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TRANSPORTATION
INSTITUTE

STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATION

COOPERATIVE
RESEARCH

HANDLING TRAFFIC IN WORK ZONES

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 292-6F
STUDY 2-18-81-292
TRAFFIC AT WORK ZONES

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16. Abstract

This report is a consolidation of results of research conducted in Study 292. The research focused on numerous topic areas relating to work zone traffic control and safety. Specific details of the research are presented in several Interim Reports and Technical Memorandums submitted to the Department.

This is the final report in a series of six reports. Other reports in the series are:

Report No.	Short Title
FHWA/TX-83/20+292-1	Road User Costs At Work Zones
FHWA/TX-84/58+292-2	Controlling Speeds in Work Zones
FHWA/TX-85/06+292-3	Selection of Channelizing Devices Using Value Engineering
FHWA/TX-85/07+292-4	Portable Changeable Message Signs in Work Zones
FHWA/TX-85/56+292-5	Operational Guidelines for Short-Term Total Freeway Closures

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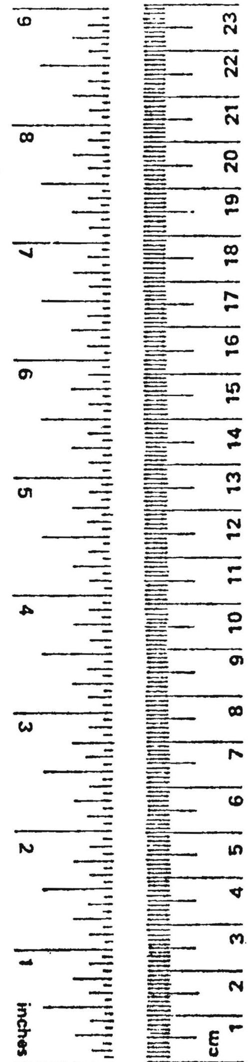
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

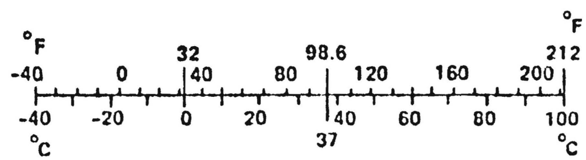
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



HANDLING TRAFFIC IN WORK ZONES

by

C. L. Dudek

S. H. Richards

and

R. C. Wunderlich

Research Report 292-6F
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Handling Traffic in Work Zones

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Benjamin W. Bohuslav, Supervising Maintenance Engineer, District 13
Walter Collier, District Maintenance Engineer, District 15
Billie E. Davis, District Maintenance Engineer, District 2
Milton Dietert, Assistant Chief Engineer of Safety and Maintenance Operations, D-18
Herman Gadeke, District Traffic Engineer, District 15
Hunter Garrison, District Maintenance Engineer, District 12
Henry Grann, Supervisory Traffic Engineer, District 18 (Retired)
Herman Haenel, Supervisory Traffic Engineer, D-18T
Bobby Hodge, Supervisory Traffic Engineer, District 2
Steve Levine, Traffic Management Supervisor, District 12
Blair Marsden, Senior Traffic Engineer, D-18T
Silas M. Prince, District Maintenance Engineer, District 11
Lewis Rhodes, Senior Traffic Engineer, D-18T
Russell G. Taylor, Engineering Technician V, District 14
Milton Watkins, District Maintenance Engineer, District 18
John Wilder, District Maintenance Engineer, District 14

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents 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

Study 292 resulted in several findings and recommendations which, when implemented, will enhance work zone operations, safety and efficiency. The following sections summarize the status of implementation of this research.

Immediate Implementation

A close working relationship with the Technical Advisory Committee resulted in the implementation of several findings and recommendations by the Districts and D-18T as the research was progressing and prior to publication of results.

Barricade and Construction Standards

Barricade and Construction Standards (B-C Sheets) are being modified in accordance with Study 292 research findings.

Speed Control

The results have provided greater insight regarding speed control techniques in work zones. Maximum speed reductions by type of roadway are suggested. The implementation of work zone speed control measures are discussed in detail.

Freeway Closures

Guidelines for advance planning, advance notification, traffic control devices and management, and the use of law enforcement for short-term freeway closures (e.g., one or two days) presented in the report can be implemented immediately.

Impacts of Lane Closures

Highway capacity data for lane closures at work zones are documented and readily used by the Department to assess the impacts of lane closures. Road user cost data associated with work zone lane closures are also presented for use during economic analyses. A queue and road user cost evaluation model, QUEWZ, was developed to assist the Districts in quickly evaluating the impacts of numerous lane closure traffic control approaches. The computer model was placed on the Department's computer and is being accessed by the Districts from their remote terminals.

Advance Warning of Lane Closures for Stationary and Moving Operations

An innovative lane-blocked sign was developed and field tested during moving operations and during frontage road pavement repairs. The sign proved successful in encouraging drivers to vacate the closed lane.

Selecting Channelizing Devices

There are a wide variety of channelizing devices currently available for use in highway work zones. Selection of the most appropriate devices is a critical task affecting both safety and job cost. Presently, there is no organized, objective selection method. The use of Value Engineering for selecting work zone channelizing devices was investigated and documented, and was found to be a good approach. An example of the application of Value Engineering was presented. The Value Engineering Approach can be used by the Department at the Division level as an aid in establishing work zone traffic control standards and for planning and allocating resources.

Training

The results of the research from Study 292 were incorporated into a new short course entitled, "Planning and Implementation of Work Zone Traffic Control". The short course was developed for the Department by the Study 292 researchers through the Texas Engineering Extension Service.

CONTENTS

1. INTRODUCTION

Each year more and more maintenance and reconstruction activities are performed on our aging highway system. Unlike new highway construction, these activities are accomplished with vehicle traffic traveling past the work area. As a result, motorist and worker safety, as well as work zone traffic flow, must be considered.

The Manual on Uniform Traffic Control Devices (1) contains standards for handling traffic at work zones. The standards in the MUTCD are somewhat general and do not always provide adequate guidance to insure safe and efficient work zone traffic operations on urban freeways.

Study Objectives

Study 292 was initiated in response to the national and local concern over work zone traffic operations and safety, particularly on urban freeways. One purpose of the study was to develop improved procedures for controlling speeds at highway work zones. To accomplish this objective, field studies were conducted on different types of highways to evaluate the short-term effects of several methods of speed control.

The study also addressed the issue of when an agency should encourage reduced speeds at a particular work zone. By visiting and observing numerous work zones, several important considerations became apparent, and the authors were able to provide guidelines of the implementation of work zone speed control measures.

The research also evaluated the use of certain special traffic control tools. Field studies were conducted to evaluate the effectiveness of portable changeable message signs (CMSs), law enforcement personnel, and an innovative advance warning sign for lane closures. The studies were conducted as a means for developing guidelines for these tools at freeway work zones.

Field studies were also conducted at freeway closures to observe traffic operations and to identify successful strategies and problem areas. General guidelines and recommendations were developed and organized into three broad categories: Advance Planning, Advance Notification, and Traffic Management.

As a means of developing guidelines for scheduling maintenance on urban freeways, field studies were conducted to determine additional work zone capacity relationships. Highway capacity data for lane closures at work zones were collected and documented for use in evaluating the impacts of lane closures. A queue and road user cost evaluation model (QUEWZ) was developed to assist the Districts in evaluating the impacts of numerous lane closure traffic control alternatives.

The use of Value Engineering for selecting work zone channelizing devices was investigated and recommended. It is anticipated that the Value Engineering approach can be used at the Division level.

The results are summarized in Chapters 2 to 11 of this Final Report as follows:

<u>Chap.</u>

2. Speed Control In Work Zones
3. Implementation of Work Zone Speed Control Measures
4. Changeable Message Signs
5. Law Enforcement Personnel
6. Innovative Advance Warning Sign For Lane Closures
7. Operational Guidelines For Short-Term Total Freeway Closures
8. Traffic Capacity Through Work Zones
9. Road User Costs Associated with Work Zone Lane Closures
10. Model to Calculate Road User Costs At Work Zones
11. Selecting Channelizing Devices Using Value Engineering

2. SPEED CONTROL IN WORK ZONES

Introduction

Excessive speeds in highway construction and maintenance work zones can adversely affect the safety of the work crew and motorists. Unfortunately, motorists do not always slow down to posted speed limits in work zones.

The objective of the research reported in Report No. 292-2 was to determine or develop effective methods of slowing traffic to acceptable speeds in work zones (2). The speed reduction capabilities of the methods were evaluated and other factors such as cost, motorist and worker safety, and institutional constraints were also considered.

Field Studies

Candidate speed control methods for work zones were identified through a literature search and recommendations from the Study 292 Technical Advisory Committee.

Following a limited number of proving ground studies, plans were made to conduct field studies at work sites on two 2-lane, 2-way highways to evaluate the short-term effects of several methods of speed control: flagging, law enforcement, CMSs, effective lane width reduction, rumble strips and conventional signing. CMSs were not available at the 2-lane sites selected and therefore were not evaluated.

A companion research project, sponsored by FHWA (3), evaluated flagging, law enforcement, CMSs, and effective lane width reduction on three types of highways: 1) undivided multilane arterial, 2) rural freeway, and 3) urban freeway. The results of this research were combined with the 2-lane, 2-way highway results and incorporated into Research Report 292-2.

Several variations (treatments) of the speed control methods were tested. Table 2-1 identifies and describes the treatments evaluated for each speed control approach. Table 2-2 presents a summary of the treatment studied by site.

Data Collection

Treatment effects on speeds were determined by evaluating speeds at 3 points within the work zone study sites. The first spot speed station at each site was located upstream and out of sight of any work zone signing or activity. The second station was immediately downstream of where the speed control treatments were implemented. This station measured initial response to the treatments. The third and final station was positioned farther

TABLE 2-1. SPEED CONTROL TREATMENTS EVALUATED

Speed Control Method	Treatment	Description
Flagging	MUTCD Procedure	Flagger equipped with red flag and orange vest, performed "Alert and Slow" signal detailed in Part VI, MUTCD.
	Innovative Procedure	MUTCD "Alert and Slow" signal enhanced by 2 additional movements: 1) Flagger motioned traffic to slow with free hand, then 2) pointed with with free hand to nearby speed sign.
Law Enforcement	Stationary Patrol Car--Lights and Radar Off	Marked patrol car parked on side of road parallel to traffic.
	Stationary Patrol Car--Lights On, Radar Off	Marked patrol car parked on side of road parallel to traffic with flashing red and blue lights on.
	Stationary Patrol Car--Lights Off, Radar On	Marked patrol car parked on side of road perpendicular to traffic with radar on and pointed toward traffic stream.
	Circulating Patrol Car[a]	Marked patrol car continuously driven back and forth through work zone without lights or radar on.
	Police Traffic Controller	Uniformed officer standing on side of road next to speed sign and manually motioning traffic to slow down.
CMS	Speed and Informational Message	1- or 3-line bulb matrix sign displaying work zone information tion message plus a speed advisory.
	Speed Message Only	1- or 3-line bulb matrix sign displaying speed advisory.
Effective Lane Width Reduction	Cones (12.5 feet)	1) On 2-lane highways, cones deployed to funnel traffic through a 12.5' wide travel path. 2) On multilane highways, cones positioned along the pavement edges leaving a 12.5 foot travel path between the cones and lane lines.
	Cones (11.5 feet)	Same as above except the travel path width decreased to 11.5 feet.
Conventional Signing	Regulatory Signing	Black-on-white regulatory speed sign with the desired work zone speed.
	Advisory Signing	Black-on-orange advisory speed sign with the desired work zone speed.
Rumble Strips[a]	8 Strips--Decreasing Spacing	Eight 1/2-inch high, polycarbonate strips installed across the travel lane in decreasing spacing, perpendicular to the travel direction.

[a]Tested only on 2-lane highways.

TABLE 2-2. SUMMARY OF TREATMENTS STUDIED BY SITE

	Urban Arterial	Rural Freeway		Urban Freeway	Rural 2-Lane, 2-Way Highway	
Treatment	Site 1 FM 1960	Site 2 IH-35 Kyle	Site 3 I-35 Selma	Site 4 I-10	Site 5 FM 2818	Site 6 SH 105
MUTCD Flagging	X	X (L)[a]	X	X	X	X
Innovative Flagging	X		X	X	X	X
Innovative Flagging Both Sides		X		X		
Stationary Patrol Car	X	X (L)	X[b]	X	X	X
Police Traffic Controller	X				X	X
Circulating Patrol Car					X	X
Stationary Patrol-Lights On				X		
Stationary Patrol-Radar On				X		
CMS-Speed-Only Message	X	X (L)		X		
CMS-Speed & Informational Message	X	X (L)		X		
CMS-Speed & Advisory-Alternate Location				X		
Effective Lane Width Reduction - 11.5'	X	X	X	X	X	X
Effective Lane Width Reduction - 12.5'	X	X	X	X	X	X
No Signing	X		X	X	X	X
Advisory Speed Signing		X				X
Regulatory Speed Signing	X		X	X	X	X
Rumble Strips					X	X[c]

[a]All treatments were implemented on the right unless noted by (L) indicating left implementation.

[b]Both left and right side treatments were studied.

[c]Rumble strips would not adhere to the pavement; thus no data were collected.

downstream of the treatment location to determine if the treatments suppressed speeds beyond the point of treatment.

Results

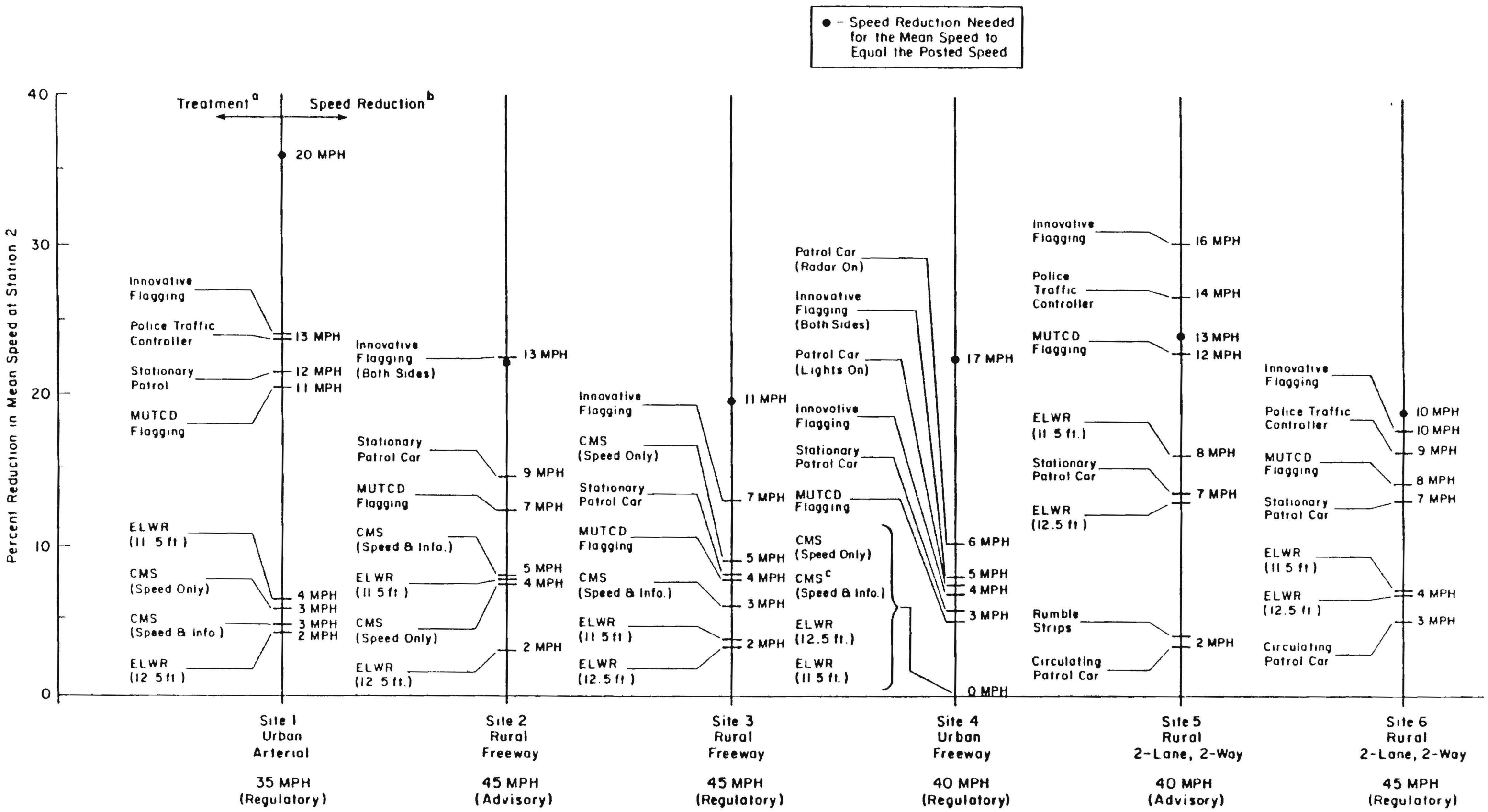
Figure 2-1 summarizes the performance of most of the speed control treatments tested. Conventional signing and rumble strips were ineffective in reducing speeds and have been omitted. The figure shows the reductions in mean speeds (in mph) and percentage speed reductions attained by each treatment on a site-by-site basis. The data in the figure are based on driver responses at Station 2 to the treatments and were generated by comparing mean speeds when a treatment was in place to mean speeds during the base condition (i.e., the normal posted work zone speed limit).

The results indicated that flagging and law enforcement were very effective methods of speed control. The best flagging treatment at each site reduced speeds an average of 19% (Table 2-3) and the best law enforcement treatment reduced speeds an average of 18%. In contrast, the best changeable message sign and effective lane width reduction (with cones) treatments evaluated reduced speeds by only 7% each. However, because they were not available, changeable message signs were not studied at the 2-lane, 2-way rural highway sites where the greatest speed reductions were observed for the other methods. It is quite likely that the performance of the changeable message signs, in terms of reductions in average speeds, would have improved had they been tested at the 2-lane, 2-way highway sites.

An innovative flagging approach (MUTCD alert and slow signal enhanced by special hand signals and eye contact with approaching motorists), MUTCD flagging, police traffic controller, and stationary patrol car were found to be very effective treatments on most highway types, whereas the circulating patrol was found to be an ineffective approach.

The innovative flagging treatment developed as part of this research resulted in larger average speed reductions than MUTCD flagging at 5 of the 6 study sites but the differences were small. For example, on one rural 2-lane, 2-way highway the innovative flagging treatment reduced the average speed by 16 mph (30%), while MUTCD flagging reduced the mean speed by 12 mph (23%). Although the differences were statistically significant, the differences were in the magnitude of only 2-4 mph.

The various flagging treatments studied produced the greatest average speed reductions at the 2-lane, 2-way rural highway sites (8-16 mph) and urban arterial sites (11-13 mph). They generally resulted in smaller average speed reductions at the freeway sites (3-7 mph), particularly the urban freeway site (3-4 mph). The results also indicated that flagging effectiveness may be improved on freeways by having a flagger on both sides of the travel lanes.



[a] The base condition signing treatment and the "no speed signing" treatment are not shown In addition, the various regulatory and advisory signing treatments tested at Site 5 are not included

[b] Between the base condition mean speed and the treatment mean speed.

[c] When the CMS was relocated closer to the work area, the Speed and Information Message treatment reduced Station 2 speeds by 2 mph (3%)

Figure 2-1. Summary of Speed Control Treatments by Site

TABLE 2-3. EFFECTIVENESS OF SPEED CONTROL METHODS[a]

Speed Control	Speed Reduction[b]			
	Amount		Percent	
	Range	Average	Range	Average
Flagging	3-16	11	(8-30)	(19)
Law Enforcement	3-14	9	(8-27)	(18)
Changeable Message Signs[c]	2- 5	3	(3- 9)	(7)
Effective Lane Width Reduction w/Cones	0- 8	3	(0-16)	(7)

[a]Based on best treatment within each speed control method on a site-by-site basis.

[b]Reduction in mean speed at Station 2 due to speed control method.

[c]No data were available for 2-lane, 2-way rural highways. The average speed reduction shown for CMSs may therefore be misleading (i.e., too low) because all the other speed control methods generally performed better at the 2-lane, 2-way highway sites.

The police traffic controller reduced average speeds between 9-13 mph at the sites studied. The average speed reduction for a stationary patrol car ranged between 4-12 mph. The stationary patrol car with emergency lights or radar on performed only slightly better than without lights or radar. The circulating patrol car treatment was only tested on the 2-lane, 2-way highway sites and was found to be the least effective of all the law enforcement treatments studied, reducing mean speeds by only 2-3 mph.

3. IMPLEMENTATION OF WORK ZONE SPEED CONTROL MEASURES

The implementation of work zone speed control involves several steps including: determining the need for speed reduction, selecting a reasonable speed, selecting a treatment based on effectiveness, practicality and cost, and selecting a location for treatment implementation. These steps are summarized below and discussed in detail in Report 292-2 (2). Also presented in the following sections is a summary of treatment implementation considerations and limitations.

Determination of the Need for Speed Reduction

The study addressed the issue of when an agency should encourage reduced speeds at a particular work zone. By visiting and observing numerous work zones, several important considerations became apparent.

Credibility

Speed control abuse and misuse at a work zone can render a speed reduction attempt ineffective and can damage the credibility of work zone speed reduction efforts in general. Abusive practices include using unreasonably low speed limits and leaving reduced speed limits in place after the work activity is removed.

Specific Goal

As with all traffic control efforts, any effort to reduce work zone speeds should be founded on an identifiable need. Speed reduction should be aimed at decreasing the number and/or severity of work zone accidents, or the potential for accidents at sites where speed-related potential hazards exist.

In addition, it should be recognized that none of the speed reductions methods are "cure-alls" which will automatically safeguard motorists and workers. In fact, other traffic control approaches (e.g., the use of a buffer area or portable barriers) may provide a safer work zone environment and alleviate the need for speed reductions.

Speed-Related Potential Hazards

Speed-related potential hazards are those which exist, or are made worse, because traffic is traveling too fast for conditions. Typical examples of speed-related potential hazards are cited below:

1. Insufficient sight distance to the work zone, particularly to a lane closure.

2. Hidden or unobvious work zone features (e.g., subtle changes in alignment, edge drop-offs etc).

3. Reduced work zone design speed. (Design speed, as used here, refers to a real speed which is based on such factors as stopping sight distance, superelevation, degree of curvature, passing sight distance, etc.)

4. Unprotected work space where an errant vehicle could result in catastrophic damage.

Passive versus Active Control

Passive speed control refers to posting a reduced speed limit on a static sign (e.g., conventional regulatory and advisory signing). It is appropriate for all sites where reduced speeds are desired in the interest of safety. Passive control alone is generally sufficient at sites where the hazards are obvious, work zone activity is present, and drivers have plenty of time and information available to make reasonable and safe speed decisions without special encouragement.

Active control refers to techniques which restrict movement, display real-time dynamic information, or enforce compliance to a passive control. Such techniques include: flagging, law enforcement, CMSs, effective lane width reduction, rumble strips, Iowa Weave sections, etc. Active control would be needed in situations where drivers were unable or unwilling to select the appropriate safe speed without "active" encouragement.

Duration of Potential Hazard

Another practical consideration is time. If a particular work activity will be in progress for an extended period of time (e.g., 1 year) it would probably be impractical to use active speed control techniques for the life of the project. First of all, it would be too costly. Secondly, it would be unnecessary since the majority of drivers would eventually become familiar with work zone conditions and drive at their own comfortable speed. A better approach might be to use active control only during the opening days of the project and then again following major changes in conditions. Passive speed control would be used during other times. The longer the work duration in terms of days of activity, the more cost-effective considerations such as detouring and portable concrete barriers become.

Selection of a Reasonable Speed

After it has been determined that reduced speeds are desirable and practical, a safe and reasonable speed should be selected. A speed control strategy should be adopted which will reduce speeds to what is safe and reasonable for the conditions. The selected speed should not be unreasonably low. The fastest speed which is still considered safe should be sought.

Existing Speeds

Several factors influence what is a safe and reasonable speed for a given work zone. First of all, it should be recognized that drivers will only slow down to a certain level regardless of the presence of a speed control treatment. Based on the study results presented in the previous chapter, reductions in average speeds range from 5 to 20 mph, depending on the type of facility. Table 3-1 presents suggested maximum speed reductions for different types of roadways based on the study results summarized in Chapter 2 (2, 3).

TABLE 3-1. SUGGESTED MAXIMUM SPEED REDUCTIONS BY TYPE OF ROADWAY

Roadway Type	Speed Reduction, Mph
Rural 2-Lane, 2-Way Highway	10-15
Rural Freeway	5-15
Urban Freeway	5-10
Urban Arterial	10-15

Work Zone Design Speed

The design speed of the various work zone features (e.g., horizontal curvature, sight distance, superelevation, etc.) also may dictate what is a safe and reasonable speed. It is very important that the design speed is not significantly lower than drivers reasonably expect or will tolerate. If the work zone design speed is too low, even active speed control may not be enough. Suggested maximum speed reductions in work zones by type of highway are shown in Table 3-1.

Work Zone Conditions

Work zones often involve workers and equipment very near the traffic stream, supply trucks entering and leaving the traffic stream, uneven pavement, shoulder drop-offs, fixed object hazards, rough pavement surfaces, distractions and a number of other potential safety hazards. Selecting an appropriate speed for a particular set of conditions requires experience, objectivity and good judgment.

It is extremely important that a reasonable speed for conditions be selected. If an unreasonably low speed is encouraged by the highway agency, drivers will quickly lose respect for the speed control effort. The loss of credibility and respect will result in reduced effectiveness of the speed control technique at the site and possibly other sites.

Location of Speed Reduction

A speed control treatment should be first initiated 500 to 1000 feet upstream of the hazardous location within the work zone. This will insure that drivers have adequate time to react, and the speed message will still be fresh in their minds when they reach the potential hazard. This applies especially to the flagging, law enforcement and CMS speed control treatments which are applied at a point.

The effective lane width reduction treatment is unique in that it is applied over a section. The lane width reduction treatment should be initiated approximately 500-1000 feet upstream of the potentially hazardous location within the work zone, and continued to a point just past the end of the potential hazard. It is critical to initiate the narrow lane section before the potential hazard so that drivers have time to adjust their speeds and to focus their attention on the potentially hazardous condition rather than on the discomfort of driving in narrow lanes.

Location Relative to Other Work Zone Features

The relative location of speed control treatments to other work zone signing is also important. Ideally, speed control should be initiated after the first advance sign and in a section which is relatively free of other work zone signs. This practice will lessen the possibility of overloading drivers with too much information. It will also maximize the amount of driver attention focused on the speed control effort.

Speed control treatments should not be placed in high driver work-load areas such as near ramps, intersections or lane closure tapers.

Downstream Effects

The studies reported in this report did not evaluate the effective length of each particular speed control treatment. However, it is reasonable to assume that all treatments will lose their impact eventually as drivers travel farther and farther through a long work zone. Therefore, it is likely that, if potentially severe hazards exist and drivers are not slowing down on their own, additional speed control applications (e.g., another flagger station, CMS or law enforcement officer) may be needed downstream.

Selection of Speed Control Treatment

Regulatory or advisory signing will not slow drivers down at work zones under normal circumstances. However, at the majority of long duration work zones where drivers become conditioned to the work zone environment and select their own safe and reasonable speed, passive control can reinforce the existing speeds and provide a sound basis of speed enforcement. Also, if used prudently, advisory speeds will warn and advise unfamiliar drivers of common potential hazards experienced routinely in work zones.

With regard to active measures, research reported herein focused on 4 speed control methods: flagging (including a police traffic controller), law enforcement (a stationary patrol car), CMSs and effective lane width reduction. The selection of one or a combination of these methods for use at a particular work zone should consider a number of interrelated factors including:

1. Duration of potential hazard requiring speed control
2. Type of facility
3. Desired speed reduction
4. Overall cost of treatment
5. Institutional constraints (e.g., availability of CMSs, police officer, patrol cars, trained flaggers).

As a guide to speed control selection, Tables 3-2 through 3-5 summarize the general advantages and disadvantages of the various speed control methods with respect to the above factors. Specific cost and implementation considerations of the various methods are discussed in the following sections.

TABLE 3-2. GENERAL ADVANTAGES AND DISADVANTAGES OF FLAGGING AND POLICE TRAFFIC CONTROL

Advantages	Disadvantages
1. Large speed reductions possible	1. Requires specially trained and conscientious personnel
2. Agency/Contractor has direct control over performance[a]	2. Fatigue and boredom necessitate frequent relief
3. Relatively inexpensive for short duration applications	3. High labor costs for long duration applications
4. Little or no disruption to traffic flow	4. Effectiveness may decrease with continuous use
5. Quick and easy to implement and remove	5. Two flaggers (one each side) may be needed on multilane roadways
6. Suitable for all types of highways and work zones	6. Additional flaggers may be needed for long sections
	7. Drivers may have a problem seeing flaggers or police traffic controllers at night

[a]The agency/contractor may not have as much control over a paid police traffic controller as it would over its own personnel. Also, availability of officers may be restricted by the police agency or officer interest. Some officers in urban areas are reluctant to attempt to manually control freeway traffic.

TABLE 3-3. GENERAL ADVANTAGES AND DISADVANTAGES OF LAW ENFORCEMENT[a]

Advantages	Disadvantages
1. Large speed reductions possible	1. Constrained by availability of police officers and patrol cars
2. Relatively inexpensive for short duration applications	2. Agency/contractor does not have direct control over performance
3. Quick and easy to implement and remove	3. High cost for long duration applications
4. Can be effective at night, especially with lights flashing	4. Competes with other police functions
5. Sporadic use may encourage reduced speeds during "non-use" periods	5. Long work zones may require additional patrol car units
6. Suitable for all types of highways and work zones	6. Success depends on good cooperation form enforcement agencies

[a]Stationary patrol car treatments only.

TABLE 3-4. GENERAL ADVANTAGES AND DISADVANTAGES OF CMSs

Advantages	Disadvantages
1. Relatively inexpensive for both short and long duration applications	1. Only modest speed reductions possible
2. Agency/contractor has direct control over performance	2. Constrained by availability of signs
3. Little or no disruption to traffic flow	3. Effectiveness may decrease with continuous use
4. Quick and easy to implement and remove	4. Sign maintenance and repair may require technical expertise
5. Suitable for all types of highways and work zones	
6. Effective at night and in inclement weather	
7. May be used in combination with other techniques (e.g., flagger, law enforcement) for best results	

[a]If sign cost is extended over sign life (sign lease cost for a single, short-duration use may be high).

TABLE 3-5. GENERAL ADVANTAGES AND DISADVANTAGES OF EFFECTIVE LANE WIDTH REDUCTION

Advantages	Disadvantages
1. Moderate speed reductions possible	1. Expensive to implement and maintain, for short duration applications, depending on devices used
2. Agency/Contractor has direct control over performance	2. May disrupt traffic flow (i.e., reduce capacity)
3. Relatively inexpensive for long duration applications, depending on devices used	3. May increase certain types of accidents
4. Retains effectiveness with continuous use and long duration use	4. Device maintenance may be expensive
5. Speed reduction achieved throughout narrow lane section	5. May not be as effective on multilane highways
	6. Not easy to implement or remove

Implementation Costs

As part of the studies, implementation costs for the various speed control approaches were assessed. The purpose of the assessment was not to attempt a detailed cost evaluation of specific treatments at individual sites, but rather to identify the major cost considerations of each approach.

Flagging

The cost of flagging includes the cost of labor, fringe benefits, equipment (e.g., flag, vest and hard-hat) and transportation to and from the site. It is important to budget for dead time (i.e., the time spent waiting for work to get started each day). Even more important is the requirement that flaggers be relieved every 1 1/2 to 2 hours. This is based on personal experience of the authors who served as flaggers during the speed control studies.

Considering all costs, a highway official in Texas estimated that it costs his agency approximately $20 per flagger-hour (in 1983 dollars) (4).

Law Enforcement

Table 3-6 presents the results of a survey of city, county and state police agencies in Texas regarding the cost of hiring off-duty officers for work zone traffic control. From the table, the hourly rates ranged from $10.00 to $22.50, with the average charge being about $15.00 per hour.

Most of the police agencies surveyed do not normally allow officers the use of a patrol car for off-duty work. The agencies said that cars were too scarce. The Texas Department of Public Safety, by state statute, will not allow off-duty officers to use state vehicles or equipment, or even to wear their uniforms.

During the survey, the police agencies were asked about furnishing on-duty officers and patrol cars for work zone speed control. Most of the agencies said they would provide assistance for no charge at selected sites. However, they do not have the resources to provide men and vehicles on a regular basis.

CMSs

In Texas, portable CMSs are not readily available for lease from traffic control suppliers. One supplier, however, offered to lease a 3-line, bulb matrix sign for $3,000 per month. This does not include operating costs such as fuel, oil and routine servicing.

TABLE 3-6. COST OF HIRING OFF-DUTY LAW OFFICERS FOR TRAFFIC CONTROL IN 1983 DOLLARS

Agency	Off-Duty Wage Rate
City of Austin	$22.50/hr.[a]
City of Arlington	$20.00/hr.
Brazos County Sheriff's Department	$10-12/hr.
City of Dallas	$15.00/hr.
City of Ft. Worth	$15.00/hr.
Harris County Sheriff's Department	$15-18/hr.
City of Houston	$15.00/hr.
City of San Antonio	$15.00/hr.[b]
Texas Department of Public Safety	$12-15/hr.[c]

[a]Rate includes use of patrol car if approved by city.

[b]Rate drops to $12/hr. after 3 hours of continuous service.

[c]State statute prohibits off-duty DPS officers from wearing their uniform or using any State equipment.

The Texas SDHPT acquired most of its CMSs by requiring contractors on major projects to buy signs for their projects. Once the projects were completed, the signs were turned over to the Department for use on future maintenance and construction projects. The practice of SDHPT buying CMSs through construction projects has ended as of this report date. The CMSs now remain the property of the contractor. The latest bid price received by the State for a 3-line sign was just under $50,000.

CMSs require routine maintenance and repair, and the cost of skilled labor and parts can be high. Also, it is common that inoperative signs must be shipped to the manufacturer for repair.

Effective Lane Width Reduction

As noted earlier, the cost of implementing reduced lane widths can vary greatly. The total cost includes the cost of the devices as well as installation, maintenance, replacement, and removal of the devices. The salvage or reuse value of the devices can be subtracted from total costs, however, to yield the net cost to the agency.

Treatment Anchoring

The studies indicated that a speed reduction technique, to accomplish its desired effects, should be anchored to an appropriate, reasonable speed. "Anchoring" refers to displaying a specific speed along with the speed control technique so that drivers know at what speed they should travel through the work zone. The speed control technique may be anchored to a regulatory speed sign, an advisory speed plate, or a speed message displayed on a CMS. Advisory speed plates are intended for use to supplement warning signs. By "anchoring" a speed reduction treatment, drivers can better relate to the treatment as a speed reduction device, and the specific meaning or intent of the device is reinforced.

Treatment Implementation Considerations

During the course of the research, several observations were made concerning how best to implement the various speed control treatments. Some of the practical limitations of the treatments were also identified. These implementation considerations and limitations are listed and discussed below.

Flagging

1. Flaggers should be conscientious and dependable workers with good vision, hearing and physical condition.

2. Flaggers are required to be properly attired in a fluorescent orange vest with reflective material. They may also wear a hard-hat. The vest will enhance the conspicuity of the flagger and connote to drivers that he/she is an official member of the work force with authority to control traffic.

3. The flagger is required to be equipped with a standard red flag or sign paddle. The flag serves as an attention-getting device and increases the target value of the flagging operation. (The research did not study the use of paddles.)

4. Flaggers should be well trained in the proper flagging procedures and signals. The studies revealed that both the MUTCD and innovative signals produce relatively large speed reductions. The innovative signal has the advantage of indicating the desired speed to motorists.

5. In the interest of personal safety, the flagger should not be in the travel lanes but rather on the shoulder, if it is wide (8-10 feet), or just off the pavement.

6. The flagging operation should be "anchored" to a speed sign. The research did not address whether a regulatory sign, advisory sign or CMS was a better anchor, but did suggest that any of them would be adequate.

7. Flagging is a physically tiring and boring activity. To be effective, a flagger should be relieved <u>at least</u> every 1 1/2 to 2 hours.

8. Flagging appeared to be most effective on 2-lane, 2-way rural highways and urban arterials, where a flagger has the least competition for drivers' attention. On freeways, two flaggers may at times be needed, one on each side of the road, in order to achieve maximum effectiveness.

9. The studies did not evaluate the effective distance of flagging operations (i.e., how far speeds remained reduced downstream of a flagger station). However, it is reasonable to assume that in a long work zone (e.g., 1 mile or more) speeds would eventually rise again. Thus, it may be necessary to establish additional flagging stations at work zones where speed hazards exist over long distances.

10. For nighttime operation, flagger stations should be illuminated and flaggers should use an approved red latern, flashlight with red wand, reflectorized paddle or redlectorized sign.

11. It may be difficult or impossible to flag during inclement weather.

12. Flagging is well suited for short duration applications (i.e., less than 1 day), and for intermittent use at long duration work zones. It is likely that flagging would diminish in ineffectiveness if it was used continuously over several days or weeks.

Law Enforcement

1. Where it was tested, manual police traffic control was the most effective law enforcement strategy. (However, a uniformed police officer was no more effective in slowing drivers than a well-trained, properly attired flagger using proper flagging signals.)

2. A stationary patrol car, anchored to a speed sign, was very effective in slowing drivers. By turning on the patrol car lights or radar unit, a stationary patrol car may improve its effectiveness marginally.

3. A circulating patrol car was the least effective law enforcement strategy evaluated in reducing overall speed.

4. Many officers apparently are reluctant to attempt to reduce speeds at freeway work zones by manual traffic control hand signals. During the studies, some officers refused to participate in the manual control treatment saying that their services were better utilized performing other traffic control functions. Some officers believed that they would not be effective, and some cited a concern over their personal safety. Officers were particularly hesitant to attempt manual traffic control at the urban freeway site.

5. To increase effectiveness during nighttime operation, a stationary patrol car probably would need to have its overhead emergency flashing lights on. This would assure that the patrol car is seen by most drivers. The safety effects of a stationary patrol car with emergency lights-on was not studied, although no problems were observed during the daylight tests. It is reasonable to assume, however, that there would be situations where the flashing lights would be too distracting and result in a safety hazard.

6. For maximum effectiveness, the patrol car should be highly visible to approaching traffic. The patrol car is only effective when in place, so attempts to pursue and ticket violators should be minimized. A second patrol unit could be used occasionally for this function if desired to possibly further enhance the effectiveness of the stationary patrol car approach.

7. The various law enforcement treatments may increase in effectiveness over a period of time as more and more drivers anticipate police presence and the threat of speed enforcement. However, if drivers eventually perceive that they will not be ticketed for violations,

the effectiveness may subside. Therefore, for long-term applications, it may be necessary to occasionally issue citations to violators.

8. It is likely that occasional use of the various law enforcement strategies will reduce speeds even when the law enforcement is not present. This was not addressed in the studies.

9. Additional stationary units may be needed to maintain reduced speeds through a very long work zone.

CMSs

1. CMSs resulted in only modest speed reductions at the sites where they were tested (i.e., urban arterial and freeway sites). It is unlikely that CMSs alone could produce very large speed reductions (e.g., greater than 10 mph). These findings are consistent with CMS studies conducted by Hanscomb (5).

2. The 2 types of messages tested (Speed versus Speed and Informational) performed approximately the same.

3. CMSs are appropriate for day and night use.

4. CMSs retain most of their usefulness during inclement weather.

5. CMSs are versatile. The speed message may be changed as conditions change, and they may be used to display other types of information and warnings as needed. They are easy to install or relocate.

6. The appropriate type and size of CMSs should be used for the conditions. Reference 6 presents CMS selection and operation considerations.

7. CMSs must be properly serviced and repaired. Acquiring necessary parts and expert labor may require shipping the sign to a distant manufacturer, or waiting for the manufacturer or his representative to service the sign locally.

8. CMSs may lose their effectiveness when operated continuously for long periods with the same messages.

9. A survey of traffic control subcontractors, conducted as part of this study, revealed that CMSs are currently not readily available for lease on a short-term basis. In Texas, where all the field studies were conducted , the highway agency is requiring that its contractors purchase CMSs for use on some major projects. When a project is completed, the sign is turned over to the agency for use at future construction and maintenance sites.

Effective Lane Width Reduction

1. Slight effective lane width reductions (e.g., 11.5 and 12.5-foot widths) will reduce speeds modestly. Although not tested, it is assumed that even narrower lanes (e.g., 9-10 feet) may greatly lower speeds. However, the studies suggested that lane reduction, if effective, also increases speed variance and erratic maneuvers.

2. In order to implement a lane width reduction technique, it is usually necessary to interrupt traffic flow and expose workers to traffic (i.e., workers must get out into traffic and install the devices).

3. There are many devices and strategies available for implementing effective reduced lane widths (e.g., cones, drums, striping, barriers, barricades, etc.). The cost, maintainability, effectiveness and safety of the various approaches varies widely. Only cones were evaluated in the studies.

4. Cones proved to be quick and easy to install and remove. However, they were frequently hit by large trucks and mobile homes when the 11.5-foot treatment was used.

5. Effective lane width reduction appears to be more practical for long duration applications (i.e., several days or more). The time and initial cost to implement are relatively great, but once installed, there is little labor or expense.

6. On roadways with 3 or more lanes per direction, it may not be possible to accomplish the desired effective lane width reduction in the middle lanes without restriping the roadway.

7. Effective lane width reduction techniques may not suppress speeds long after the end of the narrow sections. Thus, the narrow lanes must be continued throughout the area where reduced speeds are desired.

4. CHANGEABLE MESSAGE SIGNS

Introduction

CMSs can perform a critical role on high-speed highways by furnishing drivers with real-time information that advises them of problems and unexpected conditions, and telling them the best course of action. CMSs can be particularly useful at highway construction and maintenance work sites which often present drivers with unexpected traffic or detour situations. In recent years, CMSs have been made portable by placing them on trailers or pickup trucks. Portable CMSs provide the flexibility for moving the signs to various locations and allow one to display highlighted information at critical locations in work zones.

Report 292-4 discusses operational, design, and message design considerations for the use of CMSs at highway work sites (7). Some of these considerations are summarized in this chapter. The effectiveness of CMSs for speed control in work zones was discussed in Chapter 2.

Applications of CMSs

There are a variety of applications for CMSs at urban freeway construction and maintenance work zones. However, because of their flexibility and capability, CMSs are sometimes incorrectly used, thus reducing their effectiveness. The primary purpose of CMSs in work zones is to advise the driver of unexpected traffic and routing situations. Repeat drivers (i.e., familiar drivers) become accustomed to the situation after a period of time and will begin to ignore the sign. When the message is later changed for a new situation, the repeat drivers may not read the message. Prolonged use of a CMS at one location and for one purpose may, therefore, reduce the effectiveness of the sign. Thus, CMSs should generally be used for short periods of time (e.g. one to two weeks) and for special applications. Examples of special applications where CMSs can be effective in urban freeway work zones include:

1. New detours
2. Change in detours
3. Introduction of a lane drop where a continuous lane once existed
4. Special speed control measures
5. Periodic use of flaggers, and
6. Location where sight distance is restricted and congestion occurs due to a lane closure.

Characteristics of Bulb Matrix CMSs

The most commonly used CMS in work zones have bulb matrix displays. Thus, the research focused on the operation of bulb matrix signs.

The viewing face of a bulb matrix sign is formed by rectangular arrays of incandescent light bulbs mounted on sign panels. The lamp arrays used to form character lines can either be a continuous field of lamps or a fixed number of rectangular matrix modules--small banks of lamps separated by "lampless" areas (Figure 4-1). Each character in a message is formed by illuminating the relevant lamps from a matrix of 7 lamp rows and 4 or 5 lamp columns. Typically, the bulb-matrix signs used in work zones are capable of displaying up to about 7 characters per line of message.

Currently, one-line and three-line portable CMSs (Figure 4-2) are commercially available. One-line signs are well suited for messages of 4 words or less. Three-line signs allow the user to display more information to drivers, and therefore have greater flexibility and utility.

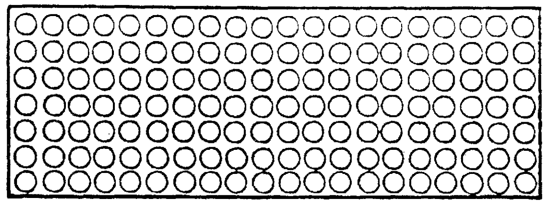
Bulb matrix signs are visible farther in advance than static signs and tend to attract the driver's attention when properly positioned with respect to the driver's line of sight.

OPERATIONAL AND DESIGN CONSIDERATIONS

Operating CMSs

When CMSs are used at a work site, a driver expects the signs to furnish reliable, accurate, and up-to-date information. All precautions must be taken to insure that these expectations are met. This means that considerable effort will be required in operating the signs.

Operating CMSs requires extra care and time to insure that the right messages are displayed at the proper time. Drivers will have negative attitudes about signs that display information that is contrary to existing conditions, display information that is not easily understood or read in ample time to make the appropriate maneuvers, or tell drivers something they already know. Once drivers lose faith in the sign, do not expect them to accept the message the next time. Thus, money may be spent operating signs that are no longer doing the job.



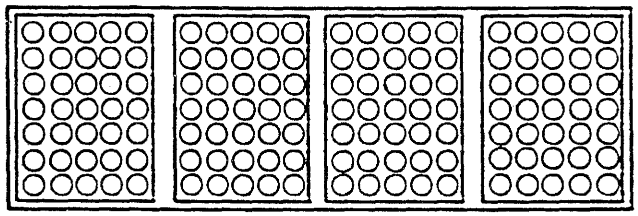


Figure 4-1. Bulb-Matrix Arrays

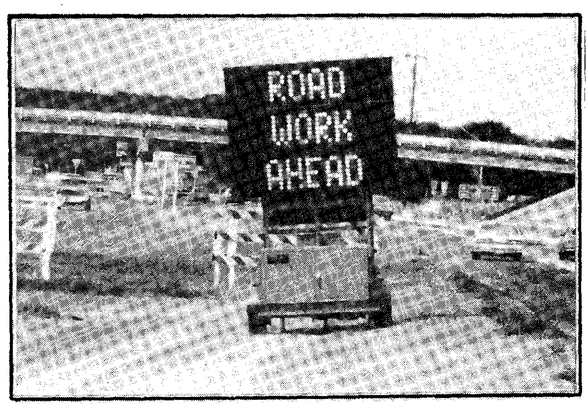


Figure 4-2. Portable Changeable Message Signs

Character Size and Legibility

The characters on a bulb CMS used at freeway work zones should be about 18 inches high. Such a sign will allow approximately 85% of the drivers to begin reading the message approximately 650 feet from the sign provided there are no obstructions (e.g. trucks) in the drivers' line of sight.

Roadside Placement of CMSs

As a general rule, CMSs should be placed only on one side of the freeway -- either left or right depending upon the need. CMSs should never be placed and operated simultaneously on both the right and left sides of the freeway. Two signs operating simultaneously on both sides tend to be distracting and confusing. Drivers are never sure which sign to look at, and chances are, they will fail to read the message. When two signs are needed, they should be placed on the same side of the roadway and should be separated by at least 1,000 feet.

Lamp Dimming at Night

Bulb matrix CMSs are highly visible during the day because of the relative intensity of the lamps with respect to the surrounding area. High intensity brightness is needed during the day to create enough contrast so that a driver can read the message. However, the intense brightness can create problems at night or during cloudy periods by distracting or "blinding" drivers. The light intensity must be reduced at night (by at least 50%) and during periods of reduced light levels so that the message will not be too bright for drivers to read.

Many signs are equipped with a photocell which automatically adjusts the intensity of the lamps. Some signs must be adjusted manually. The CMSs should be inspected during nighttime operation to insure that the appropriate light intensity is in effect.

Bulb Replacement

When light bulbs burn out on the sign, readability is affected. Messages generally become difficult to read when more than 10% of the bulbs are burned out. It is not always possible to replace defective bulbs as soon as they are noticed; however, a routine inspection and bulb replacement program will minimize the problem of poor readability.

MESSAGE DESIGN AND DISPLAY CONSIDERATIONS

Information Unit

An **information unit** refers to each separate information item given in a message which a motorist could recall and which could be a basis for making a decision. Consider the message **ROADWORK AT MILFORD, 20 MINUTE DELAY, UTOPIA TRAFFIC USE WILLIAMS STREET.** This message has five units of information as follows:

	Question	Info. Unit Required
1.	What happened?	Roadwork
2.	Where?	At Milford
3.	Who is the advisory intended for?	Utopia Traffic
4.	What is advised?	Use Williams Street

Typically, a unit of information is two words, but a unit could contain one to four words. A unit of information provides an answer to a question which a driver may pose. For example, **ROADWORK** is a one-word information unit; **AT MILFORD** is a two-word unit; **USE WILLIAMS STREET** is a three-word unit.

Message Length

Message length refers to the number of words or characters in a message. There are certain guidelines that must be followed to make sure the messages are displayed (exposed) to a driver long enough so that he can read the message in the few seconds he has while traveling at normal freeway speeds. The message must be short enough so he can read the entire message.

A good rule of thumb is that a driver will need at least one second per short word (up to eight characters) not counting prepositions, or two seconds per unit of information to read and recall a well designed message.

As mentioned earlier, most drivers (85%) can begin reading a bulb matrix CMS with 18-inch high characters approximately 650 feet upstream of the sign. Thus, while traveling at 55 mph (80.67 ft/sec) a driver has only about 8 seconds to read the message. (650 ft/80.67 ft/sec 8 sec)

The requirements of one second per word and two seconds per information unit means that a message should not be longer than 8 words or 4 units of information for drivers traveling at 55 mph.

Flashing Operations

It may sometimes be desirable to flash certain words, phrases, or the entire message to emphasize the urgency of a message. Flashing is also used to attract the driver's attention to the sign when the sign may be affected by surrounding commercial development.

Splitting (Chunking) and Sequencing Messages

Sometimes roadwork situations dictate the need for longer messages than can be displayed at one time on the CMS. A longer message can be displayed by dividing the message into chuncks and sequencing the message chunks on a sign or, if necessary, displaying separate chunks of information on two signs. Chunking must be accomplished by splitting the message into compatible phrases as illustrated below.

ROADWORK AT MILFORD	HEAVY CONGESTION	UTOPIA TRAFFIC USE WILLIAMS STREET
Phrase 1	Phrase 2	Phrase 3

Note that the words **HEAVY CONGESTION/UTOPIA TRAFFIC** are not compatible and therefore should not be chunked together. **UTOPIA TRAFFIC/USE WILLIAMS STREET** are compatible in the sense that the action statement refers to the destination group. Collectively, the message elements form a message that will stand alone like a sentence.

Delineating the End of Sequenced Messages

When a message is divided into two parts which are sequenced on the sign, the two information elements are simply alternated on the sign and the driver generally has no difficulty in understanding the message. When a message must be divided into three or more parts, the end of message must be delineated before it begins its next cycle so that a driver understands when the message is repeated. The best way to delineate the end of message is to display a series of stars (asterisks) as shown in Figure 4-3. The stars should be displayed for approximately one second. Another acceptable way to delineate is to have a blank period of approximately one second to mark the end of the message before it recycles.

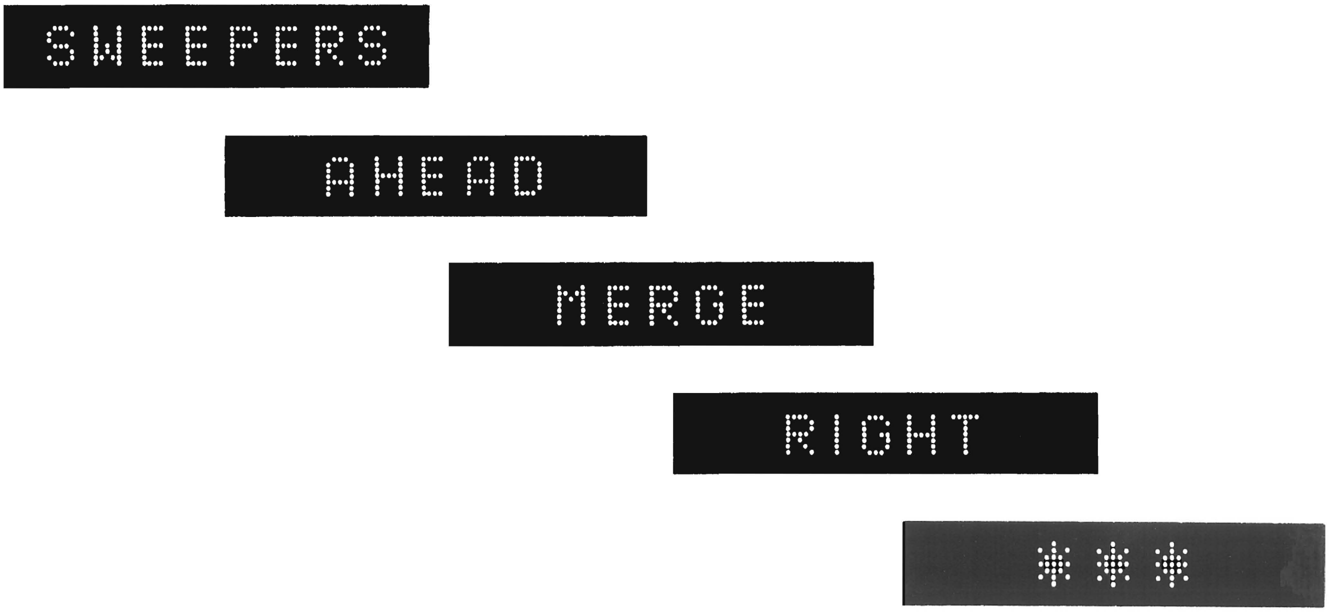


Figure 4-3. Delineating the End of a Sequenced Message

CMSs vs. Arrowboard

The arrowboard, not a CMS, is probably the best device for informing drivers of right or left lane closures. An arrowboard has high target value and is well understood by drivers to mean that a lane is closed and drivers should merge into an open lane in the direction indicated by the arrow.

When a right or left lane is closed, an arrowboard should be used. Never use a CMS in place of an arrowboard. However, there may be a few occasions when a CMS might be needed to supplement the arrowboard.

Abbreviations

Sometimes because of the limitations of the CMS size and the message length requirements, it is necessary to abbreviate words. The following are a set of abbreviations for some frequently used words on CMSs for which at least 85% of the driving public would understand if they appeared on a CMS. These abbreviations will likely be understood independent of the other words in the message.

Word	Abbreviation	Word	Abbreviation
Boulevard	BLVD	Normal	NORM
Center	CNTR	Parking	PKING
Emergency	EMER	Road	RD
Entrance, Enter	ENT	Service	SERV
Expressway	EXPWY	Shoulder	SHLDR
Freeway	FRWY, FWY	Slippery	SLIP
Highway	HWY	Speed	SPD
Information	INFO	Traffic	TRAF
Left	LFT	Travelers	TRVLRS
Maintenance	MAINT (Use RDWK)	Warning	WARN

Other abbreviations are easily understood whenever they appear in conjunction with a particular word commonly associated with it. These words and abbreviations are as follows:

Word	Abbreviation	Prompt Word	Word	Abbreviation	Prompt Word
Ahead	AHD	● Fog	Mile	MI	● [Number]
Blocked	BLKD	● Lane	Minute(s)	MIN	● [Number]
Access	ACCS	Road	Oversized	OVRSZ	Load
Bridge	BRDG	● [Name]	Prepare	PREP	To Stop
Chemical	CHEM	Spill	Pavement	PVMT	● Wet
Construction	CONST	Ahead	Quality	QLTY	● Air
Exit	EX, EXT	● Next	Route	RT	● Best
Express	EXP	Lane	Turnpike	TRNPK	● [Name]
Hazardous	HAZ	Driving	Vehicle	VEH	● Stalled
Interstate	I	[Number]	Cardinal Directions	N,E,S,W	[Number]
Major	MAJ	Accident			
Minor	MNR	Accident	Upper,Lower	UPR,LWR	Level

● = Prompt word given first

Caution should be used in employing these abbreviations with other prompt words since their high understanding has been established only with the words given in the table. For example, drivers very easily interpret BLKD as BLOCKED when it appears with LANE in the form LANE BLKD. CHEM is interpreted by drivers as CHEMICAL when used in the message as CHEM SPILL.

The following abbreviations are understood with a prompt word by about 75% of the drivers. These abbreviations would require public education prior to usage.

Word	Abbreviation	Prompt Word	Word	Abbreviation	Prompt Word
Downtown	DWNTN	Traffic	Roadwork	RDWK	Ahead (Distance)
Northbound	N-BND	Traffic			
Congested	CONG	Traffic	Township	TWNSHP	Limits
Temporary	TEMP	Route	Frontage	FRNTG	Road
Condition	COND	● Traffic	Local	LOC	Traffic

● = Prompt word given first

Certain abbreviations are prone to inviting confusion because another word is abbreviated or could be abbreviated in the same way. AVOID USING THESE ABBREVIATIONS:

Abbreviation	Intended Word	Word Erroneously Given
WRNG	Warning	Wrong
ACC	Accident	Access (Road)
DLY	Delay	Daily
LT	Light (Traffic)	Left
STAD	Stadium	Standard
L	Left	Lane (Merge)
PARK	Parking	Park
RED	Reduce	Red
POLL	Pollution (Index)	Poll
FDR	Feeder	Federal
LOC	Local	Location
TEMP	Temporary	Temperature
CLRS	Clears	Colors

5. LAW ENFORCEMENT PERSONNEL

The use of law enforcement personnel at highway maintenance and construction work zones has increased considerably in the past few years. Law enforcement officers have been used to promote the orderly flow of traffic and, consequently, worker safety.

A series of field studies was conducted at urban freeway work sites to observe law enforcement activities and their effects on traffic operations. Results of these studies were presented in a Technical Memorandum (9) and Reports 292-2 (2) and 292-5 (8). The use of law enforcement personnel for speed control at work zones was discussed in Chapter 3. Additional considerations are summarized in this chapter.

1. Law enforcement officers can perform a number of tasks at work zones. The range of activities includes:

    - Stopping traffic -- keeping it moving
    - Reducing Speeds
    - Encouraging shoulder usage -- Discouraging shoulder usage
    - Directing traffic at intersections
    - Controlling signal timing at intersections
    - Detouring traffic from main lanes to frontage roads
    - Controlling traffic at entrance ramps
    - Discouraging illegal access to and from freeways
    - Promoting compliance with traffic control devices

2. The duties of law enforcement personnel need to be specified in the Traffic Control Plan (TCP). Since many activities are possible, it is important to determine which ones are appropriate for each situation.

3. Law enforcement officers are trained traffic controllers and should be allowed some flexibility in carrying out their duties. However, their actions should fall within the general framework provided by the TCP. A meeting should be held with the officers before the work begins to explain the purpose of each traffic control task.

4. Law enforcement personnel and their vehicles should be visible to approaching drivers. The added effect of a law enforcement vehicle will be lost if it is positioned beyond the work activity or hidden by work vehicles. To be effective at most tasks, the officers must be seen by drivers.

5. At night, law enforcement officers should be stationed in adequately illuminated areas. Temporary floodlighting can be used in areas without permanent lighting. Flashlights or flares can also be used to attract attention to the officers.
6. Emergency warning lights on vehicles should only be used for

emergencies or extremely hazardous situations. The effects of emergency warning lights on motorist behavior are not fully known; however, constant use of these lights may undermine their credibility and render them ineffective when they are truly needed. In some situations, the lights could be overly distracting.

7. Law enforcement efforts should be coordinated by a law enforcement supervisor who is knowledgable in traffic control. The individual responsible for overall traffic management and the law enforcement supervisor should cooperate in making traffic control decisions.

8. A relief rotation should be implemented for law enforcement officers. Directing traffic is a physically demanding task and enough officers should be present so that rest periods, or rotation from low to high activity locations, can be provided. Law enforcement personnel must take rest periods and provisions for replacements are critical to the success of traffic management efforts.

6. INNOVATIVE ADVANCE WARNING SIGN FOR LANE CLOSURES

Introduction

Drivers need advance warning of lane closures or blockages so they can move into an open lane prior to the closure or blockage. For left or right lane closures on a 2- or 3-lane freeway section, the Advance Lane Closed Sign (CW20-5) can be used. Closure of the center lane of a 3-lane freeway section is more difficult to communicate. When the freeway section has 4 or more lanes, word descriptors like LEFT, CENTER, and RIGHT are ambiguous in designating lane closures, and therefore signing can become a problem.

The need for advance warning of lane closures also exists for moving maintenance operations. Previous research (10) identified several potential problems encountered by motorists approaching moving maintenance operations on urban freeways. Basically, the potential problems stem from the driver either not having enough information or not enough time to respond properly to the work vehicles.

The first warning a motorist receives about a lane blockage due to a moving operation is generally provided by warning devices such as arrowboards and flashing lights mounted on the last vehicle in the work caravan. Generally, no advance notification of a lane blockage is given. In many cases, the warning provided by the work vehicle is adequate. On urban freeways though, the complex nature of the driving environment creates a need for advance warning.

To address the above problems, an innovative traffic control approach involving the use of a special lane-blocked sign was field tested on urban freeways for moving maintenance operations, and on a frontage road for a fixed lane closure. The format for the special advance warning sign is shown in Figure 6-1. The design was based on previous research (11) which found that a high percentage of motorists understood the meaning.

In the studies, a trailer-mounted prototype sign was developed which could be towed to the work site and, in the case of moving maintenance operations, towed on the shoulder upstream of the work vehicles at the same speed the work caravan traveled. The message could also be presented on a truck-mounted sign or a CMS. The type of display is not critical; the message is the important aspect.

Moving Maintenance Studies

The results of five studies (12, 13) conducted to evaluate the special advance sign for moving maintenance operations can be summarized as follows:

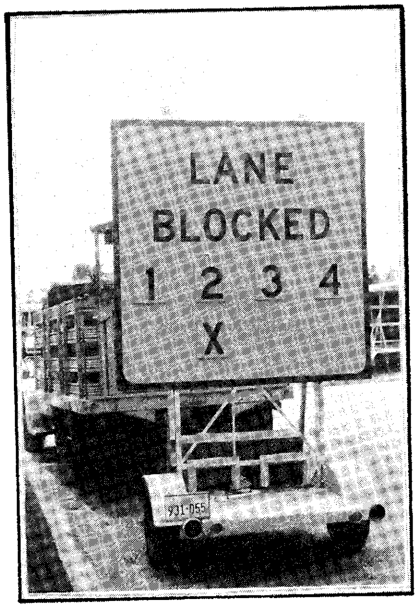


Figure 6-1. Innovative Advance Sign Message

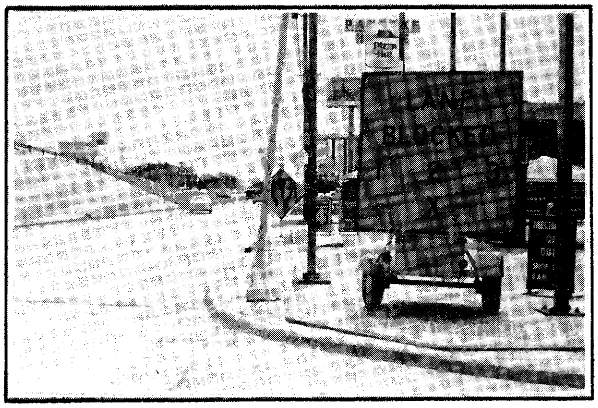


Figure 6-2. Advance Sign During Frontage Road Studies

1. The sign generally results in improved traffic operations in terms of earlier lane changing out of the blocked lane under low volume conditions.

2. The most effective placement of the sign is approximately 2500 ft. upstream of the last work vehicle.

3. The sign is effective in warning motorists of a lane blockage at vertical curves where the work vehicles are not visible to oncoming motorists. Use of the sign at vertical curves also minimizes merging into the blocked lane between work vehicles by eliminating the need for a large gap between the last work vehicle and the rest of the convoy.

4. The advance sign supplements existing warning devices and should not be used to replace the arrowboard on the last vehicle. During all studies, the arrowboard on the last vehicle was operated.

5. The sign should be positioned on the shoulder nearest the blocked lane if possible. This practice places the sign nearest the motorists who need the information the most.

The studies provided a great deal of information of the innovative sign's effectiveness. However, there is still a need to explore the following issues:

1. The sign's effectiveness under higher volume levels should be investigated.

2. The effectiveness of the sign for short-term lane closures or intermittent stop maintenance activities on multilane facilities.

Frontage Road Studies

The innovative lane blocked sign (Figure 6-2) performed as well or better than conventional signing during the frontage road studies (14). Drivers apparently understood the message and many of them responded by vacating the closed lane immediately upon seeing the sign. The innovative sign also proved to be very flexible in that it could be quickly adapted to any lane closure condition. Use of the innovative sign would therefore reduce the need for a large inventory of different signs and would save the time normally spent on conventional sign set-ups and changes. The special lane blocked sign appears to be particularly appropriate for use during slow moving or intermittent stop activities (e.g., paving operations) since the sign is very portable and the message is easily changed.

7. OPERATIONAL GUIDELINES FOR SHORT-TERM TOTAL FREEWAY CLOSURES

Introduction

Maintenance or construction work which requires closing all the main lanes of an urban freeway creates a need for special traffic management techniques. A series of three field studies (15, 16, 17) were conducted at freeway closures to observe traffic operations and to identify successful strategies and problem areas. General operational guidelines and recommendations based on the findings of the field studies were discussed and published in Research Report 292-5 (8). The guidelines and recommendations, summarized in this chapter, were not intended to provide information on all aspects of traffic control at freeway closure work zones, rather, the guidelines can be used to supplement standard work zone traffic control procedures.

The guidelines are organized into three broad categories: Advance Planning; Advance Notification; and Traffic Management. Guidelines concerning the use of law enforcement personnel were incorporated into Chapter 5. A discussion of the guidelines was presented in Report 292-5 (8).

Advance Planning Guidelines

The success of a freeway closure traffic management strategy depends on the plans made prior to the actual closure. The following recommendations are offered to aid in this process.

1. A pre-closure meeting of all the involved agencies should be held two to four weeks prior to the actual closure.

2. One individual should be designated as the Department's Traffic Control Coordinator.

3. A meeting which includes personnel directly involved in traffic management should be held just prior to the closure.

4. Local special events which coincide with the closure should be identified and considered in the scheduling of freeway closures.

5. Traffic volumes must be considered in planning a detour.

Advance Notification Guidelines

Every effort should be made to publicize the upcoming freeway closure so that motorists can avoid the area or take alternate routes to their destinations. The following advance notification practices are recommended:

1. A press release should be prepared for distribution to the local media.

2. Conspicuous signs that give notice of the upcoming closure should be installed along the freeway at least one week prior to the closure.

3. An effort should be made to notify local service agencies prior to the actual closure.

4. Advance notification of any ramp closures should begin one week in advance of a freeway closure.

Traffic Management Guidelines

Guidelines for traffic management during the closure fall into five categories: In Advance of the Detour; At the Point of Detour; Along the Detour; At the End of the Detour; and General Considerations.

In Advance of the Detour

1. Motorists should be informed that the freeway is closed ahead.

2. Motorists should be informed that they will be required to detour off the freeway.

3. Signing which encourages motorists to take alternate freeway routes should be provided.

At the Point of Detour

1. Every effort should be made to have the point of detour coincide with the physical closure of the freeway.

2. Provisions should be made for motorists who miss the detour route. If there is a possibility that drivers can miss the detour route, a "forgiving" sign system (6) which redirects drivers to the detour route should be installed.

3. Two-lane exit ramps should be provided at the point of detour whenever physically possible. The detour transition and the detour route should be designed so as to not require a speed reduction. Advisory speed signs may be used in the detour transitions but may not be necessary along the detour route.

Along the Detour

1. Oversize trailblazer (i.e., route guidance) signs clearly denoting the detour route should be placed along the detour.

2. Advance warning of any exits or turns along the detour should be provided.

3. "Forgiving" signs should be used to inform drivers who have missed exits or turns along the detour.

4. The use of non-standard signing for denoting the detour route should be avoided.

5. Traffic signals on the detour route should be re-timed to favor the detoured traffic.

At the End of the Detour

1. Two successive entrance ramps should be used to return traffic to the freeway.

2. Signing which informs motorists where they will reenter the freeway should be provided.

General Considerations

1. Inappropriate or non-applicable existing signing should be removed or covered.

2. Two CMSs should not be placed opposite one another at the same point along the roadway.

3. Flaggers should be used to promote efficient traffic flow and to provide pedestrian access along the route.

4. Temporary lighting used during nighttime operations should be positioned so that drivers are not blinded.

8. TRAFFIC CAPACITY THROUGH WORK ZONES

Introduction

In planning the traffic control for a particular work zone, it is desirable to identify all the feasible traffic control strategies and then assess the impacts of the most promising strategies. Both of these tasks (i.e., strategy identification and assessment) require an evaluation of work zone capacity.

Capacity analysis is critical in assessing the impacts of candidate work zone strategies since practically all impacts are directly related to the level of congestion at a work zone. Accidents, motorist delay, vehicle operating costs, fuel consumption, stops, air pollution, and sometimes even business losses and construction costs all increase as congestion develops and worsens at a work zone. Congestion is the result of insufficient capacity to handle traffic demand.

The 1965 Highway Capacity Manual, unfortunately, does not address work zone capacity and level of service. The following sections of this report provide information on work zone capacity which should be valuable toward the development of work zone capacity concepts for the new Highway Capacity Manual.

Sixteen capacity analysis studies (18) were conducted at urban freeway work zones in Texas as part of Study 292. The data collected was combined with the data base previously documented in Research Report 228-6 (19). The results of the combined data along with other recent research on work zone capacity for various work zone situations are summarized in this chapter.

Capacity with Work Crew at Site

Figure 8-1 illustrates the range of capacities measured at several worksites while the work crew was at the site. All volumes were measured while queues were formed upstream from the lane closures, and thus, essentially represent either the capacities of the bottlenecks created by the lane closures or the effects of drivers gawking because of the work crew and machinery. It is possible that higher flow rates may occur for very short periods of time prior to queue formation. Each point in the Figure represents the volume observed during one study; therefore, it is easy to view how the data cluster for each lane closure situation.

The designation (A,B) is used to identify the various lane closure situations evaluated. "A" represents the number of lanes in one direction during normal operations; "B" is the number of lanes open in one direction through the work zone.

The average capacity for each closure situation studied is shown in Table 8-1. The data show that the average lane capacity for the (3,2) and (4,2) combinations was approximately 1500 vehicles per hour per lane (vphpl).

The studies conducted at worksites with (5,2) and (2,1) closure situations indicate significant reductions in capacity (compared to 1500 vphpl). The average capacity for these two situations was approximately 1350 vphpl.

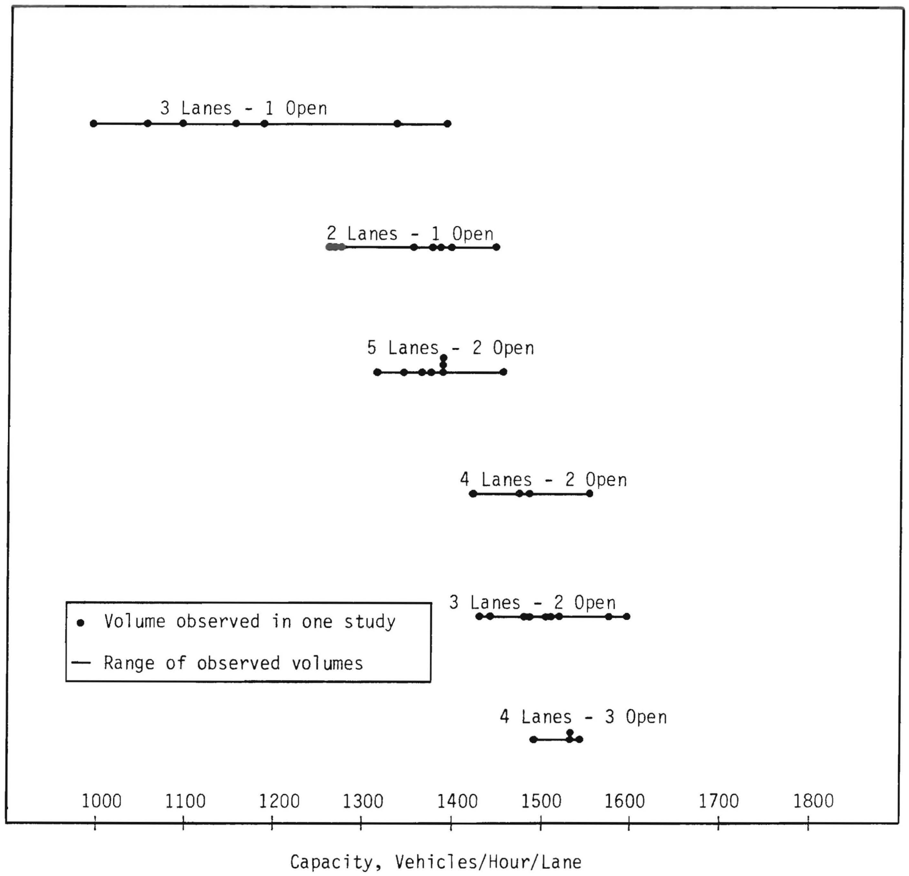


Figure 8-1. Range of Observed Work Zone Capacities for Each Lane Closure Situation Studied (Work Crew at Site)

Studies at (3,1) sites revealed even a greater reduction in capacity. The average capacity was found to be only 1170 vphpl.

Figure 8-2 shows the cumulative distributions of the observed work zone capacities. The function of the figure is to assist the user in identifying risks in using certain capacity values for a given lane closure situation to estimate the effects of the lane closures (e.g., queue lengths).

TABLE 8-1. MEASURED WORK ZONE CAPACITY

Number of Lanes		Number of Studies	Average Capacity	
Normal	Open		vph	vphpl
3	1	7	1170	1170
2	1	8	1340	1340
5	2	8	2740	1370
4	2	4	2960	1480
3	2	9	2980	1490
4	3	4	4560	1520

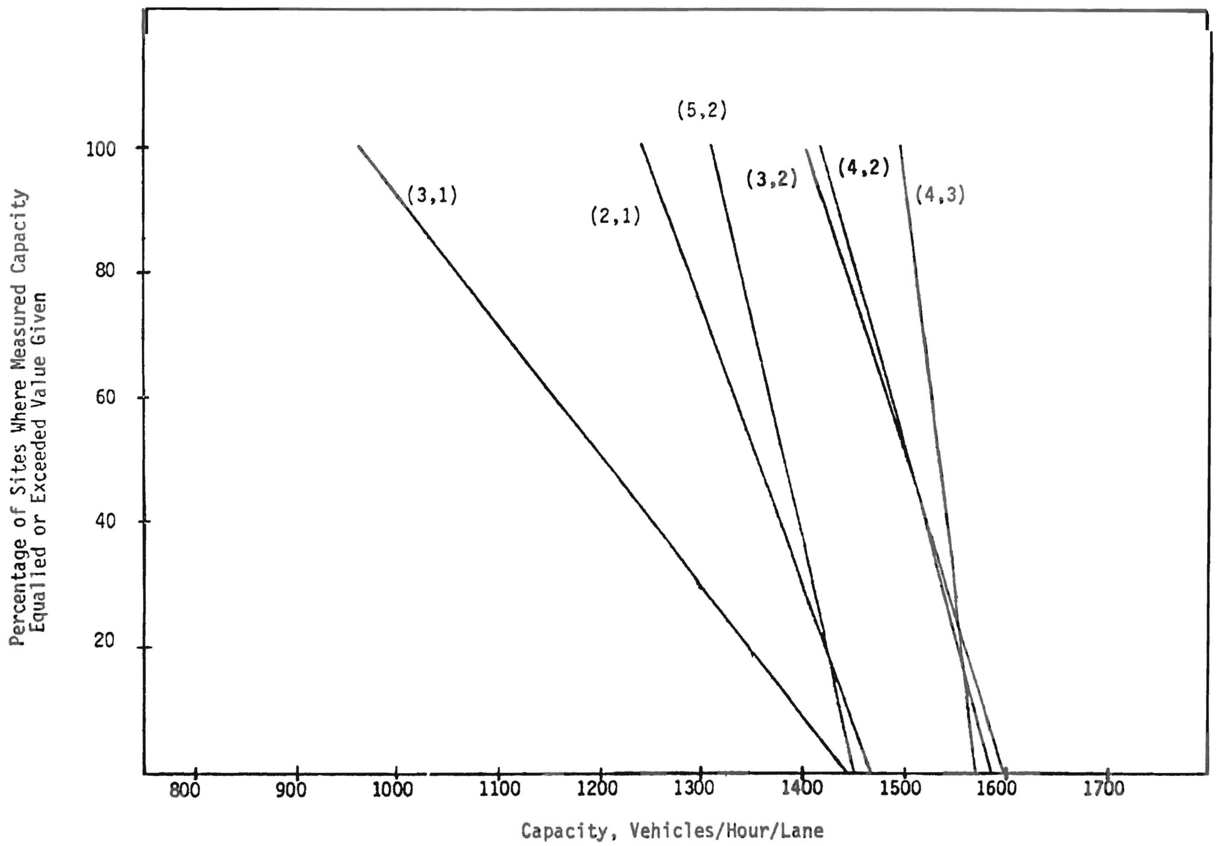
TABLE 8-2. REGRESSION EQUATIONS FOR VARIOUS LANE CLOSURE CONFIGURATIONS

Lane Closure Configuration[a]	Regression Equation[b]
(3,1)	C = 1441 + -4.808P
(3,2)	C = 1599 + -2.000P
(4,3)	C = 1571 + -0.787P
(5,2)	C = 1452 + -1.445P
(2,1)	C = 1470 + -2.294P
(4,2)	C = 1588 + -1.721P

[a]The numbers in parentheses indicate: (total number of lanes in one direction during normal operations, number of open lanes through the work zone).

[b]Where : C = Minimum Capacity

P = Confidence Level(Percentage of work zones, ranging from 0-100, whose capacity will equal or exceed computed minimum capacity).



Note: Parenthesis figures indicate (number of original lanes, number of open lanes)

Figure 8-2. Cumulative Distribution of Observed Work Zone Capacities

For example, the 85th percentile for the (3,1) situation is 1030 vphpl. This means that 85% of the studies conducted on 3-lane freeway sections with 1 lane open through the work zone resulted in capacity flows equal to or greater than 1020 vphpl. The capacity flow was equal to or greater than 1330 vphpl in only 20% of the cases studied. Thus, to assume a capacity of 1500 vphpl for (3,1) work zones would tend to underestimate the length of queues caused by the lane reduction at the vast majority of these work zones. Equations for calculating capacity based on the distributions in Figure 8-2 are given in Table 8-2.

Because of the limited amount of data, no attempt was made to statistically correlate capacity to the type of road work. However, the results indicate that there are characteristics at each worksite that affect the flow through the work zone. Presence of on-ramps and off-ramps, grades, alinement, percentage of trucks, etc., also affect the flow.

It is also interesting to note that, even at the same site, there were variations in maximum flow rate. Work activities (e.g., personnel adjacent to an open traffic lane, trucks moving into and out of the closed lanes, etc.) caused these variations.

Table 8-3 summarizes typical capacities observed in California by Kermode and Myra and those observed in Texas by TTI by type of work. The California data represent expanded hourly flow rates, whereas most of the Texas data are full hour counts. The reader is cautioned that the typical capacities by type of work zone shown in Table 8-3 for Texas freeways are based on limited data. The amount of data used to develop capacity rates for California is not known.

TABLE 8-3. SUMMARY OF CAPACITY FOR SOME TYPICAL OPERATIONS*

Number of lanes one direction (Normal Operation)	3	2	5	3 or 4	4
Number of lanes open one direction (During Work)	1	1	2	2	3
Type of Work					
• Median barrier/guardrail repair or installation	N/A	1500 vph	N/A	3200 vph *2940 vph*	4800 vph *4570 vph*
• Pavement repair	*1050 vph*	1400 vph	N/A	3000 vph *2900 vph*	4500 vph
• Resurfacing, asphalt removal	*1050 vph*	1200 vph *1300 vph*	*2750 vph*	2600 vph *2900 vph*	4000 vph
• Striping, slide removal	N/A	1200 vph	N/A	2600 vph	4000 vph
• Pavement markers	N/A	1100 vph	N/A	2400 vph	3600 vph
• Bridge repair	*1350 vph*	*1350 vph*	N/A	2200 vph	3400 vph

* Volumes not italicized represent capacity rates observed in California
Italicized volumes represent average capacities observed in Texas

N/A = Not Available

Capacity at Long-Term Construction Sites

Seven studies were conducted at long-term construction sites with (3,2) lane closure situations during the peak period while the work crew was not adjacent to the site and the work area was separated from traffic by portable concrete barriers. Table 8-4 summarizes the capacity data collected at these sites. Two lanes were open during each of the studies. The average capacity for the (3,2) lane closure situations was 1860 vphpl.

Three studies were conducted at (2,1) lane closure sites. The average capacity was found to be 1550 vphpl.

TABLE 8-4. AVERAGE CAPACITY AT LONG-TERM CONSTRUCTION SITES WHERE WORK AREA IS SEPARATED FROM TRAFFIC WITH PCBs

Number of Lanes		No. of	Capacity	Average Capacity	
Normal	Open	Studies	Range (vphpl)	vph	vphpl
3	2	7	1780 - 2060	3720	1860

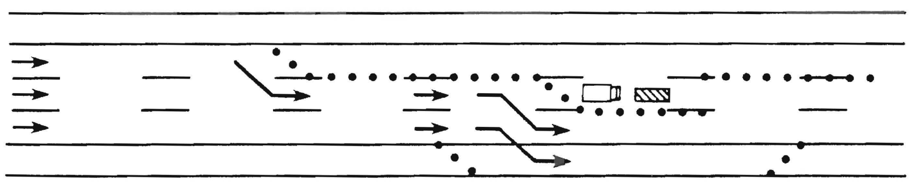
Capacity at Short-Term Sites with No Work Activity Adjacent to Traffic

One study was conducted on the North IH-610 Loop in Houston. The right two lanes of a 4-lane section were closed. There was no work activity in the closed lane immediately adjacent to traffic. A work crew and their machinery did, however, occupy the shoulder lane which was one lane removed from moving traffic. The volumes measured on the two open lanes over a period of 30 minutes were as follows: 926 vehicles in the lane adjacent to the closure and 730 vehicles in the median lane. These 30-minute volumes are equivalent to flow rates of 1850 vph and 1475 vph. It was apparent from field observations that the demand volumes were lower than the capacity of the two open lanes. Queues did not form upstream from the work activity or the cone taper. There was available capacity in the median lane. The work crew (one lane away from an open traffic lane) did not affect flow thru the work zone. It is estimated that the capacity of the two open lanes under the above-cited conditions was about 3600 vph. This volume could probably be sustained as long as queues do not form.

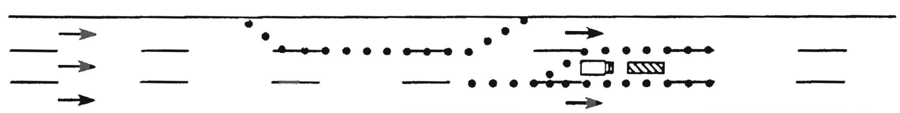
Shoulder Usage and Traffic Splitting on 3-Lane Section

Generally, when work is required on the middle lane of a 3-lane section, both the middle lane and one of the exterior lanes are closed. Table 8-2 indicates that the average capacity on the open lane may be between 1050 and 1350 vph, depending on the type of road work. Studies (20) have indicated that the capacity could be increased to 3000 vph by using a traffic control approach called "shifting," whereby drivers are encouraged to use the shoulder as an additional travel lane. In effect, two lanes are open to traffic.

The studies also indicated that the capacity could be increased to approximately 3000 vph by using a traffic "splitting" approach. In this approach, the middle lane is closed and traffic is allowed to travel on both sides of the work activity. It is important, however, that a special lane closure technique recommended be used to implement the "splitting" approach. Otherwise, considerable driver confusion could take place. The technique involves closing the left lane far upstream from the work area so that only two lanes of traffic enter the split area. Traffic is then "funneled" and split using cones--one lane to the left, and the other to the right.



Freeway Traffic Shift (Shoulder Usage)



Freeway Traffic Split

Crossovers

Table 8-5 presents the results of work zone capacity studies conducted at three work zones on 4-lane divided highways (21). From the table, the average adjusted capacities at Site 1 (a 2-lane, 2-way operation (TLTWO) work zone) were 1550 vph in the crossover direction and 1800 vph in the opposite direction. At Site 2, another TLTWO work zone, the capacity in the crossover direction was estimated to be approximately 1450 vph. The estimated capacity in the opposite direction was approximately 1720 vph. Thus, the capacity in the crossover direction at both sites was nearly 300 vph lower compared to the opposite direction.

At Site 3, where the single-lane closure approach was used, the average adjusted capacity was 1780 vph.

TABLE 8-5. WORK ZONE CAPACITIES

Study Site	Traffic Control Approach	Direction of Travel	Study Period	Raw Capacity Volume,[a] vph	Average Axle per Vehicle	Average Capacity, vph
1	TLTWO	Crossover	45 min.	N.A.[c]	N.A.	1550
		Opposite	1 hr.	N.A.	N.A.	1800
2	TLTWO	Crossover	3 hrs.	1610	2.22	1450[b]
		Opposite	3 hrs.	1880	2.19	1720[b]
3	Lane Closure	Lane Closure	1 hr.	1920	2.16	1780[b]

[a]Raw volumes are based on total traffic counter actuations divided by 2.

[b]Average Adjusted Capacity = $\frac{\text{Raw Capacity Volume X 2}}{\text{Average Axles/Vehicle}}$

[c]Not applicable since capacity counts were made directly from video tapes.

Effects of Trucks

The work zone capacity relationships discussed in this chapter represent average characteristics and do not account for site specific factors. The numbers used in Table 8-2 do not convert trucks to passenger car equivalents. For the reader who is accustomed to dealing with capacity figures, capacities in passenger car equivalents could possibly be reported as 10% higher than those stated in this report. No attempt has been made to form exact equivalency numbers because other factors apparently have more pronounced effects on short-term work zone capacity.

Two models were developed for work zone capacity, taking into account the effect of trucks (22). These models were then compared with the relationships shown in Figure 8-2 and Table 8-2 which do not consider percentage of trucks in the traffic stream.

No consistent relationship between the percent of trucks and work zone capacity was found. Incorporating the percent of trucks into the capacity model did not seem to explain the variation in capacities found for lane closures of the same type. Apparently other factors have a more pronounced effect on work zone capacity.

9. ROAD USER COSTS ASSOCIATED WITH WORK ZONE LANE CLOSURES

Introduction

There is a growing concern among highway agencies and contractors over the effects of work zone traffic control measures on work productivity, safety, construction and traffic control costs, and user costs. These issues were addressed in a recent FHWA study conducted by TTI (21). During the studies data were collected at 4 single lane closure worksites and 5 crossover (TLTWO) worksites in Texas and Oklahoma.

As part of Study 292, the SDHPT authorized further study of work zone user costs to supplement the FHWA study data. In particular, more data representing high volume conditions were needed. The additional data were collected at 5 work zones on freeways in Houston. Combining the data from the FHWA study with the Study 292 data, an analysis of work zone user costs was made based on experience at 14 sites. Details of the analysis are discussed in a Technical Memorandum (23) and the results are summarized in this chapter.

The main objective of the analysis was to determine the relationships between traffic control measures and user costs as a function of traffic volumes. The results provide a means to predict the potential user costs at a work zone based on anticipated traffic volumes and traffic control strategy. The results can also be used to verify and evaluate the output of the queue and road user cost evaluation computer model (QUEWZ) developed by TTI (see Chapter 10).

Study Results

Table 9-1 shows the user costs at the nine work sites of the FHWA study by direction of travel during periods when no significant queues were present. Table 9-2 shows the user costs at seven work sites during periods when significant queues were present. Five of these sites are new and two (one a test site) are from the previous study.

As shown at the bottom of Table 9-1, the average additional user costs for each site with no significant queues is $0.11 per vehicle in the direction of the crossover of lane closure and $0.08 in the opposite direction. By multiplying these per vehicle user costs by their corresponding average hourly vehicle volumes for each site gives an average user cost per hour per open lane of $94 for travel in the direction of the crossover or lane closure, and $55 for the opposite direction.

As shown at the bottom of Table 9-2, the average additional user cost for sites with significant queues is $0.60 per vehicle in direction of the lane closure. This amount is over five times that for sites with no significant

TABLE 9-1. ADDITIONAL USER COSTS (NO SIGNIFICANT QUEUES PRESENT)[a]

Site	Direction of Travel[b]	Type of Traffic Control[d]	Average Additional User Cost Per Vehicle			Average Hourly Vehicle Volume	Average User Cost Per Hour[e]
			Delay Cost	Operating Cost[c]	Total Cost		
1	C	L/C	$0.03	$-0.01	$0.02	273	$ 5
	0		<.01	<.01	<.01	286	<1
2	C	L/C	0.13	0.01	0.14	865	120
	0		N.A	N.A	N.A	N.A	N.A
3	C	C/0	0.16	0.03	0.20	1,139	228
	0		0.14	0.03	0.18	1,249	220
4	C	L/C	0.04	0.00	0.04	204	9
	0		0.01	0.01	0.02	175	3
6	C	C/0	0.15	0.02	0.17	1,625	276
	0		0.13	0.01	0.14	1,621	229
7	C	L/C	0.07	0.03	0.10	1,114	117
	0		0.04	0.01	0.05	260	14
8	C	C/0	0.21	-0.06	0.15	943	145
	0		0.20	-0.09	0.10	596	61
9	C	C/0	0.12	-0.02	0.10	662	64
	0		0.11	-0.03	0.08	601	46
Average	C		0.11	0.00	0.11	853	94
Average	0		0.09	-0.04	0.08	684	55

[a]Totals may not match separate values due to rounding errors and weighting of each run by the corresponding traffic volume.

[b]C -- Direction of crossover or lane closure.
0 -- Opposite direction.

[c]Operating costs include vehicle running costs and speed change cycle costs.

[d]L/C = Lane Closure
C/0 = Crossover

[e]Per lane remaining open to traffic

Source: All data in this table are from previous study [1].

TABLE 9-2. ADDITIONAL USER COSTS (SIGNIFICANT QUEUES PRESENT)[a]

Site	Direction of Travel[b]	Average Queue Length (Miles)	Average Additional User Cost Per Vehicle: Delay Cost	Average Additional User Cost Per Vehicle: Operating Cost[c]	Average Additional User Cost Per Vehicle: Total Cost	Vehicle Cost Per Mile of Queue	Average Hourly Vehicle Volume[d]	Average Hourly User Cost[d]	Average Hourly User Cost Per Mile of Queue[d]
7[e]	CQ	0.660	$0.53	$0.11	$0.64	.96	1,407	$ 895	$1,356
Test[e]	CQ	0.728	1.32	0.11	1.43	1.96	1,700	2,424	3,329
10[f]	CQ	1.280	1.15	0.01	1.16	0.91	2,480	2,877	2,248
11[f]	CQ	0.397	0.39	0.04	0.43	1.08	2,064	1,050	2,645
12[f]	CQ	0.355	0.46	-0.02	0.44	1.24	1,888	856	2,411
13[f]	CQ	0.350	0.44	0.02	0.46	1.31	2,099	1,016	2,903
14[f]	CQ	0.778	0.88	0.00	0.88	1.13	1,950	1,696	2,180
15[f]	CQ	0.636	0.44	0.01	0.45	0.71	2,344	1,055	1,659
16[f]	CQ	0.519	0.57	0.04	0.61	1.18	1,337	838	1,615
Average	CQ	0.634	0.68	0.04	0.72	1.16	1,918	1,142	2,260

[a] Totals may not match separate values due to rounding errors and weighting of each run by the corresponding traffic volume.

[b] CQ = Direction of crossover or lane closure while queue was present.

[c] Operating costs include vehicle running costs and speed cycle costs.

[d] Per lane remaining open to traffic.

[e] Sites used in previous study [1].

[f] New sites.

queue. Consequently, the average cost per hour per open lane is $1,661 for these sites compared to $94 for the same direction of travel at the sites with no queues.

The average hourly user cost per mile of queue is $3,408 for sites with significant queues. Site 10 shows that the cost per mile of queue can be very high, reaching $5,471 per hour. The results seem to indicate that the additional hourly user cost increases as the queue length increases at work zone sites with lane closures in the direction of travel. No data were collected at crossover sites experiencing significant queues.

Since all the new study sites had single or double lane closures (not crossovers), data from these sites, along with those of the previous study, are plotted in Figure 9-1 to show the relationship between additional user costs and hour vehicle volume per lane for that type of traffic control procedure. The regression curve fits the data points well, yielding an R^2 of 0.9157. The curve indicates that additional user costs for these types of work zone closures increase rapidly at demand volumes zone closures increase open lane, reaching more than 3,000 per hour at demand volumes of 2,500 vph per open lane. Data from the new sites filled some data gaps and increased the R^2.

Figure 9-2 shows the single lane closure data points and the regression curve to indicate the relationship between additional hourly user cost <u>per work zone mile</u> and hourly lane volume. The regression curve representing these data points yields an R^2 of 0.9085, which is almost as high as that shown in Figure 9-1. The additional user cost per work zone mile increases rapidly, beginning with demand volumes of 1,500 vph per open lane and rises to $3,000 at 2,250 vph.

Figure 9-3 shows the relationship between hourly user costs per work zone mile and hourly vehicle demand volume per open lane for both types of work zone control measures studied (i.e., crossovers and single-lane closures). Traffic going in the opposite direction is not reflected in these costs. The data points and the regression curves representing each type of work zone control tend to confirm the assumption that hourly user costs are higher for the crossover type than for the single-lane closure type at the same hourly demand vehicle volume. The lack of data points at higher vehicle volumes for the crossover type still prevent a definite conclusion of this assumption. However, the new data points for single-lane closures helped produce a higher R^2 that when using only the data points from the previous study.

Figure 9-4 shows the additional hourly user costs <u>per work zone mile</u> for combined lane closure types and directions of travel by hourly demand vehicle volume per open lane. Again, the new data points for the single-lane closure type increased the R^2 over that produced by only the data points from the previous study.

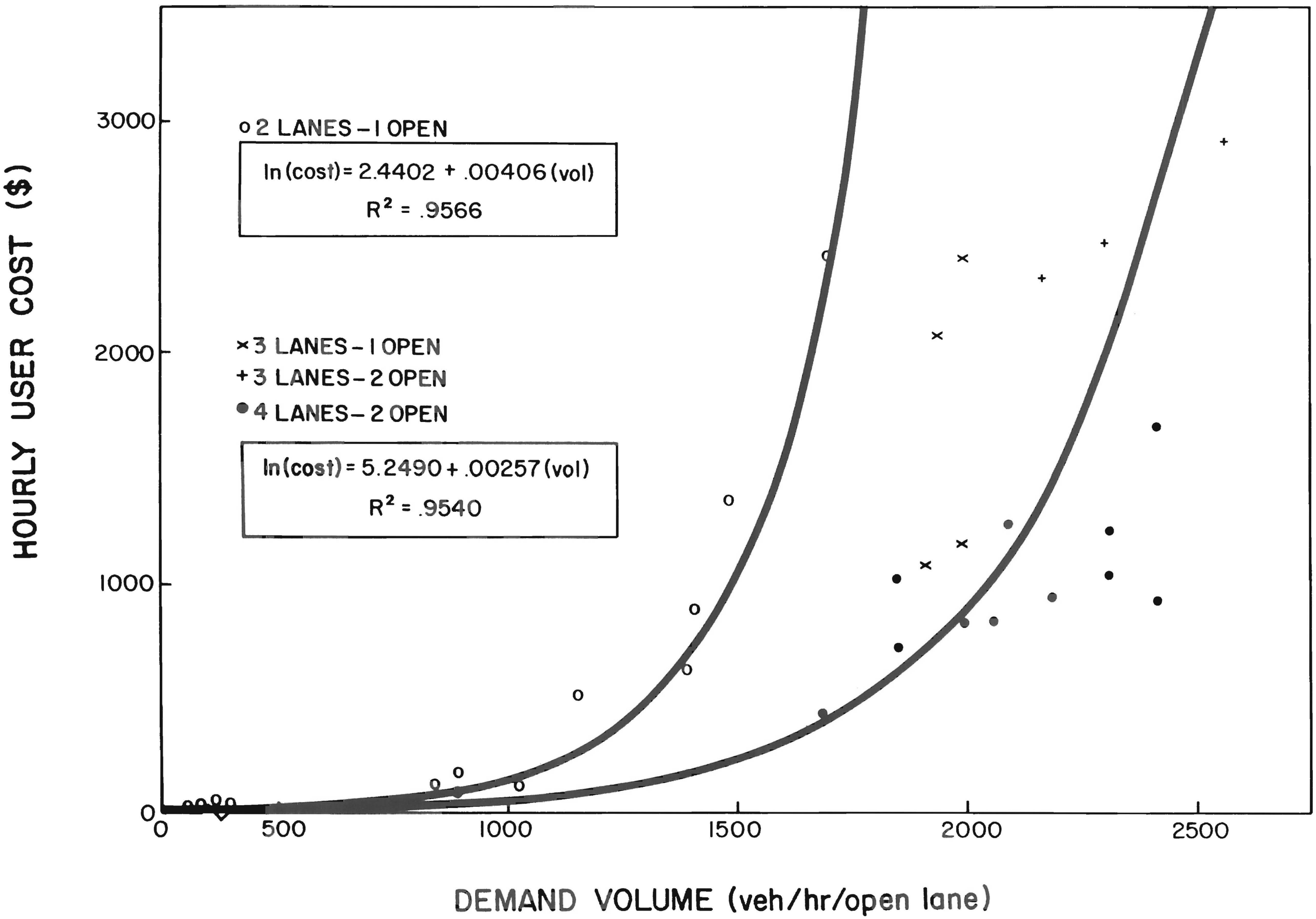


Figure 9-1. Additional Hourly User Costs for Single Lane Closures.

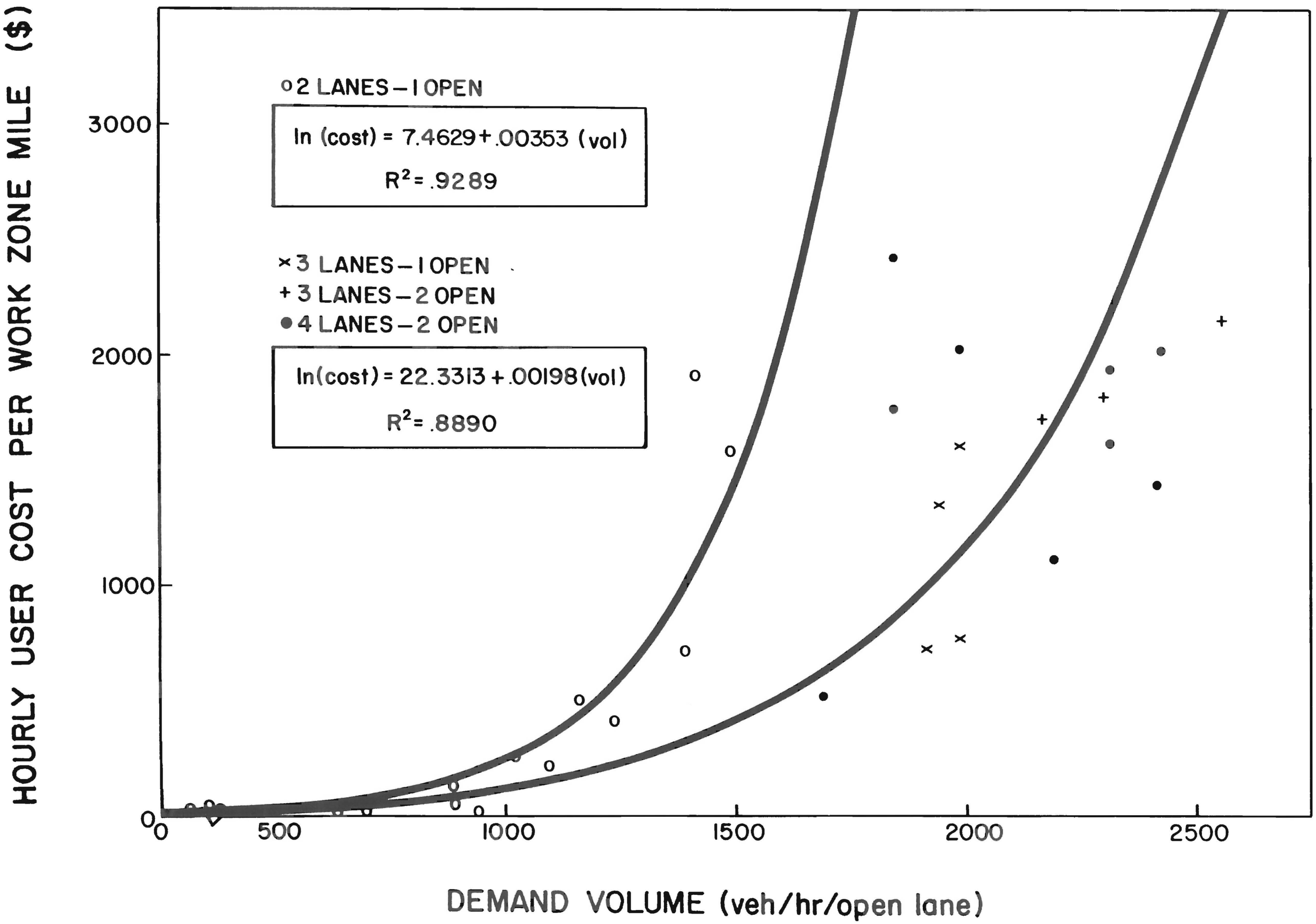


Figure 9-2. Additional Hourly User Costs Per Mile of Work Zone for Single Lane Closures.

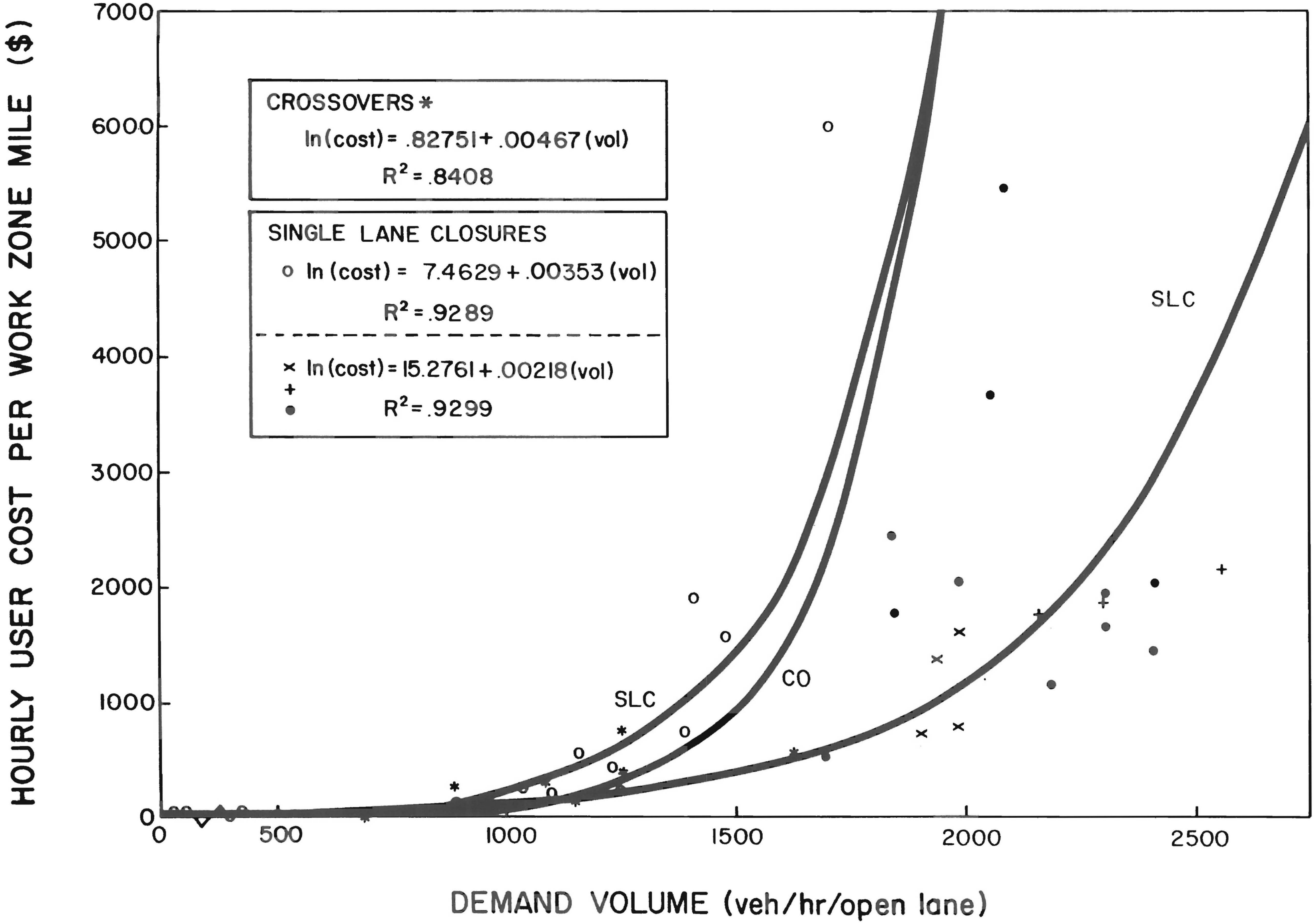


Figure 9-3. Additional Hourly User Costs Per Mile of Work Zone for Crossovers and Single Lane Closures.

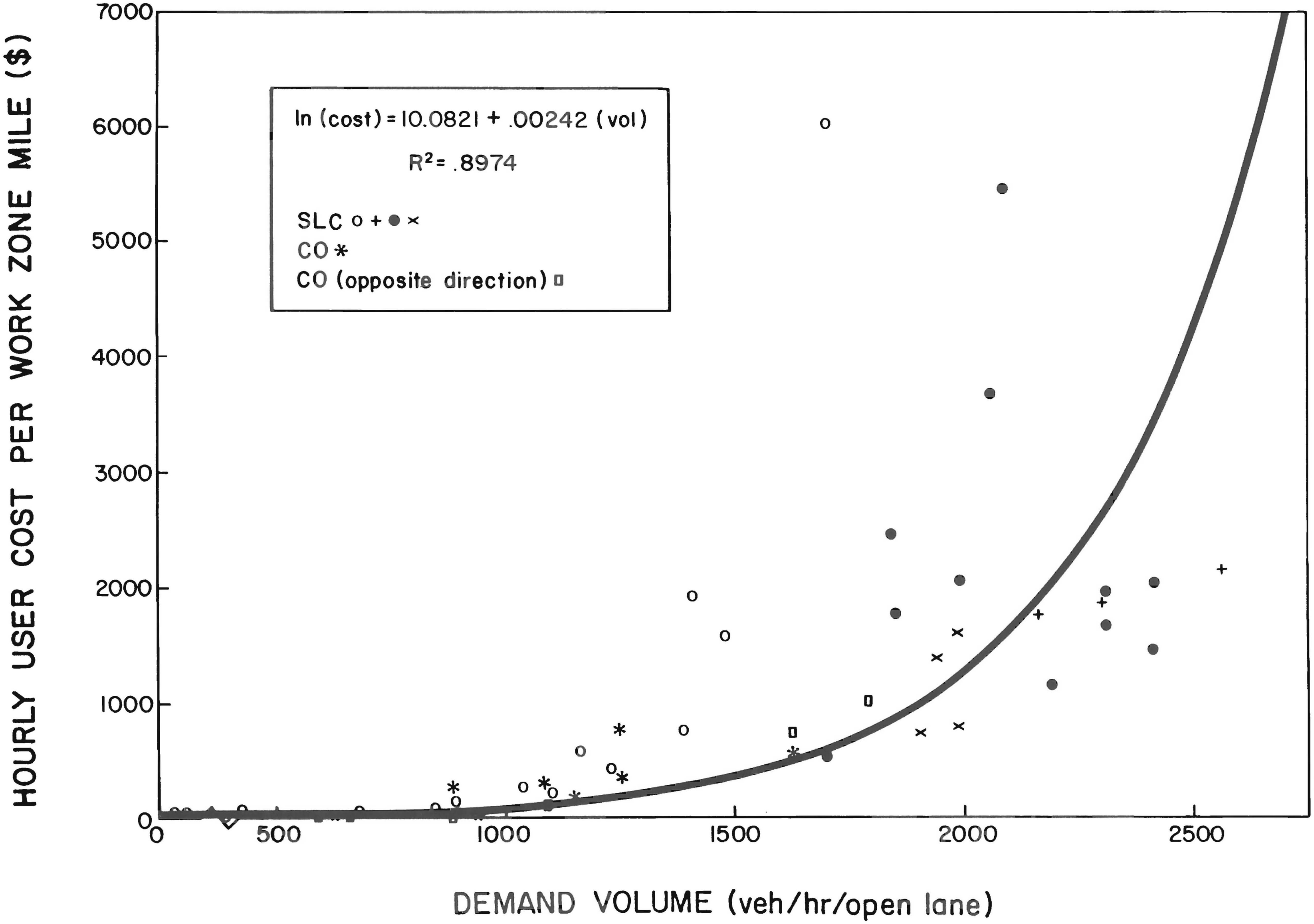


Figure 9-4. Additional Hourly User Costs for Combined Lane Closure Types.

10. MODEL TO CALCULATE ROAD USER COSTS AT WORK ZONES

Introduction

As discussed in Chapter 9, road user costs should be considered when evaluating the effects of different traffic control and lane closure strategies. These calculations are relatively simple, however, they are extremely time consuming. A computer model, QUEWZ, was, therefore, developed to calculate the road user costs resulting from lane closures through a work zone. The computer program was placed on the SDHPT's computer system and can be accessed from the remote terminals at each District. Details of the model are presented in Research Report 292-1 (24).

Characteristics of Model

QUEWZ calculates the delay costs and speed-change cycling costs of vehicles slowing down to go through a work zone, and the change in vehicle running costs through the work zone. If a queue forms, the delay costs, speed-change cycling costs, and the change in vehicle running costs in the queue are estimated. The model also estimates the average length of queue each hour.

QUEWZ represents an improvement of previous models (25, 26, 27,) by using hourly traffic volumes rather than ADTs, and recent data concerning capacities and average speeds in and around work zone sites in Texas.

The major characteristics of the model include:

1. The model can examine, in a short time period, a variety of lane closure strategies which fall into two general categories: The first type is closure of one or more lanes in a single direction of travel. The second type is a crossover, where one side of the roadway is closed and 2-lane, 2-way traffic is maintained on the other side of the roadway.

2. Hourly traffic volumes are used rather than ADT. This allows for a much more accurate estimate of average speeds, and the estimated queue when demand exceeds capacity.

3. A typical hourly speed-volume relationship is assumed in the model, but can be changed by the user as part of the input data.

4. Vehicle capacity through the work zone is not a constant parameter but based upon a distribution of work zone capacities in Texas. The model user can select the probability that his work zone capacity estimate will cover a certain percentage of work zone capacities observed in Texas (see Chapter 7). For those cases which are not

supported by Texas data, or if Texas data are not appropriate, the user can override the program-generated work zone capacity in the input.

5. A relatively small amount of data is required to run QUEWZ. The input and output data for the model are listed in Table 10-1.

TABLE 10-1. INPUT AND OUTPUT DATA FOR QUEWZ

Input Data

Required

- Lane Closure Strategy
- Total Number of Lanes
- Number of Open Lanes Through Work Zone
- Length of Closure
- Time of Lane Closure and Work Zone Activity
- Actual Traffic Volumes by Hour

Optional

- Factor to Update Cost Calculations
- Percentage Trucks
- Speeds and Volumes for Speed-Volume Curve
- Capacity Estimate Risk Reduction Factor or Work Zone Capacity
- Problem Description

Output Data

- Vehicle Capacity
- Average Speed Through Work Zone by Hour
- Hourly User Costs
- Daily User Costs
- If a Queue Develops, Average Length of Queue each Hour

Many of the items listed on Table 10-1 are apparent. A few need some additional explanation. Currently QUEWZ handles two lane-closure strategies--1) one or more lanes closed in one direction of traffic, and 2) crossover. The user is required to identify the time when lanes will be closed and reopened. For long-term road work that lasts for more than one day, the time of day when the work crews are at the site must also be specified. For short-term projects the hours of restricted capacity would coincide with the work zone activity, so the hours of work zone activity could be left blank.

The factor to update cost calculations is used to update the dollar user costs to current prices.

The QUEWZ program also allows the user to include a problem description. Such information as highway number, location of work zone, etc. can be included.

The program has constant values built into the model for all optional inputs. If the user does not specify values for the optional inputs, the program automatically uses its preset values.

The user cost calculations in QUEWZ fall into three general categories. Delay costs result from vehicles slowing down and going through the work zone at a reduced speed, and if a queue develops, the delay of vehicles in the queue. Changes in vehicle running costs come from a lower average running speed through the work zone and queue, if one develops. Speed-change cycling costs come from vehicles slowing down to go through the work zone and stop-and-go conditions if there is a queue. Dollar values of operating costs come from the AASHTO Redbook (28), and values of time from the HEEM program (29). Both are updated to December 1981 values.

Several of the user cost calculations utilize information obtained from recent TTI findings regarding work zone capacities, average speeds through work zones, characteristics of queues which have formed upstream of the closure, and the effect of work activity in the work zone on vehicle reaction while going through the work zone.

Research Report 292-1 (24) presents twenty sample lane closure problems. The estimates of user costs and queue length from QUEWZ are presented, along with some suggestions for using the output in decisions regarding lane closures through work zones.

11. SELECTING CHANNELIZING DEVICES USING VALUE ENGINEERING

The Value Engineering Approach

There are a wide variety of channelizing devices currently available for use in highway work zones. The MUTCD presents basic design standards for these devices and general guidelines for their use (1). However, it is left up to the highway agency to decide where and when to use particular devices or sets of devices. As a result, the application of work zone channelizing devices varies widely between agencies and between projects (30).

Selection of the most appropriate channelizing devices for a work zone is a critical task, affecting both safety and job cost. Presently, there is no organized, objective selection method. Devices are typically chosen based on one of the following practices:

1. Select the device with the lowest initial cost.

2. Select a device which is normally used by the agency.

3. Select a device already in stock.

4. Select the very "best" device just in case.

Each of these approaches has drawbacks, and collectively they have resulted in inflated job costs, unnecessarily large inventories, a lack of uniformity, and in some cases, improper device use.

Addressing these problems, the use of Value Engineering for selecting work zone channelizing devices was investigated and is documented in Research Report 292-3 (31). Value Engineering is a formalized problem-solving approach which attempts to accomplish a required objective at the lowest overall cost. In this case, it was used as a means for selecting channelizing devices which were effective and result in the lowest total cost to the highway agency and contractor. It is anticipated that the Value Engineering appproach can be used by the Department at the Division level as an aid in establishing work zone traffic control standards and for planning and allocating resources.

Application of Value Engineering

The Value Engineering approach can be used to select work zone channelizing devices which offer the greatest value (i.e., those devices which serve their intended purpose at the lowest overall cost). In fact, Value Engineering is particularly appropriate since it reduces costs without reducing safety below an acceptable level (32).

The selection of work zone channelizing devices using the Value Engineering approach involves 7 steps (described in detail in Report 292-3):

1. Determine the intended purpose (function) of the devices.

2. Identify available alternative devices.

3. Select appropriate measures of device performance (i.e., a means of evaluating how well a device performs its intended function).

4. Determine the performance of the alternative devices based on the selected performance measures. (If it has not already been done, alternatives which do not meet minimum performance criteria should be excluded.)

5. Estimate the total cost of each acceptable alternative.

6. Calculate the relative value of each acceptable alternative, where value = performance/cost.

7. Select the alternative with the greatest value.

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