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16. Abstract

This report addresses the seriousness of the flagger safety problem, and examines methods of improving flagger safety. Several existing devices are identified that can be used instead of flaggers as attention-getting devices at work zones. The report also discusses two alternatives that can be used instead of flaggers for control of alternating, one-way traffic at work zones on two-lane two-way highways. One method, applicable for short work zones on low-volume roads, is to place yield signs on both approaches, and allow traffic to regulate itself through the work zone. The other alternative is to use portable traffic signals that are now commercially available. Field studies of portable signals revealed that substantial savings in flagger labor costs could be realized, with only a minimal increase in motorist delay costs.

Two supplemental devices to be used with flagger control of alternating, one-way traffic were also examined. A freestanding, oversized STOP/SLOW paddle and a temporary reusable stop bar both reduced the variability in the distance at which drivers stopped in front of the flagger. These results suggest that the supplemental devices provide useful and pertinent information to drivers at flagger-controlled work zones.

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FLAGGER SAFETY AND ALTERNATIVES TO MANUAL FLAGGING

by

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and

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Research Report 406-1F
Research Study Number 2-18-86-406

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April 1987

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The Texas A&M University System
College Station, Texas

METRIC CONVERSION FACTORS

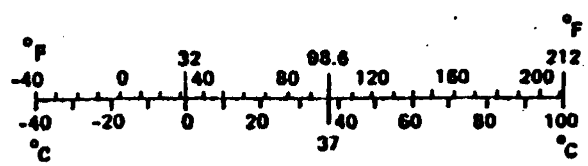
Approximate Conversions to Metric Measures

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



ABSTRACT

This report addresses the seriousness of the flagger safety problem, and examines methods of improving flagger safety. Several existing devices are identified that can be used instead of flaggers as attention-getting devices at work zones. The report also discusses two alternatives that can be used instead of flaggers for control of alternating, one-way traffic at work zones on two-lane two-way highways. One method, applicable for short work zones on low-volume roads, is to place yield signs on both approaches, and allow traffic to regulate itself through the work zone. The other alternative is to use portable traffic signals that are now commercially available. Field studies of portable signals revealed that substantial savings in flagger labor costs could be realized, with only a minimal increase in motorist delay costs.

Two supplemental devices to be used with flagger control of alternating, one-way traffic were also examined. A freestanding, oversized STOP/SLOW paddle and a temporary reusable stop bar both reduced the variability in the distance at which drivers stopped in front of the flagger. These results suggest that the supplemental devices provide useful and pertinent information to drivers at flagger-controlled work zones.

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The contents of this paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents of this report do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

IMPLEMENTATION STATEMENT

This study has examined ways of improving flagger safety. Two techniques for replacing flaggers controlling two-way traffic through one-lane work zone sections have been investigated; 1) self-regulated traffic operation (i.e., the use of yield signs on each approach), and 2) portable traffic signal systems. Both techniques are recommended as potential alternatives to flaggers under certain geometric and observational conditions.

The study has also examined methods of improving driver awareness and understanding at work zones where flaggers are used. A freestanding, oversized STOP/SLOW paddle has been shown to be an effective means of indicating when and where to stop in front of a flagger. Likewise, a temporary, reusable, rubber stop bar has been found to be an effective means of communicating to drivers where they should stop when directed to do so by a flagger or portable traffic signal. It is recommended that both devices be given consideration as optional additions to standard flagging operations.

SUMMARY

Flaggers are an effective means of controlling traffic or modifying driver behavior at work zones. The responsiveness and adaptability of flaggers allows them to be used in a variety of ways. Unfortunately, flagging is also a dangerous activity, with several flaggers being killed or injured each year. In order to minimize the potential for flagger mishap, it has become necessary to 1) determine when other techniques or devices may be used in place of flaggers, and 2) improve driver awareness and response to flaggers at work zones. Consequently, HPR Study 406, "Flagger Safety and Alternatives to Manual Flagging" was initiated in September 1985.

Recent accident reports where flaggers have been killed or injured were examined during the initial phase of this study. Also, observational studies were performed at several flagging operations to determine the factors and characteristics that tend to undermine flagger safety. Poor flagger communication with drivers and other flaggers, improper uses of signs and equipment, severe site restrictions, and improper flagger placement at the work zone all increased the hazard or danger of injury to flaggers.

Existing methods of increasing driver awareness of advance warning signs, regulatory speed limits, or the need to exit a closed lane on a multilane facility were presented. Available devices include arrowboards, changeable message signs, and flashing beacons (attached to advance warning or speed limit signs).

Two alternatives for control of two-way traffic through a one-lane work zone section traditionally handled by flaggers are presented and discussed. One alternative is to place yield signs on each approach to the one-lane section, and allow traffic to regulate itself through the work zone. This alternative has been evaluated and is recommended as an option for short work zones on low volume roadways. The second alternative is the use of portable traffic signals. Field evaluations of a fixed-time portable signal system indicated considerable savings in flagger labor costs can be realized without significantly increasing motorist delay costs. However, it was observed that drivers occasionally entered the work zone on the red indication, increasing the potential for head-on vehicle collisions. It was not possible to determine whether the increased vehicle accident potential was offset by a reduction in flagger accident potential.

Finally, a freestanding, oversized STOP/SLOW paddle and a temporary, reusable, rubber stop bar were examined at one-lane work zones where two-way traffic was controlled by flaggers. Both devices were found to reduce variability in where drivers chose to stop in front of the flagger. It appears that both devices would be useful as optional items to the set-up and operation of flagger controlled work zones.

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1. INTRODUCTION

Flaggers have been used to control traffic in work zones for many years. The flaggers role at work zones, as defined in the Texas Manual of Uniform Traffic Control Devices (TMUTCD) (1) is:

> "... to stop traffic intermittently as necessitated by work progress or to maintain continuous traffic past a work site at reduced speeds to help protect the work crew..."

The flexibility, adaptability and responsiveness of flaggers allows them to be utilized in various work zone activities. Traditional uses of flaggers include the following:

1. Control of alternating, one-way traffic through restricted one-lane work sections on two-lane, two-way highways.
2. Stopping traffic intermittently at a work zone to allow work vehicles to enter and exit the roadway.
3. Improving driver awareness of advance warning signs.
4. Cautioning motorists about temporary pavement drop-offs.

In addition, flagger use has been expanded in recent years to also include:

1. Improving driver compliance with posted speed limits through work zones (2).
2. Controlling the utilization of the shoulder as a temporary travel lane in innovative work zone traffic management schemes (3).

While the adaptability and responsiveness of flaggers makes them effective in numerous applications, their use is not without risk. Each year, several flaggers are injured or killed while performing their flagging duties, with many others narrowly avoiding mishap. Improper flagging techniques or driver understanding of flagging messages sometimes leads to improper driver response with results as serious as collisions with other vehicles or with flaggers.

Consequently, it has become necessary to re-evaluate the flagger's role in work zone traffic control. New and existing traffic control methods and attention getting devices are available which could be used instead of flaggers in certain situations. Information is needed as to when and where these alternatives can be used. In situations where flaggers are used, methods of increasing driver awareness and understanding are needed to improve work zone safety. In light of these needs, HPR study 406, "Flagger

Safety and Alternatives to Manual Flagging" was initiated in September 1985. This report presents the methods, results and conclusions of the study.

Study Objectives

The goal of Study 406 was to reduce the danger of injury to flaggers in work zones. Specifically, the objectives of this study were to:

1. Identify, develop, and evaluate alternatives to flaggers that may be used in certain work zone situations.

2. Identify, develop, and evaluate techniques for improving driver awareness and understanding at work zones where flaggers are required.

Organization of the Report

The remainder of the report has been organized into three chapters. The first chapter documents the results of an analysis of recent work zone accidents where flaggers were killed or injured. In addition, the results of observational studies at existing flagging operations are documented. This information provided input into the selection of flagging alternatives and techniques for improving flagger safety which were eventually examined in field studies. The next chapter is a synthesis of new and existing alternatives to the use of flaggers for various work zone applications. The final chapter discusses two supplementary devices to improve safety in situations where flaggers are used.

2. THE FLAGGER SAFETY PROBLEM

Efforts have been made to identify and document the types of flagger safety problems occurring in work zones, as well as the situations in which they occur. These efforts have involved a review of recent work zone accidents where flaggers have been killed or injured and observational studies at several work zones where flaggers were used.

Review of Flagger Accidents

Available accident data were gathered from the Insurance Division (D-20) of the Texas State Department of Highways and Public Safety (SDHPT), and from the Master Accident File of the Texas Department of Public Safety (DPS). The analysis focused on accidents occurring in 1983, 1984, and 1985. A sample of 13 flagger accidents were identified from the DPS Master Accident File, and 15 from SDHPT Insurance Division. While other accidents involving flaggers may have occurred during the time period, it was felt that the amount of information to be provided over that already gained from the original 28 accidents would not offset the additional manpower required to obtain them.

The occurrence of accidents involving injury or death to flaggers is summarized by highway type and accident severity in Table 2-1. Most of the accidents occurred on two-lane, two-way highways which should be expected since most flagging operations occur on two-lane, two-way highways. The table also shows that 39% of the accidents involving flaggers result in death or serious injury to the flagger. The percentage of the most serious accident types (fatal or incapacitating) was higher on multilane highways than on two-lane, two-way highways, which is probably due to the higher traffic volumes and higher travel speeds on multilane facilities.

TABLE 2-1. NUMBER AND PERCENTAGE OF FLAGGER ACCIDENTS BY HIGHWAY TYPE AND SEVERITY

	Highway Type			
Severity	Two-Lane, Two-Way	Multilane	Intersection	Total
Fatal	0	2	0	2 (7%)
Incapacitating Injury	5	3	1	9 (32%)
Possible Injury	1	0	1	2 (7%)
Non-Incapacitating Injury	10	4	1	15 (54%)
Total	**16 (57%)**	**9 (32%)**	**3 (11%)**	**28 (100%)**

It was also observed that drivers 70 years of age or older, who represent only 5% of all licensed drivers (4), were involved in 38% of the flagger accidents for which driver age information was available. It may be possible that elderly drivers, who generally have poorer vision and slower reaction times, are not being provided with enough warning time to react to the work zone and/or the presence of the flagger.

Observational Studies

To gain a better understanding of the particular factors that degrade flagger safety, studies were conducted at 6 work zone locations where flaggers were used. The traffic control plan, flagger performance, and traffic operation through the work area were examined at each work zone.

Table 2-2 summarizes the problems found at the work zones, and the effects of these problems as observed by the data collection personnel. Four major factors contributed to potential flagger safety problems: inadequate sight distance to the work zone, improper advance or supplemental signing, improper flagger communication (between themselves and with drivers), and improper flagger position at the work zone. The most severe problem observed was that of inadequate sight distance to the work zone. At one site, less than 500 ft of sight distance to the work zone was available to drivers approaching from either direction. Several motorists at this site were observed skidding to a stop to avoid hitting either the flagger or oncoming traffic once the work zone came into view. Although this site had advance warning signs 1500 ft before the work zone, motorists were still startled by the presence of the work zone.

Improper signing or arrowboard use also appeared to cause problems. In cases when improper advance signs or arrowboard use was noted, drivers approaching the work zone attempted to pass to the left of the queue waiting in front of them. The flaggers then stepped into the path of these errant vehicles, and ordered them to stop, back up, and join the end of the queue. Apparently, the sequential arrowboard at one site and wrong advance warning signs at another indicated to drivers that two-way, rather than alternating one-way movement, was being maintained through the work zone.

Improper hand and flag signals were noted at most of the sites studied (4 of the 6 locations). When improper signals were used, motorists sometimes appeared confused and unsure of the actions that were expected of them. At one location, communication between flaggers at each end of the lane closure was achieved by means of a third flagger placed at the midpoint of the work zone where he could see both ends of the lane closure. On two separate occasions, a mix-up in flagger communication resulted in traffic in both directions being allowed to proceed through the work zone at the same time. The lead vehicles in each direction met at the middle of the one lane section and had to stop abruptly, leading to a period of confusion and anger until the situation could be rectified.

TABLE 2-2. PROBLEMS OBSERVED AT FLAGGING OPERATIONS

PROBLEMS	OBSERVED EFFECTS
Inadequate Sight Distance to Flagger and Work Zone	
Less than 500 ft visibility to work zone in either direction of travel	o motorists skidded to stop when lane closure came into view o flaggers jumped out of the way to avoid being struck by vehicles
Improper Advance or Supplemental Signing	
Advance "RIGHT LANE CLOSED" and "LEFT LANE CLOSED" signs used instead of "ONE LANE ROAD AHEAD" signs Arrowboard used in sequential mode in closed lane (rather than caution mode)	o motorists attempted to pass to the left of the waiting queue, had to be stopped by the flagger, and directed to return to the end of the queue.
Improper Flagger Communication	
Flaggers at both ends of a one-lane section released traffic queues at the same time	o opposing traffic met at the middle of the work zone, resulting in driver confusion, anger, and delay
Non-standard flagger hand and flag signals used	o some motorists appeared confused, tried to go around flagger, but were finally stopped by flagger stepping in front of the vehicle
Improper Flagger Position	
Flagger located in open lane too close to the cone taper. Opposing traffic did not have room to return to their lane between end of lane closure and queue of waiting vehicles	o vehicles stopped in queue too close to the end of the lane closure o motorists had to drive over cones and get into closed lane to pass
Flagger located in middle of open lane to get drivers to stop	o no conflicts observed, but high potential for flagger injury

The final type of problem noted was that flaggers were often positioned improperly within the work zone. In the most common situation, flaggers in the open lane stood in the middle of the lane, rather than on the shoulder. This was usually necessary to get traffic to stop, but it put the flagger in an extremely hazardous situation. At one site, which is illustrated in Figure 2-1, a flagger was placed in the open lane too close to the end of the lane closure. As traffic stopped in the queue immediately in front of the flagger, no room was available for traffic coming in the other direction to get around the queue. As a result, the oncoming traffic had to drive over the cones to get back to their lane and around the queue.

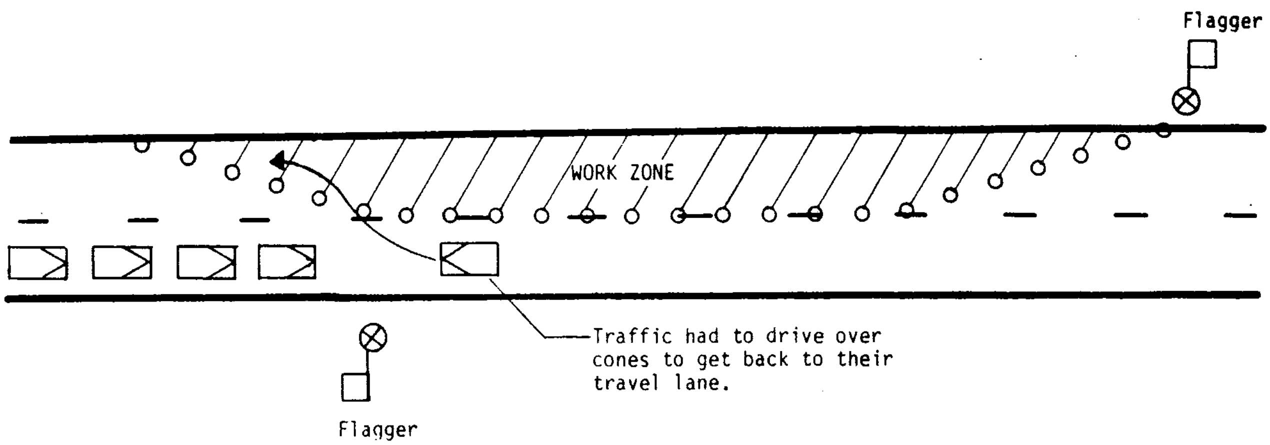


Figure 3-3. Effect of Improper Flagger Location on Traffic Operation

Summary

The available flagger accident information has shown that flagger accidents tend to be very severe and that accidents occurring on multilane facilities tend to be more severe than those occurring on two-lane, two-way highways. The high speeds and volumes on multilane facilities makes them especially dangerous to flaggers. The fact that elderly drivers are involved in more flagger accidents than expected suggests that they may need additional time and information to perceive and react to the work zone, as their vision and reaction times are probably somewhat below that of the average driver.

The observational studies have shown that situations typically exist at a work zone that place flaggers in a hazardous or dangerous position. These situations arise from equipment (i.e. sign misuse), geometric limitations at the sites, poor attitudes of flaggers, and improper flagging procedures.

Results from both the accident analysis and the observational studies illustrate the desirability of using alternatives to flaggers whenever possible. Several alternatives exist to flagger use on multilane highways, since flaggers in this capacity are commonly used as attention getting devices to advance or supplemental signing, or to the presence of the work zone. The options are more limited for two-lane, two-way highways where flaggers control alternating, one-way traffic or stop traffic intermittingly to allow work vehicles to cross the roadway and/or deliver materials to the work site. Here, the alternatives primarily involve 1) allowing traffic to regulate itself (at short work zones on low volume roads), or 2) using traffic signals to control movements. The feasibility and applicability of these alternatives are discussed later in this report.

In situations where there is a need for flaggers, such as on short duration lane closures on two-lane, two-way highways, methods of improving driver understanding and awareness of flagger directions are available. The use of a freestanding, oversized STOP/SLOW paddle and a reusable, temporary stop bar were examined as part of this study, and are discussed later in this report.

3. ALTERNATIVES TO THE USE OF FLAGGERS

Flaggers as Attention-Getting Devices

Traffic Control Plan Sheets for the State of Texas recommend the use of flaggers in two situations: 1) at a lane closure on a two-lane, two-way roadway with an inadequate field of view, and 2) at pavement drop-offs greater than six inches that are temporarily left exposed only during daylight operations. Flaggers, however, are allowed to be used in various other work zone situations where traffic, roadway, or terrain conditions warrant their use (1). Drawing attention to advance warning signs, regulatory speed limit signs and the need to exit a closed lane on a multilane highway are common uses of flaggers. However, when used in these situations, the flagger may be exposed unnecessarily, as alternative traffic control devices are available. Traffic control devices such as arrowboards, changeable message signs, and flashing beacons can be used instead of flaggers as a means of encouraging the desired driver response at a work zone.

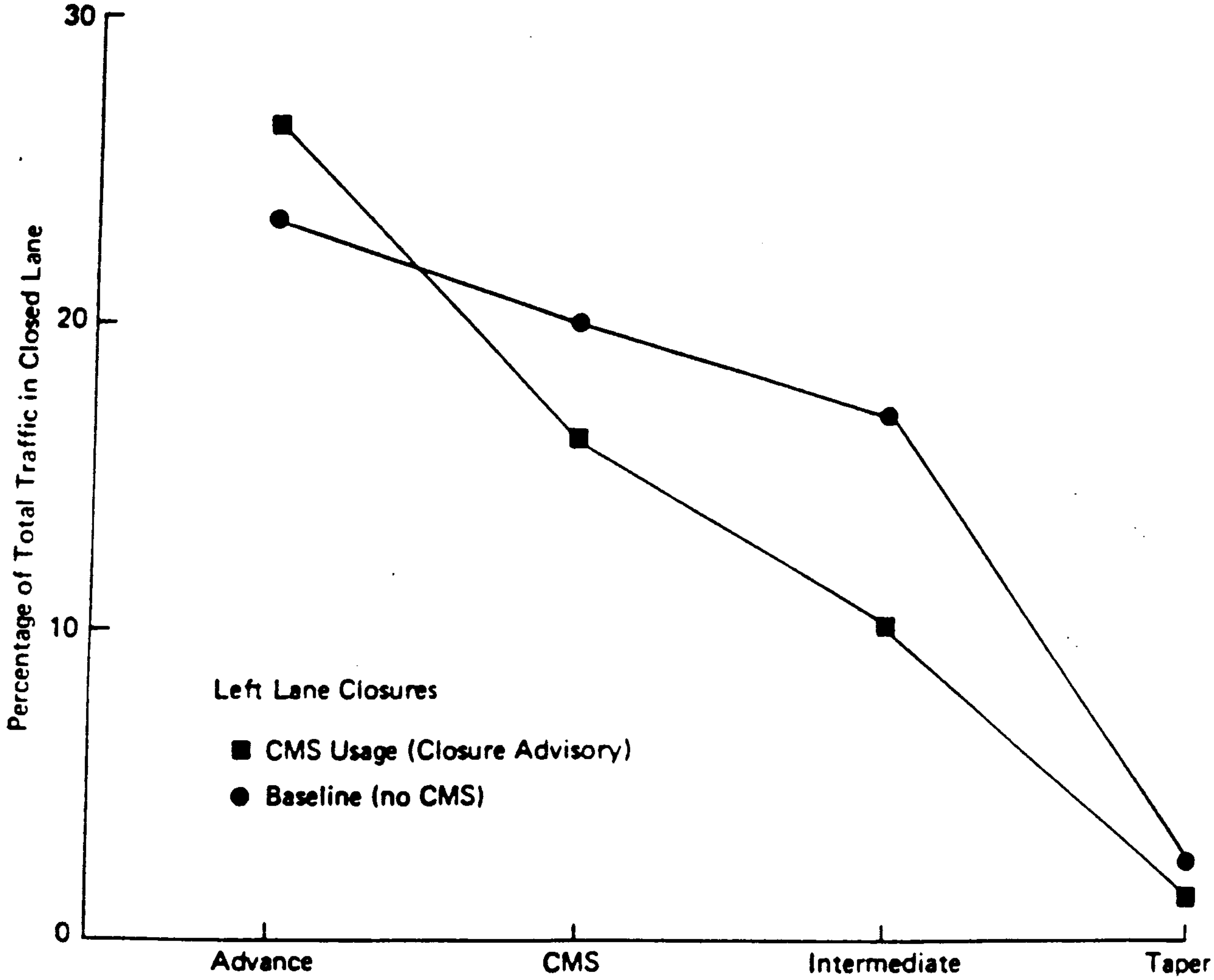
Arrowboards

Texas Traffic Control Plan Sheets already recommend flashing arrowboards (left or right arrow mode) at main lane closures on multilane roadways. A human factors study found that more than 95 percent of drivers surveyed felt that the sighting of an arrowboard meant that a lane was closed ahead. In addition, arrowboards are very conspicuous due to their flashing lights and, under good conditions, are recognizable from a distance of approximately one mile (5).

Arrowboards, in caution mode, can also replace flaggers used to draw attention to work being done on a shoulder. The arrow mode should not be used for shoulder closures which do not require the motorist to deviate from the normal path (1).

Changeable Message Signs (CMSs)

Changeable Message Signs can be used to provide motorists with improved advance warning of freeway lane closures and advisory speeds through the work zone. Recent studies (6) have demonstrated that beneficial traffic operational effects result from CMS application. Increased advance lane changing activity, smoother lane change profiles, and significantly fewer late exits (exits from the closed lane within 100 ft of the closure) were observed as shown in Figure 3-1. In addition, a study by Richards (7) found that CMSs can reduce speeds in freeway work zones by an average of 7 percent.



Lane Distribution Profiles for Left Lane Baseline and CMS Conditions (Georgia Sample)

Figure 3-1. Effect of Changeable Message Sign in Promoting Lane Exiting at a Lane Closure (6)

Flashing Beacons

Eight inch flashing beacons can be used instead of flaggers to attract a driver's attention to warning signs or points of special hazard at a work zone. A study by Lyles (8) found that average speeds approaching a work zone were 7.5 mph lower with 8 inch flasher-augmented warning signs than with standard signing without flashers.

Flaggers as Control of Alternating One-Way Traffic

As stated previously, flaggers are generally required at lane closures on two-lane, two-way highways. This requirement comes from a need for positive control of two-way traffic through a one-lane section of roadway. The next two sections discuss alternatives that are available (under certain conditions) to the use of flaggers in this capacity.

Self-Regulated Traffic Operation Through One-Lane Sections

When two-way traffic must share a section of one-lane road through a work zone, some means of active traffic control is usually required to assign vehicle movements. However, on low volume roads where the one-lane section is sufficiently short, it is permissible to eliminate the active control and allow traffic to regulate itself through the work zone. This is done by installing "YIELD TO ONCOMING TRAFFIC" signs (R1-2) at both approaches to the work zone, as illustrated in Figure 3-2.

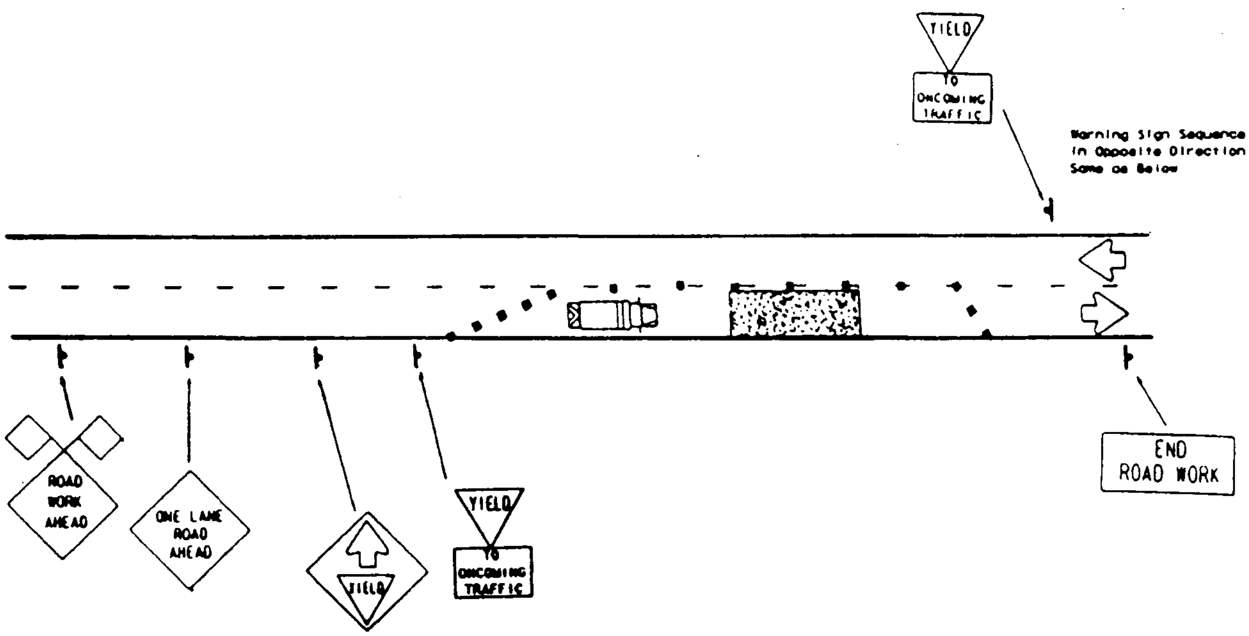


Figure 3-2. Traffic Control Plan for Self-Regulated One-Lane Traffic Operation

Theoretically, a self-regulated, one-lane section operates similarly to an uncontrolled intersection. A driver approaching the work zone must determine whether oncoming, conflicting traffic is present. If it is not, then the driver travels through the section. If conflicting traffic is present, then the driver must stop at the beginning of the section and wait until it is safe to proceed. The choice of when to proceed is based upon the driver's selection of an acceptable gap in oncoming traffic flow. An analysis of the factors that affect a driver's selection of an acceptable gap was performed to define conditions under which self-regulated traffic flow will operate effectively.

Appendix A presents an analysis of the maximum flow that can operate safely through self-regulated, one-lane sections of various lengths. The analysis assumes that closed-lane traffic instinctively yields to oncoming open-lane traffic at the one-lane section, and that traffic will operate safely and efficiently as long as most open lane traffic may approach and travel through the one lane section without stopping. As output from the analysis in Appendix A, Figure 3-3 presents a graph of estimated maximum hourly volumes as a function of the length of work zone.

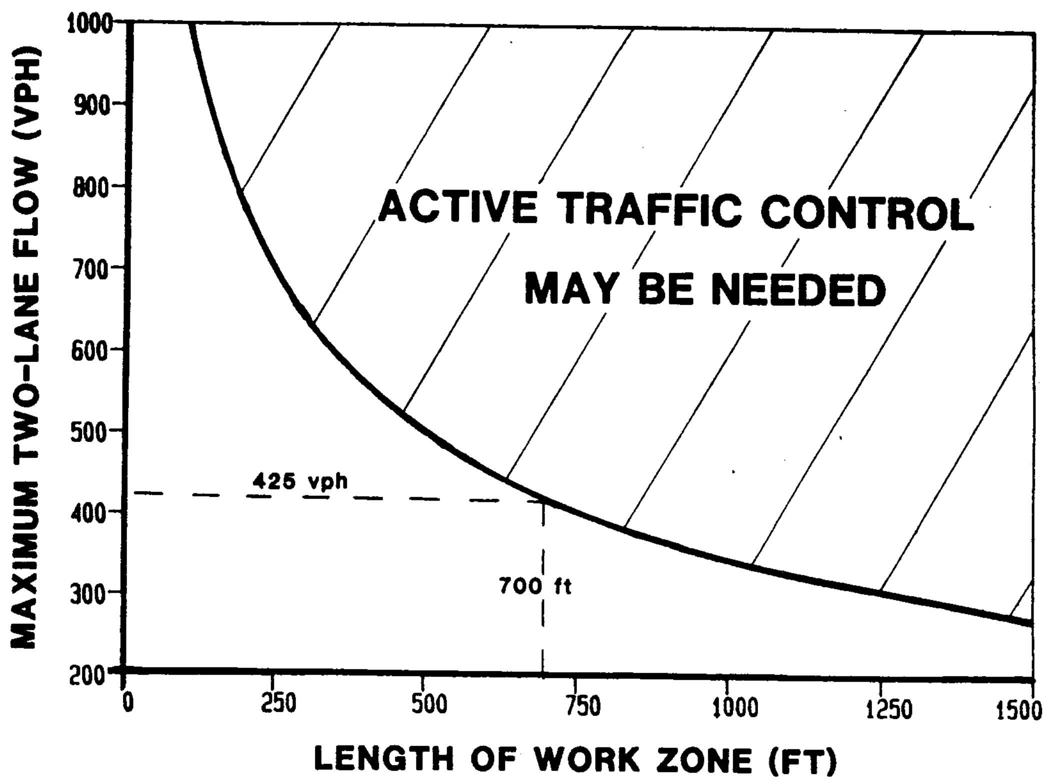


Figure 3-3. Traffic Volume - Work Zone Length Criteria for Self-Regulated Traffic Operation

Currently, Texas Traffic Control Plan Sheets recommend that traffic through a one-lane section may be allowed to regulate itself if the length of the work zone is less than 700 ft (400 ft work area plus buffer area and cone taper) and the average daily traffic on the roadway is less than 4000. As Figure 3-3 illustrates, maximum hourly volume for a work zone of 700 ft is approximately 425 vehicles per hour. This hourly volume converts to a demand of about 2800 to 4000 vehicles per day, depending on the value of the K factor used to relate hourly flow to daily traffic. The results shown in Figure 3-3 represent more of an upper limit to the permissible volumes, so it appears that current volume criteria may be too high when the length of the one lane section approaches the maximum allowed.

However, it is important to note that the permissible volume does depend heavily on the length of the one-lane section. If the section is shorter than 700 ft, considerably more traffic is permissible on the section with acceptable operating characteristics still maintained. Consequently, current criteria could be changed to allow considerably higher ADTs for short work zones than for longer work zones, such as is shown in Table 3-1.

TABLE 3-1. SUGGESTED VOLUME - WORK ZONE LENGTH CRITERIA FOR SELF-REGULATED (YIELD CONTROL) TRAFFIC OPERATIONS

Length of Work Zone (ft)[a]	Maximum Permissible Traffic (ADT)[b]
100	6500
200	5000
300	4000
400	3500
500	3300
600	3000
700	2800

[a] Based on end of lane closure to end of lane closure. This value includes the length of work area, buffer area, and cone tapers.

[b] Assumes a K-Factor (relationship between peak hourly volume and total daily volume) of 0.15.

The analysis and results of Appendix A have focused on the maximum flow allowable through a one lane section of a given length in order to maintain uninterrupted flow in the open lane. Consideration also must be given to maximum work zone lengths allowable to maintain safe, self-regulating traffic operation. Work zone lengths that are too long invite poor operation, because drivers become unable to accurately and consistently choose gaps in opposing traffic flow. Failure to choose safe gaps would result in vehicle-to-vehicle conflicts and accidents within the work zone and excessive delays to motorists. In theory, the selection of the maximum permissible length of a work zone should be based on critical gap information as a function of work zone length. Unfortunately, information of this type was unattainable during this study, and so such an investigation was not possible. Without a method of analysis or other justification for change, the current 700 ft criteria in the Texas TCP Sheets is a reasonable maximum permissible work zone length.

Portable Traffic Signals

In the past, traffic signal systems, similar to intersection installations, have sometimes been used as an alternative to flaggers to regulate alternating one-way traffic control. However, the cost of these traffic signal installations range from $25,000 to $50,000. As a result of this cost, the SDHPT has generally limited the use of traffic signals to lane closure work zones on restricted width bridges which last over 3 months.

Recently, however, several manufacturers have developed and are now marketing portable traffic signal systems. These systems are free-standing, self-contained, and easily transported. They are generally user friendly and are designed to be adaptable to a variety of situations. Consequently, portable traffic signal systems have the potential for replacing flaggers at many work zone operations requiring the control of alternating, one-way traffic.

For temporary work zone applications, portable traffic signals generally operate under fixed-time or manual control. In fixed-time operation, the signals at each end of the work zone are programmed, synchronized, and left to operate in the same manner as standard fixed-time signals at intersections. Signal timing is based on work zone length and expected traffic demand at each approach. This system does not require an operator once it has been initialized and is functioning properly at the work site.

Conversely, manually operated signals require an operator to advance the signals through the phase sequence. Because of the operator, the manual system provides superior responsiveness to changes in traffic demands and vehicle speeds. However, this system is more limited than fixed-time systems, as the operator must be able to see both approaches in order to safely control the signals and subsequent traffic movements. An operator error may cause a catastrophic failure.

Theoretically, portable signal systems may be used in place of flaggers whenever it is necessary to stop traffic intermittently. Situations where this occurs include:

1) Lane closures on two-lane, two-way highways where traffic from both directions must alternate in the remaining open lane.

2) Work vehicle crossings on location where work vehicles deliver material to the job site. In these cases, a manually-operated signal may be more appropriate since the need to stop traffic is dictated by the needs and movements of the work vehicles.

The fixed-time portable signals used for field evaluations in this study (see Appendix B) could be preprogrammed at the maintenance yard (assuming site characteristics such as work zone length and traffic demand were known), towed to the site, and be set up and operating in a few minutes. Consequently, they would be feasible for work operations lasting only 2 or 3 hours. However, their primary application would most likely be for operations lasting one-half day or longer.

Since these portable signal systems are relatively new to the market place, experience with them in actual work zone applications is limited. To aid in their eventual implementation statewide, the next section discusses several points of concern or items of interest with regard to portable signal usage. This information is based on the field evaluations of portable signals conducted as part of this study and documented in Appendix B.

Traffic Control Plan

The Traffic Control Plan used for signal control at work zones is similar to that used for flagger control, except that an orange and black symbolic signal ahead sign (W3-3) would replace the flagger ahead sign (CW20-7a), as shown in Figure 3-4. Two signal heads should face each approach, as specified in Section IV of the National MUTCD (9). It was found during the field evaluations that signals placed on both sides of the road on each approach, as Figure 3-4 depicts, improved traffic operation considerably. Large trucks, when stopped at the work zone, had a tendency to block the visibility of the near side signal. Motorists behind would try to pass to the left of the truck, assuming that it was part of the work zone and was blocking traffic. The presence of the far side signal insured that a red indication would be facing motorists, so that motorists did not try to pass.

When traffic signals are used at work zones, a stop bar should be placed 50-60 ft upstream of the signals. The stop bar identifies where drivers should stop, and also reinforces the need to stop. A supplemental temporary "STOP HERE ON RED" sign (R10-6) may be erected next to the bar to further enforce the need for stopping and add credibility to the presence of the signals.

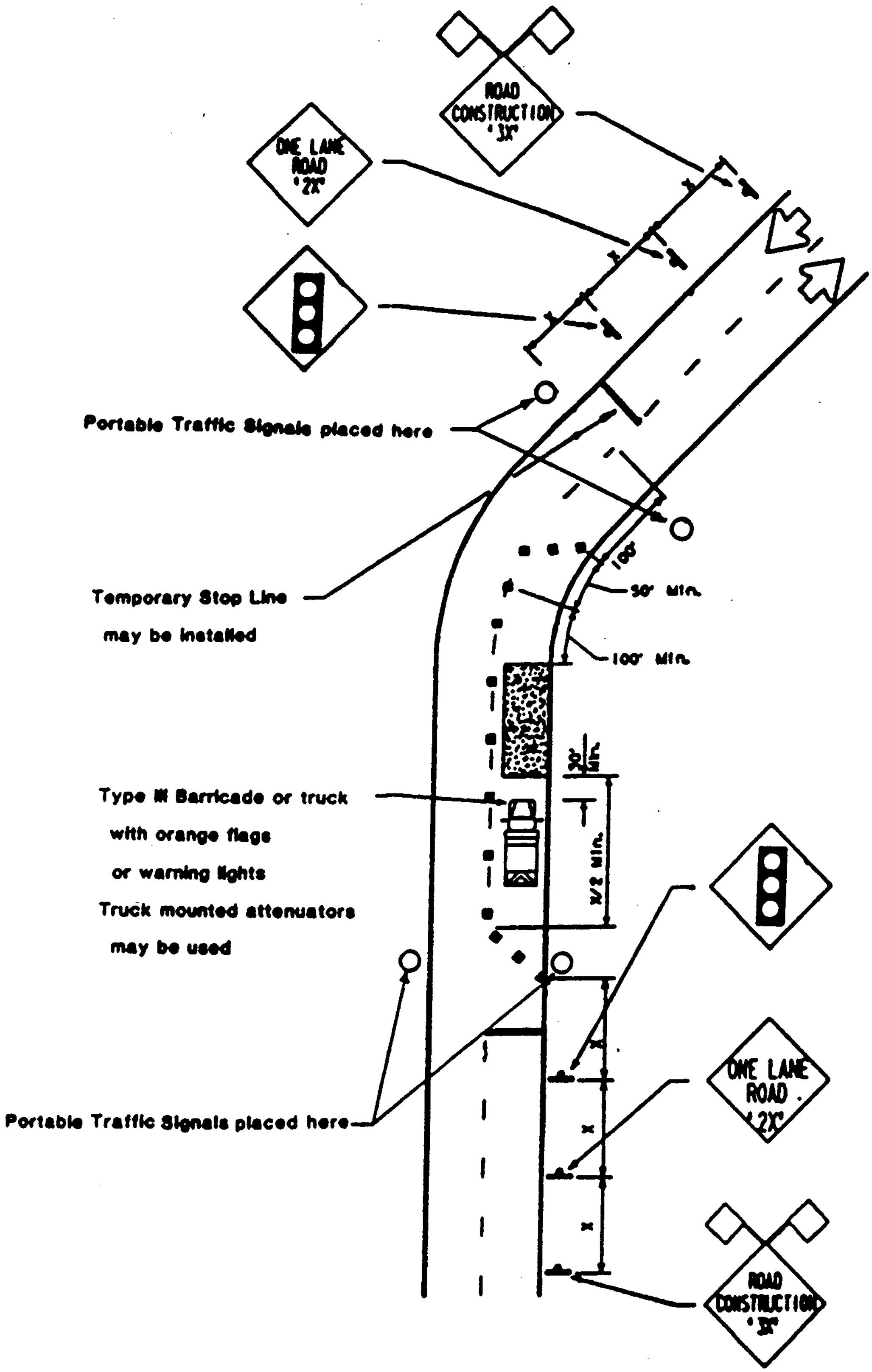


Figure 3-4. Traffic Control Plan For Portable Signal Studies

Sight Distance

Table 3-2 from the National MUTCD (9) specifies minimum sight distances to traffic signals at intersections. Sight distance to signals at work zones should meet these standards, and exceed them whenever possible. The presence of a traffic signal at a work zone may violate driver expectancy, and so driver perception-reaction times to the signals may be longer.

TABLE 3-2. MINIMUM SIGHT DISTANCES TO TRAFFIC SIGNALS

85th Percentile Speed (mph)	Minimum Visibility Distance (ft.)
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

Source: National MUTCD (9)

Length of Work Zone

It appears that portable signals are best suited to shorter work zone lengths. The all-red (clearance) phases of portable signals at work zones are based on the length of work zone. Longer work zones require longer all-red phases, which in turn require longer cycle lengths. For instance, the use of portable fixed-time signals at a 2600 ft study site required a cycle length of more than 4 minutes.

Traffic Volumes

Portable signals appear suitable over a wide range of traffic volumes. Field evaluations that were conducted at sites with traffic demands of 600 to 10,000 vehicles per day, found no noticeable problems that were volume related. However, it was observed that when a green phase terminated before all queued traffic had entered the work zone, the remaining vehicles in the queue ran the red rather than waiting for the next green. Consequently, the subsequent all-red clearance interval was not always long enough, and the opposing queue received the green before all traffic had cleared the work zone. To insure smooth operation, it is recommended that the green phase be long enough to guarantee that the queue will dissipate most (i.e. 85%) of the time. As an alternative, the all red clearance may be increased to allow "sneakers" who enter the work zone after the green has terminated to pass through the work zone without conflict.

4. IMPROVING FLAGGER SAFETY AT WORK ZONES

As the previous discussions have shown, alternatives do exist to the use of flaggers for regulating two-way traffic through a one-lane section. However, these alternatives have restrictions to their use. For instance, self-regulated work zones are only feasible on low-volume roads with short work zone lengths. Portable traffic signals, while applicable to a wider range of conditions, will not replace all flagging operations requiring one-way traffic movement. Consequently, it is necessary to focus on ways of improving flagger safety when they are used for traffic control purposes. The next two sections discuss supplementary devices to be used when flaggers control alternating one-way traffic through work zones.

Freestanding, Oversized STOP/SLOW Paddle

In an attempt to improve driver understanding and awareness of flagger commands, an oversized STOP/SLOW paddle, mounted on a freestanding base, has been developed and field tested as part of this study. Documentation of the field tests are included in Appendix C. The sign paddle was built from a 30 x 30 inch standard STOP sign (R1-1) and a 36 x 36 inch black-on-orange SLOW sign mounted back to back on a freestanding wooden frame. The top portion of the wooden frame was manually rotated by the flagger to allow either sign to face oncoming traffic. Figure 4-1 provides an illustration of the oversized sign paddle. The signs were mounted at a height of 6 ft measured to the bottom of the signs, which is approximately the same height as normal STOP or warning signs.

It should be noted that the sign paddle constructed and tested in these studies does not conform to the standards presented in Section 6F of either the Texas or National MUTCD (1,9). Specifically, the shape of the paddle should be octagon, not diamond, since the message to stop is the more critical of the information presented. Future implementation of such a freestanding paddle should obviously be with a standard shaped sign.

Previous research on driver understanding of work zone flagger signals and signaling devices has indicated that STOP/SLOW paddles are a very effective method of transmitting messages to a driver (10, 11). However, many workers complain that the typical hand-held sign paddle is too heavy and difficult to use in strong winds. They also do not appear to have the attention getting value of the more commonly used flag (11).

The oversized STOP/SLOW paddle remedies this situation by having a flagger stand next to the freestanding sign paddle, combining the high comprehension of a sign paddle with the high visibility of a flagger. The flagger does not hold the paddle, but merely rotates the sign when necessary.

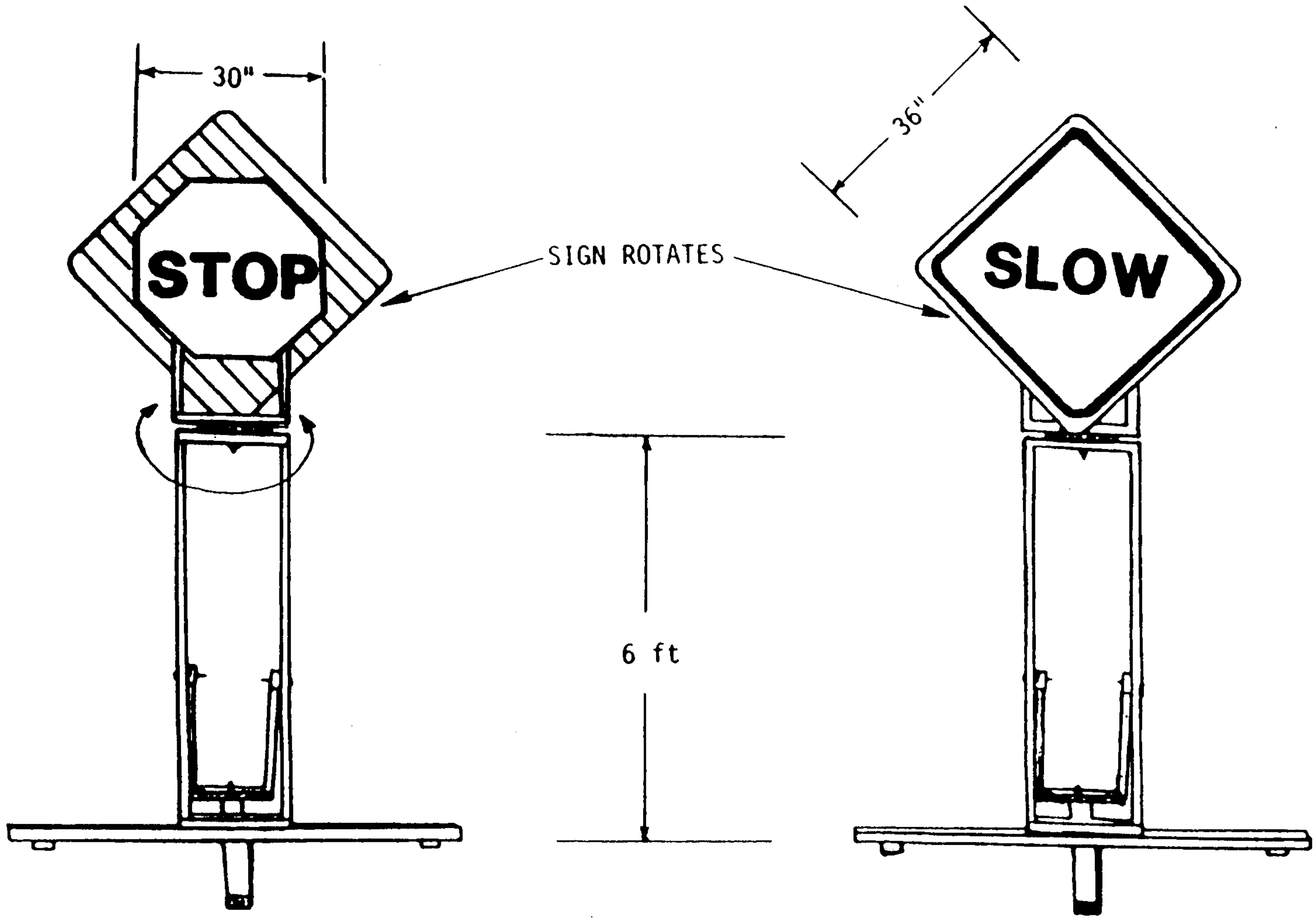


Figure 4-1. Freestanding, Oversized STOP/SLOW Paddle

The oversized STOP/SLOW paddle has the obvious advantage of being easier to identify from a greater distance than the typical 18 x 18 inch hand held paddle. The oversized paddle also provides an additional SLOW message to vehicles as they are exiting the restricted one-lane section.

The paddle may be used whenever flaggers provide control of alternating, one-way traffic movement. Mounting the paddle assembly on a small trailer would allow it to be moved easily and as often as necessary. Thus, the paddle would be feasible even for activities that move quickly, such as seal coat operations.

The paddle (even when of a non-standard shape) appears to reduce driver uncertainty about when and where to stop in front of the flagger. This was found especially true for open lane traffic. Drivers in the open lane do not have the visual cues (i.e., cone taper, work vehicles, etc.) directly in front of them that are afforded motorists in the closed lane. Consequently, the location where motorists stopped in front of the flagger varied much more from driver to driver in the open lane than in the closed lane, as measured by the standard deviation of stopping distances from the flagger. With the paddle in use, the variability in stopping points was reduced in both lanes, with the reduction much greater in the open lane, as shown in Table 4-1.

TABLE 4-1. VARIABILITY OF THE DISTANCE BETWEEN THE FLAGGER AND THE FIRST STOPPED VEHICLE

Condition	Standard Deviation (ft)	
	Closed Lane	Open Lane
No Paddle	32	99
Paddle	23	32

Temporary, Reusable Stop Bar

A stop bar, or stop line, is often found at STOP sign or traffic signal controlled intersections. Stop bars have also been used at some major work zones involving lane closures on two-lane, two-way highways where it was necessary to alternate one-way traffic for an extended period of time. The purpose of a stop bar is to identify the point which vehicles should stop behind if instructed to do so by the flagger. A stop bar may also help communicate a flagger's message to stop to an approaching motorist.

Normally, stop bars are painted on the pavement and, therefore, are not practical for minor work zone operations or major operations lasting only a few days. A reusable, temporary stop bar that could be placed across the road when needed and then picked up to be used somewhere else would be extremely practical and useful at work zones. Such a temporary stop bar was examined as part of this study. The bar consisted of six interlocking sections of white rubber, each approximately 6 inches wide, 40 inches long, and 0.4 inches thick. The sections were placed 3 long by 2 wide, making the stop bar a total of 12 inches wide and 10 feet long. The total bar weight was approximately 30 pounds.

The temporary bar is applicable to any work zone at which traffic must be stopped intermittently. The bar can be used in conjunction with flagger controlled or portable traffic signal controlled work zones. The bar can be placed on the road unsecured for short work operations or temporarily secured to the pavement with adhesive for work zones lasting a few days.

As with the oversized STOP/SLOW paddle, the bar reduces the variability in the driver's choice of stopping point in front of the flagger. Table 4-2 illustrates how the variability in stopping distances from the flagger were reduced when the stop bar was in place, especially in the open lane.

TABLE 4-2. VARIABILITY OF THE DISTANCE BETWEEN THE FLAGGER AND THE FIRST STOPPED VEHICLE

Condition	Standard Deviation (ft) Closed Lane	Standard Deviation (ft) Open Lane
No Stop Bar	32	99
With Stop Bar	21	38

The weight of the stop bar alone appears to keep it in place in most conditions. The only problem with the bar seems to be when large trucks travel over the bar at speeds in excess of 45 mph. When this occurs, the bar will sometimes move and/or be carried a short distance downstream. This problem can be cured by using adhesive tape to hold the bar in place.

The bar is quite durable. The white rubber material withstood heavy trucks and buses with no evident wear. The bar does tend to collect soil from the tires traveling across it and does not retain its initial white appearance for very long. However, the bar is quite visible to drivers even when soiled.

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Appendix A: Analysis of Traffic Flow at Self-Regulated, One-Lane Work Zone Sections

Analysis of Traffic Operation at Self-Regulated One-Lane Sections

The use of yield signs at lane closures on two-lane, two-way highways allows traffic at the work site to regulate itself. The situation of self-regulating, alternating one-way movement can be treated as a special case of an unsignalized intersection, where conflicting movements are the approaches to each end of the lane closure. Although definite right-of-way is not assigned to either approach ("YIELD TO ONCOMING TRAFFIC" signs are placed facing each approach), it will be assumed for purposes of this analysis that vehicles in the closed lane will normally yield to traffic in the open lane. This assumption seems reasonable, as closed-lane traffic is required to use the lane of opposing traffic, while open lane traffic stays in its own lane through the work zone. Furthermore, the analysis focuses on determining the capacity, or flow, on the facility such that open lane traffic generally does not have to stop to allow oncoming traffic from the closed lane to exit the work zone. The analysis relies on the assumption that open-lane vehicles pass through the work zone in some time, t_1, that reflects their unimpeded travel. If demand at the lane closure is such that all vehicles in both directions are being forced to stop, the situation degrades seriously, and total flow through the section may actually decrease.

The analysis is a modification of the procedure used by Major and Buckley (1) that considers the maximum number of vehicles that can enter into a traffic stream, based on available gaps in the stream. The actual equation is:

$$q_x = \frac{qe^{-qT}}{1 - e^{-qh}} \tag{1}$$

where,

q_x = approach demand in closed lane (veh/sec)

q = approach demand in the open lane (veh/sec)

h = minimum headway between vehicles from the closed lane traveling through the work zone (sec)

T = critical gap for drivers in the closed lane (sec)

e = base of the natural system of logarithms

The analysis assumes that a vehicle waiting in the closed lane will enter and travel through the work zone if the gap between consecutive vehicles in the open lane is greater than or equal to time T. If the open lane gap size is T+H in length, then two vehicles from the closed lane enter and pass through the work zone; for a gap of T+2H, three closed lane vehicles enter, etc. (the analysis assumes an inexhaustible supply of vehicles in the closed lane).

Unfortunately, no data is available as to critical gap sizes for drivers waiting at a lane closure. Gap acceptance criteria for intersections (2) is obviously not appropriate. For the situation being discussed here, the driver in the closed lane must estimate the length of the lane closure, the time required to travel through the work zone, and the speed and distance of vehicles approaching in the open lane. Since critical gap information as a function of work zone length was not available, a minimum gap was computed that would allow a vehicle in the closed lane to travel safely through the section before encountering a vehicle from the open lane. Most likely, such estimates will be significantly less than what drivers actually require, but under the previously mentioned operating conditions it does provide an upper limit to the estimated capacity through the section.

Figure A-1 illustrates the methodology used to calculate T for this analysis. As depicted in the figure, the driver of vehicle 0 in the closed lane begins to travel through the work zone as soon as vehicle 1 in the open lane passes point 1. It takes the driver time t_1 to get through the work zone and to point 2. This time was computed from vehicle acceleration curves found in AASHTO's A Policy on Geometric Design of Highways and Streets (3). Meanwhile, vehicle 2 approaching the work zone in the open lane also reaches point 2 at the same time as the vehicle from the closed lane. Vehicle 2 continues its travel through the work zone at speed V_2, until it reaches point 1. The gap T necessary between vehicles in the open lane is:

$$T = t_1 + L/V_2 \qquad (2)$$

where,

T = gap size (sec)

t_1 = travel time through work zone for vehicle from closed lane (sec)

L = length of lane closure (ft)

V_2 = speed of vehicle traveling through work zone from open lane (ft/sec)

This analysis will assume a conservative travel speed for open lane vehicles through the work zone of 35 mph. A plot of gap size T, computed in the above manner, versus length of lane closure is shown in Figure A-2.

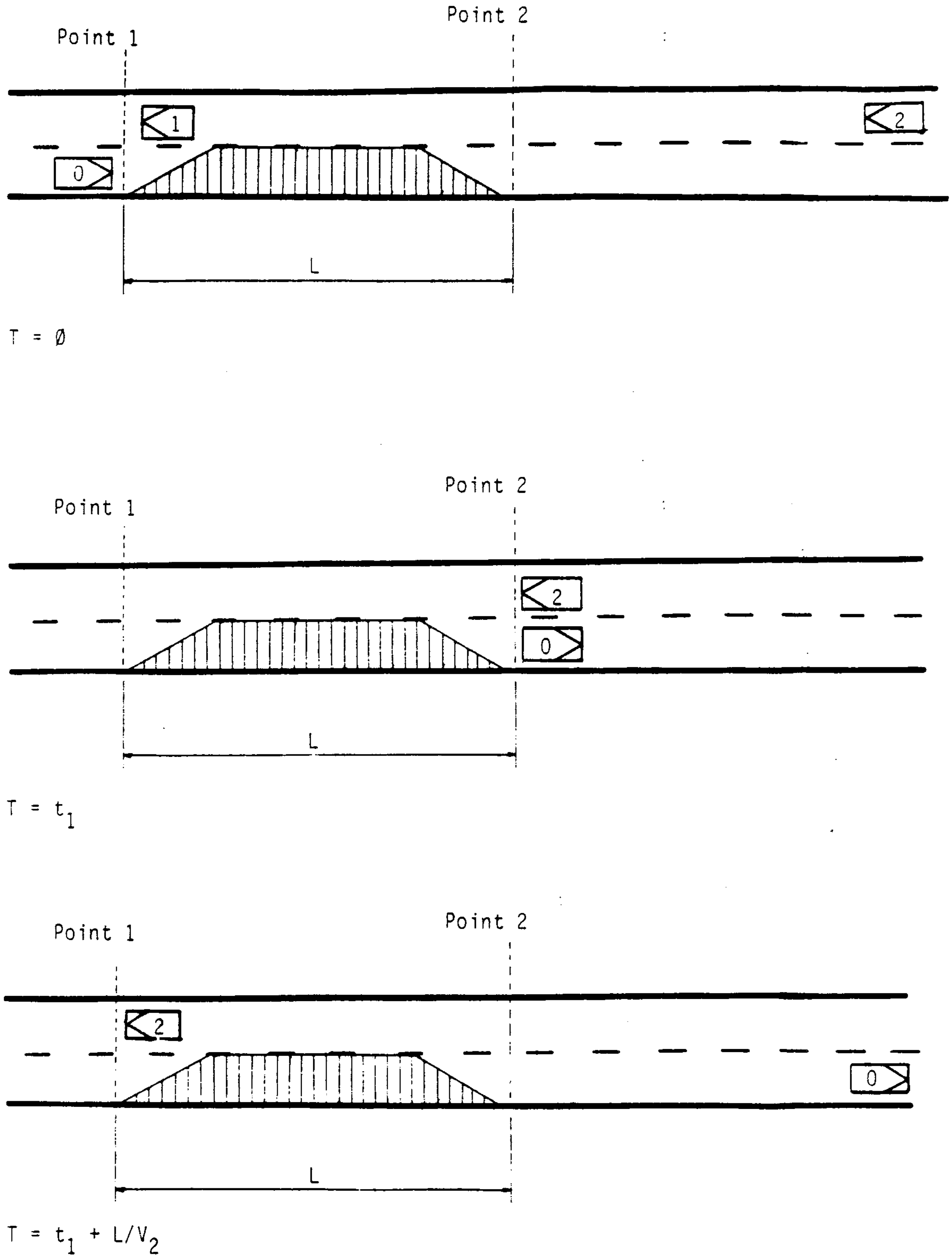

Figure A-1. Schematic Sequence of Events for Computing Minimum Gap Size Needed in Open-Lane Traffic

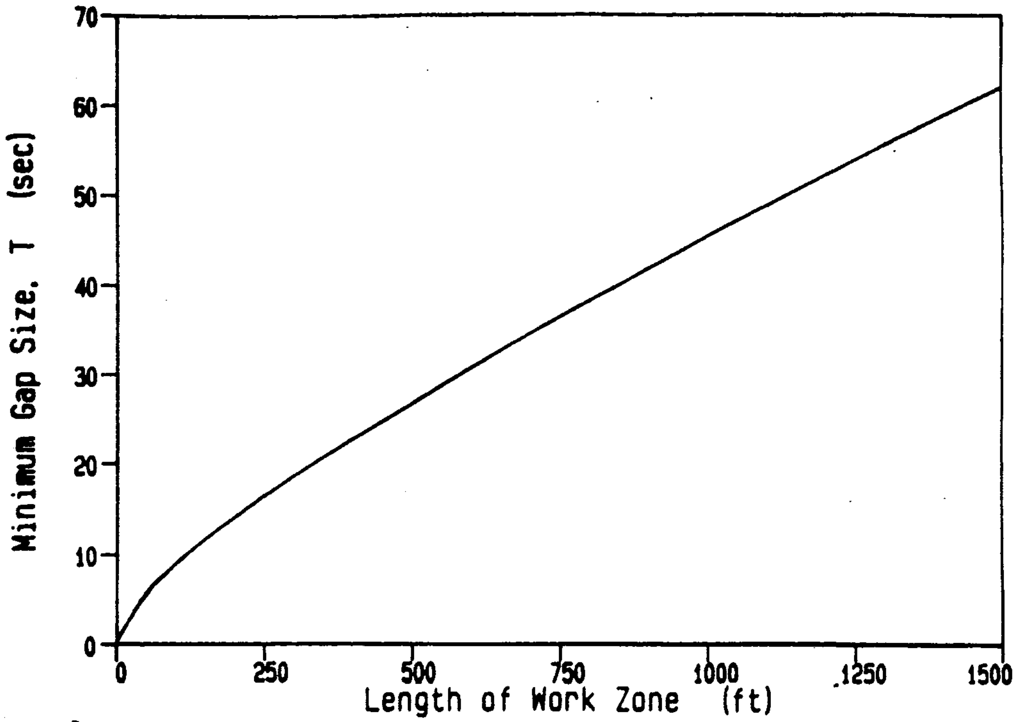

Figure A-2. Effect of Work Zone Length on Minimum Gap Size Needed in Open Lane

Once an estimate of critical gap size is obtained, efforts turn once again to Equation (1). It becomes necessary to determine q_x and q for various critical gap sizes. Assuming that the directional split between open and closed lanes is 50/50 (q_x = q), Equation (1) becomes

$$q = \frac{qe^{-qT}}{1 - e^{-qh}} \qquad (3)$$

Simplifying and rearranging terms in the equation yields

$$e^{-qT} + e^{-qh} - 1 = 0 \qquad (4)$$

By using a root searching technique (4), it was possible to determine q for various values of T. In the above equation, q represents the flow per lane (open or closed) such that the number of acceptable gaps in the open lane traffic is equal to the traffic demand in the closed lane. In turn, multiplying this by 2 provided the total demand volume possible in both directions of travel. A plot of total hourly volume versus gap size T is shown in Figure A-3. Information from Figures A-2 and A-3 are then combined into Figure A-4, a plot of total hourly volume versus length of lane closure.

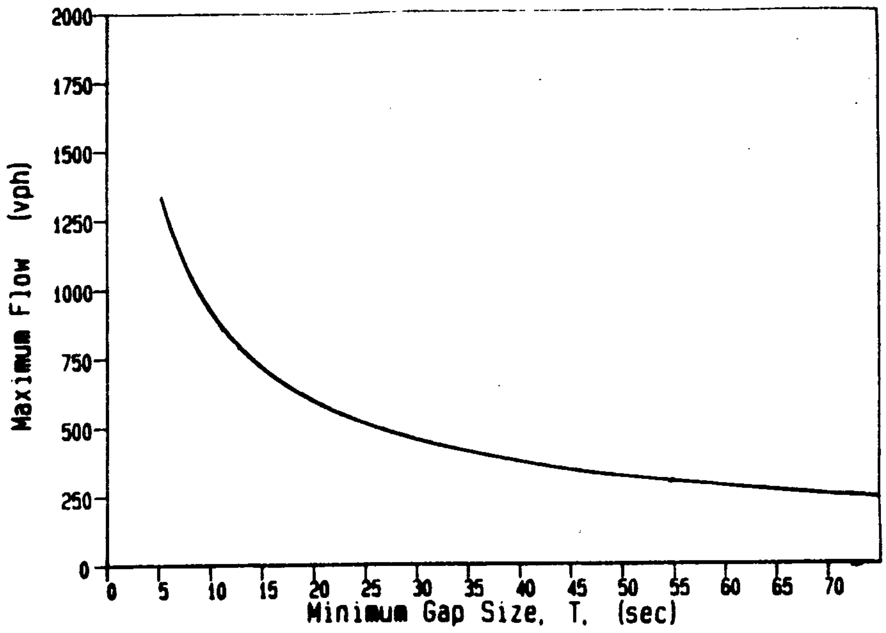

Figure A-3. Effect of Minimum Gap Size Needed in Open Lane on Maximum Flow Through Work Zone

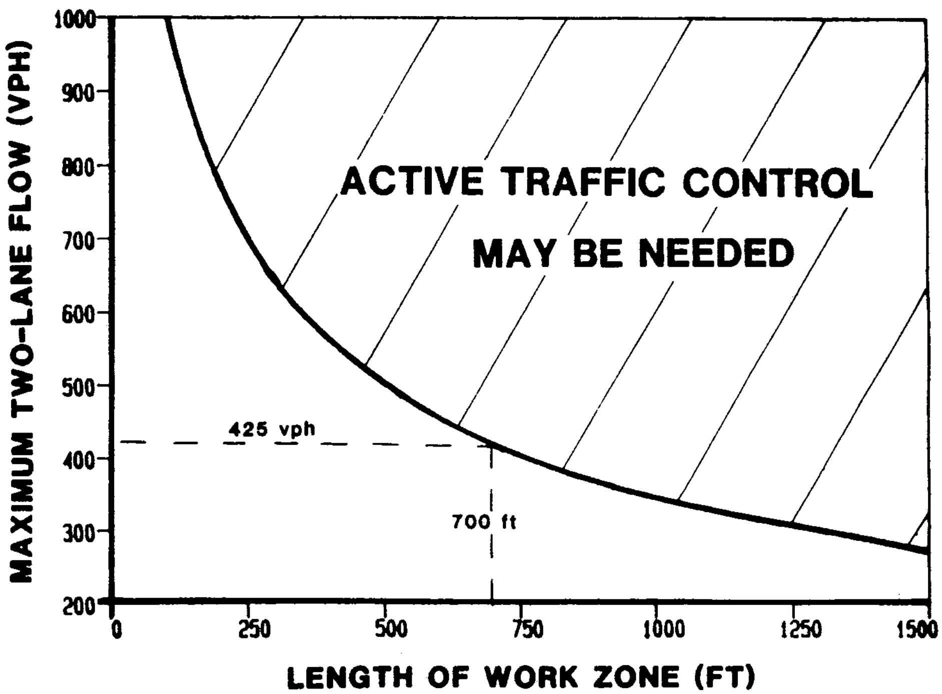

Figure A-4. Effect of Work Zone Length on Maximum Flow Through Work Zone

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Appendix B: Field Studies of a Fixed Time Portable Traffic Signal System

Field Study Procedure

Portable fixed-time traffic signals, were tested at three work zone locations on two-lane, two-way rural highways in Texas. At each location, the portable signals replaced flaggers in alternating one-way traffic through a one-lane section of road. Traffic volumes at these locations ranged from 600 to 10,000 AADT. The lengths of the work zones where the portable signals were tested also varied. The characteristics of the study sites are summarized in Table B-1. Also shown in Table B-1 are the signal timing parameters used at each site. Study sites 1 and 2 were one-day work zones, while work at site 3 lasted two days. At site 3, flaggers were used for traffic control the first day and signal control was used the second.

TABLE B-1. SUMMARY OF STUDY SITE AND SIGNAL TIMING CHARACTERISTICS

					Signal Timing Settings (sec)		
Site	District	Highway	Traffic Volumes 1985 AADT	Work Zone Length (ft.)	Cycle Length	Green Phase	All-Red Clearance
1	11	FM 942	600	600	78	10	26
2	14	FM 969	2400	2600	246	30	90
3	2	FM 1709	10,000	1100	140	30	37

Sites 1 and 2 had sight distances in excess of 1000 ft to the work zone on both approaches, while severe horizontal and vertical geometry at site 3 limited sight distance to less than 500 ft in either direction. None of the sites had visibility from one end of the lane closure to the other.

The traffic control plan for the sites was similar to that used for flagger controlled minor work zone operations (1), except that an orange and black symbolic signal ahead sign (W3-3) replaced the flagger ahead sign in advance of the closure, as illustrated in Figure B-1.

A variety of data were collected during the operation of the portable signals, including: traffic volumes, driver compliance to the signals, and vehicle stopped-delay. Delay and compliance data were collected for about four hours each day, during the time that work was actually being performed in the closed lane. Stopped-delay data were also collected for flagger control on the first day of the lane closure at site 3. This type of data was not available from sites 1 and 2, which were only one-day operations.

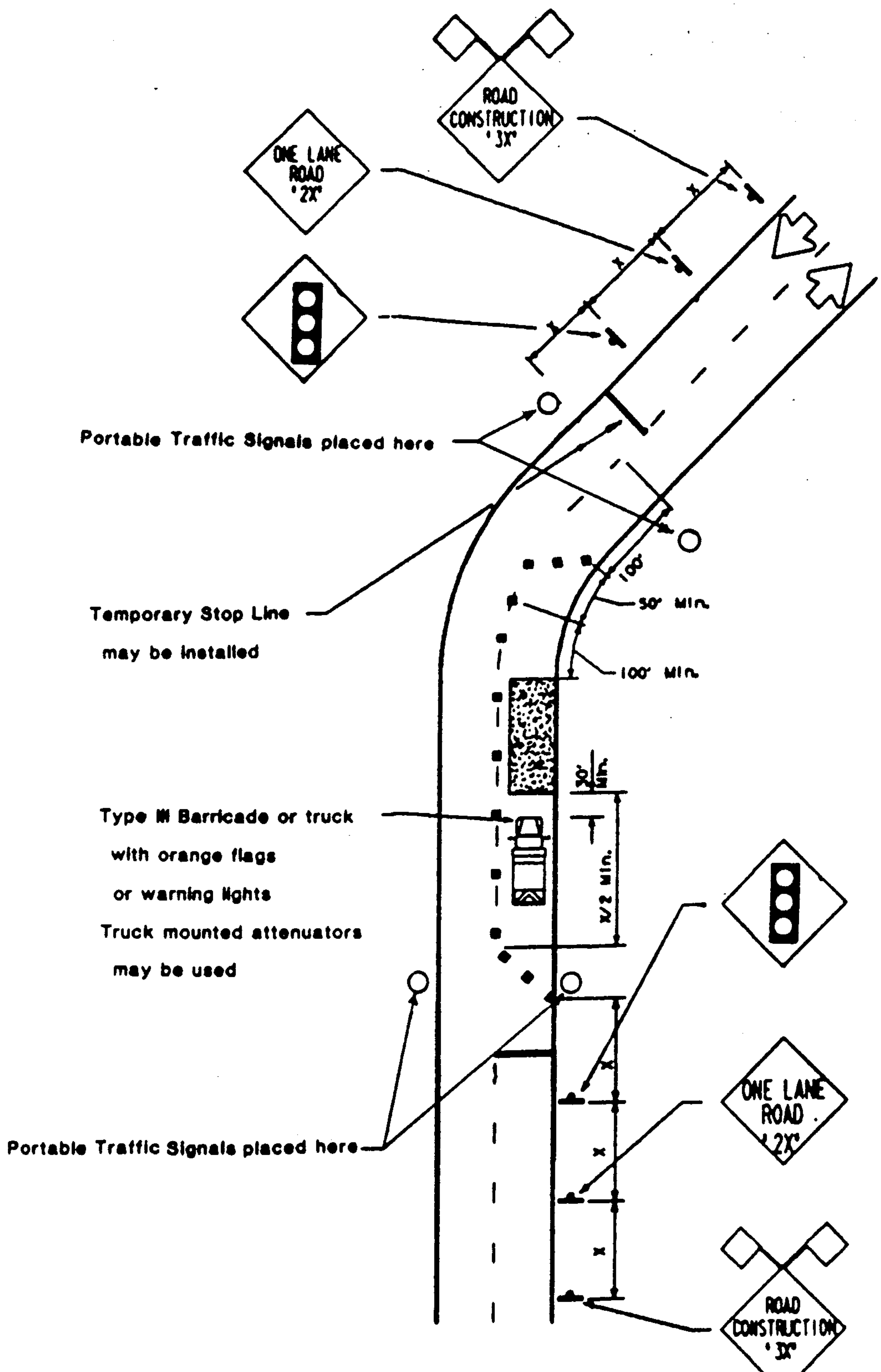

Figure B-1. Traffic Control Plan for Portable Signal Studies

However, data collection personnel at site 1 noted that all vehicles approaching the work zone were isolated arrivals. It was assumed that flaggers would have allowed these vehicles to pass through the work zone without stopping, since they were the only vehicle present at that particular time. Consequently, averaged stopped-delay per vehicle would have been negligible had flaggers been the method of traffic control. Unfortunately, a similar estimation was not possible at site 2, due to the greater traffic volumes and longer work zone. Nevertheless, it was possible to compare vehicle stopped-delay for flagger-controlled and signal-controlled operation at sites 1 and 3.

Study Results

Motorist Delay

One of the advantages of flaggers is that they are responsive to random vehicle arrivals and gaps in the traffic stream, and can assign traffic movements through the work zone so as to minimize vehicle stops and delays. Fixed-time signals do not react to isolated random vehicle arrivals. Rather, motorist delay under signal control is a function of the timing parameters (cycle length, green phase time, etc.). Consequently, motorist delay should increase at a work zone when fixed-time portable signals are used in place of flaggers. At site 1, which had low traffic demand, this was found to be the case. Table B-2 shows how average stopped-delay per vehicle was higher at site 1 when traffic signals were used.

However, flaggers were not found to have as distinct an advantage over fixed-time signals when traffic demands were greater. As Table B-2 indicates, average stopped-delay at site 3 was nearly identical for both flagger and signal control. This site was a longer work zone than site 1, and had dramatically higher traffic demand. Flaggers at site 3 could not allow vehicles to pass through the work zone as they arrived (as could have been done at site 1), but instead had to methodically assign traffic movement to one direction, then the other. In effect, flaggers duplicated the operation of the fixed time signals. Consequently, average stopped-delay per vehicle was very similar for the two types of traffic control.

The above data indicate that, at higher traffic volumes, fixed-time signals at a work zone lane closure can provide a level of service to drivers comparable to that provided by flaggers. However, when volumes are low, signals provide a significantly poorer level of service than that attainable with flagger control. While the quality of service provided to drivers is an important factor to be considered, it is also important to examine the effects of signal control from an economic standpoint. Thus, the next step in the comparison process was to compute total additional motorist delay generated by the portable traffic signals over that incurred (or would have incurred) under flagger control. Total additional stopped-delay per hour are shown in the last column of Table B-2. The values at both sites are nearly identical, and amount to less than 0.5 vehicle-hours of additional stopped-delay per hour.

TABLE B-2. COMPARISON OF STOPPED DELAY
FLAGGER CONTROL VS. FIXED-TIME SIGNAL CONTROL

Site	Hourly Volume	Average Stopped Delay (sec/veh) Flagger	Signal	Additional Delay	Additional Delay (veh-hours/hour)
1	50	0	24	24	0.3
(v/c=0.13)					
3	750	36	38	2	0.4
(v/c=0.9)					

[a] Estimated from observed traffic arrivals. No vehicles would have been forced to stop at this location had flaggers been used.

The large increase in average delay at site 1 affected only a small number of motorists, while the large number of drivers at site 3 were affected by only a small increase in delay.

The small cost of additional motorist delay at the two study sites was more than offset by the savings in flagger labor costs. As shown in Table B-3, fixed-time portable traffic signals provided significant cost savings over the use of flaggers. Computed savings at sites 1 and 3 amounted to 9 and 14 dollars per hour, respectively. Although the actual savings will be somewhat less as capital and maintenance costs of the signals are not included in the table, the system still appears to have been a cost-effective alternative to flagger control at these sites.

TABLE B-3. SUMMARY PORTABLE SIGNALS COSTS AND BENEFITS

Site	Cost of Additional Motorist Delay ($/hour)[a]	Savings in Labor Costs ($/hour)[b]	Savings Achieved by Portable Signals ($/hour)
1	3.12	12.00	8.88
3	4.16	18.00	13.84

a) Based on recent estimates of value of travel time for passenger cars = $10.40/vehicle-hour (2)

b) Based on typical wage and benefits of approximately $6/hour for Maintenance Technician I working for SDHPT.

Driver Non-Compliance to Traffic Signals

One of the major concerns surrounding the use of portable signals at work zones is with whether or not drivers will obey them. Failure of a driver to obey the signal could lead to a serious head-on collision with an oncoming vehicle within the work zone.

Table B-4 presents the results of the non-compliance data collected at each site. Column 1 is the total number of motorists observed approaching and passing through the work zone, while column 2 presents the number of those vehicles which entered the work zone while facing a red indication. Columns 1 and 2 were then used to generate column 3, the rate of observed non-compliance per 1000 vehicles. While the rates indicate that non-compliance was not a major problem, the results show that a few vehicles were observed to enter the work zones on the red. These vehicles were stopped by research and/or work personnel before they had travelled very far into the site, so no accidents or major conflicts occurred. However, the potential for mishap was obviously present in these instances.

TABLE B-4. SUMMARY OF MOTORIST NON-COMPLIANCE TO TRAFFIC SIGNALS

Site	# Motorists Observed	# Motorists Running Red	Rate/1000 vehicles
1	43	0	0
2	400	2	5
3	500	2	4

Although not shown in Table B-4, two different types of violations occurred at sites 2 and 3. The first violation type involved vehicles which initially came to a stop, but then entered the work zone while the light was still red. It appeared that the drivers of the vehicles did see the signals, but then chose to proceed through the work zone on the red, even though they could not see completely through the work zone. (As stated previously, none of the sites had visibility from one end of the work zone to the other). This type of non-compliance indicates that portable signals may have a credibility problem in these types of work zone applications. It may be possible to improve their credibility somewhat by putting out a temporary stop line 50 to 60 feet in advance of the signal, and placing a temporary STOP HERE ON RED sign (R10-6) (1) next to the stop bar. These devices are commonly used at signalized intersections, so they may add credibility to portable signals in work zone applications. These devices were installed on one approach at Site 1. Although the sample size was too small to draw any solid conclusions about the effectiveness of these devices, drivers at this site were observed to consistently stop immediately behind the stop bar and to wait until the light turned green.

The other type of violations occurring at sites 2 and 3 involved vehicles that ran the red light and entered the work zone without stopping, suggesting that they never even saw the signals. Unfortunately, it may be quite difficult to reduce or eliminate these types of incidents. It was suggested that the manufacturer of the portable signals increase the wattage of the lamp heads in order to make them more visible in daylight. Other attention-getting devices may be available to increase the conspicuity and attention-getting capability of the signals. However, identification and experimentation with these types of devices was beyond the scope of this study.

Conclusions

Based on these limited studies, fixed-time signals appear to be an effective alternative to the use of flaggers for alternating one-way traffic through a work zone. Significant savings in flagger labor costs can be realized with what appears to be a minimum of additional delay costs to motorists. However, the trade-offs between reduced flagger accidents and possibly increased vehicle accidents in work zones cannot be estimated at this time. Continued research and experience with portable signal use at work zones will be needed before the full benefits and costs associated with their use are known.

References

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration. Washington, D.C. 1978.

2. U. K. Chui and W. F. McFarland. The Value of Travel Time: New Estimates Developed Using a Speed-Choice Model. Texas Transportation Institute Research Report 396-2F. College Station, TX. May 1986.

Appendix C: Field Studies of Temporary Stop Bar and Oversized, Freestanding Sign Paddle

Field Study Procedure

The reusable, temporary stop bar and oversized sign paddle were evaluated at work zone locations on two-lane, two-way rural highways near Port Arthur (District 20) and Keller (District 2). Due to an earlier than expected completion of work activity at the District 2 site, very little operational data were collected. Consequently, the remainder of the discussion will focus on the Port Arthur site. At this location, a lane was closed and flaggers were used to alternate one-way traffic through the work zone. The Port Arthur site was a straight and level section of highway with virtually no development in the general area. The AADT at this site was approximately 7000 with no observable peak times. At the work zone, the eastbound lane was closed over a 3/4-mile section to allow a shoulder to be added. Flaggers with two-way radios were used at each end of the work zone to alternate traffic through the restricted section.

Advanced signing at the approaches to the work zone consisted of the following signs: 1)ROAD CONSTRUCTION AHEAD with 40 MPH advisory speed plate, 2) BE PREPARED TO STOP, 3) ONE LANE TRAFFIC AHEAD with 1000 FT supplemental plate, and 4) FLAGMAN AHEAD. The signs were spaced approximately 500 ft apart.

Three different treatments were examined during this field study in both the open and closed lanes.

1. Existing.

   Consisted of the standard MUTCD set up with flaggers using only flags and hand signals to communicate with approaching vehicles.

2. Temporary Stop Bar.

   Same as the Existing set up with addition of the temporary stop bar placed across the lane of traffic being stopped by the flagger. The flagger was allowed to stand anywhere behind the stop bar.

3. Oversized STOP/SLOW Paddle.

   Same as the Existing set up with addition of the oversized STOP/SLOW paddle placed just off the roadway adjacent to the flagger.

Three types of data were collected during the field study for each of the three treatments.

1. Vehicle Stopping Points at Work Zone Approaches.

   Distances between the flagger and stopping point of the first vehicle (measured to front of vehicle) as well as distances between the stop bar and the first vehicle when the stop bar was in use were measured to the nearest foot.

2. Vehicle Through Speeds at Work Zone Approaches.

   Vehicles approaching the work zone that were instructed by the flagger to proceed through the work zone without stopping were timed with a stopwatch over a 200 ft section located just prior to the position of the flagger. The times were recorded and later converted to speed in mph.

3. Vehicle Approach Speeds to the Work Zone and Points of Brake Application.

   A car following technique using a vehicle equipped with a time-speed-distance measuring instrument was used to record travel speeds of approaching vehicles. The approach speeds were recorded in 500-ft intervals from approximately 3000 ft in advance of the work zone to the point at which the vehicle came to a stop. While collecting speed profile data, the distance from the flagger that the vehicle first applied his brakes (as witnessed by the brake lights) was also recorded.

Data were collected over a 2 day period. Each treatment was studied for approximately 2 hours in the open and closed lanes each day. Table C-1 shows the order in which the treatments were studied. This order allowed each treatment to be studied over a different time period than the first day.

TABLE C-1. TREATMENT ORDER

DAY ONE

Time Period	Open Lane	Closed Lane
8:00 a.m. - 10:00 a.m.	Existing	Stop Bar
11:00 a.m. - 1:00 p.m.	Sign Paddle	Existing
2:00 p.m. - 4:00 p.m.	Stop Bar	Sign Paddle

DAY TWO

Time Period	Open Lane	Closed Lane
8:00 a.m. - 10:00 a.m.	Stop Bar	Sign Paddle
11:00 a.m. - 1:00 p.m.	Existing	Stop Bar
2:00 p.m. - 4:00 p.m.	Sign Paddle	Existing

Results

Stopping point data collected on the first vehicle directed to stop by the flagger are summarized in Table C-2. The data suggest that the temporary stop bar and the oversized STOP/SLOW sign paddle were useful in helping drivers decide when and where to stop in front of the flagger. The variability of the distance between the flagger and the first stopped vehicle was greatly reduced when using the stop bar and sign paddle.

TABLE C-2. DISTANCE BETWEEN THE FLAGGER AND THE FIRST STOPPED VEHICLE

Treatment	Closed Lane			Open Lane		
	N	Average (ft)	Standard Deviation (ft)	N	Average (ft)	Standard Deviation (ft)
Existing	44	57	32	54	67	99
Stop Bar	46	47	21	45	43	38
Sign Paddle	51	50	23	45	38	32

N = Sample Size
1 ft = .305 m

As can be seen in Table C-2, the standard deviations of stopping distances from the flagger were reduced when either the stop bar or sign paddle were used, as compared to the existing conditions with no supplemental devices. Smaller variability was evident in the closed lane, most likely due to additional visual information behind the flagger (i.e., cone taper, work area) that helped drivers decide where to stop. In the open lane, this additional visual information was not present, and so the variability in driver stopping points was higher. In the same vein, because the additional visual information was not afforded to open-lane drivers, the supplemental devices were extremely useful, and the reduction in standard deviation from the existing condition was highest for the open lane.

Stopping distances from the flagger were found to have a non-normal (skewed to the right) distribution, so a direct statistical comparison of the standard deviations was not possible. Nevertheless, the data does suggest that the two devices did provide useful information to drivers about where to stop behind the flagger.

The temporary stop bar was very effective at identifying a point for the drivers to stop behind. Only 5 of 91 vehicles (5.5%) encroached upon the stop bar and no vehicles totally passed the stop bar. Thus, the flaggers were able to regulate the distance between themselves and the first stopped vehicle. Flaggers generally felt comfortable standing 20 to 30 feet behind the stop bar.

Speed data collected on approaching vehicles that were directed by the flagger to proceed through the work zone are summarized in Table C-3. As can be seen, neither the average nor standard deviation of the through speeds was significantly different among any of the three treatments.

TABLE C-3. APPROACH SPEEDS OF VEHICLES DIRECTED BY THE FLAGGER TO PROCEED THROUGH THE WORK ZONE (mph)

Treatment	Open Lane		Closed Lane	
	Average	Standard Deviation	Average	Standard Deviation
Existing	51.0	9.1	45.2	7.3
Stop Bar	49.3	7.8	46.2	8.9
Sign Paddle	48.1	8.5	45.9	7.2

1 mph = 1.61 km/h

The stop bar, whose purpose is to identify a stopping point, was not expected to have an effect on through speeds. It was felt, however, that the oversized SLOW sign might reduce through speeds. As seen in Table C-3, this was not the case. Apparently, drivers proceeded through the work zone at what they felt to be a comfortable and reasonable speed. The slightly lower through speeds in the closed lane can be explained by the lane changing maneuver required at the beginning of the lane closure.

It should be noted that flaggers made no attempt to slow traffic by using hand or flag signals during any of the treatments. Also, the geometrics of the site and location of the work crew relative to the through lane allowed relatively high speeds.

Speed profile data collected on vehicles approaching the work zone showed no substantial difference between the existing and sign paddle treatments in either the open or closed lane. Again, drivers approached the work zone at whatever speed they felt comfortable, regardless of the treatment in place.

Interest focused mainly on the effect the sign paddle may have on where drivers first began to decelerate in advance of the work zone. The stop bar was not expected to have an effect on speed profiles, as it is not visible at any significant distance from the work zone. Average speed profiles for the existing and sign paddle treatments in each lane are illustrated in Figures C-1 and C-2.

The data collected on distances from the flagger when vehicle brake lights were first detected was examined using an analysis of covariance model. It was hypothesized that point of brake light application would depend on the speed of the vehicle and whether it was the first, second, ..., nth vehicle in a platoon or queue. Therefore, the covariance model employed these two variables in addition to study treatment (existing, stop bar, sign paddle).

The results of the analysis showed that no treatment, factor, or interaction terms were statistically significant. Neither the sign paddle or the stop bar influenced motorists speeds approaching the work zone.

The flaggers using the supplemental devices during the field study commented that the oversized sign paddle helped drivers respond better to the stop and proceed commands. Many of the flaggers would point to the sign paddle as vehicles approached.

Conclusions

Based on these limited studies, the temporary stop bar and oversized sign paddle appear to be effective devices in helping drivers understand when and where to stop in front of the flagger if instructed to do so. The stop bar and sign paddle, however, appeared to have little effect on the speeds of vehicles instructed to proceed through the work zone or on the speeds of vehicles approaching the work zone.

The stop bar and sign paddle were evaluated independently of one another. It is recommended, however, that they be used in conjunction with one another by placing the stop bar approximately 30 ft in advance of the flagger and sign paddle. In addition, a more portable design for the sign paddle should be developed. It is possible that a small trailer could be modified to hold such a paddle so that it could be towed from location to location as needed.

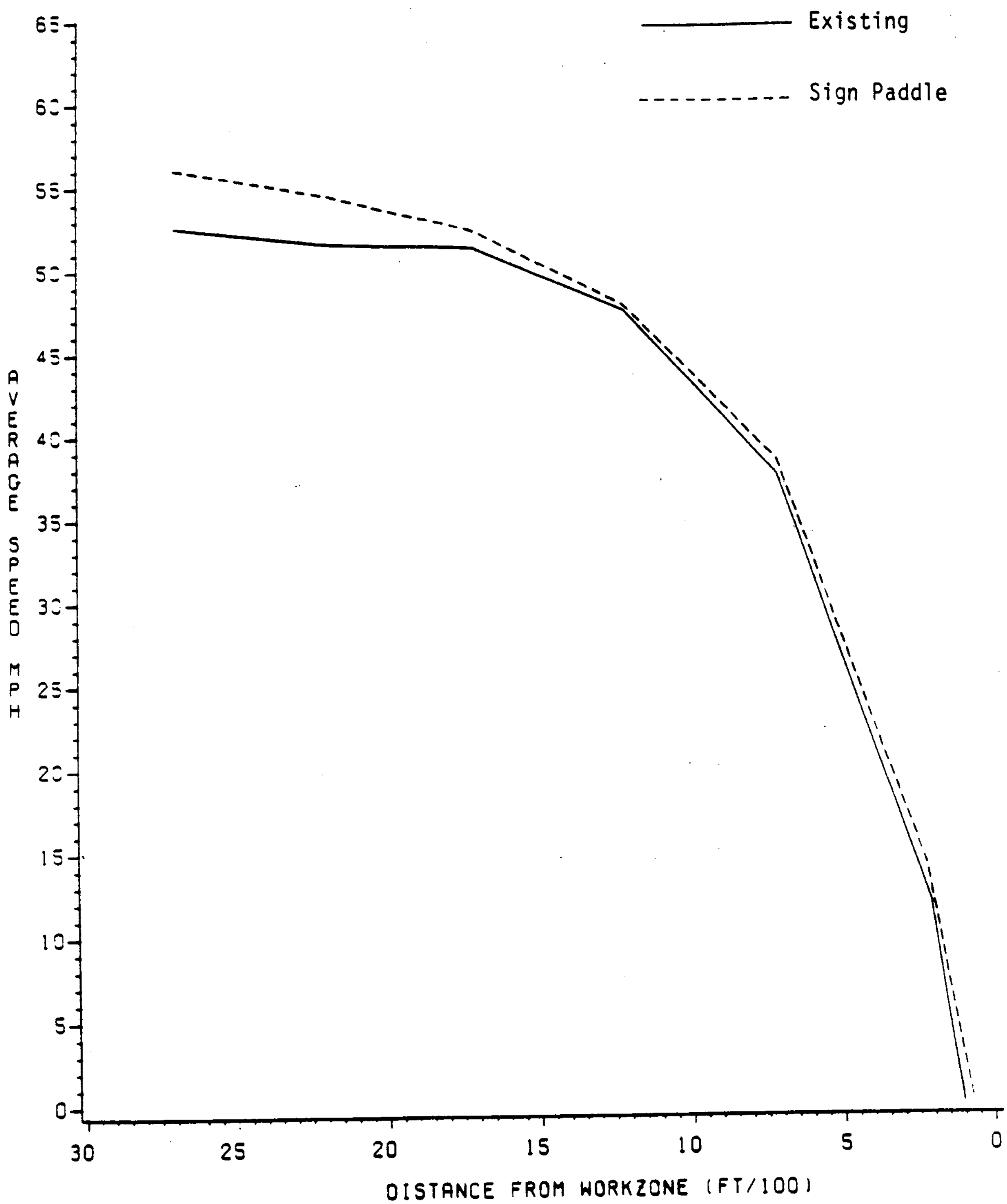

Figure C-1. Average Speed Profile Comparisons for Open Lane

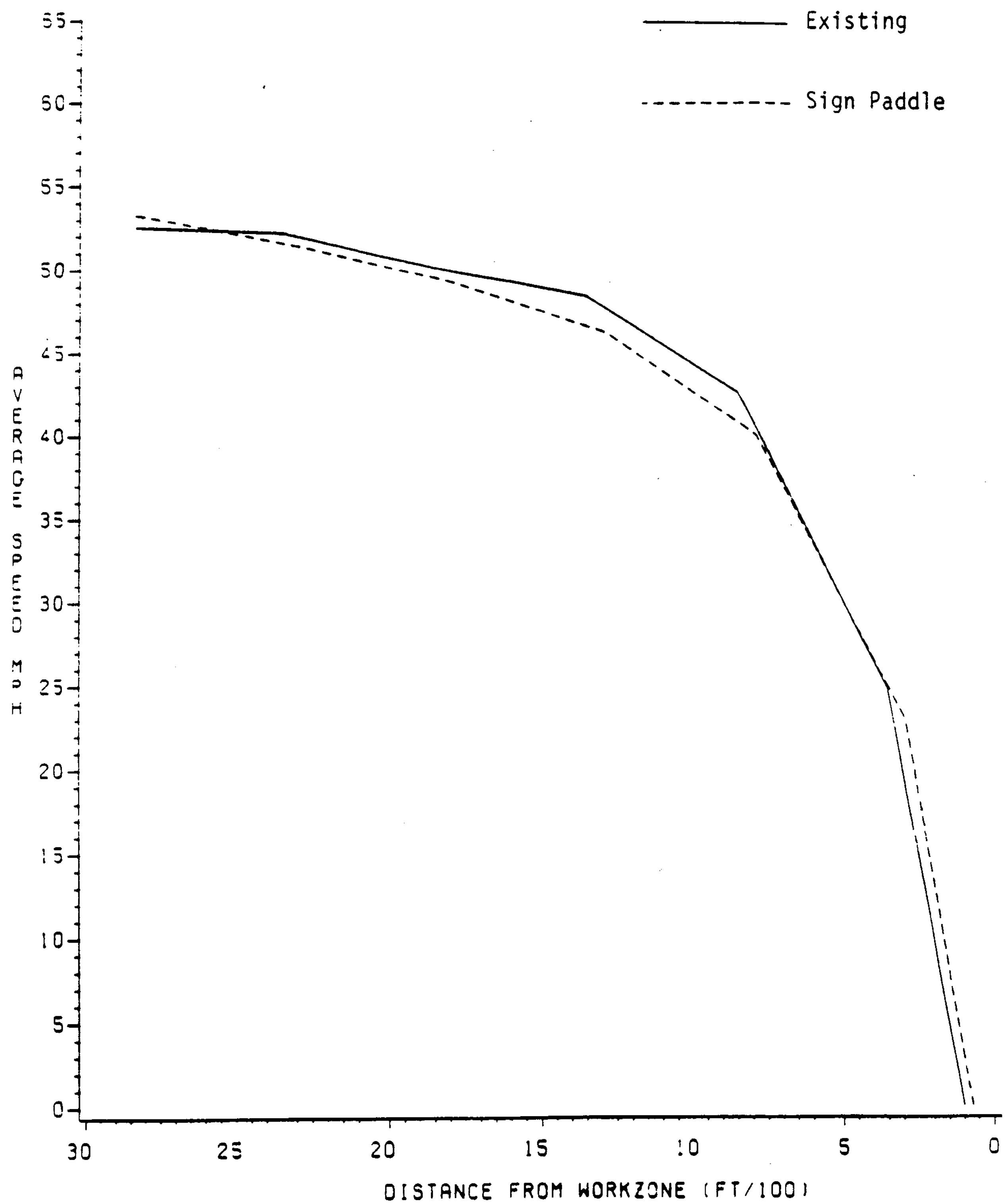

Figure C-2. Average Speed Profile Comparisons for Closed Lane

References

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, Washington, D.C. 1978.

2. S. H. Richards, N. D. Huddleston, and J. D. Bowman. Driver Understanding of Work Zone Flagger Signals and Signaling Devices. Research Report 228-3. Texas Transportation Institute. College Station TX. January 1981.

3. R. Q. Brackett, et al., Protection of Personnel in Maintenance and Construction Zones. Research Report 330-1. Texas Transportation Institute. College Station, TX. October 1985.