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Work Zone Traffic Control Delineation for Channelization

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Turner-Fairbank Highway Research Center
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FOREWORD

This research was initiated by a request from the Federal Highway Administration's Office of Traffic Operation. The *Manual on Uniform Traffic Control Devices* (MUTCD) provides several devices that can be used to delineate the path of vehicles through work zones. The study was to compare the use of drums, barricades, panels, cones, and tubes to develop more definitive guidelines as to where and how each device should be used. It was hypothesized that fewer large devices, such as drums, could be used in place of the small devices, such as cones, to do the same job. The research failed, however, to find a significant difference in motorists' understanding and behavior among the devices and the spacings between devices that were tested.

This report will be distributed with one copy to each region and two copies to each division office. One of the division copies should be sent to the State. The report will be sent to the Transportation Research Information Service Network, Department of Transportation Library, and the National Technical Information Service (NTIS) in Springfield, Virginia, to be available for interested parties.

for R. J. Betsold
Director, Office of Safety and
Traffic Operations Research
and Development

NOTICE

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16. Abstract

This report describes a study of the delineation requirements for work zone traffic control. The research included a comprehensive review of past studies and current practices, and an examination of current standards. It was concluded that, in spite of the increasing number of different types of channelizing devices, there appears to be no scientific basis for the spacing criteria for the use of devices for channelization purposes in the taper or tangent sections of a work zone.

A laboratory-based testing procedure was used to determine the most appropriate spacing configuration. An interactive video system was used to test subject recognition distances of eight different device types spaced at the standard distance, 1.5 times and 2.0 times the standard distance. Over 240 subjects were tested. The results indicated variability between the performance of most channelizing devices across the spacings tested.

Field testing was undertaken at six actual work zones. Right and left closures were used to test the various device-spacing configurations under both day and night conditions. Manual and automated methods were used to gather the field data for traffic approaching a work zone. The study area included four points equally spaced over the 2000 ft (600 m) before the work zone and the activity at the start of the taper for the lane closure. The tests were undertaken under the hypothesis that the most effective treatment would minimize the percentage of traffic in the closed lane at the start of taper.

Field data were analyzed for 2100 5-minute observation periods. Statistical analysis of the data determined neither type of device (round barrels, oblong barrels, Type II barricades, and cones with reflectorized collars) or device spacing (55, 80, and 110 ft) [16.5, 24.7, 33.0m] had a significant effect on driver lane changing behavior. Recommendations for locating work zones to maximize the sight line on the approach to the taper are presented.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

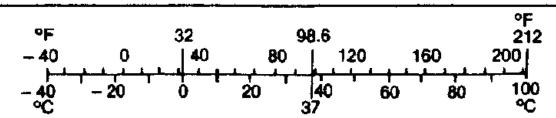
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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CHAPTER 1: INTRODUCTION

BACKGROUND

A variety of traffic control devices and installation configurations for work zone delineation are permitted under the current Manual of Uniform Traffic Control Devices (MUTCD).[1] These are shown in figure 1. Applications of the various configurations were noted in the review of the literature and the survey of current practices. It was determined that the primary delineation devices used are:

- Round drums (18 in diameter) [45 cm diameter].
- Oblong drums.
- Type II barricades (8 by 24 in) [20 by 60 cm].
- Vertical panels (8 by 24 in) [20 by 60 cm].
- Cones (28 in tall) [70 cm] with reflective collars.
- Tubes (36 in tall) [90 cm] with reflective collars.

These devices are used in various configurations to delineate lane or shoulder closures or median crossover situations and channelize traffic through work zones. The devices represent one element of work zone traffic controls. Advanced warning signs, arrow panels, supplemental beacons, signs or flags, and pavement markings are used in conjunction with the channelization devices.

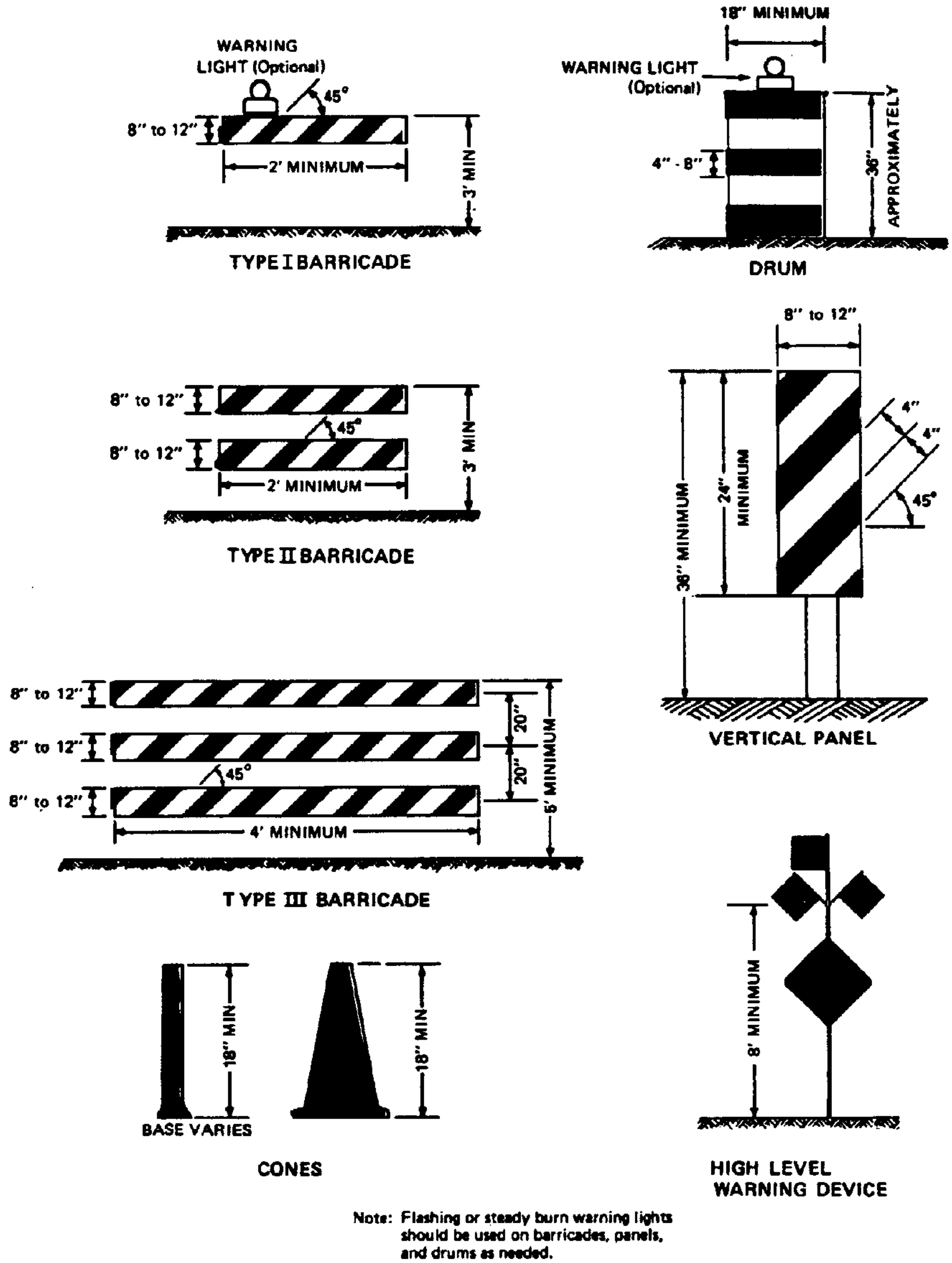
While the MUTCD permits the use of various types of channelization devices for work zone delineation, it recommends common criteria for their spacing on taper and tangent sections. The current standard requires that devices be spaced on tapers at a maximum distance in feet equivalent to the speed limit.[1] A standard also exists for determining the required length of the taper, and thus the number of devices required for urban or rural highway situations. The standard suggests that the channelization devices can be spaced further apart on tangent sections. It states, "Devices placed on the tangent to keep traffic out of the closed lane should be spaced in accordance with the extent and type of activity, the speed limit of the roadway, and the vertical and horizontal alignment of the roadway such that it is apparent the roadway is closed to traffic." Current practice is to space devices on the tangent at the same spacing as on the taper or something greater.

Background studies indicate that the taper spacing criterion is based on professional judgment and not scientific research. Given the differences in the types, sizes, and target values of devices, the appropriateness of the spacing criteria has been questioned. The effectiveness of the various devices may be affected by the extent and type of work activity, the use of other traffic control devices, the nature of traffic, the horizontal and vertical alignment of the roadway, and cross-sectional features.

This effort evaluated the relative effectiveness of the various types of devices at different spacing configurations using both laboratory and field testing procedures. Three different spacing configurations were tested for a 55 mi/h [88 km/h] speed in the laboratory and the field. These were based on variations of the recommended MUTCD criteria for spacing of devices on the taper at a distance in feet equivalent to the speed limit. The three configurations tested were:

- 1.0 x speed limit (55 ft) [16.5 m].
- 1.5 x speed limit (82.5 ft) [24.7 m].
- 2.0 x speed limit (110 ft) [33.0 m].

In all cases, the MUTCD guidelines for length of taper for a lane closure were followed (ie, length = posted speed limit x width of offset).



Note: 1 in = 2.5 cm; 1 ft = 30 cm. Source: Reference 1.

Figure 1. MUTCD approved channelization devices.

The testing conducted in this research included evaluations of each device at each spacing for right- and left-lane closures and median crossover situations. Lane closures were represented by deploying the devices along a taper in advance of the lane to be closed. The median crossover situations were represented by deploying devices tangent to the travel lane in advance of the taper. The tests were designed to provide data that would confirm the validity of the current MUTCD spacing guidelines or lead to recommendations for changes in the guidelines.

RESEARCH OVERVIEW

The research was conducted in four phases. The first phase identified current practices and determined the extent to which previous research addressed the effectiveness of the various elements of traffic control for work zones. In this phase of the project, the literature was reviewed and discussions with practitioners conducted. A summary of current practices is provided in chapter 2 of this report.

The second phase of the project involved laboratory testing of channelization device effectiveness. The tasks undertaken during this phase were aimed at establishing a basic understanding of motorist perceptions of the devices under different configurations and at narrowing the number of device-spacing configurations to be considered in subsequent field tests. The second phase efforts included:

- Creating simulated work zone situations where different devices and configurations could be filmed for viewing by test subjects.
- Implementing a means to present the test scenes to subjects in a randomized fashion and record their comprehension and recognition distances.
- Testing a large number of subjects representing a cross section of the driving population.
- Statistically analyzing the results to determine if there are significantly different degrees of driver performance among the various device and spacing conditions.
- Analyzing the results to determine candidate devices and configurations for field testing.

Chapter 3 of this report describes the methodologies used for conducting the laboratory tests, presents the results, and summarizes the conclusions drawn from the tests.

The third phase of the effort involved field testing of various device-spacing configurations at actual work zones. The third phase efforts included:

- Identifying typical work zones sites and securing permission to conduct tests at these locations.
- Conducting tests of the different device-spacing configurations at the work zone taper and gathering pertinent measures of motorist behavior.
- Compiling traffic operations data using automatic traffic recorders.
- Creating a data base of traffic data stratified by treatment, time-of-day, type of situation, and traffic conditions.
- Analyzing the data to determine if differences in effectiveness could be detected for the various device-spacing configurations.

The field testing procedures and findings are described in greater detail in chapter 4 of this report.

The last phase of the project involved interpreting the findings of the laboratory and field studies. The findings were considered in the context of their implications on current guidelines in the MUTCD. The impacts of possible revisions to the guidelines were assessed in terms of safety and cost effectiveness. The conclusions and recommendations derived from the research are presented in chapter 5 of this report.

CHAPTER 2: STATE-OF-THE-PRACTICE REVIEW

The first phase of the project reviewed the state of the practice. Past research on work zone delineation and agency standards for work zone traffic control were reviewed. Various types of channelization devices were identified, their effectiveness was assessed, the applications of spacing criteria were compared, and costs were considered. Highway agency personnel were also contacted to obtain their perceptions of device effectiveness, application criteria viability, and motorist responses. This chapter summarizes the current state of the practice and outlines the areas where additional research is needed.

CHANNELIZATION DEVICES

The purpose of channelizing devices in work zone traffic control is to provide a clearly visible path for motorist through situations where lanes are closed. Effective work zone traffic control plans requires the designer to minimize the number and severity of curves, minimize elevation changes, provide a smooth unobstructed roadway surface (minimize distractions and weaving), and eliminate miscues in guidance information, for example, gaps in channelizing devices, conflicting delineation. Barrels, barricades, panels, drums, cones and tubes are the primary devices available for work zone channelization. Table 1 provides a summary of the features and assessments of the primary devices noted in NCHRP Report 236.(12) Table 2 provides the recommendations for the application of these devices provided in NCHRP Report 236.(12)

A considerable amount of variation can be found in the designs of the devices used for work zone traffic control. The devices are manufactured by several firms offering various design features to provide devices that can be easily handled, that will reduce damage to errant vehicles, and that can be procured at a reasonable cost. Consequently, there are differences in shape, size, weighing, reflectivity, and support systems. Figure 2 provides illustrations of the various types of channelization devices found on the market. Many State agencies have adopted minimum standards for devices used on roads in their jurisdictions. Typically, these standards address the size of devices and the use of reflectorized sheeting.

While a great deal of variability exists in the basic design of these devices, even more variability occurs in the use of the devices and over time. It is not uncommon to find devices in use that are in poor repair or that fail to meet minimum standards. Devices in use over extended periods of time become covered with construction dirt, and can be damaged by errant vehicles or in handling and storage. Operations, such as repaving leave the devices extremely discolored due the tars used. Devices are often knocked out of position and not replaced during work periods. It can also be observed that device deployment is usually done by eye to save the time measuring exact lateral and longitudinal positions. This applies to the devices as well as to other elements of the traffic control plan.

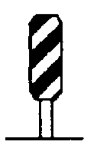
Design Principles for Channelizing Devices

Research in work zone traffic control has been undertaken to develop and evaluate the various designs for devices and treatments. The general principles emanating from these research efforts are outlined below.

Barricades

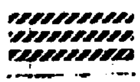
- Visible area (rail size) impacts driver behavior. On higher speed facilities (45+ mi/h) [72+ km/h] optimum device size is one rail (Type I) 36 in [90 cm] long by 12 in [30 cm] wide. This size induces speed reduction of 3 to 4 mi/h [4.8 to 6.4 km/h]. Adding additional visible area has little effect. A 24-in [60-cm] by 12-in [30-cm] rail does not induce as much speed reduction but

Table 1. Summary of primary work zone delineation devices.

Device	Current Standard Usage						Literature Commentary
	Source	Height (min)	Width (min)	Colors/ Configuration	Stripe Width	Visibility Requirements	
Cones 	MUTCD	18-in	variable	fluorescent orange	variable	Must be reflectorized or lighted at night.	o Larger sizes should be used on higher speed roadways. o Regular cones have greater target value than tubes. o Use of orange flag in tip suggested for anytime. o Cone use is primarily delineation and channelization rather than warning with high target value. o Tubes primarily for daytime temporary use. They usually replace cones when lane space is at a premium, i.e. bridges. o Cones generally suggested for smaller, less hazardous zones which cause only minor impedence to traffic flow. o Must make provision for cones so that they will not be blown over or displaced.
	others in use	28-in 30-in 36-in	base 12-in tip 2.5-in	flourescent orange	4-in white cone collars	Minimum brightness for white is 150 candelas, 300 preferred; cones should be replaced or supplemented at night with steady burn lights	
Tubes (tubular cone) 	MUTCD	18-in	variable	flourescent orange	variable	Must be reflectorized or lighted at night.	
	others in use	28-in 36-in	tip 2.5-in	flourescent orange and yellow	4-in white or amber collars	Minimum brightness for reflective collars is 150-300 candellas; pylons should not be used at night without lights or reflective collars.	
Vertical Panel 	MUTCD	24-in high (min) 36-in from ground	8- to 12-in wide	Orange and white sloping at 45 degrees to traffic.	4- to 6-in	Entire area should be reflectorized with a material that has a smooth sealed outer surface. Should place lights on panel after dark.	o Panels are used where space is at a minimum - should always be secondary to barricades. o Suggest panel use for traffic separation or shoulder barricading.
	others in use	48-in from ground		Horizontal stripes and chevron stripes.		Minimum brightness for white is 70-75 candellas and for orange 25-70 candellas.	
Drum 	MUTCD	18-in diameter	36-in	Orange and white horizontal, circumferential.	4- to 8-in	Must have at least 2 orange and 2 white stripes. During dark, lights should be placed on drum.	o Very high target value with great visibility but the least portable of all devices. o For use at sites of longer length. o Drums seem more formidable and present a greater obstacle thereby giving good vision warning. o One application of drums is to show an unusual vehicle path made necessary by the work activity.

Note: 1-in = 2.5-cm. Source: Reference 12.

Table 1. Summary of primary work zone delineation devices (continued).

Device	Current Standard Usage						Literature Commentary
	Source	Height (min)	Rail Size (length by width)	Colors/ Configuration	Stripe Width	Visibility Requirements	
Type I Barricade 	MUTCD	36-in	24-in (min) by 8- to 12-in	Orange and white sloping at 45 degrees	6-in (4-in for rails less than 36-in)	Entire area shall be reflectorized with a material that has a smooth sealed surface. Lights an option after dark.	o Types I and II generally used when traffic is still maintained on the roadway. o Type II is usuually for partial or complete road closure. o Some researchers and engineers feel that Type I and Type II are interchangeable. o Number of barricades used should be minimized to reduce fixed object accidents. o Diagonal stripes are more distinct at closer distances than chevron pattern, yet both have the same target value. Chevron only effective to give directionality at 200 ft or less. o Many consider barricades to have best target value of all devices. o Barricades provide easy mount for signs and warning lights. o Barricades should not be used unless the hazard is greater than the hazard of hitting the barricade. o Utah's chevron barricade is known as the "channelizing arrow."
	others in use	---	72-in (min) by 6- to 12-in	Black and white	4-in	Minimum brightness for orange is 25-70 candellas, for white 70-250 candellas.	
Type II Barricade 	MUTCD	36-in	24-in (min) by by 8- to 12-in	Orange and white sloping at 45 degrees	6-in (4-in for rails less than 36-in)	Same as MUTCD above.	
	others in use	---	--- by 6- to 12-in	Black and white	---		
Type III Barricade 	MUTCD	60-in	48-in by 8- to 12-in	Orange and white sloping at 45 degrees	6-in (4-in for rails less than 36-in)	Same as MUTCD above.	
	others in use	---	72- to 96-in by 6- to 12-in	Black and white	---	When used for road closure, should have warning lights.	
Type IV Barricade 	Utah DOT			Orange and white chevrons	10-in		

Note: 1-in = 2.5-cm.

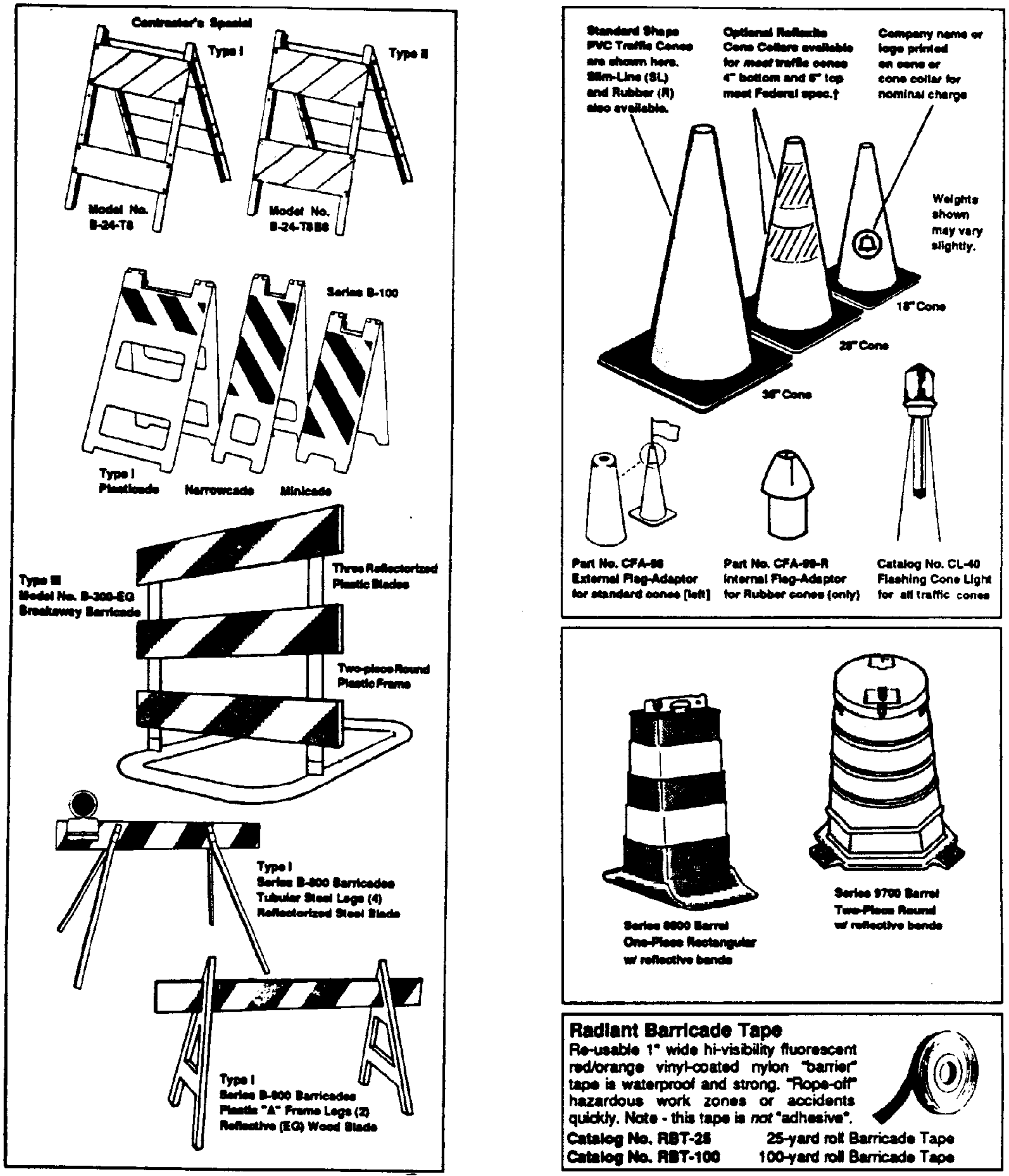
Source: Reference 12.

Table 2. Summary of device application recommendations.

Device	Application Guidelines	Minimum Dimensions	Stripe Configuration	Color	Minimum Stripe Width	Spacing
Cone	Interchangeable with other devices. Applicable for all work zone situations.	28-in or greater for high speed facilities.	2 or 3 bands totaling 150-200 in^2 of SIA 250 (preferably higher) material.	All orange cone with yellow or white reflectorization.	N/A	MUTCD
Tubular Cone	Interchangeable with other devices. Applicable for all work zone situations.	28-in or greater for lane closures or diversions. 4-in diameter.	1 band -high or low mounting of same material as cones.	All orange tube with yellow or white reflectorization.	12-in	MUTCD
Barricades	Applicable for all work zone situations. Type I suitable for all channelization situations.	Rail - 12-in wide by 24-in long. Height according to MUTCD.	Diagonal, but not to be used to convey direction. Consider chevron to convey direction.	One orange to one white.	6-in	MUTCD One-half speed limit in taper and double speed limit acceptable in tangent area where no work activity or traffic delays.
Verical Panels	Interchaneable with other devices. Applicable for all work zone situations.	12-in wide 24-in height Ground clearance - MUTCD	Diagonal or horizontal. Consider chevron to convey directional change.	One orange to one white.	6-in	Same as barricade.
Drums	Interchangeable with other devices. Applicable for all work zone situations.	Same as MUTCD	Horizontal	One orange to one white.	6-in	Same as barricade.
Steady-Burn	Should be used at night whenever feasible. Especially effective for tapers and approach ends. Use in visually noisy environments to improve detection capability. Use where curvature present to supplement reflective materials.	N/A	N/A	Amber.	N/A	On all devices in taper. All or alternate devices in tangent.

Note: 1-in = 2.5-cm.

Source: Reference 12.



Note: 1-in = 2.5-cm.

Figure 2. Illustrations of typical channelizing devices.

other driver responses, for example, point of lane change, are as good as with the larger rail. This is an optimum device size for 45 mi/h [72 km/h] or below work zones. A conventional two rail (Type II, 24- by 8-in [60- by 20-cm] rails) barricade is adequate for 45 mi/h [72 km/h] or below sites. A Type I with this smaller rail is not as effective as the Type II.

- Diagonal or vertical stripes are equally well detected. Neither has any directional guidance meaning for drivers. Chevrons do provide clear directional meaning.

- Stripe width should be 6-in [15-cm], particularly at work zones with 45+ mi/h [72 km/h] speed limits. The commonly used 4-in [10-cm] stripe is not as detectable at the longer distances needed at higher speeds.

Panels

- Visible area should be 12- by 24-in [30- by 60-cm] for 45+ mi/h [72+ km/h] work zones. Narrower panels are less effective and wider panels have no beneficial impact.

- Diagonal or horizontal striping is equally detectable and chevrons provide directional information.

Drums

- A 36-in [90-cm] high plastic drum is equally as effective as the larger barricade.

- Eight inch [20-cm] horizontal reflectorized striping is necessary on oblong drums to achieve detectability at night.

Cones

- The 28- or 36-in [70- or 90-cm] cones are necessary on 45+ mi/h [72+ km/h] facilities.

- For cones to be equally effective at night as other channelizing devices, two bands of high-intensity reflectorization are necessary. The two bands should total 75 to 100 in^2 [187.5 to 250 cm^2] of visible sheeting. This is roughly about the same amount of sheeting as a 12- to 14-in [30- to 35-cm] collar. For maximum effect the two bands should be separated by 3 in [7.5 cm] of orange cone.

- Measures to assure cone stability are necessary.

Tubes

- A tube must be 28-in [70-cm] or larger to be equivalent to other channelizing devices.

- One 12-in [30-cm] band of high intensity sheeting maximizes tube performance at night.

- Measures to assure tube stability are necessary.

Steady Burn Lights

- Highly visible and detectable at approximately 4,500 ft [1,350 m].

- Useful on vertical and horizontal curves.

- Promote earlier lane changing.

Application Principles for Channelizing Devices

Research has also been undertaken to analyze the effectiveness of the applications of various devices as part of work zone traffic control plans. This research has concluded that:

- Current taper and spacing formulas are adequate.
- One-half speed limit spacing elicits small speed reduction (3 mi/h) [4.8 km/h].
- One-half speed limit spacing in the taper could be useful in high-speed situations where other speed control measures are difficult to apply.
- Double speed limit spacing is effective in tangent sections if speed limit traffic flow is maintained. If flow speed greatly decreases the distance between devices, it gives the illusion that the work zone is over and weaving increases.
- Equal amounts of orange and white or somewhat more white are the most effective color ratios.

Based on these findings, it was concluded that when appropriately designed and applied, the six types of devices can be equally effective for inducing desired driver behavior.(12) The important implication of this finding is that there is no need to maintain large inventories of different types of devices. It was also concluded that the direction of diagonal stripes has no impact on driver understanding. This implies that there is no need to have left- or right-sided devices. The key is to have the device markings similarly aligned within a particular work zone.

CHANNELIZING DEVICE EFFECTIVENESS

NCHRP Report 236 contains a comprehensive review of the literature relevant to channelizing devices and driver performance measures.(12) The review presented below addresses the relevant literature published since 1981. Of particular interest was the performance of specific channelizing devices and specific arrays of channelizing devices, especially those associated with lane closures and median crossovers.

A 1981 study examined the use of chevron patterns on traffic control devices in work zones.(2) Observers rated candidate chevron patterns in a laboratory setting. The most promising devices were evaluated in a field test where position of lane change was measured in an actual work zone. It was concluded that:

> The results of this study do not support a recommendation that the chevron patterns be used on all channelizing devices. Except for those relating to the Type I chevron barricade, the conclusions do not clearly and consistently favor the chevron patterns. Since, in general, distinct differences in effectiveness are not attributable to the differences in patterns used on a specific type of device, panel, or barricade, we may conclude that the effectiveness of a channelizing device is not based primarily on the pattern used. The chevron patterns generally were rated slightly better or equal to the currently used patterns with which they were compared. The responses of drivers as measured by the position of lane changing were similar for the two types of patterns.

Another 1981 study evaluated a variety of devices, including Type III barricades, for improving delineation in long-term lane closures or diversions.(3) The project compared 7-ft [2.1-m] tall by 8-in [20-cm] wide vertical panels with Type III barricades. The vertical panels:

- Took up less space horizontally.
- Could be seen over the tops of lead vehicles.

- Could be used in narrow median shoulders to close off a left lane.
- Were less of a hazard on impact since all components were made of plastic.
- Were stackable.

The panels and barricades were compared in a before (barricades) and after (panels) design. There was no control group and no counterbalancing to control for ordering effects or adaption. The following were reported at the 95 percent level of confidence, with the panels:

- Lane weaves remained unchanged day and night.

- Lane encroachments decreased from 13 to 7 percent during the day and from 14 to 7 percent at night.

- During rain, lane weaves decreased from 6 to 3 percent during the day and from 8 to 3 percent during the night and lane encroachments decreased from 2 to 1 percent at night.

- Speed averages and variances remained unchanged day and night.

It was concluded that although tall vertical panels have many advantages over Type III barricades and did decrease lane encroachments at night, they did not change mean speeds or speed variances. Since it is not clear that reduction in mean speed is an appropriate MOE, this conclusion may not be appropriate and tall vertical panels may justify additional evaluation.

An evaluation of channelizing devices for two-lane two-way operations (TLTWO) was conducted in 1983.(7,8) A study panel prioritized eight candidate device concepts and selected two channelizing device concepts for further study. Although the two "finalists" were not evaluated, the report does provide a listing of functional requirements, performance criteria and testing procedures. For these special types of channelizing devices, the following appearance-related requirements for device visibility were derived:

> Sight Distance: Devices should be visible both day and night in both clear and rainy weather. Sight distance requirements on the order of 900 ft [225 m] have been determined desirable for traffic control devices where decision and subsequent maneuvering are required.(5) For TLTWO channelization between transitions, however, no time is needed for decision and path changing.
>
> Delineation. The channelizing system should appear as a line of devices, thus continually reminding motorists that they are in a TLTWO zone. Since the application being studied is on a freeway alignment between transitions, no path guidance is needed. Horizontal curves on freeways are typically three degrees or less. Intermittent devices must merely reinforce the double yellow centerline. For intermittently placed devices, this need will be met as long as several devices remain in sight as one moves through the TLTWO zone.
>
> Visibility Criteria: Devices should be visible for a distance of 500 ft [150 m] on a clear day and 300 ft [75 m] on a clear night when illuminated by low-beam automobile headlights.

FHWA research conducted in 1978 developed performance criteria for channelizing devices such as barricades, cones, vertical panels and drums, based on driver information needs and decision sight distance.(9) Driver decision sight distance involves driver detection, recognition, decision, response, and maneuver times. It was found that drivers needed between 10.2 and 11.7 seconds, based on the "worst case" maneuver response being a lane change. The visibility distances for 55 mi/h [88 km/h] were computed to be between 825 and 950 ft [247.5 to 285 m] and for 60 mi/h [96 km/h] to be between 900 and 1050 ft [270 and 315 m]. The laboratory study design described in this report was able to measure detection/recognition responses in this range.

In another FHWA research effort (1982) driver information needs in work zones were examined.[5] The objectives of the study were to: (a) determine information drivers need to travel through work zones safely and efficiently, (b) determine how this information can best be conveyed to the drivers, and (c) determine where improvements to the present system of work zone traffic control are needed. The study began with an analysis of driver tasks for eight major work zone types: lane closure, shoulder closure, roadside, lane diversion, crossover, temporary detour, detour to alternate routes, and reduced lane width. A set of information content needs was identified for each work zone type.

The analysis considered the driver information requirements for the entire work zone and determined how these needs should be met with signs, arrow boards, delineation and channelizing devices. Most of the specific recommendations involved specific sign content (messages) and sign placement. The analysis did not attempt to determine what portion of the drivers information needs could be or should be provided by the array of channelizing devices.

A Colorado study in 1984 evaluated the orange diamond pattern on white background, vertical panel as a construction zone obstacle marker and traffic channelizing device.[21] Subjective evaluations were compiled from photographs taken of the panels installed in a construction zone. They also noted "no evidence of adverse reaction to the diamond pattern; there were no incidents or accidents in the construction zone that would indicate otherwise." The report recommended the use of the diamond vertical panel when no directional message component is required.

Included as an appendix to the Colorado report was a letter from the American Traffic Safety Services Association (ATSSA). That letter described an ATSSA evaluation of the diamond pattern barricade rail. Their evaluation involved taking slides at 250, 500, 750, and 1,000 ft [75, 150, 225, and 300 m] from the start of the taper, during both daytime and darkness. Subjective comparisons were made by using two projections, side by side. ATSSA concluded:

- Of all the barricade panel designs evaluated, the diamond pattern was the least effective in terms of visibility and effectiveness as a channelizing device. This was true both day and night.

- The most effective pattern was the standard diagonal orange and white stripe.

- From the comments and discussion of observers, there is an indication that for a series of devices, the diagonal stripe pattern does convey a message of direction. NCHRP Report 236 concluded that drivers do not recognize the direction message of a diagonal stripe, but the test was done in a laboratory with subjects being shown a slide of a single device. Further study is needed to determine how drivers react under actual conditions.

- In comparing different size barricade panels, the 12- by 36-in [30- by 90-cm] panel was the most effective followed by the 12- by 24-in [30- by 60-cm] and the 8- by 36-in [20- by 90-cm].

- The evaluation definitely seemed to support the conclusion of NCHRP Report 236 that shorter, wider boards are more effective than long narrow ones with the same area.

- The Type II barricade used in this evaluation (8- by 24-in) [20- by 60-cm] was less effective than the Type I with a wider top board. This seems to support a conclusion of NCHRP Report 236.

- Without question, the most effective traffic control device at night was the steady burn light. In all cases, none of the devices was visible from 1,000 ft [300 m] and most were not visible from 750 ft [225 m] and barely visible from 500 ft [150 m]. In all cases, however, steady burn lights were clearly visible from well beyond 1,000 ft [300 m] and they very clearly defined the taper. This is also consistent with NCHRP Report 236.

An Ohio study (1985) conducted a field evaluation of six different reflector/barrier markers.[6] The evaluation consisted of subjective judgments of the visual effectiveness of the various devices and observed driver "tendencies." The retroreflectivity of the six devices was also measured in a laboratory using FTMS 370. The author concluded:

- The 12-in [30-cm] high by 6-in [15-cm] diameter mini-barrels on the top of the PCB at 25 ft [7.5 m] spacing provided adequate delineation. The cylindrical shape reduced any need for orientation of retroreflectors toward oncoming traffic.

- The 6- by 18-in [15- by 45-cm] hazard panel provided adequate delineation in straight sections. However, the installation was cumbersome and proper orientation on curves could not be achieved for maximum reflectivity for both directions of travel with the same unit.

- The Safe-T-Spin rotating reflector provided noticeable delineation of the PCB both in daytime and at night, while the location experienced a steady breeze. The tendency of motorists to shy away from the PCB was observed when the device was spinning. The use of the Safe-T-Spin might be beneficial where motorists need to be kept farther away from the PCB (or any other traffic control device or hazard). Since the device depends on wind for spinning and optimum detectability, its spinning action cannot be relied on at all times.

- The reflectors (Stimsonite, Astro-Optics, and Reflexite units) by themselves did not provide adequate delineation.

NCHRP Report 236 and subsequent related work more specifically addressed the role of signs in providing advance warning and the role of channelizing devices in outlining the appropriate path through the work zone.[10,11] He summarized the purpose of channelizing devices, provided some general design principles, and listed some general application principles. Two of the conclusions are of particular interest: (a) the six types of channelizing devices can be equally effective or inducing desired driver behavior, and (b) speed limit spacing formula are adequate. This project will address these two issues.

DEVICE SPACING CRITERIA

The MUTCD provides specifications for the use of channelizing devices for several types of lane closure and median crossover situations. Selected excerpts are presented in appendix A of this report. Figure 6-7 of the MUTCD describes a typical application on a four-lane undivided roadway where half of the roadway is closed. Figure 6-8 of the MUTCD describes a similar situation on a four-lane divided roadway where the diverted traffic crosses over the median. Figure 6-9 shows the channelizing device configuration where half of a four-lane divided roadway is closed. Figure 6-10 describes how the channelizing devices should be deployed when closing several lanes on a multilane highway. In each of the situations, the same taper formula is specified:

$$L = S \times W \text{ for speeds of 45 mi/h [72 km/h] or more, or}$$

$$L = WS / 60 \text{ for speeds of 40 mi/h [64 km/h] or less}$$

where: L = minimum length of taper,
S = numerical value of posted speed limit prior to work zone or 85th percentile speed, and
W = width of offset.

The MUTCD also specifies that "the maximum spacing between channelizing devices on a taper should be approximately equal in feet to the speed limit." The same device spacing is suggested in each of these three different situations.

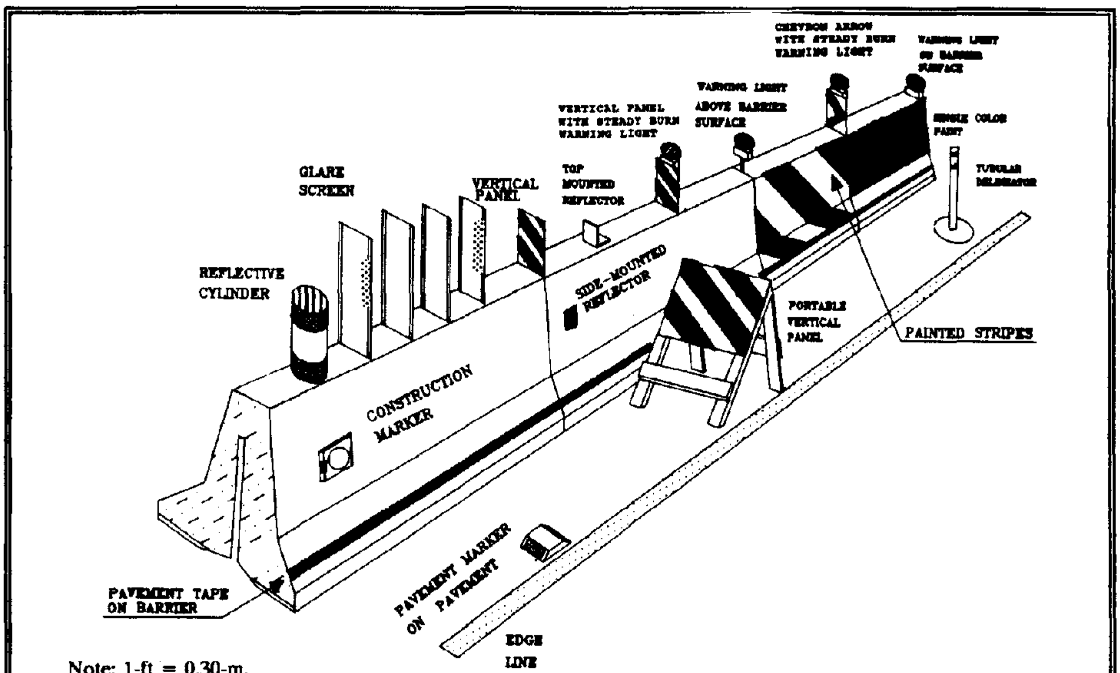
Although the length of the taper in each of the three situations is the same, there is a difference in the required length of the tangent section between two tapers when more than one lane is closed. When two lanes are closed on a four-lane highway (either divided or undivided), the tangent section should be half the length of the taper section. When two lanes are closed on a multilane highway, the MUTCD calls for a tangent section of 2L (twice the length of the taper).

A paper published in 1988 studied accident experience at short- and long-term freeway work zones.[17] It indicates that accident rates increased by an average of 88 percent during the existence of a long-term work zone. A nearly constant rate of 0.80 accidents/mi/day was noted for short-term work zone situations. In investigating the reasons for the increased accident experience, it was determined that major discrepancies existed between standards and practice. The discrepancies were more pronounced for the short-term work zones. It was noted that tapers were not consistent, an average of two devices was missing, and wide variations existed in the application and placement of advanced warning signs and arrow panels.

A study of barrier delineation treatments used in work zones focused on devices to augment the delineation of concrete safety-shaped barriers (CSSB).[10] The study considered top- and side-mounted reflectors, paints, raised pavement markers, warning lights, vertical panels, chevrons, reflective cylinders, reflective tapes on the side of the barrier, tubular markers, glare blades, vertical panels with warning lights, and ground-mounted vertical panels. The study concluded that delineators may need to be spaced more closely on curves that turn to the left. The smaller the radius of curvature, the greater the need for reduced spacing. A survey of state practices relative to the use and spacing of delineators was undertaken as part of this study. Figure 3 presents the results of the survey. It can be noted that there is a wide range of spacing requirements.

A similar study was undertaken at three limited access highway sites in Virginia in which steady-burn warning lights and reflectorized panels on CSSB's were compared. In these comparisons, closely spaced raised pavement markers were used to supplement the other delineation devices. The testing involved measurements of vehicle lateral position and speed and included observations for day and night and wet and dry conditions. It was concluded that reflectorized panels using high intensity sheeting should replace steady burn lights on tangent sections and that closely spaced raised pavement markers should be used as a supplement to other devices where alignment changes occur.

The use of steady burn lights on drums for tangent sections was evaluated in a study conducted in Ohio.[13] The research plan involved the use of test subjects driving an instrumented vehicle under day, night, rainy, and foggy conditions through a highway work zone. The tangent section of the work zone was delineated with drums having high intensity reflective sheeting. Steady burn lamps were installed on the drums for some tests and removed for others. Data were gathered for speed, lateral placement, acceleration noise, conflicts, and driver preference. Statistical analyses of the data led to the conclusion that steady burn lamps were not needed for work zones on rural sections of divided highways. This study did not involve altering the spacing of the drums during the tests.



Note: 1-ft = 0.30-m.

State	Device	Spacing	Position
California	Reflectors	MUTCD	Top
Virginia	Chevron arrow Type C Warning lights Vertical panel Reflectors	80-ft 80-ft 80-ft MUTCD	Top Top Top Top/side
Ohio	Reflectors	100 ft on curves < 5 degrees 50 ft on curves > 5 degrees MUTCD	Top/side
New Jersy	Type C Warning lights Reflector paddles	20 - 100 ft 100 ft on tangents 50 ft on sharp curves	Top Top Top
Illinois	Type C Warning lights Reflectors Vertical Panels Chevron arrow	20 - 100 ft MUTCD 50 - 100 ft 50 - 100 ft	Top Top Top Top
Michigan	Reflectors Reflective paddles Type C Warning lights Veritical panels	20 - 150 ft 5 - 150 ft 20 - 50 ft 50 ft	Top Top Top Top
Pennsylvania	Type C Warning lights Reflectors Vertical panels	50 - 80 ft 40 ft 40 ft	Top Top/side Base
Maryland	Reflectors Type C Warning lights	50 - 80 ft less than 50 ft on sharp curves 30 - 80 ft less than 50 ft on sharp curves	Top/side Top
New York	Type C Warning Lights Pavement markers on barrier	50 - 100 on flat curves/tangents 10 - 20 ft on sharp curves 4 - 6 ft	Top Base

Figure 3. Spacing standards for supplemental CSSB delineators.

COST CONSIDERATIONS

Studies have investigated the use of value engineering principles in selecting work zone channelizing devices.[15,16] Work zone channelizing devices are typically chosen on the basis of one of the following practices:

- Select the device with the lowest initial cost.
- Select a device that is normally used by the agency.
- Select a device already in stock.
- Select the "very best" device.

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

The selection of the most appropriate channelizing device for a work zone situation is a critical task. It requires an objective consideration of several factors including cost, safety, maintainability, availability, uniformity, project life, and work zone conditions. Because there is no widely accepted objective means for selecting work zone channelizing devices, the need for a proven approach like value engineering is well founded.

Value engineering is a formalized problem-solving approach directed at analyzing the function of an item to achieve the required function at the lowest overall cost. Two features of value engineering set it apart from other formal problem-solving techniques. First, it is concerned with function (i.e., identifying the desired function of an item or service). Second, it attempts to establish the relative value of alternatives for accomplishing a function.

The relationship between value (or worth as it is often called) and function is expressed in the following equation:

$$\text{Value} = \text{Functional Performance}/\text{Cost}$$

From this equation, it is seen that value may be increased by: (a) reducing costs, if performance is maintained or (b) increasing performance, but only if increased performance is needed and wanted and the user is willing to pay for it, or both (a) and (b).

The intent of value engineering is to find solutions that achieve the required function at the lowest overall cost. Value engineering does not strive to save dollars; dollar savings are automatic and maximum. In emphasizing function, value engineering lessens the chance that existing hardware limitations or established practices will confine creative thinking. Thus value engineering promotes objective and innovative problem solutions.

The selection of work zone channelizing devices using the value engineering approach involves the following seven steps:

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 on the basis of selected performance measures. (If it has not already been done, alternatives that 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.

Value engineering appears to be a useful and practical tool for selecting work zone channelizing devices. It provides an objective means of evaluating any number of alternative devices using whatever performance and cost data are available. Most important, it encourages the selection of low-cost devices that are safe and effective under the assumed conditions.

To be most effective, a value engineering study should be based on comprehensive and accurate information. One goal of the present project is to generate quantitative information on the relative effectiveness of the various delineation devices and alternative device configurations. This information, and the value engineering approach, allows the most effective device-spacing configurations to be identified.

The safety effectiveness of channelization devices represents the second major area of concern. Work zone accidents currently represent a major highway safety problem. A 1986 study described the characteristics of Maryland car/tractor trailer collisions that occurred in work zones.(19) A 187 such accidents occurred between 1983 and 1984 in Maryland. The following conclusions are possibly relevant to the role of channelizing devices in work zone safety:

- Twice as many Interstate road accidents occurred on wet roads as on noninterstate roads.

- Almost three times as many interstate accidents occurred at night than for noninterstate highways.

- Major reported causes of construction/maintenance accident cases were: (a) failure to drive within a single lane (4 out of every 10 cases), (b) failure to reduce speed (1 out of every 10 cases), (c) failure to yield right of way (1 out of every 10 cases), and (d) failure to drive within the designated lane (1 out of every 10 cases).

- By contributing circumstances, the major accident cause for both truck and car drivers on Interstate highways was failure to drive within a single lane (1 out of every 4 cases for trucks, 2 out of every 10 cases for cars).

- A high correlation was noted between in-State licensed cars and daylight accidents and between out-of-State licensed cars and nighttime accidents.

A New York State Department of Transportation (NYSDOT) study analyzed the use of plastic drums for work zone channelization.(18) The emphasis of the study was on the advantages of plastic drums in terms of reduced injury severity and reduced maintenance costs. It did, however, confirm that the high incidence of nighttime accidents in work zone taper and crossover areas underlines the importance of highly visible and properly installed channelizing devices. Some concern was expressed about the effectiveness of oblong drums:

> The flat side of the drum should present adequate target area to approaching motorists. FHWA is currently considering changes to the Federal MUTCD to specify an 18-in [45 cm] minimum width regardless of the orientation of the drum. Thus, it seems very appropriate that this project is examining the relative effectiveness of oblong drums at various orientations.

STATE OF THE PRACTICE

The current state of the practice was determined by reviewing documents containing standards and contacting public agencies. The Manual of Uniform Traffic Control Devices (MUTCD) and the Traffic Control Device Handbook (TCDH) were considered the primary standards documents. In addition, a training program offered by American Traffic Safety Services on work zone traffic control was reviewed. A survey of nine States and a number of manufacturers/suppliers was also conducted to determine current practices and device designs. The following paragraphs discuss the practices related to the selection and spacing of devices for work zone traffic control.

Current Standards

The current official procedures for using channelizing devices at construction zone lane closures and median crossovers are described in the MUTCD.[1] This document provides details on the design and use of regulatory, warning and guide signs, markings, lighting devices, as well as channelizing devices.

Section C of the MUTCD describes the function and application of various channelizing devices. Recommended dimensions for seven types of channelizing devices are provided:

- Type I Barricades - single 8- to 12-in by 24-in [20- to 30-cm by 60-cm] panels.
- Type II Barricades - double 8- to 12-in by 24-in [20- to 30-cm by 60-cm] panels.
- Type III Barricades - triple 8- to 12-in by 48-in [20- to 30-cm by 120 cm] panels.
- Cones - 18-in [45-cm] minimum.
- Tubes - 18-in [45-cm] minimum.
- Drums - 18-in [45-cm] wide by 36-in [90-cm] high.
- Vertical Panel - 8- to 12-in [20- to 30-cm] wide by 24-in [60-cm] high.

The recommended size and orientation of the orange and white striping for each device is given. The MUTCD does specify that traffic cones have a greater target value than do tubular-shaped devices, but makes no further statements of the relative effectiveness of devices.

The MUTCD also states that drums may be highly visible and "give the appearance of being formidable objects and, therefore command the respect of drivers." There is no other mention made of the relative effectiveness of the various types of devices in different situations. The MUTCD treats all seven devices equally in terms of required spacing and recommended length for taper and tangent sections.

The TCDH was designed and written to be used with the MUTCD and explains how to apply the standards to various work zone situations.[22] The use of signs, markings, lighting devices, delineation, traffic signals and channelizing devices are explained. The information on channelizing devices provided by the TCDH mirrors the MUTCD, with one notable exception. The TCDH describes the four-lane undivided roadway situation where half the roadway is closed by using a copy of MUTCD figure 6-7. A single lane closure on a four-lane divided highway is depicted using MUTCD figure 6-9. A multiple lane closure on a multilane highway is shown using MUTCD figure 6-10.

The TCDH (figure 6-18, appendix C) depicts a typical application where one roadway of a four-lane divided highway is closed using a figure similar to MUTCD figure 6-8, with one important exception. The TCDH calls for the length of the tangent section between the two lane closing tapers to be twice the length of the taper. The MUTCD specification for this section is one-half the length of the taper. The TCDH recommended tangent length is compatible with the taper length recommended for high-speed situations such as multiple lane closures on a multilane highway (figure 6-10). The MUTCD recommendation is identical to a four-lane undivided roadway where half the roadway is closed (MUTCD figure 6-7).

The TCDH specifications for channelizing devices are identical to those provided by the MUTCD. There is, however, some additional discussion about the advantages and disadvantages of the various devices. These comments largely address such factors as ease of use (i.e., cones are lightweight and easy to use) and specific applications (i.e., vertical panels are advantageous in narrow areas). There is no discussion of the relative effect of the various devices on driver behavior.

The American Traffic Safety Services Association (ATSSA) is a non-profit association organized for the purpose of promoting the best interest of the companies that provide traffic control and safety devices, materials, and services to governmental agencies and private industry. ATSSA sponsors a training course for work site traffic supervisors. The course is largely based on the MUTCD and the TCDH but provides some additional information. Specifically, the section on channelizing devices describes the advantages and disadvantages of cones, tubes, drums, barricades, and vertical panels.

Survey of Current Practices

Nine States were contacted to determine how lane closures and median crossovers are currently being delineated. A State official, typically the traffic engineer, was contacted and the purpose of the project was explained. Each was asked to provide specific information on the delineation devices used and the spacing used when installed on tangents and tapers. Table 3 provides a tally of the responses received from the nine States. Not all States responded to all the questions so there are not always nine responses to each question. Although these responses do not constitute a statistically valid survey, they do provide some interesting information. First, there is greater variability in the type of devices used than in the spacing configurations used. Plastic drums (both round and oblong) are the most frequently used devices while barricades (Type I, II or IIIs) are far less commonly used. Most States appear to use devices of the minimal size specified in the MUTCD. All of the States either meet or exceed the MUTCD recommendations for minimum spacings between devices and minimum taper length.

Nine manufacturers/suppliers of work zone traffic control devices were also contacted. Each firm was identified through ATSSA as a major supplier of channelizing devices. Each supplier was asked for product specifications (information on the operational and functional characteristics of the devices they sell) and placement specifications (information on the suggested or recommended installation procedures). Although most of the suppliers responded, most of the responses did not provide the requested information. No useful product performance specifications were provided such as, detection distance or retroreflectivity. Virtually all of the suppliers purported that their products "meet or exceed MUTCD standards" but did not provide any relevant psychophysical performance information. By "meeting... standards," the manufacturers are merely asserting that their products are built to the physical dimensions specified by the MUTCD. Apparently most advertising claims of "easier," "better," "brighter," etc. are largely subjective or the unsolicited comments of satisfied customers.

SUMMARY AND CONCLUSIONS

The state of the practice review provided a comprehensive overview of work zone channelization devices, their applications, and assessments of effectiveness. The following conclusions were made:

- A wide variation in the types of devices that are considered acceptable for use in work zone channelization exists. Six different devices are outlined in the MUTCD and variations of these designs can be found in the standards used by state and local agencies.

- Variations in the design features of devices are further promulgated by the competition between manufactures to develop devices that are more durable, better able to stand up to traffic influences, more cost effective, and easier to handle.

- Further variations in the visibility of channelization devices results from the effects of age, weather, handling, work area dirt, and traffic incidents.

- Basic research has been conducted into the various aspects of work zone traffic control including the effectiveness of various types of devices, the influence of advance warning signs, pavement markings, the use of arrow panels, and warning lights. The research has identified design features and application practices that have been adopted into MUTCD or state standards.

- The effects of roadway alignment, cross section, and lighting have been considered in many of the research studies on work zone traffic controls, but the current MUTCD recommendations for device spacing do not consider situational features.

- There appears to be no scientific basis for the spacing criteria for devices used for channelization purposes in the taper or tangent sections of a work zone.

- Agencies generally follow the MUTCD spacing criteria as standards, but assuring that crews and contractors follow these standards has been difficult.

- From a contractors viewpoint, it is desirable to use as few devices as possible without jeopardizing safety.

These conclusions support the need to analyze the effectiveness of spacing related to the various types of approved devices.

Table 3. Summary of device-spacing standards identified in State agency contacts.

Device	Dimensions	Percent	Percent Reporting Device Application: Lane Closure: Almost Always	Lane Closure: Often	Lane Closure: Sometimes	Lane Closure: Almost Never	Median Crossover: Almost Always	Median Crossover: Often	Median Crossover: Sometimes	Median Crossover: Almost Never
Type I Barricade	8-in by 24-in	33%	---	---	44%	33%	---	11%	---	67%
	8-in by 36-in	11%								
Type II Barricade	8-in by 24-in	33%	11%	---	22%	33%	11%	22%	---	---
	8-in by 36-in	11%								
Type III Barricade	8-in by 72-in	22%	11%	---	44%	33%	11%	---	33%	22%
	48-in by 60-in	11%								
Vertical Panels	8-in by 24-in	56%	---	33%	---	44%	11%	33%	---	33%
	12-in by 36-in	11%								
	18-in by 36-in	11%								
Metal Drums	18-in Diameter	22%	---	11%	---	78%	---	---	---	78%
Round Plastic Drums	18-in Diameter	67%	---	67%	11%	11%	33%	22%	11%	22%
Oblong Plastic Drums	18-in by 9-in	33%	22%	22%	22%	22%	---	33%	---	33%
Cones	18-in High	22%	22%	67%	11%	---	22%	---	11%	44%
	28-in High	67%								
	36-in High	11%								
Tubes	18-in High	---	---	33%	---	67%	---	---	11%	67%
	28-in High	22%								
	36-in High	67%								
	40-in High	11%								

Note: 1-in = 2.5-cm.

CHAPTER 3: LABORATORY TESTING

A variety of traffic control devices and installation configurations for work zone delineation were identified in the review of the literature and the survey of current practices. While the MUTCD permits the use of these various devices for work zone delineation, it recommends a common spacing criteria for the tapers. The focus of the second phase of the research was to determine the most appropriate spacing configuration for each type of device using a laboratory-based testing procedure. The results of the laboratory comparisons provided insights into which device-spacing configurations are most effective.

TEST PLAN OVERVIEW

A plan was formulated to test each of the devices under each of the spacing configurations for right- and left-lane closures and median crossover situations. Lane closures were represented by deploying the devices along a taper in advance of the lane to be closed. The median crossover situations were represented by deploying devices tangent to the travel lane in advance of the taper. The tests were designed to obtain motorist response data for the 96 test scenarios shown in figure 4. Over 280 persons, selected from patrons of a local department of motor vehicles (DMV) office and representing a cross section of drivers, participated as subjects in the test. Their responses were analyzed to evaluate driver performance relative to the various conditions.

Preliminary research had shown that the nighttime condition represents the most critical situation. Therefore, the simulated driving scenes were all of nighttime conditions. The tests minimized the influence of continual visual reference aids or distractions that could alter driver performance by using an unopened section of highway with no adjacent development. Distractor signs were randomly included in the test media to assess the impacts of distractions relative to performance. To focus strictly on the effectiveness of device-spacing configurations, arrow boards and other forms of construction zone signing were not included in the test media.

The objective of the laboratory testing was to gain fundamental insights into motorist responses to various device spacing configurations and to narrow the number of device-spacing conditions to be considered in subsequent field tests. In order to accomplish these objectives it was necessary to:

- Create simulated work zone situations where different devices and configurations could be filmed for viewing by test subjects.
- Implement an effective means to present the test scenes to subjects in a randomized fashion and record comprehension and recognition distances.
- Conduct ests for a large number of subjects representing a cross section of the driving population.
- Statistically analyze the results to determine if there are significantly different degrees of driver performance between the various device and spacing conditions.
- Interpret results to focus on the devices and configurations for further field testing.

This chapter describes the laboratory research procedures, the results obtained, and the interpretation of the findings.

Interactive video techniques were developed to test motorist comprehension of various device-spacing configurations in work zone situations. In order to test driver responses to a uniform set of visual stimuli, a series of highway scenes showing different construction zone treatments was created. These

WORK ZONE SITUATION	Left-Lane Closure						Right-Lane Closure					
DEVICE LOCATION	Taper			Tangent			Taper			Tangent		
DEVICE TYPES / SPACING (ft)	55	82	110	55	82	110	55	82	110	55	82	110
Round Drums 18-in diameter)												
Oblong Drums												
Oblong Drums - Skewed 45^{O}												
Oblong Drums - Skewed 90^{O}												
Type II Barricades												
Vertical Panels												
Cones (28-in with collars)												
Tubes (28-in with collars)												

Figure 4 - Fundamental plan for the laboratory testing.

scenes were then presented to test subjects in preset sequences by a microcomputer controlled video player/recorder. The computer found particular segments of highway on the videotape, displayed then to the test subjects, and recorded their responses. Subjects were asked to indicate when they were able to determine lane closures by pressing certain keys on the keyboard. The computer recorded the moment subjects responded and the nature of the response.

The resultant data provided the basis for statistical analysis of the number of responses, the accuracy of responses, and recognition distances. The analysis scheme also considered the effects of various perspectives of the roadway, driver characteristics, and the impacts of distractors. The following sections describe the research procedures used.

HIGHWAY SCENES

A series of nighttime highway lane scenes was created by setting-up mock lane/shoulder closures and median crossovers on an unopened section of roadway. Highway scenes were created for the following combinations of conditions:

- Device spacings of 55-, 82.5-, and 110 ft [16.5-, 24.7-, and 33.0-m].
- Various types of devices including cones, plastic tubes, round drums, oblong drums, vertical panels, and Type II barricades.
- Randomly placed distractors.
- Driving in the left or right lane.
- Right lane, left lane, and shoulder closure situations.
- Lane closure and median crossover configurations.

In each case, the same segment of straight, level highway was used. The highway section was in an undeveloped area, so there were no elements that would distract the driver or alter lighting levels. All filming runs were made using only the low beams on the vehicle. Cameras were mounted in the vehicle to provide a driver's eye view of the road. All passes of the filming vehicle were made at a travel speed of 50 mi/h [80 km/h]. The weather was clear and dry on each night that a test condition was filmed. The resulting video recordings were believed to represent a driver's perception of a roadway at night.

Testing involved the use of three different sets of roadway scenes having different types, configurations, and spacings of devices for the delineation of right-lane, left-lane, and shoulder work zones. In each case two orders of scenes were used to minimize the possible effects of subject learning or fatigue on the results. Thus, a total of six different scene sets were used with 46 scenes in each. A total of 138 different highway scenes were necessary to depict the various combinations of the following variables:

- Device Type.
    - tubes (TB).
    - cones (C).
    - vertical panels (VP).
    - type II barricades (TT).
    - oblong drums, skewed 90 degrees (SB).
    - oblong drums, skewed 45 degrees (AB).
    - oblong drums, no skew (FB).
    - round drums (RB).
- Configuration.
    - devices start on taper (TAP).
        - for right lane closure.
        - for left lane closure.
    - devices on tangent then taper (T/T).
        - for right lane closure in median crossover.
        - for left lane closure in median crossover.
    - devices close right shoulder (SHR).
    - devices close left shoulder (SHL).
- Approach Lane.
    - vehicle driving in right lane (R).
    - vehicle driving in left lane (L).
- Spacing.
    - 55-ft [16.5-m] between devices (55).
    - 82.5-ft [24.7-m] between devices (82).
    - 110-ft [33.0-m] between devices (110).
- Presence of a Distractor.
    - No distractor (N).
    - Distractor in scene (Y).

Each tape was structured to begin with a set of scenes and an audio track describing the types of situations the subjects would see and outlining how they were expected to respond. The introduction was followed by three practice scenes that allowed subjects to "get a feel" for the test procedures.

TEST PROCEDURES

The interactive video system used for testing displayed the video scenes and allowed subjects to indicate when they recognized the nature of the work zone. The computer noted the key code and video frame number when a response was given by the subject. The correctness of subject responses was established by comparing the key code to the table of scene characteristics. The frame number references to the closure points were determined to permit computation of the recognition distance. The computer also recorded the number of key entries by the subjects to discern if they changed their minds.

Software was developed to initialize the system, provide for input of data on each subject, provide instructions to the subjects, select test segments and display them on the video monitor, and record the recognition point (frame number) and the key pressed (answer code). A circuit board added to the microcomputer permited software control of the video player-recorder. Using this equipment, computer processing speed was fast enough to record successive subject responses within fractions of a second.

Testing was conducted according to standard procedures. Subjects were selected at random but in an manner that provided a cross section of males and females across all age groups. Subjects received a brief verbal explanation of the test and the system. They went through the training and practice sequences and were given an opportunity to ask questions prior to the start of the test. Subjects were monitored during the test, but no further instructions were given. At the completion of the test, subjects were asked about their preferences for work zone delineation.

DRIVER RESPONSES

The testing was conducted at a department of motor vehicles office where a good cross section of drivers could be found at any time of day. Over 280 subjects were tested. The distribution of drivers is given in table 4. The data were screened to eliminate subjects who apparently failed to understand the test or quit prior to its completion. This resulted in the elimination of about a half dozen subjects.

Subjects responded to the test media (i.e., highway scenes) by pressing one of three keys on the computer keyboard:

- Right cursor - When the subject thought the right lane was being closed.
- Up cursor - When no lane was being closed, i.e., only a shoulder closure was occurring.
- Left cursor - When the subject thought the left lane was being closed.

These three keys were labeled with right-pointing, up-pointing, and left-pointing arrows respectively. The computer recorded the scene frame number being presented at the touch of the key. The computer beeped to indicate that the keystroke had registered.

ANALYSIS OF RESULTS

The objective of this research was to determine if a difference exists in the effectiveness of various types of devices at different spacings for work zone delineation. The research hypothesis may be stated as: There is no significant difference in driver performance in work zone situations for standard devices at various spacings. Driver performance for this research was measured in terms of correct responses and recognition distances. The analysis was structured to focus on spacing under different deployment configurations. The following paragraphs describe the data analysis undertaken to support or reject the above hypothesis. The paragraphs follow the sequence of the analysis.

Table 4. Profile of subjects tested.

Age Group	Tape A Male	Tape A Female	Tape B Male	Tape B Female	Tape C Male	Tape C Female	Totals Male	Totals Female
16-20	2	4	0	2	2	2	4	8
21-25	11	9	4	1	3	3	19	13
25-30	12	13	4	4	5	6	21	23
31-35	6	6	4	3	3	4	13	13
36-40	8	5	2	0	4	2	14	7
41-45	4	4	1	2	2	3	7	9
46-50	7	2	3	4	1	2	11	8
51-55	3	4	3	1	2	6	8	11
56-60	3	3	3	1	2	3	8	7
61-65	2	2	2	3	2	1	6	6
66+	2	4	2	11	8	3	12	18
Totals	60	56	29	32	34	35	123	123
							Total Subjects:	246

The data set for analysis consisted of one record for each scene shown to each subject. A record was included even if the subject failed to respond to a particular scene. This resulted in a total of 10,994 records for analysis. Table 5 gives a summary of the characteristics of this data set. The largest percentage of the data records (cases) were associated with tape A, with the remainder approximately split for tapes B and C. It can be noted that the sample was almost equally split into males and females. By design, the scenes were relatively equally divided into eight device groups ranging from 8.7 to 13.0 percent. It was discovered after the testing was completed, however, that one test condition (cones at 110 ft [33-m] spacing in tangent then taper configuration) had inadvertently been excluded.

Table 5 also indicates the relative distribution of cases by configuration type. Because the taper (TAP) and tangent then taper (T/T) configurations were the focus of the study, they represent the largest proportion of the cases for each tape. The shoulder closure situations were added to require subjects to differentiate between lane closing and no lane closing situations. The distribution of scenes by spacing reflects the difference between tapes A, B, and C. The number of combinations that a subject needed to see was too great to allow more overlapping of scenes among the various spacing groups. A small set of common scenes were included in the overall scheme to allow the determination of influences. In most cases, the driver's approach perspective was from the right lane. Distractors were only used in a few instances.

Table 5. Dataset factor distributions.

Factor	Order Group	Tape A	Tape B	Tape C
	Cases	5,060	2,806	3,128
		(Percentage of Cases)		
Subject Sex	Male	48.2	52.5	51.5
	Female	51.8	47.5	48.5
Devices	Acute Barrels (AB)	13.0	10.9	10.9
	Cones (C)	13.0	8.7	8.7
	Fat Barrels (FB)	8.7	13.0	13.0
	Round Barrels (RB)	15.2	17.4	15.2
	Skinny Barrels (SB)	15.2	13.0	17.4
	Tubes (TB)	13.0	15.2	10.9
	Type II (TT)	8.7	10.9	10.9
	Vertical Panels (VP)	13.0	10.9	13.0
Configuration	Left Shoulder Closed (SHL)	8.7	8.7	10.9
	Right Shoulder Closed (SHR)	8.7	8.7	8.7
	Tangent then Taper (T/T)	39.1	39.1	37.0
	Taper (TAP)	43.5	43.5	43.5
Spacing	55-ft [16.5-m]	76.1	4.3	4.3
	82.5-ft [27.4-m]	0.0	69.6	0.0
	110-ft [33.0-m]	23.9	26.1	95.7
Approach Lane	Left Lane (L)	8.7	8.7	8.7
	Right Lane (R)	91.3	91.3	91.3
Distractors	No	91.3	91.3	91.3
	Yes	8.7	8.7	8.7

The question of whether age influenced the results was addressed. It was determined that driver performance in terms of the number of correct responses before the closure point decreased with increasing age. There was no significant difference in the percent correct responses by spacing group. The effects of subject sex were also reviewed. It was determined that male drivers performed no differently than female drivers in this test.

Initially, gross measures of performance were analyzed. These measures are presented in table 6. The measures include the percentage of times subjects responded correctly the first time, the percentage of times they were correct with their final responses, and the percentage of subjects that had given the correct response by the point of closure. It can be noted that similar trends in performance occur for each tape group. Generally, the percentage correct increases with proximity to the closure point. For example, for tape A, 64 percent were correct on the first response, 42 percent correct before reaching the closure point, and 85 percent correct ultimately. The percent ultimately correct must be treated cautiously, however, because it becomes obvious that a closure is taking place after the point of inflection. The tests were conducted so that all responses were captured, even those occurring after the closure point. It was concluded that comparisons should be based only upon responses before the closure point.

Table 6. Summary of gross measures of performance.

Factor	Order Group	Tape A	Tape B	Tape C
	Cases	5,060	2,806	3,128
		(Percentage of Cases)		
First Response Correct	No	36.0	36.4	32.6
	Yes	64.0	63.6	67.4
Final Response Correct	No	14.7	18.8	13.1
	Yes	85.3	81.2	86.9
Correct Response by Closure Point	No	58.3	65.2	60.6
	Yes	41.7	34.8	39.4

In looking at the responses, it was noted that a number of subjects changed their minds while viewing the scenes. It was evident that some initial guessing took place and that there were some difficulties in determining the meaning of the devices. Subsequently, it was determined that it would be most appropriate to focus on the last response before the closure point. The reaction time of the subjects also had an impact on performance. Subjects uncertain about the meaning of devices were sometimes unable to respond before the computer ended the scene. Since the test procedures did not mimic the driving task, it was not possible to assess subject response under uncertainty (ie, slowing or initiating a lane change).

Analysis of variance (ANOVA) procedures focused on those scenes depicting the key factors. A core of 32 scenes from each of the tapes was isolated. The scenes depicted one of the eight devices in a taper (TAP) or tangent then taper (T/T) configuration. Only scenes viewed from the right lane were considered in this analysis. A 3 x 8 x 2 x 2 ANOVA design for spacing, device, configuration, and closing lane factors was used with repeated measures on the last three factors. This approach eliminated the confounding effects of non-closures, different driver perspectives, and distractors. A total of 7,104 data records comprised this core group.

A difficulty was encountered in this approach because of the absence of data for one of the conditions. The analysis of variance for repeated measures requires a complete design. To overcome this difficulty, an analysis of the correlations between the various conditions was performed on the overall data set. This analysis indicated that correct responses for cones at 110-ft [33.0-m] spacings in left-side tangent then taper configurations was very closely correlated with those for tubes at 110-ft [33.0-m] spacings in left-side tangent then taper configurations. The value for the missing cell was then statistically fabricated to permit the use of ANOVA for repeated measures.

The ANOVA for the core group used the percentage of correct responses before the closure point as the primary measure of performance. The analysis found a significant interaction for spacing, device type, and configuration. Table 7 gives the mean percent correct for various devices, configurations, and spacing conditions. In general, there are appropriate trends in the results. Because the devices are listed in order of their relative reflective area, the percentages decrease when moving down any of the columns. In many cases, the percentages decrease with increased spacing, but the results are not consistent. It can also be noted that performance is better for right-side closing compared to left-side closing (all scenes considered here are from the right lane). Similar trends are noted when the results are collapsed over all configurations as shown in table 8.

Table 7. Summary of mean percent correct responses by closure for various device-spacing situations.

	Configuration											
	Taper Left			Taper Right			T/T Left			T/T Right		
Spacing (ft)	55	82	110	55	82	110	55	82	110	55	82	110
Device												
RB	28	25	18	57	50	47	44	55	34	66	43	38
FB	34	18	28	54	57	46	47	36	34	44	34	37
AB	33	27	31	58	43	52	43	41	29	36	57	31
SB	27	16	24	39	34	48	46	34	41	41	34	35
TT	42	27	28	54	50	57	56	39	44	32	39	31
VP	27	23	9	32	30	28	37	18	19	33	36	28
C	14	14	12	30	23	28	14	7	21	39	25	24
TB	14	18	9	36	27	25	20	27	21	27	27	35

Note: 1-ft = 0.3048 m.

Table 8. Summary of mean percent correct response for devices and spacings.

	Spacing (ft)		
	55	82.5	110
Device Type			
Round Barrels (RB)	49	43	34
Fat Barrels (FB)	45	36	36
Acute Barrels (AB)	42	42	36
Skinny Barrels (SB)	38	30	37
Type II (TT)	46	39	40
Vertical Panels (VP)	32	27	21
Cones w/ Collars (C)	24	17	21
Tubes w/ Collars (TB)	24	25	22
All Devices	38	32	31

Note: 1-ft = 0.03048 m.

The ANOVA results derived from considering the 7,104 core cases indicated that several significant interactions existed. Table 9 gives the effects that were analyzed. Those flagged with an asterisk were found to be significant. While intuitively some of these interactions are reasonable when considered singly, the four-way interaction presents a situation that is difficult to interpret. It was not possible to isolate individual factors when such interdependency existed for the overall dataset.

The ANOVA results indicated there are statistically significant differences associated with the following cells:

- Vertical panels at 55- and 82.5-ft [16.5- and 27.4-m] result in significantly better performance than at 110-ft [33-m] spacings for left-side taper situations.
- Vertical panels at 82.5- and 110-ft [27.4- and 33.0-m] spacings result in significantly poorer performance than at 55-ft [16.5-m] spacings for left-side tangent then taper situations.
- Round barrels at 82.5- and 110-ft [16.5- and 33.0-m] spacings function significantly poorer than at 55-ft [16.5-m] spacings under right-side tangent then taper situations.
- Acute barrels at 82.5-ft [27.4-m] spacings function significantly better than those at 55- and 110-ft [16.5- and 33.0-m] spacings for right-side tangent then taper situations.

The underlying four-way interactions limited further interpretation.

The analysis indicated a considerable amount of within cell variation. This could be attributed to the cross section of subjects, the difficulty of the visual task, and unavoidable distractions in the testing area. Other procedural and experimental design factors are not believed to have contributed to the within cell variance. For example, tested subjects rarely realized that the film sequences were taken on the same section of roadway.

The analysis was collapsed across all lane configurations to consider only device and spacing, as presented in table 9. The main effect of spacing is not statistically significant, but the main effect of device is significant (<0.0005). The interaction effect of device and spacing is also significant (0.004). For round barrels, there was a significant difference between the spacings at 55- and 110-ft [16.5- and 33.0-m]. For vertical panels there was also a significant difference between the spacings of 55- and 110-ft [16.5- and 33.0-m]. This confirms the initial hypothesis that there is an important relationship between device and spacing.

Table 9. Summary of ANOVA tests of significance by factor.

Factor or Combination	Significance Level
• Spacing	0.206
• Spacing and device	0.004 *
• Devices	< 0.0005 *
• Configuration	0.069
• Spacing and configuration	0.649
• Lane closing	< 0.0005 *
• Spacing and closing	0.708
• Spacing, device, and configuration	0.054
• Devices and configuration	0.030 *
• Spacing, devices, and closing lane	< 0.0005 *
• Devices and closing lane	0.009 *
• Configuration and closing lane	< 0.005 *
• Spacing, configuration, and closing lane	0.567
• Devices, configuration and closing lane	0.021 *
• Spacing, devices, configuration, & closing lane	< 0.0005 *

Note: "*" indicates that a significant difference exists.

From a traffic engineering perspective, recognition distance is an important concern. The driver's ability to see and perceive the nature of a lane closure dictates how devices should be deployed. Table 10 gives the mean recognition distances for each of the device, spacing, and configuration conditions. The distances are expressed in feet. The number of observations associated with each cell is also shown. These recogni-tion distances were all positive values since they are only associated with correct responses prior to the actual closure point. In fact, drivers can safely negotiate a lane closing even after the closure point has been passed. When the closure occurs in the adjacent lane only there is no risk in passing the closure point. This implies that the results are conservative.

The mean recognition distances were analyzed for device and spacing effects. Table 11 presents the mean recognition distance for each device and spacing combination. The mean recognition distance decreases with the relative amount of reflective area provided by the device. There are scattered indications that increased spacing reduces mean recognition distances, but these are not consistent.

An analysis was also conducted to compare the oblong barrel group (FB, AB, and SB) over the various spacings. There was no significant difference for the spacing effect, but significant effects for device and spacing by device. There was no significant difference between the performance for fat barrels versus acute barrels, but significant difference existed for skinny barrels versus the fat and acute barrels.

Analyses were conducted to determine if there were ordering or learning effects apparent in the data. No order group differences were noted when the data for 17 of the early test group subjects was ignored. The apparent ordering bias attributed to these subjects was considered the result of the early test procedures. To analyze learning effects, performance by relative position of groups of scenes was compared. The results for scenes viewed in the first half of the test versus those viewed in the second half of the test were compared. Performance was consistently better for the scenes viewed in the second half of the test for all orders. This was believed to be the learning effect. During the 20-minute duration of the test each subject saw 46 scenes. The subjects performed better for the latter scenes in all cases. This might be expected given the similarities that were found among the scenes as a result of using the same section of roadway under night conditions.

Table 10. Summary of mean recognition distance for correct responses by closure for various device/spacing situations.

	Configuration											
	Taper Left			Taper Right			T/T Left			T/T Right		
Spacing (ft)	55	82	110	55	82	110	55	82	110	55	82	110
Device												
RB	167	207	157	257	367	189	508	389	431	464	437	530
	31	11	12	63	22	32	49	24	23	72	19	26
FB	199	174	166	273	261	265	482	393	467	527	453	548
	38	8	19	60	25	31	52	16	23	48	15	25
AB	178	148	162	243	251	224	430	460	493	354	318	306
	36	12	21	64	19	35	47	18	20	39	25	21
SB	183	129	110	226	279	200	335	450	406	407	275	461
	30	7	16	43	15	33	51	15	28	45	15	24
TT	191	179	169	247	246	209	439	437	482	525	249	453
	46	12	19	60	22	39	62	17	30	35	17	21
VP	213	207	232	253	362	225	447	412	583	467	521	484
	30	10	6	35	13	19	41	8	13	36	16	19
C	152	139	135	239	257	206	485	328	508	335	422	508
	15	6	8	33	10	19	15	3	16	43	11	16
TB	135	160	227	319	210	291	313	402	570	333	299	343
	15	8	6	39	12	17	22	12	14	30	12	24

Notes: (1) The mean recognition distance (ft) appears over the number of observations.
(2) 1-ft = 0.3048 m.

Table 11. Summary of mean recognition distance for devices and spacings.

	Spacing (ft)		
Device Type	55	82.5	110
Round Barrels (RB)	349	350	327
Fat Barrels (FB)	370	320	362
Acute Barrels (AB)	301	294	296
Skinny Barrels (SB)	288	283	294
Type II (TT)	351	278	328
Vertical Panels (VP)	345	376	381
Cones w/ Collars (C)	303	287	339
Tubes w/ Collars (TB)	275	268	415
All Devices	280	307	343

Note: 1-ft = 0.3048 m.

INTERPRETATION OF FINDINGS

The above analyses led to the following findings:

- An ANOVA indicated that several significant interactions existed within the entire set of factors. The four-way interactions made interpretation of the results difficult.
- Collapsing the experimental matrix to the core scenes allowed an analysis of the effects of device type and spacing. The interaction of device and spacing was significant.
- Recognition distances for correct responses before the point of closure show trends similar to those noted for percentage of correct responses.
- Ancillary analysis of driver sex indicated no difference in performance.
- Analysis of driver age indicated that older drivers tend to perform poorer for all device, spacing, and configuration combinations.
- There was a consistent learning effect noted. The subjects tended to perform better for scenes in the latter part of each set.
- The ordering procedures used for this study did not significantly influence performance.

The Bonferroni inequality was used to examine the differences among the performance of the various devices and the differences among the performance of each device at the various spacing distances tested. This test was done so that the 24 mean performance scores given in Table 7 could be compared. This relatively conservative test generates the percentage difference that is needed to be able to state that one mean score is statistically different from another. Because there were a varying number of observations in each group, a total of 6 different percentages were computed, 3 for comparisons among devices at 55, 82, and 110-ft [16.5-, 27.4-, and 33.0-m] spacing and 3 for comparisons among the three spacings for each device.

As shown in figure 5, when examining the differences among the devices at the 55-ft [16.5-m] spacing a difference of at least 10 percent is needed to conclude that the devices are different at statistically significant level. The bars under the devices are used to show which devices are similar, i.e., not statistically different. Cones, tubes, and vertical panels are essentially equal while the larger devices are also essentially equal to one another, but different from the smaller devices.

The device effectiveness at the 82-ft [27.4-m] spacing is shown next in figure 5. For comparisons across this subset a difference of at least 16 percent is needed to demonstrate statistical significance. At the 82-ft [27.4-m] spacing cones, tubes, vertical panels, and skewed oblong barrels are not significantly different. Round barrels, oblong barrels at all orientations, and Type II barricades are also not significantly different from one another. Except for the worst devices (cones and tubes) and the best devices (round barrels and acute barrels) all of the devices are essentially equivalent at this spacing.

When comparing the various devices at the 110-ft [33.0-m] spacing a mean difference greater than or equal to 13 percent is needed to conclude that the differences between devices is statistically significant (see figure 5). Notice that cones, tubes, and vertical panels are equivalent while all of the larger devices are also essentially equal. The center dashed line in this figure depicts the surprising conclusion that round barrels and tubes are statistically equivalent at the 110-ft [33.0-m] spacing. Although the mean scores are 22 percent for tubes and 34 percent for round barrels, the 12 percent difference is 1 percent shy of the amount needed to demonstrate inequality.

```
Comparison:  Between devices at 55-ft [16.5-m] spacing

Difference Required for Significance:  10%
  Percent:  24     24     32     38     42     45     46     49
  Device:   C      TB     VP     SB     AB     FB     TT     RB
           -------------------
                         -------------
                                 --------------------------
                                      --------------------------


Comparison:  Between devices at 82-ft [27.4-m] spacing

Difference Required for Significance:  16%
  Percent:  17     25     27     30     36     39     42     43
  Device:   C      TB     VP     SB     FB     TT     AB     RB
            -------------------------
                -----------------------------------
                         --------------------------------
                              --------------------------------


Comparison:  Between devices at 110-ft [33.0-m] spacing

Difference Required for Significance:  13%
  Percent:  21     21     22     34     36     36     37     40
  Device:   C      VP     TB     RB     FB     AB     SB     TT
           ------------------
                         ------------
                                 --------------------------------
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Note: Dashed line connects statistically similar means, as determined by Bonferroni inequality

Figure 5. Comparisons between delineation device performance at various spacings.

Figures 6, 7 and 8 illustrate comparisons among the effectiveness of each type of device at 55- and 82-ft [16.5- and 27.4-m] spacings, 82- and 110-ft [27.4- and 33.0-m] spacings and 55- and 110-ft [16.5-and 33.0-m] spacings respectively.

In figure 6 the mean effectiveness of each device at 55-ft [16.5-m] spacings is listed along the top of the matrix. The mean effectiveness of each device at 82-ft [27.4-m] spacings is listed down the side of the matrix. The cell shading indicates when there is a significant difference between the device-spacing combination shown. For example, RB, AB and TT at 82-ft [27.4-m] spacings performed significantly better than either cones or tubes at 55-ft [16.5-m] (i.e. upper right-hand corner). A mean difference of 14 percent was needed to demonstrate a difference between the 55- and 82-ft [16.5- and 27.4-m] spacings. None of the individual devices showed this much difference. For 82-ft [27.4-m] spacing 6 of the 8 devices had lower mean scores relative to 55-ft [16.5-m] but, none of the effects were statistically significant.

Figure 7 shows the performance of the various devices at 82- and 110-ft [27.4- and 33.0-m]. Comparisons between the 82- and 110-ft [24.4- and 33.0-m] spacings require a difference of 15 percent in the mean scores. As was the case with the previous matrix, the lack of shaded cells generally indicates that the 110-ft [33.0-m] spacing is not significantly different than the 82-ft [27.4-m] spacing for most devices tested. Again, no single device showed that much change in mean score among 82- and 110-ft [27.4- and 33.0-m] spacings. All of the larger devices (barrels and Type II's) at 110-ft [33.0-m] are still more effective than cones at 82-ft [27.4-m] (right-hand shaded cells). It is not surprising that the smaller devices (cones, tubes and vertical panels) at 110-ft [33.0-m] are less effective than some of the larger devices (RB, AB & TT) at 82-ft [27.4-m] (shaded cell at the lower left).

Figure 8 shows the performance of the eight devices at 55-ft [16.5-m] versus 110-ft [33.0-m]. The comparisons among 55- and 110-ft [16.5- and 33.0-m] spacings required a 12 percent difference for a statistically significant inequality. Only one device, the round barrels, did significantly better at 55-ft [16.5-m] than at 110-ft [33.0-m]. Round barrels are better with 55-ft [16.5-m] spacings than all other devices at 110 ft [33.0-m] except the Type II barricades. Cones and tubes at 55-ft [16.5-m] are worse than Type II barricades and most of the various barrel configurations at 110-ft [33.0-m].

The variability among the effectiveness of the eight different devices tested makes it difficult to make simple generalizations about the effect of spacing on device performance. The results of the laboratory testing, although logically consistent, are not easy to interpret. They are consistent in that the bigger devices performed better, generally, than the smaller devices. And, when given devices were spaced closer together, they performed better than when they were further apart. The problems in interpreting the results are that: (a) many of the apparent differences are not statistically significant (due partly to large standard deviations), (b) the magnitude of the effect because of device spacing is not similar for the various devices, and (c) the differences among the various types of devices were much greater than anticipated. This last effect was especially surprising because each of the tested devices was found to be "interchangeable" in NCHRP Report 236. Like NCHRP 236, however, considerable variability was found in array detection distance among drivers.

Two other hypothetical outcomes would have been much easier to explain. For example, we might have found that all devices performed equally well, at the 55-, 82- and 110-ft [16.5-, 27.4- and 33.0-m] spacings. This would suggest that the 82- and 110-ft [27.4- and 33.0-m] spacings should be tried in the field to verify their apparent equality with the 55-ft [16.5-m] spacing. Or, we might have found that the 55-ft [16.5-m] spacing was significantly better than either the 82- or 110-ft [27.4- or 33.0-m] spacings for all devices. This would suggest that 55-ft [16.5-m] spacing is best for all devices and we would verify that finding in the field testing.

Unfortunately the results of the laboratory analysis are not clear-cut. Round barrels were significantly better with 55-ft [16.5-m] spacings than they were with 110-ft [33.0-m] spacings. The 82-ft [27.4-m] spacing was not significantly worse than the 55-ft [16.5-m] spacing. Thus, it might appear appropriate to verify in the field testing that 82-ft [27.4-m] spacing is as effective as 55-ft [16.5-m] spacing for this device.

However, the variability among the performance of the various devices makes this conclusion less clear-cut. The larger devices, barrels and barricades, were more visible even at 110-ft [33.0-m] than the smaller devices were at 55-ft [16.5-m]. Thus, it may not be appropriate that the field testing be undertaken to demonstrate that barrels are as effective at 82-ft [27.4-m] as at 55-ft [16.5-m] when barrels at the largest spacing tested were still better than tubes, cones or vertical panels at the tightest spacing.

In evaluating the effectiveness of construction zone delineation devices, NCHRP Report 236 noted large variability among subjects in both laboratory and closed field testing. The laboratory portion of this project found similarly large standard deviations even when a much larger subject sample size was used. This suggests that the use of laboratory and controlled field testing of these devices is inappropriate. Testing one component of work zone traffic control (i.e., channelization devices) out of context may be structuring a task that is either too difficult or too artificial. Since the task is so difficult or artificial, a greater variability in subject performance tends to occur.

The laboratory study did not indicate a significant difference in the performance of most channelizing devices whether they are spaced at 55-, 82- or 110-ft [16.5-, 27.4-, or 33.0-m]. This provided reasonable confidence that open field testing of the increased spacing would not result in increased risk. It appeared appropriate to by-pass the planned closed field testing and expand the level of effort planned for the open field testing. This allowed additional effort to be concentrated on obtaining more useful operational measures.

DEVICE EFFECTIVENESS AT 55-FT [16.5-M] SPACING

DEVICE EFFECTIVENESS AT 82-FT [27.4-M] SPACING

	RB 49 %	TT 46 %	FB 45 %	AB 42 %	SB 38 %	VP 32 %	C 24 %	TB 24 %
RB 43 %								
AB 42 %								
TT 39 %								
FB 36 %								
SB 30 %								
VP 27 %								
TB 25 %								
C 17 %								

LEGEND:
- RB - Round Barrels.
- FB - Oblong drums with skew.
- AB - Oblong drums with 45 degree skew.
- SB - Oblong drums with 90 degree skew.
- TT - Type II barricades.
- VP - Vertical panels.
- CC - Cones with reflective collars.
- TB - Tubes with reflective collars.

Note: 14 percent difference in mean score needed to demonstrate statistical inequality. Shaded cells indicate statistically different mean scores.

Figure 6 - Comparison of specific device effectiveness at 55- and 82-ft [16.5- and 27.4-m] spacings.

DEVICE EFFECTIVENESS AT 55-FT [16.5-M] SPACING

DEVICE EFFECTIVENESS AT 110-FT [33.0-M] SPACING

	RB 49 %	TT 46 %	FB 45 %	AB 42 %	SB 38 %	VP 36 %	C 24 %	TB 24 %
TT 40 %								
SB 37 %								
AB 36 %								
FB 36 %								
RB 34 %								
TB 22 %								
VP 21 %								
C 21 %								

LEGEND:
- RB - Round Barrels.
- FB - Oblong drums with skew.
- AB - Oblong drums with 45 degree skew.
- SB - Oblong drums with 90 degree skew.
- TT - Type II barricades.
- VP - Vertical panels.
- CC - Cones with reflective collars.
- TB - Tubes with reflective collars.

Note: 15 percent difference in mean score needed to demonstrate statistical inequality. Shaded cells indicate statistically different mean scores.

Figure 7 - Comparison of specific device effectiveness at 55- and 110-ft [27.4- and 33.0-m] spacings.

DEVICE EFFECTIVENESS AT 82-FT [27.4-M] SPACING

DEVICE EFFECTIVENESS AT 110-FT [33.0-M] SPACING

	RB 43 %	AB 42 %	TT 39 %	FB 36 %	SB 30 %	VP 27 %	TB 25 %	C 17 %
TT 40 %								
SB 37 %								
AB 36 %								
FB 36 %								
RB 34 %								
TB 22 %								
VP 21 %								
C 21 %								

LEGEND:
- RB - Round Barrels.
- FB - Oblong drums with skew.
- AB - Oblong drums with 45 degree skew.
- SB - Oblong drums with 90 degree skew.
- TT - Type II barricades.
- VP - Vertical panels.
- CC - Cones with reflective collars.
- TB - Tubes with reflective collars.

Note: 12 percent difference in mean score needed to demonstrate statistical inequality. Shaded cells indicate statistically different mean scores.

Figure 8 - Comparison of specific device effectiveness at 82-and 110-ft [16.5- and 33.0-m] spacings.

CHAPTER 4: FIELD TESTING

Field tests were conducted at construction sites to determine the effectiveness of the various devices under different spacing conditions. In these tests, the behavior of motorists was monitored to determine relative effectiveness. The desired impact of work zone channelization devices is to induce motorists to vacate the lane being closed before the start of the taper and to adjust their speeds accordingly. Therefore, a field testing procedure to monitor lane occupancy and traffic speeds on the approach to a lane closure was implemented. The field testing approach and findings are described in this chapter.

TEST PLAN OVERVIEW

The objective of the field testing effort was to determine if there were performance differences for the following combinations of devices and spacing conditions:

Devices
- Round barrels.
- Oblong barrels (skinny side facing traffic).
- Type II barricades.
- Cones with collars.

Spacing
- 55-ft [16.5-m] spacing (existing standard for 55 mi/h [88 km/h] roads).
- 80-ft [27.4-m] spacing (approximately 50 percent greater spacing).
- 110-ft [33.0-m] spacing (double the existing spacing).

In order to accomplish this objective it was necessary to:

- Develop a procedure for capturing pertinent traffic operational measures in the work zone.
- Identify work zone situations where different devices and configurations could be deployed.
- Establish techniques to record field data in a systematic manner.
- Obtain the field data from different sites under day and night conditions.
- Statistically analyze the data to determine if there were significant differences in traffic performance among the various device and spacing conditions.

The data were expected to provide the basis for revised guidelines for work zone delineation. This chapter describes the procedures used, the roadway and work zone situations selected, and the data gathered.

ROADWAY AND WORK ZONE SITUATIONS

Initially, it was believed that relatively similar work zone areas could be found to allow the data gathered to be compared across sites without introducing significant locational biases. The original goal was to select similar roadway situations having the following features:

- Level and straight alignment.
- Posted speed of either 45 or 55 mi/h [72 or 88 km/h].
- Median separation from opposing traffic.
- Limited interruptions from merging or crossing traffic.
- Two-lane cross section with shoulders.
- Moderate levels of traffic permitting free flow conditions.
- No major roadside elements that could distract the driver.
- No lighting.

Variations in these site features increased the potential sources of external bias in the data. It soon became obvious that controlling for these variations would be difficult.

Candidate sites for the field tests were identified initially from construction contract lists and maintenance schedules of State agencies. Work zone traffic control plans and the knowledge of agency staff served to provide the information needed to make location selections. After sites were identified, contacts were made with project engineers and contractor representatives to assess current project status.

A site with a new lane closure was considered the ideal situation. In such a situation, driver response to the device and its spacing are believed to be more indicative of its effect. Over time, motorists become familiar with a work zone site and react on the basis of previous experience. Because scheduling of data collection efforts to coincide with the beginning of highway work was difficult, existing construction sites with low percentages of commuter traffic were also considered acceptable.

Data were gathered at each of the sites given in table 12. The varied features of the sites necessitated that a case study approach be used for the analysis. Table 12 presents a summary of the location, alignment, speed limit, cross section geometry, type of work zone, and other features of each site. Table 13 presents the sites by the two primary factors - side of closure and day/night operation. Right-lane closures predominate because they represent situations where most traffic must make a lane change (assuming that motorists drive to the right as prescribed). Many of the sites were set up only during daylight hours making it impossible to gather nighttime condition data.

The basic set of device-spacing treatments was planned for each of the sites under both day and night conditions. The plan was to gather data for each of the conditions noted in the matrix shown in figure 9. Early completion of work activities or procedural anomalies sometimes prevented completion of the full set of treatments. In some cases, additional treatment conditions were included (i.e., the use of barrels with steady burn beacons).

Table 12. Site summary.

Code Location (Direction of Travel)	Alignment Vertical	Alignment Horizontal	Speed Limit	Lane Closed	Construction Activity
MD01 - US 40/48 west of MV Smith Road (WB)	- 3.0%	Curve RT	55	LT Lane	New Const.
MD02 - US 40/48 at MV Smith Road (EB)	- 2.0%	Tangent	55	LT Lane	Resurfacing
	- 2.0%	Tangent	55	RT Lane	Resurfacing
MD03 - US 40/48 east of MV Smith Road (EB)	+ 0.4%	Tangent	55	LT Lane	Resurfacing
	+ 0.4%	Tangent	55	RT Lane	Resurfacing
MD04 - US 40/48 east of MV Smith Road (EB)	+ 0.4%	Curve RT	55	LT Lane	Resurfacing
	+ 0.4%	Curve RT	55	RT Lane	Resurfacing
VA01 - I-95 south of Skipper, VA exit (NB)	+ 0.2%	Tangent	65	RT Lane	Reconstruct
VA02 - I-66 west of Marshall, VA Exit (EB)	+ 0.5%	Tangent	65	RT Lane	Resurfacing

Note: All sites had asphalt surface except VA01 which had a concrete surface.

Table 13. Categorization of sites.

Situation Type	Day Operation	Night Operation
Right Lane Closure	MD02	VA01
	MD03	
	MD04 *	
	VA01	
	VA02 *	
Left Lane Closure	MD01	MD01
	MD02	
	MD03	
	MD04 *	

Note: "*" indicates incomplete data set.

DEVICE	Side	SPACING					
		55 ft		82.5 ft		110 ft	
		Day	Night	Day	Night	Day	Night
Round Barrels	Right						
	Left						
Oblong Drums	Right						
	Left						
Type II Barricades	Right						
	Left						
Cones with collars	Right						
	Left						

Figure 9. Test conditions matrix.

FIELD PROCEDURES

Traffic data were gathered in the vicinity of the work zones at points in advance of the lane closure situation as shown in figure 10. Data were gathered at five points in advance of the lane closing and at one point downstream from the lane closure.

Three measures of performance (MOP) were used to assess the effectiveness of the various device and spacing combinations for lane closures. These measures included:

- Lane occupancy.
- Traffic speeds.
- Conflicts or erratic maneuvers.

The lane occupancy measures indicate when the motorist makes the necessary maneuver. It was decided that ideally this maneuver should be completed before the start of the taper. The distribution of traffic by lane at four points upstream from the start of the taper and at the taper was observed. This followed the hypothesis that the more visible the delineation, the sooner the motorist would move to the proper position on the road. Traffic speeds were also recorded at the beginning of the study section and at the beginning of the work zone. It was anticipated that some motorists would reduce their speeds to increase the time available to determine an appropriate response to the traffic controls. Last, conflicts at the taper were recorded. The conflicts provided a relative measure of motorists failing to realize the need to leave the closed lane and being forced to make an abrupt maneuver to avoid encroaching into the work zone.

While all of the measures could have been gathered at each point, it was determined that it was not necessary to do so. Speed data were gathered at points at the beginning and end of the study section. Lane occupancy data were gathered to allow a profile of lane changing behavior to be prepared. Conflicts data were gathered at the taper area to provide a measure of the frequency with which motorists took risks at the lane closure.

Study sites were selected at locations where uncongested conditions existed so that drivers were free to change lanes as soon as a lane closing was perceived. It was assumed that drivers would change lanes as soon as the need is perceived. The differences in the device-spacing combinations of the channelizing devices would influence the perception distance and, hence, driver behavior. Driver behavior was recorded in terms of lane occupancy, speeds, and conflicts/erratic maneuvers. Lane occupancy was considered the primary MOP. Conflicts and erratic maneuvers were recorded at the taper as an indication of possible failure of the device-spacing combination to direct the motorist of the need to change lanes. Traffic speeds upstream and at the taper were also gathered to determine if the nature of the device-spacing configuration influenced motorists speeds. Speed changes do not necessarily indicate the effectiveness of the device as motorists try to complete passes of slower moving vehicles. Some motorists by habit reduce their speeds to better assess a situation while others often ignore advisory work zone speeds.

A Kentucky study used percentage lane occupancy as the primary MOP in an evaluation of variable message signs, supplemental lane closure signs, and rumble strips used in addition to standard lane closure warning devices.[14] Measurements were taken at the taper, 500 ft [150 m] before the taper, and 0.9, 1.8, and 3.6-mi [1.45, 2.90, and 5.80 km] before the taper. A Texas study also used percentage of traffic in both travel lanes as the primary MOP.[4] Comparisons were made between the standard MUTCD and several candidate advisory signing treatments. Data were collected at 3,000, 1,500, 1,000, and 500 ft [150 m] from the beginning of the taper and at the beginning of the taper. Data was collected for one hour at each site for each condition being evaluated and significant differences among the advance signing treatments were found.

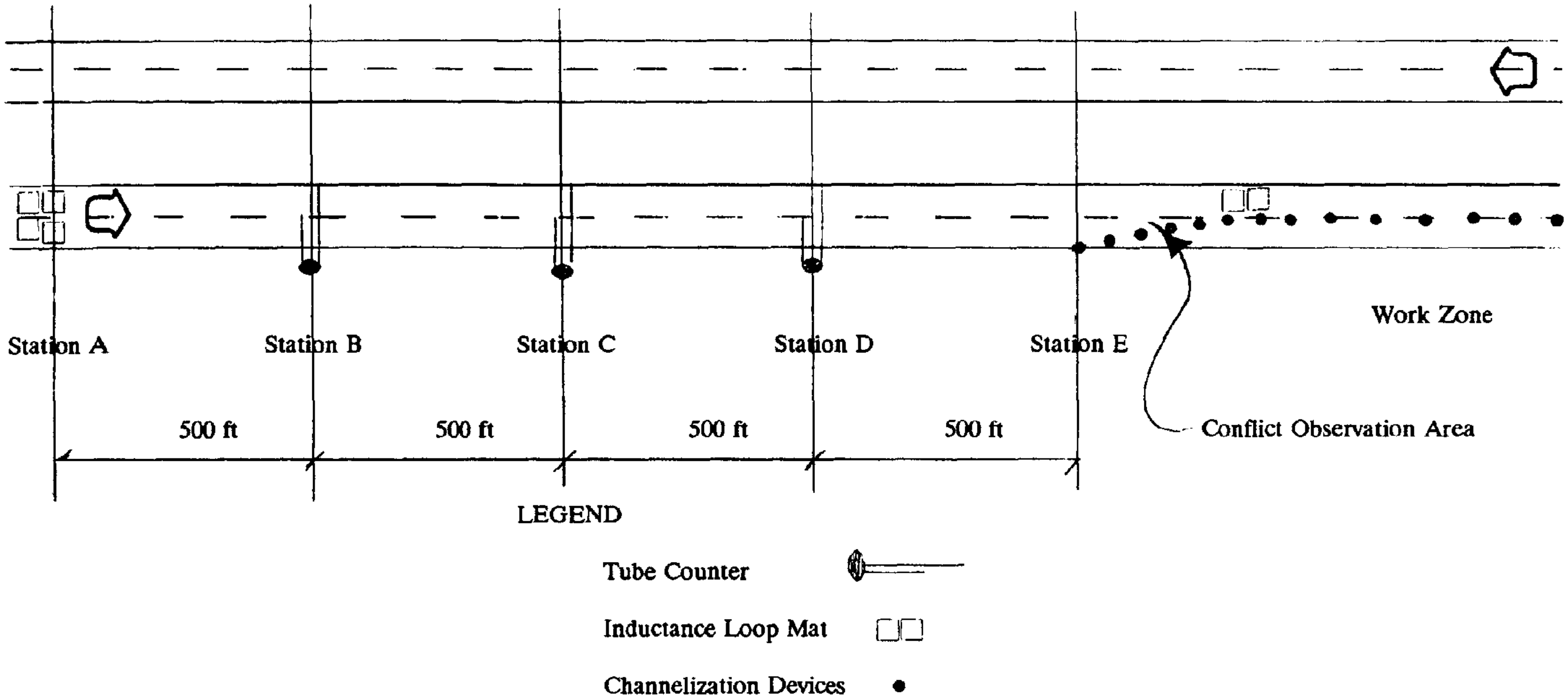


Figure 10. Diagram of data collection scheme.

Since lane changing behavior represents the most unambiguous measure of the effectiveness of work zone delineation, it is the preferred MOP. Lane occupancy measures represent the simplest means to represent changes in lane use by vehicles approaching work zones.

Data was collected using automatic traffic recorders and manual observations. The field procedures involved the installation of data collection equipment at 500 ft [150 m] intervals measured from the start of the taper for the lane closure. When feasible, upstream and downstream speeds were gathered using inductive loop mats (Stations A and D). Tube counters were placed at points 500, 1000, and 1500 ft [150, 300, 450 m] from the start of the taper to gather lane occupancy data. Data were gathered for 5-minute periods for approximately 1 hour or 150 vehicles under free-flow traffic conditions for each device-spacing configuration per site.

An observer at station D recorded the number of vehicles in the closed lane at the start of the taper and the number of merge conflicts. Another observer gathered the downstream speeds using radar. These two observers were used for all data collection periods. Other observers or data recording equipment were used to gather upstream speeds and lane occupancy data. All observers made notes on traffic anomalies that could potentially bias the data.

Data were gathered for periods ranging from 0.5 to 3.0 hours for each treatment condition. When possible, similar treatment conditions were tested on different days to experience variable traffic conditions. Both day and night data were gathered for long term lane closure situations.

During the field studies, motorist behavior was observed to record brake light applications, conflicts, or erratic maneuvers. These observations were concentrated at the start of the taper to determine if there was a noticeable confusion factor presented to the motorist by the device or spacing configuration. A brake light application was defined as an occurrence of a vehicle in a free-flow state with the driver applying brakes at the beginning of the taper. Brake light applications were taken to imply that the motorist was uncertain about the situation being encountered and was adjusting speed to accommodate it. Speed change, expressed by applying the brake, is only one example of driver behavior. It was not possible to record changes in vehicular deceleration that, in many cases, occurred instead of a brake application. A merge conflict was defined as a situation where vehicles in adjacent lanes competed for the position in the open lane into the taper area.

On a number of occasions, vehicles were observed to be in a passing mode into the taper. If one or more of the vehicles was required to brake in order to make a merge or complete a merge, then it was recorded as a merge conflict. Generally, traffic conditions were light enough so that motorists were readily able to change lanes. In some cases, overtaking slower vehicles near the work zone put motorists in the situation that they had to complete the passes in the taper area.

Lastly, an erratic maneuver was defined as an abrupt change of lanes by a motorist. It was recorded if it occurred near the start of the taper without the influence of other vehicles.

Observations were conducted for day and nighttime conditions. Brake light applications were seen more frequently at night and the increase in frequency can be attributed to the fact that motorists could not determine the road alignment beyond the reach of their headlights. Consequently, as they approached a work zone they did not know whether there was some immediate work activity taking place just beyond the work zone and compensated for this uncertainty by applying their brakes.

DATA PROCESSING

The field effort generated numerous individual data sets that were integrated into a master data set that consisted of the following information:

- Date and time period.
- Lighting code.
- Weather code.
- Location code.
- Side of roadway closed.
- Device code.
- Spacing code.
- Total vehicles count.
- Count of vehicles by lane and by station.
- Percentage occupancy by lane and by station.
- Traffic speeds by lane at station A.
- Traffic speeds by lane at station E.
- Number of merge conflicts at the taper.
- Number of brake light applications at the taper.

One record was created for each 5-minute interval of data collection and ancillary records were created for speed observations. Appendix C lists the data integrated into the project database.

Data gathered at each of the sites were keyed or downloaded from the data collection equipment into files for each time period and device configuration. The individual files of data were merged to form a single, integrated data base. A data base management software system was used to facilitate the entry, editing, organization, and retrieval of the information. The data were manually checked and reviewed for accuracy using various software tools.

Data gathered from the manual counts and traffic recorders were combined into a database covering the study periods. Observations were recorded for 5-minute intervals. The data recorded for each interval included upstream and downstream average speeds and standard deviations, traffic counts by lane and vehicle classification at each station, tube counts by lane and station, and number of merge conflicts and brake light applications by vehicle type. In addition, each data record indicated the device type, spacing, lighting condition, and anomaly codes.

The following types of devices were tested during the field studies:

- Round Barrels (RB).
- Standard Barrels (STD).
- Barrels with Beacons (BB).
- Oblong Barrels with narrow side to traffic (SB).
- Type II Barricades (TT).
- Cones with Reflective Collars (CC).

The codes for these devices that appear in the computer printouts are indicated. All of the devices except the standard barrels and barrels with beacons conformed to the current MUTCD standards for size and reflectivity. The standard barrels and barrels with beacons were devices used by the contractor to conform to State standards. Both Maryland and Virginia standards called for high-intensity reflective sheeting, that exceeds the national standard. The conditions that included flashing beacons on the channelization devices varied by State. In Maryland the beacons were found on alternating devices. In Virginia, they were placed on each device.

During the test periods, three basic spacing criteria were used. These were 55-, 82.5- (referenced as 80-), and 110-ft [16.5-, 27.4-, and 33.0-m]. Every effort was made to gather performance data for each of the spacing criteria at each site. This was not possible in some cases because the completion of the construction operations or the impacts of adverse weather on the research schedule. In some cases, it was possible to test devices at a 41.25-ft (referenced as 40-ft) [8.2-m] spacing. The shorter spacing was tested primarily for the smaller devices.

Sample printouts summarizing the data gathered for each time period at a site are shown as figures 11 and 12. These output reports provide a summary of all the data gathered or computed. From this data a number of traffic performance measures were computed. These measures included:

- Differences in car speeds upstream and downstream in the study section.
- Differences in truck speeds upstream and downstream in the study section.
- Percentage of traffic in the closing lane at station A.
- Percentage of traffic in the closing lane at station B.
- Percentage of traffic in the closing lane at station C.
- Percentage of traffic in the closing lane at station D.
- Percentage of traffic in the closing lane at station E.
- Percentage of car traffic in the closing lane at station E.
- Percentage of truck traffic in the closing lane at station E.
- Rate of conflict occurrence in the taper area.
- Rate of brake light applications in the taper area.
- Traffic volume level in terms of v/h.
- Percentage of trucks in the traffic stream.

A sample performance summary listing these measures is shown as figure 13.

Not all of these measures are considered to have the same importance or reliability. The lane occupancy and conflicts data taken at station E are considered to be the most important measures of the effect of the various device and spacing configurations. These data were gathered by a trained observer and the data defined the treatment periods used in the final analysis. Data derived from the road tubes and traffic recorders are considered less reliable. There are gaps in these data because of equipment failures and difficulties in downloading the information. Speed data were gathered using radar during most of the treatment periods. Radar was used as the primary means of gathering downstream speeds. Upstream speeds were gathered using radar only at short-term work zones where placing the mats for the duration of the construction operation was not considered feasible.

The database includes information on traffic performance on the approach to right- and left-lane closures on four lane divided freeways. Six sites were used in the field study effort. These sites were considered to be similar, but there were differences in alignment, speed limit, traffic conditions, and work zone conditions that may have influenced the results. These influences were common to all conditions tested at a given site, permitting inferences about the effectiveness of various device-spacing configurations to be made. The trends observed among sites may provide evidence about the effectiveness under different conditions. This must be considered important since work zones can occur anywhere.

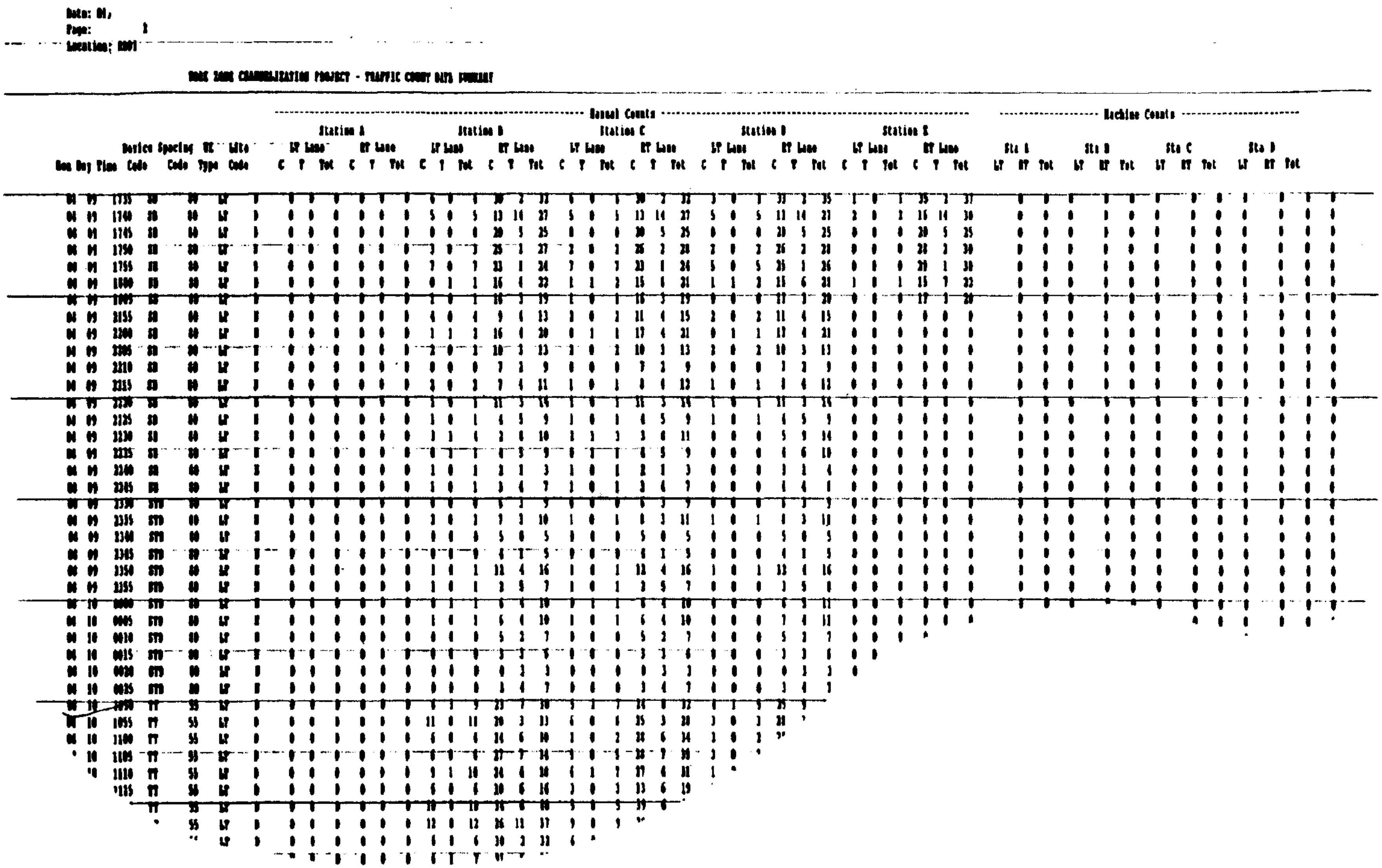


Figure 11. Sample counts data summary report.

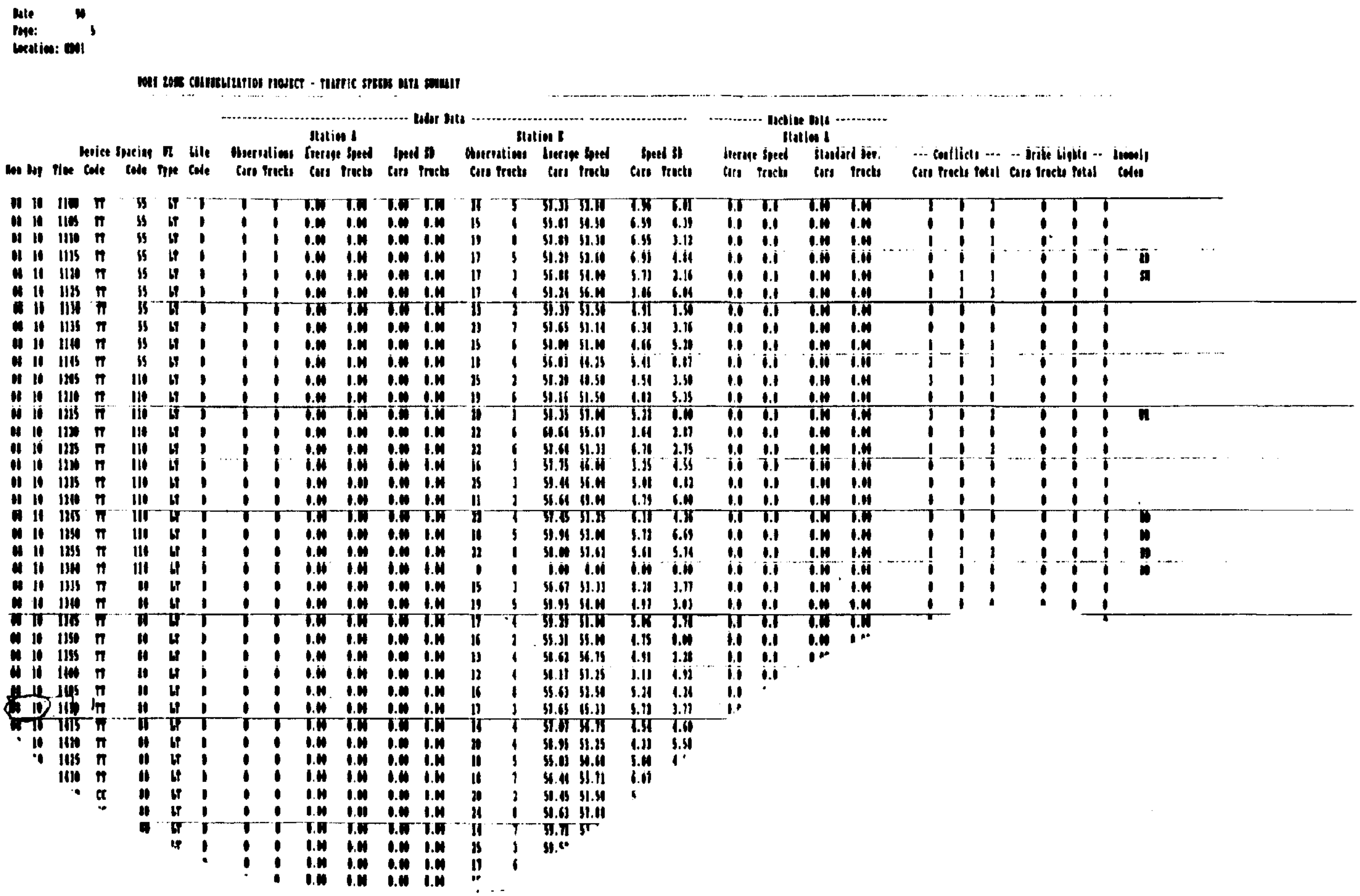


Figure 12. Sample speed and conflicts data summary report.

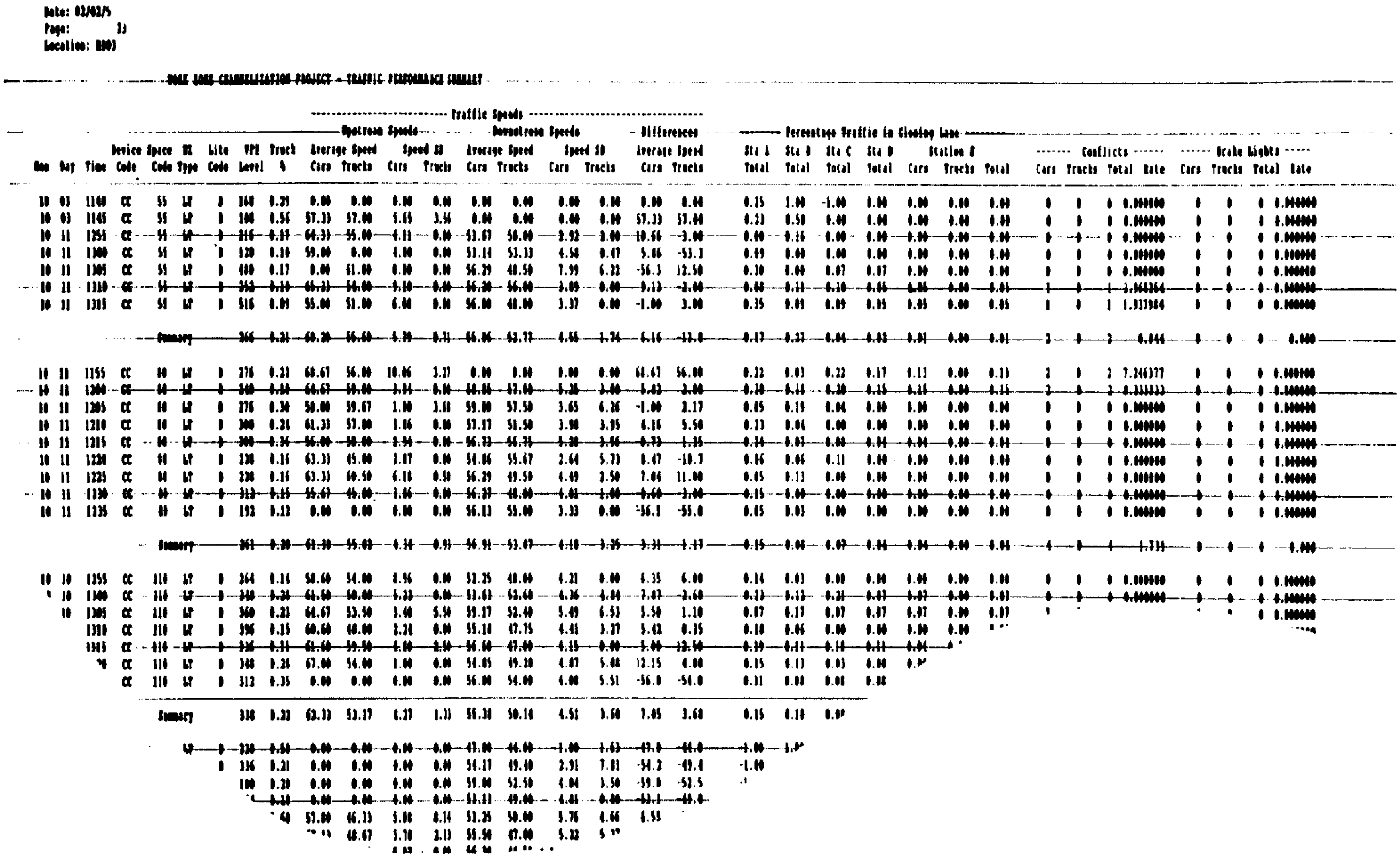


Figure 13. Sample performance summary.

DATA ANALYSIS

A number of questions existed relative to the performance of the various device spacing configurations at work zone situations. The intent of the statistical analysis of the field data was to provide answers to these questions. The important questions were:

- At each site, is there a performance difference among devices? Are these performance differences by device type consistent for speed, speed change, lane distributions, and conflict measures?
- For each of the sites, is there a difference in the performance for the various spacing levels? Are the performance trends consistent for speed, speed change, lane occupancy, and conflict behavior?
- For each site, are the individual device spacing conditions different from each other and are trends for speed, speed change, lane occupancy, and conflict measures consistent across all of these combinations?
- Are there groupings of device spacing combinations that function essentially equivalently for each site?
- What are the trends for the various device types for nighttime conditions, and are these trends consistent across the various measures?
- For each site under nighttime conditions, are the spacing effects consistent across the various measures?
- Do the measures of performance display similar trends under nighttime conditions for the various device spacing combinations?
- For each site, to what extent are the performance measures different for day or nighttime conditions under similar device spacing configurations? For the individual sites, are there basic volume level groupings for which device spacing performance is similar?

When considering all of the data for all of the sites, the following questions needed to be answered:

- Over all the sites, can a difference be noted among the device types used for the various measures of performance?
- Over all the sites, can a difference be noted relative to the spacing of devices for the various measures of performance?
- For all sites, is there a considerable difference among the performance for various device spacing combinations over the various measures of performance?
- Are there groupings of similar performance for the various device spacing combinations over all the sites?
- Can the differences in performance among sites be explained by one or more of the following factors: volume levels, horizontal and vertical alignment, type of work zone, and relative percentage of truck traffic?

These questions were addressed in the review of the basic field data and the subsequent statistical analyses.

A variety of analyses were undertaken using the data gathered in the field studies. These analyses ranged from the inspection of the trends in the data to the application of various analysis of variance

(ANOVA) techniques. Various data items were used and different relationships considered. It was determined that the percentage of traffic represented the best dependent variable because it was gathered by observation and was available for all treatment conditions. The analyses also considered conflict rates, brake light applications, and speed differentials in an attempt to isolate the factors influencing the effectiveness of the various device-spacing configurations.

The following sections provide summaries of the pertinent results of the testing of the various device-spacing configurations at each location. In each case, the site features and work zone characteristics are described and the associated influences discussed. Traffic conditions are also indicated. The basic differences among treatment conditions are presented and the findings of the statistical analyses are discussed.

Site MD01 - US 40/48 WB west of MV Smith Road

Work Zone Type

This site was located at the beginning of an 18-mi [28.8 km] construction area between Hancock and Cumberland, Maryland. A left-lane closure was in place during the study period. This was a long-term work zone delineated with standard barrels (high-intensity sheeting) having steady burn beacons on every other barrel in the taper. An arrow panel was placed at the third channelizing device.

Alignment Features

Traffic approached on a tangent with a slight downhill grade. The taper itself was located on a gradual curve to the right. The arrow panel was fully visible to motorists at 1200 ft [360 m] from the beginning of the taper. Advance warning signs were provided one-mile [0.62 km], one-half mile [0.31 km], and 1000 ft [300 m] from the beginning of the taper. Traffic was separated by a 30- to 40-ft [9- to 12-m] median having a double beam guardrail. The on-ramp from MV Smith Road ended about 600 ft [180 m] from the start of the taper. This ramp carried very little traffic, so it had no affect.

Traffic Conditions and Influences

Traffic volumes at this site were considered light with a moderate percentage of trucks in the traffic stream. During the daytime observation periods, traffic ranged from 212 to 460 v/h with trucks comprising 14 to 33 percent of the total. Nighttime volumes ranged from 12 to 159 v/h with 22 to 59 percent of the total being trucks. Traffic approaching the work zone was not influenced by any major traffic impediments for at least 8 mi [12.8 km]. This was reflected in the speeds, which ranged from 56 to 59 mi/h [90 to 94 km/h] on the average during the day to 54 to 58 mi/h [88 to 94 km/h] at night. Some minor roadside work or maintenance took place during the study period, but it did not have an influence on traffic in the study area.

Treatment Results

Table 14 gives the percentage of traffic in the closed lane at each station prior to and at the start of the taper. The table presents the percentage of traffic in the closed lane for each device at the three spacings tested. Because of equipment difficulties, no data are available for station A at 2,000 ft [600 m]. However data is available for the various test conditions at the other stations (B, 1,500 ft [450 m], C, 1,000 ft [300 m], and D, 500 ft [150 m] prior to the taper) and at the start of the taper. Data for other night treatments are not presented because traffic volumes were considered too low.

There are variations in the distribution of traffic on the approaches to the taper. While traffic moves from the closed lane as it approaches the taper, the spatial distribution on the lane changes is not consistent. The randomness of traffic arrival and headway conditions contributes to the differences in the percentages.

Statistical methods were used to determine if significant trends exist in driver response to the different treatment conditions. Table 15 gives the percentage of traffic in the closed lane at the start of the taper. A two-way ANOVA (device x spacing) performed on the MD01 daytime data in Table 15 found no main effects due to devices or spacing and no interaction effects between devices and spacing. A similar ANOVA on the night data revealed significant main effects due to devices and spacings (round barrels vs. Type II barricades) and an interaction effect. At this site under night conditions, Type II barricades spaced at 55-ft [16.5-m] had significantly more traffic in the closed lane (7 percent) than any of the other treatment.

Table 14. Percentage of traffic in closed lane prior to and at start of taper for MD01.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
MD01	Left	Day	Cones	1500 ft	20	21	21
				1000 ft	15	17	17
				500 ft	13	14	13
				taper	02	02	02
			Round Barrels	1500 ft	22	14	--(a)
				1000 ft	22	10	--
				500 ft	08	09	15
				taper	03	02	03
			Oblong Barrels	1500 ft	20	12	19
				1000 ft	16	12	15
				500 ft	12	08	10
				taper	03	03	03
			Type II Barricades	1500 ft	21	18	17
				1000 ft	15	12	13
				500 ft	11	09	10
				taper	03	04	04
MD01	Left	Night	Type II Barricades	1500 ft	14	11	15
				1000 ft	11	07	10
				500 ft	03	05	05
				taper	07	00	01

Notes: (a) "--" Indicates that a value was not established due to incomplete data set or inadequate sample size.
(b) 1-ft = 0.30-m.

Table 15. Percentage of traffic in closed lane at start of taper for MD01.

Site Code	Lane Closed	Light Condition	Device Type	Spacing (ft) 55	80	110
MD01	Left	Day	Cones	02	02	02
			Round Barrels	03	02	03
			Oblong Barrels	03	03	03
			Type II Barricades	03	04	04
	Left	Night	Round Barrels	01	01	01
			Type II Barricades	07	00	01

Note: 1-ft = 0.30 m.

Site MD02 - US 40/48 EB east of MV Smith Road

Work Zone Type

This work zone was set up to divert traffic alternately between the right and left lanes to allow resurfacing of a 4.5 mi [7.2 km] section of highway. The site was located about 1.5 mi [2.4 km] from the end of a long upstream work area, but it was believed that traffic approaching the study site was flowing freely. This work zone was set up only during daylight hours when resurfacing activities were in progress. The contractor delineated the work zone using standard barrels and an arrow panel at the beginning of the taper. Advance signing conformed to Maryland SHA standards. Stand-mounted aluminum signs were used.

Alignment Features

The work zone at this location was at a point beyond the crest of a vertical curve. The horizontal alignment on the approach was a gentle curve to the left that ended in a tangent section about 1,800 ft [300 m] from the start of the taper. A sharper curve to the left was encountered beyond the end of taper. Just beyond the crest of the vertical curve traffic passed under the overpass carrying MV Smith Road. On- and off-ramps at this interchange began and terminated near the boundaries of the study area. These ramps carried very little traffic because only a ranger station and a construction field office were in the area.

Traffic Conditions and Influences

Traffic at this site was light to medium. Volumes ranged from 232 to 415 v/h with 15 to 38 percent being trucks. Traffic, at times, came in surges because this site was located about 1 mi [0.62 km] from the end of the 18-mi [28.8 km] construction area. Traffic passing through the long work zone often was delayed by slow moving trucks, the movement of construction equipment, or temporary blockages for blasting. Traffic speeds averaged 57 to 63 mi/h [95 to 101 km/h] for the study periods. The higher speeds were believed to have been the result of having just traversed a long single-lane construction section.

Treatment Results

Table 16 gives the percentage of traffic in the closed lane prior to and at the start of the taper. In the case of the left-lane closure the percentage of traffic in the closed lane at the upstream position started at between 27 and 34 percent and was down to between 4 and 9 percent by the start of the taper.

Data in table 17 was analyzed using a two-way ANOVA (device x spacing) for night and left-lane closure situations. There were no significant effects for device, spacing, or device by spacing interactions.

Table 16. Percentage of traffic in closed lane prior to and at start of taper for MD02.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
MD02	Left	Day	Oblong Barrels	2000 ft	27	32	30
				1500 ft	13	15	18
				1000 ft	10	15	13
				500 ft	09	15	13
				taper	06	09	07
			Type II Barricades	2000 ft	26	30	34
				1500 ft	19	--[a]	--
				1000 ft	17	14	12
				500 ft	10	08	07
				taper	08	06	04
			Cones	2000 ft	--	32	32
				1500 ft	--	30	--
				1000 ft	--	14	12
				500 ft	--	12	09
				taper	05	06	06
			Round Barrels	taper	04	05	16

Notes: (a) "--" Indicates that a value was not established due to incomplete data set or inadequate sample size.
(b) 1-ft = 0.30-m.

Table 17. Percentage of traffic in closed lane at start of taper for MD02.

Site Code	Lane Closed	Light Condition	Device Type	Spacing (ft) 55	80	110
MD02	Left	Day	Cones	05	06	06
			Round Barrels	04	05	16
			Oblong Barrels	06	09	07
			Type II Barricades	08	06	04
	Right	Day	Cones	13	12	24
			Round Barrels	18	18	09
			Oblong Barrels	11	06	15

Note: 1-ft = 0.3-m.

Site MD03 - US 40/48 EB between MV Smith & Orleans Roads

Work Zone Type

This work zone was set up at about the midpoint of the section between MV Smith and Orleans roads. It was situated such that it was on a long tangent section with a very gentle upgrade. It had a wide, wooded median that totally blocked any view of opposing traffic. Both right- and left-lane closures were set up at this point during the several weeks data were gathered at this site. The arrow panel was located at the beginning of the taper and it was clearly visible from the first advance warning sign approximately 1 mi [0.62 km] away. The area was bordered by tall trees, which helped make the flashing arrow standout during daytime hours. This was a daytime only work zone.

Alignment Features

The study section was located near the end of a long tangent section on a gentle upgrade. The straight, level alignment provided the best possible view of the lane closure, particularly when traffic volumes were light. During data collection at this site, only temporary centerlines existed on the resurfaced roadway.

Traffic Conditions and Influences

Traffic conditions at this location were similar to those at site MD02. The same upstream influences existed, but the traffic was more dispersed by this point (approximately 4 mi [6.4 km] from the end of the major construction zone). Volumes during the observation periods ranged from 202 to 351 v/h with trucks comprising 14 to 38 percent of the traffic. Some platooning of vehicles by class was noted, but passenger cars generally operated in a free-flow mode. Drivers may have been influenced by the limited amount of pavement markings on the approach to the point of lane closure. Traffic speeds averaged 51 to 58 mi/h [82 to 93 km/h] during the observation periods.

Treatment Results

Table 18 gives the percentage of traffic in the closed lane prior to and at the start of the taper. The data indicates a trend to lower percentages in the closed lane at the start of taper, but the there are variations in the rate of decrease. These are probably due to variations in the volume and platooning of traffic.

Table 19 gives the percentage of traffic in the closed lane at the start of the taper. For the left-lane closure a two-way ANOVA (device by spacing) revealed a significant effect due to devices. Round barrels were more effective (1 percent) over all spacings than oblong barrels (4 percent), and Type II barricades (4 percent). For the right-lane closure, there was a significant main effect due to devices. Round barrels performed better (3 percent) than cones (6 percent), oblong barrels (9 percent), and Type II barricades (15 percent). Cones were significantly better than Type II barricades. A significant main effect of spacing for the right-lane closure revealed that the 82-ft. [27.4-m.] spacing (5 percent) was more effective than the 55-ft. [16.5-m.] and 110-ft. [33.0-m.] spacing (11 and 9 percent respectively).

Table 18. Percentage of traffic in closed lane prior to and at start of taper for MD03.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
MD03	Left	Day	Cones	2000 ft	17	16	15
				1500 ft	14	10	22
				1000 ft	04	07	08
				500 ft	02	04	05
				taper	01	04	03
			Round Barrels	2000 ft	11	14	12
				1500 ft	04	09	21
				1000 ft	02	0	0
				500 ft	02	01	0
				taper	01	01	0
			Oblong Barrels	2000 ft	20	23	21
				1500 ft	17	12	12
				1000 ft	14	07	09
				500 ft	11	04	05
				taper	05	03	03
			Type II Barricades	2000 ft	22	22	21
				1500 ft	07	06	11
				1000 ft	06	08	07
				500 ft	04	07	06
				taper	03	06	04
MD03	Right	Day	Cones	2000 ft	46	43	36
				1500 ft	21	20	01
				1000 ft	11	19	16
				500 ft	11	18	21
				taper	05	06	06
			Round Barrels	2000 ft	41	26	26
				1500 ft	25	04	10
				1000 ft	08	06	31
				500 ft	08	03	57
				taper	06	02	02
			Oblong Barrels	2000 ft	30	45	34
				1500 ft	27	32	30
				1000 ft	22	13	21
				500 ft	16	08	18
				taper	11	03	12
			Type II Barricades	2000 ft	54	52	63
				1500 ft	39	27	34
				1000 ft	35	20	25
				500 ft	28	14	21
				taper	21	07	17

Note: 1-ft = 0.30-m.

Table 19. Percentage of traffic in closed lane at start of taper for MD03.

Site Code	Lane Closed	Light Condition	Device Type	Spacing (ft) 55	80	110
MD03	Left	Day	Cones	01	04	03
			Round Barrels	01	01	0
			Oblong Barrels	05	03	03
			Type II Barricades	03	06	04
	Right	Day	Cones	05	06	06
			Round Barrels	06	02	02
			Oblong Barrels	11	03	12
			Type II Barricades	21	07	17

Note: 1-ft = 0.30-m.

Site MD04 - US 40/48 EB between MV Smith & Orleans Roads

Work Zone Type

This work zone was set up approximately 1,000 ft [300 m] from the location of site MD03, but at a position which was the start of a curve to the right. Initially, a left-lane closure situation existed for testing. After one-half day, the contractor switched the work zone to the right-side of the road. This resulted in a situation where the channelization devices were placed on an arc along the curve to the right. The devices were then not visible to approaching motorists in the right lane. The devices were also hidden by the arrow panel because of the curvature of the road.

Alignment Features

The approach to this location was similar to that noted for site MD03. The long tangent section led up to this position, but there was a shallow sag vertical curve between the two positions. The work zone was set up to start at the beginning of a curve to the right.

Traffic Conditions and Influences

Traffic conditions were similar to those noted for Site MD03. Traffic was light on the single day that observations were made at this site ranging from 218 to 327 v/h. Gaps in the 5-minute intervals shown in the data summaries resulted from periods during which no traffic was observed. Trucks were noted to comprise 18 to 31 percent of the traffic and speeds averaged 53 to 56 mi/h [85 to 90 km/h].

Treatment Results

As given in table 20, the limited time available at this site resulted in the testing of fewer devices and spacing combinations. Trends similar to those noted earlier in the percentage of traffic in the closed lanes are apparent. Statistical analysis consisted of a one-way ANOVA or t-test for each device to determine if there where significant spacing differences using the data in Table 21. There was a significant difference for Type II barricades with the 110-ft. [33.0-m.] spacing indicating a worse performance than for the 55-ft. [16.5-m.] spacing. No other significant differences were found.

Table 20. Percentage of traffic in closed lane prior to and at start of taper for MD04.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
MD04	Left	Day	Cones	2000 ft	07	10	--
				1500 ft	06	09	--
				1000 ft	03	12	--
				500 ft	03	05	--
				taper	02	02	--
	Right	Day	Oblong Barrels	2000 ft	47	54	45
				1500 ft	36	41	40
				1000 ft	46	48	48
				500 ft	21	25	23
				taper	18	21	14
			Type II Barricades	2000 ft	43	--	55
				1500 ft	32	--	53
				1000 ft	50	--	38
				500 ft	20	--	36
				taper	15	--	27

Note: 1-ft = 0.30-m.

Table 21. Percentage of traffic in closed lane at start of taper for MD04.

Site Code	Lane Closed	Light Condition	Device Type	Spacing (ft) 55	80	110
MD04	Right	Day	Oblong Barrels	18	21	14
			Type II Barricades	15	--	27
	Left	Day	Cones	02	02	--

Note: 1-ft = 0.30-m.

Site VA01 - Interstate 95 NB south of Exit 2 at Skippers, VA

Work Zone Type

A long-term right lane closure was in place at this location for major rehabilitation of the pavement in this area. The contractor used round barrels with steady burn beacons on the taper. An arrow panel was located near the end of the taper behind a wall of concrete safety shaped barriers that started near the last four devices. An 8-in [20-cm] wide stripe was painted diagonally across the closing lane to provide additional delineation of the lane closing. Center line stripes were also eradicated upstream of the taper to encourage drivers to move over sooner at this location.

Alignment Features

This location featured a long, level, tangent approach. The travel lanes were separated by a 40- to 50-ft [12- to 15-m] wide open median.

Traffic Conditions and Influences

Traffic volumes at this site were in the moderate to high range. Daytime volumes ranged from 436 to 674 v/h and nighttime volumes ranged from 189 to 554 v/h. Trucks constituted 18 to 36 percent of the daytime traffic and 20 to 58 percent at night. The alignment and higher speed limits allowed in Virginia contributed to higher observed traffic speeds. Speeds averaging between 59 and 63 mi/h [94 and 101 km/h] were noted during the day and 57 to 65 mi/h [91 to 104 km/h] at night.

Treatment Results

Table 22 gives the percentage of traffic in the closed lane prior to and at the start of the taper. The data indicated trends similar to that for the other sites. Missing or limited data prevented further analysis of the lane changing profiles.

Table 23 gives the data for percentage of traffic in the closed lane at the start of the taper. A two-way ANOVA for device and spacing found a significant effect for day conditions at VA01. Round barrels with steady burn lights (18 percent) were significantly worse than the oblong barrels (8 percent), cones (7 percent), and round barrels (5 percent). This is not surprising because the barrels with steady burn lamps were those being used by the contractor. They were in poor condition and did not have the high intensity reflective sheeting as did the other round barrels. A two-way ANOVA for night conditions revealed a significant effect due to device, whereby cones (9 percent) were worse than round barrels (5 percent).

Table 22. Percentage of traffic in closed lane prior to and at start of taper for VA01.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
VA01	Right	Day	Round Barrels w/ SBL's	2000 ft	32	36	31
				1500 ft	18	33	24
				1000 ft	--	--	--
				500 ft	24	11	16
				taper	18	21	16
			Cones	1500 ft	22	21	23
				1000 ft	10	11	12
				500 ft	--	--	--
				taper	09	07	06
			Round Barrels	taper	05	06	05
			Oblong Barrels	taper	06	10	07
		Night	Cones	1500 ft	26	26	25
				1000 ft	15	17	17
				500 ft	09	15	11
				taper	09	08	12
			Round Barrels	1500 ft	26	21	28
				taper	07	03	03
			Oblong Barrels	taper	08	06	--

Note: 1-ft = 0.3-m.

Table 23. Percentage of traffic in closed lane at start of taper for VA01.

Site Code	Lane Closed	Light Condition	Device Type	Spacing (ft) 55	80	110
VA01	Right	Day	Cones	09	07	06
			Round Barrels	05	06	05
			Oblong Barrels	06	10	07
			Round Barrels w/s	18	21	16
		Night	Cones	10	08	12
			Round Barrels	07	03	03
			Oblong Barrels	08	06	--

Notes: 1-ft = 0.30-m.

Site VA02 - Interstate 66 EB near Marshall, VA

Work Zone Type

At this site a right lane closure was set up for daytime resurfacing operations. This work zone actually took three different starting locations over a 1.5 mi [0.93 km] stretch of highway on different days. The contractor used an arrow panel at the start of the taper and advance warning signs, but these signs were not moved to conform to state standards when the work zone moved. The signs were generally in very poor condition.

Alignment Features

The highway was generally straight and the vertical alignment rolled gently in the study area. A major interchange occurred beyond the end of one work zone site. To compensate, data for exiting vehicles or those influenced by them were not gathered. The pavement in this area had not been restriped, so only temporary centerline markings were in place.

Traffic Conditions and Influences

Traffic volumes during the data collection periods were moderate to high with v/h levels ranging from 392 to 648. Traffic speeds also tended to be high with averages ranging from 55 to 64 mi/h [88 to 102 km/h]. Truck traffic generally ranged from 11 to 23 percent. The presence of the interchange resulted in about 6 percent of the traffic exiting.

Treatment Results

As indicated in table 24, only limited data was available for this site. Table 24 shows the lane distribution data was only available at station A and the start of the taper. It can be noted that higher percentages of traffic were observed making lane changes in the taper than at any of the other sites. This was attributed to a lower degree of effort by the contractor in work zone traffic control.

A two-way ANOVA on the percentage of traffic in the closed lane at the taper revealed significant main effects and an interaction effect for device by spacing. Oblong barrels performed significantly better at 110-ft. [33.0-m.] spacing than they did at either 55- or 82-ft. [16.5- or 27.4-m.] while there were no significant differences for round barrels.

Table 24. Percentage of traffic in closed lane prior to and at start of taper for VA02.

Site	Lane Closed	Light Condition	Device Type	Station	Spacing (ft) 55	80	110
VA02	Right	Day	Round Barrels	2000 ft	38	39	39
				taper	18	16	17
			Oblong	2000 ft	32	42	34
				taper	15	18	04

Note: 1-ft = 0.30-m.

Comparisons Between Sites

An overall summary of the changes in the percentage of traffic in the closed lane for all locations, devices, and spacings is presented in table 25. The variability discussed for each site is noted in this summary. While the differences in the features of the locations discourage rigorous detailed analyses of the data across sites, some comparisons across the sites suggests similarities in performance. In general, the percentage of vehicles in the closed lane at the start of the taper can be noted to increase with the higher spacings. Also, the percentage can be noted to increase as the size of the devices decreases. Statistical analysis of the data indicate that there is no consistent effect for device or spacing across the various sites.

If the percentages are averaged for each location and lighting condition, it can be noted that the lowest overall amount of traffic in the closed lane at the taper can be found for sites MD03 and VA01. These two sites had the most ideal alignment allowing the work zone to be clearly visible a half mile [0.31-km] from the start of the taper. The other sites had less than ideal vertical or horizontal alignment and consequently more traffic remained in the closed lane at the start of the taper.

Downstream speeds of cars at the start of the taper are shown in Table 26. These data represent the mean speeds for a sample of cars as they passed through the taper section. For the Maryland sites the speed limit was 55 mi/h [88 km/h] and the Virginia sites were posted at 65 mi/h [105 km/h]. There were no work zone speed limits in effect any of the sites. It can be noted that there is generally limited variation in the speeds within specific device and spacing categories. Two-way ANOVA (device x spacing) were used to analyze each site condition. Out of the 10 analyses, four had significant main effects for spacing. Significant spacing by device interactions occurred for six of the ten sets of data. While the differences in speeds were inconsistent among treatements and among sites, the existence of significant differences may suggest that there are correlations to other factors. These factors could not be identified in this study.

The conflict rate for each of the treatment conditions was also analyzed. Table 28 provides a summary of the conflict rates for each site and treatment condition. Again it can be noticed that there is considerable variability in the data. A two-way ANOVA (devices x spacing) were used to analyze each site condition. There were no significant main effects for spacing. Only 2 of the 8 analyses had significant device by spacing interactions. From these results, it was was not possible to conclude that there were spacing effects on conflicts. The limited duration of the observation periods that were possible under this study may have precluded gathering a sufficient sample of traffic operations data to provide a stable estimate of conflicts.

COST EFFECTIVENESS ANALYSIS

A cost effectiveness analysis was undertaken to assess the impacts of various spacing conditions on the cost of setting up a work zone lane closure. Rental rates were used as the basis for cost computations under the assumption that better quality devices would be used. Rental rates were obtained from local suppliers and the number of devices necessary for the taper determined for 40-, 55-, 80-, and 110-ft [8.2-, 16.5-, 27.4-, or 33.0-m] spacing options. The resulting daily costs are given in table 29.

On a daily basis costs ranged from $12.80 for round barrels spaced at 40-ft [8.2-m] to $2.80 for cones with collars at 110-ft [33.0-m]. Labor costs associated with the handling and placement of the devices on the taper were similarly low and essentially similar for each device. The relatively low total costs associated with the most expensive device at the smallest spacing would indicate that the maximum delineation treatment should be used. These costs present approximately one-tenth of the cost of renting an arrow panel for a day. The risks associated with vehicular encroachment of the work zone would far outweigh the costs.

Table 25. Summary of percentage traffic in closed lane at taper for all treatment conditions and sites.

Location	Closure Type	Light Condition	Spacing (ft)	Round Barrels	Oblong Barrels	Type II Barricades	Cones Collars
					Channelization Device Deployed		
MD01	Left	Day	55	0.03	0.03	0.03	0.02
			82	0.02	0.03	0.04	0.02
			110	0.03	0.03	0.04	0.02
MD01	Left	Night	55	0.01	0.00	0.03	----
			82	0.01	----	0.03	----
			110	0.01	0.00	0.00	0.00
MD02	Left	Day	55	0.04	0.06	0.08	0.05
			82	0.05	0.09	0.06	0.06
			110	0.16	0.07	0.04	0.06
MD02	Right	Day	55	0.14	0.11	0.12	0.13
			82	0.16	0.06	0.19	0.12
			110	0.09	0.15	0.09	0.24
MD03	Left	Day	55	0.01	0.05	0.03	0.01
			82	0.01	0.03	0.06	0.04
			110	0.00	0.03	0.04	0.03
MD03	Right	Day	55	0.06	0.11	0.21	0.05
			82	0.02	0.03	0.07	0.06
			110	0.02	0.12	0.17	0.06
MD04	Left	Day	55	0.04	----	----	0.02
			82	----	----	----	0.02
			110	----	----	----	----
MD04	Right	Day	55	----	0.18	0.15	----
			82	----	0.21	----	----
			110	----	0.14	0.27	0.11
VA01	Right	Day	55	0.05	0.06	0.12	0.09
			82	0.06	0.09	0.12	0.07
			110	0.05	0.07	0.08	0.06
VA01	Right	Night	55	0.07	0.11	0.12	0.10
			82	0.03	0.07	0.13	0.08
			110	0.03	0.06	0.09	0.12
VA02	Right	Day	55	0.18	0.15	0.20	----
			82	0.16	0.18	----	----
			110	0.17	0.04	0.13	----

Note: 1-ft = 0.3-m.

Table 26. Summary of downstream traffic speeds for all treatment conditions and sites.

Location	Closure Type	Light Condition	Spacing (ft)	Round Barrels	Oblong Barrels	Type II Barricades	Cones Collars
				Channelization Device Deployed			
MD01	Left	Day	55	----	57.94	56.64	59.05
			82	----	58.79	57.49	58.08
			110	----	56.97	58.09	58.97
MD01	Left	Night	55	54.71	----	58.03	55.20
			82	56.57	----	56.62	57.58
			110	----	----	-----	-----
MD02	Left	Day	55	58.07	59.73	57.59	----
			82	56.32	58.07	59.63	----
			110	59.28	59.63	59.50	----
MD02	Right	Day	55	57.70	58.49	58.02	59.99
			82	60.00	61.27	58.75	61.02
			110	62.02	59.17	57.39	59.54
MD03	Left	Day	55	54.11	54.93	56.72	55.17
			82	51.24	54.88	55.59	57.15
			110	54.18	55.22	56.51	55.32
MD03	Right	Day	55	56.12	57.11	58.24	55.82
			82	55.00	57.24	56.99	56.16
			110	53.08	56.37	56.14	55.93
MD04	Left	Day	55	----	----	----	----
			82	----	----	----	----
			110	----	----	----	----
MD04	Right	Day	55	----	56.89	55.80	----
			82	----	55.53	58.50	----
			110	----	56.00	55.61	----
VA01	Right	Day	55	60.90	60.40	61.06	60.82
			82	60.61	60.03	61.60	62.44
			110	60.30	60.39	61.38	59.74
VA01	Right	Night	55	59.75	----	62.54	64.25
			82	57.07	----	61.06	59.97
			110	57.35	----	60.66	60.59
VA02	Right	Day	55	60.98	60.07	----	----
			82	60.35	54.52	----	----
			110	59.99	63.54	----	----

Note: 1 mi/h = 0.62 km/h.

Table 27. Summary of conflict rates at taper for all treatment conditions and sites.

Location	Closure Type	Light Condition	Spacing (ft)	Round Barrels	Oblong Barrels	Type II Barricades	Cones Collars
				Channelization Device Deployed			
MD01	Left	Day	55	0.33	2.13	1.10	1.76
			82	1.88	1.75	1.08	2.35
			110	0.67	3.00	1.00	1.24
MD01	Left	Night	55	----	----	----	----
			82	----	----	----	----
			110	----	----	----	----
MD02	Left	Day	55	0.56	0.25	1.46	0.50
			82	0.42	0.71	0.56	0.80
			110	0.25	0.92	0.67	0.44
MD02	Right	Day	55	0.92	0.20	----	0.00
			82	0.08	0.09	----	0.30
			110	0.22	0.33	----	0.14
MD03	Left	Day	55	0.00	0.57	0.20	0.25
			82	0.00	0.29	0.50	0.56
			110	0.00	0.25	0.50	0.29
MD03	Right	Day	55	0.14	0.14	0.00	0.07
			82	0.12	0.06	0.40	0.06
			110	0.09	0.00	0.69	0.25
MD04	Left	Day	55	----	----	----	----
			82	----	----	----	----
			110	----	----	----	----
MD04	Right	Day	55	----	0.33	0.11	----
			82	----	0.56	----	----
			110	----	0.33	0.17	----
VA01	Right	Day	55	0.22	0.71	----	0.26
			82	0.12	0.48	----	0.41
			110	0.04	0.24	----	0.50
VA01	Right	Night	55	0.25	----	----	0.62
			82	0.42	----	----	0.09
			110	0.00	----	----	0.42
VA02	Right	Day	55	0.00	0.00	----	----
			82	0.09	0.17	----	----
			110	0.17	0.00	----	----

Note: 1-ft = 0.3-m.

Table 28. Costs associated with the rental of devices at different spacings.

Device	Daily Rental Rate	Device Spacing (ft) [Number Required for Taper] 40 [20]	55 [15]	82 [10]	110 [8]
Round Barrels	$ 0.64	$ 12.80	$ 9.60	$ 6.40	$ 5.12
Oblong Barrels	0.58	11.60	8.70	5.80	4.64
Type II Barricades	0.33	6.60	4.95	3.30	2.64
Cones with Collars	0.35	7.00	5.25	3.50	2.80

Notes: (1) 1-ft = 0.3-m.
(2) Daily rental rates derived from data provided by suppliers.

INTERPRETATION OF FINDINGS

The field study effort investigated the performance of various channelization devices in real work zone situations. Although the laboratory study demonstrated there were few significant differences in the visibility of a given device at various spacings, it clearly demonstrated a great deal of variability between the visibility of the various channelizing devices tested. It was hypothesized that different channelizing devices and different spacings between channelizing devices would produce differences in driver lane changing behavior. Surely a driver would more rapidly vacate a lane where the lane closure consisted of an array of barrels spaced 55-ft [16.5-m] apart than a lane closure consisting of 28-in [70 cm] cones spaced 110-ft [33.0-m] apart.

The field experiment results failed to indicate a consistent effect across the different test conditions. There were 32 test conditions where it was possible to use the percentage of traffic in the closed lane at the start of the taper to compare the effects of different channelizing devices and different spacings. There were six conditions where statistically significant results were obtained. In four of those six test conditions the 80-ft [27.4-m] spacing did better than either the 55- or 110-ft [16.5-m or 33.0-m] spacing. In the remaining two conditions the 55-ft [16.5-m] spacing actually did worse than the 110-ft [33.0-m] spacing. It was expected that a direct relationship between number of devices and driver performance would be found (i.e., an increase in spacing between devices would cause an increase in the number of motorists remaining in the closed lane at the start of the taper). Instead, there appears to be no apparent relationship between the number of channelizing devices used in the taper and the behavior of drivers approaching the taper.

The field study results provide no clear indication of the influence of various device-spacing configurations. If the experimental results had consistently shown superior performance at the 55-ft [16.5-m] spacing and progressively poorer performance at the 80- and 110-ft [27.4- and 33.0-m] spacings we would have positive proof that the current standard is appropriate. If the experimental results had consistently shown equal performance at the 55- and 80-ft [16.5- and 27.4-m] spacings and poorer performance at the 110-ft [33.0-m] spacing it would provide strong evidence to relax the current standard. Although one might argue that the experimental results indicate that channelizing device spacing has little affect on driver behavior and the use of fewer devices is suggested, this conclusion must be carefully considered.

It is important to recognize that the experimental testing took place under relatively favorable circumstances. Each test site had all of the required advance signing and delineation as well as a flashing arrow panel. Although testing was done at night, no testing was done during fog or inclement weather. All the devices used were new and their positions monitored continuously. The effectiveness of the device array with larger spacings would also be more adversely affected by damaged, worn, knocked-down or missing devices. Further, all tests took place under relatively low volume conditions to allow observations under free-flow conditions. Drivers able to change lanes at will were observed to change lanes well up stream as well as to use the taper to complete the lane change. As traffic volumes increased, the freedom to change lanes was reduced and drivers were observed to make lane changes closer to the taper. The speed data gathered in this effort suggest that traffic did not slow appreciably to make the necessary lane changes. The importance of the visibility of more devices under heavier traffic conditions was not addressed in these experiments.

Perhaps the role played by the channelizing devices increases as the complexity of the driving task increases. It is likely that the effectiveness of the devices may be highly influenced by the nature of backgrounds (i.e., urban or rural), the presence of construction activities in the work zone, the relative proportions of traffic and their distributions in time and space, and the overall plan for work zone traffic control. While the number of test sites was too small for rigorous analysis of the performance of various channelizing devices across sites, the data trends and field observations suggest that the devices worked better where the driver had full view of the entire work zone traffic control scheme. Advance information on a lane closure was reinforced when the arrow panel and devices could all be seen well upstream of the actual lane closure. While the type of device and its spacing could not be discerned from 2,000 ft [600 m] upstream, the combined effect of all devices provided the delineation information needed by the driver to make a lane change well advance of the work zone.

The most reasonable conclusion that can be drawn from the experiments conducted is that the existing standards for channelizing device placement are overly conservative for many work zones. At locations where there is a clear line of sight and advance signing and an arrow panel are in place, the spacing of channelizing devices has no apparent effect on lane changing behavior. Increased spacing may not be desirable in situations where work activities are taking place close to the taper, or where traffic may be seeking exit points. Wider spacings in these situations invites inadvertent vehicle intrusions.

The difficulty in getting uniform conditions at the six sites prevents detailed analysis of the performance of device-spacing configurations across all sites. The data, observations, and the cost analysis of spacing options have led to the following conclusions:

- There are differences in the performance of devices used for channelization when measured by the percentage of traffic in the closed lane at the start of the taper. The data gathered showed some trends which would suggest that device size and spacing influence the results, but the differences did not prove to be statistically significant.

- Differences in the approach geometrics for the six sites would suggest that the highest performance is achieved when the advance warning signs, the arrow panel and the channelizing devices are perceived together. A higher level of traffic was noted in the closed lane for the sites were horizontal or vertical curves restricted the driver's view of the lane closure.

- The limited data using devices in poor condition validates intuition.

CHAPTER 5. CONCLUSIONS & RECOMMENDATIONS

SUMMARY OF FINDINGS

Findings were derived in each phase of this effort and they served to focus the efforts of subsequent phases. The findings of the various phases are summarized in the following paragraphs.

The review of the literature and state-of-the-practice studies involved a comprehensive overview of the topic and resulted in the following conclusions:

- A wide variation exists in the types of devices considered acceptable for use in work zone channelization. Six different devices are outlined in the MUTCD and variations of these designs can be found in the standards and practices used by State and local agencies.

- Variations in the design features of devices are further promulgated by the competition between manufacturers to develop devices that are more durable, better able to stand up to traffic influences, more cost effective, and easier to handle.

- Further variations in the visibility of channelization devices results from the effects of age, weather, handling, work area dirt, and traffic incidents.

- Basic research has been conducted into the various aspects of work zone traffic control including the effectiveness of various types of devices, and the influence of advance warning signing, arrow panels, and supplemental delineation. This research has identified design features and application practices that have been adopted into MUTCD or State standards.

- There appears to be no scientific basis for the spacing criteria for the use of devices for channelization purposes in work zones.

- Agencies generally follow the MUTCD spacing criteria as standard, but ensuring that crews, and contractors follow the standard has been difficult.

- From a contractor's view, it is best to use as few devices as possible without jeopardizing safety.

These conclusions support the need to analyze the effectiveness of spacing related to the various types of approved devices.

The laboratory phase of this research involved testing the perceptions of drivers relative to different work zone situations and device-spacing configurations. Testing was done using a pseudo driving simulator developed using interactive video technology. Over 240 subjects participated in the tests which included exposure to 160 different videotaped situations. The interactive video system gathered data on the correctness of driving response and the point at which various types of lane closure or median crossover situations were perceived. The analysis of the data led to the following conclusions:

- The number of correct responses and mean recognition distances derived from the data gathered in the tests indicated some tendencies, but no overall trends.

- There are no strong relationships between the spacing of different types of devices and the performance of driver subjects. Significant differences were noted for some combinations of devices and spacings, but no overall spacing effect was detected.

- The application of order statistics indicated that there were groups of devices that worked in a similar fashion under different spacing conditions. These analyses led to the conclusion that cones and tubes function similarly. Round and oblong barrels function similarly. Oblong barrels and Type II barricades also exhibited similar performance.

- Many subjects noted a preference for the larger devices because "they form an obvious orange and white wall" in the closed lane.

- The similarities allowed the narrowing of treatment candidates for the field testing phase. The lack of a strong spacing effect led to the decision to forego the closed field testing and pursue field tests at real work zones.

- Interaction effects were noted to exist between some combinations of devices and spacings.

These conclusions directed the field testing efforts.

The field testing efforts were undertaken at six different locations. Right- and left-lane closures were used to test the various device-spacing configurations under both day and night conditions. Manual and automatic methods were used to gather the field data for traffic approaching a work zone. The study area included four points equally spaced over the 2,000 ft [600 m] before the work zone and the activity at the start of the taper for the lane closure. The tests were undertaken under the hypothesis that the most effective treatment would minimize the percentage of traffic in the closed lane at the start of the taper. After the analysis of field data gathered for 2,150 5-minute observation periods, the following conclusions were reached:

- Although some differences in the performance of devices at the various spacings were observed, no consistent trends were found. The differences in many cases were small, making it difficult to ascertain the validity of any apparent trends.

- The influence of percentage trucks, traffic speeds, and distribution of traffic on the approaches was not apparent from the results.

- The results could not be compared across sites because of differences in site features, but it appeared that work zones set up in locations that maximized their visibility functioned better.

- There were no indications that the size of a device affected a driver's reaction to a closed lane situation. In addition, it appeared that advance warning signs and arrow panels have more impact on motivating lane changes than do channelizing devices.

- Statistical analysis of the data determined there are no significant differences among most treatment conditions.

- An analysis of the costs associated with the deployment of devices in the taper indicated that very small differences associated with the different spacing options.

These findings were weighed collectively in developing recommendations.

INTERPRETATION OF FINDINGS

The type and spacing of devices may not be the most critical factor relative to guidelines for establishing work zones. A sight line criteria is probably a more valid means to determine which types of devices should be used in which situations. Of course, the overriding issue here is educating contractors and highway agency personnel to select the set up points for lane closures intelligently. The data gathered in this study indicate that when motorists have full view of the arrow board and the channelization devices from a considerable distance, they react by changing lanes well in advance of the work zone. Slight variations occur in the average distance from the work zone that the lane changes are made. In many cases, however, and partly in the interest of saving a few minutes of time or dollars of cost, work zones are set up in less than optimal locations. Lane closure points should be selected so that the motorist perceives both the arrow panel and the channelization devices in concert with each other. The initial advance warning sign provides information for a situation beyond the normal visibility range of most motorists, but by the half-mile [0.31 km] point the devices should be fully seen.

A common practice is to rely heavily on the arrow panel as the primary means of indicating a lane closure situation. Efforts should be made to locate the arrow board at a point where a half-mile [0.31 km] or more visibility of the arrow panel itself can be obtained. In situations such as on a crest vertical curve or a curve to the left or right, the arrow panel may be visible but the alignment of the roadway makes the devices invisible to a point sometimes less than a 1,000 ft [300 m] away from the lane closure. Motorists approaching a lane closure situation that is on the down-side of a crest vertical curve may see the arrow panel well before the devices are seen because of the alignment differences. This occurs even where the grades are slight in terms of the upgrade and downgrade leading to the crest vertical curve. Similarly, on a horizontal curve to the right, a right-lane closure will disappear behind the arrow panel and the curve. A left-lane closure on a slight curve to the left will mean that the devices will disappear into the curve on the left side or into the arrow panel.

Field observations seem to indicate that under low volume conditions, one of two phenomena will occur. Motorists will have responded to the advance warning signing and moved over well in advance of the lane closure, or they carry their lane changing into the taper itself, having not been "intimidated" to move over sooner by what would appear to be a clear set of objects blocking the lane ahead of them.

Given these observations, the question becomes how should the guidelines for the establishment of work zones be altered. The guidelines should indicate that work zones should be set up so that, where possible, the full taper is visible to the motorists for a minimum of 1,500 ft [450 m]. The key elements of that guideline are first, the 1,500 ft [450 m] criterion, would permit a motorist to see both the arrow panel and the channelization devices in concert with each other as they approach the work zone. This should allow motorists to take advantage of gaps in traffic, to make their merge further upstream from the lane closure, and in the process, avoid conflicts and congestive situations that may occur otherwise.

The second key element to that revised guideline is "where possible." It is not always possible to find a tangent section of roadway with clear lines of visibility near where the work has to go on. In many cases, a marginally visible site is selected to save on the number of channelization devices that have to be placed. For temporary work zones, the number of devices that are saved are few. Moving the work zone 500 ft [150 m] upstream to provide a better sight line for the motorist would imply that only 8 to 12 additional cones or barrels would be needed to delineate the work area in the tangent section of the situation. Each of these devices is amortized or rented for pennies a day and most crews are very proficient at the set up and removal of these devices at work zones. For long-term work zones, the costs may be greater if concrete barriers are used, but, the longer term of the work zone and the decreased risks associated with accidents could easily justify the extra expenditures over the duration of the work activity.

There is the added benefit of increased visibility for situations where work zone transitions are taking place. These transitions can be the set up times or the change over times associated with the work zone. At these times, a number of workers are on the roadway moving arrow panels and devices into different positions. The risk is greater in situations where their visibility is compromised.

CONCLUSIONS

The following conclusions resulted from the findings of the laboratory and field studies:

- The spacing of channelizing devices (55-, 80-, and 110-ft) [16.5-, 27.4-, and 33.0-m] and the type of channelizing device (round barrels, oblong barrels, cones with reflective collars, and Type II barricades) apparently does not have a consistent affect on the lane changing behavior of drivers approaching a work zone. The effect of advance warning signs and the arrow panel are such that the role of the visibility of the channelizing devices in influencing driver behavior is minimal.

- The study looked at the performance of traffic at six different work zone sites. Difficulties in identifying sites prevented the analysis of six homogeneous sites. But because work zones must occur at less than ideal situations, the result was six different key study situations. An analysis across sites shows consistent trends in the performance of devices and spacing configurations. The degree of difference varies as a result of the features at each of the sites. In general, under low volume conditions, motorists will tend to move out of the lane to be closed at a point well in advance of the work zone because the opportunities to change lanes are virtually unlimited. Under congested conditions, these opportunities are not the same and motorists therefore are forced to find less than acceptable gaps in the traffic stream in order to change lanes..

- Lane changes to vacate the closing lane will take place further upstream as a function of the visibility of the work zone. For the sites used in the study, those that involved horizontal or vertical constraints to the visibility of the arrow board and the closure devices tended to have a higher frequency of traffic using the taper to complete lane change maneuvers. In reviewing traffic operations under nighttime conditions, motorists tended to react more cautiously, applying their brakes, where darkness prevented a better picture of the work zone situation and the possible risks to be encountered downstream. Under nighttime conditions, the illumination of the arrow panel offered a considerable advance warning to motorists of the lane closure situation.

- Driver's of trucks have a height advantage as they approach work zone situations and therefore have a better perception of the nature of the work zone situation than do drivers of passenger vehicles. Truck drivers, either because of load concerns or regulations, tend to posture themselves into the proper lane sooner than do drivers of passenger cars.

Given the findings of this study, there is insufficient evidence to recommend changes to the national MUTCD. Several recommended considerations for the MUTCD and some guidelines for practice are outlined in the following sections.

RECOMMENDATIONS FOR REVISIONS TO THE MUTCD

The findings of this research do not suggest the need for major changes to the basic spacing criteria for channelizing devices in the vicinity of the taper at work zones. However, the data do suggest that the following revisions be considered for incorporation into the MUTCD:

- Provide a differential spacing criteria that is dependent on the sight line existing at the approach to the work zone.

- At locations with clear sight lines, it may be appropriate to allow wider device spacing (i.e., 82 ft) [27.4-m], provided advance signing and an arrow panel are in place.

- By requiring fewer devices at locations with a clear sight line, the MUTCD would encourage the relocation of the work zone to a place where the overall effectiveness would be improved.

It is believed that these recommendations provide a reasonably safe and fair compromise between the concerns of safety and efficiency associated with setting up work zones. Prudence is always encouraged in situations where the length of the work zone is dictated by design features and the buffer between the end of the taper and the area where equipment and men will be working is very limited.

GUIDELINES FOR IMPROVED PRACTICE

The findings of this research cannot suggest the need for changing the basic spacing criteria for work zones, particularly in the vicinity of the taper. However, the observations and tendencies of the data suggest that the following guidelines be adopted for setting up work zones:

- Work zones should be sited in a location that provides a minimum of 2000 ft [600 m] of visibility for the arrow panel and 1200 ft [360 m] of visibility for the channelization devices.

- Where sight distances may be limited, use larger devices or more devices on the taper.

- Direct work crews to periodically check the condition and positioning of the devices on the taper.

- Require channelization devices to have minimum levels of color and reflectivity at all times. Devices damaged by accidents or handling or degraded by weather, or construction residues should be retired or refurbished.

In efforts to identify work zone sites for this study, it was noted that many work zone delineation treatments are marginal at best in terms of their quality after time. It should be a requirement that these work zone setups are maintained on a daily basis to provide uniform spacing and to replace devices that are knocked out of alignment or damaged to the point of having reduced reflective area.

Discussions with contractors indicated a preference for designs that facilitate stacking and ease of installation. For example, hollow barrels with integral weighting, are more effective for contractors.

These guidelines are considered prudent. There is not a sufficient amount of cost savings that could offset the effectiveness of a well laid out set of channelization devices. Keeping at least the same number of devices is conservative considering that some devices may be knocked over or out of position. Adverse weather, distractions, or other traffic may limit the view of the devices. Therefore, it would seem conservative to maintain the status quo.

NEEDS FOR FUTURE RESEARCH

The scope of this research did not permit sufficient investigation into a number of delineation questions related to work zone situations. The following areas would warrant additional research:

- Relative importance of the arrow panel to the device type and spacing was not analyzed. Many of the practitioners talked to indicated that the arrow panel was worth 95 percent of the effectiveness of a lane closure situation. Field experiments with and without arrow panels are warranted. The relative importance of the arrow panel to the devices could shed useful insights into the best way to integrate the elements of traffic control at a work zone.

- The research did not analyze the device spacing effectiveness on the tangent sections within work zones. Questions still exist relative to the trade-offs between the convenience of using smaller devices, such as cones, over the length of a work zone and the impacts of spacing. Where spacing is great, motorists often will enter the work zone area or the closed lane to pass slower moving vehicles within the work zone. This is particularly true where construction activity is not apparent.

In a related matter, the need exists to evaluate the design of devices for the tangent sections to find a design that is both convenient to install and to store yet highly effective against knock down and motorist noncompliance.

- Some contractors indicated that the approved devices have limited effectiveness during winter conditions and Northern climates, particularly because of the impacts of snow plowing operations on roadways with long-term lane closures. In these situations, the need exists to investigate the benefits of other devices, such as Type III barricades or the larger varieties of the devices tested in this research.

- The research focused on two-lane roadways and the effectiveness of delineation involving the closure of one of two lanes. It is believed that the results of this research are transferable to wider highways, but it may be necessary to conduct further research to validate this assumption, particularly with respect to the relative effects of spacing from various perspective angles.

- The research did not evaluate the effect of advance warning signs for work zones. It may be prudent to alter advance signing sequences where sight distances for work zones are limited.

- This research involved six different sites, but in every case there was a significant buffer area between the start of the taper and the actual construction activity. It may be that the presence of construction activity has an influence on motorist lane changing behavior.

APPENDIX A - RECOMMENDED FREEWAY WORK ZONE SET UP

NOTES:

1. Taper Formula:

   $L = S \times W$ for speeds of 45 or more.

   $L = \frac{WS^2}{60}$ for speeds of 40 or less.

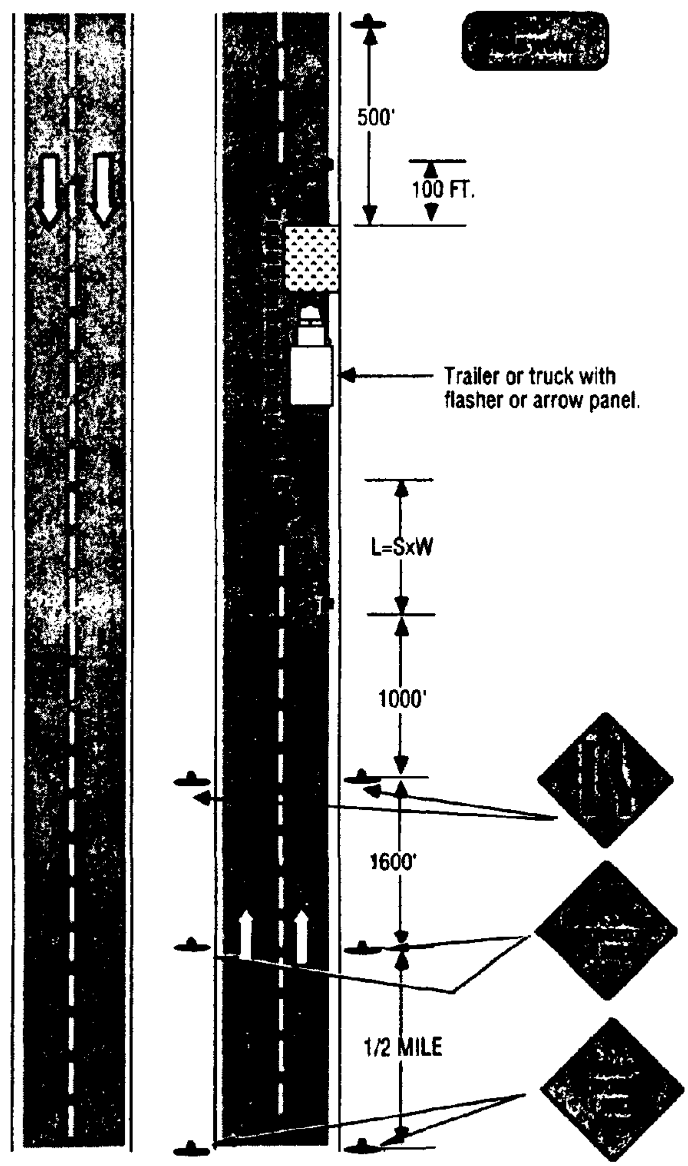
   Where:

   L= Minimum length of taper.

   S= Numerical value of posted speed limit prior to work or 85 percentile speed.

   W= Width of offset.

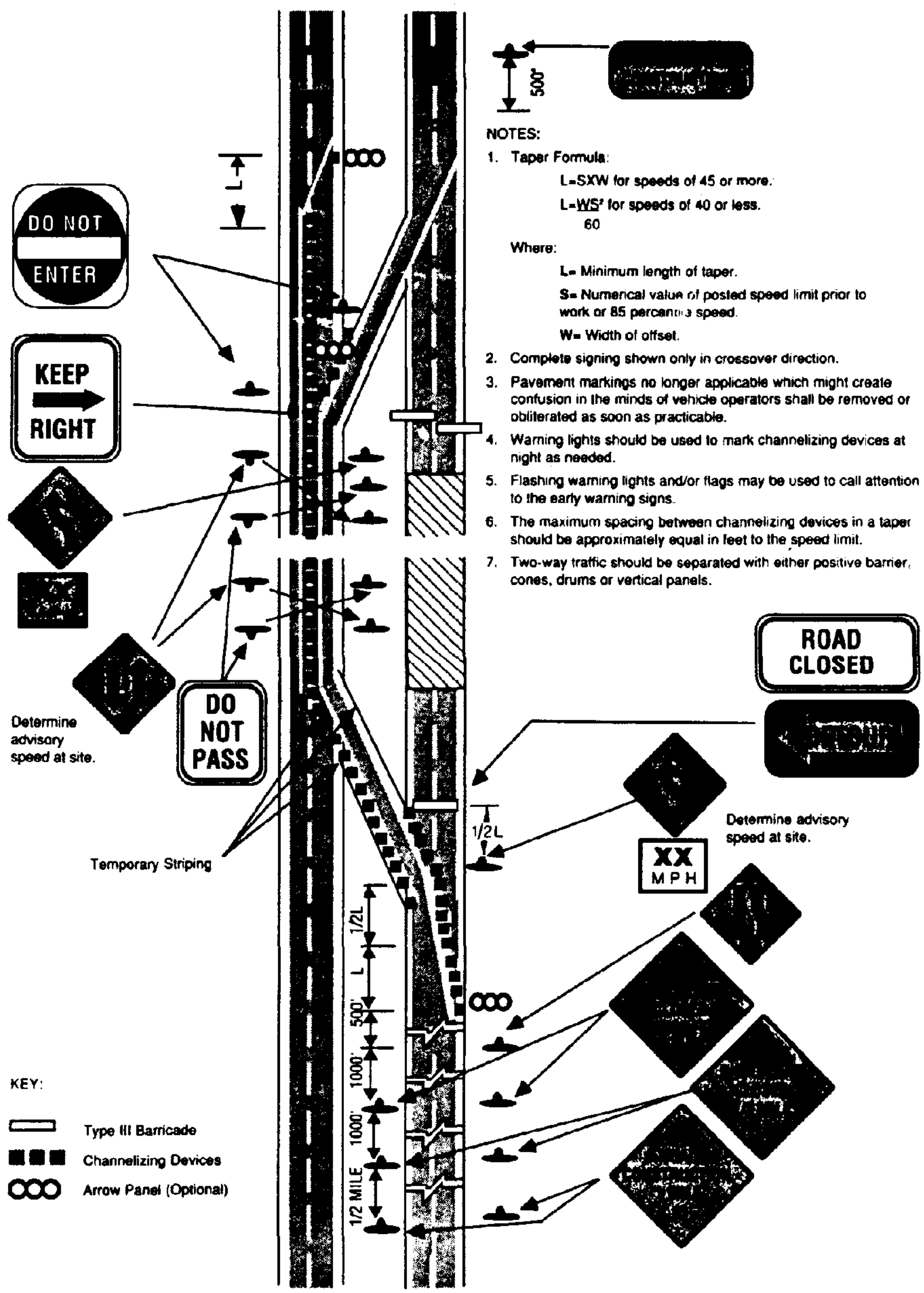
2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.



KEY:
■■■ Channelizing Devices

Source: Reference 1.

Figure 14 - MUTCD recommended layout for lane closure on divided highway.



Source: Reference 1.

Figure 15 - MUTCD recommended layout for median crossover on divided highway.

APPENDIX B - STUDY SITE DESCRIPTIONS

US 40/48 West of MV Smith Road (MD01)

This site has a gentle curving alignment to the right. The vertical alignment brings traffic over a crest vertical curve just beyond the overpass for MV Smith Road. The two lanes of traffic are 12-ft [3.6-m] wide, there is a 5-ft [1.5-m] wide left shoulder and a 12-ft [3.6-m] wide right shoulder. An on-ramp from MV Smith Road ends at approximately station C. There is only limited traffic using this ramp, given that it serves the Wildlife Management Area and the contractor's office for one of the projects on 40/48. Daily ramp volumes are estimated to be less than 75 vehicles. This site is a long-term lane closure on the left-hand side. An arrow panel was placed at the position of the second barrel and the barrels were not equivalently spaced at 55 ft [16.5-m] because the closure is on a curve. The district engineer believes that the barrels should be spaced slightly differently on the curve to provide a uniform visual image to the drivers. The device spacing established by the district engineer and the contractor was used the basis for the field studies at this site. Sixteen devices were used on this curved lane closure, slightly more than would be the norm for a straight-on lane closure.

Motorists had at least 1,000 ft [300 m] clear view of the arrow panel. Truck drivers having a higher seated position, had a slightly greater view of the work zone. Except for the advance warning signs, driver behavior at station A was not influenced by the existence of a work zone. The devices in place at this location were round barrels with steady burning lamps on intermittent barrels. The devices used had the high intensity sheeting required by Maryland specifications. Four different devices were tested during both day and nighttime conditions in a similar spacing arrangement to that provided by the contractor with the exception of the removal of devices for the 80- and 110-ft [27.4- and 33.0-m] spacing conditions.

Traffic at this location occurred in a random fashion and was essentially uninfluenced by upstream construction for the distance of some 18 mi [28.8 km]. The volumes were in the below medium range except at night where they dropped off significantly to less than 100 per hour. About one-third of the traffic was truck traffic.

US 40/48 East of MV Smith Road Interchange (MD02)

This site involved two lanes on a slight curve to the right after having passed over a crest vertical curve. Drivers had approximately 1,500 ft [450 m] of clear view of the arrow panel and the curve was gentle enough that they had a clear picture of the full lane closure treatment. The taper began approximately 400 ft [120 m] after the motorist passed under the overpass for MV Smith Road, approximately 200 ft [60-m] after the end of the taper, the on-ramp from MV Smith Road eastbound to US 40/48 intersected the roadway. Ramp volumes were not considered a significant factor at this site given that the only appreciable traffic was dump trucks hauling asphalt to the resurfacing project.

The work zone was set up in accordance with Maryland standards with an arrow board at the beginning of the taper and 13 devices spaced approximately 55-ft [16.5-m] apart over the left of the work zone. Cones were used over the next 3 mi [4.8 km] of roadway during the lane closure term. This was a daytime only work zone and we were able to observe traffic from the first day this lane closure existed. Positions of all the devices were marked on the pavement so that when the work zone was set up on consecutive days, we were able to replicate the same treatment conditions.

Traffic at this site was in the low range and somewhat sporadic. Traffic coming out of the two-lane, two-way operational area that represented most of the 18 mi [28.8 km] construction zone upstream was the reason for traffic being sporadic. Traffic had approximately 1 mi [0.62 km] to disperse on a two-lane section prior to reaching the work zone; therefore, a significant amount of the traffic had dispersed and was in a free-flow state at the time it reached the point of taper.

US 40/48 Between MV Smith Road and Orleans Road (MD03)

The alignment at this site is generally straight. It is approximately a 1 percent upgrade from station A. Traffic comes around a curve before station A and then has a clear, straight-on view of the work zone from that point. The pavement at this location was unmarked except for some 2-ft [0.6-m] stripes down the middle. It was being resurfaced, so traffic operated over the base course while awaiting the final wearing course for this segment of roadway. Ordinarily this piece of roadway would have had two 12-ft [3.6 m] wide lanes, a 5-ft [1.5 m] wide left-hand shoulder and a 12-ft [3.6 m] wide right-hand shoulder. The entire pavement surface has been replaced and the only markings are the centerline markings.

The testing scheme involved starting with the contractor's round barrels, which were placed at 55 feet using the measuring wheel. The contractor used 14 barrels to close off the left-lane. The work zone was set up on various days as the contractor made the several passes for resurfacing in this area. This site lies approximately 3-1/2 mi [5.6 km] from the end of the long construction zone, allowing traffic to disperse significantly more than at the previous site.

The traffic at this site could be categorized as being in the low category. It arrived in dispersed platoons such that vehicles have plenty of freedom to change lanes as they approach the work zone.

US 40/48 Between MV Smith Road and Orleans Road (MD04)

The alignment at this site has the same characteristics as site MD03, except for the fact that it lies at the start of a gentle curve to the right. The site was at the very end of a long tangent section. The pavement at this location was unmarked except for some 2-foot stripes down the middle. It was being resurfaced, so traffic operated over the base course awaiting the final wearing course for this segment of roadway. Ordinarily this piece of roadway would have had two 12-ft [3.6 m] wide lanes, a 5-ft [1.5 m] wide left-hand shoulder and a 12-ft [3.6 m] wide right-hand shoulder. The entire pavement surface has been replaced and the only markings are the centerline markings.

In this situation, the devices on the left-lane closure were very obvious to the motorists from the half-mile point. However, for the right-lane closures, the devices became hidden by the arrow panel from the half-mile [0.31 km] point. This prevented allowing this site to be considered the same as the other MD03 sites. Consequently, it was designated as MD04 and there is a partial data set available for this site. It may be possible to use the left-lane condition information, but not the right-lane condition information.

I-95 Northbound South of Emporia, Virginia (VA01)

This site has an essentially straight alignment and very little change in vertical grade. The site is located approximately 4 mi [6.4 km] north of the North Carolina/Virginia border on I-95. The concrete pavement at this location is being rehabilitated so there is a right-lane closure with barrel devices and an arrow panel followed by portable concrete barriers over the 3 mi [4.8 km] length of the construction project. There are service roads adjacent to the highway on either side, but these these were somewhat hidden by trees. This was a long-term work zone with signing in accordance to Virginia standards.

Traffic at this section of roadway was in the medium to heavy range. During the time periods when traffic was observed, traffic operated under free-flow conditions. The volumes were, however, probably three to four times higher than those at sites in Maryland. A considerable portion of the traffic is truck traffic as well.

I-66 Eastbound near Marshall, Virginia

The alignment at this site was generally straight and level. The data collection efforts took place at three similar locations in a 3 mi [4.8 km] stretch of eastbound I-66 near Marshall, Virginia. The roadway had a 300 ft [90 m] wide median in this area. One lane closure positions selected by the contractor was close to the interchange with Route 17, which was less than desireable for the data collection effort. Traffic exiting I-66 or influenced by an exiting vehicle was ignored.

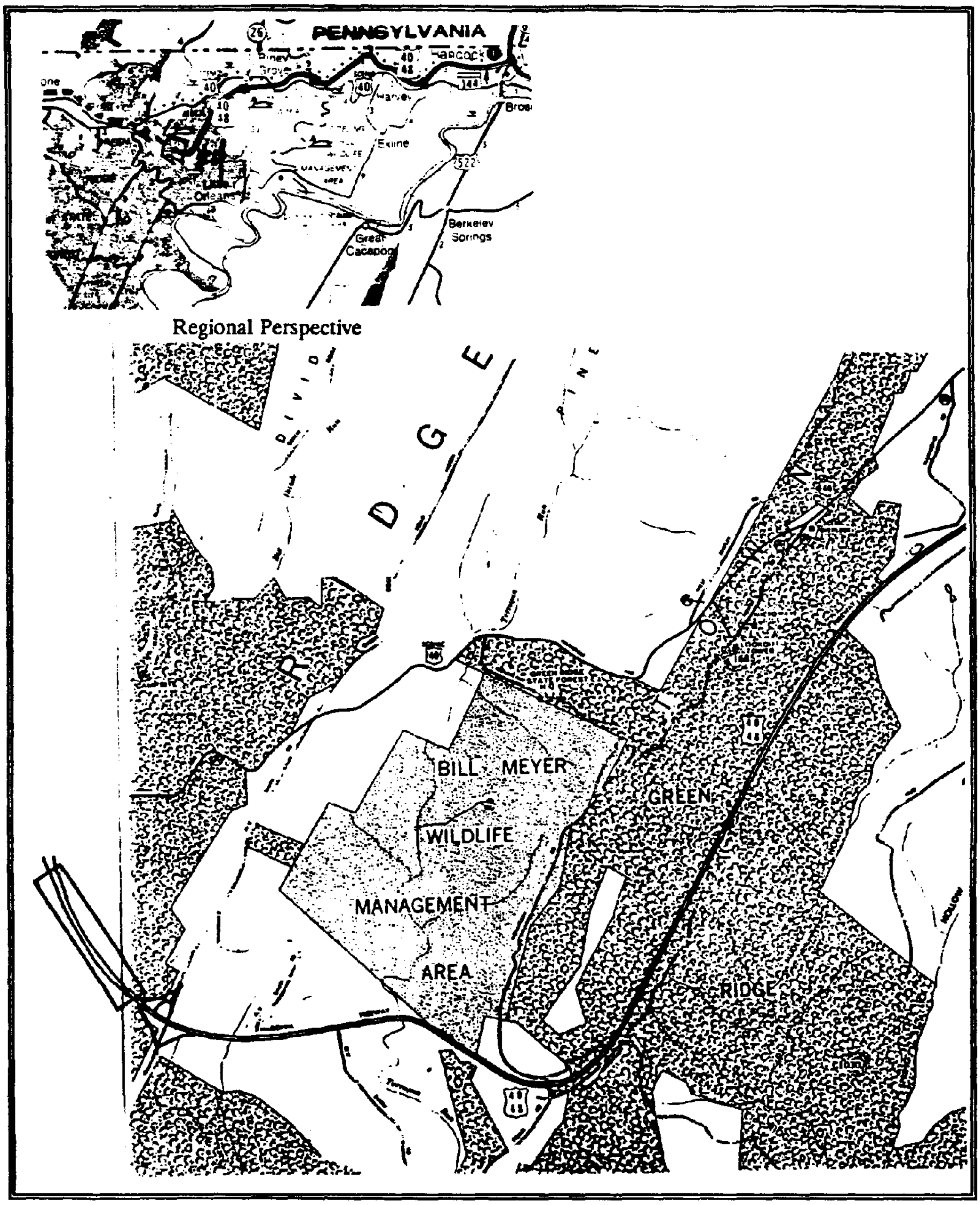


Figure 16. Map showing US 40/48 study sites.

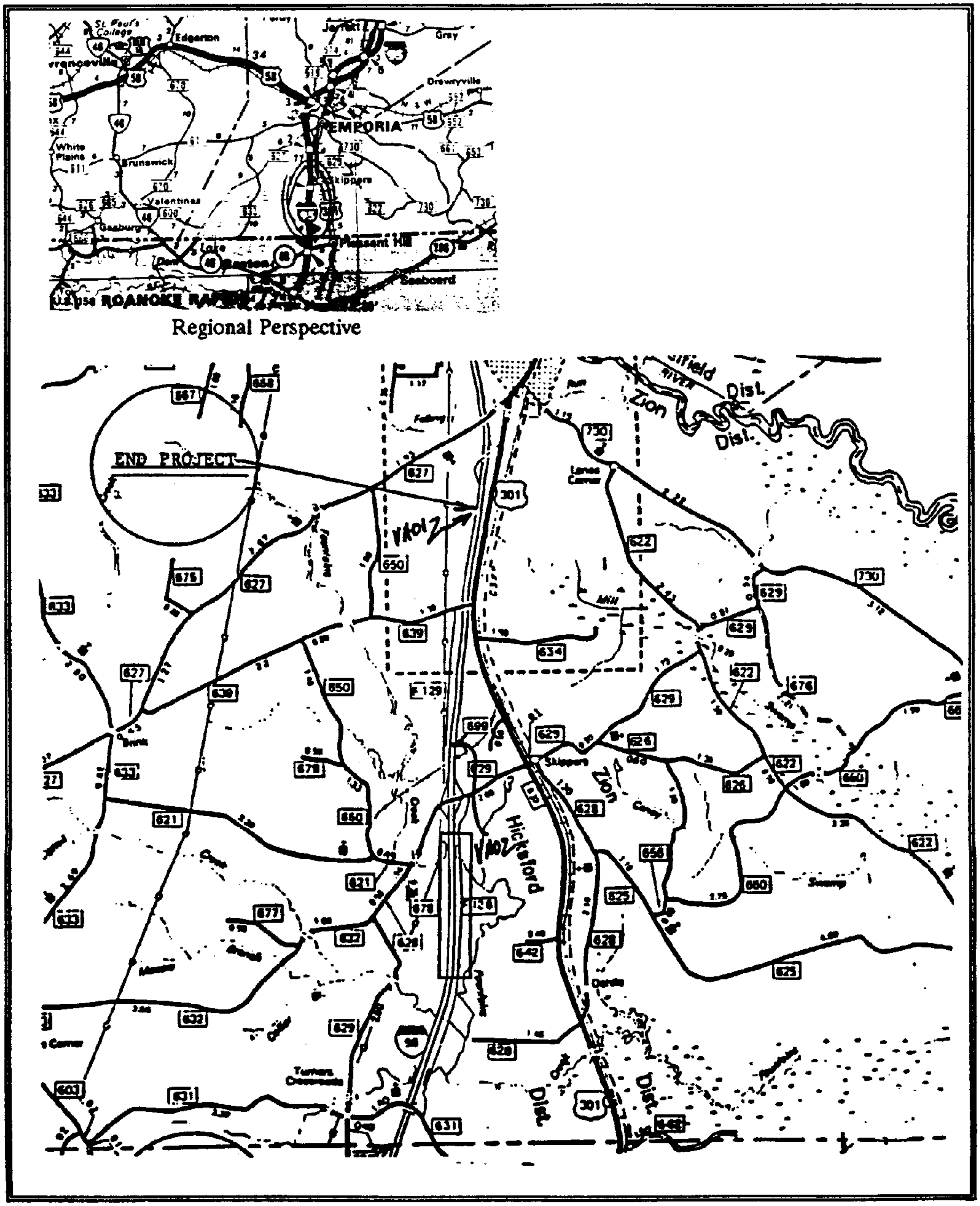


Figure 17. Map showing I-95 study site.

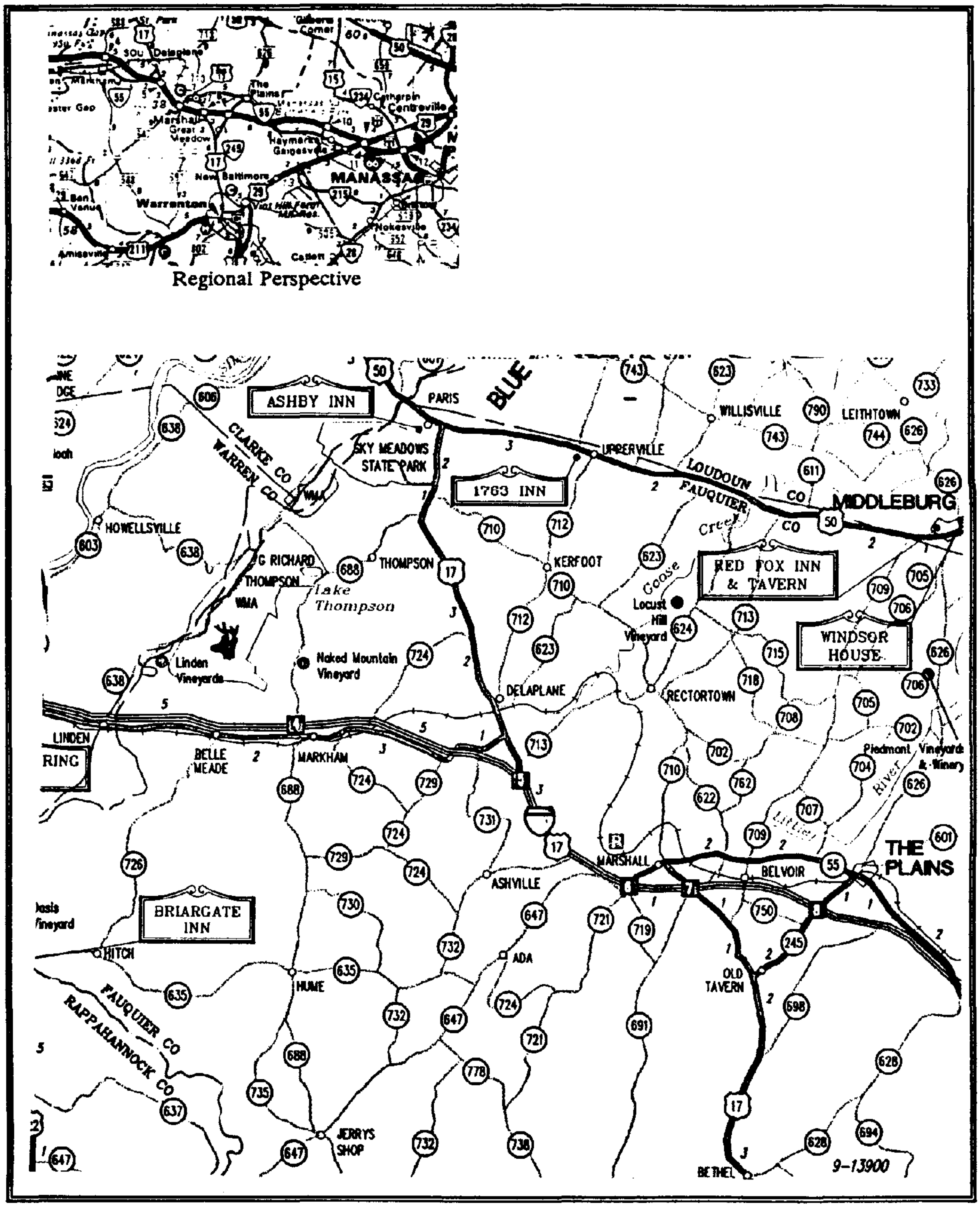


Figure 18. Map showing I-66 study site.

APPENDIX C - DATA BASE DESCRIPTION

The data base created for the work zone field studies consists of three primary files as described below:

- Location file -- This file contains pertinent features of the site and the testing that went on at that location. Included are factors of alignment, lane width, roadside environmental conditions and equipment utilized. The key code for this file is the location ID.

- Schedule file -- This file contains the information about the conditions tested and the time and date that these conditions were tested.

- Traffic data file -- This file contains the various items of traffic information gathered during each of the five-minute recording intervals. Each of these records includes the site ID, the date and time, and the upstream and downstream speed data, the volume counts at Stations A, B, C and D, the data taken by the two counters, and the conflicts data gathered at the taper point. The information in this file was aggregated for speed and counts.

The various data files are described in the Data Documentation.

A file integrating information from each of the files served as the basis for the analysis described in this report. Table 28 provides a description of the information contained in this file.

Table 28. Master integrated data file description.

Variable	Description
LOCID	Location Identification
	MD01 - US 40/48 WB west of MV Smith Road (Maryland)
	MD02 - US 40/48 EB east of MV Smith Road (maryland)
	MD03 - US 40/48 EB between MV Smith & Orleans Roads (Maryland)
	MD04 - US 40/48 EB between MV Smith & Orleans Roads (Maryland)
	VA01 - I 95 NB south of Exit 1 (Skippers, Virginia)
	VA02 - I 66 EB west of Exit 8 (Marshall, Virginia)
WZTYPE	Work zone type code
	RT - right lane closure
	LT - left lane closure
MON	Month of data collection
DAY	Day of data collection
TIME	Start of five minute observation period (military time)
DEVCOD	Device code
	RB - round barrels
	SB - skinny barrels
	TT - type II barricades
	CC - cones with reflective collars
	STD - standard barrels
	BB - standard barrels with steady burn lamps
	BASE - time periods with no treatment in place
	TRAN - time periods when treatments were being changed
SPCOD	Spacing code
	40 foot
	55 foot
	80 foot
	110 foot
LITECOD	Light conditions code
	D - daytime
	N - nighttime
SPDCSTA	Average speed of cars at Station A
SPDTSTA	Average speed of trucks at Station A
SPCCNT	Number of car speed observations
SPTCNT	Number of truck speed observations
SPDSTA	Average speed of all traffic at Station A
SPDVCSTA	Standard deviation of car speeds at Station A
SPDVTSTA	Standard deviation of truck speeds at Station A
SPDVSTA	Standard deviation of all traffic speeds at Station A
RTLNCSTA	Cars in right lane at Station A
RTLNTSTA	Trucks in right lane at Station A
LTLNCSTA	Cars in left lane at Station A
LTLNTSTA	Trucks in left lane at Station A
RTLNSTA	Total traffic in right lane at Station A
LTLNSTA	Total traffic in left lane at Station A
RTLNCSTB	Cars in right lane at Station B
RTLNTSTB	Trucks in right lane at Station B
LTLNCSTB	Cars in left lane at Station B
LTLNTSTB	Trucks in left lane at Station B
RTLNSTB	Total traffic in right lane at Station B

Table 28. Master integrated data file description (Continued).

LTLNSTB	Total traffic in left lane at Station B
RTLNCSTC	Cars in right lane at Station C
RTLNTSTC	Trucks in right lane at Station C
LTLNCSTC	Cars in left lane at Station C
LTLNTSTC	Trucks in left lane at Station C
RTLNSTC	Total traffic in right lane at Station C
LTLNSTC	Total traffic in left lane at Station C
RTLNCSTD	Cars in right lane at Station D
RTLNTSTD	Trucks in right lane at Station D
LTLNCSTD	Cars in left lane at Station D
LTLNTSTD	Trucks in left lane at Station D
RTLNSTD	Total traffic in right lane at Station D
LTLNSTD	Total traffic in left lane at Station D
RTLNCSTE	Cars in right lane at Station E
RTLNTSTE	Trucks in right lane at Station E
LTLNCSTE	Cars in left lane at Station E
LTLNTSTE	Trucks in left lane at Station E
RTLNSTE	Total traffic in right lane at Station E
LTLNSTE	Total traffic in left lane at Station E
SPCCNTE	Number of car speed observations at Station E
SPTCNTE	Number of truck speed observations at Station E
SPDCSTE	Average speed of cars at Station E
SPDTSTE	Average speed of trucks at Station E
SPDSTE	Average speed of all traffic at Station E
SPDVCSTE	Standard deviation of car speeds at Station E
SPDVTSTE	Standard deviation of truck speeds at Station E
SPDVSTE	Standard deviation of all traffic speeds at Station E
CONFE	Number of merge conflicts observed at Station E
CNFCE	Number of car merge conflicts observed at Station E
CNFTE	Number of truck merge conflicts observed at Station E
BRAKLIT	Number of brake light applications noted at Station E
BRKCE	Number of car brake light applications noted at Station E
BRKTE	Number of truck brake light applications noted at Station E
ANOMCOD	Traffic anomaly codes P - police stopped in study zone RB - police pass through study area VS - vehicle stops in study zone W - workmen in study zone SM - slow moving/wide vehicle passes ER - equipment repair SP - very light precipitation DD - device knocked out of position UB - downstream blockage causing back-up O - other
CNTAL	Tube count left lane Station A
CNTAR	Tube count right lane Station A
CNTA	Total tube count at Station A
TRSPDAL	Traffic speed at Station A for left lane
TRSPDAR	Traffic speed at Station A for right lane
CNTBL	Tube count left lane Station B

Table 28. Master integrated data file description (Continued).

CNTBR	Tube count right lane Station B
CNTB	Total tube count at Station B
CNTCL	Tube count left lane Station C
CNTCR	Tube count right lane Station C
CNTC	Total tube count at Station C
CNTDL	Tube count left lane Station D
CNTDR	Tube count right lane Station D
CNTD	Total tube count at Station D
CNTE	Total machine count at Station E
TRSPDE	Traffic speeds at Station A (machine based)
TRSPDVE	Traffic speed standard deviation at Station A (machine based)
TRSPDVLA	Car speeds at Station A (machine based)
TRSPDVRA	Truck speeds at Station A (machine based)
PA	Percentage of traffic in closing lane at Station A
PB	Percentage of traffic in closing lane at Station B
PC	Percentage of traffic in closing lane at Station C
PD	Percentage of traffic in closing lane at Station D
PCE	Percentage of cars in closing lane at Station E
PTE	Percentage of trucks in closing lane at Station E
PE	Percentage of traffic in closing lane at Station E
CRATE	Rate of conflicts
BLRATE	Rate of brake light application
SPDFC	Car speed differential upstream to downstream
SPDFT	Truck speed differential upstream to downstream
VPH	Traffic volume level in vehicles per hour
TRCK	Percentage of trucks in the traffic stream
OBS	Number of observations during the period
VLEV	Volume level code 1 = $<$ 400 VPH 2 = $>$ 400 VPH
TLEV	Truck percentage level 1 = $<$ 20 % 2 = $>$ 20 %
VTLEV	Volume level and percent trucks code (not used)
SFLAG	Tube data adjustment flag A = Adjustment made to machine data at Station A B = Adjustment made to machine data at Station B C = Adjustment made to machine data at Station C D = Adjustment made to machine data at Station D
CA	Adjusted count of vehicles in the closed lane at Station A
CB	Adjusted count of vehicles in the closed lane at Station B
CC	Adjusted count of vehicles in the closed lane at Station C
CD	Adjusted count of vehicles in the closed lane at Station D
CE	Adjusted count of vehicles in the closed lane at Station E

APPENDIX D - ANALYSIS SUMMARIES

The following pages are the computer print-outs showing the pertinent data and performance measures for the various locations and conditions studied. Included are:

Date: 02/09/90
Page: 1
Location: ND01

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	TL Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Upstream Average Speed Trucks	Upstream Speed SD Cars	Upstream Speed SD Trucks	Downstream Speeds: Average Speed Cars	Downstream Average Speed Trucks	Downstream Speed SD Cars	Downstream Speed SD Trucks	Differences: Average Speed Cars	Differences Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Conflicts Trucks	Conflicts Total	Conflicts Rate	Brake Lights: Cars	Brake Lights Trucks	Brake Lights Total	Brake Lights Rate
BB	55	LT	D	442	0.18	58.50	50.75	4.42	4.59	57.77	51.04	4.95	3.71	0.74	-3.46	-1.00	0.23	0.18	0.15	0.00	0.00	0.00	13	14	27	3.666	0	0	0	0.000
CC	55	LT	D	460	0.16	58.17	51.26	4.97	5.33	59.19	53.97	5.10	4.32	0.16	-0.19	-1.00	0.20	0.15	0.13	0.02	0.00	0.02	29	8	37	3.838	0	0	0	0.000
CC	80	LT	D	440	0.20	56.99	48.10	4.49	4.87	58.19	52.79	4.96	4.62	0.29	-1.26	-1.00	0.21	0.17	0.14	0.01	0.00	0.02	34	20	54	5.388	0	0	0	0.000
CC	110	LT	D	422	0.14	58.17	51.70	4.42	4.55	59.25	52.73	5.00	4.33	0.82	1.92	-1.00	0.21	0.17	0.13	0.02	0.00	0.03	30	8	38	3.546	0	0	0	0.000
DD	55	LT	D	234	0.24	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.08	0.03	0.00	0.03	7	1	8	1.515	0	0	0	0.000
DD	80	LT	D	312	0.17	56.59	51.43	4.26	4.92	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.14	0.12	0.09	0.03	0.00	0.03	10	6	16	5.358	0	0	0	0.000
DD	110	LT	D	212	0.33	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.15	0.03	0.01	0.04	6	0	6	1.233	0	0	0	0.000
SB	55	LT	D	394	0.18	58.17	50.03	4.71	3.92	57.42	50.14	5.34	5.09	0.99	-0.03	-1.00	0.20	0.16	0.13	0.02	0.00	0.03	39	10	49	5.374	0	0	0	0.000
SB	80	LT	D	358	0.17	-1.00	-1.00	-1.00	-1.00	58.62	53.31	5.42	5.03	-1.00	-1.00	-1.00	0.12	0.12	0.08	0.02	0.00	0.02	11	9	20	5.039	0	0	0	0.000
SB	110	LT	D	406	0.20	59.10	51.23	4.50	4.24	57.04	50.91	5.33	5.27	1.99	0.04	-1.00	0.19	0.15	0.10	0.03	0.00	0.03	37	8	45	7.800	0	0	0	0.000
STB	55	LT	D	367	0.21	59.03	53.42	4.73	3.95	57.64	50.09	5.43	4.44	1.40	-4.31	-1.00	0.22	0.16	0.11	0.01	0.00	0.03	32	17	49	3.916	0	0	0	0.000
TT	55	LT	D	436	0.16	-1.00	-1.00	-1.00	-1.00	56.42	51.29	5.47	4.31	-1.00	-1.00	-1.00	0.20	0.15	0.12	0.03	0.00	0.03	20	3	23	2.628	0	0	0	0.000
TT	80	LT	D	369	0.19	-1.00	-1.00	-1.00	-1.00	57.47	53.12	5.23	3.70	-1.00	-1.00	-1.00	0.18	0.13	0.09	0.04	0.00	0.04	11	2	13	3.555	0	0	0	0.000
TT	110	LT	D	418	0.16	-1.00	-1.00	-1.00	-1.00	58.04	51.31	5.06	3.87	-1.00	-1.00	-1.00	0.17	0.13	0.10	0.04	0.00	0.04	17	4	21	2.756	0	0	0	0.000

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	WZ Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Trucks	Total	Rate	Brake Lights: Cars	Trucks	Total	Rate
AA	55	LT	B	159	0.22	56.02	49.78	4.81	2.58	55.82	49.47	4.89	2.22	0.80	-0.05	-1.00	0.12	0.17	0.08	0.06	0.01	0.07	0	0	0	0.000	0	0	0	0.000
AA	80	LP	B	-1	-1.00	56.83	49.34	4.27	4.05	56.03	50.73	3.96	3.62	-0.01	-1.35	-1.00	0.43	0.28	-1.00	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
CC	55	LT	B	-1	-1.00	56.35	50.87	2.01	3.99	54.08	49.19	1.89	1.02	2.27	1.69	-1.00	-1.00	0.46	-1.00	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
CC	80	LP	B	-1	-1.00	50.43	47.83	5.15	3.59	57.36	49.55	3.70	2.67	1.07	-1.72	-1.00	0.16	0.19	-1.00	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
RS	55	LP	B	64	0.49	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.04	0.01	0.00	0.01	3	0	3	0.887	6	1	7	3.413
RS	80	LT	B	138	0.32	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.05	0.00	0.00	0.00	2	0	2	0.694	0	0	0	0.000
RS	110	LP	B	86	0.58	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.02	0.00	0.00	0.01	0	0	0	0.000	2	19	21	11.840
SD	80	LP	B	-1	-1.00	57.73	49.46	4.32	2.47	56.49	50.66	5.27	3.82	1.11	6.38	0.02	0.10	0.06	0.03	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
STD	80	LT	B	-1	-1.00	-1.00	-1.00	-1.00	-1.00	57.54	51.06	4.46	3.71	-1.00	-1.00	-1.00	0.04	0.04	0.01	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
TT	55	LP	D	-1	0.00	-1.00	-1.00	0.00	0.00	58.07	55.38	4.36	-1.00	0.00	0.00	-1.00	0.14	0.11	0.03	0.03	0.00	0.03	0	0	0	0.000	13	1	14	0.000
TT	80	LP	B	-1	-1.00	57.73	49.40	5.19	2.91	56.71	51.96	4.76	3.05	1.74	-0.32	0.14	0.11	0.07	0.05	0.01	0.00	0.03	0	0	0	0.000	4	2	6	-1.000
TT	110	LT	B	12	1.00	57.53	49.95	5.02	2.72	56.93	52.01	5.70	2.03	2.97	3.77	0.16	0.15	0.10	0.05	0.00	0.00	0.00	0	0	0	0.000	0	0	0	0.000

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Location: HD02

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	SL Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Trucks	Total	Rate	Brake Lights: Cars	Trucks	Total	Rate
CC	55	LP	D	349	0.15	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.05	0.00	0.05	5	0	5	1.211	2	0	1	0.595
CC	80	LP	D	337	0.20	60.75	40.07	4.64	6.83	58.58	56.26	4.04	2.08	2.17	-7.20	0.32	-1.00	0.13	0.14	0.06	0.00	0.06	11	1	12	1.814	15	0	15	2.039
CC	110	LP	D	415	0.15	61.10	46.69	4.67	7.23	58.90	57.24	3.53	2.90	2.20	-10.5	0.33	-1.00	0.12	0.09	0.06	0.00	0.06	4	0	4	1.036	14	0	14	1.575
BB	55	LP	D	351	0.19	60.33	38.10	4.62	4.07	58.11	50.36	2.69	4.99	2.22	-17.4	0.30	0.94	0.26	0.16	0.03	0.00	0.03	7	0	7	1.437	2	0	2	0.240
BB	80	LP	D	378	0.17	60.07	44.20	3.20	10.17	58.96	50.00	2.06	1.38	0.40	-12.5	0.35	0.90	0.32	0.00	0.04	0.00	0.04	4	0	4	0.989	3	0	3	0.332
BB	110	LP	D	369	0.15	59.31	44.40	3.51	6.61	59.06	54.70	3.32	2.66	0.24	-10.4	0.30	0.96	0.29	-1.00	0.10	0.01	0.11	3	0	3	0.703	3	0	3	0.649
SB	55	LP	D	381	0.30	61.75	45.37	3.40	6.26	60.00	55.55	3.88	3.84	1.92	-5.63	0.30	0.47	0.31	0.10	0.05	0.01	0.06	3	0	3	0.909	2	0	2	0.771
SB	80	LP	D	290	0.26	58.47	46.11	4.38	6.30	57.83	53.35	3.72	3.32	1.30	-8.07	0.31	0.48	0.46	0.15	0.08	0.01	0.09	4	1	5	1.246	6	0	6	1.083
SB	110	LP	D	295	0.25	60.66	47.07	4.30	7.12	58.15	55.46	2.24	2.54	2.65	-8.66	0.30	0.22	0.16	0.13	0.07	0.00	0.07	10	1	11	2.811	12	0	12	2.730
TT	55	LP	D	325	0.26	61.20	48.16	5.07	5.21	56.81	55.65	3.24	2.59	4.29	-6.59	0.33	0.22	0.17	0.11	0.06	0.02	0.08	16	3	19	3.514	17	1	18	3.500
TT	80	LP	D	309	0.25	59.73	46.83	4.65	6.05	59.37	55.96	4.40	2.30	0.41	-1.51	0.31	-1.00	0.14	0.00	0.06	0.00	0.06	5	0	5	1.723	7	1	8	3.412
TT	110	LP	D	391	0.20	51.80	45.44	3.74	5.65	59.75	56.52	3.07	1.97	-0.95	-10.2	0.34	-1.00	0.12	0.07	0.04	0.00	0.04	6	0	6	1.207	8	1	9	2.493

Date: 02/09/90
Page:
Location: MD02

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	WZ Type	Site Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Trucks	Total	Rate	Brake Lights: Cars	Trucks	Total	Rate
CC	55	ET	D	339	0.16	62.38	49.96	4.55	5.85	59.57	55.10	3.65	1.67	2.66	-5.16	0.56	0.00	0.04	-1.00	0.15	0.04	0.18	4	0	4	0.471	2	0	2	0.230
CC	80	ET	D	298	0.18	62.36	48.99	4.15	5.94	60.98	57.75	5.16	2.00	1.58	-6.93	0.57	0.02	0.04	-1.00	0.12	0.05	0.17	6	0	6	0.681	2	0	2	0.181
CC	110	ET	D	378	0.15	62.08	49.12	5.04	7.35	59.39	55.38	4.72	3.76	2.69	-6.26	0.53	0.01	0.10	-1.00	0.16	0.03	0.19	6	0	6	0.993	8	0	8	1.312
BB	55	ET	D	332	0.20	59.12	47.22	4.68	8.11	57.35	54.07	5.01	3.44	2.09	-9.92	0.47	0.22	0.13	0.30	0.10	0.04	0.14	10	1	11	1.372	22	1	23	2.774
BB	80	ET	D	303	0.17	59.77	46.84	4.89	5.75	59.12	55.77	3.88	4.02	1.02	-9.45	0.47	0.00	0.14	-1.00	0.13	0.03	0.16	3	0	3	0.501	2	0	2	1.706
BB	110	ET	D	435	0.19	60.63	47.31	3.81	8.13	62.72	55.25	4.49	4.41	-2.12	-9.40	0.41	0.00	0.08	-1.00	0.08	0.01	0.09	2	0	2	0.342	4	0	4	0.617
SS	55	ET	D	301	0.22	59.01	54.30	5.29	3.02	57.13	45.75	5.59	5.52	1.97	9.33	0.62	0.01	0.16	-1.00	0.11	0.03	0.14	2	0	2	0.295	5	0	5	0.741
SS	80	ET	D	322	0.20	59.23	53.61	3.31	2.25	61.39	47.73	4.01	5.91	-2.16	11.11	0.58	0.00	0.13	-1.00	0.07	0.02	0.09	3	0	3	0.414	10	0	10	1.531
SS	110	ET	D	273	0.20	59.55	50.35	4.21	5.42	61.68	49.34	3.64	4.05	-2.20	1.01	0.58	0.00	0.23	0.40	0.11	0.02	0.13	4	0	4	0.676	7	0	7	1.110
TT	55	ET	D	335	0.24	59.61	46.76	5.42	4.47	56.95	54.03	6.33	3.21	3.98	22.35	0.54	0.00	0.09	0.47	0.09	0.03	0.12	0	1	1	0.168	9	0	9	1.798
TT	80	ET	D	288	0.19	60.12	47.91	4.40	6.39	58.31	55.66	4.02	3.57	1.19	-2.51	0.56	0.18	0.20	0.31	0.16	0.02	0.19	3	0	3	0.398	24	2	26	3.226
TT	110	ET	D	327	0.17	61.59	49.20	3.97	5.56	57.00	55.74	4.15	5.14	4.67	0.80	0.51	0.00	0.08	-1.00	0.08	0.01	0.09	2	0	2	0.285	6	0	6	0.948

Date: 02/09/90
Page: 5
Location: KD03

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	WZ Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Trucks	Total	Rate	Brake Lights: Cars	Trucks	Total	Rate
CC	55	LT	0	266	0.21	60.30	55.60	5.79	0.71	55.06	52.77	4.55	1.74	6.16	-13.8	0.17	0.27	0.04	0.02	0.01	0.00	0.01	2	0	2	0.844	0	0	0	0.000
~~CC~~	~~80~~	~~LT~~	~~0~~	~~361~~	~~0.20~~	~~61.10~~	~~55.03~~	~~4.34~~	~~0.93~~	~~56.91~~	~~53.07~~	~~4.14~~	~~3.25~~	~~3.31~~	~~1.17~~	~~0.15~~	~~0.08~~	~~0.03~~	~~0.04~~	~~0.04~~	~~0.00~~	~~0.04~~	~~4~~	~~0~~	~~4~~	~~1.731~~	~~0~~	~~0~~	~~0~~	~~0.000~~
CC	110	LT	0	338	0.22	62.33	53.17	4.27	1.33	55.38	50.14	4.51	3.60	7.05	3.68	0.15	0.10	0.08	0.05	0.03	0.00	0.03	2	0	2	0.855	0	0	0	0.000
BB	55	LT	0	287	0.33	58.33	52.00	2.87	2.84	51.82	49.28	3.91	3.46	4.04	7.67	0.12	0.58	0.02	0.02	0.01	0.00	0.01	0	0	0	0.000	2	0	2	0.641
~~BB~~	~~80~~	~~LT~~	~~0~~	~~356~~	~~0.24~~	~~59.39~~	~~48.43~~	~~6.36~~	~~5.36~~	~~51.44~~	~~47.46~~	~~3.81~~	~~3.14~~	~~7.85~~	~~1.03~~	~~0.27~~	~~0.91~~	~~0.00~~	~~0.01~~	~~0.01~~	~~0.00~~	~~0.01~~	~~0~~	~~0~~	~~0~~	~~0.000~~	~~0~~	~~0~~	~~0~~	~~0.000~~
BB	110	LT	0	210	0.30	58.56	54.21	5.89	4.68	54.82	49.69	3.39	3.30	3.91	12.53	0.16	0.72	0.00	0.01	0.00	0.00	0.00	0	0	0	0.000	0	0	0	0.000
SS	55	LT	0	286	0.20	59.84	54.83	4.33	0.17	55.14	50.70	3.93	5.25	4.70	4.14	0.21	0.16	0.14	0.11	0.04	0.01	0.05	3	1	4	2.060	4	0	4	1.145
~~SS~~	~~80~~	~~LT~~	~~0~~	~~321~~	~~0.26~~	~~58.51~~	~~52.88~~	~~3.77~~	~~0.00~~	~~54.66~~	~~49.08~~	~~4.98~~	~~3.25~~	~~3.28~~	~~2.42~~	~~0.22~~	~~0.10~~	~~0.07~~	~~0.04~~	~~0.03~~	~~0.00~~	~~0.03~~	~~2~~	~~0~~	~~2~~	~~0.795~~	~~1~~	~~0~~	~~1~~	~~0.331~~
SS	110	LT	0	279	0.28	59.40	53.69	4.00	1.36	54.44	50.88	5.56	3.93	4.81	2.76	0.21	0.15	0.09	0.05	0.03	0.00	0.03	2	0	2	0.882	0	0	0	0.000
TT	55	LT	0	286	0.33	59.78	53.12	3.10	0.62	56.86	53.47	4.28	3.70	3.05	-6.58	0.22	0.07	0.06	0.04	0.03	0.00	0.03	2	0	2	0.926	0	0	0	0.000
~~TT~~	~~80~~	~~LT~~	~~0~~	~~331~~	~~0.21~~	~~60.95~~	~~54.18~~	~~3.96~~	~~0.57~~	~~56.25~~	~~50.88~~	~~5.10~~	~~3.30~~	~~4.70~~	~~-7.52~~	~~0.22~~	~~0.08~~	~~0.08~~	~~0.07~~	~~0.05~~	~~0.00~~	~~0.05~~	~~5~~	~~0~~	~~5~~	~~1.414~~	~~1~~	~~0~~	~~1~~	~~0.417~~
TT	110	LT	0	314	0.30	63.06	54.52	3.71	1.34	56.43	50.23	4.57	3.82	6.61	4.29	0.21	0.10	0.07	0.06	0.04	0.00	0.04	4	0	4	0.834	2	0	2	0.427

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

						Traffic Speeds: Upstream Speeds				Traffic Speeds: Downstream Speeds				Traffic Speeds: Differences		Percentage Traffic in Closing Lane							Conflicts				Brake Lights			
Device Code	Space Code	WZ Type	Lite Code	VPH Level	Truck %	Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Average Speed Cars	Average Speed Trucks	Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Cars	Trucks	Total	Rate	Cars	Trucks	Total	Rate
CC	40	RT	D	270	0.22	61.14	56.00	3.91	1.20	54.87	53.86	3.83	2.58	5.26	2.78	0.74	0.42	0.32	0.25	0.18	0.00	0.19	0	0	0	0.000	0	0	0	0.000
CC	55	RT	D	194	0.25	59.65	53.47	4.05	4.86	55.14	51.84	4.94	3.92	4.51	-2.15	0.51	-0.11	0.65	0.11	0.05	0.01	0.05	0	1	1	0.205	1	0	1	0.309
CC	80	RT	D	198	0.23	59.68	54.33	4.94	3.25	55.70	52.30	5.00	4.02	4.03	-1.39	0.49	-0.11	0.67	0.16	0.11	0.01	0.12	1	0	1	0.289	1	0	1	0.208
CC	110	RT	D	270	0.36	60.84	51.89	6.25	5.85	56.65	51.24	5.02	4.43	4.19	0.65	0.36	0.01	1.00	0.21	0.03	0.02	0.06	1	1	2	0.579	1	0	1	0.579
RR	55	RT	D	297	0.22	61.02	55.06	3.94	3.11	55.02	52.18	3.07	3.27	6.00	3.39	0.46	-0.15	0.55	0.08	0.03	0.02	0.06	2	0	2	0.332	1	0	1	0.058
RR	80	RT	D	382	0.15	61.47	51.99	5.01	5.78	54.30	50.30	6.11	3.34	7.17	-4.80	0.26	0.04	1.00	0.03	0.02	0.01	0.02	1	0	1	0.473	1	0	1	0.453
RR	110	RT	D	277	0.21	59.02	53.46	4.70	5.19	53.49	49.21	4.12	2.94	5.52	-1.00	0.22	0.08	1.00	0.57	0.02	0.00	0.02	1	0	1	0.344	0	0	0	0.000
SS	55	RT	D	270	0.32	61.02	53.00	4.73	1.95	56.91	52.08	4.37	3.99	5.27	0.69	0.48	-0.08	0.21	0.15	0.08	0.03	0.11	2	0	2	0.332	0	0	0	0.000
SS	80	RT	D	338	0.26	59.73	53.03	4.30	0.65	57.68	51.39	4.46	3.77	2.23	-4.90	0.44	0.01	0.13	0.08	0.03	0.00	0.03	0	1	1	0.260	4	0	4	0.765
SS	110	RT	D	267	0.26	60.53	51.46	2.70	1.46	56.83	51.40	4.07	3.35	6.22	-0.01	0.51	-0.14	0.21	0.18	0.09	0.02	0.12	0	0	0	0.000	1	0	1	0.220
TT	55	RT	D	241	0.23	60.60	54.88	2.88	1.66	58.42	53.76	4.54	2.50	2.18	-4.37	0.54	0.18	0.35	0.20	0.14	0.05	0.19	0	0	0	0.000	0	0	0	0.000
TT	80	RT	D	331	0.14	59.09	50.00	5.90	0.33	57.19	49.44	4.18	3.35	2.40	-10.9	0.53	0.26	0.20	0.14	0.06	0.01	0.07	3	0	3	0.846	1	0	1	0.219
TT	110	RT	D	351	0.34	61.76	59.03	3.06	1.17	55.61	50.63	3.97	3.39	6.73	14.52	0.63	0.29	0.25	0.21	0.13	0.06	0.20	5	4	9	1.293	0	0	0	0.000

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WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

						Traffic Speeds										Percentage Traffic in Closing Lane							Conflicts				Brake Lights			
						Upstream Speeds				Downstream Speeds				Differences																
Device	Space	PL	Lite	VPH	Truck	Average Speed		Speed SD		Average Speed		Speed SD		Average Speed		Sta A	Sta B	Sta C	Sta D	Station E										
Code	Code	Type	Code	Level	%	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Total	Total	Total	Total	Cars	Trucks	Total	Cars	Trucks	Total	Rate	Cars	Trucks	Total	Rate
CC	55	LP	D	254	0.31	61.50	57.65	6.31	3.76	56.73	50.69	4.88	3.31	6.77	6.96	0.07	0.07	0.06	0.04	0.03	0.00	0.03	0	0	0	0.000	0	0	0	0.000
CC	00	LP	D	203	0.26	60.72	50.48	5.22	3.46	55.34	57.04	4.32	4.31	5.37	-0.06	0.10	0.08	0.06	0.05	0.02	0.00	0.02	0	1	1	0.386	2	0	2	0.773
BB	55	LP	D	297	0.24	59.75	55.58	4.86	2.99	52.93	48.77	4.30	3.55	7.35	6.88	0.11	0.05	0.07	0.04	0.04	0.00	0.04	0	0	0	0.000	0	0	0	0.000

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WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	WZ Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts: Cars	Trucks	Total	Rate	Brake Lights: Cars	Trucks	Total	Rate
CC	110	RT	D	818	0.21	61.00	57.64	5.29	2.35	55.81	52.22	4.78	2.21	5.27	5.42	0.41	0.30	0.06	0.14	0.09	0.03	0.11	1	0	1	0.772	0	0	0	0.000
SB	55	RT	D	327	0.24	61.37	57.29	4.61	4.05	56.13	52.45	3.79	1.29	5.24	4.83	0.47	0.38	0.13	0.21	0.12	0.05	0.17	1	0	1	0.881	0	0	0	0.000
SD	80	RT	D	321	0.22	60.87	56.06	4.06	3.34	55.53	51.91	3.30	3.51	5.35	4.15	0.54	0.46	0.08	0.25	0.18	0.04	0.21	3	2	5	1.945	0	0	0	0.000
SB	110	RT	D	307	0.23	60.16	57.53	4.91	2.70	55.07	51.08	4.49	1.75	4.21	6.15	0.47	0.40	0.05	0.31	0.13	0.01	0.14	3	0	3	0.827	0	1	1	0.309
TT	55	RT	D	303	0.18	60.60	57.42	4.40	2.91	55.01	50.71	4.66	1.63	4.59	7.52	0.41	0.35	0.23	0.20	0.14	0.00	0.15	1	0	1	0.370	0	0	0	0.000
TT	110	RT	D	260	0.19	60.23	55.67	4.71	3.23	55.70	50.00	3.70	3.35	4.59	5.58	0.55	0.54	0.38	0.36	0.22	0.05	0.28	1	0	1	0.604	0	0	0	0.000

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WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	VZ Type	Lite Code	VPH Level	Truck %	Traffic Speeds – Upstream Speeds – Average Speed Cars	Upstream Average Speed Trucks	Upstream Speed SD Cars	Upstream Speed SD Trucks	Downstream Speeds – Average Speed Cars	Downstream Average Speed Trucks	Downstream Speed SD Cars	Downstream Speed SD Trucks	Differences – Average Speed Cars	Differences Average Speed Trucks	Percentage Traffic in Closing Lane – Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts Cars	Conflicts Trucks	Conflicts Total	Conflicts Rate	Brake Lights Cars	Brake Lights Trucks	Brake Lights Total	Brake Lights Rate
BB	55	RT	D	623	0.22	66.12	57.58	4.50	4.78	61.33	50.84	5.00	6.26	4.79	6.78	0.31	0.18	-1.00	0.07	0.16	0.01	0.17	5	3	8	1.514	71	20	91	16.050
BB	80	RT	D	473	0.32	65.82	60.07	4.91	2.99	62.79	55.00	4.87	4.38	3.03	5.00	0.36	0.33	-1.00	-1.00	0.19	0.02	0.21	3	0	3	0.532	44	12	56	13.030
BB	110	RT	D	596	0.33	66.78	59.91	5.46	4.46	61.08	53.92	5.12	4.31	4.71	5.12	0.31	0.24	-1.00	-1.00	0.13	0.04	0.16	1	2	3	0.394	48	22	70	13.280
CC	40	RT	D	524	0.34	-1.00	-1.00	-1.00	-1.00	62.84	55.59	4.48	4.74	-1.00	-1.00	-1.00	0.21	0.11	0.02	0.05	0.01	0.06	1	1	2	0.391	14	4	18	3.614
CC	55	RT	D	544	0.30	-1.00	-1.00	-1.00	-1.00	60.73	55.00	4.89	4.32	-1.00	-1.00	-1.00	0.22	0.10	-1.00	0.08	0.01	0.09	5	0	5	0.834	18	8	26	2.455
CC	80	RT	D	537	0.31	-1.00	-1.00	-1.00	-1.00	62.56	55.92	4.54	3.62	-1.00	-1.00	-1.00	0.21	0.11	-1.00	0.06	0.01	0.07	5	2	7	0.797	17	9	26	2.735
CC	110	RT	D	674	0.20	66.12	60.98	5.38	4.01	60.45	53.16	5.19	3.97	6.32	8.95	0.24	0.23	0.02	-1.00	0.07	0.01	0.07	8	1	9	0.651	31	2	33	2.310
EE	55	RT	D	436	0.39	-1.00	-1.00	-1.00	-1.00	60.89	53.92	5.47	5.04	-1.00	-1.00	-1.00	0.11	-1.00	0.00	0.04	0.01	0.05	3	1	4	0.609	19	7	26	3.234
EE	80	RT	D	513	0.36	-1.00	-1.00	-1.00	-1.00	60.60	53.37	5.14	5.15	-1.00	-1.00	-1.00	0.33	-1.00	-1.00	0.05	0.01	0.06	2	0	2	0.271	32	25	57	6.690
EE	110	RT	D	491	0.31	-1.00	-1.00	-1.00	-1.00	60.07	54.81	4.34	4.69	-1.00	-1.00	-1.00	0.17	0.00	0.00	0.04	0.01	0.05	1	0	1	0.057	30	10	40	2.989
SB	55	RT	D	500	0.31	-1.00	-1.00	-1.00	-1.00	59.74	55.20	4.60	4.17	-1.00	-1.00	-1.00	0.15	-1.00	0.01	0.04	0.02	0.06	4	1	5	1.570	18	6	24	3.999
SB	80	RT	D	501	0.33	-1.00	-1.00	-1.00	-1.00	59.97	54.96	5.30	4.63	-1.00	-1.00	-1.00	0.23	-1.00	0.01	0.08	0.02	0.09	8	2	10	1.216	37	16	53	5.000
SB	110	RT	D	510	0.36	-1.00	-1.00	-1.00	-1.00	60.36	55.19	4.38	4.06	-1.00	-1.00	-1.00	0.16	-1.00	0.00	0.06	0.01	0.07	3	1	4	0.374	36	18	54	6.404
TT	55	RT	D	659	0.15	66.32	60.31	6.55	4.39	61.01	53.28	5.06	4.98	5.05	8.19	0.30	-1.00	0.00	-1.00	0.11	0.01	0.12	4	0	4	0.441	6	0	6	0.692
TT	80	RT	D	660	0.18	69.03	59.08	5.08	4.02	61.83	53.11	4.61	4.29	6.88	8.21	0.31	-1.00	0.03	0.02	0.10	0.02	0.12	7	1	8	0.440	45	5	50	3.702
TT	110	RT	D	566	0.24	-1.00	-1.00	-1.00	-1.00	61.31	52.30	4.72	4.87	-1.00	-1.00	-1.00	-1.00	0.10	0.01	0.07	0.01	0.08	3	0	3	0.336	34	7	41	5.960

WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	WZ Type	Lite Code	VPH Level	Truck %	Upstream Speeds: Average Speed Cars	Upstream Speeds: Average Speed Trucks	Upstream Speeds: Speed SD Cars	Upstream Speeds: Speed SD Trucks	Downstream Speeds: Average Speed Cars	Downstream Speeds: Average Speed Trucks	Downstream Speeds: Speed SD Cars	Downstream Speeds: Speed SD Trucks	Differences: Average Speed Cars	Differences: Average Speed Trucks	Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts Cars	Conflicts Trucks	Conflicts Total	Conflicts Rate	Brake Lights Cars	Brake Lights Trucks	Brake Lights Total	Brake Lights Rate
BB	55	RT	B	-1	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.19	0.02	-1.00	-1.00	-1.00	-1.00	0	0	0	-1.000	0	0	0	-1.000
CC	40	RP	R	240	0.51	-1.00	-1.00	-1.00	-1.00	59.73	54.27	4.93	5.13	-1.00	-1.00	-1.00	0.21	0.15	0.10	0.04	0.00	0.04	0	0	0	0.000	3	2	5	1.936
CC	55	RT	B	554	0.00	-1.00	-1.00	0.00	0.00	64.94	55.03	5.16	-1.00	0.00	0.00	-1.00	0.26	0.15	0.09	0.08	0.02	0.09	8	0	8	1.122	39	5	44	6.157
CC	80	RT	F	189	0.60	-1.00	-1.00	-1.00	-1.00	61.07	54.80	5.44	4.40	-1.00	-1.00	-1.00	0.26	0.17	0.13	0.06	0.02	0.09	1	0	1	0.446	9	14	23	11.562
CC	110	RP	R	338	0.28	-1.00	-1.00	-1.00	-1.00	60.82	54.62	5.31	4.50	-1.00	-1.00	-1.00	0.25	0.12	0.11	0.10	0.01	0.11	6	0	6	1.214	19	8	27	5.555
DD	55	RT	B	310	0.42	-1.00	-1.00	-1.00	-1.00	59.12	53.78	5.33	4.90	-1.00	-1.00	-1.00	0.26	-1.00	22.67	0.05	0.07	0.12	2	1	3	0.638	16	10	26	6.696
DD	80	RT	F	252	0.46	-1.00	-1.00	-1.00	-1.00	56.72	53.75	4.63	4.15	-1.00	-1.00	-1.00	0.21	-1.00	24.03	0.04	0.00	0.04	4	1	5	1.031	11	15	26	8.805
DD	110	RP	N	336	0.54	-1.00	-1.00	-1.00	-1.00	57.48	55.77	7.83	3.35	-1.00	-1.00	-1.00	0.20	-1.00	19.34	0.01	0.02	0.03	0	0	0	0.000	7	19	26	5.655
EE	55	RT	B	361	0.00	-1.00	-1.00	0.00	0.00	61.66	54.19	4.10	-1.00	0.00	0.00	-1.00	0.15	0.15	0.11	0.09	0.02	0.11	2	0	2	0.430	19	13	32	6.888
EE	80	RT	B	301	0.44	-1.00	-1.00	-1.00	-1.00	60.97	55.87	3.35	-1.00	-1.00	-1.00	-1.00	0.21	0.14	0.07	0.06	0.01	0.07	0	0	0	0.000	10	0	10	2.791
EE	110	RP	N	192	0.60	-1.00	-1.00	-1.00	-1.00	56.74	53.86	3.45	4.09	-1.00	-1.00	-1.00	0.25	-1.00	6.17	0.05	0.01	0.06	0	0	0	0.000	8	11	19	8.368
TT	55	RT	B	304	0.35	-1.00	-1.00	-1.00	-1.00	62.50	55.60	4.79	4.18	-1.00	-1.00	-1.00	0.24	0.14	0.04	0.10	0.02	0.12	1	1	2	0.316	12	4	16	3.872
TT	80	RT	B	305	0.41	-1.00	-1.00	-1.00	-1.00	60.97	55.80	5.31	3.99	-1.00	-1.00	-1.00	-1.00	0.15	0.10	0.09	0.03	0.13	1	1	2	0.397	8	2	10	2.909
TT	110	RP	N	349	0.50	-1.00	-1.00	-1.00	-1.00	60.92	54.16	5.63	3.72	-1.00	-1.00	-1.00	-1.00	0.10	0.04	0.07	0.02	0.09	0	0	0	0.000	4	0	4	1.038

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WORK ZONE CHANNELIZATION PROJECT - TRAFFIC PERFORMANCE SUMMARY

Device Code	Space Code	HZ Type	Lite Code	VPH Level	Truck %	Traffic Speeds: Upstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Downstream Speeds: Average Speed Cars	Average Speed Trucks	Speed SD Cars	Speed SD Trucks	Differences: Average Speed Cars	Average Speed Trucks	Percentage Traffic in Closing Lane: Sta A Total	Sta B Total	Sta C Total	Sta D Total	Station E Cars	Station E Trucks	Station E Total	Conflicts Cars	Conflicts Trucks	Conflicts Total	Conflicts Rate	Brake Lights Cars	Brake Lights Trucks	Brake Lights Total	Brake Lights Rate
HB	55	RT	1	456	0.10	66.03	53.12	4.73	2.63	61.11	51.37	5.73	6.39	4.91	-1.47	0.39	-1.00	-1.00	-1.00	0.15	0.04	0.19	0	0	0	0.000	0	0	0	0.000
HB	80	RT	1	405	0.31	65.40	58.04	4.12	3.15	60.44	53.54	6.31	4.94	5.06	4.40	0.30	-1.00	-1.00	-1.00	0.12	0.04	0.16	1	0	1	0.301	0	2	2	0.389
HB	110	RT	1	392	0.19	65.97	60.00	5.11	3.97	60.01	55.19	5.55	5.59	5.96	4.82	0.39	-1.00	-1.00	-1.00	0.15	0.03	0.18	1	1	2	0.397	1	1	2	0.534
SB	55	RT	1	523	0.19	63.60	59.01	4.67	2.19	60.51	54.88	5.71	4.01	3.51	4.84	0.33	0.00	-1.00	-1.00	0.13	0.02	0.15	0	0	0	0.000	0	0	0	0.000
SB	80	RT	1	500	0.19	63.00	59.04	6.65	3.50	56.65	48.06	7.41	4.01	8.55	5.06	0.42	0.00	-1.00	-1.00	0.16	0.03	0.18	1	0	1	0.210	0	0	0	0.000
SB	110	RT	1	464	0.18	65.07	59.40	4.40	1.24	63.28	54.51	5.29	2.20	1.79	-1.39	0.34	0.00	-1.00	-1.00	0.04	0.00	0.04	0	0	0	0.000	0	0	0	0.000
TT	55	RT	1	640	0.11	66.56	56.71	3.36	3.35	63.37	56.26	5.59	4.01	3.39	1.64	-1.00	-1.00	-1.00	-1.00	0.18	0.02	0.20	7	0	7	1.369	3	0	3	0.471
TT	110	RT	1	494	0.17	67.03	59.36	6.13	3.11	60.46	54.13	6.00	3.70	7.43	5.63	0.35	-1.00	-1.00	-1.00	0.11	0.02	0.13	2	1	3	0.562	3	0	3	0.471

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