Technical Report Documentation Page

1. Report No. FHWA/TX-87/377-2F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Traffic Control for Short Duration and Stop-and-Go Maintenance Operations on Four-Lane Divided Roadways		5. Report Date March 1988 6. Performing Organization Code
7. Author(s) C. L. Dudek, G. L. Ullman, K. N. Balke, R. A. Krammes		8. Performing Organization Report No. Research Report 377-2F
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, TX 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Study No. 2-18-85-377
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation: Transportation Planning Division P.O. Box 5051 Austin, TX 78763		13. Type of Report and Period Covered Final Report (September 1984-November 1987) 14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA
Study Title: Traffic Control for Stop-and-Go and Short-Term Maintenance/Construction Operations and Techniques for Installing Lane Closures

16. Abstract

This report summarizes the results of research conducted to develop and evaluate reduced traffic control set-ups for short duration and stop-and-go maintenance operations (those lasting less than 20 minutes per work location) on four-lane, divided highways. Several candidate signing treatments were developed and compared to the standard Texas Manual On Uniform Traffic Control Devices (TMUTCD) set-up for a minor operation on multilane divided roadways. Comparisons were made of 1) the effect of the signing treatments on where drivers exited the closed lane as they approach the lane closure, and 2) the manpower and time requirements for the set-up and removal of the TMUTCD treatment and one of the candidate treatments. Study results indicate that a changeable message sign or a Texas "LANE BLOCKED" sign placed 1500 ft before the cone taper results in drivers exiting the closed lane farther upstream than other signing treatments or the TMUTCD treatment. Studies of the set-up and removal times for the TMUTCD and the "LANE BLOCKED" treatments show that the "LANE BLOCKED" treatment requires significantly less time to install and remove than the TMUTCD treatment.

17. Key Words Work Zone Traffic Control, Traffic Operations, Roadway Maintenance Operations, Freeway Work Zone Traffic Control	18. Distribution Statement No restrictions. This Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	96	

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

TRAFFIC CONTROL FOR SHORT DURATION AND STOP-AND-GO MAINTENANCE OPERATIONS ON FOUR-LANE DIVIDED ROADWAYS

by

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Research Report 377-2F
Research Study Number 2-18-85-377

Sponsored by

Texas State Department of Highways and Public Transportation
in cooperation with
U. S. Department of Transportation, Federal Highway Administration

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843

March 1988

METRIC CONVERSION FACTORS

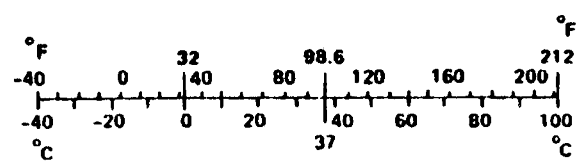
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

The authors wish to thank Mr. Lewis Rhodes (D-18STO) who served as the SDHPT Technical Coordinator for this study for his valuable comments and guidance during this research. The authors would also like to thank the members of the Study 377 Technical Advisory Committee for their help and assistance. A listing of those members is given below.

Ben Bohuslav	District 7 (formerly District 13)
Walter Collier	District 15
Bill Davis	District 2
Herman Gadeke	District 15
Larry Galloway	District 12
Hunter Garrison	District 12 (retired)
Herman Haenel	D-18STO
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Tom Kelley	District 18
Steve Levine	District 12
Blair Marsden	D-18STO
John Miller	District 18
Morgan Prince	District 11
Lewis Rhodes	D-18STO
Mark Thorp	D-18STO
Carl Voight	District 14 (retired)
John Wilder	District 14

A special thanks is also given to Messrs. Bill Davis (District 2, retired), Glenn Elliot (District 2), and Bob Brock (District 18) for their assistance with the field studies. Finally, the efforts of Mr. Teofilo Rebagay (District 12) and Dr. Olga Pendleton (TTI) during the collection and analysis of the field study data are gratefully acknowledged.

SUMMARY OF FINDINGS

A number of field studies were performed as part of Study 377 to evaluate the effectiveness of several candidate signing treatments for short duration and stop-and-go maintenance operations on four-lane divided roadways with AADTs less than 30,000 vpd. The candidate treatments were compared to a standard TMUTCD setup for minor operations on multi-lane divided roadways in terms of where drivers exited the closed lane in advance of the work zone. The candidate treatments consisted on various static and dynamic signs placed 1500 ft from the work zone together with an arrow panel (the primary information source for drivers approaching the work zone) placed immediately in front of the work zone.

The results of a limited number of initial studies showed that the cone taper, placed immediately at the beginning of the work zone, resulted in drivers exiting the closed lane farther upstream than when no cone taper was present. This was true for all of the candidate signing treatments studied. Consequently, subsequent additional studies of the candidate treatments were conducted only with the cone taper present at the work site.

The results of the field studies showed that a Changeable Message Sign and a Texas "LANE BLOCKED" sign were most effective in getting drivers to exit the closed lane farther upstream from the work zone. This was true both for median and shoulder lane closures. These treatments were found to be even more effective than the standard TMUTCD setup.

The setup and removal times for the TMUTCD and Texas "LANE BLOCKED" treatments were observed at several maintenance operations in Districts 2 and 18. These studies showed that the "LANE BLOCKED" treatment required only about one-half of the time and manpower to install and remove that the TMUTCD treatment required.

IMPLEMENTATION STATEMENT

Based on the results of the field studies conducted for Study 377, it is recommended that either a Changeable Message Sign or a Texas "LANE BLOCKED" sign, placed 1500 ft upstream of the work zone, should be used (in conjunction with a cone taper and a flashing arrow panel) for traffic control during short duration and stop-and-go maintenance operations on four-lane divided highways with AADT's less than or equal to 30,000 vehicles per day. As part of this report, guidelines for installing and removing lane closures for short duration and stop-and-go maintenance operations are included in Appendix A.

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1. INTRODUCTION

The Texas Manual on Uniform Traffic Control Devices (1) (TMUTCD) illustrates the traffic control devices and set-ups required for many typical highway and street maintenance operations. Generally speaking, the different operations are classified into three broad categories; major operations, minor operations, and moving operations. Major operations require traffic control to direct or warn drivers during both day and night conditions. Minor operations last less than one daylight period, and so require traffic control to warn traffic during day conditions only. Both major and minor maintenance operations generally remain stationary throughout the day. In contrast, moving operations are those where the work zone moves during daylight conditions. Moving operations are further subdivided into fast moving operations (with average speeds greater than 5 mph) and slow moving operations (with average speeds less than 5 mph and/or intermittent stops).

Many maintenance activities require a very short period of time to complete. Often, only 15 to 20 minutes is spent at a particular highway location performing the actual maintenance work. At the present time, these types of maintenance activities (to be referred to as short duration and stop-and-go operations in this report) are grouped in with slow moving maintenance operations. Specific definitions of the stop-and-go and short-duration operations are included in Chapter 2 of this report.

Statement of the Problem

At the present time, the TMUTCD definition of slow moving maintenance operations encompasses the short duration and stop-and-go operations. However, traffic control requirements for these types of operations are not well defined, especially when these operations must be performed on high-speed divided facilities. Consequently, maintenance officials often use the traffic control set-up specified in the TMUTCD for a major or minor maintenance lane closure when they have to close a highway travel lane for maintenance operations that last only 15 to 20 minutes at a particular location on a highway. The actual placement of the advanced warning signs and the channelizing devices that are part of the lane closure set-up often takes longer than the actual work activity to be performed.

The traffic control requirements for short duration and stop-and-go maintenance operations should be portable, inexpensive, and effective in directing vehicles out of the closed travel lane (2). The need exists to develop a reduced traffic control set-up for short duration and stop-and-go maintenance operations that is portable and still effective in directing drivers safely and efficiently through the maintenance operations on multilane divided highways.

Study Objectives

The specific objectives of the study were as follows:

1. Based on an analysis of driver information and traffic control requirements for short duration and stop-and-go maintenance operations, develop reduced candidate traffic control set-ups (configurations) for these types of maintenance operations on multilane divided roadways. Due to limited study funds and time frame, these candidate configurations were limited to maintenance operations on four-lane divided highways with traffic volumes equal to or less than 30,000 AADT.

2. 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.

3. Conduct field studies to assess the potential benefit to the Department in implementing one of the acceptable candidate lane closure traffic control set-ups with reduced traffic control devices.

4. Based on the results of the field studies, develop guidelines regarding the use of reduced traffic control for short duration and stop-and-go lane closures on four-lane divided highways.

2. BACKGROUND

Definitions

The TMUTCD classifies maintenance and construction operations into three broad categories:

1. Major Operations

2. Minor Operations

3. Moving Operations

The definitions were updated in the Traffic Control Plan (TCP) Training Guide (3) included with the new TCP Plan Sheets transmitted to the SDHPT Districts in January 1986.

Major Operations

A work zone that will require traffic control devices to warn or direct traffic during both daylight and/or nighttime conditions.

Minor Operations

A work zone that will require traffic control devices to warn or direct traffic during daylight periods only. At the end of each workday, all work zone traffic control devices should be removed from the view of all motorists and no unusual conditions or hazards should exist that require advance warning to the driving public. The TMUTCD also specifies that minor operations on roadways with high traffic volumes and high speeds should be considered as major operations.

Moving Operations

A work activity that requires work vehicles and the work zone to move during daytime conditions. This category is further subdivided into the following classifications.

Fast Moving Operations -- A work activity that maintains an average speed of 5 mph or more.

Slow Moving Operations -- A work activity that maintains an average speed of less than 5 mph. This type of operation may involve intermittent stop conditions of no longer than 2 hours.

This definition of slow moving operations encompasses a wide range of work activities and operations. For purposes of this research, it was necessary to develop more precise definitions and further subdivide this category. Based on telephone conversations with several SDHPT District Maintenance Engineers, the following definitions were developed.

Short Duration Operations -- A work activity of approximately 20 minutes or less in duration that is performed at only one location on a roadway.

Stop-and-Go Operations -- A work activity of approximately 20 minutes or less in duration that is performed at more than one location on a roadway.

Figure 2-1 illustrates both a short duration and a stop-and-go maintenance operation. For Case I (short duration) of Figure 2-1, note that only one work activity is performed on the roadway. As long as the work activity lasts less than 20 minutes, the work zone could be classified as a short duration maintenance operation. However, if the work crew makes more than one stop of up to 20 minutes at each stop on a particular highway, as depicted in Case II of Figure 2-1, then the work zone would be classified as a stop-and-go maintenance operation. The primary distinguishing factors between these two types of operations, then, is the number of stops that a work crew makes on a section of highway.

Based on the above new definitions, the following represents a revised classification of maintenance operations for the sake of discussion in this report.

1. Major Operations
2. Minor Operations
3. Short Duration Operations
4. Stop-and-Go Operations
5. Moving Operations

Table 2-1 provides a list of some of the regularly performed maintenance activities, categorized based on the above classification.

Characteristics of the Different Maintenance Operations

There are several key distinguishing characteristics that help explain the differences between the different types of maintenance operations. Table 2-2 summarizes some of these characteristics. Note from this table that the number of vehicles and the number of vehicles used for each type of operation are approximately the same.

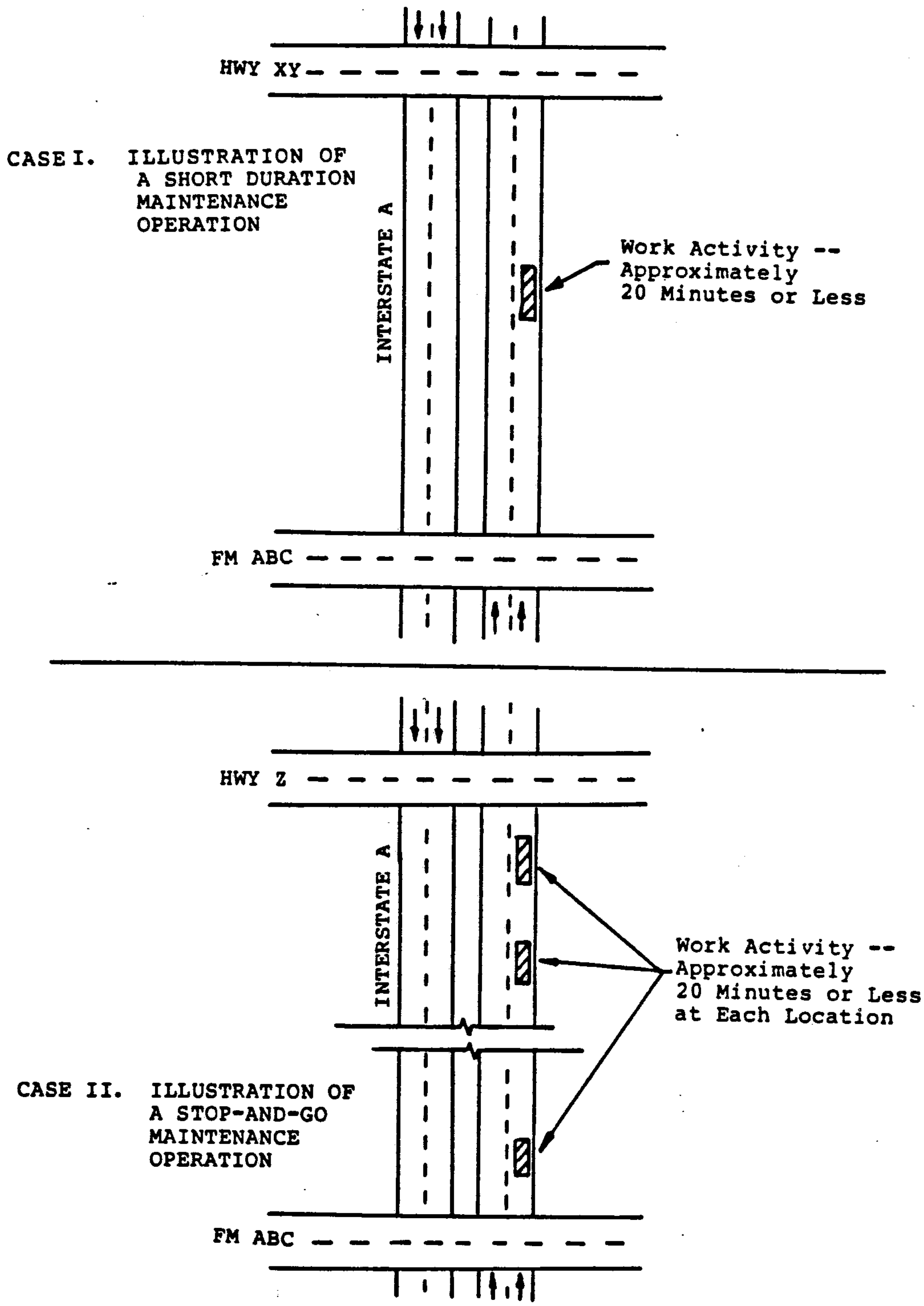


Figure 2-1. Illustration of Short Duration and Stop-and-Go Maintenance Operations.

TABLE 2-1. CLASSIFICATION OF TYPICAL WORK ACTIVITIES

Type of Operation	Typical Work Activities
Major or Minor Maintenance	- Pavement Repairs (Concrete) - Utility Construction - Long-Term Pavement Repairs
Short Duration Maintenance	- Inspection of Drainage Structures* - Relamping of Street Lights and Signals* - Servicing of Litter Barrels* - Treatment of Pavement Bleeding (with sand) - Guardrail Maintenance* - Measurement of Bridge Clearance
Stop-and-Go Maintenance	- Temporary Pothole Patching - Crack Sealing - Planning or Profiling Pavement Bumps - Shoulder Maintenance* - Cleaning of Traffic Signs*
Moving Maintenance	- Roadway Inspection - Mowing - Herbicide Spraying - Blading of Shoulders - Snow Plowing/Sanding - Sweeping/Vacuuming - Pavement Striping - Raised Pavement Marker Replacement

* Work activity is usually performed on the shoulder. Only in unusual conditions will a lane closure be required.

TABLE 2-2. CHARACTERISTICS OF MAINTENANCE OPERATIONS

CHARACTERISTICS	MAJOR	MINOR	SHORT DURATION	STOP-AND-GO	MOVING
Time Duration	> 1 daylight period	< 1 daylight period	15 to 20 minutes	15 to 20 minutes	< 5 minutes
Mobility	Stationary	Stationary	Intermittent stops (different highway)	Intermittent stops (same highway)	Continuously
Number of Work Vehicles	More than 3	More than 3	2 to 3	2 to 3	2 to 3
Number of Personnel	More than 4	More than 4	2 to 4	2 to 4	2 to 4
Time Spent Outside Vehicle	Varies	Varies	15 to 20 minutes	15 to 20 minutes	None
Type of Equipment	Heavy equipment	Heavy equipment	Hand Operated; small tools	Hand Operated; small tools	Mobile (paint striper)
Required Traffic Control	3 static signs; channelizing devices;arrow panel	3 static signs; channelizing devices; arrow panel	(Not covered in MUTCD)	(Not covered in MUTCD)	Caravan; arrow panel; signing (optional)

The most significant differences among operations can be found in the mobility and worker exposure (measured as the time spent outside the work vehicles) characteristics. Moving maintenance operations move continuously down a travel lane or lanes at speeds typically from 5 to 15 mph. With proper planning, very few stops are required to complete the activity. If stops do occur, they are generally unscheduled and may be due to mechanical difficulty or inadequate supplies. The duration of the stops have been observed to range from momentary to more than one hour (4). The work crew performs the majority of the work task from inside the maintenance vehicles and is usually not outside the vehicles exposed to oncoming traffic for substantial lengths of time.

On the other hand, major and minor maintenance operations are typically stationary and require more time and equipment to perform the work activity. For the most part, the maintenance personnel must perform the work task while outside of the work vehicles. Thus, the exposure to the work crew to oncoming traffic is usually greater in these types of maintenance operations.

Short duration and stop-and-go operations have some characteristics of both minor operations and moving operations. Like moving operations, short duration and stop-and-go operations are relatively mobile. Usually, these types of operations can be completed in a short period of time, typically less than 20 minutes. Once the work activity has been completed at a location, the maintenance crew moves to the next work location, whether it is downstream on the same roadway (as in a stop-and-go operation) or located on a different roadway (as in a short duration operation). On the other hand, these operations also have similarities to minor operations. For example, when the work crew is at a given location, the types of tasks performed in short duration and stop-and-go operations often require the workers to be out of the vehicles and physically exposed to oncoming traffic. However, the amount of time that they are exposed to traffic at any one location is relatively short.

Traffic Control Requirements for Short Duration and Stop-and-Go Maintenance Operations

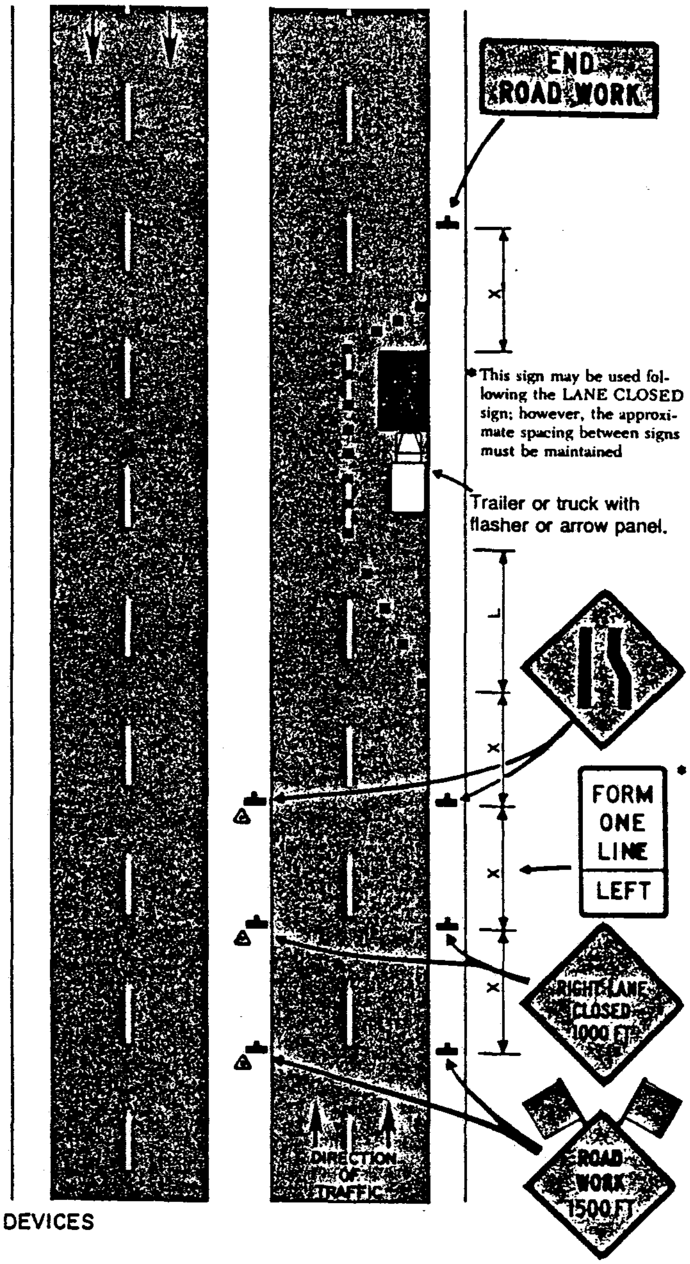
Because the work activity for minor operations is primarily stationary and because worker exposure to traffic is fairly high, the traffic control that is typically used with a minor maintenance operation is relatively extensive. An example of the traffic control plan for a minor operation on a multilane divided facility is shown in Figure 2-2. The TMUTCD specifies that three static advance warning signs and a cone taper be used to close a travel lane. The TMUTCD also states that a flashing arrow panel may be used as part of the traffic control; however, it should be used to supplement the other traffic control devices (1).

Traffic control for moving maintenance operations on multilane divided roadways is portable and consists of relatively few traffic control devices. As shown in Figure 2-3, the traffic control plan for a moving operation

NOTES:

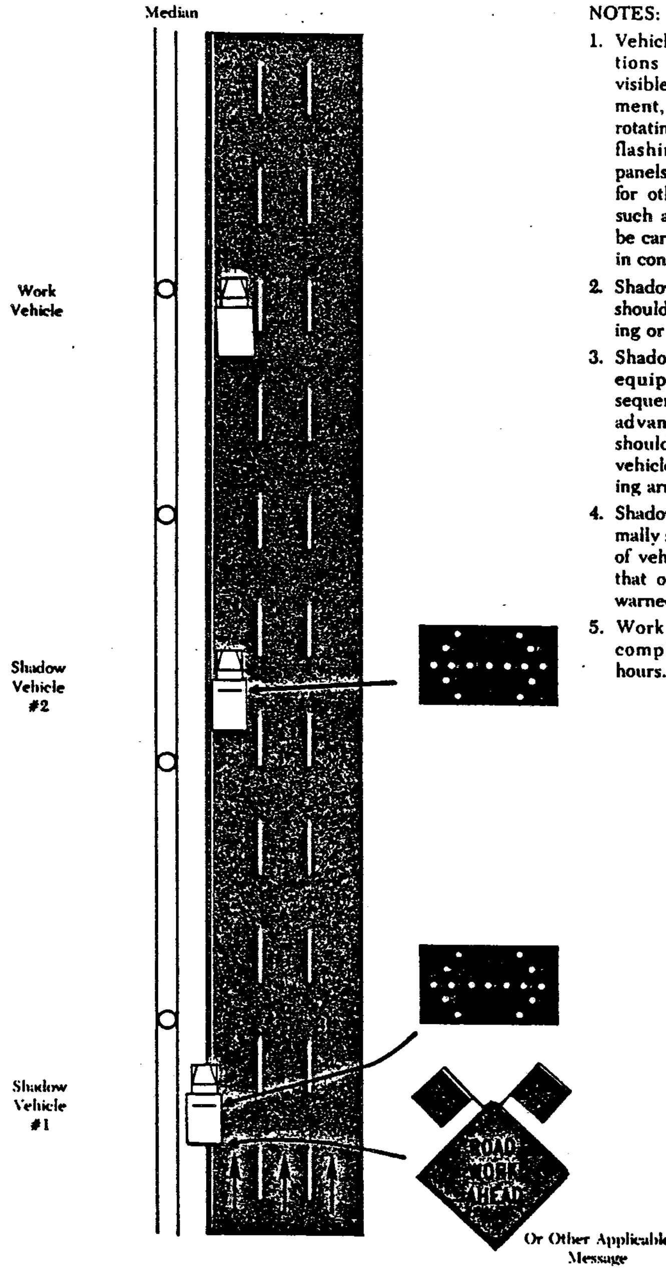
1. Taper Formula:
   $L = S \times W$ for speeds of 45 or more.
   $L = \frac{WS^2}{60}$ for speeds of 40 or less.
   Where:
   L = Minimum length of taper.
   S = Numerical value of posted speed limit prior to work or 85 percentile speed.
   W = Width of offset.
2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.
3. Flashing warning lights and/or flags may be used to call attention to the advance warning signs and/or equipment.
4. All distances and spacings shown are approximate.
5. The word UTILITY may be substituted for ROAD in all signs where applicable.
6. One or more flaggers to be used where traffic, road conditions, or terrain warrant their use.

Posted Speed or 85% Speed (MPH)	X Min. Distance (feet)
30 or less	80
35	120
40	160
45	240
50	320
55	500



KEY:
■■ CHANNELIZING DEVICES
▲ OPTIONAL

Figure 2-2. TMUTCD Traffic Control Plan for Minor Operations on Multi-lane Divided Roadways.



NOTES:

1. Vehicles used for these operations should be made highly visible with appropriate equipment, such as: flashing lights, rotating beacons, flags, signs and flashing or sequencing arrow panels. Also, it may be desirable for other traffic control devices such as cones and barricades to be carried on the vehicle for use in controlling traffic.
2. Shadow Vehicle #2, when used, should be equipped with a flashing or sequencing arrow board.
3. Shadow Vehicle #1 should be equipped with a flashing or sequencing arrow board and an advance warning sign. Sign should be mounted on rear of vehicle so as not to obscure flashing arrow.
4. Shadow vehicle #1 should normally stay upstream of any queue of vehicles that may develop so that oncoming vehicles may be warned of the road work ahead.
5. Work should normally be accomplished during off-peak hours.

Figure 2-3. TMUTCD Traffic Control Plan for Moving Operations on Multi-lane Divided Roadways.

consists of a caravan of vehicles, delineated with flashing lights, rotating beacons, flags, signs, and a flashing or sequencing arrow panel (1). Here, the arrow panel has become the primary traffic control device due to its high target value and legibility distance (4). As stated previously, workers generally perform moving maintenance work from within the vehicle and so are not directly exposed to moving traffic for substantial lengths of time.

The type of traffic control devices to be used in a short duration or stop-and-go operation should reflect characteristics from major or minor as well as moving maintenance operations. In terms of portability and ease of installation and removal, the traffic control for short duration and stop-and-go operations should reflect that of a moving operation. In terms of providing driver information and promoting work safety, the traffic control should be similar to major or minor maintenance operations. Ideally, short duration or stop-and-go maintenance traffic control should be composed of as few devices as possible while still providing adequate worker safety and driver information. Also, since a short duration and stop-and-go maintenance operation exhibit many of the same types of characteristics, it is assumed for purposes of this research that the same traffic control plan could be used for both types of operations.

Given the above broad description of traffic control needs for short duration and stop-and-go operations, the next step becomes deciding which and how many specific traffic control devices (signs, channelizing devices, etc.) are really necessary for these types of operation. The concept of Positive Guidance, developed by Alexander et. al. (5) provides a theoretical basis for identifying necessary driver responses in advance of a work zone. In turn, it is then possible to hypothesize appropriate types and locations of information to promote proper responses and minimize undesirable actions or consequences. A discussion of Positive Guidance and its application to driver information requirements at work zone lane closures on multilane highways is included in Appendix A.

Based on the analysis of Positive Guidance and driver information requirements at work zones, a traffic control set-up was developed for a short duration or stop-and-go operation that consists of an arrow panel located at the beginning of the work zone, coupled with an advance warning sign 1500 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 it is used for major or minor work zone operations (4,6,7,8). Consequently, it was hypothesized that the arrow panel would serve as the primary source of information to drivers for short duration and stop-and-go operations, while the other traffic control devices would supplement the arrow panel, informing drivers that they are approaching a hazard and reinforcing the implied maneuver warning information of the arrow panel.

To evaluate the proposed traffic control model for short duration and stop-and-go operations, a series of field studies were conducted at a number of work zone locations on rural or suburban four-lane divided highways. The studies were designed to determine which advance warning sign(s) were most effective, when used with the arrow panel, in getting drivers to exit the closed lane upstream from the work zone. The studies were also designed to determine whether it was necessary to use a cone taper with the arrow panel and advance warning sign(s). Traffic control set-up and removal time and effort could be reduced significantly if a cone taper was not used. The next chapter presents the study approach to these field studies, while the results of the field studies are presented in Chapter 4.

3. STUDY APPROACH FOR EVALUATING THE EFFECTIVENESS OF PROPOSED SHORT DURATION AND STOP-AND-GO TRAFFIC CONTROL

A series of field studies were conducted to evaluate six candidate advance warning sign configurations for use at short duration or stop-and-go maintenance operations on four-lane divided highways where it is necessary to close a travel lane. These configurations used fewer advance warning signs than are included in a standard TMUTCD configuration for a minor maintenance operation, and so were expected to require less set-up and removal time than the TMUTCD configuration. The purpose of the field studies was to compare the effectiveness of each candidate configuration to the standard TMUTCD set-up in terms of safely encouraging drivers to exit the closed lane in advance of the work activity. The studies were also used to determine if it was necessary to use a cone taper with the arrow panel and candidate signing configurations.

The standard TMUTCD set-up for minor freeway maintenance work (involving a lane closure) consisted of three static advance warning signs, a cone taper and an arrow panel placed behind the cone taper in the closed lane. Figure 3-1 presents a schematic diagram of the layout of this set-up.

The first sign a driver encounters when approaching a work zone is a "ROAD WORK AHEAD" sign (CW21-4D), located 1500 ft from the cone taper, which informs drivers that some type of road work exists ahead. This sign does not provide any specific information about the closure itself.

The next sign encountered, 1000 ft from the cone taper, is the "RIGHT/LEFT LANE CLOSED AHEAD" sign (CW20-5D), which provides the driver information that 1) the work zone ahead is a lane closure, and 2) the closure is either a left or right lane closure.

The final advance warning sign in this set-up is the symbolic lane closed sign (CW4-2). This sign, located 500 ft from the cone taper, illustrates to drivers in the closed lane that a lane change maneuver must be performed.

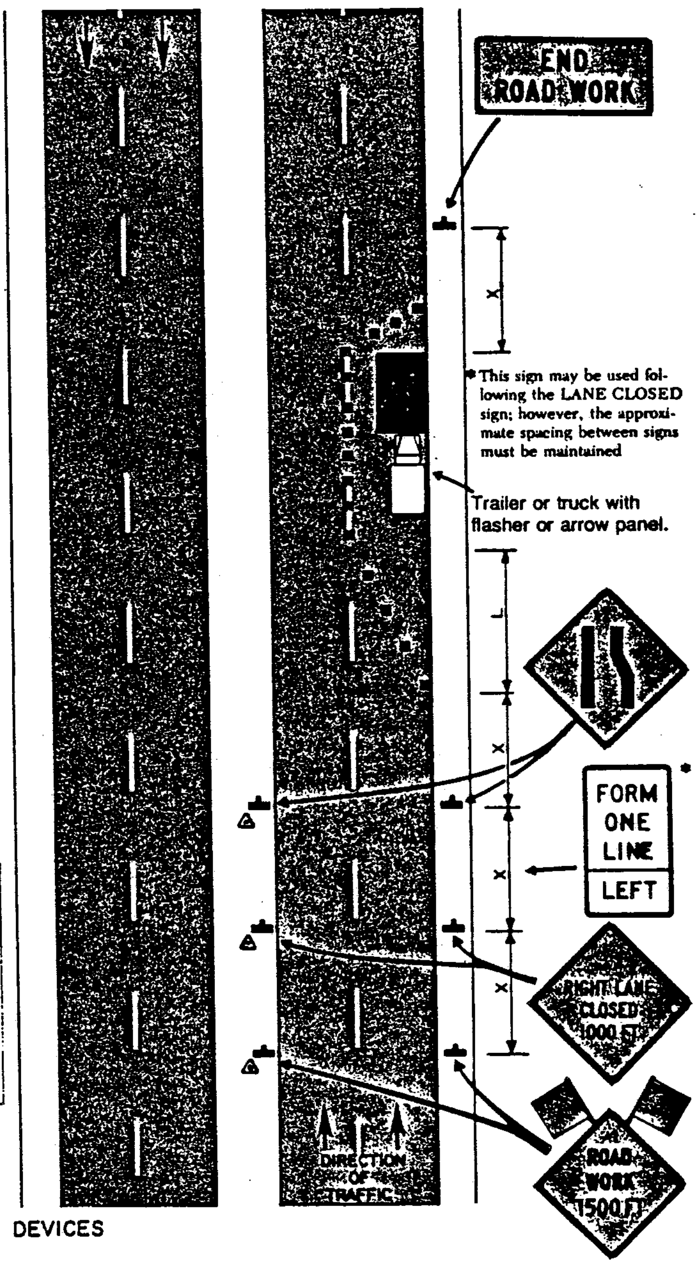
The cone taper, located after the advance warning signs, is used to direct drivers out of the closed lane, and identifies the last location at which the lane change maneuver out of the closed lane may be performed.

In the standard TMUTCD set-up, the function of the arrow panel is to supplement the other traffic control devices. The panel can be located either adjacent to the beginning of the cone taper or behind the taper in the closed lane. For purposes of this research, the arrow panel was located behind the cone taper.

NOTES:

1. Taper Formula:
   $L = S \times W$ for speeds of 45 or more.
   $L = \frac{WS^2}{60}$ for speeds of 40 or less.
   Where:
   L = Minimum length of taper.
   S = Numerical value of posted speed limit prior to work or 85 percentile speed.
   W = Width of offset.
2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.
3. Flashing warning lights and/or flags may be used to call attention to the advance warning signs and/or equipment.
4. All distances and spacings shown are approximate.
5. The word UTILITY may be substituted for ROAD in all signs where applicable.
6. One or more flaggers to be used where traffic, road conditions, or terrain warrant their use.

Posted Speed or 85% Speed (MPH)	X Min. Distance (feet)
30 or less	80
35	120
40	160
45	240
50	320
55	500



KEY:
▪▪ CHANNELIZING DEVICES
△ OPTIONAL

Figure 3-1. TMUTCD Traffic Control Plan for Minor Operations on Multi-lane Divided Highways.

Description of the Candidate Signing Configurations

Six different signing configurations were developed by TTI to be studied. Each configuration was to be evaluated with and without a cone taper in place in advance of the work zone lane closure. As stated in Chapter 2, it was hypothesized that the arrow panel would be the primary source of information to drivers at the work zone, and so would be used under all candidate signing and cone taper conditions. A brief description of each candidate configuration is provided below.

<u>Alternative 1 -- "ROAD WORK AHEAD"</u>

For this configuration, dual "ROAD WORK AHEAD" signs were placed 1500 ft upstream from the beginning of the cone taper. This sign provides little information about the closure, and only indicates that some type of road work exists ahead. This configuration relies on the flashing arrow panel in the cone taper to inform the driver that the lane is closed and that he must be in the open lane when he reaches the work zone. Figure 3-2 provides a schematic diagram of this treatment.

<u>Alternative 2 -- "RIGHT/LEFT LANE CLOSED AHEAD"</u>

This configuration involved placing dual "RIGHT/LEFT LANE CLOSED AHEAD" signs 1500 ft from the beginning of the cone taper. In this configuration, these signs are located 500 ft farther upstream than where they are located in the standard TMUTCD set-up for minor maintenance operations. This sign uses a word message to reinforce the information about which lane is closed that is implied by the arrow panel. Figure 3-3 illustrates this treatment.

<u>Alternative 3 -- Symbolic Lane Closure</u>

In this configuration, symbolic lane closed signs were placed on each side of the travel lanes 1500 ft in advance of the cone taper. This sign reinforces the message of the arrow panel to exit the closed lane. When coupled with the arrow panel, information about the proper driver response to the work zone is provided farther upstream than the standard TMUTCD set-up. The information provided by this sign is similar to that of the word message in Alternative 2, but is presented visually in this configuration. A schematic diagram of this treatment is provided in Figure 3-4.

<u>Alternative 4 -- Changeable Message Sign</u>

For alternative 4, a portable changeable message sign (CMS) was placed 1500 ft upstream from the cone taper. Due to their high target value, these devices can be seen farther upstream than static signs. In addition, a sense of urgency is implied because of the flashing of the message.

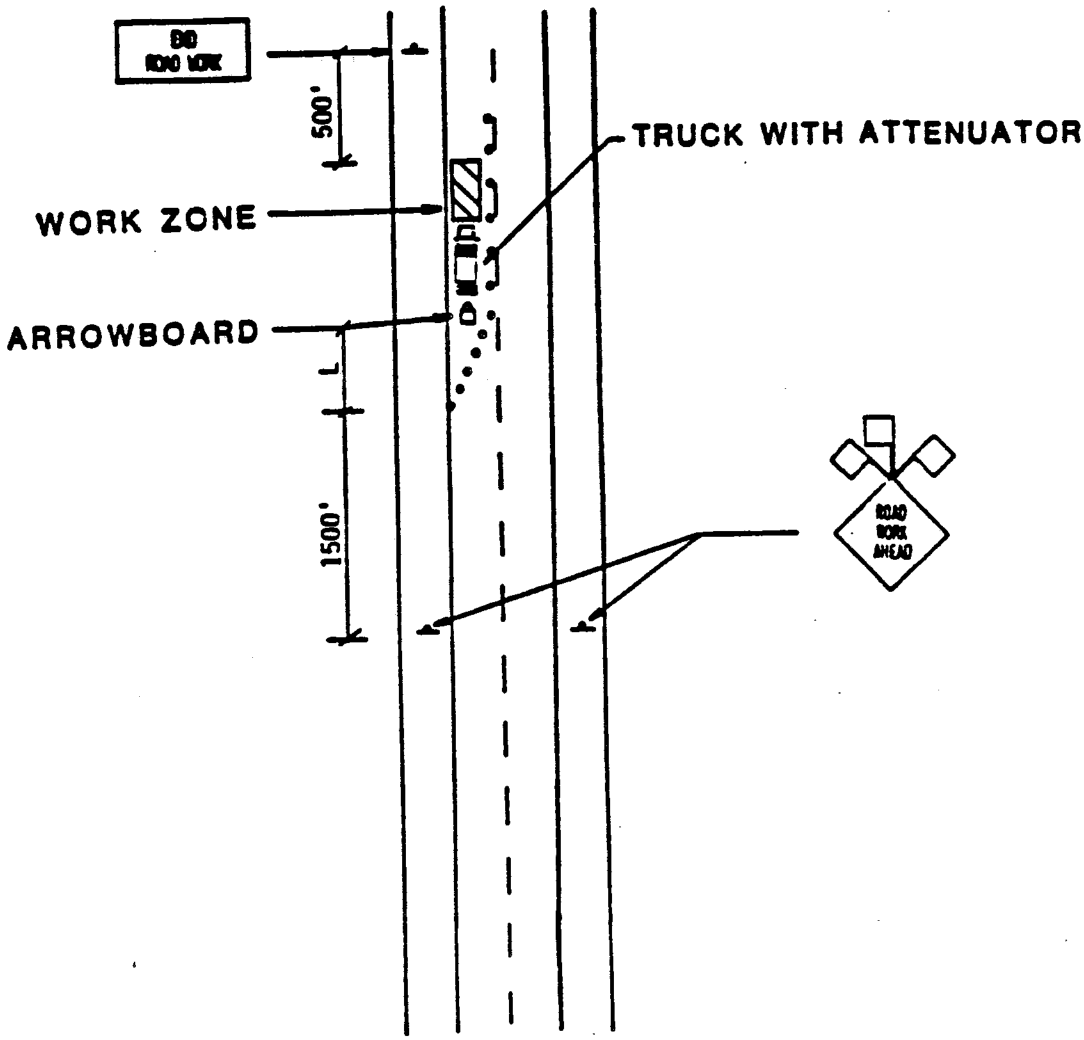


Figure 3-2. Schematic Diagram of "ROAD WORK AHEAD" Candidate Signing Treatment.

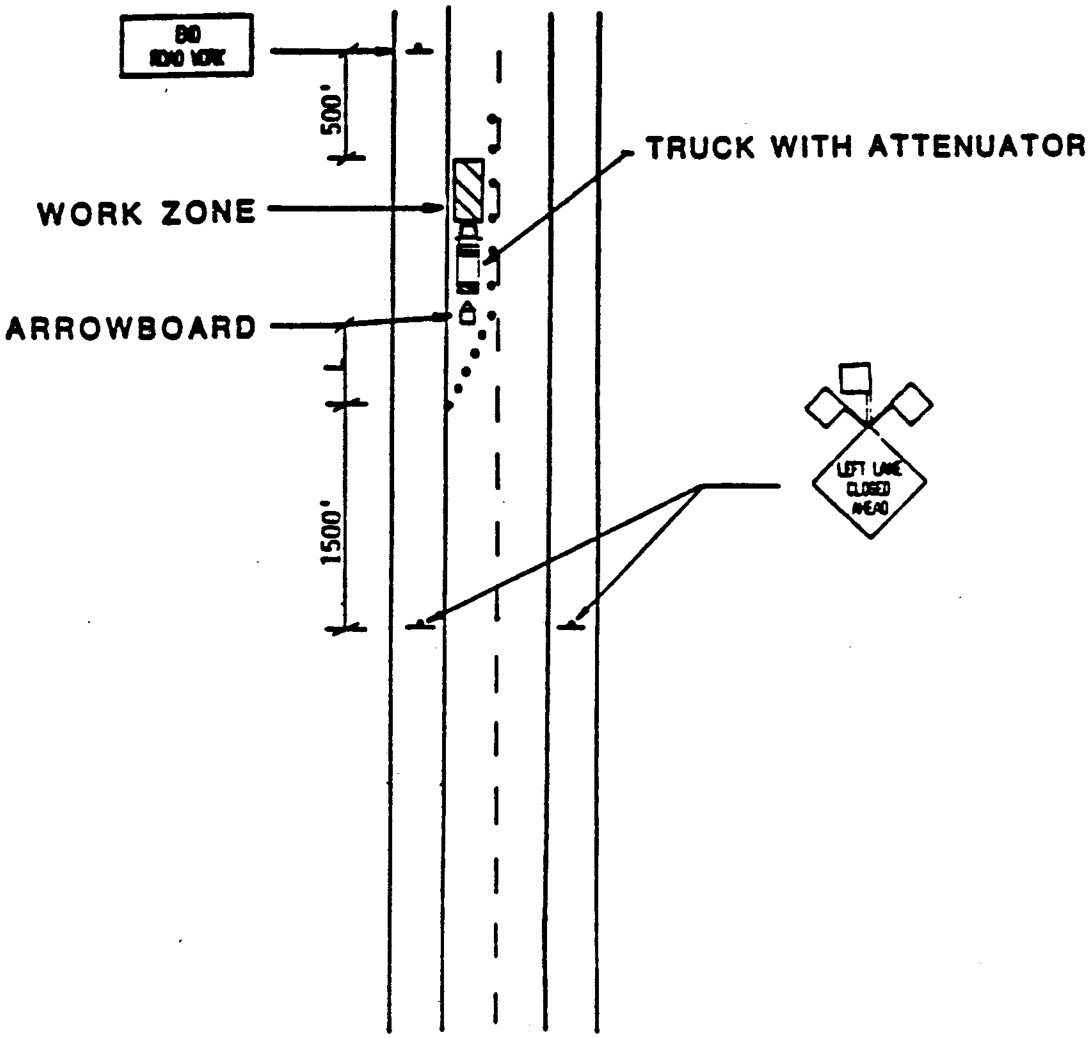


Figure 3-3. Schematic Diagram of "RIGHT/LEFT LANE CLOSED AHEAD" Signing Treatment.

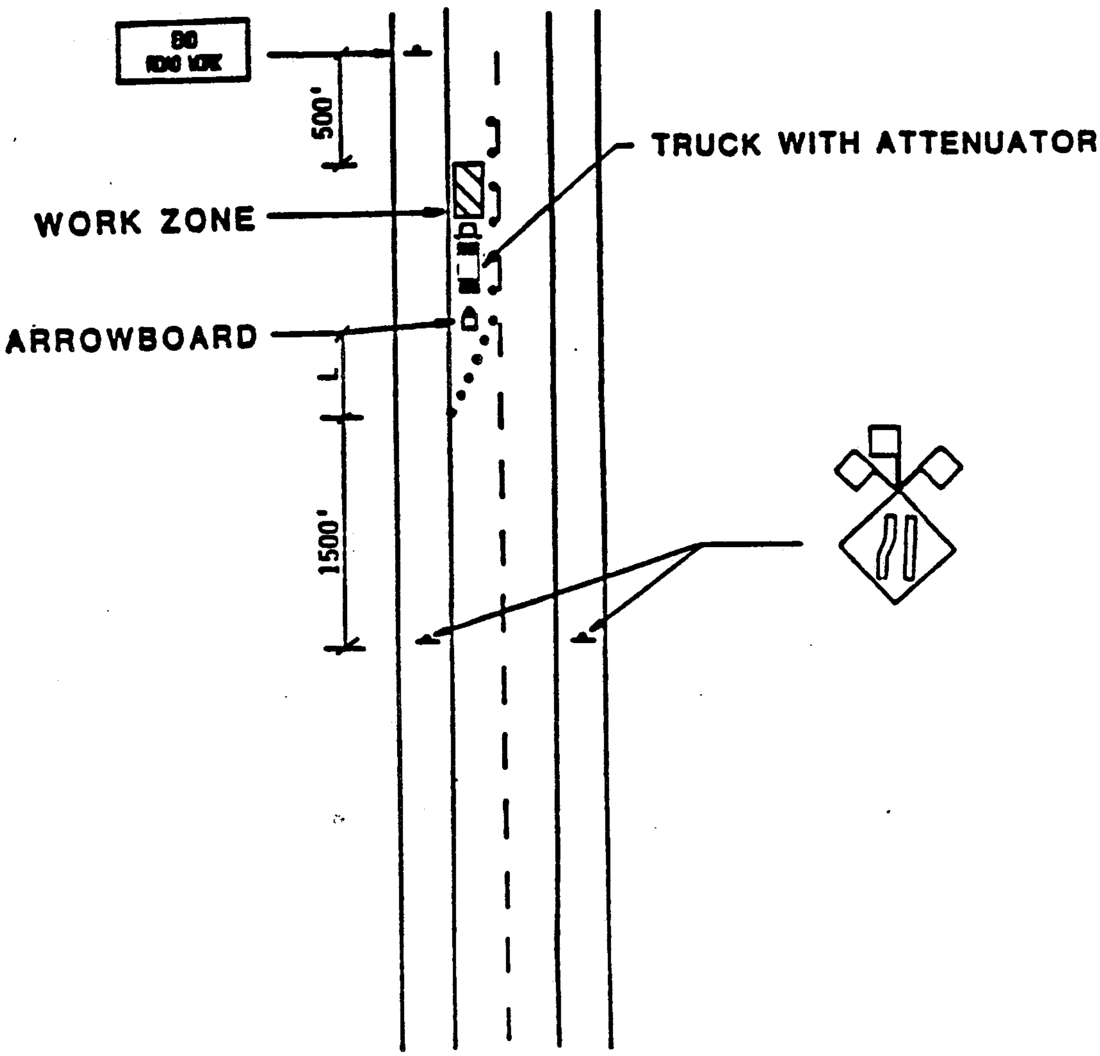


Figure 3-4. Schematic Diagram of Symbolic Lane Closed Signing Treatment.

In this study, a three-line CMS was used at all of the study sites. The message displayed by the CMS was:

ROAD	**RIGHT/LEFT**
WORK	**LANE**
AHEAD	**CLOSED**

Thus, the same information contained on the first two static signs of the TMUTCD set-up was displayed to the driver by one traffic control device. Figure 3-5 is the schematic diagram of this treatment.

Alternative 5 -- "LANE BLOCKED" Sign

The Texas "LANE BLOCKED" sign (CW20-6) was originally designed for moving maintenance (4) operations. This sign is larger than a normal static TMUTCD advance warning sign (7-ft by 7.5-ft) and so can be seen by drivers farther upstream. The sign provides clear and concise information about which lane is temporarily closed and which lane is open to traffic through the work zone. 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 signing configurations, this sign was placed 1500 ft upstream from the cone taper. Figure 3-6 presents the schematic diagram of this candidate signing configuration.

Alternative 6 -- Expanded TMUTCD

At the request of the Federal Highway Administration, the final signing configuration tested in the field studies was an expanded version of the TMUTCD set-up. This configuration involved moving all three of the TMUTCD advance warning signs 500 ft farther upstream than their current position. In addition to moving the signs, a second set of symbolic lane closure signs were inserted 500 ft from the cone taper. In this configuration, drivers are presented with the more important information about which lane is closed 500 ft farther upstream than under the standard TMUTCD set-up. Figure 3-7 illustrates the layout of this signing configuration.

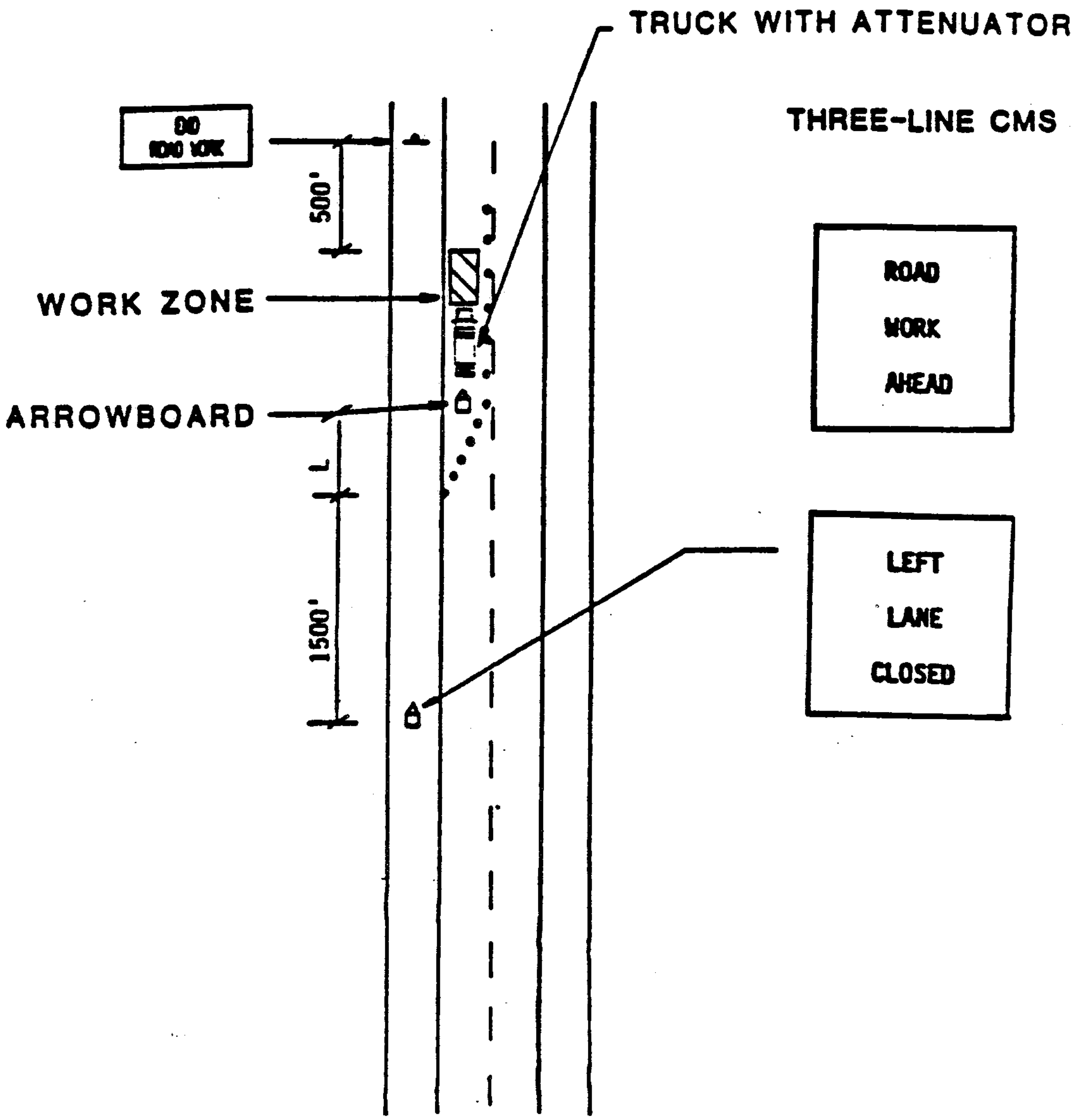


Figure 3-5. Schematic Diagram of CMS Signing Treatment.

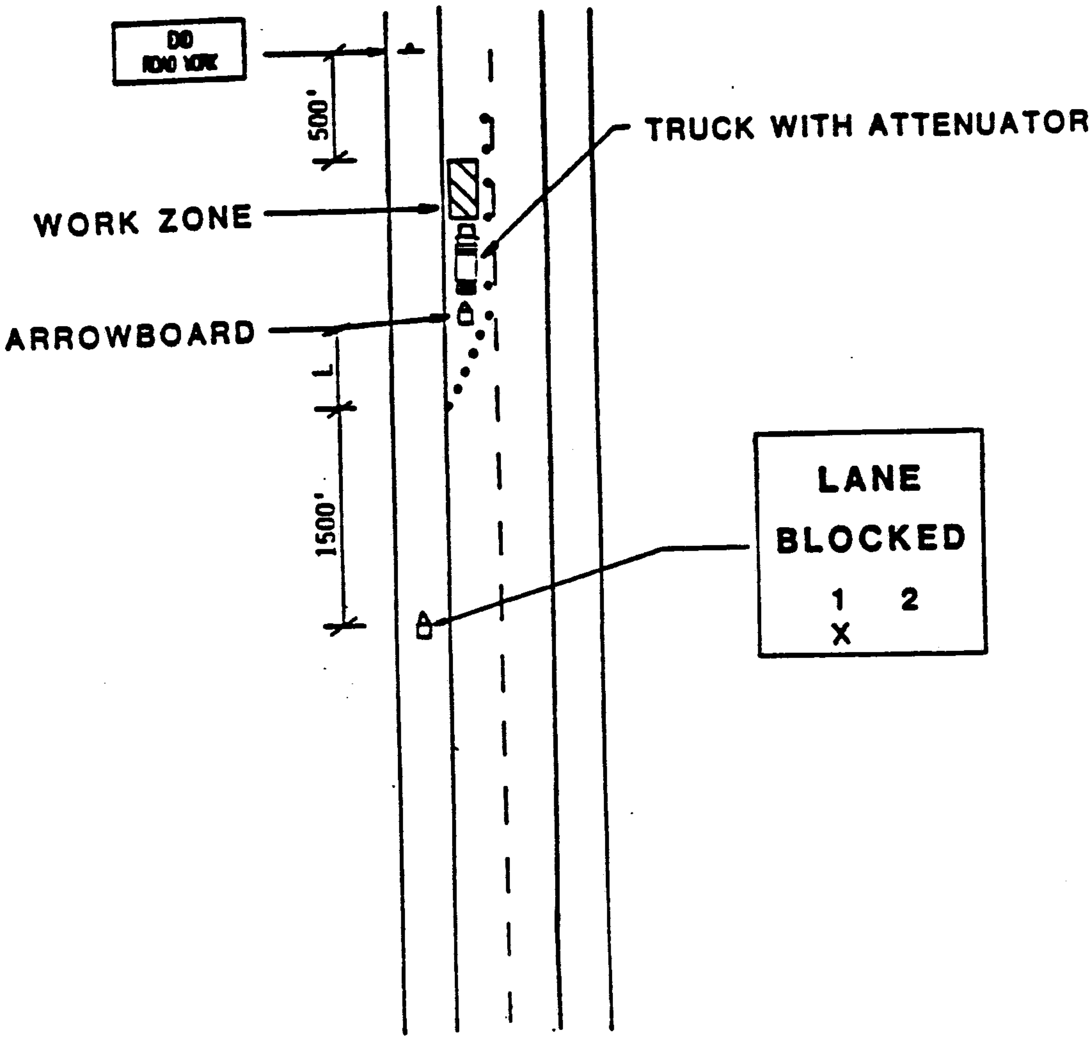


Figure 3-6. Schematic Diagram of Texas "LANE BLOCKED" Signing Treatment.

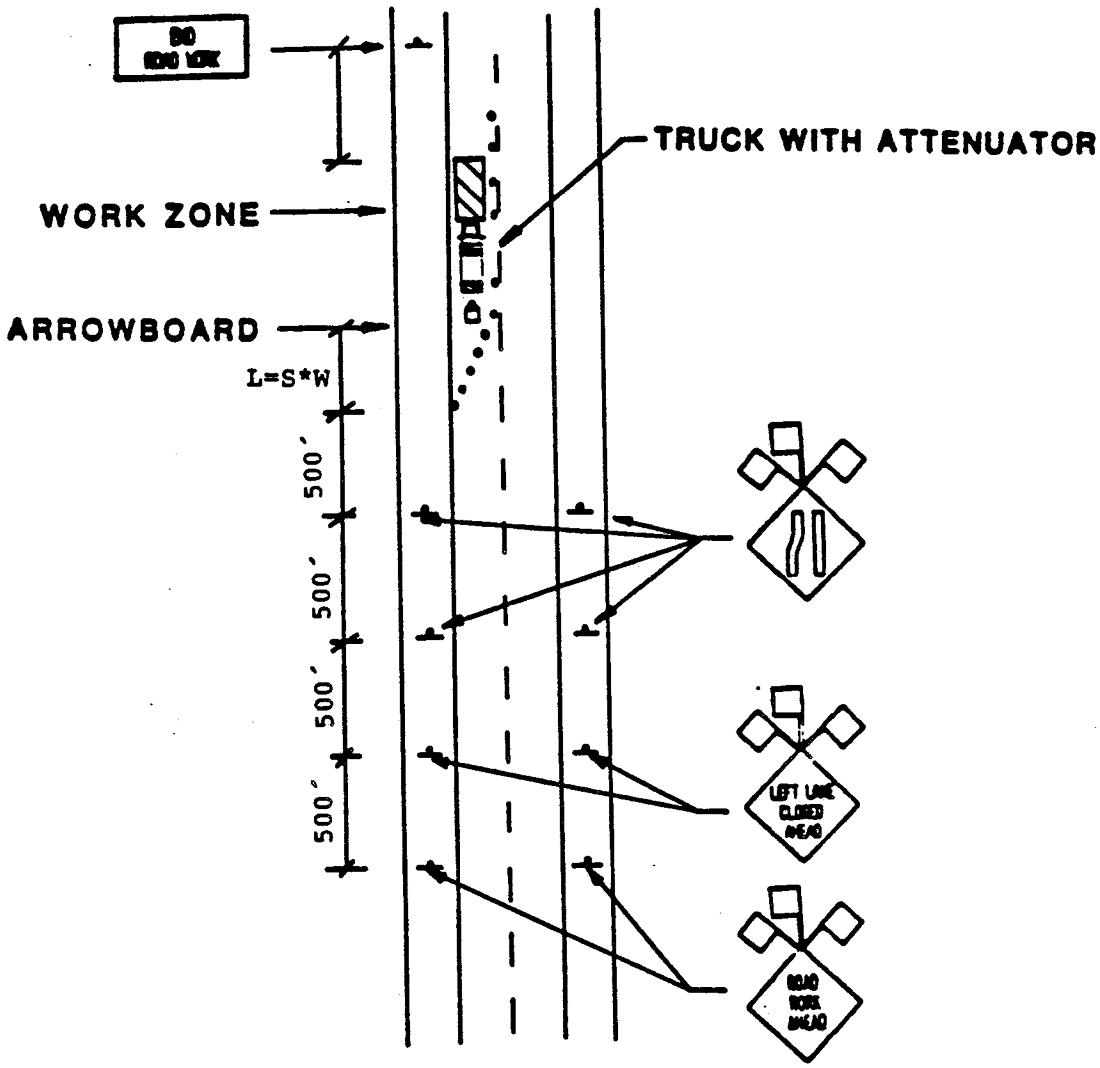


Figure 3-7. Schematic Diagram of Expanded TMUTCD Signing Treatment.

Data Collection Methodology

Two types of data were collected during the field studies. Traffic volumes were recorded at five locations upstream of the work zone. The first location (labeled "station 1") was positioned approximately 2500-3000 ft upstream from the cone taper. This station was assumed to be upstream from the effects of the signing configurations, and so was used as a control location for each site. The remaining locations ("stations 2, 3, 4, and 5") were positioned 1500 ft, 1000 ft, 500 ft, and 0 ft from the beginning of the cone taper. An example of where lane distribution data were collected at one of the study sites is shown in Figure 3-8.

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.

Data were collected one hour at each site for the TMUTCD and each of four candidate treatments for a total of five hours per site. Data were collected only during the daylight, off-peak periods.

Measures-of-Effectiveness

The primary MOE used to evaluate the signing configurations was the proportion of traffic volumes (measured at the various stations upstream from the work zone) that was still in the closed travel lane. Comparisons were made of the proportion remaining in the closed lane for the candidate signing treatments to 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.

The other MOE used in this study was erratic manuevers recorded at or approaching the work zone. Erratic maneuvers were classified according to their severity and type of manuever performed. For this evaluation, 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.

Experimental Design

Originally, a two-phase study was proposed. In the first phase, the candidate signing treatments would be evaluated and compared to the standard TMUTCD treatment with a cone taper in place at the work zone. In the second phase, the candidate and standard TMUTCD treatments would be evaluated without a cone taper present at the work zone.

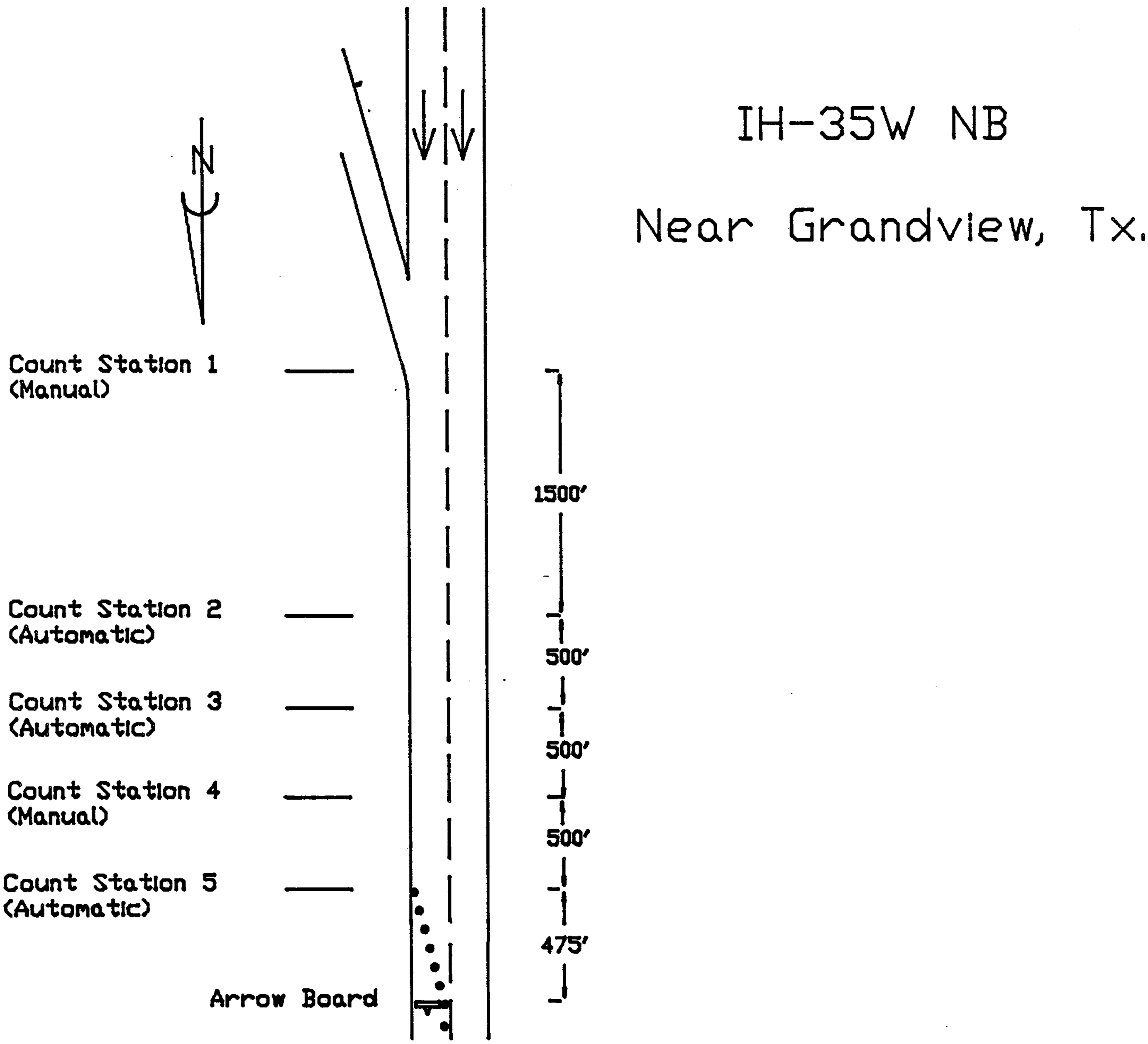


Figure 3-8. Example of Lane Distribution Data Collection Locations at Study Sites.

Several factors were expected to have an effect upon the data that would be collected to evaluate the TMUTCD and candidate signing configurations as well as the effect of the cone taper. It was felt that the type of lane closure (left lane, right lane), site specific factors (i.e., sight distance, geometrics, etc.), and time-of-day variations would all possibly affect the study results.

Four field studies were initially conducted of the six candidate signing treatments. For each study, the standard TMUTCD and four of the six treatments were studied. Two of the studies were of a right lane closure and two of a left lane closure. Also, one of each of the right and left lane studies were conducted with and without a cone taper in place. Sight distance restrictions at the two other sites limited the studies to the signing configurations with the cone taper in place. For each study, data were collected for one hour with each of the TMUTCD and four of the candidate signing configurations in advance of the work zone. The characteristics of these initial study sites are given in Table 3-1. Table 3-2 presents the candidate signing treatments and cone taper condition (with, without) examined at each of these studies.

Based on the results of these initial studies (see Chapter 4), it was decided to abandon further analysis of the treatments without a cone taper, due to concerns about driver and worker safety. Also, the initial list of six treatments was trimmed to the following four configurations:

1. "ROAD WORK AHEAD" sign

2. Symbolic Lane Closure sign

3. CMS

4. Texas Lane Blocked sign

An experimental design was developed of the four remaining candidate treatments, accounting for the factors listed previously (type of closure, study site, time-of-day), and incorporating the initial studies already conducted. A latin square design was proposed for both left lane and right lane closures. For each study, the sequence of configurations would be changed from site to site to allow all configurations to be evaluated at each hour in the data collection day. Table 3-3 presents the experimental design for this study.

TABLE 3-1. SUMMARY SITE CHARACTERISTICS FOR INITIAL STUDIES

	SITE 1	SITE 2	SITE 3	SITE 4
Location	IH-35W, Near Grandview	IH-35W, North of IH-820	IH-30, West of IH-820	IH-30, Near US-80
Date	4/9 - 4/11/85	5/21/85	8/20 - 8/21/85	8/28/85
AADT	10,000 vpd	28,000 vpd	30,000 vpd	30,000 vpd
Area	Rural	Rural	Rural	Rural
Sight Distance	> 1/2 mile	1600 feet	> 1/2 mile	> 1/2 mile
Vertical Alignment	Slight Upgrade	Upgrade	Slight Downgrade	Downgrade
Horizontal Alignment	Straight	Right Curve	Straight	S-Curve
Maintenance Activity	Pothole Patching	Concrete Repairs	Shoulder maint.	Shoulder maint. /pavement repair
Lane Closed	Shoulder	Median	Median	Shoulder
Treatments Studied Without Cone Taper	Yes	No	Yes	No

AADT = Annual Average Daily Traffic
vpd = vehicles per day

TABLE 3-2. SUMMARY OF CANDIDATE TREATMENTS EXAMINED IN INITIAL FIELD STUDIES

Treatment	Site 1		Site 2		Site 3		Site 4	
	With Cone Taper	W/O Cone Taper	With Cone Taper	W/O Cone Taper	With Cone Taper	W/O Cone Taper	With Cone Taper	W/O Cone Taper
TMUTCD	X	X	X	-	X	X	X	-
"ROAD WORK AHEAD"	X	X	X	-	X	X	-	-
"RIGHT/LEFT LANE CLOSED AHEAD"	X	X	-	-	-	-	-	-
Symbolic Lane Closed	-	-	X	-	X	X	X	-
CMS	X	X	X	-	X	X	X	-
"LANE BLOCKED"	X	X	X	-	X	X	X	-
Expanded TMUTCD	-	-	-	-	-	-	X	-

X denotes treatment was studied

\- denotes treatment was NOT studied

TABLE 3-3. EXPERIMENTAL DESIGN FOR FIELD STUDIES

Shoulder Lane Closures:

Sequence	Study No. 1	2	3	4	5	6
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

Median Lane Closures:

Sequence	Study No. 1	2	3	4	5	6
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	CMS

Note:

TMUTCD = Standard TMUTCD
SYM = Symbolic Lane Closed
LB = Texas "LANE BLOCKED" Sign
RWA = "ROAD WORK AHEAD"
CMS = Changeable Message Sign

Study Site Selection and Description

A series of field studies was conducted at rural and suburban freeway work zones in Districts 2 (Ft. Worth) and 18 (Dallas). The study sites were selected with help from District Maintenance Engineers. The criteria for selecting study sites were as follows:

1. Relatively low traffic volumes (i.e., AADTs that were equal to or less than 30,000 vpd), so that queues would not form upstream of the work zone when a travel lane was closed.

2. Adequate sight distance of at least 1500 ft to the arrow panel (beginning of the lane closure).

3. Each site had to have an 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.

Table 3-4 identifies the study sites used by date of study, highway, location, site conditions, and work activity.

TABLE 3-4. SUMMARY OF STUDY SITE CHARACTERISTICS

Study Number	Location	Date	Lane Closed	Area	Sight Distance	Vertical Alignment	Horizontal Alignment	Maintenance Activity
1	IH-35W, Near Grandview	4/9/85	Shoulder	Rural	> 1/2 mi.	Slight Upgrade	Straight	Pothole Patching
2	IH-35W, North of IH-820	5/21/85	Median	Rural	> 1/4 mi.	Upgrade	Right Curve	Concrete Repairs
3	IH-30 WB, West of IH-820	8/21/85	Median	Rural	> 1/2 mi.	Slight Downgrade	Straight	Shoulder Repairs
4	IH-30 EB, Near US-80	8/28/85	Shoulder	Rural	> 1/2 mi.	Downgrade	S-Curve	Pavement Repairs
5	IH-30 EB, Near US-80	8/29/85	Shoulder	Rural	> 1/2 mi.	Downgrade	S-Curve	Pavement Repairs
6	IH-45 SB at Mars Rd.	7/22/86	Shoulder	Rural	> 1/2 mi.	Slight Upgrade	Straight	Pavement Repairs
7	IH-45 SB at Mars Rd.	7/23/86	Median	Rural	> 1/2 mi.	Slight Upgrade	Straight	Pavement Repairs
8	US-75 SB at Wilmeth Road	7/29/86	Median	Rural	> 1/2 mi.	Slight Upgrade	Straight	Shoulder Repairs
9	US-75 SB at Wilmeth Road	7/30/86	Median	Rural	> 1/2 mi.	Slight Upgrade	Straight	Shoulder Repairs
10	US-75 SB at Wilmeth Road	8/19/86	Shoulder	Rural	> 1/2 mi.	Slight Upgrade	Straight	Pavement Repairs
11	US-75 SB at Wilmeth Road	8/20/86	Shoulder	Rural	> 1/2 mi.	Slight Upgrade	Straight	Pavement Repairs
12	US-75 NB at FM-543	8/21/86	Median	Rural	> 1/2 mi.	Slight Upgrade	Straight	Shoulder Repairs

4. RESULTS OF CANDIDATE SIGNING TREATMENT EVALUATIONS

Initial Study Results

As stated in Chapter 3, four field studies were initially conducted to evaluate six candidate signing configurations with and without the cone taper present. Because of sight distance restrictions at sites 2 and 4, it was not possible to evaluate the signing configurations without the cone taper at these sites. Also, the TMUTCD and only four of the six candidate configurations could be studied on any given day at a particular study site. Despite these limitations, the initial studies provided useful information regarding the relative performance characteristics of the candidate signing configurations and the effect of the cone taper in advance of the work zone lane closure. On the basis of these initial results, the list of candidate configurations was reduced to four treatments, and the decision was made to abandon further field studies of the signing treatments without the presence of the cone taper.

Cone Taper Effects

The results of the field studies at sites 1 and 3 show that, regardless of the candidate treatment in place, drivers tended to exit the closed lane farther upstream when the cone taper was in place. This is illustrated graphically in Figure 4-1, which shows the proportion of the closed lane traffic volumes which was still in the closed lane at 1500 ft, 1000 ft, and 500 ft before the cone taper for the CMS signing treatment. For both median and shoulder lane closures, the proportion of drivers remaining in the closed lane at the various locations was greater without the cone taper in place, suggesting that more drivers exited the closed lane farther upstream when the cone taper was present. The performance of the TMUTCD treatment with a cone taper present is included in each graph for comparison purposes. Similar figures for the other candidate treatments examined with and without a cone taper are shown in Appendix C. In nearly all cases, the trends were the same; the presence of the cone taper resulted in drivers exiting the closed lane farther upstream than when the cone taper was not in place.

During one study without the cone taper present, a severe erratic manuever was observed. A tractor-trailer truck locked its brakes and skidded to a stop just before running into the arrow panel. This incident prompted TTI and SDHPT officials to reconsider whether to continue field studies of the signing configurations without the use of a cone taper. After consideration of the data collected and experiences at the study site, it was decided that future studies would be limited to the candidate treatments with the cone taper in place.

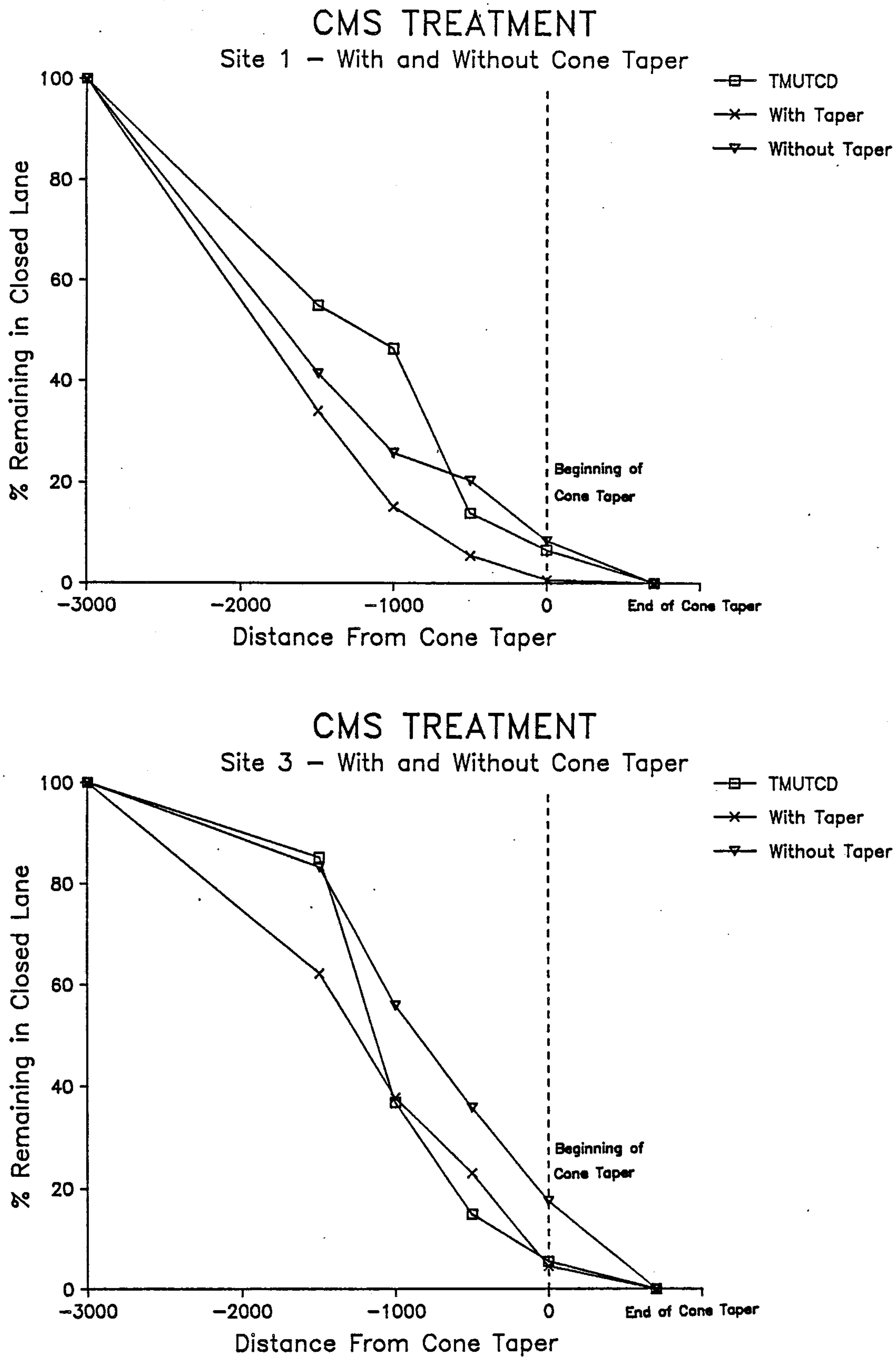


Figure 4-1. Effect of CMS Signing Treatment With and Without a Cone Taper (Sites 1 and 3).

Evaluation of Candidate Signing Treatments

The initial studies also provided useful information about the relative performance of the candidate treatments in terms of their ability to influence drivers to exit the closed travel lane. Figures 4-2 through 4-5 present a site by site comparison of the TMUTCD and candidate signing treatments (with a cone taper present) examined at that site. Those treatments that resulted in fewer drivers remaining in the closed lane were considered to be the most effective. The relative rankings of the treatments examined at each site are shown in Table 4-1. Overall, the innovative "LANE BLOCKED" and CMS treatments were generally the most effective. The "ROAD WORK AHEAD" treatment, on the other hand, consistently ranked the poorest. The "RIGHT/LEFT LANE CLOSED AHEAD", Symbolic Lane Closed sign, and expanded TMUTCD treatments all generally performed similarly when compared to each other and to the standard TMUTCD set-up.

After the analysis of the data from these four studies, it was apparent that the performance of the "RIGHT/LEFT LANE CLOSED AHEAD" and Symbolic Lane Closure treatments were quite similar. This was expected, since both signs provide the same type of information, one in a word format and the other in a visual format. Consequently, it was decided that it was not necessary to continue evaluation of both of these treatments, and so the "RIGHT/LEFT LANE CLOSED AHEAD" treatment was removed from further analysis.

In addition, the evaluation of the expanded TMUTCD treatment was abandoned after these initial studies. This treatment involves the set-up and removal of more signs than even the standard TMUTCD set-up. The evaluation of this treatment at site 4 did not suggest that it was any more effective than any of the other treatments, except for the "ROAD WORK AHEAD" treatment. Since the objective of this research was to develop and evaluate reduced traffic control treatments for short duration and stop-and-go operations, it was decided to discontinue additional study of this treatment.

Results of Complete Evaluation of Candidate Signing Treatments

Eight additional studies were conducted and combined with the data from the four initial studies. The additional studies were limited to the analysis of the TMUTCD and four candidate treatments ("ROAD WORK AHEAD," Symbolic Lane Closed, CMS, and Texas "LANE BLOCKED") with a cone taper in place at the work zone. The results of the analysis of the combined data are presented below.

Median Lane Closure

Table 4-2 presents the average proportion of traffic in the closed lane at the data collection stations upstream of the work zone for those sites where the median lane was closed to traffic. At the data collection location 3000 ft from the cone taper (station 1), the proportion of traffic in the closed lane was found to be very similar for all (the TMUTCD and candidate) treatments, and ranged from 30.7 to 32.8 percent. A Chi-Square test of the

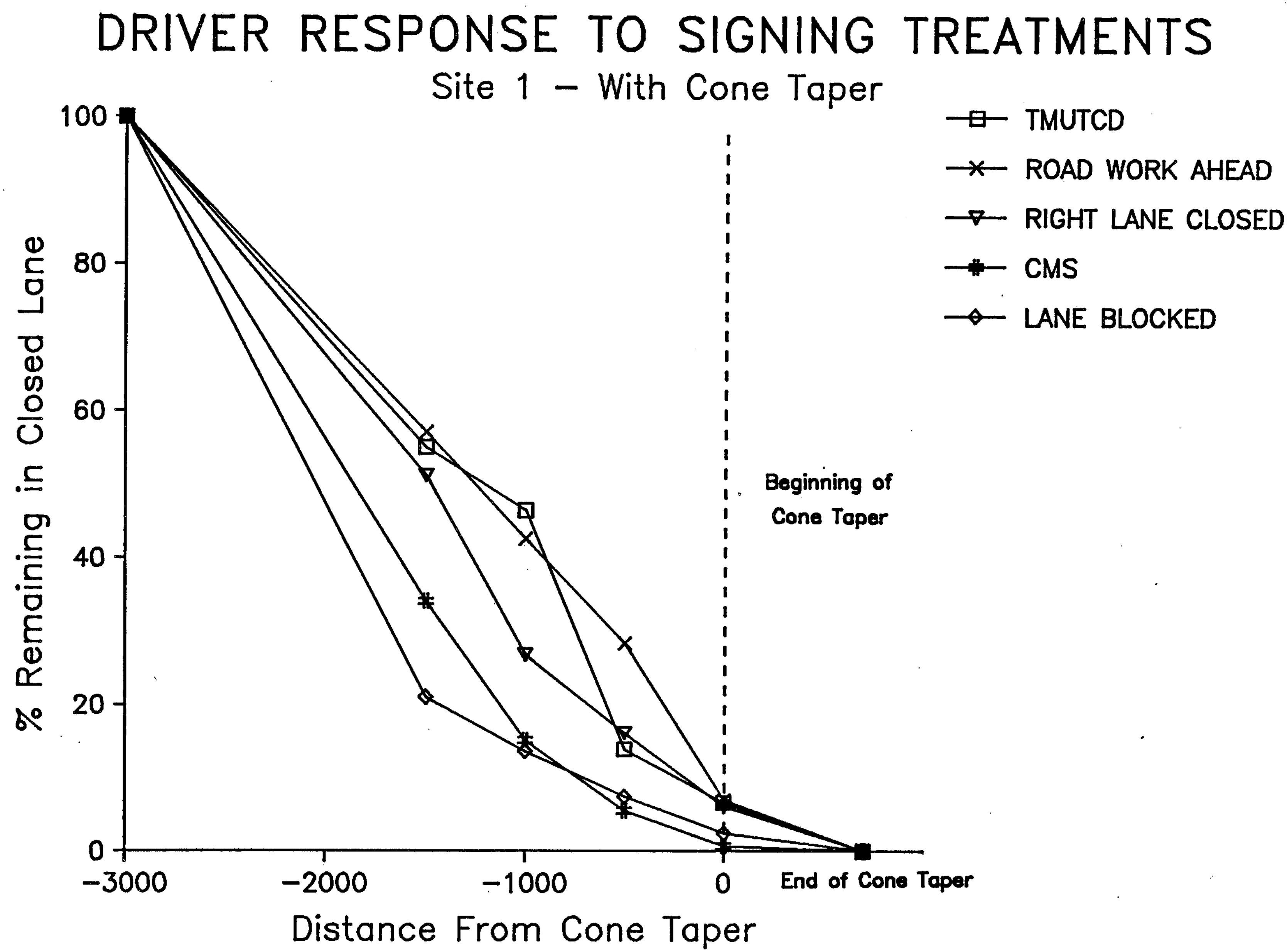


Figure 4-2. Effect of TMUTCD and Candidate Signing Treatments at Site 1 (With a Cone Taper).

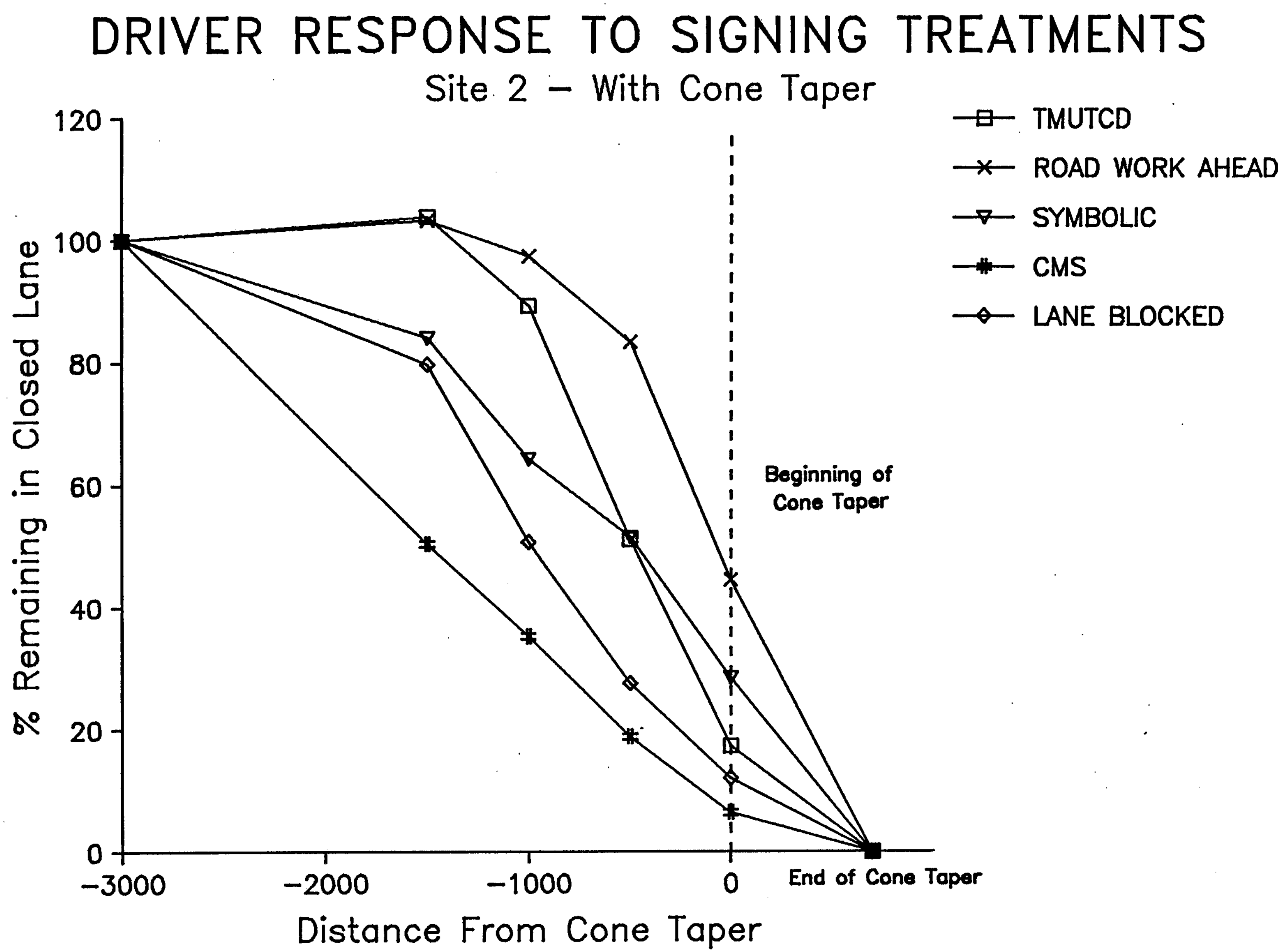


Figure 4-3. Effect of TMUTCD and Candidate Signing Treatments at Site 2 (With a Cone Taper).

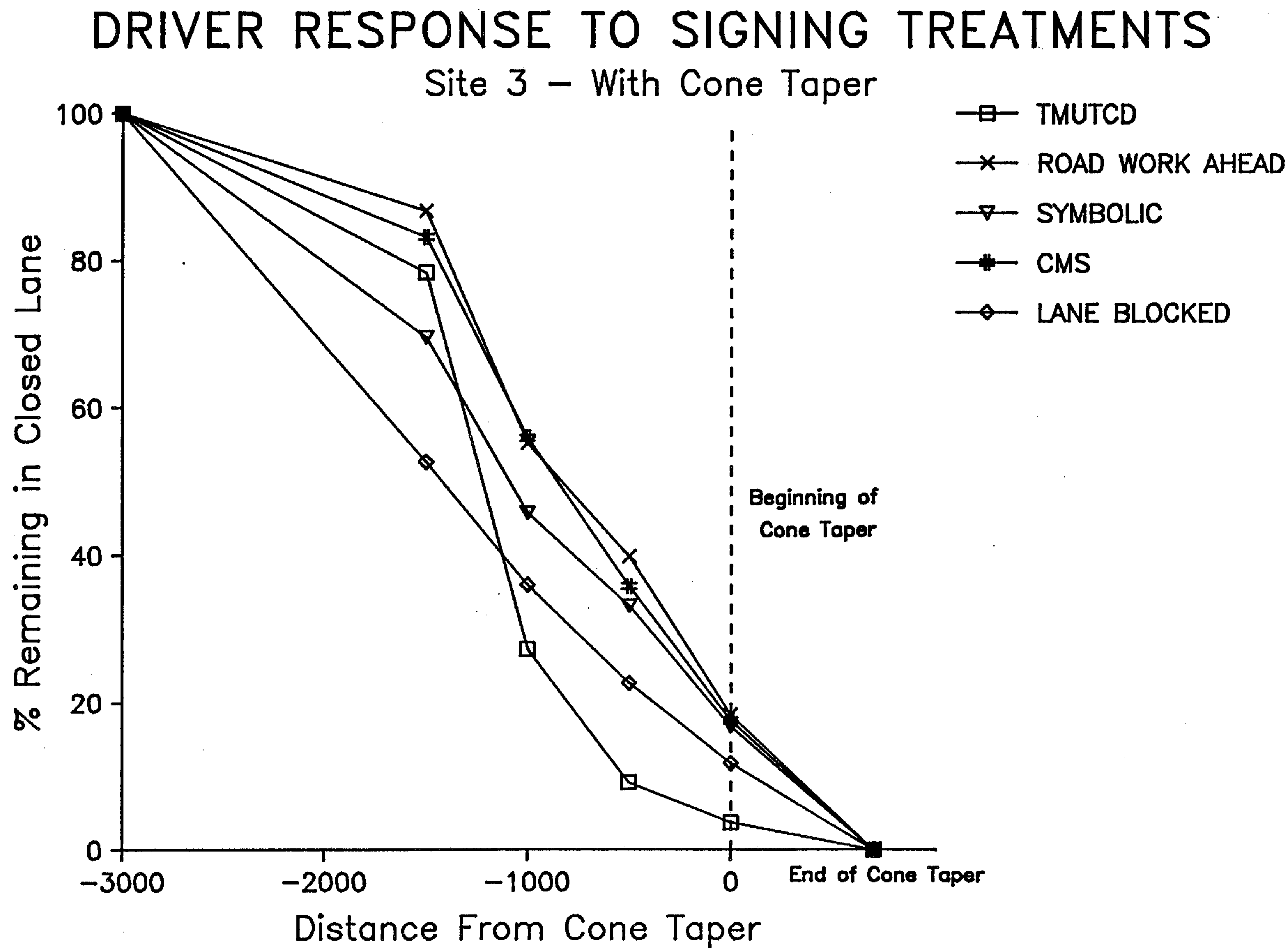


Figure 4-4. Effect of TMUTCD and Candidate Signing Treatments at Site 3 (With a Cone Taper).

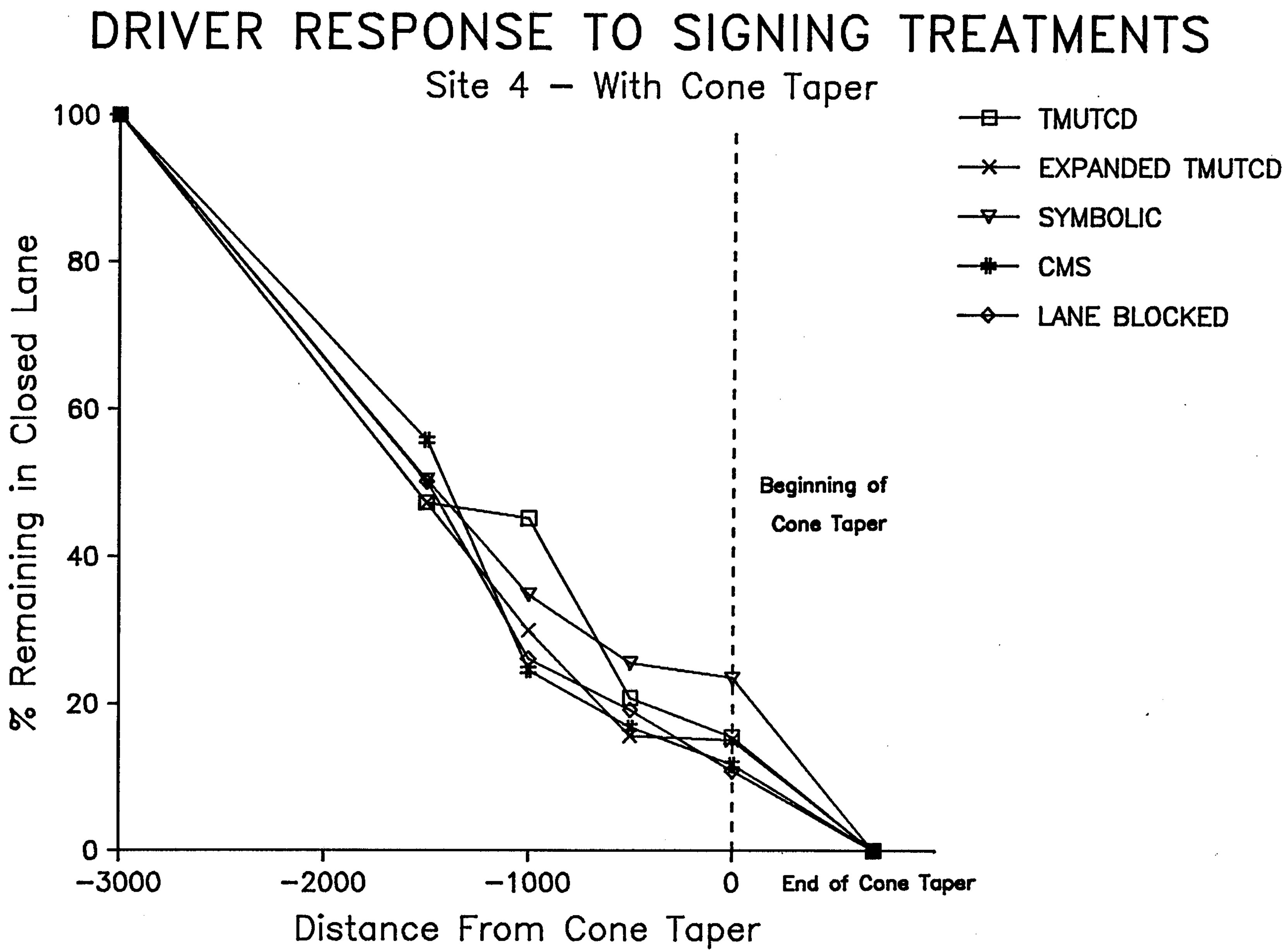


Figure 4-5. Effect of TMUTCD and Candidate Signing Treatments at Site 4 (With a Cone Taper).

TABLE 4-1. RANKING OF TREATMENTS BY LANE DISTRIBUTION PERFORMANCE

	TMUTCD	"ROAD WORK AHEAD"	"RIGHT/LEFT LANE CLOSED AHEAD"	SYMBOLIC LANE CLOSED	CMS	"LANE BLOCKED"	EXPANDED TMUTCD
MEDIAN LANE CLOSURE							
With Cone Taper	4	5	-	3	2	1	-
Without Cone Taper	2[d]	5	-	3	4	1	-
SHOULDER LANE CLOSURE							
With Cone Taper	5	7	4[a]	6[c]	2	1	3[c]
Without Cone Taper	4[d]	5	3	-	2	1	-

[a] Studied at Site 1 only

[b] Studied at Site 3 only

[c] Studied at Site 4 only

[d] Treatment not studied without a cone taper. Ranking only for purposes of comparing performance of candidate signing treatments to a standard TMUTCD Lane Closure Set-up.

TABLE 4-2. PROPORTION OF VEHICLES IN CLOSED LANE MEDIAN LANE CLOSURE (ALL SITES)

Treatment	Distance From Beginning of Cone Taper (ft) 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

equality of the proportions (a contingency test for independence between the proportion and treatment type) indicated that the proportions were the same. This result was expected since it was assumed that traffic had not yet been affected by the type of treatment present at the work zone.

However, the proportions in the closed lane were found to differ significantly between treatments at the data collection locations 1500, 1000, and 500 ft from the cone taper (Stations 2, 3, and 4). To obtain a better perspective of how the various treatments affected traffic in the closed travel lane, the volumes in the closed lane were normalized to the first data collection location in order to represent the proportion of traffic still in the closed lane at the other data collection locations. These "normalized" proportions are shown graphically in Figure 4-6. As can be seen in Figure 4-7, the proportion of traffic remaining in the closed lane was highest for the "Road Work Ahead" treatment, and lowest for the CMS and "LANE BLOCKED" treatments. Interestingly, the proportions were essentially the same for both the CMS and "LANE BLOCKED" treatments. The proportions of traffic remaining in the closed lane under each treatment suggests that 1) the CMS and "LANE BLOCKED" treatments were most effective in influencing drivers in the closed lane to exit the closed lane farther upstream, 2) the Symbolic Lane Closed sign treatment performed as well as the TMUTCD treatment (but not as well as the CMS and "LANE BLOCKED" Treatments), and 3) the "ROAD WORK AHEAD" treatment was the least effective of the treatments evaluated.

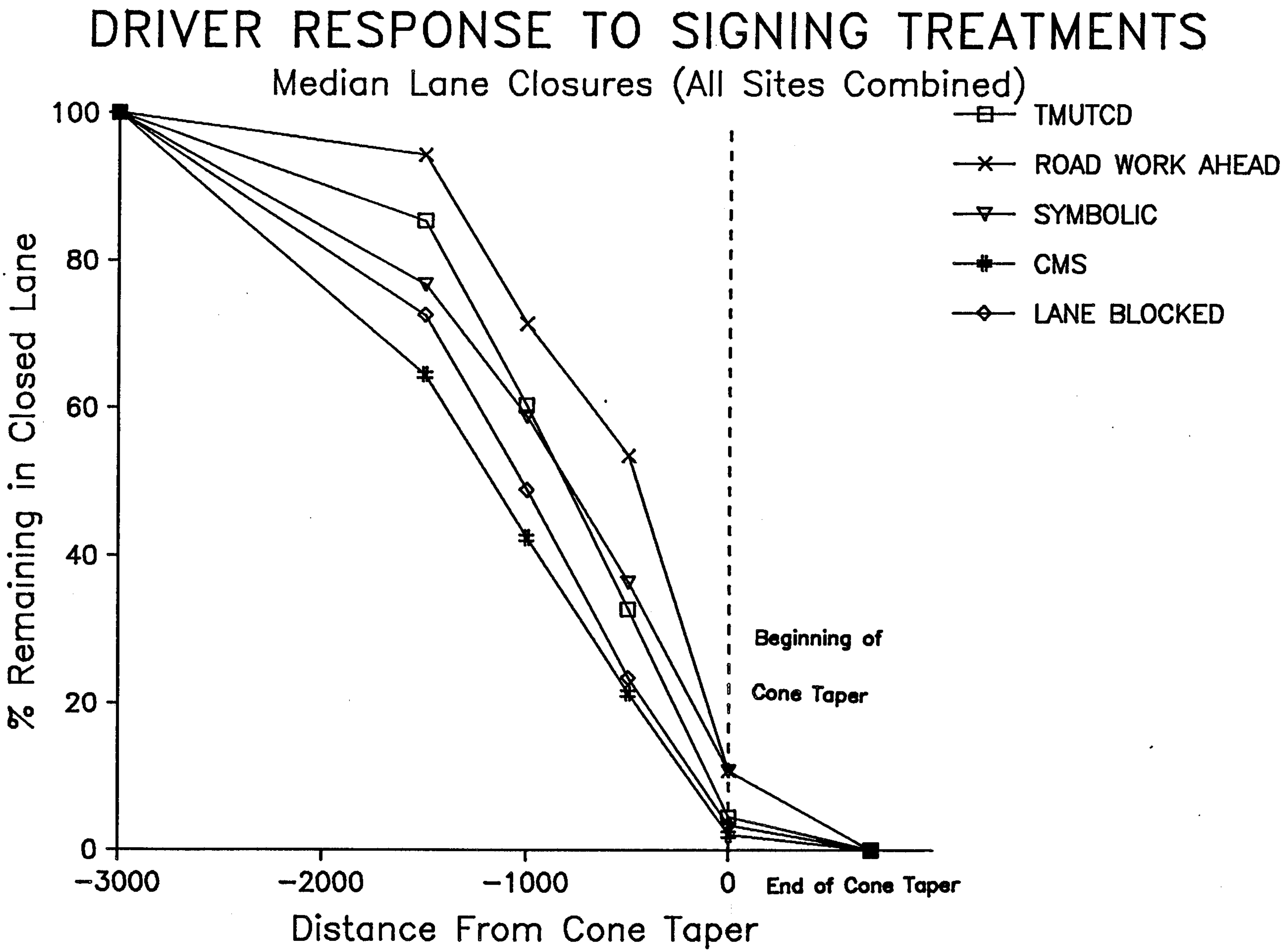


Figure 4-6. Average Effect of TMUTCD and Candidate Signing Treatments (Median Lane Closures).

Shoulder Lane Closure

Table 4-3 presents the average proportion of vehicles in the closed lane under each treatment for those sites where the right (shoulder) lane was closed to traffic. Again, the results of a Chi-Square test for the data 3000 ft from the cone taper (the control station) showed no significant differences among the various treatments. The proportions at this station (assumed to be upstream from the effects of the different treatments) were between 65.6 and 67.2 percent. The results at the other data collection locations, however, do show significant differences among treatments, with the proportion of traffic in the closed lane the highest under the "ROAD WORK AHEAD" treatment and lowest under the CMS and "LANE BLOCKED" treatments. As before, the results of the Symbolic Lane Closure and TMUTCD treatments were similar, and fell in between the "ROAD WORK AHEAD" results and those of the CMS and "LANE BLOCKED" treatments.

TABLE 4-3. PROPORTION OF VEHICLES IN CLOSED LANE SHOULDER 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

As with the data from the median lane closures, the shoulder lane data were normalized to show the proportion of traffic remaining in the closed lane at the various data collection locations. This data is shown in Figure 4-7. The trends are similar to that of the median lane closures; the CMS and "LANE BLOCKED" treatments were most effective in influencing drivers to exit the closed travel 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 of the treatments examined 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, due to the diverse nature of work zones themselves and other site-specific factors that influence driver behavior at a location. For example, Figure 4-8 shows the variation in performance observed over the shoulder lane study sites for the standard TMUTCD treatments. 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 treatment.

Analysis of Erratic Maneuvers

A second type of data collected during the studies of the candidate treatments were erratic maneuvers performed at or just in advance of the cone taper/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.

At the study sites where the cone taper was in place, erratic maneuvers and conflicts at the study sites were found to be extremely rare events under any of the treatments studied. There were only five incidents overall where 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 with the standard TMUTCD treatment in place). None of these incidents resulted in any type of damage or injury to motorists, 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 for the "Road Work Ahead") were any more hazardous to drivers than any other, including the TMUTCD treatment. The "Road Work Ahead" treatment resulted in a few erratic maneuvers during the studies, however.

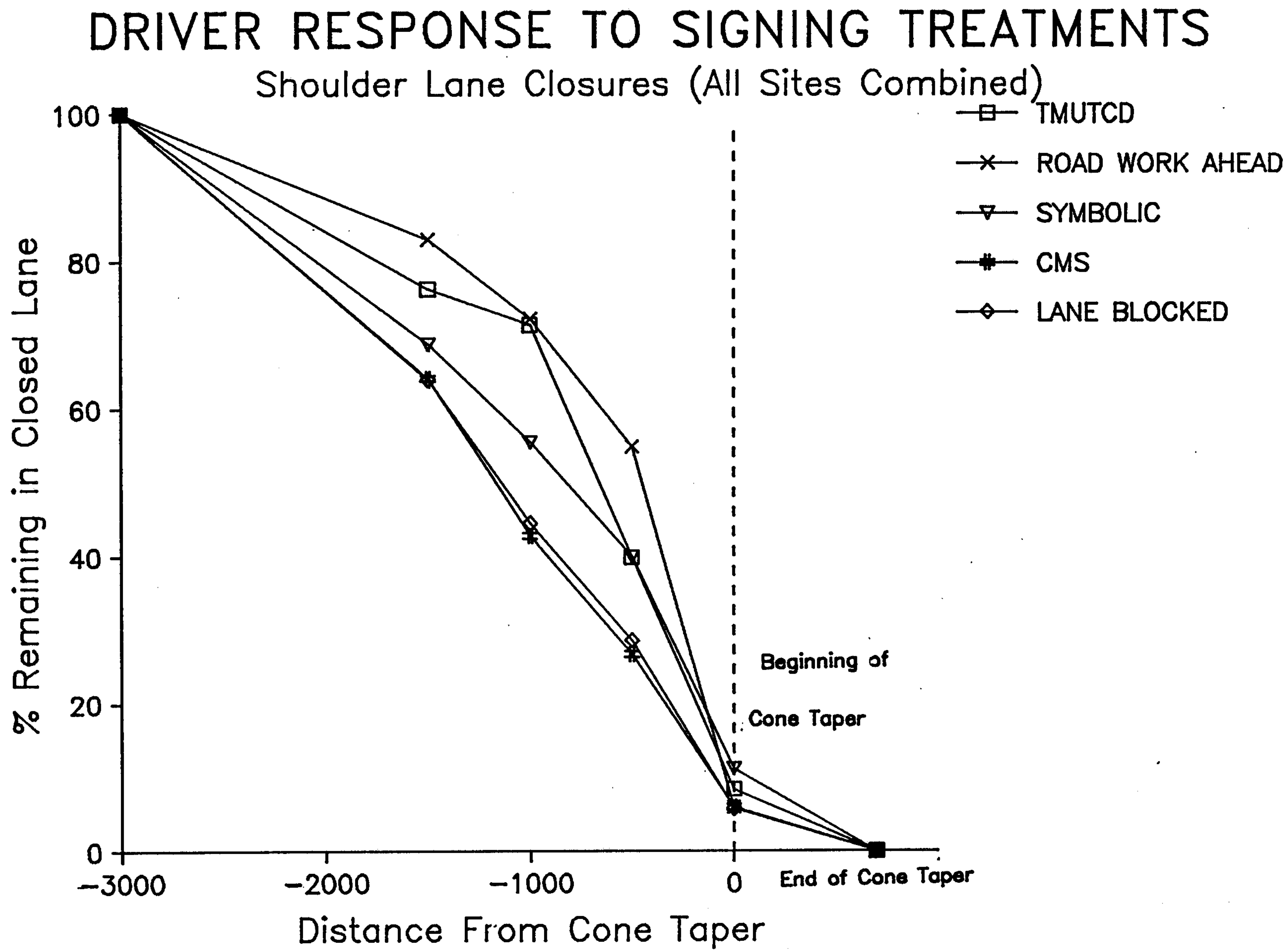


Figure 4-7. Average Effect of TMUTCD and Candidate Signing Treatments (Shoulder Lane Closures).

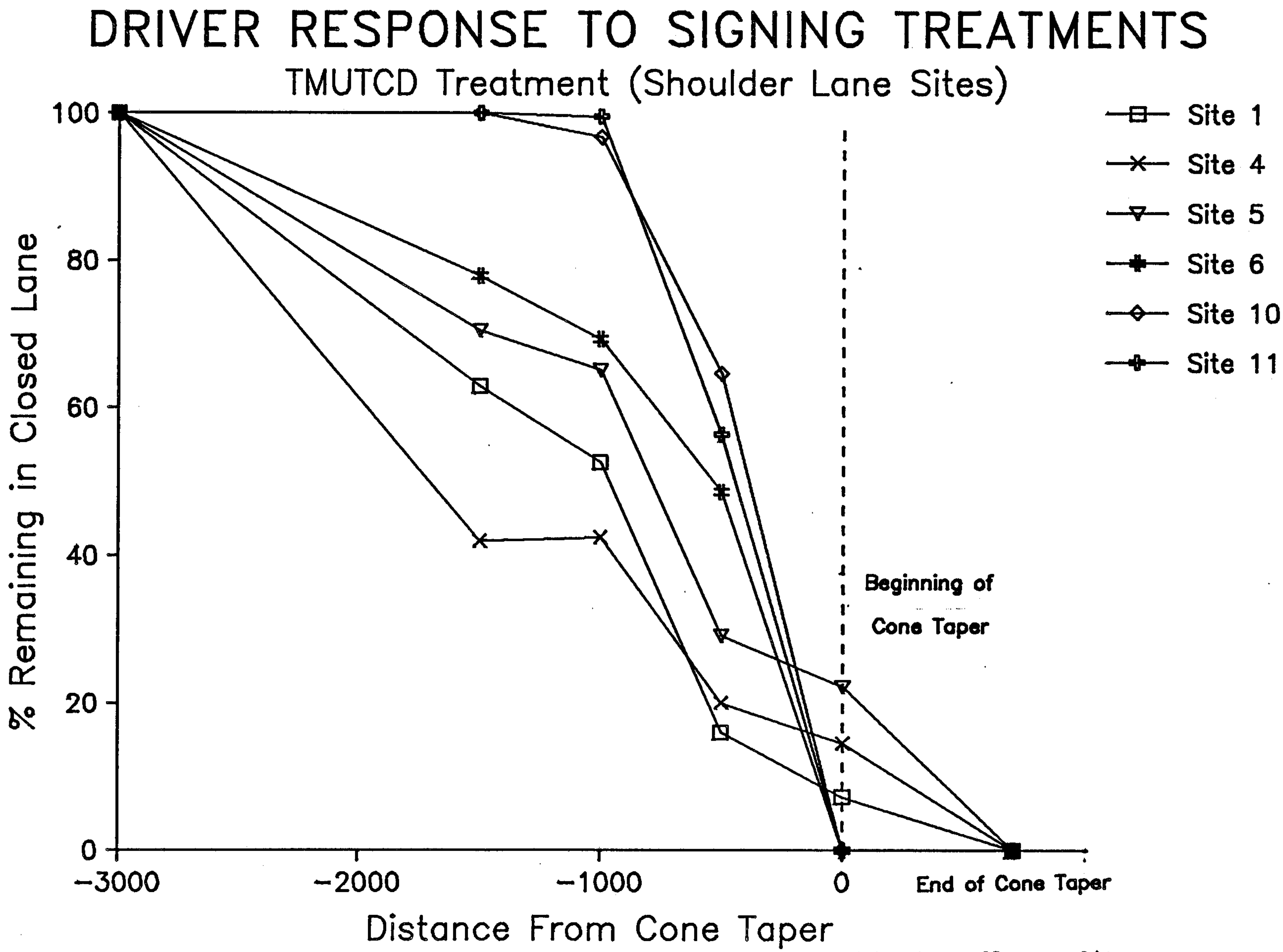


Figure 4-8. Variation in Effect of TMUTCD Signing Treatment at Shoulder Lane Closure Sites.

Summary

Twelve field studies were conducted at work zone locations on rural/suburban four-lane divided highways to evaluate the effectiveness of four candidate reduced traffic control lane closure set-ups proposed for short duration and stop-and-go maintenance operations. The results of the field studies show that the CMS and Texas "LANE BLOCKED" treatments were the most effective (of those treatments 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 appeared to be nearly as effective as the TMUTCD in this regard, but both of these treatments were not as effective as the CMS or "LANE BLOCKED" treatments. Finally, the "ROAD WORK AHEAD" treatment was found to be the least effective treatment of those studied.

The erratic maneuver data that was collected at the study sites did not suggest that any of the candidate treatments were particularly hazardous or caused confusion or other problems for drivers. However, there were very few serious erratic maneuvers observed during evaluation of any of the treatments (including the TMUTCD treatment), so statistical analysis of this data was not possible.

Based on the results of these studies, the use of the CMS or Texas "LANE BLOCKED" treatments is recommended for short duration and stop-and-go lane closures on four-lane divided highways with AADTs of up to 30,000. Both of these treatments include the use of the arrow panel and a cone taper immediately in advance of the work zone.

5. DEMONSTRATION STUDIES OF REDUCED TRAFFIC CONTROL FOR SHORT DURATION AND STOP-AND-GO OPERATIONS

Based on the results of the field studies of several candidate reduced traffic control set-ups for short duration and stop-and-go maintenance operations (see Chapter 4), the Texas "LANE BLOCKED" sign and CMS were judged to be the most effective treatments of those examined in terms of encouraging drivers to exit the closed lane farther upstream. It was also apparent from those studies that the performance of the "LANE BLOCKED" and CMS treatments resulted in very similar responses by drivers as to when they chose to exit the closed lane. Consequently, the use of either treatment for short duration and stop-and-go maintenance operations on four-lane divided highways with traffic volumes less than or equal to 30,000 AADT was recommended.

The final step in the evaluation process was to determine the benefit to the Department achieved with the use of the reduced traffic control for short duration and stop-and-go operations. A number of observational studies were conducted to determine the time and labor requirements for 1) the standard TMUTCD set up for a minor maintenance operation on a multi-lane divided highway, and 2) the Texas "LANE BLOCKED" treatment recommended for use with short duration and stop-and-go maintenance operations.

Method of Evaluation

TTI solicited the help of the maintenance sections of District 2 (Ft. Worth) and 18 (Dallas) for this evaluation. TTI personnel made numerous visits to these Districts for the purpose of observing the traffic control (either the TMUTCD or the Texas "LANE BLOCKED" treatment) set-up and removal used in actual maintenance activities within each District. Data were collected on the site-specific characteristics of each maintenance location, (e.g., land use, geometrics, traffic volumes), type of work activity being performed, number of maintenance personnel present and/or involved in the set-up or removal of the traffic control devices. Also, the length of time required to set-up and remove the traffic control devices was recorded.

District 2 normally uses the standard TMUTCD traffic control minor operations when performing short duration and stop-and-go maintenance on multi-lane highways. TTI performed 30 observational studies of the TMUTCD traffic control set-up and removal in District 2. The types of work activities performed as part of the maintenance operations included pavement crack sealing, pavement patching, and shoulder repairs.

TTI made eight trips (three to District 2, five to District 18) to evaluate the use of the Texas "LANE BLOCKED" treatment. Attempts were made to collect additional data, but adverse weather conditions on the scheduled study dates and other problems hampered data collection efforts. In addition, it was necessary to discard two of the evaluations of the "LANE BLOCKED" treatment performed in District 18. The initial evaluation was of this treatment was discarded because it was the first opportunity the District personnel had to use the "LANE BLOCKED" sign. Consequently, the maintenance personnel were not familiar with the hardware and procedures of using the sign, and so traffic control set-up took considerably longer than on subsequent days. The fourth study of this treatment in District 18 was also discarded because the sign became jammed when attempting to place into its travelling position, and required additional time and effort to free it and secure it for travel. Because these were unusual circumstances and not necessarily representative of the common use of the sign, these observations were deleted from the database.

Evaluation Results

The data collected regarding the set-up and removal times of the TMUTCD and "LANE BLOCKED" treatments were combined and averaged. These results are provided in Table 5-1. On the average, three people helped set-up and remove the TMUTCD treatment, while two people were generally used to set-up and remove the "LANE BLOCKED" treatment. To account for this difference in personnel, the time required to set-up and remove each treatment was normalized to represent the total man-time required. As Table 5-1 shows, the use of the "LANE BLOCKED" treatment resulted in significantly lower labor effort to set-up and remove. Set-up times were reduced from 23.0 man-minutes for the TMUTCD treatment to 11.9 man-minutes for the "LANE BLOCKED" treatment, a reduction of 11.1 man-minutes (52%). Likewise, removal times were reduced 8.7 man-minutes on the average (50%), from 17.3 man-minutes for the TMUTCD treatment to 8.6 man-minutes for the "LANE BLOCKED" treatment. Overall, then, the "LANE BLOCKED" treatment resulted in a nearly 20 man-minute savings over the TMUTCD treatment per work site.

While the database for the set-up and removal times for the Texas "LANE BLOCKED" treatment is somewhat limited, it should be obvious that the set-up and removal times are significantly reduced from that required with the standard TMUTCD traffic control set-up. In addition to the labor savings achieved, the amount of direct worker exposure to oncoming traffic during traffic control set-up and removal is reduced also.

TABLE 5-1. COMPARISON OF AVERAGE LABOR EFFORT EXPENDED IN TRAFFIC CONTROL SIGNING SET-UP AND REMOVAL (PER SITE)

Average Effort Per Site (Man-Minutes)

	Traffic Control Treatment		
	TMUTCD	LANE BLOCKED	Reduction
Average Effort Expended:			
Sign Set-Up	23.0	11.9	11.1
Sign Removal	17.3	8.6	8.7
TOTAL	40.3	20.5	19.8

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APPENDIX A: GUIDELINES FOR INSTALLING AND REMOVING LANE CLOSURES FOR SHORT DURATION AND STOP-AND-GO MAINTENANCE OPERATIONS

GUIDELINES FOR INSTALLING AND REMOVING LANE CLOSURES FOR SHORT DURATION AND STOP-AND-GO MAINTENANCE OPERATIONS

Introduction

This document provides general guidelines and considerations for the safe and efficient installation and removal of lane closures for short duration and stop-and-go maintenance operations on four-lane freeways. These guidelines were developed as part of Study No. 2-18-85-377 entitled "Traffic Control for Stop-and-Go and Short-Term Maintenance/Construction Operations and Techniques for Installing Lane Closures."

Short duration an stop-and go operations are a special category of maintenance activities. A short duration operation is a maintenance activity lasting 20 min or less at a fixed location. Examples of short duration operations include maintaining guardrail, inspecting drainage structures, and treating bleeding pavement with sand. A stop-and-go operation consists of a series of short duration operations at two or more locations along a highway. Examples of stop-and-go operations include patching potholes and sealing cracks. Neither the Texas Manual on Traffic Control Devices (TMUTCD) nor the Traffic Control Plan (TCP) Sheets developed by the Texas State Department of Highways and Public Transportation (SDHPT) provide special guidelines for short duration or stop-and-go operations. Therefore, the typical traffic control setup for these operations has been based upon the requirements for minor operations in the TMUTCD and the TCP Sheets. As a result, in many cases the traffic control setup takes longer than the maintenance activity itself.

The guidelines that are presented in this document were designed specifically for short duration and stop-and-go maintenance operations. The recommended traffic control setup has been found to be equally effective at informing drivers about the lane closure and to require less time to install in comparison with the traffic control setups currently used for these operations. The guidelines are intended to provide a more consistent procedure for installing and removing the setup.

Traffic Control Setup for a Freeway Lane Closure at Stop-and-Go and Short Duration Lane Closures

The traffic control setup for a freeway lane closure during a stop-and-go and short duration maintenance operation is illustrated in Figure A-1. The setup consists of a single advance warning sign placed on the right shoulder approximately 1,500 ft in advance of the beginning of the taper, an arrow panel placed in the taper, and channelizing devices forming the taper and lane closure.

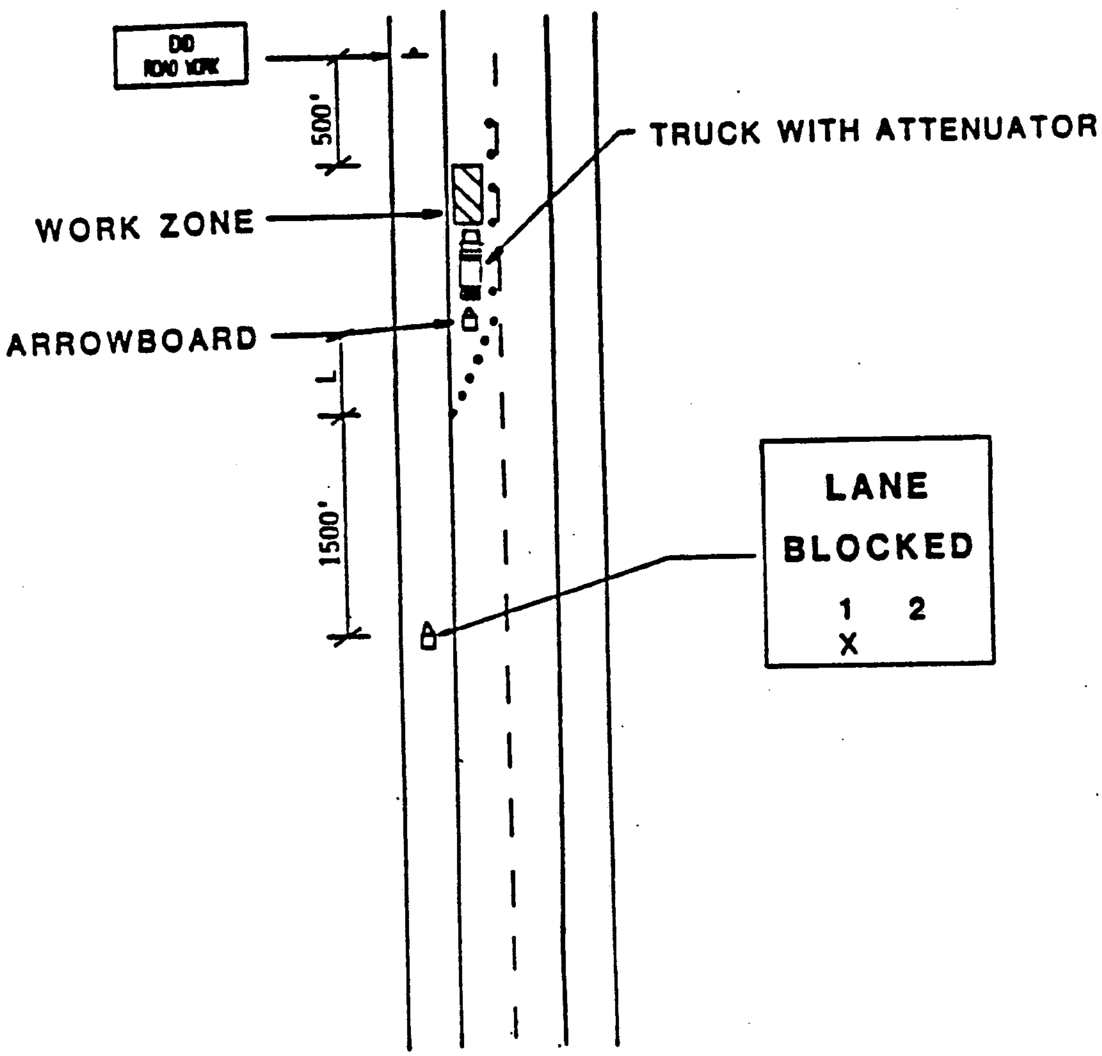


Figure A-1. Traffic Control Set-Up for Stop-and-Go and Short Duration Maintenance Operation.

The advance warning sign may be either a LANE BLOCKED sign or a Changeable Message Sign (CMS). The LANE BLOCKED sign is currently used for moving maintenance operations. An example of a LANE BLOCKED sign is illustrated in Figure A-1. The sign identifies the freeway lanes in one direction by number, starting with a "1" to represent the left-most lane. It indicates which lanes are closed with a large "X" mounted under the lane number. The number of lanes and the indication of which lanes are closed can be quickly and easily changed.

A CMS may be used in place of the LANE BLOCKED sign. The message from the LANE BLOCKED sign may be duplicated on a three-line CMS.

The flashing arrow panel should be placed on the shoulder at the beginning of the taper. If placement on the shoulder is not feasible the arrowboard may be placed on the closed lane at the end of the taper.

Four types of channelizing devices may be used for freeway lane closures: cones, vertical panels, drums, and barricades. Typically, cones will be used for stop-and-go and short duration operations. The length of taper and spacing between channelizing devices should conform to the requirements specified in the TMUTCD. The requirements are summarized in Table A-1, which is a copy of Table VI-1a from the TMUTCD.

Vehicle and Manpower Requirements

It is recommended that at least two vehicles be used to install and remove the lane closure. One vehicle would be used for the actual placement and removal of devices. The second vehicle would serve as a shadow vehicle. Additional vehicles may be used as necessary for storing channelizing devices or for towing arrow panels, LANE BLOCKED signs, and CMSs. As a minimum, the vehicles should be equipped with cab-top flashing warning lights. If available, it would be desirable to use a vehicle with a truck-mounted vehicle attenuator as the shadow vehicle. It would also be desirable to provide radio communications between the vehicles.

It is preferable to assign three or four workers the tasks of placing and removing work zone traffic control devices. All workers should wear reflectorized orange vests and hard hats. One or two of the workers should also be responsible for monitoring the traffic control devices during the maintenance operation so that devices knocked over or out of place can be returned to their proper position. It would be desirable to develop a regular crew that is accustomed to working together, in order to improve communications and enhance safety during the installation and removal of the lane closure.

It is recognized that the availability of law enforcement personnel for traffic control in work zones varies by jurisdiction. However, when conditions warrant, their assistance should be solicited.

TABLE A-1. TYPICAL TRANSITION LENGTHS AND SUGGESTED MAXIMUM SPACING OF DEVICES

Posted Speed*	Formula	Minimum Desirable Taper Lengths** 10' Offset	11' Offset	12' Offset	Suggested Maximum Spacing of Device On a Taper	On a Tangent
30	$L = \frac{WS^2}{60}$	150'	165'	180'	30'	60'-75'
35		205'	225'	245'	35'	70'-90'
40		265'	295'	320'	40'	80'-100'
45	L = WS	450'	495'	540'	45'	90'-110'
50		500'	550'	600'	50'	100'-125'
55		550'	605'	660'	55'	110'-140'
60		600'	660'	720'	60'	120'-150'

*85th Percentile Speed may be used on roads where traffic speeds normally exceed the posted speed limit.
**Taper lengths have been rounded off.

Source: (1)

Preparations

Adequate planning and preparations prior to leaving for the site are critical to the safety of the lane closure installation. Work that can be done beforehand will make the installation more efficient and therefore minimize the exposure of workers to traffic.

The traffic control devices should be inspected for any needed maintenance or cleaning. Signs, supports, and channelizing devices should be in usable condition. Arrow panels and CMSs should be fueled and have all bulbs working. If possible, the message on the LANE BLOCKED sign (lane numbers and indication of which lanes are closed) should be prepared or the CMS should be programmed before leaving for the work site.

The traffic control devices should be organized on the work vehicles so that they are readily accessible at the work site.

Installation of the Lane Closure

The traffic control crew should arrive at the work site before any of the crew and vehicles involved in the actual work activity. The vehicles used in the traffic control setup should park on the right shoulder at the location of the advance warning sign. Upon parking at the site, the vehicles' four-way flashers and cab-top flashing lights should be turned on and should be kept on throughout the setup operation.

The recommended order for the installation of the lane closure is:

1. Placement of the LANE BLOCKED sign or CMS
2. Placement of the arrow panel
3. Placement of the channelizing devices in the taper
4. Placement of the channelizing devices in the lane closure
5. Placement of the END ROAD WORK sign (optional)

<u>Placement of the LANE BLOCKED Sign or CMS</u>

The first step in installing the lane closure is the placement of the LANE BLOCKED sign or CMS. The sign should be placed on the right shoulder approximately 1500 ft in advance of the beginning of the cone taper. Also, the sign should be placed so that drivers can see it from at least 1500 ft away. To enhance safety, a flagger may be used to alert and slow traffic as well as to serve as a lookout for oncoming traffic while other workers place the sign.

Placement of the Arrow Panel

The second step in the installation procedure is the activation and placement of the arrow panel. After the LANE BLOCKED sign or CMS has been placed, the vehicles should be driven on the shoulder to the beginning of the taper. The arrow panel should be positioned on the shoulder near the beginning of the taper. Then, the arrow panel should be raised and turned on. A flagger may be positioned on the shoulder at the beginning of the taper to alert and slow traffic as well as to serve as a lookout for oncoming traffic while the arrow panel is being activated and placed. If the arrow panel is to be placed on the closed lane at the end of the taper, it may be moved into position after it has been activated on the shoulder. Arrow panels should be seen from 1500 ft away.

Placement of the Channelizing Devices in the Taper

Perhaps the most potentially hazardous step in the installation of the lane closure is the placement of the channelizing devices in the taper. Motorists must have adequate warning about the lane closure. Therefore, the taper should be formed after the advance warning sign has been placed and the arrow panel has been activated and placed. The flagger may also be useful to alert and slow motorists. In addition, the flagger may contribute to the safety of the workers by serving as a lookout for oncoming traffic while the channelizing devices are being placed. If cones are used they should be at least 28 inches high.

The cones, or other channelizing devices, used to form the taper, may be placed, at the proper spacing, either by workers on foot or from the rear of a vehicle. The taper should extend from the edge of the paved shoulder to the lane line.

After the taper has been completed, the flagger may be relieved of his flagging duties and may join the rest of the setup crew.

Placement of the Channelizing Devices in the Lane Closure

After the taper is in place, the shadow vehicle should be positioned behind the vehicle carrying the cones. The crew should position themselves in the vehicle carrying the cones. This vehicle should proceed down the closed lane at a pace that allows the workers to place the cones at the proper spacing. The shadow vehicle should follow 50 to 100 ft behind.

Channelizing devices should be spaced more closely than the maximum allowed spacing at locations in the work zone that will have intense work activity, pavement edge drop offs, or heavy equipment in operation near the open traffic lane.

Optionally, at the end of the work zone, a short taper back to the shoulder may be provided.

Placement of the END ROAD WORK Sign

After the cones have been placed, an END ROAD WORK sign may be erected on the shoulder no more than 500 ft downstream from the end of the work zone. Use of the END ROAD WORK sign is optional.

Removal of the Lane Closure

At the end of the work activity the work zone should be free from any trace of work activity and the removal of the lane closure may begin. The lane closure should be removed in the opposite order that it was placed. As with the setup of the closure, it is desirable to use a shadow vehicle in addition to the vehicle required for the actual removal of the traffic control devices.

Removal of the END ROAD WORK Sign

The first step in the removal of the lane closure is to take down the END ROAD WORK sign at the end of the work zone.

Removal of the Channelizing Devices in the Lane Closure

The removal of the cones in the lane closure should proceed from the end of the work zone to the taper. The workers should situate themselves as they did for placing the devices. The vehicles should travel upstream in reverse at a slow, steady pace in the closed lane.

Removal of the Channelizing Devices in the Taper

Upon reaching the taper, the vehicle should be parked on the shoulder upstream of the arrow panel. The arrow panel should be placed in tow before beginning to remove the taper. A flagger may be positioned on the shoulder at the beginning of the taper to alert and slow traffic and to serve as a lookout for oncoming traffic while the taper is being removed. With the arrow panel flashing and, optionally, the flagger alerting traffic at the beginning of the taper, the cones in the taper may be removed.

Removal and Deactivation of the Arrow panel

After the taper has been removed, the arrow panel should be turned off and cranked down to the proper position for transporting.

Removing the Advance Warning Sign

After the taper has been removed and the arrow panel removed and deactivated, the crew should drive to the advance warning sign. The sign may then be removed and placed in tow. When all signs and channelizing devices have been secured in the vehicles for transporting, the crew may leave the site.

APPENDIX B. POSITIVE GUIDANCE APPROACH FOR WORK ZONE TRAFFIC CONTROL

Positive Guidance

Alexander et. al. (5) developed a model that is useful in describing the ordinary driving task. According to Alexander, the driving task consists of three levels; control, guidance, and navigation. At the control level, the driver deals mainly with those activities and sources of information which directly relate to the physical manipulation of the vehicle. Information at this level is transmitted by the vehicle itself and is received by the driver through natural sensing mechanisms. The driver reacts to this information and controls the vehicle via the steering wheel, accelerator, brake, etc. With practice and experience, the control function of the driving task can be performed in normal situations without the driver exerting much effort.

Next, the guidance level of the driving task refers primarily to the selection of a safe speed and path on a highway. Activities at the guidance level include lane positioning, car following, and vehicle passing. Information must be analyzed and a decision must be made so that a control action can be executed. The roadway, traffic control devices, other vehicles as well as the surrounding environment are sources of information at this level of the driving task.

The final level deals with navigation. Included at this level are activities such as trip planning, route following, and destination finding. Sources of information used at this level include maps, guide signs, and landmarks.

Depending on the level of the driving task and the action required, the amount of information needed and the time needed to process that information varies. Post, Alexander and Lunenfeld have presented the concept of decision sight distance (9), which can be defined as:

> The distance at which a driver can detect a signal (hazard) in an environment of visual noise or clutter, recognize it (or its threat potential), select appropriate speed and path, and perform the required action safely and efficiently.

Alexander et. al. state that Positive Guidance is an engineering tool designed to enhance the safety and operational efficiency of hazardous locations (5, 9). The concept of Positive Guidance is that, given sufficient information, drivers may avoid accidents at potentially hazardous locations. The Positive Guidance concept recognizes the different levels of driver performance with the guidance level taking "primacy" over the navigational task. An operational definition of Positive Guidance is:

Any information carrier, including the highway, that assists or directs the drivers in making speed or path decisions provides guidance information to the driver. Positive guidance information is provided when that information is presented unequivocally, unambiguously, and conspicuously enough to meet decision sight distance criteria and enhance the probability of appropriate speed and path decisions.

The goal of Positive Guidance is to present information pertaining to the guidance level of the driving task so that the driver has an increased probability of selecting the most appropriate speed and path for the prevailing highway conditions so as to avoid a system failure. System failures vary from delay and being lost to fatal accidents, the degree of severity of the system failure directly related to the level of the driving task at which the failure occurred.

Positive Guidance in Work Zones

Applying the principles of Positive Guidance and, more specifically, decision sight distance, Hulbert and Burg (10) developed a hazard avoidance model of the driving task. Figure B-1 illustrates this model for a typical lane closure. The model describes a sequence of events which occur in the hazard avoidance process. The model starts at the point of detection and proceeds until the avoidance maneuver has been completed.

McGee and Knapp (11) used principles of Positive Guidance to identify areas or zones in which certain information about a work zone should be provided a driver. Figure B-2 shows how each of the information handling zones fit together at a typical lane closure. In all five of the zones shown in Figure B-2, drivers are subject to different stimuli and information devices.

The Advance Zone is the area before the driver is first exposed to the work zone. This zone begins where the first warning sign is visible to the motorist.

The Approach Zone is where the motorist must detect and recognize that a hazard is present. Here, the motorist must formulate the appropriate control alternatives and prepare to execute the elected alternative. This zone is located upstream of the hazard a distance equal to the decision sight distance.

The Non-Recovery Zone is the area where the motorist must execute the control maneuver. The length of this zone corresponds to the stopping sight distance.

The Hazard Zone is simply the length of the work zone, including the channelizing devices. The Downstream Zone is that area beyond the hazard where a driver can safely return to normal operating conditions.

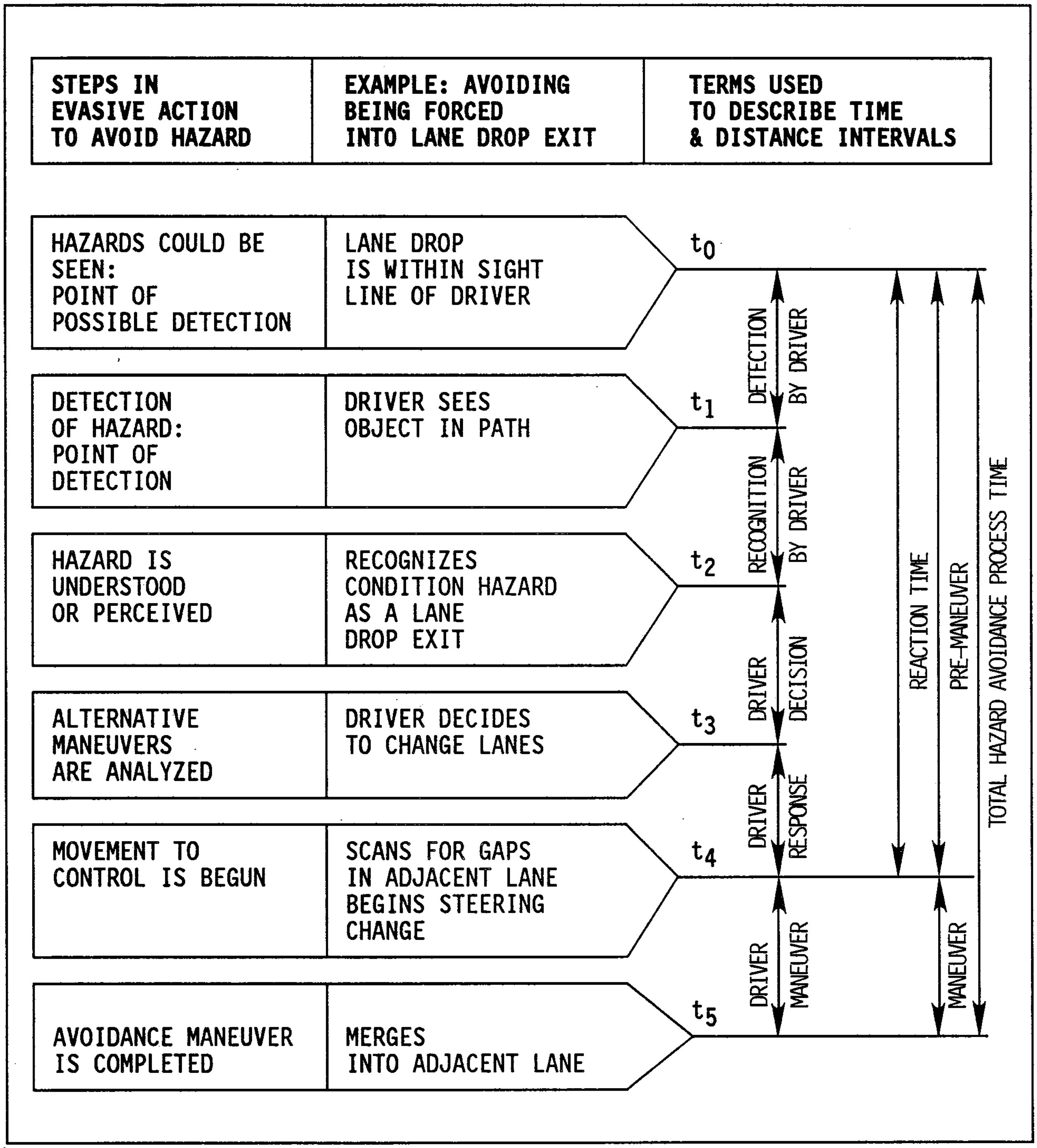
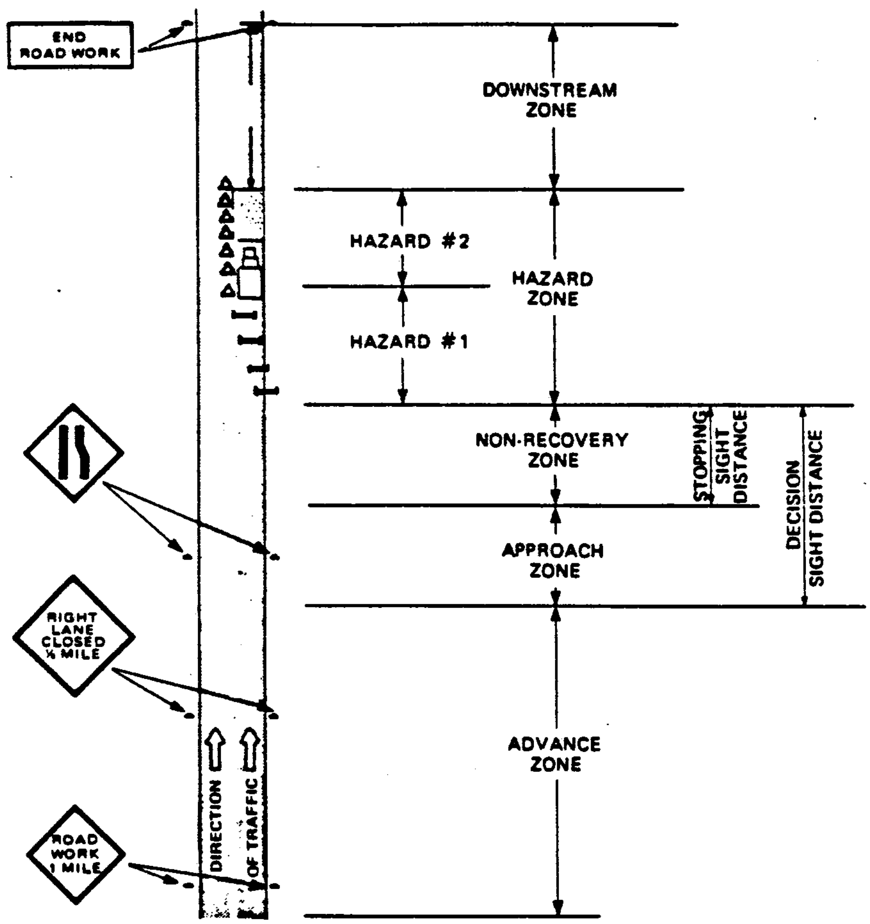


Figure B-1. Hazard Avoidance Model for a Typical Lane Closure. (Reference 10)



Note: [1]Non-Recovery, Approach and Advance Zone are not plotted to any scale for this example.
[2]Diagram including sign placement taken from MUTCD

Figure B-2. Typical Information Handling Zones.
(Reference 11)

Based on the information content and intended function, Hostetter, et. al. grouped work zone traffic control devices into information classes (12). The first information class, Feature Warning, deals with those traffic control devices that inform the driver that some feature of the work zone is potentially hazardous. The next class, Maneuver Warning, identifies what the driver must do to negotiate the feature (such as a lane change, turn, or stop). Another important class is that of Feature Location, which identifies the location at which or by which a specific maneuver must be accomplished. Other important information classes defined by Hostetter include Prohibitory/Restrictive Location, Speed Advisory, Speed Change Warning, Speed Limits, Route Guidance, and Confirmation.

Application of Positive Guidance Principles to Traffic Control Requirements of Short Duration and Stop-and-Go Maintenance Operations

Figure B-3 shows the information handling zones and corresponding potential hazard avoidance model developed by McGee and Knapp superimposed on the TMUTCD traffic control plan for a minor maintenance operation on a four-lane divided highway. Also shown in this figure are the information classes for each type of traffic control device used in this plan. Note that within each information handling zone, the driver is provided with a specific class of information to facilitate the execution of the hazard avoidance process. For example, in the Approach Zone, the driver must recognize the nature of the potential hazard that he/she is about to encounter, and so a Feature Warning "LEFT LANE CLOSED AHEAD" sign is provided.

Table B-1 shows the driver level of performance and the type of information required in each of the information handling zones for the minor maintenance lane closure operation. The table also shows the standard TMUTCD traffic control devices that are used to fulfill the driver information requirements for this type of work zone.

In a similar vein, Figure B-4 and Table B-2 present the information handling zones for the moving maintenance operations. Note in Table B-2 that the only sources of information provided by the traffic control plan for the moving operation are the flashing arrow panel attached to the rear vehicle and the actual work vehicles themselves. The driver must both perceive and recognize the hazard in the approach zone to the work caravan, and since the maneuver location is not clearly defined, the driver must also execute the hazard avoidance maneuver in the non-recovery zone. Consequently, this traffic control plan requires drivers to process the information presented in a shorter period of time than for minor operations. However, research (4, 6) has shown this traffic control plan is effective in informing drivers of the lane closure. One possible explanation for this is that the greater conspicuity of the flashing arrow panel allows drivers to detect the hazard far enough upstream to properly process the information and react appropriately.

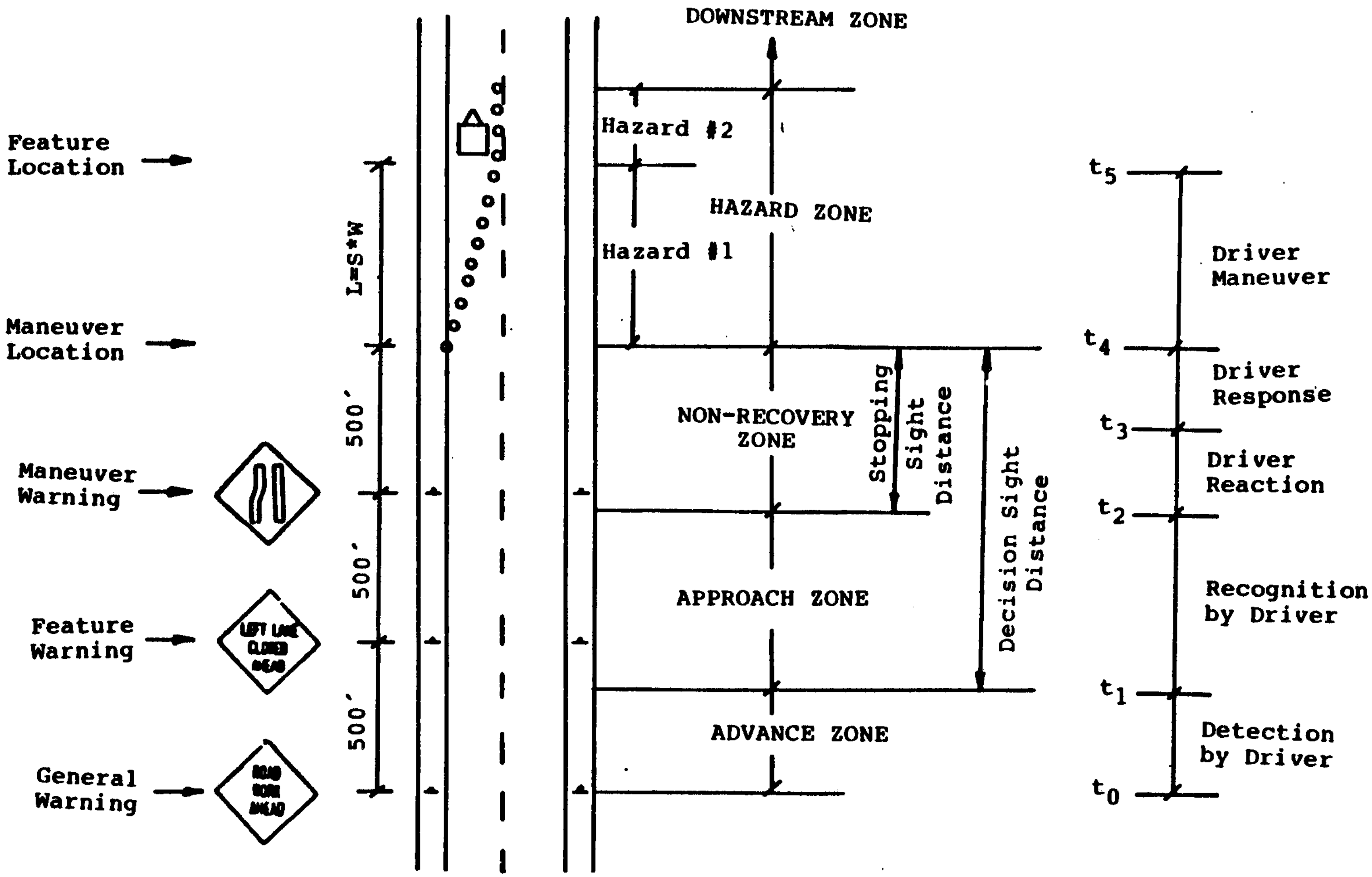


Figure B-3. Information Handling Zones for a Minor Maintenance Operation.

Table B-1. Hazard Avoidance Model for a Minor Maintenance Lane Closure.

ZONE DESIGNATION	DECISION SIGHT DISTANCE MODEL TERM	DRIVER LEVEL OF PERFORMANCE AND PERCEPTION	TYPE OF INFORMATION REQIRED	INFORMATION CLASS	TRAFFIC CONTROL DEVICE
Advance Zone	t_0	Navigational	Alerting / Warning	General Warning	"ROAD WORK AHEAD"
Approach Zone	t_1	Detection of Hazard/ Shift to Guidance	Warning of Hazard Type	Feature Warning	"RIGHT/LEFT LANE CLOSED AHEAD"
Non-Recovery Zone	t_2	Recognize Hazard	Identify Necessary Maneuver	Maneuver Warning	Symbolic Lane Closed Sign
	t_3	Shift to Control Function	Prepare to Execute Maneuver		
Enter Transition	t_4	Begin Tracking Task/ Control Function	Location to Begin Maneuver	Maneuver Location	Cone Taper
Hazard Area	t_5	Return to Guidance Function	Location to Complete Maneuver	Feature Location	Arrow Panel
Downstream Zone		Maneuver Completed/ Return to Navigational	Reinforce Hazard Information		Channelizing Devices

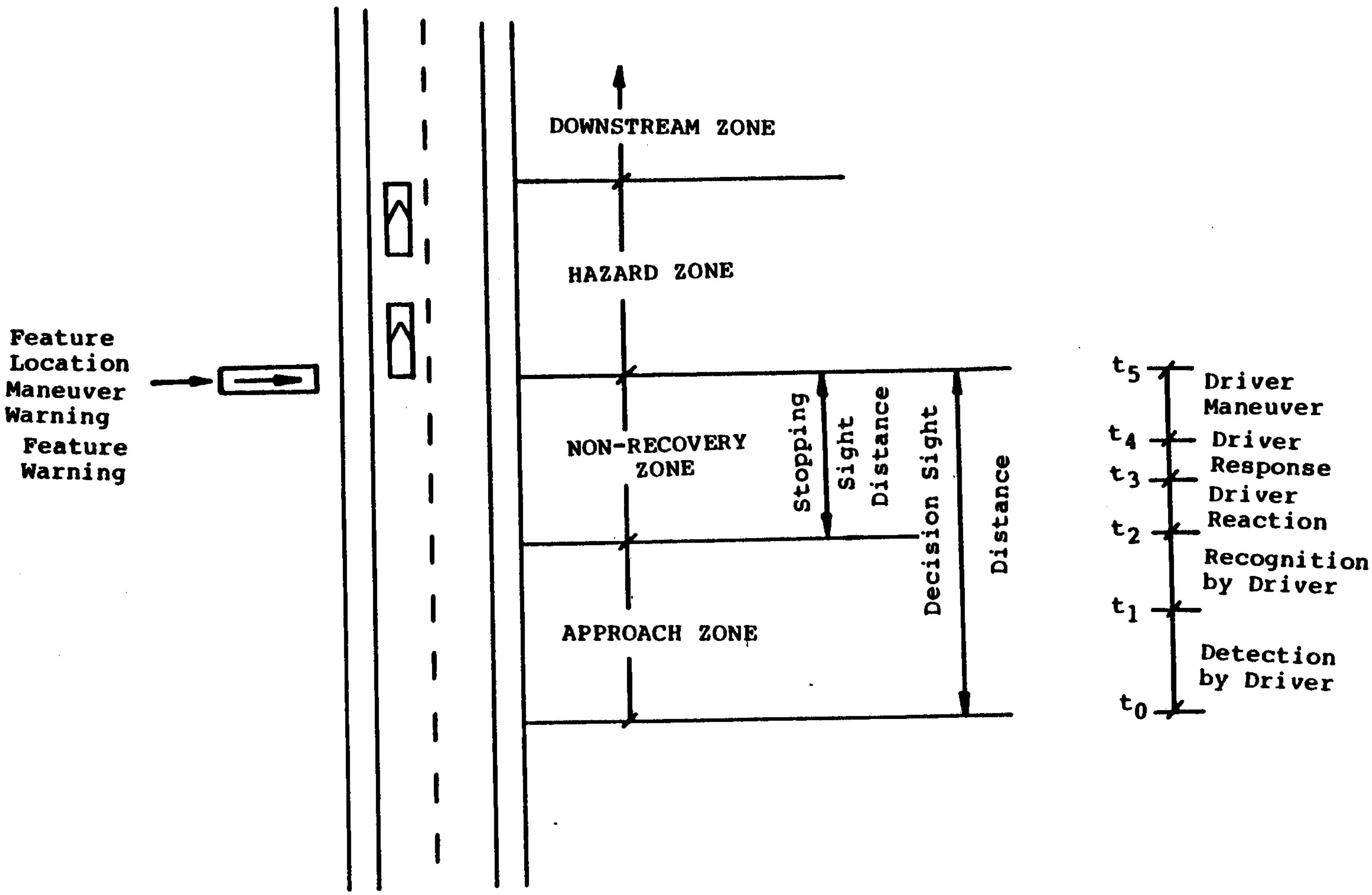


Figure B-4. Information Handling Zones for a Moving Maintenance Operation.

Table B-2. Hazard Avoidance Model for a Moving Maintenance Operation.

ZONE DESIGNATION	DECISION SIGHT DISTANCE MODEL TERM	DRIVER LEVEL OF PERFORMANCE AND PERCEPTION	TYPE OF INFORMATION REQIRED	INFORMATION CLASS	TRAFFIC CONTROL DEVICE
Approach Zone	t_0	Detection of Hazard/	Warning of Hazard Type	Feature Warning	Arrow Panel
	t_1	Shift to Guidance			
Non-Recovery Zone	t_2	Recognize Hazard	Identify Necessary Maneuver	Maneuver Warning	Arrow Panel
	t_3	Prepare to Execute Maneuver			
	t_4	Execute Maneuver/ Control Function	Location to Begin Maneuver	Maneuver Location	Arrow Panel
Hazard Area	t_5	Return to Guidance Function	Location to Complete Maneuver	Feature Location	Arrow Panel/ Caravan
Downstream Zone		Maneuver Completed/ Return to Navigational	Reinforce Hazard Information		Caravan

Ideally, the traffic control plan for short duration and stop-and-go operations should provide the driver with sufficient information to safely and efficiently negotiate through the work zone with as few traffic control devices as possible. Enabling the driver to recognize the hazard farther upstream appears to be the key to developing an effective traffic control plan. By allowing the driver to recognize the hazard in the Advance Zone, more time becomes available for the driver to execute the hazard avoidance maneuver.

Figure B-5 presents the conceptual hazard avoidance model for a short duration and stop-and-go traffic control plan. This conceptual plan uses the arrow panel as the primary source of information. An advance warning sign is used to inform the driver of the hazard he/she is approaching and also to reinforce the implied maneuver warning of the arrow panel.

Table B-3 shows the driver level of performance anticipated to occur in each information handling zone with the proposed reduced advance traffic control. This table also shows what information would be provided in each zone and possible devices that can be used to provide that information.

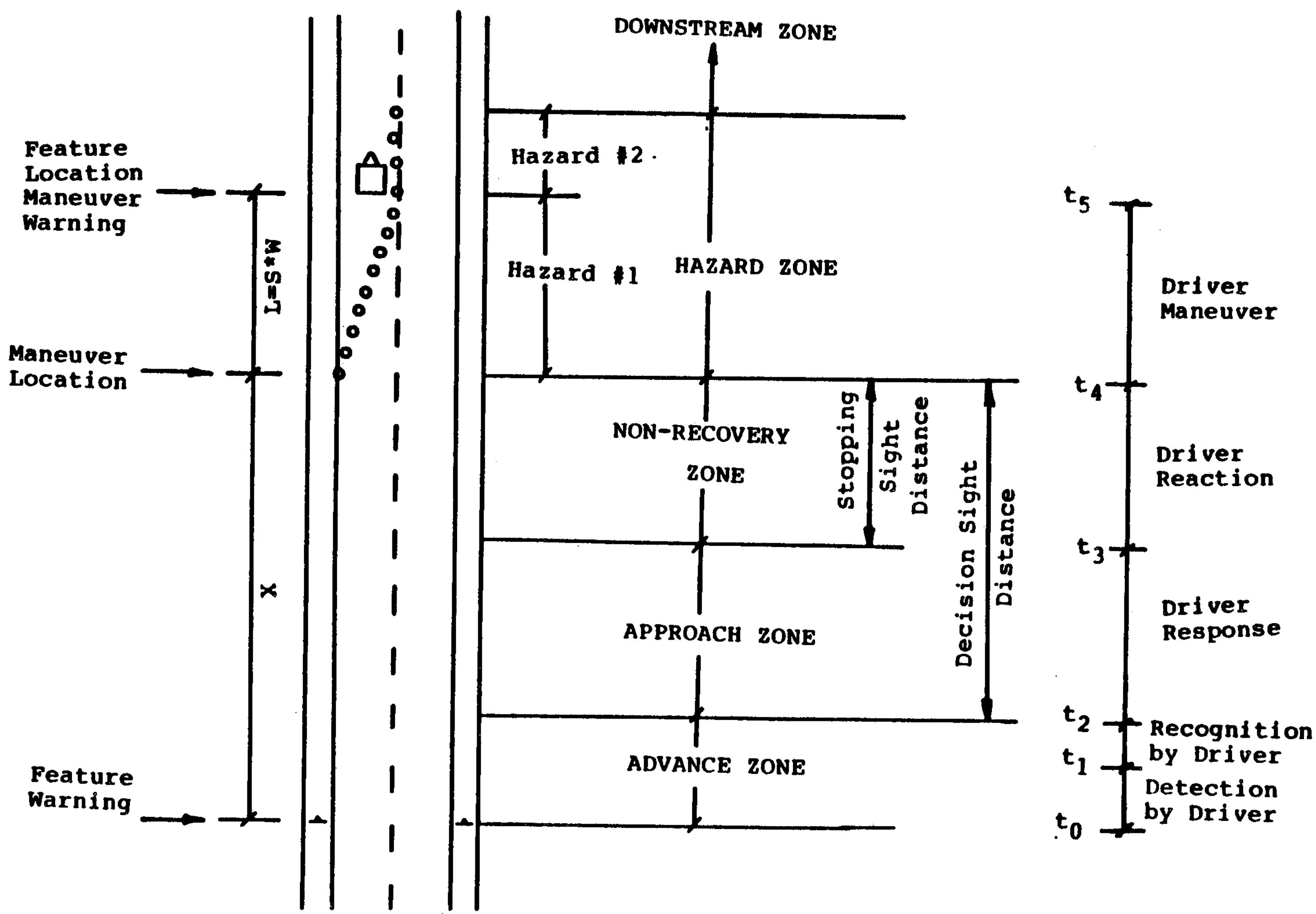


Figure B-5. Information Handling Zones for a Short Duration and Stop-and-Go Maintenance Operation.

Table B-3. Hazard Avoidance Model for Short Duration and Stop-and-Go Maintenance Operations.

ZONE DESIGNATION	DECISION SIGHT DISTANCE MODEL TERM	DRIVER LEVEL OF PERFORMANCE AND PERCEPTION	TYPE OF INFORMATION REQIRED	INFORMATION CLASS	TRAFFIC CONTROL DEVICE
Advance Zone	t_0	Navigational	Alerting / Warning	Feature/ Maneuver Warning	Candidate Signing Treatments
	t_1	Detection of Hazard/ Shift to Guidance	Warning of Hazard Type		
Approch Zone	t_2	Recognize Hazard	Identify Necessary Maneuver	Maneuver Warning	Arrow Panel
Non-Recovery Zone	t_3	Shift to Control Function	Prepare to Execute Maneuver		Arrow Panel
Enter Transition	t_4	Begin Tracking Task/ Control Function	Location to Begin Maneuver	Maneuver Location	Cone Taper
Hazard Area	t_5	Return to Guidance Function	Location to Complete Maneuver	Feature Location	Arrow Panel
Downstream Zone		Maneuver Completed/ Return to Navigational	Reinforce Hazard Information		Channelizing Devices

APPENDIX C: SCHEMATIC DIAGRAMS OF STUDY SITE LOCATIONS

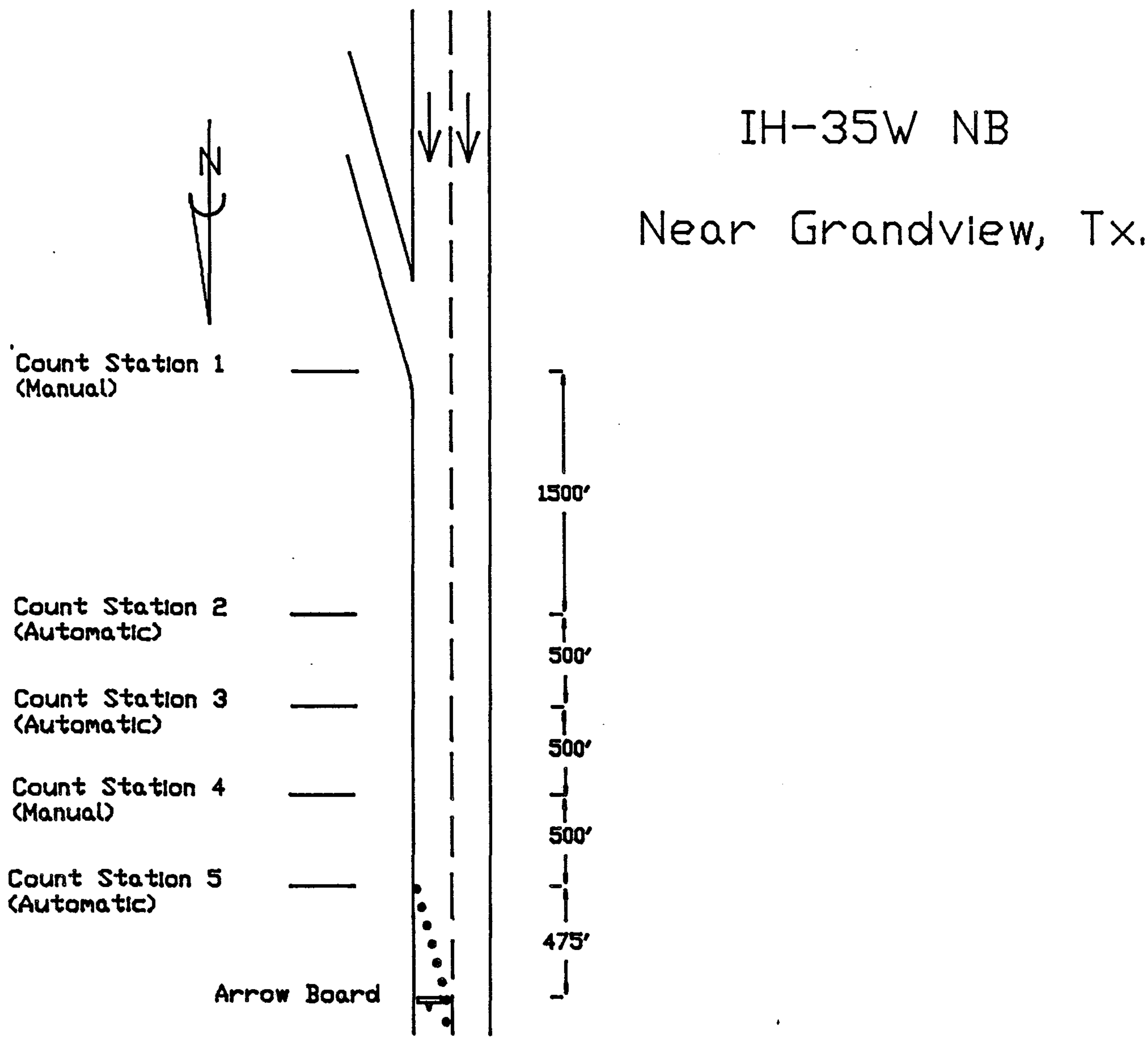


Figure C-1. Site Plan of IH-35W NB Near Grandview, Texas.

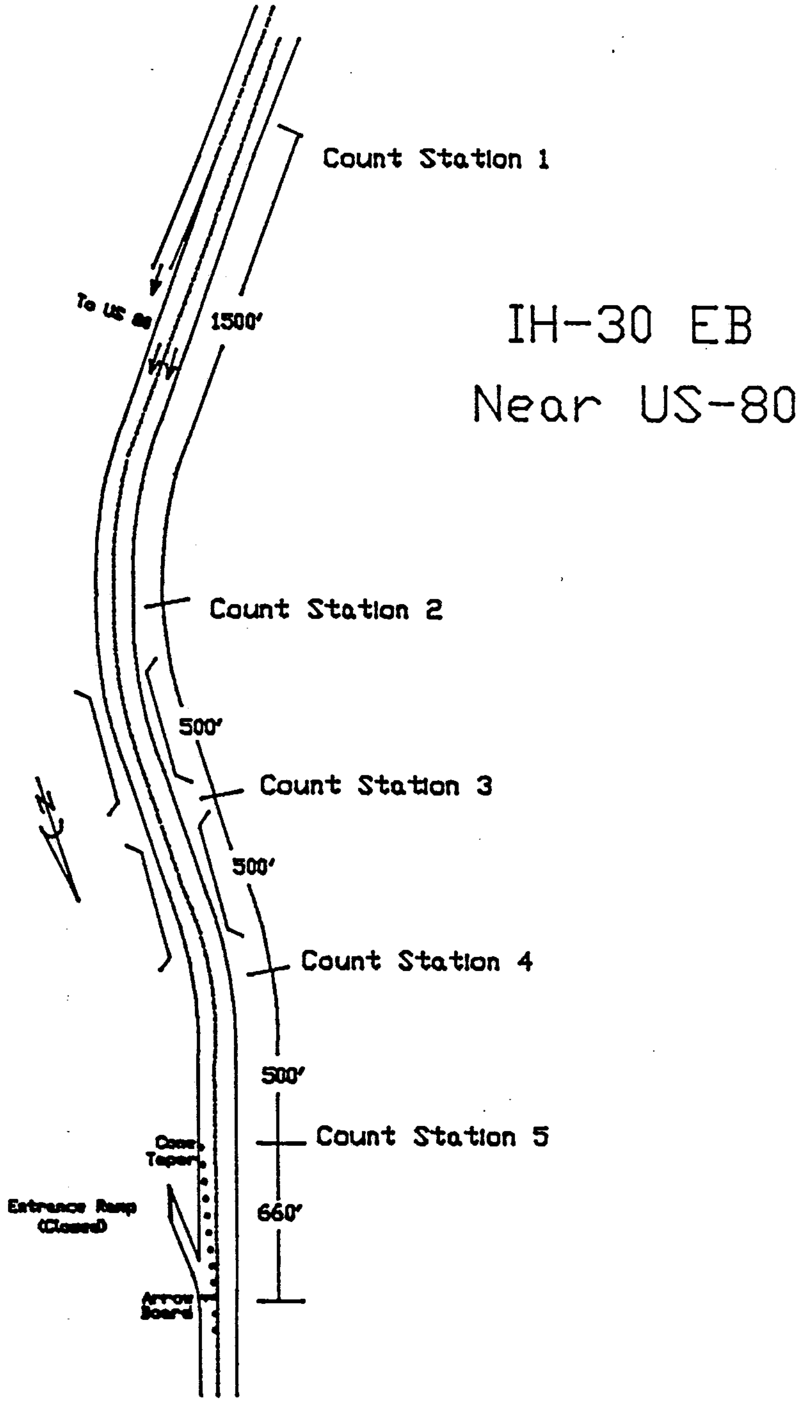


Figure C-2. Site Plan for IH-30 EB Near US-80

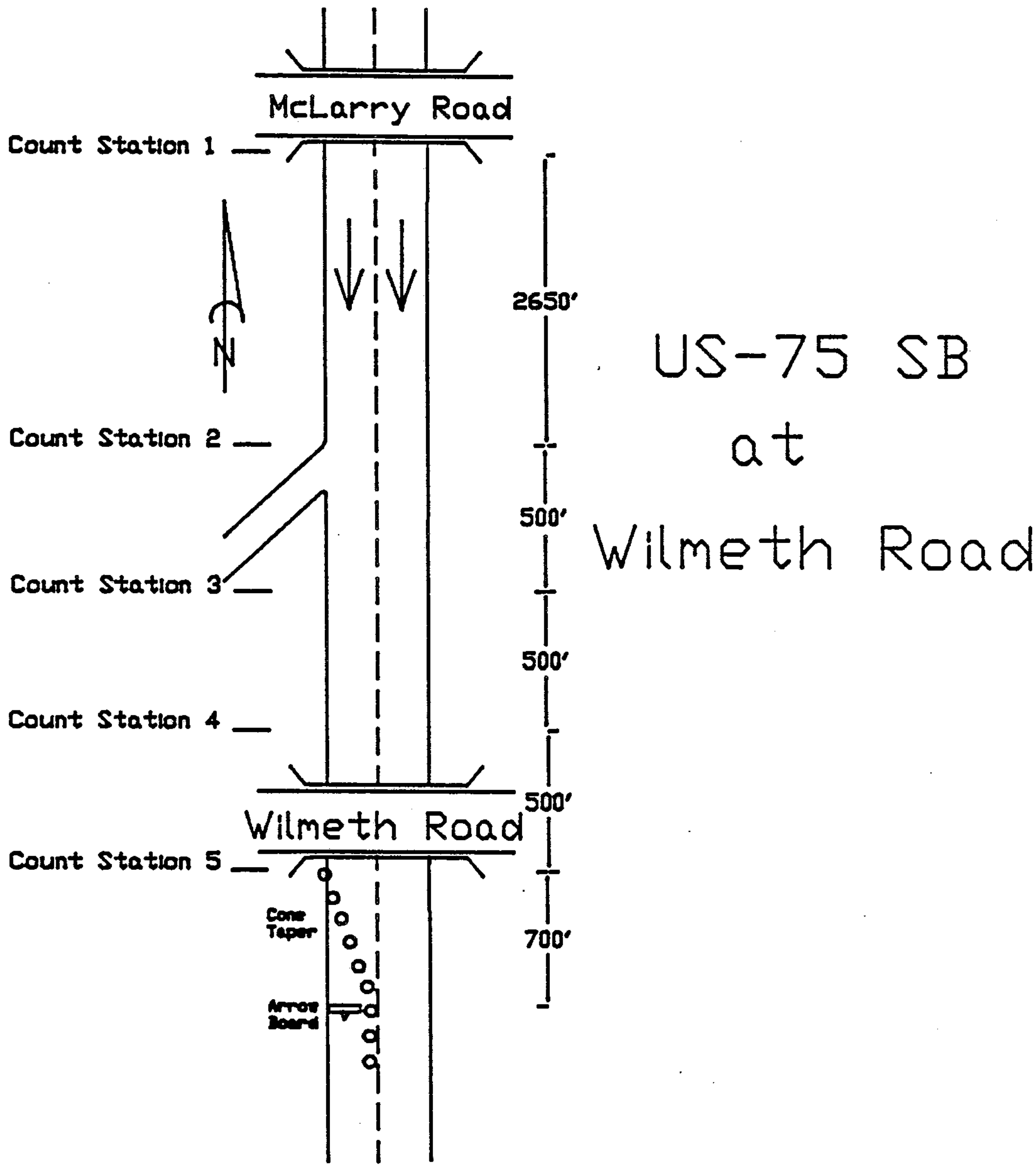


Figure C-3. Site Plan of US-75 SB at Wilmeth Road.

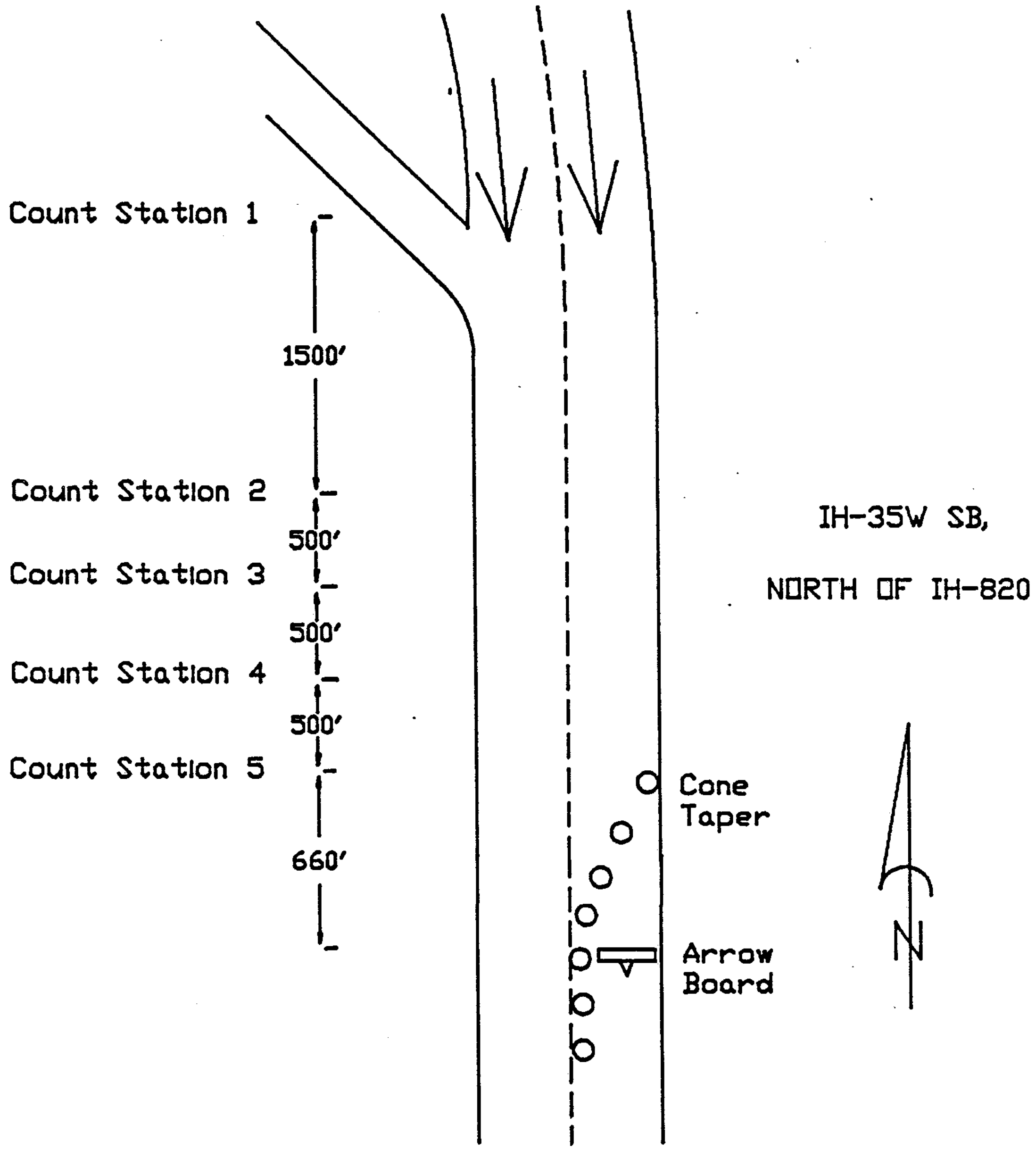


Figure C-4. Site Plan for IH-35W SB North of IH-820.

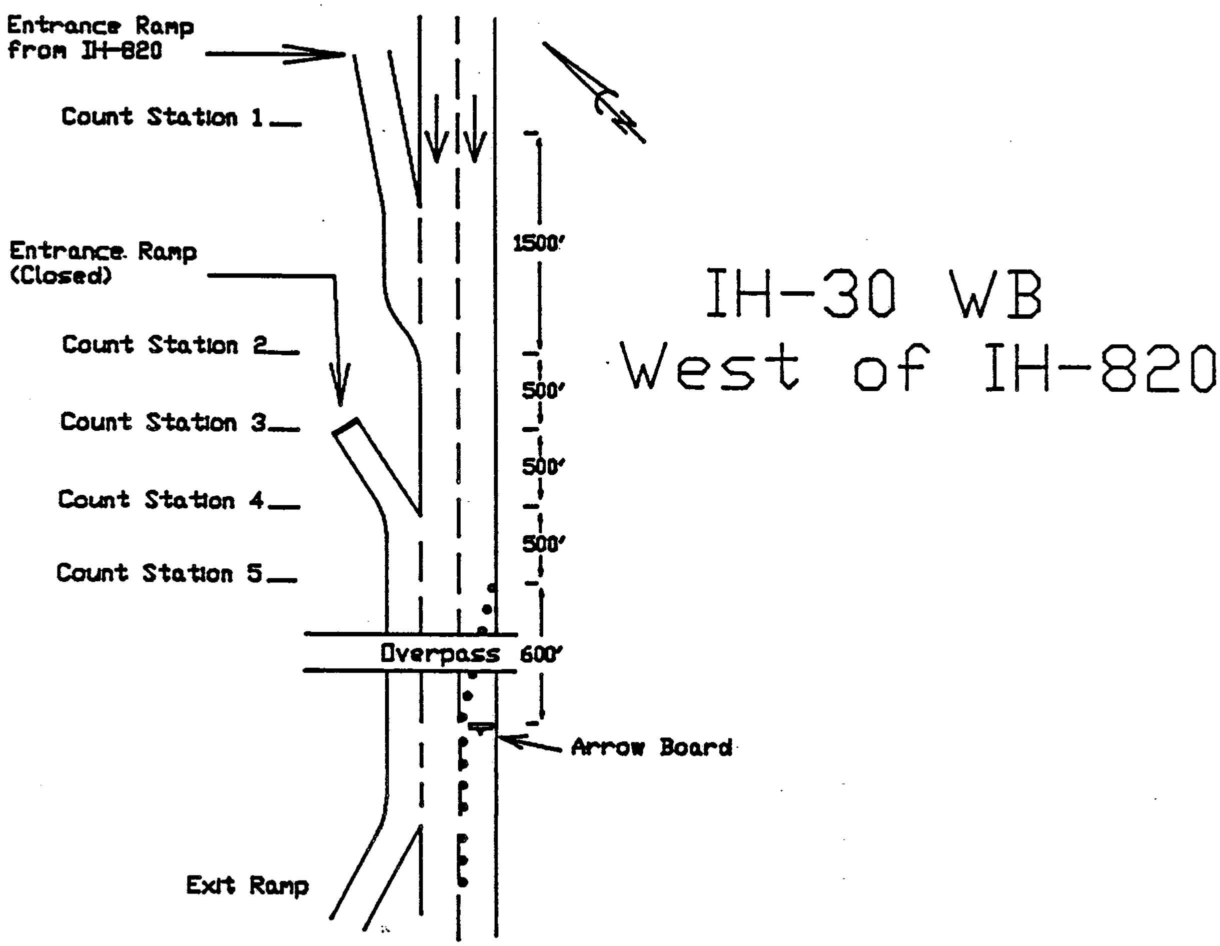


Figure C-5. Site Plan for IH-30 WB West of IH-820.

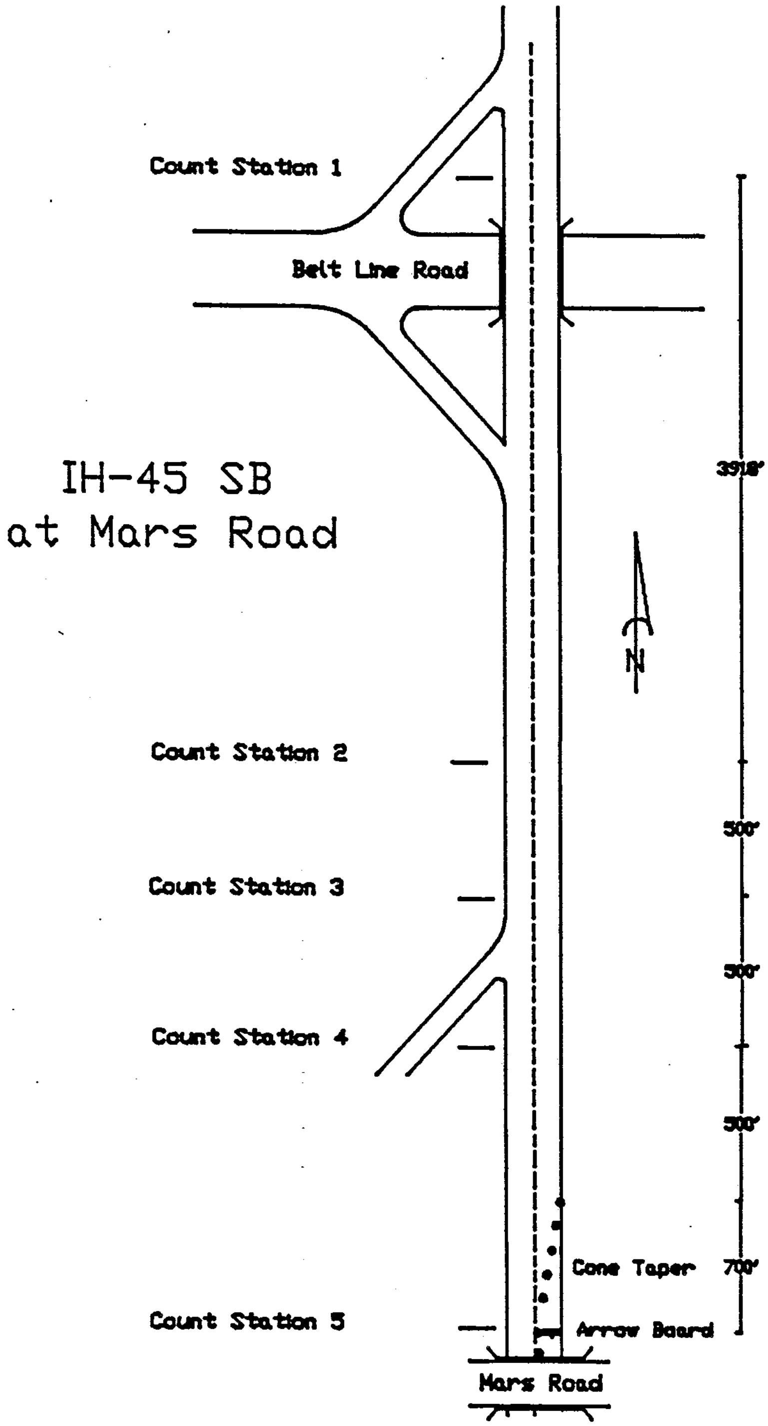


Figure C-6. Site Plan of IH-45 SB at Mars Road.

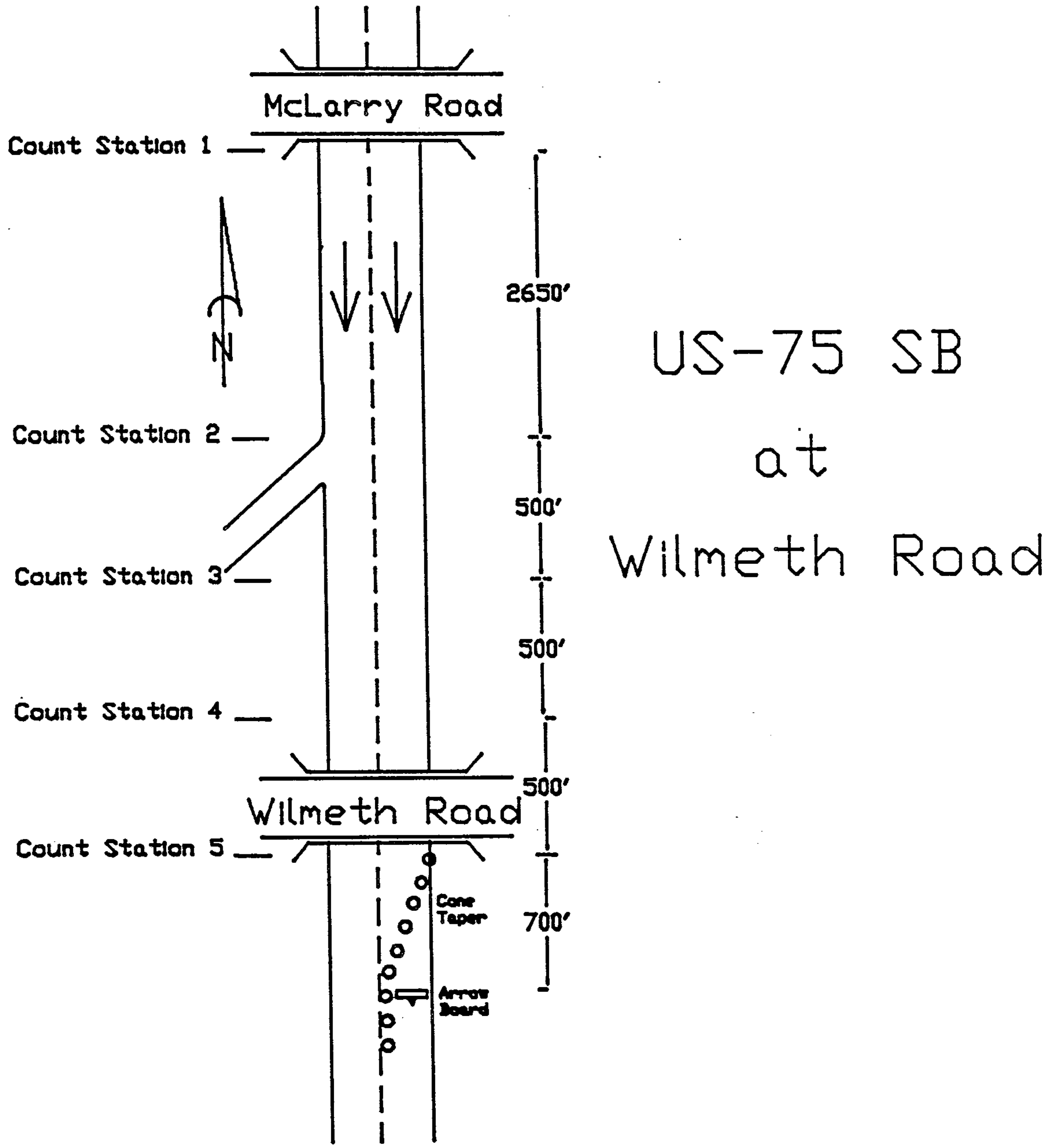


Figure C-7. Site Plan for US-75 SB at Wilmeth Road.

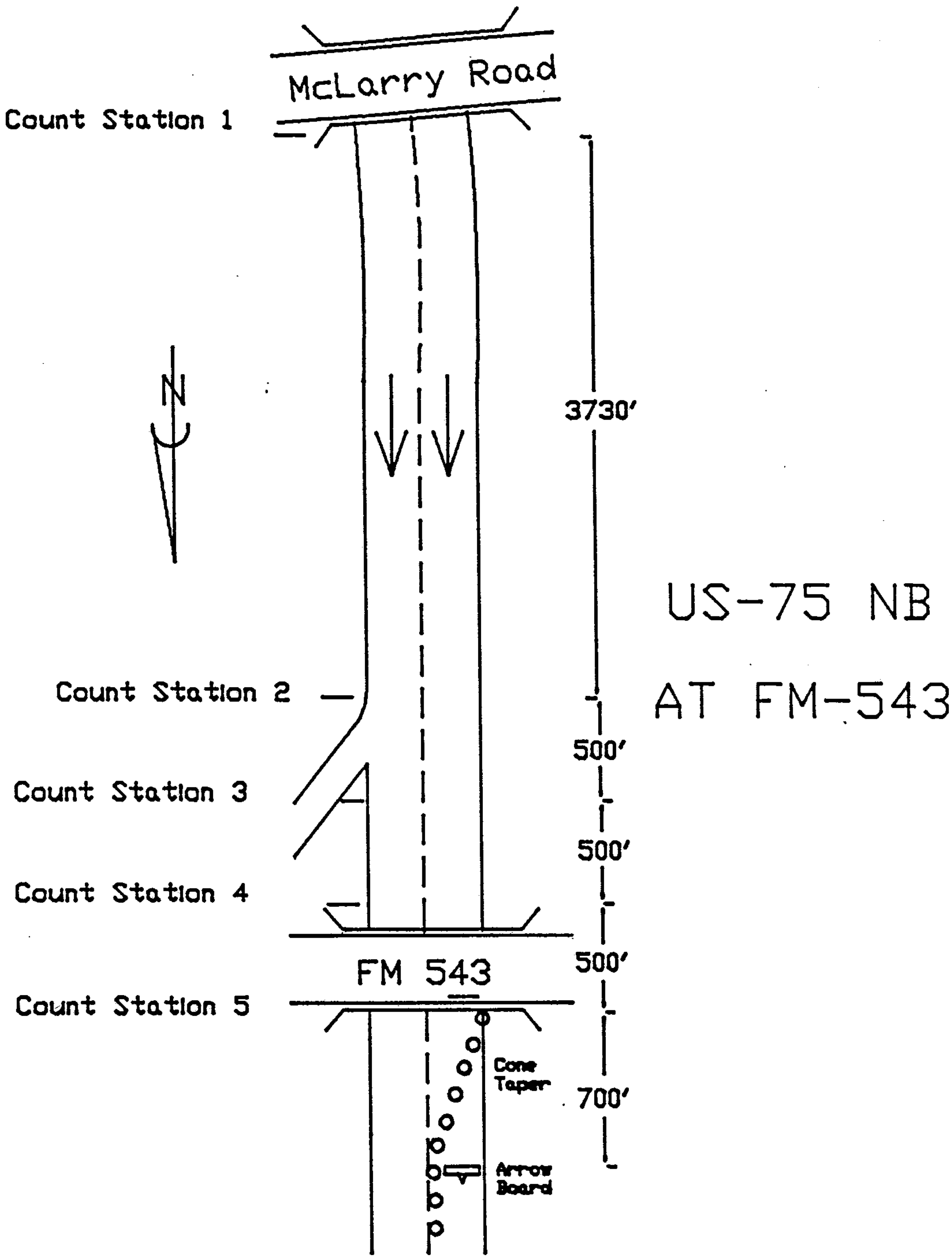


Figure C-8. Site Plan for US-75 NB at FM 543.

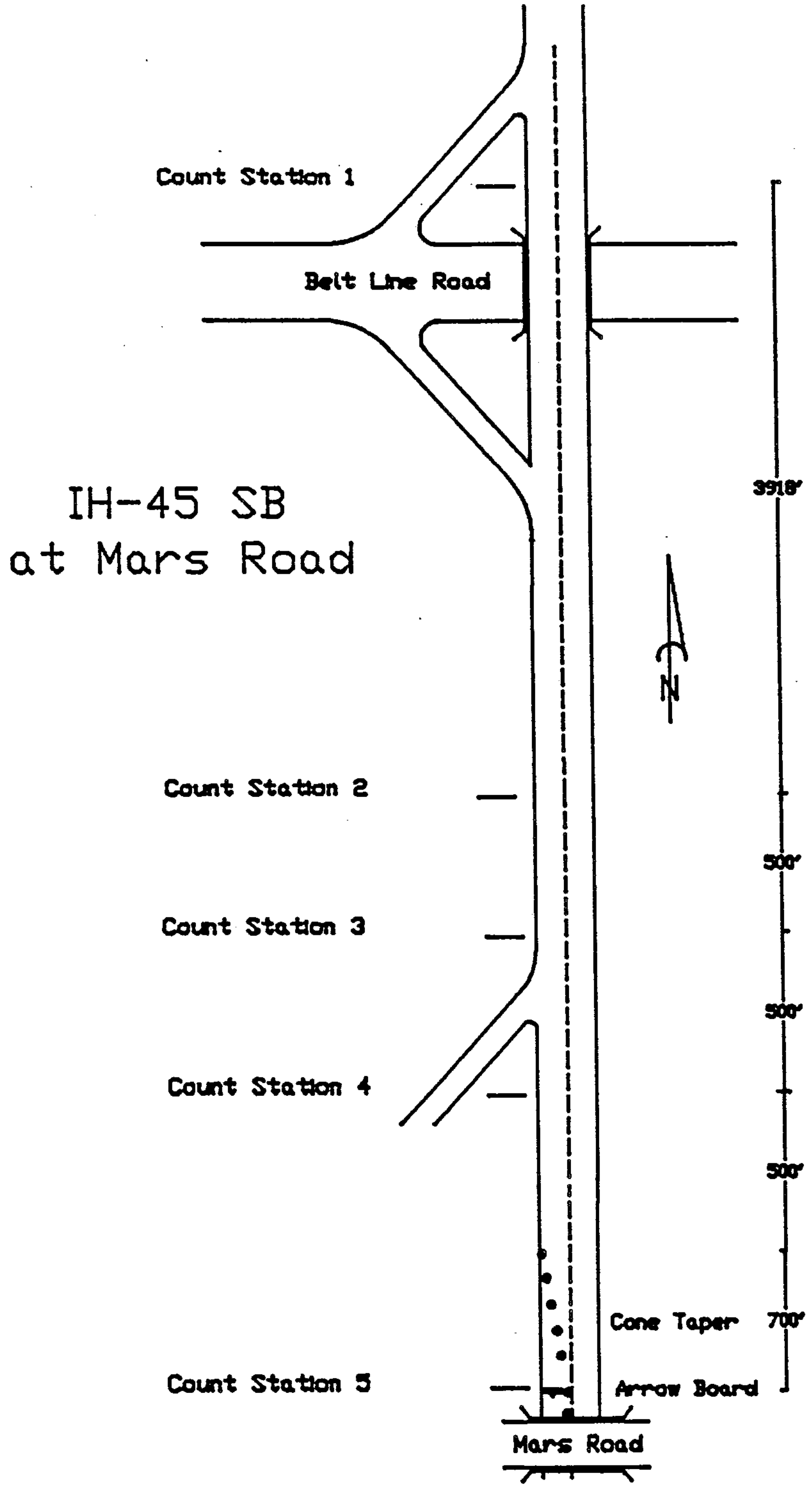
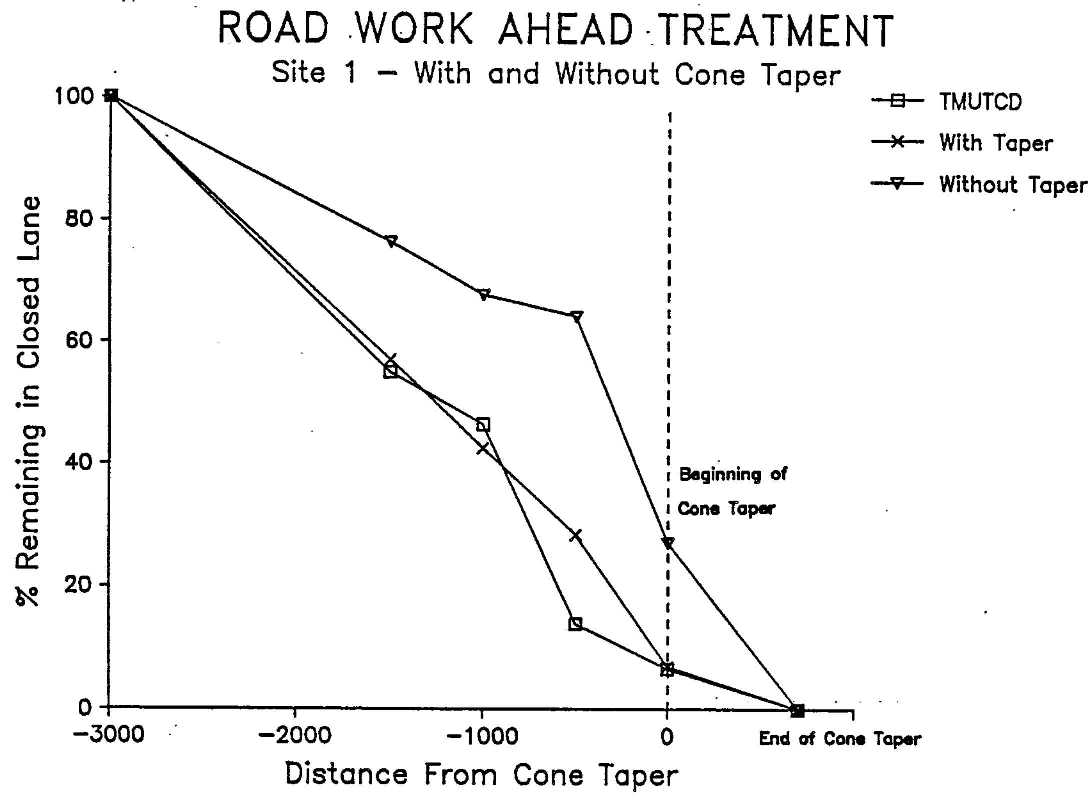


Figure C-9. Site Plan for IH-45 SB at Mars Road.

APPENDIX D: EFFECT OF CANDIDATE SIGNING TREATMENTS WITH AND WITHOUT A CONE TAPER



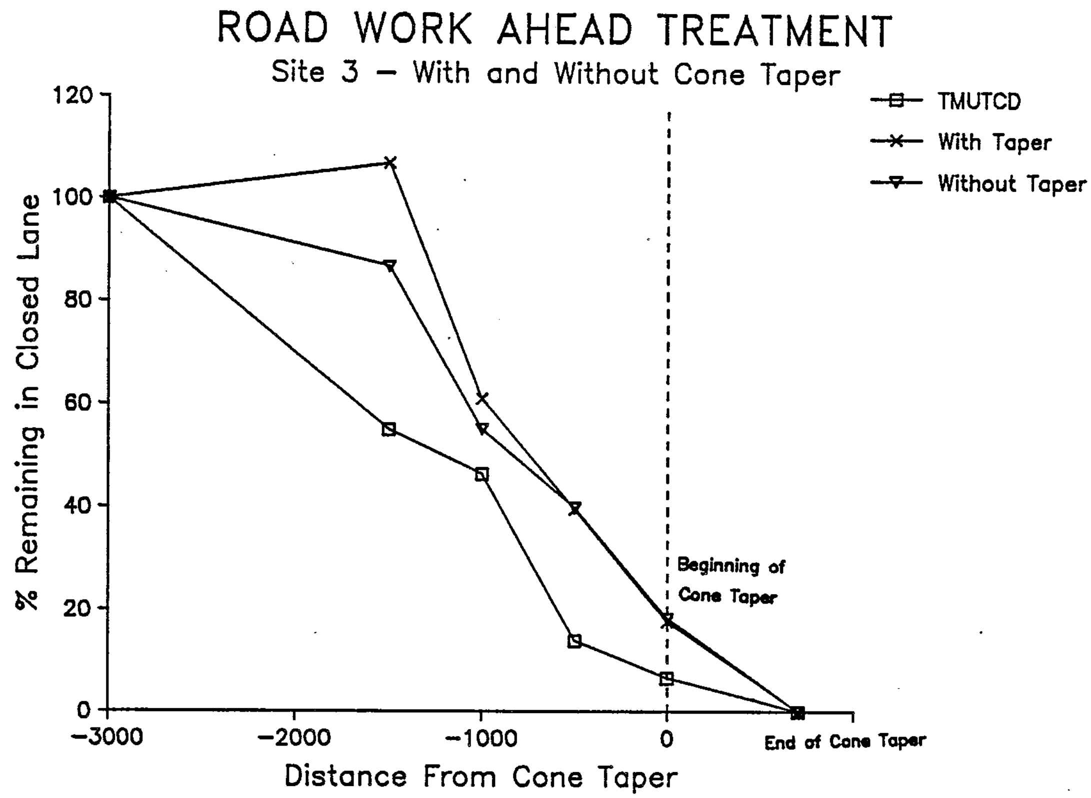


Figure D-1. Effect of "ROAD WORK AHEAD" Signing Treatment With and Without a Cone Taper (Sites 1 and 3).

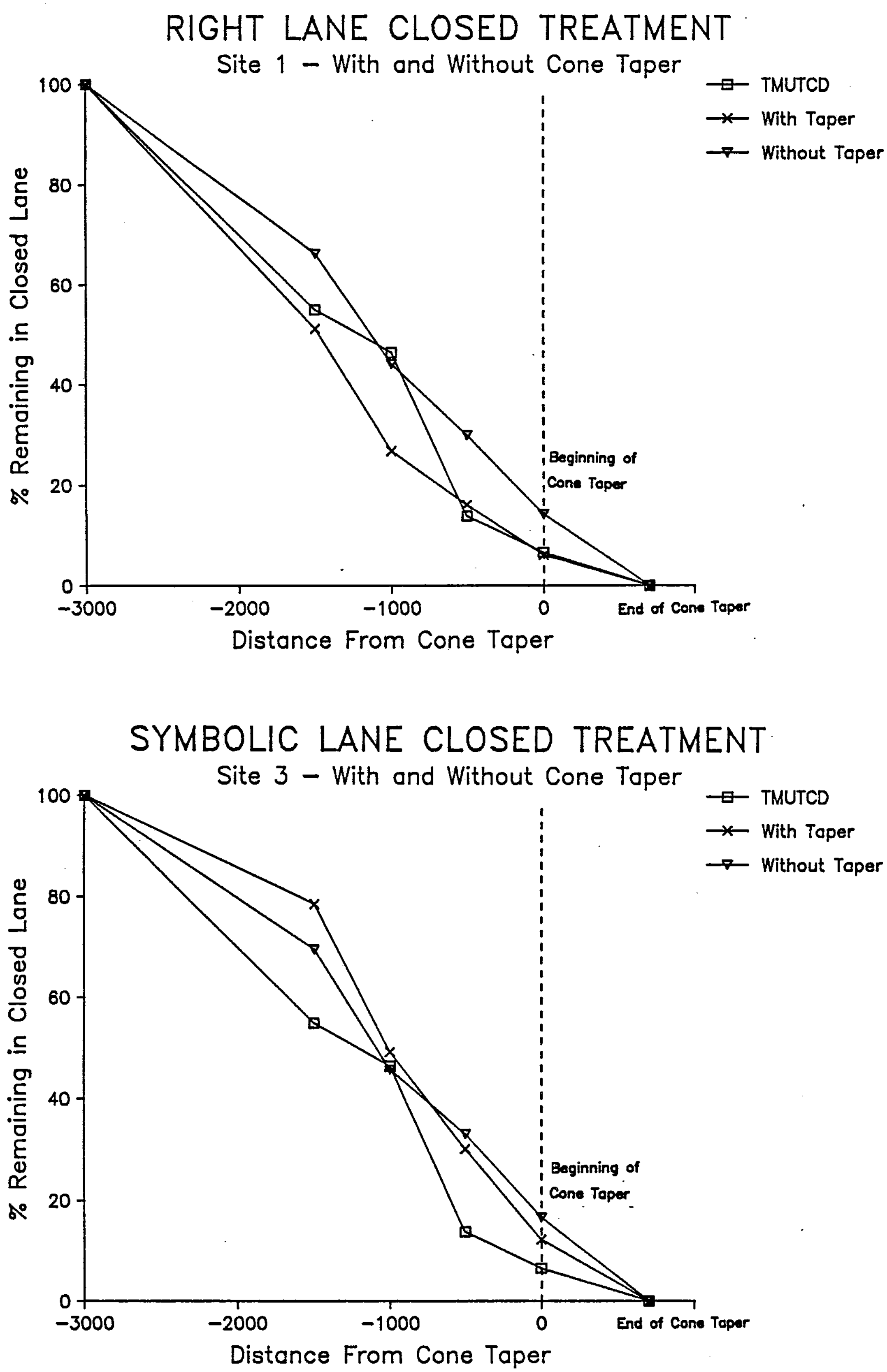
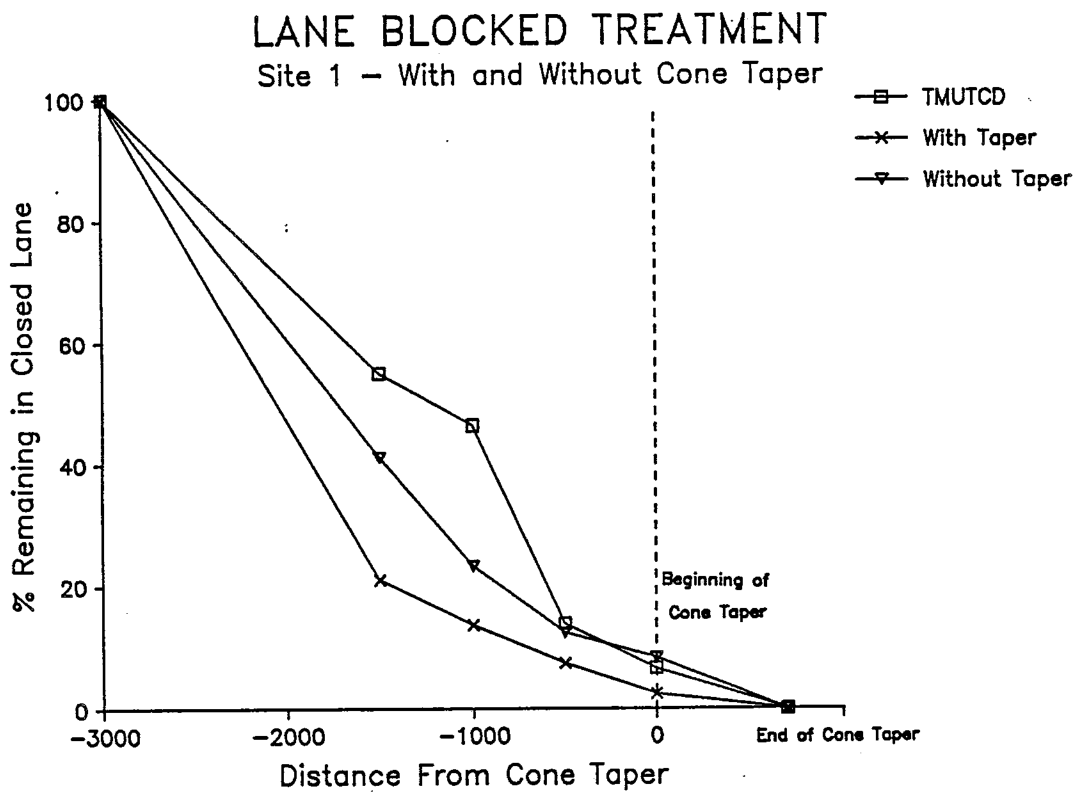


Figure D-2. Effect of "RIGHT LANE CLOSED AHEAD" and Symbolic Lane Closed Signing Treatments With and Without a Cone Taper (Sites 1 and 3).



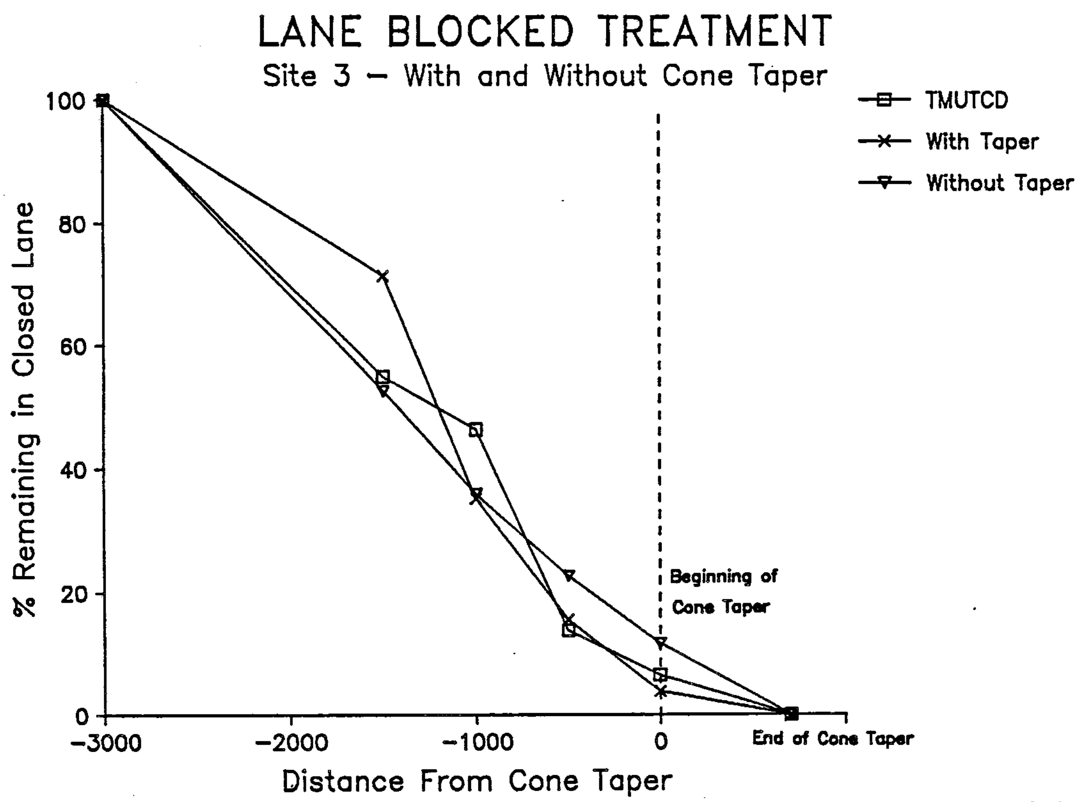


Figure D-3. Effect of Texas "LANE BLOCKED" Signing Treatment With and Without a Cone Taper (Sites 1 and 3).