected these would alert drivers to change lanes and move to the open lane.

CB Wizard Alert System

The trailer-mounted CB wizard alert system broadcasts a work zone alert and information for advance warning about a lane closure on a CB radio channel. The wizard was placed approximately 6 miles (9.67 km) upstream of the lane closure and transmitted the following message when the right lane was closed: "This is the Missouri Department of Transportation. The right lane of Eastbound I-70 is closed ahead. Watch for slow or stopped traffic." A similar message was transmitted when the left lane was closed. It was expected that this would bring an earlier lane change response by truck drivers and lower speeds upstream of the closure.

DATA COLLECTION

The field research was conducted on a highway with a 70 mph speed limit, but the posted speed limit approaching the work zone was reduced to first 60 mph and then 50 mph. The devices were tested at a stationary long-term work zone on eastbound Interstate 70 (I-70) near Columbia, Missouri. Interstate systems are similar throughout the United States, so the results may be representative of similar facilities in other states. The pavement related work at this site included cold milling, pavement repair and resurfacing. The average daily traffic was approximately 14,600 vehicles, with 25.6 % non-passenger vehicles in the eastbound direction of travel. The right lane of the eastbound highway was closed first, followed by the left lane.

Data were collected at four locations along the approach to the work zone, as shown in Figure 1, before any of the devices were in place and again after they were installed. Vehicle speeds, volumes, and vehicle classifications were collected in 15-minute intervals. Data for the white lane drop arrows and the CB wizard alert system were collected separately. Data for the orange rumble strips were collected while the CB wizard alert system was operating. Due to breaks in the pneumatic tubes, it was not always possible to collect data at all four sites during all time periods, but a minimum of 24 hrs of data were collected for each device tested.

The vehicles were grouped into passenger vehicles (2 axles), non-passenger vehicles (more than 2 axles), and all vehicles. The times of the observations were classified according to light conditions as day, night, and twilight (dawn to dusk). Finally, the levels of service in the closed and passing lanes were used to group the data into uncongested conditions, where both lanes had levels of service A, B, C, or D, or congested conditions, in which at least one of the lanes had level of service E or F.

The driver survey was conducted at a nearby truck stop, about 3 miles upstream of the lane closure. Surveys were conducted between approximately 9:00 am and 5:00 pm on several days. In addition, accident data were collected from one mile upstream of the first counter site through the end of the work zone, and observations were made regarding the ease of installing and removing these devices and their durability.

RESULTS

The traffic control devices were primarily intended to reduce traffic speeds, speed variability, and the percentage of vehicles in the closed lane. The data analysis examined the difference in the parameters before and after the devices were installed. The primary measures of effectiveness were lane distributions, speed mean, and speed variance; however, other parameters were also studied for significance in the evaluation of the traffic control devices. For the before and after studies, the analysis took into consideration the effects of time of day and class of vehicle. Due to the small amount of data for the dawn/dusk periods, a difference

would be extremely difficult to identify. A more detailed description of the data analysis and results appears in the complete report on this project (*7*).

Percentage of Vehicles in the Closed Lane

Table 1 summarizes the average changes in the percentage of vehicles in the closed lane for the four sites studied. When the white lane drop arrows and the CB wizard alert system were in place, the percentage of vehicles remaining in the closed lane decreased. However, the decrease associated with the white lane drop arrows was only significant at the two detectors farthest upstream from the arrows. Drivers at these two locations would not have seen the arrows yet, so either the effects of the arrows were propagated upstream, or some other factors caused the response while the arrows were in place. The white lane drop arrows were associated with greater decreases during the day than during the night, and they were associated with a greater reduction of passenger vehicles than non-passenger vehicles in the closed lane.

TABLE 1 Change in Vehicles in the Closed Lane

Vehicle Type	Time	Traffic Control Device*		
		White Lane Drop Arrows# % (%)	Wizard System# % (%)	CB Wizard Alert System and Orange Rumble Strips# % (%)
All Vehicles	Day	-1.7 (20.8)	-2.9 (15.8)	+0.13 (2.95)
	Night	-1.4 (7.1)	-3.1 (7.5)	-2.0 (11.7)
Passenger Vehicles	Day	-1.8 (21.7)	-1.8 (12.0)	+1.44 (1.78)
	Night	-1.7 (22.5)	-0.3 (0.3)	-1.5 (10.6)
Non-Passenger Vehicles	Day	-1.0 (32.0)	-4.4 (29.8)	+0.1 (12.25)
	Night	-1.8 (17.8)	-6.2 (44.0)	-2.5 (11.5)

*White lane drop arrows and CB wizard alert system were compared to no devices; CB wizard alert system and orange rumble strips were compared to CB wizard alert system alone.
#The first number represents the percentage change of 2-lane flow, or the change in the closed lane's share of all traffic; the second number represents the percentage change within the closed lane. For example, if each lane carried 50 vehicles before and the closed lane carried no vehicles after, the cell would have the values –50% (100%).

The CB wizard alert system may be more effective during the day than during the night. The effect was greater on non-passenger vehicles than on passenger vehicles, which was expected, since the CB wizard alert system is used mostly by non-passenger vehicles. During the day, the percentage of vehicles in the closed lane during congested conditions increased at Sites 3 and 4, but this was not statistically significant.

When the orange rumble strips were added to the wizard system, the percentage of vehicles in the closed lane did not change. For the CB wizard alert system and orange rumble strips, there was a left-lane closure in operation. Table 1 shows an increase in the percentage of vehicles in the closed lane during the day and a decrease during the night. During the night, the CB wizard alert system and orange rumble strips had a similar effect on both passenger and non-passenger vehicles.

Mean Speed

A general trend of reduction in speed means was observed for the white lane drop arrows and the CB wizard alert system (Tables 2 and 3). Data for the CB wizard alert system and orange rumble strips show a small increase in the mean speed of the vehicles in the driving lane, which coincides with the increase in the percentage of vehicles in the closed lane during similar conditions. In general, the greater the reduction of percentage of vehicles in the closed lane, the greater the reduction in mean speed. Changes observed for both the white lane drop arrows and the CB wizard alert system were greater during the night than during the day, and there was a greater reduction in the mean speed in the passing lane than in the driving lane.

TABLE 2 Change in Mean Speed During the Day

Vehicle Type	Lane #	Traffic Control Device*		
		White Lane Drop Arrows mph (%)	Wizard System mph (%)	CB Wizard Alert System and Orange Rumble Strips mph (%)
All Vehicles	Dr Ln	-8.4 (14.0)	-5.6 (9.3)	0.6 (1.1)
	Ps Ln	-3.4 (5.4)	-6.0 (9.6)	-1.0 (1.8)
Passenger Vehicles	Dr Ln	-9.8 (15.9)	-8.5 (13.5)	0.4 (0.9)
	Ps Ln	-7.2 (10.9)	-9.4 (14.1)	-1.3 (2.2)
Non-Passenger Vehicles	Dr Ln	-3.1 (5.4)	-3.3 (5.3)	0.5 (0.9)
	Ps Ln	-4.8 (3.2)	-5.3 (9.0)	-5.3 (8.8)

#White lane drop arrows and CB wizard alert system were tested when the driving lane was closed; CB wizard alert system in conjunction with orange rumble strips was tested when the passing lane was closed.
*White lane drop arrows and CB wizard alert system were compared to no devices; CB wizard alert system and orange rumble strips were compared to CB wizard alert system alone.

TABLE 3 Change in Mean Speed During the Night

Vehicle Type	Lane #	Traffic Control Device*		
		White Lane Drop Arrows mph (%)	Wizard System mph (%)	CB Wizard Alert System and Orange Rumble Strips mph (%)
All Vehicles	Dr Ln	-9.7 (16.)	-8.5 (13.8)	-1.4 (2.4)
	Ps Ln	-6.9 (10.9)	-19.6 (33.7)	-1.0 (1.4)
Passenger Vehicles	Dr Ln	-9.6 (16.7)	-7.8 (12.6)	-1.6 (2.7)
	Ps Ln	-6.6 (10.4)	-28.8 (46.2)	-1.4 (2.1)
Non-Passenger Vehicles	Dr Ln	-16.2 (29.4)	-11.7 (19.3)	-1.0 (1.8)
	Ps Ln	-3.7 (5.8)	-3.4 (5.4)	-0.1 (0.8)

#White lane drop arrows and CB wizard alert system were tested when the driving lane was closed; CB wizard alert system in conjunction with orange rumble strips was tested when the passing lane was closed.
*White lane drop arrows and CB wizard alert system were compared to no devices; CB wizard alert system and orange rumble strips were compared to CB wizard alert system alone.

It was expected that the CB wizard alert system would affect non-passenger vehicles more than passenger vehicles, but the data show a greater effect on passenger vehicles. It is interesting to note that, during the night, a 46.2% reduction in the mean speed of passenger vehicles was observed, compared to 5.4% reduction in the mean speed of non-passenger vehicles. Data from both the white lane drop arrows and the CB wizard alert system showed a greater reduction in the mean speeds of passenger vehicles than non-passenger vehicles. On average, data for both the white lane drop arrows and the CB wizard alert system showed a reduction in the mean speed of about 10%. The speed reduction was greater in the driving lane than in the passing lane. The data for the white lane drop arrows indicate a greater effect on non-passenger vehicles during the night time than during the day. Adding the orange rumble strips to the CB wizard alert system resulted in small speed reductions.

Corresponding to the decrease in the mean speeds, there was an increase in the percentage of vehicles below the speed limit in all cases. The CB wizard alert system showed a much greater increase in the percentage of vehicles below the speed limit than the white lane drop arrows. There were similar reductions in the 85th percentile speed and 15th percentile speed, as discussed in the detailed report of the study (*7*).

Standard Deviation of Mean Speed

A small standard deviation of the mean speed for vehicles approaching a work zone is desirable. The changes in standard deviations were both positive and negative (Tables 4 and 5). The observed effect on standard deviation was greater during the night than during the day. The standard deviation in the driving lane increased during the day, and on further analysis (*7*), it was found that this increase was most apparent in passenger vehicles.

TABLE 4 Change in Standard Deviation of Mean Speed During the Day

Vehicle Type	Lane #	Traffic Control Device*		
		White Lane Drop Arrows mph (%)	Wizard System mph (%)	CB Wizard Alert System and Orange Rumble Strips mph (%)
All Vehicles	Dr Ln	+0.3 (3.8)	+1.7 (23.5)	-0.1 (2.7)
	Ps Ln	-0.3 (2.6)	-0.7 (8.4)	+1.2 (19.9)
Passenger Vehicles	Dr Ln	+0.4 (4.5)	+1.6 (22.7)	-0.2 (3.2)
	Ps Ln	+0.1 (2.4)	-0.7 (2.9)	+1.5 (19.3)
Non-Passenger Vehicles	Dr Ln	-0.6 (22.4)	-1.9 (50.0)	+0.4 (7.4)
	Ps Ln	-0.5 (8.3)	-1.2 (18.6)	+0.8 (22.9)

White lane drop arrows and CB wizard alert system were tested when the driving lane was closed; CB wizard alert system in conjunction with orange rumble strips was tested when the passing lane was closed.
* White lane drop arrows and CB wizard alert system were compared to no devices; CB wizard alert system and orange rumble strips were compared to CB wizard alert system alone.

TABLE 5 Change in Standard Deviation of Mean Speed During the Night

Vehicle Type	Lane #	Traffic Control Device*		
		White Lane Drop Arrows mph (%)	Wizard System mph (%)	CB Wizard Alert System and Orange Rumble Strips mph (%)
All Vehicles	Dr Ln	-1.9 (23.5)	+1.4 (22.7)	-0.1 (0.2)
	Ps Ln	-0.3 (4.6)	-0.8 (6.2)	+0.2 (6.4)
Passenger Vehicles	Dr Ln	-1.6 (19.9)	+1.7 (27.0)	0.0 (0.5)
	Ps Ln	+ 0.2 (2.6)	0.0 (7.8)	0.0 (1.1)
Non-Passenger Vehicles	Dr Ln	-0.5 (26.1)	+1.5 (32.0)	-0.1 (1.3)
	Ps Ln	-0.3 (5.1)	+0.3 (10.2)	-0.3 (5.1)

White lane drop arrows and CB wizard alert system were tested when the driving lane was closed; CB wizard alert system in conjunction with orange rumble strips was tested when the passing lane was closed.
* White lane drop arrows and CB wizard alert system were compared to no devices; CB wizard alert system and orange rumble strips were compared to CB wizard alert system alone.

Data for the CB wizard alert system indicate little effect on passenger vehicles, especially in the driving lane. Though the CB wizard alert system was associated with a lower standard deviation of mean speed of non-passenger vehicles during the day, the standard deviation increased at night. Even though data for both the white lane drop arrows and the CB wizard alert system show a greater effect on reducing the mean speeds of passenger vehicles, they show an increase in the standard deviations, which may be an indication of erratic maneuvers of drivers of passenger vehicles. The CB wizard alert system and the orange rumble strips data show an increase in the standard deviation of mean speed in the closed passing lane.

Driver Survey Results

The responses to the driver survey questions are summarized in Table 6. The CB wizard alert system was installed a few miles in advance of the work zone; therefore, people driving into the work zone were more likely to hear the message than were people driving in the opposite (westbound) direction. The majority of the drivers understood all or part of the message, and 97.3% of the drivers felt the information they received was at least somewhat useful. The drivers surveyed were enthusiastic about using the CB radios to give warnings about work zones and lane closures.

Accident Analysis

The time periods when the devices were in place were too short to indicate a statistically significant reduction in accidents. However, a sharp rise in accidents could indicate that the devices are hazardous.

TABLE 6 Frequencies of Responses to Driver Survey Questions

Items	Proportion			
What type of vehicle?	Heavy truck or trailer (87.8%)	Light truck/Van (8.1%)	Bus (1.6%)	Passenger car (2.4%)
Which direction of travel?	Eastbound (62.7%)	Westbound (37.3%)	-	-
How many years driving this type of vehicle?	< 1 year (2.4%)	1-2 years (6.5%)	2-5 years (35.0%)	> 5 years (56.1%)
How far in advance of a work zone are warning signs needed?	< 1 mile (32.5%)	1-2 miles (14.6%)	3-5 miles (41.5%)	≥ 6 miles (38.2%)
Did you know about the lane closure before starting your trip?	Yes (41.5%)	Yes, but forgot (0.8%)	No (57.7%)	-
How did you found out about the lane closure?	Radio (4.3%)	CB radio conversation (47.1%)	CB radio recorded message (41.4%)	Word of mouth (5.7%)
Did you hear the message in the vehicle you are driving?	Yes (60.2%)	No (39.8%)	-	-
Did you understand the message?	Yes (64.8%)	Yes, but message not clear (31.1%)	No (4.0%)	No opinion (0.0%)
Do you find the information useful?	Very useful (39.5%)	Useful (57.9%)	Not useful (1.3%)	No opinion (1.3%)
Did you drive through a work zone with a recorded CB radio warning before?	Yes (36.1%)	No (63.8%)	-	-
How hazardous are interstate work zones compared to normal highway segments?	More Hazardous (55.3%)	About the same (34.1%)	Less hazardous (7.3%)	No opinion (3.2%)

No accidents were found to have occurred because of the technologies that were tested. The types of accidents that would be expected to occur due to the traffic control devices include:

- The white lane drop arrows were expected to help the drivers still in the closed lane to change lanes, which would be expected to cause a changing lane accident. No lane-changing accidents occurred when the arrows were placed on the pavement.
- The CB wizard alert system was expected to increase the driver awareness of the work zone well in advance and prepare drivers for the conditions ahead. Drivers would be expected to slow down and change to the open lane well in advance of the lane closure. If the CB wizard alert system were to cause an accident, it would be expected to be of the changing lane type. No changing lane accidents occurred when the CB wizard alert system was tested.
- The orange rumble strips were expected to warn drivers still in the closed lane and traveling at high speeds to slow down and change lanes. If the orange rumble strips were to cause an accident, it would be expected to be either a changing lane or out of control type accident. No accidents of either type occurred while the orange rumble strips were in place.

Durability and Removeability

Orange Rumble Strips

The traffic control contractor's first attempt to install the orange rumble strips occurred shortly after a light rain—the pavement surface appeared to be dry. The personnel laid out the strips, walked on the surface area of the strips to apply pressure, then rolled their pickup truck tires over the surface area. By the next morning and after a heavy rain, most of the strips had lost adhesion and had been removed from the pavement by traffic.

Approximately one month later, on thoroughly dry pavement, the contractor's installation was successful. The strips were laid in place and a 200 lb (90 kN) roller was used to apply pressure (per the manufacturer's instructions). The process, including a temporary lane closure and installation of the strips, required approximately three-and-one-half hours for a two-person installation team. The strips remained in good condition for eight days. Strip removal exhibited no particular difficulties and required approximately two hours (including a temporary lane closure) for a two-person team with no special tools.

White Lane Drop Arrows

The traffic control contractor's personnel laid out the arrows, walked on the surface area of the arrows to apply pressure, then rolled their pickup truck tires over the surface area. The installation process, including a temporary lane closure, required approximately two hours for a two-person team. The arrows remained in good condition for seven days. Arrow removal required approximately two hours (including a temporary lane closure) for a two-person team with no special tools and exhibited no particular difficulties.

CONCLUSIONS

This study examined the effect of white lane drop arrows, the CB wizard alert system, and orange rumble strips on vehicle speeds, lane distributions, and vehicle conflicts at a long-term work zone in Missouri. Data indicate that the white lane drop arrows and CB wizard alert system were effective in reducing the speed of traffic approaching the work zone. Data for the CB wizard alert system in conjunction with the orange rumble strips show only small effects on vehicle speeds when compared to the CB wizard alert system alone. When compared to the white lane drop arrows, the CB wizard alert system was more effective. The results correlate well with the expectation that the use of CB radio is prevalent among non-passenger vehicles. Though it was not possible to test the orange rumble strips alone, they were tested while the CB wizard alert system was operating. The orange rumble strips did not bring about a large change with respect to the CB wizard alert system alone. The devices also showed a significant reduction in the percentage of vehicles below the speed limit—about 40% with the white lane drop arrows and up to 120% with the wizard system. The devices were not found to be hazardous, as they did not cause any accidents. They are easy to install and remove, and they worked for the lifetime of this work zone. Thus, the devices are easy-to-use with short-term work zones. Because the arrows and rumble strips were in place for approximately one week, durability for longer periods cannot be projected based on this study.

ACKNOWLEDGMENTS

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