# Traffic Control for Short-Duration Maintenance Operations on Four-Lane Divided Highways

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**The authors summarize the results of research conducted to develop and evaluate reduced traffic control sign treatments for short-duration maintenance operations involving lane closures on four-lane divided highways with traffic volumes of 30,000 or fewer vehicles per day. Several candidate sign treatments were developed and compared with the standard traffic control configuration for a lane closure on a four-lane divided roadway. The effect of the sign treatments on the proportion of drivers that moved out of the closed lane at several locations immediately upstream of the lane closure was studied. Study results indicate that the Texas LANE BLOCKED sign or a changeable-message sign placed 1,500 ft before the cone taper influenced drivers to exit the closed lane farther upstream from the work zone than the other candidate sign treatments tested or the standard traffic control treatment.**

All streets and highways require periodic maintenance and repair work that necessitates the closure of one or more travel lanes. Proper traffic control is essential during these maintenance activities to ensure the safety of motorists and workers while permitting the maintenance work to be completed in a timely manner. The *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*) provides traffic control guidelines for some of the more typical highway and street maintenance operations. For example, the specified traffic control configuration for a lane closure on a multilane roadway consists of channelizing devices and a series of advance warning signs placed upstream of the work area. Considerable time and effort is usually expended installing and removing traffic control devices at a particular location. For maintenance operations that last several hours, the time and effort involved is easily justified.

However, many roadway maintenance activities require only a very short period of time to complete. Often, only 15 to 20 min is spent at a particular highway location performing the actual maintenance work. A work crew may make several of these short-duration stops along a section of roadway for such activities as pothole patching, crack sealing, or pavement bump planing or profiling. Conversely, work activities such as bridge clearance measurements or guardrail maintenance require a work crew to spend 15 to 20 min at single locations on different roadways.

For these short-duration maintenance operations, the actual placement of the advance warning signs and the channelizing devices that are required by the MUTCD often takes longer than the actual work itself. This traffic control effort limits the productivity of the work crew performing these quick repairs. Perhaps more important, worker exposure to traffic during traffic control installation and removal is greater than the exposure during the actual maintenance work itself. Consequently, there is a need for a reduced traffic control configuration for short-duration maintenance operations that requires less installation and removal time than the standard traffic control configuration specified in the MUTCD, but that is still effective in directing drivers safely and efficiently through the work zone. Such a reduced configuration would lessen worker exposure time during traffic control device placement and removal, lessen motorist exposure time to the lane closure itself, and allow maintenance crews to be more productive. In response to this need, the Texas State Department of Highways and Public Transportation (SDHPT) sponsored a study by the Texas Transportation Institute (TTI) to develop and evaluate candidate traffic control configurations for short-duration maintenance activities. In order to make the research effort reasonable in scope, the study concentrated only on four-lane divided highways with traffic volumes of 30,000 or fewer vehicles per day (vpd). This paper presents the methodology and findings of that research.

The specific objectives of the study were as follows:

- To develop candidate traffic control configurations for short-duration maintenance operations on four-lane divided highways with traffic volumes of 30,000 or fewer vpd, and
- To conduct field studies at actual maintenance operations on four-lane divided highways to evaluate the effectiveness of the candidate configurations in directing drivers out of the closed travel lane.

## DEVELOPMENT OF CANDIDATE TRAFFIC CONTROL CONFIGURATIONS

The configuration of traffic control devices normally used during a lane closure on a four-lane divided highway in Texas is shown in Figure 1. The arrangement consists of three static advance warning signs, a cone taper, and an arrow panel placed behind the cone taper in the closed lane. This configuration is specified for a minor maintenance operation (less than one daylight period) on a four-lane divided roadway in the *Texas Manual of Uniform Traffic Control Devices* (*2*) (to be referred to as the standard TMUTCD treatment).

Following standard TMUTCD treatment, as the work zone is approached, the first advance warning sign seen by drivers is a ROAD WORK AHEAD (CW21-4D) sign. The sign is

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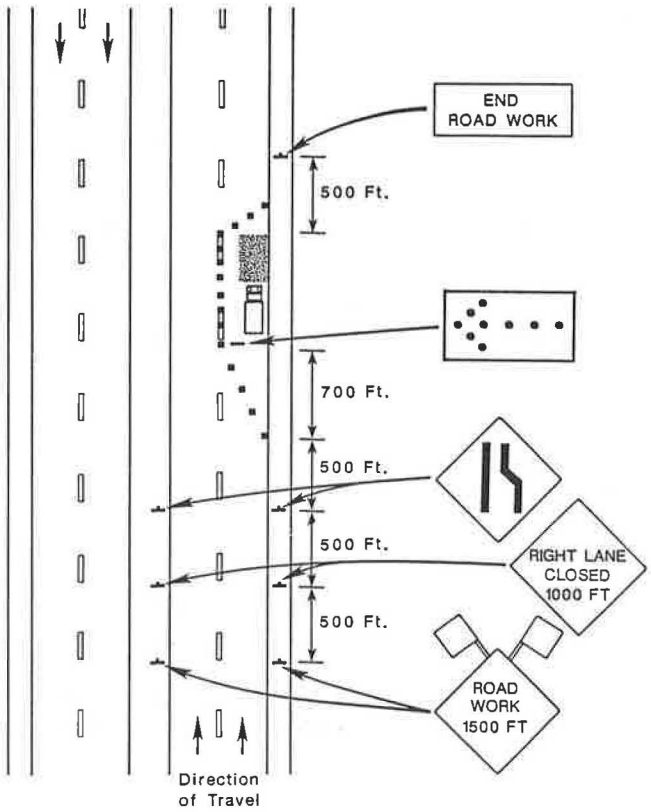


**FIGURE 1 Standard TMUTCD traffic control configuration for a lane closure on a four-lane divided highway.**

located 1,500 ft from the cone taper and informs drivers that some type of road work exists ahead. The next warning sign—placed 1,000 ft from the cone taper—is the RIGHT/LEFT LANE CLOSED AHEAD (CW20-5D) sign, which indicates to drivers that a travel lane is closed and implies that a lane change maneuver may be required. The final advance warning sign—located 500 ft from the cone taper—is the symbolic LANE CLOSED (CW4-2) sign. The symbol pictured on the sign also indicates to drivers that a lane is closed and that a lane change maneuver may be needed.

An analysis of driver information requirements at work zones was performed—based on "positive guidance" concepts (*3, 4*)—in order to develop the reduced traffic control configuration for short-duration maintenance operations. A complete discussion of this analysis may be found in the study documentation (*5*). Ideally, the reduced configuration would use as few devices as possible while still providing adequate worker safety and driver information (*5*).

On the basis of the analysis of driver information requirements, a reduced traffic control configuration was developed that consisted of an arrow panel positioned behind the cone taper, coupled with an advance warning sign placed 1,500 ft upstream of the work zone. Research has shown the arrow panel to be the primary source of information to drivers approaching moving maintenance operations, and may be the primary source of information when used for stationary work-zone operations (*6–9*). It was hypothesized that the arrow panel would serve as the primary source of information to drivers for the reduced traffic control configuration, whereas an advance warning sign placed 1,500 ft upstream would supplement the arrow panel. The upstream sign would inform drivers that they are approaching a work zone hazard and possibly reinforce the lane change information provided by the arrow panel. Figure 2 shows a schematic layout of the candidate traffic control configuration for short-duration maintenance operations.

Once the basic reduced traffic control configuration was selected, the next step was to determine which advance warning sign should be used 1,500 ft upstream of the work zone. A number of possibilities were considered in the early stages of the research. Four sign treatments were eventually selected for complete field evaluation. Each treatment differed with respect to the amount of information provided to the driver, where the information was provided, and the conspicuity of the devices. A brief description of each candidate configuration is provided below.

### Treatment 1—ROAD WORK AHEAD

For this configuration, dual ROAD WORK AHEAD signs (identical to the first sign encountered in the standard TMUTCD traffic control configuration) were placed 1,500 ft upstream from the beginning of the cone taper. This sign does not provide information about the closure, but indicates that some type of road work exists ahead. This candidate configuration relies on the flashing arrow panel in the cone taper to inform drivers that the lane is closed and that they must be in the open lane when they reach the work zone.

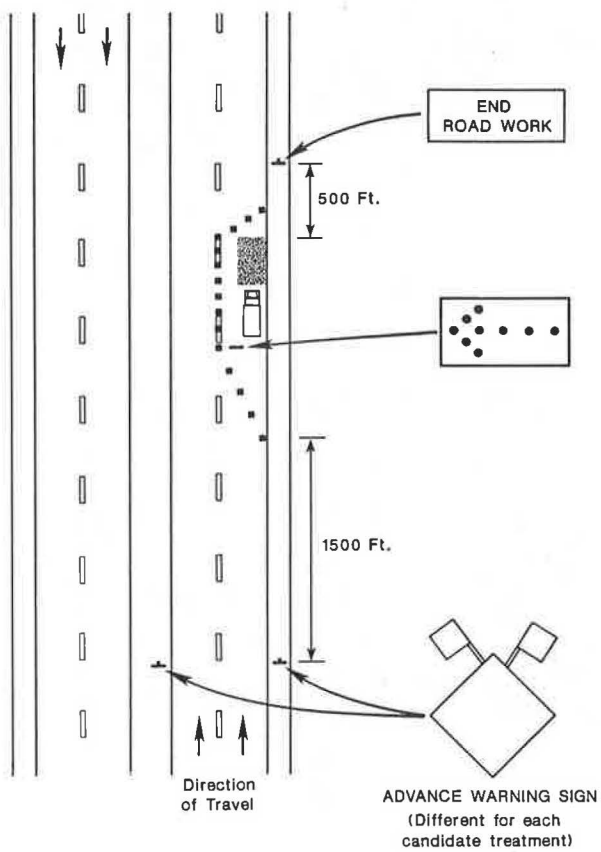


**FIGURE 2 Candidate traffic control configuration for short-duration maintenance operations.**

### Treatment 2—Symbolic LANE CLOSED Sign

For this treatment, symbolic LANE CLOSED signs (identical to the third signs encountered in the standard TMUTCD traffic control configuration) were placed on each side of the travel lanes 1,500 ft in advance of the cone taper. This sign reinforces the message of the arrow panel to exit the closed lane. Referring to Figure 1, the lane closure information supplied by the sign is provided farther upstream than in the standard TMUTCD traffic control configuration.

### Treatment 3—Changeable-Message Sign

Treatment 3 utilized a portable changeable-message sign (CMS) placed 1,500 ft upstream from the cone taper. These signs have a high target value and can typically be seen farther upstream than standard static advance warning signs. In addition, a sense of urgency is implied because of the flashing of the message.

In effect, the information provided by the first two advance warning signs in the standard traffic control configuration is consolidated into this one sign. Figure 3 shows the CMS used in this study.


**FIGURE 3 Changeable-message signs used in study.**

### Treatment 4—Texas LANE BLOCKED Sign

The Texas LANE BLOCKED sign was originally designed for moving maintenance operations (Figure 4). It furnishes clear, unambiguous information to the driver about which lane is blocked and which lane is open to traffic. The sign is larger than a normal static MUTCD advance warning sign (7 by 7.5 ft), providing a legibility distance that allows drivers to adequately perceive and process the information presented. The colors used for the sign are black letters on an orange background, consistent with the color coding signifying construction or maintenance work activity. As with all of the other sign treatments evaluated in this study, the sign was placed 1,500 ft upstream from the cone taper.

## STUDY APPROACH

A series of field studies was conducted to evaluate the four candidate traffic control treatments and determine how effectively each treatment encouraged drivers to exit the closed lane in advance of the work zone. The standard TMUTCD traffic control configuration served as the basic treatment. If a candidate treatment was to be judged effective, it had to perform at least as well as the standard treatment in persuading drivers to exit the closed travel lane.


**FIGURE 4 The Texas LANE BLOCKED sign.**

### Experimental Design

Several factors were identified that could affect the data that would be collected to evaluate the standard and candidate traffic control treatments. It was hypothesized that the type of lane closure (left lane, right lane), site-specific factors (sight distance, geometrics, type of drivers), and time-of-day variations could possibly affect the study results. An experimental design was developed for the standard TMUTCD and four candidate treatments accounting for (a) type of closure, (b) study site conditions, and (c) time of day. A chi-square design was developed for both left-lane and right-lane closures. Each treatment would be evaluated at each site, but the sequence in which they were evaluated would change from site to site. Table 1 presents the experimental design for this study.

### Data Collection Methodology

Data were collected for 1 hr at each site for the TMUTCD and each of four candidate treatments for a total of 5 hr per site. Data were collected only during the daylight, off-peak periods. Two types of data were collected during the field studies. Traffic volumes were recorded at five locations upstream of the work zone. These volumes were recorded in 5-min intervals by lane and vehicle type, and subsequently combined into hourly volumes coinciding with the time at which the evaluation of each treatment began and ended. The first location (Station 1) was positioned approximately 2,500 to 3,000 ft upstream from the cone taper. This station was assumed to be upstream from the effects of the sign configurations, and therefore was used as a control location for each site. The remaining locations (Stations 2, 3, 4, and 5) were positioned 1,500 ft, 1,000 ft, and 500 ft from the beginning of the cone taper as well as at the beginning of the cone taper itself. Figure 5 shows where lane distribution data were collected at one of the study sites.

In addition to traffic volumes, videotape recordings were made of traffic approaching the work zone. Data were collected at, and just upstream of, the cone taper from a bucket truck or other vantage point.

### Measures of Effectiveness

The primary measure of effectiveness (MOE) used to evaluate the sign treatments was the percentage of traffic in both travel lanes (measured at the various stations upstream from the

TABLE 1 EXPERIMENTAL DESIGN FOR FIELD STUDIES

| | Study Site No. | | | | | |
|---|---|---|---|---|---|---|
| Sequence | 1 | 2 | 3 | 4 | 5 | 6 |
| **Right Lane Closures:** | | | | | | |
| 1 | TMUTCD | LB | RWA | SYM | CMS | LB |
| 2 | RWA | CMS | TMUTCD | CMS | LB | SYM |
| 3 | SYM | SYM | CMS | LB | TMUTCD | RWA |
| 4 | CMS | RWA | LB | TMUTCD | SYM | TMUTCD |
| 5 | LB | TMUTCD | SYM | RWA | RWA | CMS |
| **Left Lane Closures:** | | | | | | |
| 1 | TMUTCD | LB | CMS | SYM | RWA | LB |
| 2 | RWA | CMS | LB | TMUTCD | SYM | TMUTCD |
| 3 | SYM | SYM | TMUTCD | CMS | LB | RWA |
| 4 | CMS | RWA | RWA | LB | TMUTCD | SYM |
| 5 | LB | TMUTCD | SYM | RWA | CMS | LB |

Note:

TMUTCD = Standard TMUTCD Treatment

SYM = Symbolic Lane Closed Sign

LB = Texas "LANE BLOCKED" Sign

RWA = "ROAD WORK AHEAD" Sign

CMS = Changeable Message Sign

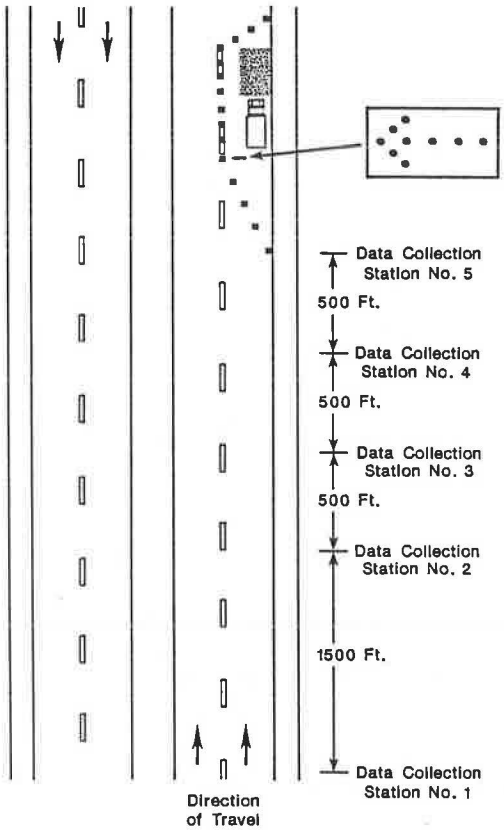


**FIGURE 5 Example of data collection locations at the study sites.**

work zone) that was in the closed lane at each data collection location. Comparisons were made of these percentages for the candidate sign treatments and the standard TMUTCD treatment. For a candidate treatment to be considered effective, the proportion of traffic in the closed lane at Stations 2, 3, and 4 had to be as low as that observed for the standard TMUTCD treatment.

One other MOE used in this study was erratic maneuvers recorded at or approaching the work zone. Erratic maneuvers were classified according to their severity and type. For this evaluation, only the more severe types of conflicts or maneuvers were considered, such as impacts with the cone taper or other traffic control devices and severe vehicle braking or skidding to avoid hitting a traffic control device or other vehicle.

### Study Site Selection and Description

A series of field studies was conducted at rural and suburban freeway work zones near Ft. Worth and Dallas, Texas. The study sites were selected with help from SDHPT personnel. The criteria for selecting study sites were as follows:

- Relatively low traffic volumes (i.e., traffic volumes that were of 30,000 or fewer vpd), so that queues would not form upstream of the work zone when a travel lane was closed;
- Adequate sight distance of at least 1,500 ft to the arrow panel; and
- Actual maintenance work activity being performed and a reason to have a travel lane closed. In addition, the actual work activity had to be located a considerable distance downstream of the lane closure and cone taper.

## STUDY RESULTS

### Left Lane Closure

Data collected at each site where a left (inside) lane closure was studied were pooled for statistical analysis. Table 2 presents the average percentage of vehicles in the closed left lane at the data collection stations upstream of the work zone. At the data collection location 3,000 ft from the cone taper (Station 1), the percentage of traffic in the closed lane was found to be very similar for all treatments (TMUTCD and candidate) and ranged from 30.7 to 32.8 percent. A chi-square test of the equality of the proportions (a contingency test for independence between the proportion of traffic in the closed lane and that for the treatments) indicated that the percentages were the same for each treatment. This result was expected since it was assumed that traffic had not yet been affected by the traffic control treatment present at the work zone. However, the percentages in the closed lane were found to differ significantly between treatments at each of the data collection locations 1,500, 1,000, and 500 ft from the cone taper (Stations 2, 3, and 4). Generally speaking, the LANE BLOCKED and CMS treatments yielded the lowest proportion of traffic in the closed lane at each of these data collection locations. Furthermore, the LANE BLOCKED and CMS treatments were not found to be statistically different from each other, indicating that their performance was nearly identical in terms of influencing drivers to exit the left travel lane.

TABLE 2 PERCENTAGE OF VEHICLES IN CLOSED LANE: LEFT LANE CLOSURE (ALL SITES)

| | Distance From Beginning of Cone Taper (ft) | | | |
|---|---|---|---|---|
| Treatment | 3000 | 1500 | 1000 | 500 |
| TMUTCD | 33.2 | 28.1 | 20.1 | 11.0 |
| ROAD WORK AHEAD | 32.8 | 29.3 | 22.7 | 16.7 |
| Symbolic Lane Closed | 32.2 | 24.9 | 19.6 | 11.9 |
| CMS | 32.4 | 20.7 | 13.5 | 6.7 |
| LANE BLOCKED | 30.7 | 22.3 | 15.0 | 7.2 |

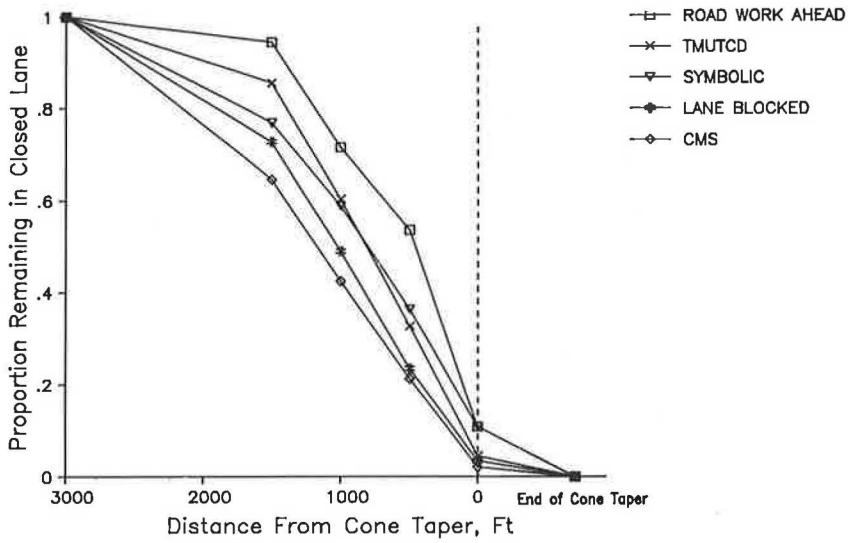


**FIGURE 6 Average effect of TMUTCD and candidate signing treatments (left-lane closures; all sites combined).**

A slightly different perspective of how the standard TMUTCD and the candidate treatments affected traffic was obtained by normalizing the volumes measured at each of the data collection locations in the left (closed) lane and dividing them by the volume recorded in the left lane at the first data collection location. The resulting proportions illustrate how the treatments affected traffic in the left lane as it approached the work zone. These normalized proportions are shown in Figure 6. As can be seen, the proportion of traffic remaining in the closed left lane was highest for the ROAD WORK AHEAD treatment and lowest for the CMS and LANE BLOCKED treatments. As found in the chi-square test, the proportions were essentially the same for both the CMS and LANE BLOCKED treatments. These proportions show that (a) the CMS and LANE BLOCKED treatments were most effective in influencing motorists to exit the closed lane farther upstream, (b) the symbolic LANE CLOSED treatment performed as well as the TMUTCD treatment (but not as well as the CMS and LANE BLOCKED treatments), and (c) the ROAD WORK AHEAD treatment was the least effective of the signs evaluated.

TABLE 3 PERCENTAGE OF VEHICLES IN CLOSED LANE: RIGHT LANE CLOSURE (ALL SITES)

| | Distance From Beginning of Cone Taper (ft) | | | |
|---|---|---|---|---|
| Treatment | 3000 | 1500 | 1000 | 500 |
| TMUTCD | 66.6 | 52.0 | 50.4 | 25.7 |
| ROAD WORK AHEAD | 66.4 | 59.4 | 49.7 | 38.0 |
| Symbolic Lane Closed | 67.2 | 45.8 | 36.8 | 26.3 |
| CMS | 65.6 | 44.3 | 27.8 | 17.5 |
| LANE BLOCKED | 66.3 | 42.3 | 29.4 | 18.9 |

### Right Lane Closure

Table 3 presents the average percentage of the total approach volume that was in the closed lane under each treatment for those sites at which the right lane was closed to traffic. Again, the results of a chi-square test for the data 3,000 ft from the cone taper (Station 1) showed no significant differences among the various treatments. The percentages at this station for each of the treatments were between 65.6 and 67.2. The results at the other data collection locations, however, show significant differences among treatments, with the percentage of traffic in the closed right lane the highest for the ROAD WORK AHEAD treatment and lowest for the CMS and LANE BLOCKED treatments. The results of the symbolic LANE CLOSED and TMUTCD treatments were similar and fell between the ROAD WORK AHEAD results and those of the CMS and LANE BLOCKED treatments.

The data for the right-lane closures were normalized in the same manner as that for the left-lane closed data to show the proportion of traffic remaining in the closed right lane at each of the data collection locations. These data are shown in Figure 7. The trends are similar to those for the left-lane closures; the CMS and LANE BLOCKED treatments were most effective in influencing drivers to exit the closed right lane farther upstream, the symbolic LANE CLOSED and TMUTCD

treatments performed similarly but less effectively than the CMS or LANE BLOCKED treatments, and the ROAD WORK AHEAD treatment was the least effective in encouraging drivers to exit the closed lane.

It should be noted that the values in the tables and figures represent averages over the study sites examined. In actuality, considerable variation in performance for each treatment was observed from site to site, which was due to the diverse nature of work zones themselves and other site-specific factors that influence driver behavior at a location. For example, Figure 8 shows the variation in performance for the standard TMUTCD treatment observed over the study sites where the right lane was closed. Similar site variation was also evident for the candidate treatments. However, the relative performance of the TMUTCD and candidate treatments was, for the most part, consistent on an individual site basis. That is, the CMS and LANE BLOCKED treatments were generally the most effective, followed by the symbolic LANE CLOSED and TMUTCD treatments, with the ROAD WORK AHEAD treatment generally the least effective.

### Analysis of Erratic Maneuvers

The second type of data collected during the studies of the candidate treatments was erratic maneuvers occurring at or just ahead of the cone taper and work zone. These data were obtained by videotaping traffic movements at the cone taper from a bucket truck or other vantage point. The data were collected to determine whether the candidate treatments resulted in a greater number of erratic or unsafe maneuvers at the lane closure.

Erratic maneuvers and conflicts at the study sites were found to be extremely rare events under any of the treatments stud-

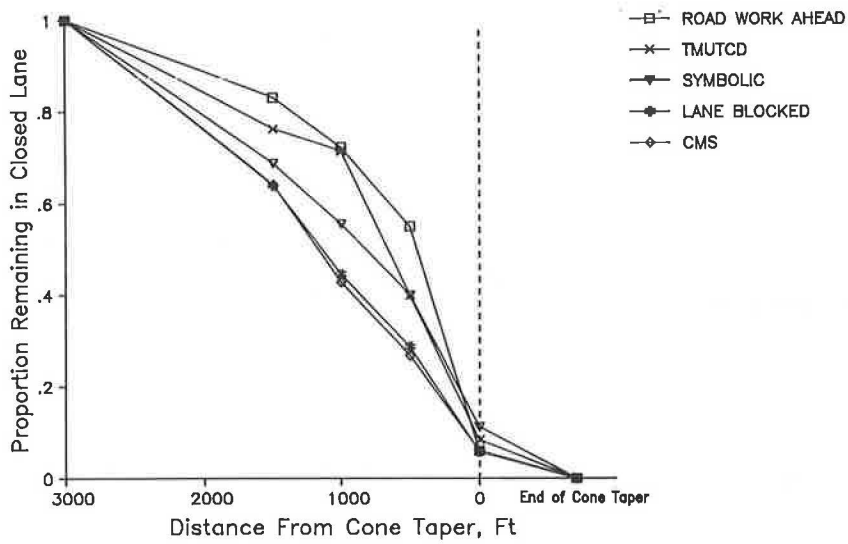


**FIGURE 7 Average effect of TMUTCD and candidate sign treatments (right-lane closures; all sites combined).**

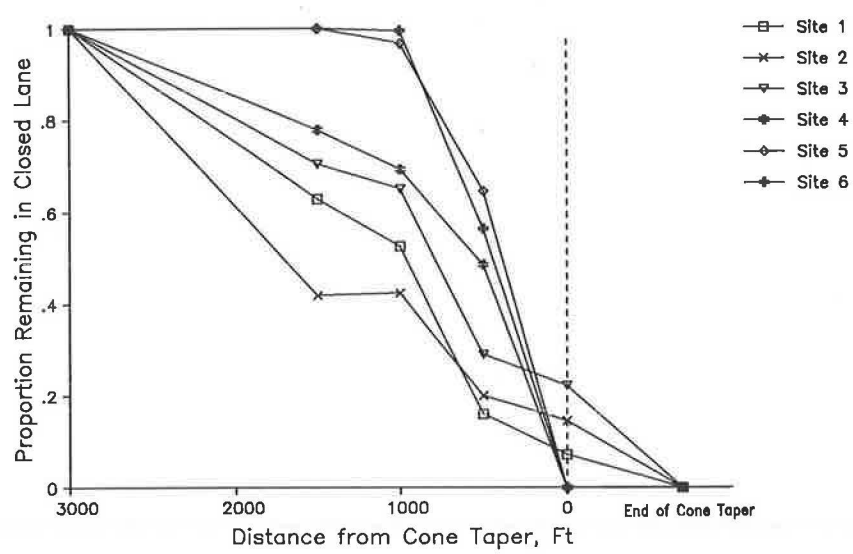


**FIGURE 8 Variation in effect of TMUTCD sign treatment (right-lane closure sites).**

ied. There were only five incidents overall in which a vehicle ran into the cone taper. However, four of these occurred when the ROAD WORK AHEAD treatment was in place (the fifth incident occurred during the study of the standard TMUTCD treatment). None of these incidents resulted in any type of damage or injury to drivers, workers, vehicles, or traffic control devices. Because of the limited number of these incidents, it was not necessary (or possible) to perform any type of statistical analysis. Nevertheless, it did not appear that any of the treatments (except the ROAD WORK AHEAD) was more hazardous to drivers than any other, including the TMUTCD treatment.

## SUMMARY AND CONCLUSIONS

Twelve field studies were conducted at work-zone locations on rural or suburban four-lane divided highways to evaluate the effectiveness of four candidate traffic control treatments proposed for short-duration maintenance operations in which a lane closure is required. The results of the field studies show that the Texas LANE BLOCKED and CMS treatments were the most effective (of those examined) in influencing a greater proportion of drivers to exit the closed travel lane farther upstream from the work zone. In addition, the symbolic LANE CLOSED treatment was nearly as effective as the standard TMUTCD configuration in this regard but neither of these was as effective as the CMS or LANE BLOCKED treatments. Finally, the ROAD WORK AHEAD treatment was found to be the least effective of the signs studied.

The erratic-maneuver data collected at the study sites showed few serious erratic maneuvers during evaluation of any of the treatments (including the standard TMUTCD configuration). Erratic maneuvers may have been more prevalent during the evaluation of the ROAD WORK AHEAD treatment. However, it was not possible to determine this conclusively.

On the basis of the results of these studies, the Texas LANE BLOCKED or CMS treatments were recommended to the SDHPT for short-duration maintenance operations (that require a lane closure) on four-lane divided highways with traffic volumes of 30,000 or fewer vpd and with at least 1,500 ft of sight distance to the work-zone lane closure. Both of these treatments include the use of an arrow panel and a cone taper immediately ahead of the work zone. The LANE BLOCKED sign costs considerably less than a CMS and can be easily constructed in the maintenance shop, making it an attractive alternative.

Care should be taken not to extend the results of these studies to sites with characteristics not similar to those evaluated. Specifically, it is not known whether these reduced traffic control treatments would be effective at work-zone locations with limited sight distance, on divided highways with more than two lanes per direction, or on four-lane divided highways with traffic volumes exceeding 30,000 vpd. Additional research would be necessary to evaluate the treatments under each of these types of conditions before their effectiveness could be assured.

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