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Evaluation of Supplementary Traffic Control Measures for Freeway Work-zone Approaches

Kristen L. Sanford Bernhardt[1], Mark R.Virkler[2], and Nawaz M. Shaik[3]

[1]Assistant Professor, [2]Associate Professor, [3]Research Assistant, Department of Civil and Environmental Engineering, University of Missouri-Columbia, E2509 Engineering Building East, Columbia, MO, 65211, [1](573)884-6330, sanfordk@missouri.edu, [2](573)882-7434, virklerm@missouri.edu, FAX(573)882-4784

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Abstract. Controlling traffic in work-zones to improve safety continues to be a major concern for highway agencies. Three traffic control devices – white lane drop arrows, the CB wizard alert system, and orange rumble strips – were tested for their effectiveness in improving merging, and reducing speed and speed variance at an interstate highway work-zone in Missouri. Based on the results of the study described, the lane drop arrows, CB message, and rumble strips can be expected to promote some increases in early merging and some decreases in mean speeds of vehicles approaching an interstate highway work-zone with a lane drop. Effects of all three devices on speed variance are inconclusive. However, because of the difficulty in summarizing across the many variables involved (day/night/dawn/dusk, open/closed lane, vehicles class, etc.), it is recommended that anyone considering the use of the devices examine the full report.

INTRODUCTION

Safety in work-zones has been recognized as a significant problem for many years. Studies of crashes in work-zones have found a higher crash rate for work-zones than for other sections of the road (*1,2,3,4*). 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.

The Manual on Uniform Traffic Control Devices (MUTCD) describes the use of signs, signals, hand-signaling devices, channelizing devices, and deflection and attenuation devices along the approach to and within a work-zone (*5*). In an effort to improve the flow conditions approaching work-zones, four states – Missouri, Kansas, Iowa and Nebraska – cooperated in a pooled-fund study of various additional traffic control devices, called the Midwest Smart Work-zone Deployment Initiative (MwSWZDI). Three traffic control devices – white lane drop arrows, CB wizard alert system, and orange rumble strips – were tested in Missouri. This paper describes these evaluations, as well as the results of evaluations of two of the devices in Iowa and Kansas. The hypotheses tested in Missouri 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. The research also provided information about 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, as well as the ease of device installation and removal.

WORK ZONE SAFETY AND TRAFFIC CONTROL

Not only have studies of crashes in work-zones found a higher crash rate for work-zones than for other sections of the road, the frequency of crashes in work-zones appears to be substantially greater than indicated by accident record systems (*1*, *4*). Crash databases tend to provide limited information about the types and causes of crashes in work-zones (*6*). Studies of crash characteristics also indicate that it is possible to reduce these crash rates by improving the application of traffic control devices in and approaching work-zones.

Wang et al. (*4*) found that the majority of crashes in work-zones involve rear-end collisions, which are related to large standard deviations in speed. They also found that work-zones have a higher percentage of sideswipe accidents than other sections of the highway, and that work-zone crashes occur most frequently on freeways and major state arterials. The predominant factors contributing to work-zone crashes appear to be failure to drive within a single lane, failure to reduce speed, failure to yield right of way and failure to drive within the designated lane (*7*). Another study of the characteristics of crashes (*1*) indicated that following too closely and improper lane changing contributed to the majority of work-zone crashes.

Work-zones are also hazardous locations for workers, due to the proximity of workers and traffic. An analysis of serious and fatal injuries to highway workers in New York (*8*) found that 22% of all serious worker injuries and 43% of fatal worker injuries resulted from traffic crashes. Two-thirds of the injuries to pedestrian workers occurred from vehicles intruding into marked workspaces and striking workers or flaggers.

Research has shown that, regardless of the technologies used within a work-zone, once a driver has entered a work-zone, he or she is unlikely to increase speed significantly until after leaving the work-zone (*9*). Venugopal and Tarko (*10*) indicate that work-zone approaches are as dangerous as the work-zones themselves. Therefore, efforts should be focused on reducing the speeds of vehicles before they enter the work-zone and reducing crashes by guiding the vehicles in a safe manner.

In a simulation study of traffic control at freeway work-zones (*11*), Nemeth and Rouphail reported that an early merge could significantly reduce the potential problem by reducing speed variance. They also observed that the merging behavior was related to the traffic conditions rather than to presence of lane closure signs. A driver survey indicated that drivers in the closed lane followed cues from sightings of the work-zone and from other drivers.

Numerous studies have examined the effects of various traffic control devices in and approaching work-zones. Devices that have been examined include radar drones (*12*), police radar (*13*), changeable message signs (CMSs) with and without accompanying radar (*7*), and speed-monitoring displays (*14*). A best practices directory documents existing state Department of Transportation uses of traffic control devices in and around work-zones (*15*).

While we did not find evaluations of the removable lane drop arrows or the CB Wizard in the literature, several researchers have studied different types of rumble strips. A 1989 synthesis report (*16*) found that no uniform standards exist for the use of rumble strips for work-zones. There was a general agreement that rumble strips should only be used for special conditions where standard traffic control devices have proven to be ineffective and where the potential for accidents can be readily identified by failure to comply with conventional traffic controls. Rumble strips were also found to be not very effective in reducing speeds in work-zones. However, in a study evaluating rumble strips in Kentucky (*17*), Pigman and Agent observed that the percentage of traffic in the closed lane decreased from 11.0% to 4.1% (at 0.1 miles before the taper) when rumble strips were used in addition to standard lane closure, variable message sign and supplemental signs. The study recommended using rumble strips where other devices do not reduce late merges and there is excessive congestion.

OBJECTIVE

The study described examined the effectiveness of the three traffic control devices located in the approach to a highway 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 farther upstream in the work-zone approach;

3. To determine the opinion of drivers traveling through the work-zone about the CB wizard alert system;
4. To determine if these devices change the crash rate; and
5. To determine the ease of installation and removal and the durability of the devices.

The devices were expected to provide an advance warning of the lane closure, to encourage motorists to reduce vehicle speed, to reduce the speed variance, to perform for the life of the project, and to be safe for motorists. Table 1 shows the specific measures of effectiveness associated with each objective.

TRAFFIC CONTROL DEVICES

The sections below describe the three devices tested in this project – removable white lane drop arrows, the CB Wizard Alert System, and removable orange rumble strips.

White Lane Drop Arrows

The arrows, which were placed at a 45-degree angle to the travel direction, are approximately 8 feet (2.4 m) long and 0.09 inches (2.3 mm) thick (Figure 1). The large size of the arrows and their reflective white color provide visual and aural feedback to drivers. Three arrows were placed along the approach to the work-zone; their positions and distances from the lane closure are shown in Figure 2. The arrows were expected to alert drivers to change lanes and move to the open lane.

CB Wizard Alert System

The solar-powered, trailer-mounted CB wizard alert system broadcasts a work-zone alert and information for advance warning about potentially hazardous conditions on a CB radio channel (Figure 3). The CB message was broadcast on Channel 19 from a location approximately 6 miles (9.67 km) upstream of the lane closure. The system 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. The message was expected to bring an earlier lane change response by truck drivers and lower speeds upstream of the closure.

TABLE 1 Measures of Effectiveness

Objective	Measures
Promote advance merging	Lane distribution
Reduce speed	Mean speed
	85th percentile speed
	Mean speed of fastest 15% of vehicles
	10-mph pace
Reduce speed variance	Standard deviation of speed
	% of vehicles in 10-mph pace
Determine driver opinion of CB Wizard	Driver survey results
Perform for life of project	*For Lane Drop Arrows and Rumble Strips*
	Observed ease of installation
	Observed condition before removal
	Observed ease of removal
	For CB Wizard Radio
	Observed ease of installation
	Observed ease of use
Provide for safety	Number of crashes related to each traffic control device

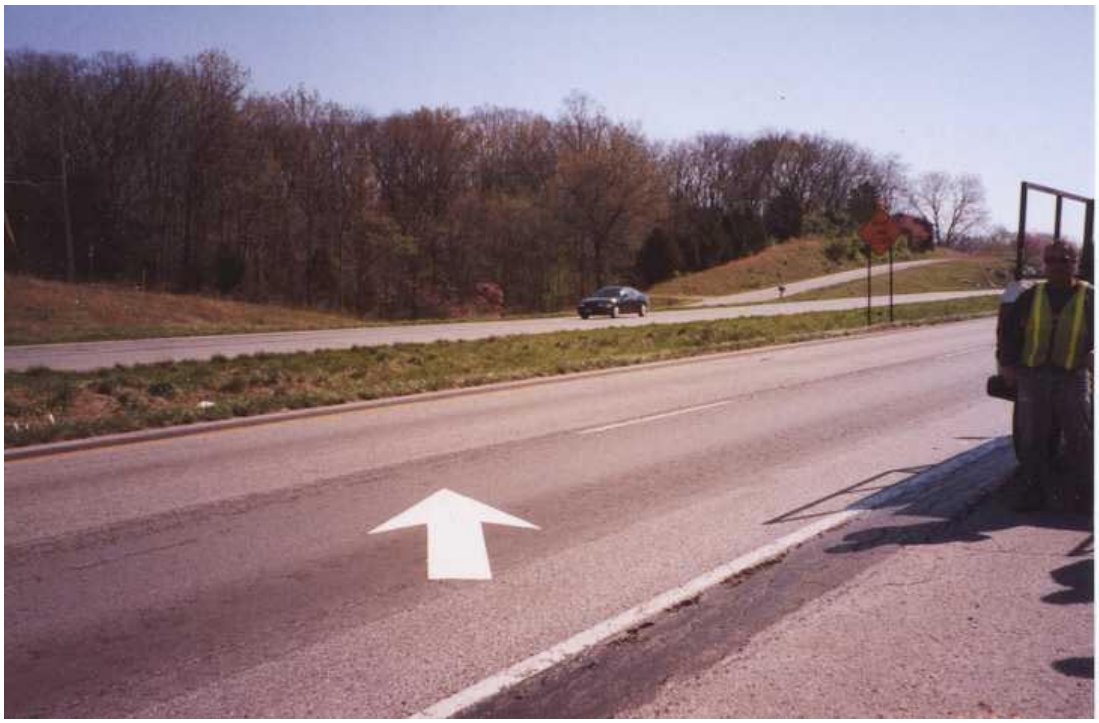

FIGURE 1 White lane drop arrow.

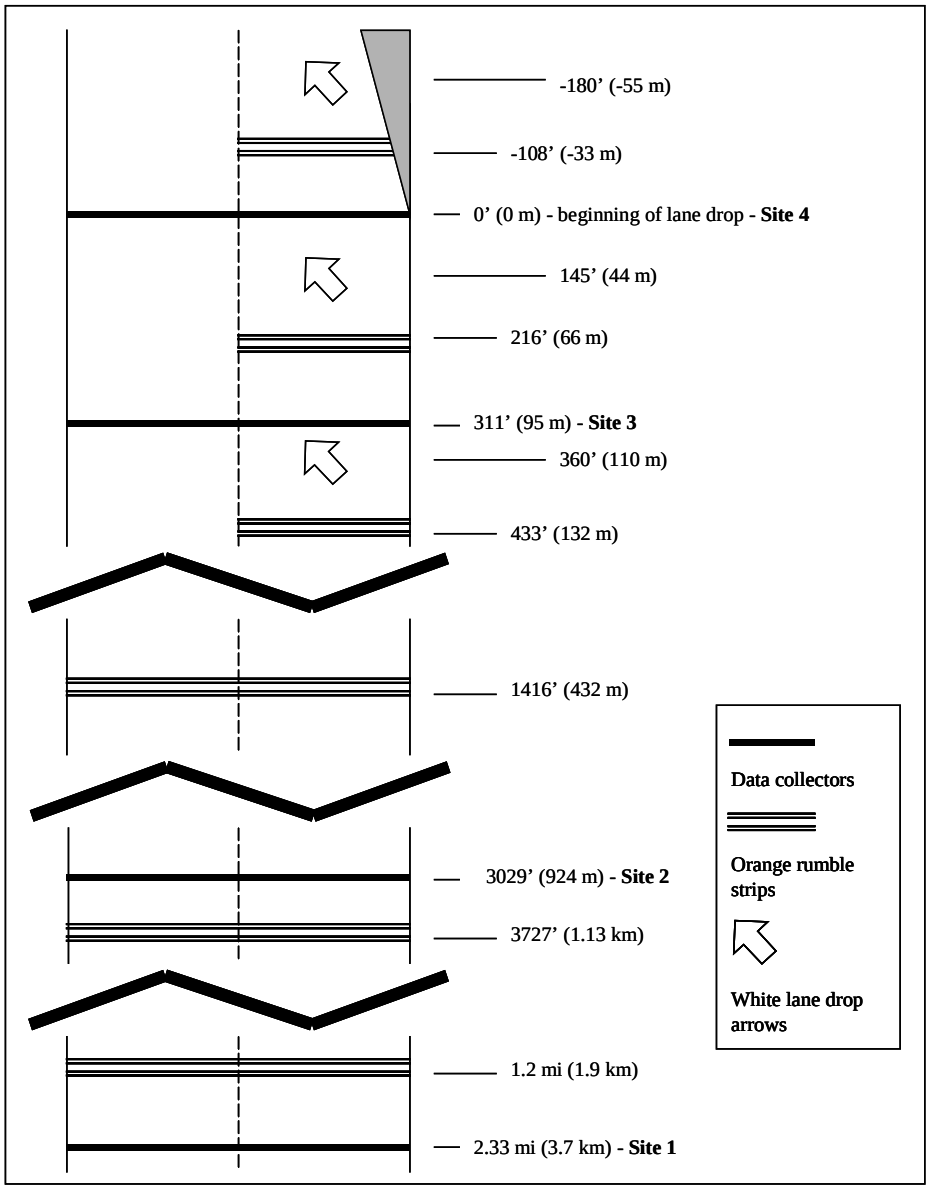

FIGURE 2 Schematic locations of detectors and devices in work-zone approach – right lane closed.

Orange Rumble Strips

The rumble strips, which can be cut to length, are four inches (0.1 m) wide and 0.15 inches (3.8 mm) thick. A vehicle passing over the rumble strips experiences a slight bump, which alerts a driver to hazards ahead. The orange color designates the construction site. Each set deployed in the work-zone contained six rumble strips, which were placed on 10 foot centers at the site farthest from the lane drop, 5 foot (1.5 m) centers at the next site and 2 foot (0.6 m) centers at the remaining sites (Figure 4). At the first 3 sites (farthest upstream from the work-zone), the rumble strips spanned both lanes, while at the sites closest to

FIGURE 3 CB Wizard Alert System.

the work-zone they spanned only the closed lane. Two attempts were made to evaluate the rumble strips. On the first installation attempt, six sets of rumble strips were installed at locations approaching the work-zone (Figure 2), while on the second attempt, only four sets of rumble strips were installed (Figure 5). The rumble strips were expected to alert drivers still in the closed lane and approaching the lane closure to change lanes and reduce speed.

STUDY DESIGN

The following sections describe the test site and data collection and classification schemes.

Test Site

The site selected for the research was an interstate freeway (I-70) passing through Columbia, Missouri. The highway normally has a 70-mph (113 km/hr) speed limit, but the posted speed limit approaching the work-zone was reduced first to 60-mph (97 km/hr) and then to 50-mph (80 km/hr). The average daily traffic was approximately 14,600 vehicles, with 25.6% non-passenger vehicles (three or more axles) in the eastbound direction of travel. There were full shoulders on both sides of the road. The right lane (driving

FIGURE 4 Orange rumble strips on 2-ft centers.

lane) was closed during the first part of the study, when the arrows and CB Wizard were evaluated (Figure 2). The left lane (passing lane) of the eastbound highway was closed during the second part of the study, when the rumble strips were evaluated (Figure 5).

Data Collection

Sets of pneumatic tubes for data collection were installed at four locations along the approach to the work-zone, as shown in Figure 2. Vehicle speeds, volumes, and vehicle classifications were collected in 15-minute intervals before each of the devices was in place (before cases) and again after each was installed (after cases). 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. Although the intent was to test each device alone and in combination, the constraints of working within the timetable and environmental conditions of a real construction project prevented this.

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 before and after data were collected for each device tested. The rumble strips were first installed on April 13, 1999, but most detached from the pavement by the next

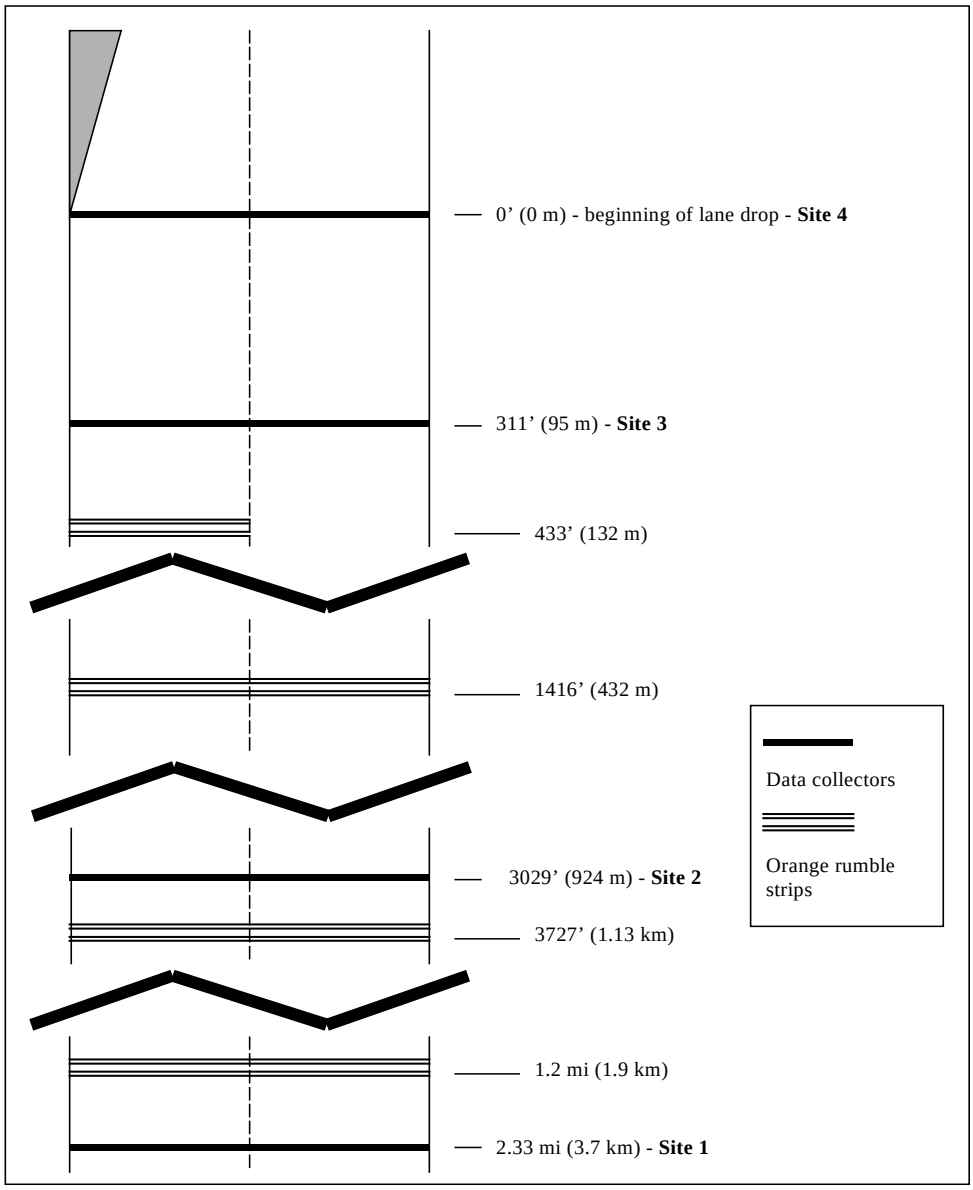

FIGURE 5 Schematic locations of detectors and devices in work-zone approach – left lane closed.

day. The second installation occurred on May 19, 1999. All rumble strip data analyzed were collected during the second installation, as it is unknown how long the rumble strips were in place before they detached from the pavement on the first attempt. Speed data were also collected from a permanent count station a few miles upstream from the first data collection site to help determine whether general traffic conditions changed from one day to the next.

The driver survey for the CB Wizard was conducted at a nearby truck stop, about 3 miles (4.8 km) upstream of the lane closure. Surveys were conducted between approximately 9:00 am and 5:00 pm on

several days. In addition, crash data were collected from one mile (1.6 km) upstream of the first counter site through the end of the work-zone, and the ease of installing and removing these devices and their durability were observed.

Data Classification

The vehicles were grouped into passenger vehicles (two axles), non-passenger vehicles (more than two axles), and all vehicles. The times of the observations were classified according to light conditions as day, night, and twilight (dawn/dusk) using the U.S. Naval observatory readings of sunset and sunrise.

The levels of service in the closed and passing lanes were used to group the data into uncongested conditions (both lanes had densities corresponding to levels of service A, B, C, or D) or congested conditions (at least one of the lanes had a density corresponding to level of service E or F). A more detailed description of the data analysis and results appears in the complete reports on this project (*18*, *19*).

RESULTS

The primary measures of effectiveness used to analyze the data were lane distribution, mean speed, and speed variance upstream of the work-zone. In addition, the percentage of vehicles below the speed limit, the percentage of vehicles in the 10-mph pace, the 85th percentile speed, and the mean speed of the fastest 15% of vehicles were calculated. The lane distribution is considered to be improved if fewer vehicles remain in the lane closed downstream in the after case than in the before case. Mean speed, speed variance, 85th percentile speed, and mean speed of the fastest 15% of vehicles are improved if they decrease in the after case, whereas higher percentages of vehicles below the speed limit and in the 10-mph pace are considered improvements.

Each “before and after” comparison is a test of the hypothesis that the characteristic under study is the same in the before and after cases (i.e., the characteristic did not change). The level of significance (α) used was 0.05. This means that if there was no change, the test can be expected to reach that conclusion correctly (that there is no statistically significant difference) in 95% of the comparisons. However, in 5% of the cases in which there was no change, the test can be expected to indicate a statistically significant difference (this is called a Type I error). Significance testing of the parameters used a two-tailed Student’s

t-test with a level of significance $\alpha = 0.05$. An F-test was also conducted at the same level of significance to find significant differences in the speed variance.

The following sections present summary results for the effects of each of the devices on lane distribution, mean speed characteristics, and speed variance characteristics. Detailed tables for all combinations of characteristics appear in (*18, 19*). Results from data collected at the permanent count station indicate that there was little variation in the lane distributions and mean speeds in any of the before and after case pairs, but that the speed variance varied widely.

Lane Drop Arrows

When the lane drop arrows were in place, the driving lane was closed downstream. Data were collected at all 4 sites (as shown in Figure 2). However, at Sites 1 and 2, drivers had not yet seen the arrows.

Lane Distribution

The lane distribution was significantly improved for all vehicles and passenger vehicles at Sites 3 and 4 during the day (after percentages were 0.2% - 5% lower). No significant increases in the percentage of vehicles remaining in the closed lane occurred, and no significant differences occurred at night or during dawn/dusk.

Mean Speed Characteristics

During the day, mean speeds increased at Sites 1 and 2 but decreased at Sites 3 and 4 (most decreases were small, but one was 17 mph). There was some increased compliance with the speed limit at Site 3, but there were also scattered increases in 85th percentile speed. Results for the mean speed of the fastest 15% of vehicles were also mixed.

At night, mean speeds again increased at Sites 1 and 2 and decreased at Site 3 (by 1 - 3 mph). There was some decreased compliance with the speed limit. Reflecting the mean speed results, the 85th percentile speed and the mean speed of the fastest 15% of vehicles also increased at Sites 1 and 2 and decreased at Sites 3 and 4.

During dawn/dusk, mixed results were observed for all measures, with both significant increases and decreases.

Speed Variance Characteristics

During the day, the standard deviation of speeds decreased for all vehicles at Site 4 in the driving lane (by 7 mph). No other significant differences were observed. Significant increases in the percentage of vehicles in the 10-mph pace occurred at night at Sites 1 and 2; no other significant differences were observed.

CB Wizard

When the CB Wizard was operating alone, the driving lane was closed downstream. Data were collected at Sites 1, 2, and 3. The message broadcast point was approximately 3 miles (4.8 km) upstream of the first data collection site, so it would have been possible to hear the message before reaching any of the sites.

Lane Distribution

During the day, lane distributions improved at Site 1 for all three vehicle categories, and at Sites 2 and 3 for all vehicles and passenger vehicles (after percentages were 1.2% - 13% lower). Lane distributions also improved at night at Site 1 for all three vehicle categories (6% - 15%), and at Site 2 and 4 for all vehicles and non-passenger vehicles. During dawn/dusk, lane distributions improved for all vehicles and non-passenger vehicles at Site 1 (10% - 15%).

Mean Speed Characteristics

During the day, mean speeds increased at Site 1 but decreased at Sites 2 and 3 (by 0.7 - 3 mph). Compliance with the speed limit improved at Site 3 for all three vehicles categories, and the 85th percentile speed decreased at Site 3. The mean speed of the fastest 15% of vehicles increased for passenger vehicles at Site 1, but decreased for passenger vehicles at Site 3.

At night, mean speeds again increased at Site 1 but decreased at Sites 2 and 3 (by 1.5 - 3.5 mph). Improved compliance with the speed limit was scattered, and the 85th percentile speed increased at Site 1 but decreased at Sites 2 and 3. The mean speed of the fastest 15% of vehicles increased at Site 1, decreased at Site 2, and showed mixed results at Site 3.

During dawn/dusk, mean speeds again increased at Site 1 but decreased at Sites 2 and 3 (by 2 - 3 mph). Changes in compliance with the speed limit were mixed, the 85th percentile speed increased at Site 1 and showed mixed changes at Site 2, and the mean speed of the fastest 15% of vehicles increased at Sites 1 and 2 for passenger vehicles.

Speed Variance Characteristics

No significant changes in standard deviation occurred. Significant decreases in the percentage of vehicles in the 10-mph pace were observed at Sites 1 and 2.

Rumble Strips

Data for the orange rumble strips (for both the before and after cases) were collected while the CB Wizard was operating. During this time, the passing lane was closed downstream. Data were collected at Sites 1, 2, and 4. Drivers at Site 1 would not yet have seen the rumble strips, however.

Lane Distribution

During the day, lane distributions at Site 4 improved for all three vehicle categories under congested conditions (after percentages were 5% - 20% lower). The lane distribution also improved at Site 2 for all vehicles and passenger vehicles during the day (5%), and for all vehicles at night (1.5%). It slightly worsened at Site 1 at night. No other significant differences were observed.

Mean Speed Characteristics

During the day, mean speeds decreased at almost all sites (by 2 - 20 mph). Large increases in compliance with the speed limit were observed at all sites for all three vehicle categories. The 85th percentile speed decreased at Sites 2 and 4 for all vehicles categories, as did the mean speed of the fastest 15% of vehicles.

At night, mean speeds decreased at Site 4 (by 5 - 10 mph), and results were mixed at Site 2. Compliance with the speed limit improved at Site 4 for all three categories, and the 85th percentile speed decreased at Site 4. At Sites 1 and 2, however, the 85th percentile speed increased for non-passenger vehicles in the closed lane. The mean speed of the fastest 15% of vehicles decreased at Site 4 for all vehicle categories but increased at Site 2 for non-passenger vehicles in the closed lane.

During dawn/dusk, the mean speed of non-passenger vehicles decreased at Site 4 (by 6 - 26 mph), while their compliance with the speed limit at Site 4 increased. The 85th percentile speed of the non-passenger vehicles also decreased at Site 4, as did the mean speed of the fastest 15% of vehicles. However, the mean speed of the fastest 15% of non-passenger vehicles increased at Site 2.

Speed Variance Characteristics

No significant differences in standard deviation were observed. Significant decreases in the percentage of vehicles in the 10-mph pace occurred during the day at Site 2.

Driver Survey Results

The responses to the driver survey questions are summarized in Table 2. The CB wizard alert system was installed 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. 66.6% of the drivers who were traveling toward the work-zone heard the message. 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.

Crash Analysis

The time periods when the devices were in place were too short to indicate a statistically significant reduction in crashes. However, a sharp rise in crashes could indicate that the devices are hazardous. No crashes were found to have occurred because of the technologies that were tested. The types of crashes that might be expected to occur due to the traffic control devices are discussed below.

- The white lane drop arrows were expected to help the drivers still in the closed lane to change lanes, which might be expected to cause a changing lane crash. No lane changing crashes occurred when the arrows were placed on the pavement.
- 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 a crash, it might be expected to be either a changing lane or out of control type crash. No crashes of either type occurred while the orange rumble strips were in place.

TABLE 2 Frequencies of Responses to Driver Survey Questions

Items	Proportion			
What type of vehicle are you driving?	Heavy truck or trailer (87.8%)	Light truck/Van (8.1%)	Bus (1.6%)	Passenger car (2.4%)
Which direction are you traveling?	Eastbound (62.7%)	Westbound (37.3%)	—	—
How many years have you driven 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 do you think warning signs are 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 recorded message in the vehicle you are driving?	Yes (60.2%)	No (39.8%)	—	—
Did you understand the recorded message?	Yes (64.8%)	Yes, but message not clear (31.1%)	No (4.0%)	No opinion (0.0%)
Do you find the recorded information useful?	Very useful (39.5%)	Useful (57.9%)	Not useful (1.3%)	No opinion (1.3%)
Had you driven 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%)

- 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 a crash, it might be expected to be of the changing lane type. No changing lane crashes occurred when the CB wizard alert system was tested.

Ease of Installation, Durability, and Removal

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.

CB Wizard Alert System

The CB message exhibited no great difficulty in set-up or use. Roughly one-half hour was required to become familiar with the equipment, with instruction by a company representative. As part of this process, three individuals recorded trial messages. Particular effort was required to produce a succinct, clear script. One individual required several attempts to record a clear message, free of verbal mistakes. Once a successful message was recorded, the recording equipment, mounted on its trailer, was towed to its deployment site.

Orange rumble strips

The traffic control contractor's first attempt to install the orange rumble strips occurred shortly after a light rain (but 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 temporary lane closures for each of the two lanes 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 temporary lane closures) for a two-person team with no special tools.

Results of Related MwSWZDI Studies

The MwSWZDI evaluated fourteen devices/technologies in Year 1 of the initiative (*18*). The removable lane drop arrows were studied only as described. However, the rumble strips and the CB Wizard were evaluated by more than one state.

Rumble Strips

The Kansas Department of Transportation evaluated the rumble strips on a rural two-lane highway in advance of a lane closure. In Kansas, rumble strips are standard traffic control for this type of work-zone, so the removable rumble strips were installed further upstream of the standard rumble strips. The results indicated that although the thickness of the rumble strips was not sufficient to provide audible and tactile warning, the color of the strips alone was sufficient to have a positive effect on 85th percentile speed and mean speed.

The Iowa Department of Transportation also evaluated the rumble strips. Their goal was to examine the rumble strips at approaches to stop signs on different pavement types. The study concluded that the rumble strips are durable and that when they are applied in a double thickness, they produce an audible sound and bump for passenger vehicles, but not for larger vehicles.

CB Wizard

The Kansas Department of Transportation evaluated the CB Wizard on a rural interstate highway in advance of a lane closure and median crossover. No statistically significant changes were observed.

The Iowa Department of Transportation also evaluated the CB Wizard on a rural interstate highway in advance of a striping operation. Driver responses to the message were positive.

CONCLUSIONS

This study examined the effect of white lane drop arrows, the CB wizard alert system, and orange rumble strips on lane distributions, mean vehicle speed characteristics, and speed variation at a long-term work-zone in Missouri. The study also evaluated the ease of installation and removal and durability of all

three devices, and the user acceptance of the CB Wizard. In addition to the results of the Missouri evaluations, this paper also described results of studies of the rumble strips and the CB Wizard in Kansas and Iowa.

Lane Distribution

The results of this study indicate that the removable lane drop arrows may encourage earlier merging when two freeway lanes are reduced to one for a work-zone. This effect was only noticeable close to the taper for the lane drop, where the arrows were located. Examination of the effect of arrows placed farther from the taper would clarify the length of their impact.

Data indicate that a recorded CB message may promote merging well in advance of the work-zone, while the combination of rumble strips and the CB message have little additional effects beyond those experienced with the message alone. Although it was anticipated that the recipients of CB message would be primarily drivers of non-passenger vehicles, the positive effects were noticed for all classes of vehicles studied. The broadcasting of the message well in advance of the work-zone may have promoted the very early merging.

Mean Speed Characteristics

The arrows and CB message are both associated with increases in mean speed characteristics at sites further upstream from the work-zone. However, they are associated with decreases in these characteristics at sites closer to the work-zone. Data indicate that the rumble strips in conjunction with the CB message are associated with greater improvements in mean speed characteristics than the CB message alone. Compliance with the speed limit greatly increased, and the magnitude of all effects increased closer to the work-zone taper.

Speed Variation

Results of effects of the devices on speed variance are inconclusive. Very few statistically significant increases or decreases were observed, and data from the permanent count station indicate that these values varied widely from one day to another even in an area several miles upstream of the work-zone.

Installation, Durability, and Removal Issues

This study demonstrated that the removable lane drop arrows and orange rumble strips can be used on an interstate highway construction zone. For the orange rumble strips, application on dry pavement with a 200-lb roller should be viewed as a requirement. The primary costs of the rumble strips and the arrows include the material, several hours of labor for installation and removal, and any additional traffic delay or hazard caused by the temporary lane closures required for installation and removal.

Based on the results of this study, a recorded CB message near the beginning of a lane closure on an interstate highway work-zone can be expected to be heard and understood by a high proportion of truck drivers. There is strong evidence that truck drivers appreciate the warning and will adjust their lane choice based on the warning. The primary costs of the CB Wizard Alert System include the system itself and staff time for installation, recording the message, and removal. No lane closures are required as the system is installed, operated, and removed without traffic disruption.

The devices were not found to be hazardous, as they did not cause any crashes. They are easy to install and remove, and they worked for the time they were in place. Because the arrows and rumble strips were in place for approximately one week, durability for longer periods cannot be projected based on this study.

Recommendations

Based on the results of the study described, the lane drop arrows, CB message, and rumble strips can be expected to promote some increases in early merging and some decreases in mean speeds of vehicles approaching an interstate highway work-zone with a lane drop. These results are consistent with those of the other states' evaluations. Effects of all three devices on speed variance are inconclusive. However, because of the difficulty in summarizing across the many variables involved (day/night/dawn/dusk, open/closed lane, vehicles class, etc.), it is recommended that anyone considering the use of the devices examine the full report (*18*, *19*). Additional observations include:

- The rumble strips were not thick enough to produce a considerable amount of audible sound for trucks; thicker strips may have a greater impact, but they may also cause safety problems for smaller vehicles.

- The rumble strips should be evaluated alone, which was not possible given the constraints of the work-zone site used for this study. In addition, evaluations of the devices in all possible combinations could determine a configuration with maximum positive impacts.
- Further study of how earlier merging of vehicles affects the capacity of the work-zone approach and corresponding delays is needed, as it is possible that the earlier merging promoted may have negative impacts. Preliminary work in this area is described in (*20*).
- The devices were evaluated soon after installation. Therefore, the results reported reflect the short-term response. If the devices were to be in place for many months, driver response may change.

The MwSWZDI is currently investigating a different set of technologies for Year 2 of the initiative, and Year 3 is in the planning stages, with possible expansion in state participation.

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