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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **236**

EVALUATION OF TRAFFIC CONTROLS FOR HIGHWAY WORK ZONES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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EVALUATION OF TRAFFIC CONTROLS FOR HIGHWAY WORK ZONES

R. F. PAIN, H. W. McGEE, and B. G. KNAPP
BioTechnology, Inc.
Falls Church, Virginia

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AREAS OF INTEREST:
- MAINTENANCE
- CONSTRUCTION AND MAINTENANCE EQUIPMENT
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- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will be of special interest to traffic and construction engineers responsible for the development of traffic control plans for work zones as well as to manufacturers of traffic control devices. The findings identify the relative effectiveness of commonly used channelizing devices (i.e., barricades, panels, cones, and tubes) and will be particularly useful to Federal, state, and local agencies in updating their traffic control manuals. A wide range of channelizing devices in lane closure situations was tested through a series of laboratory tests, controlled field tests using instrumented vehicles on closed highway sections, and studies of driver behavior at actual construction sites. Safety of lane closures is of particular concern in view of the increasing emphasis on reconstruction activities.

Channelizing devices described in Part VI of the *Manual on Uniform Traffic Control Devices* (MUTCD) have generally evolved from other devices rather than as a result of scientific testing as to what best stimulates driver awareness of work-zone situations. As a result, there was a need for an evaluation of currently used devices as well as a determination of potential improvements. The objective of this research was to evaluate the effectiveness of channelizing traffic control devices and to determine how these devices should be designed and used to guide drivers as they approach and proceed through a work zone. Research included device size, shape, reflectorization, internal illumination, and spacing for both day- and night conditions; only stationary work zones were studied (i.e., major reconstruction type projects).

This research was carried out in two phases—NCHRP Project 17-4, "Evaluation of Traffic Controls for Street and Highway Work Zones," and NCHRP Project 17-4(2), "Evaluation of Traffic Cones and Tubes for Street and Highway Work Zones." The effectiveness of barricades, panels, cones, and tubes was initially investigated in Project 17-4 through a series of tests including simulated conditions in a laboratory setting, controlled field tests using instrumented vehicles on closed highway sections, and observation of driver performance at actual construction sites. Because the traffic cones and tubes tested in the first phase displayed relatively poor characteristics under nighttime conditions, further study of these devices using improved reflectorization and internal lighting was conducted in the second phase, Project 17-4(2). The second phase consisted of controlled studies on closed highway sections. Both phases were conducted by Bio-Technology, Inc., and the combined findings are described in this report.

One of the most confounding aspects of research related to traffic control in work zones is the complex interaction among all of the devices that are generally present. When advance warning signs, arrowboards, changeable message signs, lane markings, flagmen, and channelizing devices are all used on a construction project, isolation of the effects of a single device is an extremely difficult task. NCHRP and FHWA have conducted numerous research projects related to many of these devices as part of Project 1Y in FHWA's Federally Coordinated Program. For example, completed studies cover arrowboards, changeable message signs *(NCHRP Report 235)*, pavement markings, and, as reported herein, channelizing devices. Other projects are currently underway or will soon be initiated. It is important for the reader of reports from any of these studies to recognize that the findings pertain only to one type of device and do not fully address the question of applications of devices in combination. Furthermore, a responsible authority, such as the National Advisory Committee of Uniform Traffic Control Devices, needs to assess the findings of the individual research studies to develop recommended practice for the total work zone treatments. Therefore, although the findings presented in this report represent the most comprehensive evaluation of channelizing devices undertaken to date, they do not constitute recommendations for practice at this time.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Projects 17-4 and 17-4(2) by the Transportation and Traffic Safety Program of BioTechnology, Inc. Mr. Roger Petzold, now Highway Engineer with the Federal Highway Administration, was the Principal Investigator for most of Project 17-4. Upon his departure, Dr. Hugh W. McGee, Associate Program Manager for Transportation & Traffic Safety, now Vice President, Wagner-McGee Associates, Inc., assumed that responsibility. Dr. Richard Pain, Staff Scientist, directed and Ms. Beverly Knapp, Senior Research Associate, conducted the laboratory and instrumented vehicle studies; both contributed to all portions of the project. Other staff members who contributed to the project were James Sanders, David Chamberlain, Judith McDivitt, David Mazza, and Fred Hanscom.

As a subcontractor, Midwest Research Institute assited in the literature review task and the collection and analysis of traffic conflict data for the field evaluation task. Dr. William Glauz directed the MRI team members who consisted of Jerry L. Graham and Donald J. Migletz.

The Institute for Research provided staff assistance in the conduct of the controlled field study.

Task 4 could not have been conducted without the use of the instrumented vehicle (DPMAS) generously provided by the National Highway Traffic Safety Administration and the highway facility itself made available to us by the Pennsylvania Department of Transportation.

For Project 17-4(2) Dr. Richard Pain was the Principal Investigator. Contributing staff included Ms. Beverly Knapp, Ms. Sharon Wood, Ms. Carole Frazier, and Mr. Charles Edwards.

The field data collection was done on a facility graciously provided by the Virginia Department of Traffic and Transportation. Extensive logistic support of Project 17-4(2) was generously given by the P.D. Brooks Co. of Richmond.

Throughout all phases of this project device and reflective material manufacturers and American Traffic Services Association (ATSA) members have donated large quantities of their products for testing. Sincerest thanks are extended to each of them for their support.

EVALUATION OF TRAFFIC CONTROLS FOR HIGHWAY WORK ZONES

SUMMARY

The channelization devices described in Part VI of the *Manual on Uniform Traffic Control Devices* have developed as an evolvement from other devices, rather than as a result of scientific testing as to what best stimulates driver awareness of work zone situations. This study was undertaken to provide data on the design and use of channelization devices so that they can be more effectively used to guide drivers as they approach and proceed through a work zone. The project focused on channelization devices consisting of cones, barricades, drums, vertical panels, and steady-burn lights, and was limited to stationary, long-term work zones on freeway type facilities.

A comprehensive literature review was conducted to identify: (1) the safety problem at highway work zones as it relates to channelization devices, (2) the use and effectiveness of traffic control devices in work zones, and (3) measures which can be used to evaluate the performance of channelization devices. The findings of the literature review supported the original contentions that there are many types and designs of channelization devices used and, furthermore, that data are lacking which support current design of these devices or their arrangement on the job.

The next task prior to actual experimentation was to develop performance measures that would reflect driver's responses and the relative effectiveness of particular devices. The results of the literature review and an Information-Decision-Action (IDA) task analysis procedure were used to derive candidate performance measures. By analyzing the driving task, it was possible to identify the desired driver and vehicle responses and, in turn, translate these into performance measures for evaluation. The more discriminating measures proved to be: 1. laboratory—accuracy of design identification; 2. closed-field-array detection distance, point of lane change, speed change, path consistency; and 3. field—mean speed, speed profile and variance, point of lane change.

The experimental program consisted of three types of studies. The first of these was laboratory studies to optimize the design characteristics of barricades and panels. The design features studied were: stripe configuration (horizontal, vertical, diagonal, and chevron), width, and meaning; white-to-orange color ratio; and height-to-width ratio. The results of the laboratory testing provided preliminary findings regarding channelization device design which were further examined and validated in the field studies.

The next experiments were conducted on a closed highway using an instrumented vehicle driven by test subjects. First, devices with varying sizes, spacings, reflectivity, and auxiliary lighting (steady-burn lights) were compared to determine their relative effectiveness in eliciting desired driver responses. This study provided additional findings related to the effectiveness of alternate devices and device designs when placed in a channelization array. Second, cone and tube design was optimized in terms of amount, type, and configuration of reflective material day and night.

The final experiment was conducted in a real-world situation wherein three types of devices (cones, barricades, and vertical panels) with design and layout variations were tested at three work zone types—a traffic diversion site, a left-lane closure site, and a right-lane closure site.

The primary design and application findings for each type of channelization device were synthesized across the various types of experimentation and are summarized in Table I.

Other general findings of interest include:

1. Array detection distances of 3100–5000 ft in the day and somewhat shorter distances at night (2050–4000 ft).

Table I. Summary of recommendations for use and design of channelization devices for freeway-type operations.

Device	Application Guidelines	Minimum Dimensions	Stripe Configuration	Color	Minimum Stripe Width	Spacing
Cone	• Interchangeable with other devices • Applicable for all work zone situations	• 28" or greater for high speed facilities	• 2 or 3 bands totaling 150-200 in^2 of SIA-250 (preferably higher) reflective material*	All orange cone yellow or white reflectorization	N/A	MUTCD
Tubular Cone	• Interchangeable with other devices • Applicable for all work zone situations	• 28" or greater for lane closures or diversions • 4" diameter	• 1 band—high or low mounting of same material as cones	All orange tube yellow or white reflectorization	12"	MUTCD
Barricades	• Applicable for all work zone situations • Type 1 suitable for all channelization situations	• Rail—12" wide 24" long • Height—MUTCD	• Diagonal, but not to be used to convey direction • Consider chevron to convey direction	1 orange to 1 white	6"	• MUTCD • ½ SL in taper and double speed limit acceptable in tangent area where no work activity or traffic delays
Vertical Panels	• Interchangeable with other devices • Applicable for all work zone situations	• 12" wide • 24" height • Ground clearance—MUTCD	• Diagonal or horizontal • Consider chevron to convey directional change	1 orange to 1 white	6"	Same as barricade
Drums	• Interchangeable with other devices • Applicable for all work zone situations	• Same as MUTCD	• Horizontal	1 orange to 1 white	6"	Same as barricade
Steady-Burn	• Should be used at night whenever feasible • Especially effective for tapers and approach ends • Use in visually noisy environment 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

*75-100 in^2 visible to the driver.

2. Considerable variability in array detection distance between drivers for most devices, particularly at night.
3. For barricades, panel, and drums, the mean point of lane change is further away from the array at night than in daylight. However, for cones and posts there was little difference, or the reverse was found.
4. Extensive variability in point of lane change among drivers was evident, particularly at night for larger devices.
5. In every group, regardless of device, one to four subjects drove to within 20–300 ft of the taper before changing lanes.
6. All devices elicited a shift in lateral placement towards the left edge of the lane away from the devices.
7. There were differences in displacement (weaving or path consistency) elicited by devices. The 3-ft × 12-in. Type II, 8-in. × 24-in. panel, and 36-in. cone showed the least weaving.
8. Speed reduction is controlled by device size during the day. Amount of visible reflective surface at night controls speed reduction, array detection distance, and lane changing.
9. Size and visible area have greater impact on behavior than device shape.
10. Direction is conveyed only by arrow/chevron type stripe configurations—not diagonals.

In conclusion, channelizing devices serve both a driver alerting and path guidance function. Devices configured as described in the table are equally effective and should be considered interchangeable. Regardless of the device, each type obtains its maximum effectiveness when properly deployed as a system or array of devices. Motorists do not respond to a single channelization device, but to the path that is defined by the array. Therefore, it is important that care be taken in the layout and maintenance of these devices.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

Today, with the Interstate Highway System nearly complete, there is a shift in emphasis from spending of highway monies for the building of new facilities to improving the quality of service on existing facilities. This shift has made the task of maintaining traffic on the highway facilities during reconstruction even more critical. The problem is compounded by generally rising traffic volumes, especially in urban areas.

To accommodate traffic through or around construction zones, the construction activity and the traffic controls must be coordinated to provide safe and expeditious movement of traffic while the construction activity progresses as rapidly, safely, and efficiently as possible. When these two goals come in conflict, tradeoffs occur between the safety of traffic and construction workers and the costs of traffic and construction delay.

Studies have shown that many construction work areas experience increases in accident rates during construction when compared to a similar period before construction (*1, 2*). Inappropriate use of traffic control devices, poor traffic management, inadequate zone designs, and a general misunderstanding of the unique problems associated with construction zones have led to these increases. Construction zone traffic controls are often hastily conceived and seldom reconsidered. Because of a general lack of knowledge about construction zone operations, traffic control design is often done by simply referring to a typical drawing in a manual. The operational consequences are that short transition zones and inadequate lateral clearances are often imposed where they could be less restrictive. Also, barriers are installed in areas where they are not functional, and ineffective barrier systems are used.

Traffic control devices are used to alert drivers of impending conditions, warn them of hazards, and direct them through the proper path. These devices include signs, signals, hand signaling devices, channelization and delineation devices, deflection and attenuation devices, high level warning devices, and lighting devices. The application of traffic control devices and, in particular, channelization devices, in construction zones appears to vary widely between agencies and between construction projects. This indicates a general lack of knowledge regarding the safety effectiveness of these devices. Devices described in Part VI of the *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*), have developed simply as an evolvement from other devices, rather than as a result of scientific testing as to what best stimulates driver awareness of work zone situations. This study (NCHRP Projects 17-4 and 17-4(2)) was prompted by the realization that data were lacking that would support the current design of these devices or their arrangement on the job to provide the best guidance for the driver and protection of the worker.

OBJECTIVES AND SCOPE

The overall objective of the research was to determine the effectiveness of selected types of work zone traffic control devices and to determine how these devices should be designed and used to guide drivers as they approach and proceed through a work zone on freeway type facilities. The selected types of devices were limited to those which provide channelization (i.e., barricades, cones, tubes (also called posts), drums, panels, and steady-burn lights). The research did not examine flashing arrowboards (because this device had been examined in a Federal Highway Administration project), signs, or markings. Furthermore, the research was restricted to stationary, long-term work zones and did not examine moving operations or short-term (less than 24 hours) projects. Finally, the field research was conducted on 55-mph speed limit highways; consequently, most of the results deal with this type of facility. However, some of the results of the initial laboratory studies apply to all devices in general without regard to highway type.

Within the context of the main objective there were six specific assignments:

1. Critically review all research that supplied valid driver performance data on the effectiveness of traffic control devices used in work zones.
2. Devise appropriate measures of performance that reflect driver responses and the relative effectiveness of particular devices for use in subsequent tasks.
3. Test and evaluate present and alternate markings for barricades, cones, drums, and vertical panels. Items to be

considered include rail width, level of reflectivity, width and arrangement of stripes (i.e., horizontal, vertical, sloping, and chevron).

4. Using the results of Task 3, determine the relative effectiveness of each channelizing system in stimulating desired driver response through testing and evaluation. The evaluations should include various sizes and spacings of devices.

5. Determine the need and applications for the use of flashing and steady-burn lights in work zones.

6. Evaluate in actual work zone conditions the effectiveness of the devices used in combination with other traffic control devices.

RESEARCH APPROACH

To meet the principal objective and satisfy the intent of the assignments, a research plan was adopted which consisted of five tasks. These tasks and the type of work performed are summarized as follows:

1. *Literature Review*—The literature review was a comprehensive compilation and synthesis of all literature supplying information on the use and effectiveness of traffic control devices in work zones. It consisted of three parts. Part 1 was a literature search of all documents relating to four topic areas: (1) accidents in highway work zones, (2) the use of traffic control devices in work zones, (3) the effectiveness of traffic control devices in work zones, and (4) driver performance measures. Part 2 was a review of information contained in selected state, local, and utility manuals on uniform traffic control devices. Part 3 was a limited survey of manufacturers of traffic control devices for work zones to determine the types and configurations of devices manufactured and ideas on design modifications.

2. *Derivation of Performance Measures*—The purpose of this task was to develop appropriate measures of performance that would reflect driver response and the relative effectiveness of particular devices. These measures were to be used in the subsequent tasks. In addition to the literature review, this was accomplished by a driving task analysis for a typical work zone situation. By analyzing the driving task for the various work zone areas, it was possible to identify the desired driver and vehicle responses and, in turn, translate these into performance measures for device evaluation.

The next three tasks comprised a series of studies that were designed to first optimize the design characteristics (i.e., size, stripe width and configurations, and pattern); second, compare the relative effectiveness of alternate device types and various configurations and spacings of each; and third, evaluate in an actual work zone setting the selected devices used in combination with other traffic control devices. These tasks were:

3. *Optimization of Markings for Channelization Devices*—The intent of this task was to optimize the design characteristics for barricades and panels. The design characteristics were: stripe configuration, width, and meaning; white-to-orange color ratio; and height-to-width ratio. A laboratory methodology was employed whereby 30 subjects were shown stimulus slides through a tachistoscope at a speed of less than 1 sec to introduce errors in discriminating between stimuli. (Cone and tube optimization studied in Task 4 involved manipulation of reflectivity characteristics which were not amenable to laboratory methods.)

4. *Effectiveness of Channelization Devices, Controlled Field Studies*—This task was designed to determine the relative effectiveness of several channelizing devices and device schemes in eliciting desired driver responses. Configurations of these devices with varying sizes, spacings, reflectivity, and auxiliary lighting (steady-burn lights) were tested on closed highway facilities using an instrumented vehicle. (Because cone and tube performance degraded significantly at night additional work was carried out under Project 17-4(2) to optimize nighttime performance without sacrificing daytime performance. Cone and tube parameters studied were: amount of reflective area, number of bands of reflective material, collar mounting position, type of reflective material, device size, and spacing. Two sets of tests were conducted. The first was a variation of the original test method and the second a replication of that method. Also, additional data on one- and two-rail barricades and Types II and III reflective sheeting were gathered.)

5. *Effectiveness of Channelization Devices, Field Evaluation Study*—The final effort (Task 5) was to evaluate the effectiveness of selected channelization devices when used collectively under actual field conditions. The results of the previous tasks were used in selecting alternate devices for testing and the experimental plan. These devices were tested at work situations similar to those depicted in the typical MUTCD layouts, and included different highway types.

The research results are presented in the remainder of this report. Chapter Two discusses the principal findings corresponding to the five research tasks and the cone and tube optimization studies. Chapter Three synthesizes and interprets the findings reported in Chapter Two for the purpose of producing suggested guidelines for the application of channelizing devices in work zones. Chapter Four covers the conclusions and recommendations for further research. Chapter Five contains a bibliography. Each of the work tasks has a corresponding appendix. Appendix A includes a detailed description of the literature review process, an annotated bibliography, a matrix portraying the derivation of performance measures from the literature, and a summary of the information found in state and local government and utility company manuals for use of traffic control devices. Appendix B documents the detailed task/information analysis and resulting derivation of performance measures. Appendixes C, D, and E are comprehensive reports of the laboratory experiments, controlled field studies, and field evaluation, respectively. Appendix F presents the research done in further evaluating the effectiveness of the various types of traffic cones and tubes, especially for nighttime operations.

CHAPTER TWO

FINDINGS

The principal findings of the study are presented in five sections corresponding to the five research tasks. The first part summarizes the highlights of the literature review. The second section presents findings on the derivation of performance measures. The third section discusses laboratory experiments which focused on optimizing the design characteristics of barricades and panels. The fourth section provides the findings of the experiments, conducted on closed highway facilities, which were designed to determine (1) optimal cone/tube design and (2) the relative effectiveness of several channelizing devices and schemes applied collectively. The fifth section reports the results of the field evaluation study in which several device schemes were tested under "real world" conditions and compared against a standard device treatment. Each of these sections is supported by an appendix (A through F) which describes the task in detail.

LITERATURE REVIEW

As the first step in the evaluation of channelizing devices for use in work zones, the literature review identified the problem area and uncovered current operations. Table A-2 in Appendix A is a subject by reference matrix for the literature reviewed. A complete bibliography is included in Chapter Five.

The genesis of the study area arose from the recognition that highway work zones apparently divert the attention of the driver from his normal driving task and, thereby, constitute a potential hazard. Given this hazard situation, the possibility of roadway accidents exists; and, in fact, various reports document this problem (*1, 4, 5, 6, 7*). A few of these accident studies specifically relate some casualty to the misuse of traffic control devices. For example, Lisle et al. (*8*) reported on the crash incidence of timber barricades on the I-495 Beltway widening in Northern Virginia. Yet most are simply more general statements of accident occurrence in construction areas, noting that more accidents seem to occur on a highway containing a construction zone than the same stretch before the zone was implemented (*7, 9, 10*). Also, there is a difference reported for day versus night operations in work zone areas (i.e., fewer accidents occur during night construction periods than on ordinary nights) (*11*). Some sources are just a reporting of accident statistics without regard to the actual devices on the work site.

The fact that traffic control devices continue to be hit is well known. Migletz (*10*) reports that devices set in a lane closure situation are much more likely to evoke an incident than devices simply protecting the shoulder. Single-vehicle fixed-object accidents quite often involve drums and similar large devices which become hazardous projectiles that can hit workers. Anecdotal information from device rental company personnel supports the fact that damage and losses of equipment are very widespread. Row (*12*) concludes that somehow, in this work zone setting, the driver receives neither proper visual stimulation nor sufficient warning to avoid the collision incident.

Table 1 is a summary of information on channelization devices used in work zones based on the specifications of the *Manual of Uniform Traffic Control Devices* and a survey of other state and utility company manual specifications that present variations to the MUTCD. The right hand column of the table presents some commentary from these documents and from research literature impacting on the use and effectiveness of the devices. The full listing of the reports, summaries, and manuals surveyed is detailed in Appendix A.

The table as presented is device specific in that the specifications and commentary are related to individual devices. A few other issues from the literature of a more general nature are worthy of mention. These arise from the fact that devices as considered here are usually placed in an array rather than singly, and some standards for layout and set-up have been put forth. The channelization devices are almost always part of an entire work zone information system, with the other components being signs, arrow panels, pavement markings, flagpersons, etc., (*13, 14*).

The devices in question—cones, barricades, panels, and drums—are considered to be channelizing devices, primarily for delineation guidance through the zone and to protect work operations from traffic flow. However, discussions about these devices do not always speak of them as serving the simple, channelizing, protecting function, since they speak of "target value," warning and alerting potential. The MUTCD states that:

> . . . the function of channelizing devices are [sic] to warn and alert drivers of hazards created by construction or maintenance activities in or near the travelled way, and to guide and direct drivers safely past the hazards.

It is fairly well agreed that cones, tubes, and panels are sufficient to channelize in small operations, but a larger more extensive zone seems to require barricades (*9*). The National Safety Council's report purports that Type I and Type II barricades are the key channelizing devices, and that cones, panels, and drums are simply auxiliary substitutes given certain constraints of the zone. Some researchers feel that barricades and drums serve a protective function only (*5, 7, 15*).

The MUTCD states that the channelizing devices are elements in a total system of traffic control and shall be preceded by a subsystem of warning devices such as signs and arrow panels. The New York MUTCD supports this further by mandating that drums shall never be placed on the roadway without advance warning signs to accompany them.

Table 1. Summary of information on certain channelization devices used in work zones.

Device	Current Standard Usage						Literature Commentary
	Source	Height (minimum)	Width (minimum)	Color(s)/ Configuration	Stripe Width	Visibility Requirements	
CONE	MUTCD	18"	Variable	Fluorescent orange	Variable	Must be reflectorized or lighted at night	• Larger sizes should be used on higher speed roadways (15) • Regular cones have greater target value than tubes • Use of orange flag in tip suggested for anytime • Cone use is primarily delineation and channelization rather than warning with high target value • Tubes primarily for daytime temporary use. They usually replace cones when lane space is at a premium (19) i.e. bridges (20) • Cones generally suggested for smaller, less hazardous zones (5) which cause only a minor impedance to traffic flow • Must make provision for cones so that they will not be blown over or displaced (15)
	Others in use	28", 30" 36"	Base—12" Tip—2½"	Fluorescent orange	4" white cone collars	Minimum brightness for white 150 candelas, 300 preferred; cones should be replaced or supplemented at night with steady burn lights	
TUBE (Tubular Cone) 	MUTCD	18"	Variable	Fluorescent orange	Variable	Must be reflectorized or lighted at night	
	Others in use	28" 36"	Tip—2½"	Fluorescent orange and yellow	4" white or amber collars	Minimum brightness for reflective collars 150-300 candelas; pylons should not be used at night without lights or reflective collar	

Yet, Graham et al. (*1*) note that drivers make speed and lateral position changes on encountering a zone based on geometrics of the zone and devices rather than the signs or other advance warning types of displays. Clear definitions of the information display systems elements are not universally accepted.

One issue of vital importance is the taper length and spacing for devices. The MUTCD (1978 revision) recommends two standard formulas based on the work of Graham et al. (*16*).

> . . . minimum desirable length of taper is computed by $L = S \times W$ for all freeway and expressways with posted speed of 45 mph or greater. The formula $L - W^2/60$ should be used to compute taper length on urban, residential or other streets where the posted speed is 40 mph or less. Under either formula,
> L = taper length in feet
> W = width of offset in feet
> S = posted speed or off-peak 85 percentile speed. . . .

Most state and utility manuals agree with this, with minor variations at the lowest speeds where space of zone is at a minimum. In urban settings, this is compensated for by the use of high level warning devices, and in freeway settings, inadequate tapers of sight distance call for the use of arrow panels. The systems approach is again underscored here.

The spacing for devices follows the rule that devices in a taper should be approximately as many feet apart as the posted speed limit (*3*). Devices in the tangent are subject to the degree of protection needed for the zone. The Minnesota MUTCD has a spacing rule of 20 ft apart for speeds 0–35 and 50 ft apart for 40–50 mph (1 ft = 0.3048 m.; 1 mph = 0.609 km/h). Yet, the actual zone dictates the spacing since even the MUTCD advocated drive-throughs and inspections to determine what is adequate by judgment. In one case—for example, a right lane closure, 4-lane divided highway—cones are 150 ft apart on shoulder (before taper), 2 ft apart in taper, then 75 ft apart along tangent (40–50 mph).

Night versus day operations evoke differences in use. Night operations usually do not have heavy traffic flow with which to contend, yet visibility is degraded for those few motorists driving at night. Thus all manuals prescribe some illumination and/or reflectivity standards for nighttime operation (see Table 1). Predominantly orange colored devices must have some kind of illumination (i.e., steady-burn or flashing lights or reflective attachments, e.g. cone collars).

Many manuals, including the MUTCD, as well as research literature, simply state that the device must be visible in enough time for the driver to negotiate them in a proper and safe manner. Recent research by authors of this report rec-

Table 1 Continued

Device	Source	Minimum Height	Rail Width	Length (Min.)	Color(s)/ Configuration	Stripe Width	Visibility Requirements	Literature Commentary
TYPE I BARRICADE 	MUTCD	3′	8″ min.-12″ max.	2′	Orange and white sloping at 45°	6″ (4″ for rails less than 3′)	Entire area shall be reflectorized with a material that has a smooth, sealed outer surface. Lights on option after dark	• Types I and II generally used when traffic is still maintained on the roadway • Type II is usually for partial or complete road closure • Some researchers and engineers feel that Type I and Type II are interchangeable (21)
	Others in use	–	6″–12″	6′	Black and white	4″	Minimum brightness orange 25-70 candelas white—70-250 candelas	• Number of barricades used should be minimized to reduce fixed object accidents (1)
TYPE II BARRICADE 	MUTCD	3′	8″ min.-12″ max.	2′	Same as MUTCD above	6″ (4″ for rails less than 3′)	Same as MUTCD above. Lights on option after dark	• Diagonal stripes more distinct at closer distance than chevron pattern, yet both have same target value. Chevron only effective to give directionality at 200′ or less. (22) (5)
	Others in use	–	6″–12″	–	Black and white	–		• Many consider barricades to have the best target value of all devices (22) • Barricades provide an easy mount for signs and warning lights
TYPE III BARRICADE 	MUTCD	5′	8″ min.-12″ max.	4′	Same as MUTCD above	6″ (4″ for rails less than 3′)	Same as MUTCD above. Lights on option after dark	• Barricades should not be used unless the hazard is greater than the hazard of striking the barricade (7)
	Others in use	–	6″–12″	6′ 8′	Black and white	–	When used for road closure, should have warning lights	
TYPE IV 	UTAH DOT				Orange and white chevrons	10″		• Utah's chevron barricade is known as the "channelizing arrow."

ommends a minimum nighttime visibility distance for reflective channelizing devices to be 900 ft at 55 mph (*17*). A very recent small study toward a performance standard for Type A flashing lights (*18*) has begun to examine various distances for hazard lighting based on their performance as perceived by drivers. Such devices must be highly visible in themselves, yet should also be accompanied by advance warning signs and devices, and by suitable lighting devices at night (*21*).

On construction projects, channelizing devices often remain on the roadway for long periods of time. Many reports and manuals (*1, 13, 21, 23*) emphasize the need to inspect and maintain the devices so that they remain clean and spaced as set-up for continued proper visibility. FHWA (*20*) reported that in one project, the Dan Ryan Expressway in Chicago, 70 to 100 barricades were lost or destroyed per day. It is necessary to patrol and maintain what is set out in order for effectiveness to be assured. No matter what correct combination of channelizing devices, warning devices, signs, and markings are established as a system, it will be less than optimal if not seen as specified.

The understanding from many sources is that channelizing devices are just components in an entire information system for the work zone, and that all components must be inspected and maintained periodically for proper operation. Even so, a test of some of the variety of standards uncovered, along with variations on these, is in order to determine how rigid or flexible field engineers can be in manipulating the given components. The findings of analytic, laboratory, closed (controlled) field, and field evaluation studies reported in this chapter provided information on this subject.

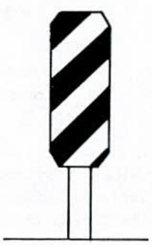
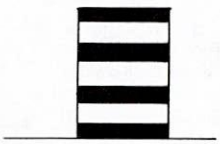
DERIVATION OF PERFORMANCE MEASURES

General

The objective of the second task was to derive appropriate measures of performance that reflect driver response and the relative effectiveness of particular devices. These measures were then to be used in the three subsequent tasks: (1) a laboratory experiment of individual device design (Task 3), (2) a controlled field experiment testing alternative devices used collectively (Task 4), and (3) an evaluation of selected devices applied to actual work zone situations (Task 5).

Two activities were pursued to derive the appropriate performance measures. The first was a review of the literature to identify candidate measures. The results of this effort are

Table 1 Continued

Device	Current Standard Usage						Literature Commentary
	Source	Dimensions	Height	Color(s)/ Configuration	Stripe Width	Visibility Requirements	
VERTICAL PANEL 	MUTCD	8"–12" wide x 24" high (min.)	36" from ground	Orange and white sloping at 45° to traffic	4–6"	Entire area shall be reflectorized with a material that has a smooth sealed outer surface Should place lights on panel after dark	• Panels are used where space is at a minimum—should always be secondary to barricades (5) • Suggest panel use for traffic separation or shoulder barricading
	Others in use		48" from ground	Horizontal stripes & chevron stripes		Minimum brightness white 70-75 candelas orange 25-70 candelas	
DRUM 	MUTCD	18" diameter	36"	Orange and white horizontal circumfer-ential	4–8"	Must have at least 2 orange and 2 white stripes. During dark, lights should be placed on drums	• Very high target value with great visibility but the least portable of all devices • For use at sites of longer length (5) a full zone • Drums seem more formidable and present a grearter obstacle thereby giving a good vision warning (15) • One application of drums is to show an unusual vehicle path made necessary by the work activity (15)

reported in Table A-1 and served as "input" to the remainder of the task. The second activity was an analytical assessment of the driving task requirements for a typical work zone situation. By analyzing the driving task it was possible to identify the desired driver and vehicle responses and, in turn, translate these into performance measures for evaluation. This driving task analysis was particularly useful in defining those measures which were relevant to the field evaluation study.

The discussions of the performance measures used for the laboratory experiment (Task 3) and the controlled field testing (Task 4) are best presented in the context of their individual reports. Hence the reader is referred to Appendixes C and D for that information. This section will present an example of how the driving task analysis was used to develop candidate performance measures for the field evaluation. Appendix B contains complete documentation of this task.

Work Zone Driving Task and Related Measures

The technique followed in deriving performance measures was an adaptation of the information-decision-action (IDA) analysis procedure. By applying the IDA analysis to the problem at hand, it is possible to identify appropriate performance measures by first determining the task requirement sequence (i.e., action) as the driver approaches and passes through various sections of the construction zone. Then from identifying the information requirements, at least in generic terms, it can be established whether or not any of the devices being studied are a factor in eliciting the appropriate driver response. Finally, the appropriate performance measures can be identified based on driving tasks and whether or not the devices being studied are likely to affect the driving task.

This procedure is shown in Figure 1, which is a task analysis for the advance area of a construction zone. This figure identifies the action to be taken by the driver, the information requirement and sources (devices) available to meet the requirement, and the possible performance measures that may be used to measure driver and vehicle behavior.

For practical purposes, this area (zone) begins with the first information of a construction zone. In Figure 1 the ROAD WORK 1 MILE sign is the beginning of the approach area, which could be defined as either: the point where the signing informs the motorist what action is required (e.g., RIGHT LANE CLOSED) and where it is to take place (e.g., 1/2 MILE); the point of possible first sighting of the hazard (i.e., the taper devices); the decision sight distance—an established distance based on information processing.

In this area there is no special or unusual driving task requirement. The primary task is to maintain a quasi-steady driving state, which simply means maintenance of the

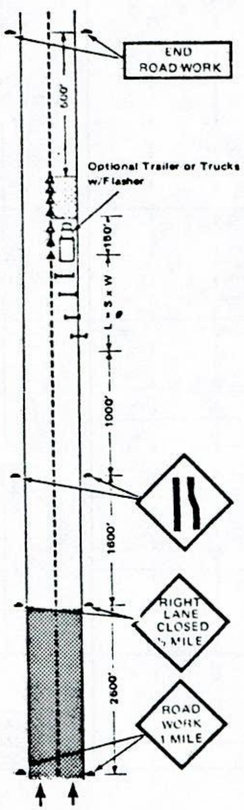
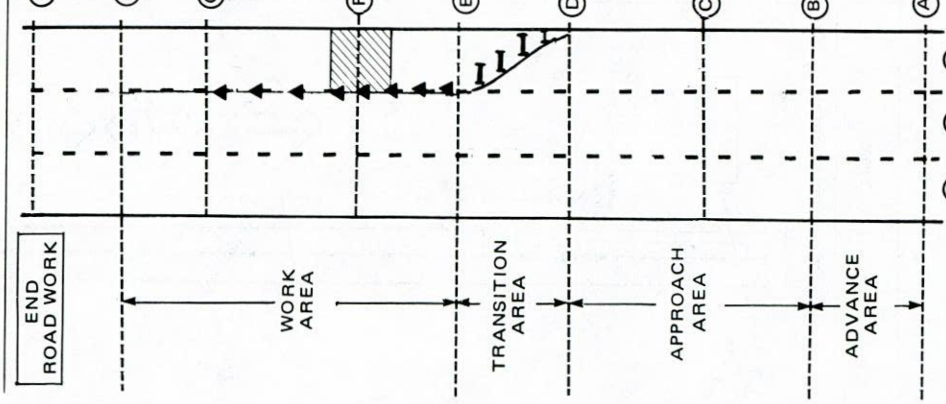
LOCATION	ACTION TO BE TAKEN	INFORMATION REQUIREMENT/SOURCES	PERFORMANCE MEASURES	COMMENTS
1. ADVANCE OR WARNING AREA 	A. Maintain QUASI-STEADY STATE – No change in speed or path required	**REQUIREMENT** Driver needs only to be made aware of construction activity ahead **SOURCES** 1. Advance warning sign(s) e.g. W20-1 2. Driver may have view of channelization devices or flashing arrow board if there is long sight distance	**A. VEHICLE** 1. Speed • mean, 85th percentile • variance	– Base value for comparison with other areas
			2. Headway – all lanes	– Not directly comparable to other areas unless number of lanes is continued thru zone
			3. Placement • mean • variance	– Difficult to compare with other areas
			4. Conflicts/Erratic Maneuvers a. sudden speed reduction b. brake light application c. swerving, weaving d. slow moving	
			5. Volume (by lane)	
			B. DRIVER 1. Recognition of Signal – • reaction time • head/eye movements • recall 2. Preference 3. Understanding	– Requires instrumented vehicle, test subjects

Figure 1. Task analysis for advance area.

desired or required lateral (lane placement) or longitudinal (speed, headway) control. Because the driver usually cannot see the construction area ahead and cannot determine from the advance signing what specific action is required, there is not likely to be a significant change in his quasi-steady driving state, at least none that could be attributed to the devices of interest in this study.

Performance measures to be obtained here, if at all, would include those typical traffic flow measures which could be used as base values to compare with other zones. These are identified in Figure 2.

In a similar fashion task analyses were made for five other areas of a construction zone: the approach area, the transition area, the work area and the activity area (the latter area



Possible Data Collection Points	Measurements: Speed	Lateral Placement	Headway	Volume	Merge Point	Conflicts/ Erratic Maneuvers
(I) *Downstream Point* — area of return to pre-construction normal driving.	N/A	N/A	N/A	N/A	N/A	N/A
(H) *End Construction Point* — end of construction and therefore end of device.	N/A	N/A	N/A	N/A	N/A	N/A
(G) *Non Activity Point* — any area between E and H where there is no construction activity and represents "normal" speed/path thru construction.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
(F) *Activity Point* — area(s) of construction activity where drivers may make further modifications in speed/path.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
(E) *Entry Point* — end of transition where drivers have stabilized their speed position, influenced by devices.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
(D) *Transition Point* — Begin of taper, final opportunity for merge — highest incidence of transitions, conflicts; directly influenced by channelization devices	Lanes 1 & 2	—	—	All lanes	Lane 1 to 2 and Lane 2 to 3 Measure Over Entire Area	Lanes 1 & 2
(C) *Approach Point* — area where change in speed/path occur and are influenced by channelization devices	Lanes 1 & 2	—	—	All lanes		Lanes 1 & 2
(B) *Control Point* — used for base values which reflect measures prior to influence of channelization.	Lanes 1 & 2	Lane 1, maybe 2	Lane 1	All lanes		Lanes 1 & 2
(A) *Advance Point* — represents "normal" flow measures un-influenced by construction area.	N/A	N/A	N/A	N/A	N/A	N/A

Figure 2. Data collection points and measures.

refers to locations where actual work is being performed), and the existing transition area.

Figure 2 summarizes the task analysis and specifies where the appropriate performance measures could be collected. Only one case, the lane closure on a divided highway, is illustrated. Several potential data collection points can be identified along with the appropriate measures. These include:

A. *Advance Point*—At or before the advance warning sign advising motorists of construction ahead. Should be a "normal" driving condition; therefore, no data collection requirements are anticipated here.

B. *Control Point*—At or just before the beginning of the approach area. The measure noted in Figure 2 should be used as control values to compare with other points.

C. *Approach Point*—This point can be arbitrarily established as the mid-point between the beginning of the approach area and the transition area. In this general area, motorists are likely to be involved in speed changes and lane changes. Measures that should be collected include speed (lanes 1 and 2), volume by lane, merge point, and conflicts or erratic maneuvers.

D. *Transition Point*—The same measures collected for the approach point should be collected at the beginning of the transition area.

E. *Entry Point*—This is defined as the end of the transition area. All of the measures noted in Figure 2 should be collected here.

F. *Activity Point*—At some locations where there is construction activity, the measures noted in Figure 2 should be collected to determine if they differ from those in a nonactivity area.

G. *Nonactivity Point*—This can be any point between E and H where there is no construction activity. The same measures as listed in E should be collected. It is possible that measures for E could be used for this point.

The other data collection points, H and I, are shown in Figure 2 for completeness but not for locations for data collection, as in this situation.

OPTIMIZATION OF DEVICE DESIGN

General

The purpose of the third task was to optimize the design characteristics of barricade and panel channelizing devices. Tube and cone optimization are described in following sections. This was accomplished by performing a series of four laboratory studies. The purpose here was not to generate one optimally detectable single channelizing device, but rather to select for field testing those design elements most conducive to detection and identification and eliminate those soliciting consistently poor performance. Although a laboratory experiment is not intended to be a direct simulation of the driving task, it can be made more relevant if the subjects' tasks are similar and the information load is similar to that of driving.

A primary driver activity is acquiring visual information about the highway and its immediate environs. A wide variety of visual configurations confront the driver, who must constantly search the roadway for appropriate guidance and navigation cues. This search and detection process is particularly important in a work/construction zone setting, where there are unexpected changes in the roadway and often there are many distracting visual cues.

The following parameters were studied: design/configuration of stripes; width of stripes (3 levels); color ratio of stripes, orange-to-white; meaning of various design configurations; detectability of visible areas, height-to-width ratio combinations; and experimental methodological variables as they impinge on aforenamed parameters.

A visually noisy and fairly abstract background picture was created. Four of these pictures were placed together to form a square, each quadrant of the square being the same picture. Small stimuli, e.g., bar or panel of a particular stripe width, orange-to-white color ratio, height-to-width ratio, and stripe design (horizontal, vertical, 45° slant, chevron) were placed on one quadrant of the square, and another picture taken. The resultant slide was then projected tachistoscopically at a fast speed (0.4 to 0.8 sec). The subject's task was to search the four quadrants, identify the type of design (horizontal, etc.), and identify the shape (bar or panel). Figure 3 is a photoreduced copy of the stimulus background, and Figure 4 shows selected samples of the device stimuli used for each of the four studies. The blotches of gray on Figure 3 are different colors on the actual slides. This presents a total image of geometric lines overlaid with color visual noise. In making the stimulus slides, the placement of device stimuli was completely random, both for choice of quadrant and placement within the quadrant.

The construction and projection of each stimulus on the screen were accomplished in such a way as to simulate the visual experience of the actual channelizing devices with 4-in., 6-in., or 8-in., (10.15-cm, 15.3-cm, or 20.35-cm) stripe widths. This was accomplished by computing the approximate visual angle for each stimulus as it appeared on the screen and then having respondents sit at distances approximating perception of these stimuli at 100 to 150 ft (31 to 46 m). In the four experiments performed, the respondents were seated at 10 to 15 ft (3.1 m to 4.6 m) to simulate this perceptual condition (figures are approximate).

The measures of performance for subjects responding to these stimuli were, thus, a Q score (quadrant detection), a C score (configuration identification), and an S score (shape identification). A subject scored "1" for correct response in each, or zero if incorrect. These three were then summed for each stimulus for each subject to obtain a combined index score for performance for each stimulus. All subjects in each experiment saw all stimuli. Therefore, the same basic subjects-by-treatments analysis of variance (ANOVA) could be applied to the performance data obtained. This basic model prevails in all four studies.

In addition, subjects were asked to indicate how confident they were of their responses on a scale of 1 (low) to 5 (high). All of these measures were collected on a response sheet, samples of which may be seen in Figure 5.

One of the experiments also included a task designed to determine what, if any, meaning was conveyed to drivers by the various stripe configurations. Subjects were presented with a lane choice situation in which they encountered a channelizing device blocking the center lane and requiring movement to the left or right.

Finally, the first experiment also examined the influence of

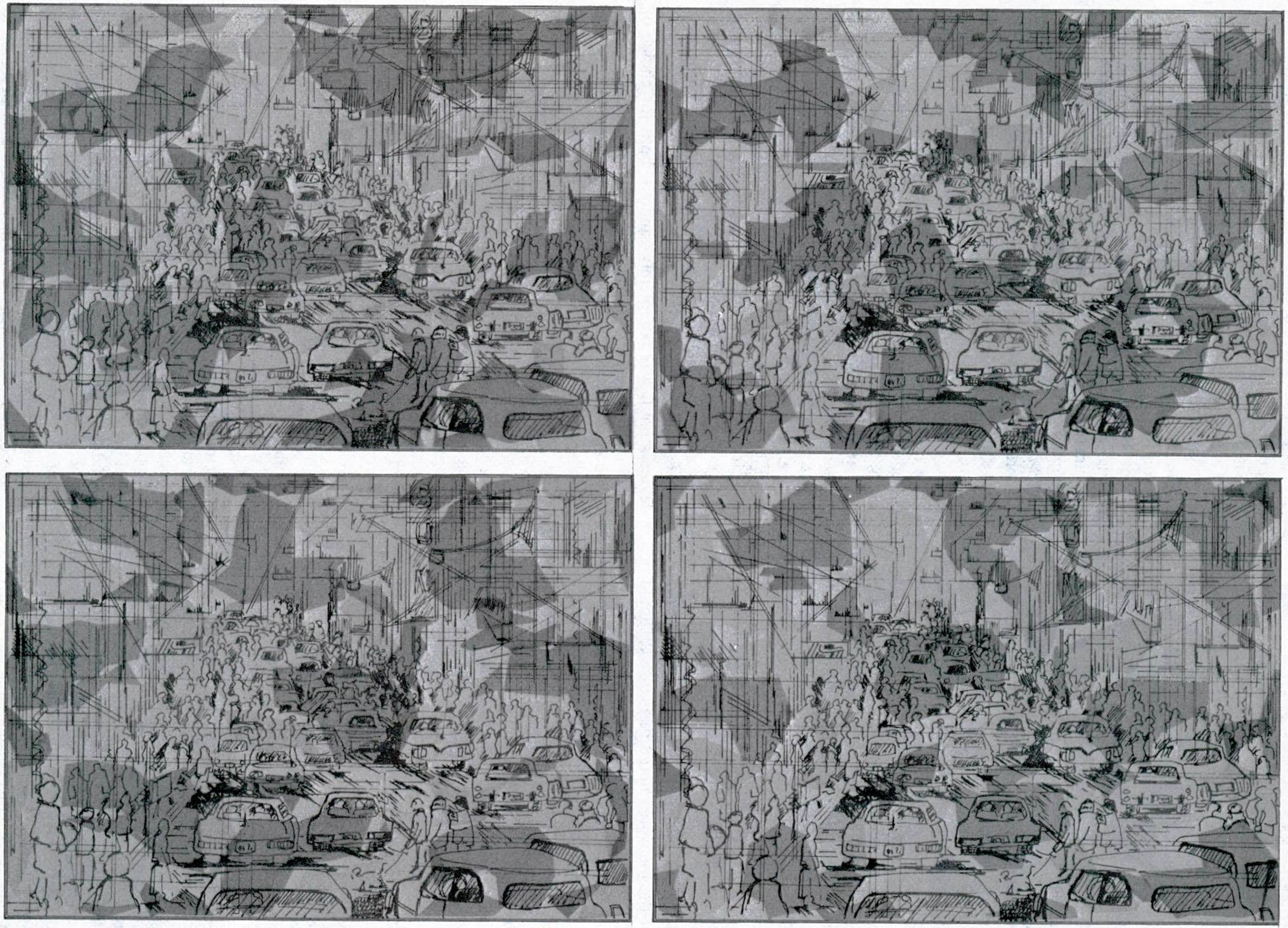


Figure 3. Background used for experiments.

secondary variables of the primary variable device design. These secondary variables were: males vs. females in the sample; ages of subjects in the sample; driving experience of subjects in the sample; exposure duration of stimulus against background (dark vs. light); subjective confidence ratings by subjects for each response.

Thirty licensed drivers, ranging in age from 17 to 60 years, were obtained and tested for each of the four experiments. Subject information was collected after each experiment, including age, sex, driving experience, and comments (if any). The stimulus slides were shown and subjects marked the response sheets. For the scope of these small studies, the effects of sex, age, and driving experience were relatively inconsequential. The stimuli were presented at two speeds—one high and one low (0.4 and 0.8 sec). Performance for each was markedly separable, and the faster speed was chosen for use in subsequent testing. The high (faster) speed showed the greater difference among the 4-, 6-, and 8-in. stripe widths.

Another secondary factor was the effect of placing the stimulus against a dark background versus placing it on a lighter background (contrast). Overall contrast ratios were similar enough to not be a significant factor in detectability. Most of the variance in subject performance was due to differences in design configuration.

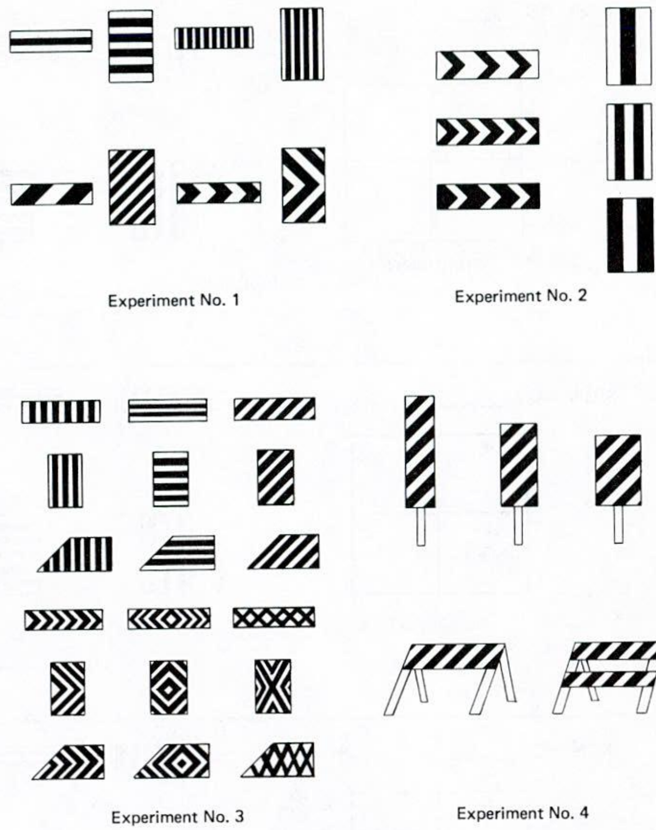


Figure 4. Samples of some stimuli used in each of the four experiments.

Experimental Analyses and Results

Optimum Stripe Width

The purpose of the first experiment was to determine the optimum stripe width for use on channelizing devices. Simulated 4 in., 6 in., and 8 in. (10.16 cm, 15.3 cm, and 20.35 cm) stripes were studied. The mean index performance score as previously described was analyzed by the subjects by treatments ANOVA. Finally, correlation coefficients were generated (Table 2) to determine whether any relationship existed between the subjects' actual performance and their confidence in their response.

The 4-in. simulated width was found to be clearly inferior to stripes of 6 in. or 8 in. (Table C-3 and Fig. C-2). This was demonstrated by separate analyses of variance to examine the effects of stripe width by each of the two shapes (Tables 3 and 4 and Figs. 6 and 7). In most cases, the difference between the 4-inch and 8-inch widths was significant. The same was not true between the 6-inch and 8-inch widths, suggesting that either would be acceptable for use on devices in the real world. The 8-inch is preferable when cost-effective, since it elicited superior detection performance in most cases, although not statistically significant.

Optimal Color Ratio

The purpose of experiment 2 was to determine the optimal color ratio (white-to-orange) to be used on barricades, panels, and drums. Each design configuration examined in experiment 1 (horizontal, vertical, diagonal, chevron) was prepared in a simulated 6-in. stripe width using white-to-orange color coverage of 1:2, 1:1, and 2:1.

The analysis of variance, treatments by subjects, was performed using the total index score for each stimulus presentation (Table 5 and Fig. 8). In general, the 2:1 white-to-orange is slightly advantageous, although not generally significant from the 1:1. The 1:2 white-to-orange, essentially an overabundance of orange, is generally inferior. Logic explains these findings in part. The stimuli were generally seen against a multicolored, visually noisy background, simulating some cluttered construction areas to be found in the real world. The bright white best stands out against this general dim melange of background noise. Were the bright orange to be viewed in a cleaner, open, white pavement type situation, results would likely reflect a superiority. Thus, the laboratory conditions have more effectively addressed the more common visually cluttered and/or dim ambient conditions in which equal or more white than orange contrasts with the background.

Inherent Meaning of Device Designs

This experiment was conducted to determine what, if any, inherent meaning was conveyed by the stimuli used in the previous experiments. For example, do chevrons and diagonal stripes indicate a particular direction or path to follow if a driver encounters them in an actual situation? The test of this question was a forced lane choice, left or right divergence from the center lane of travel upon encountering one of the devices in the center lane ahead.

To do this, the subjects were shown a slide of a roadway containing a barricade in the center lane and necessitating a move to the right or left. In this experiment, the background consisted of a drawing of a 6-lane (3 in each direction) freeway. An artist's rendering of this (a reduced black and white photograph) is shown in Figure 9. Models of barricades of the

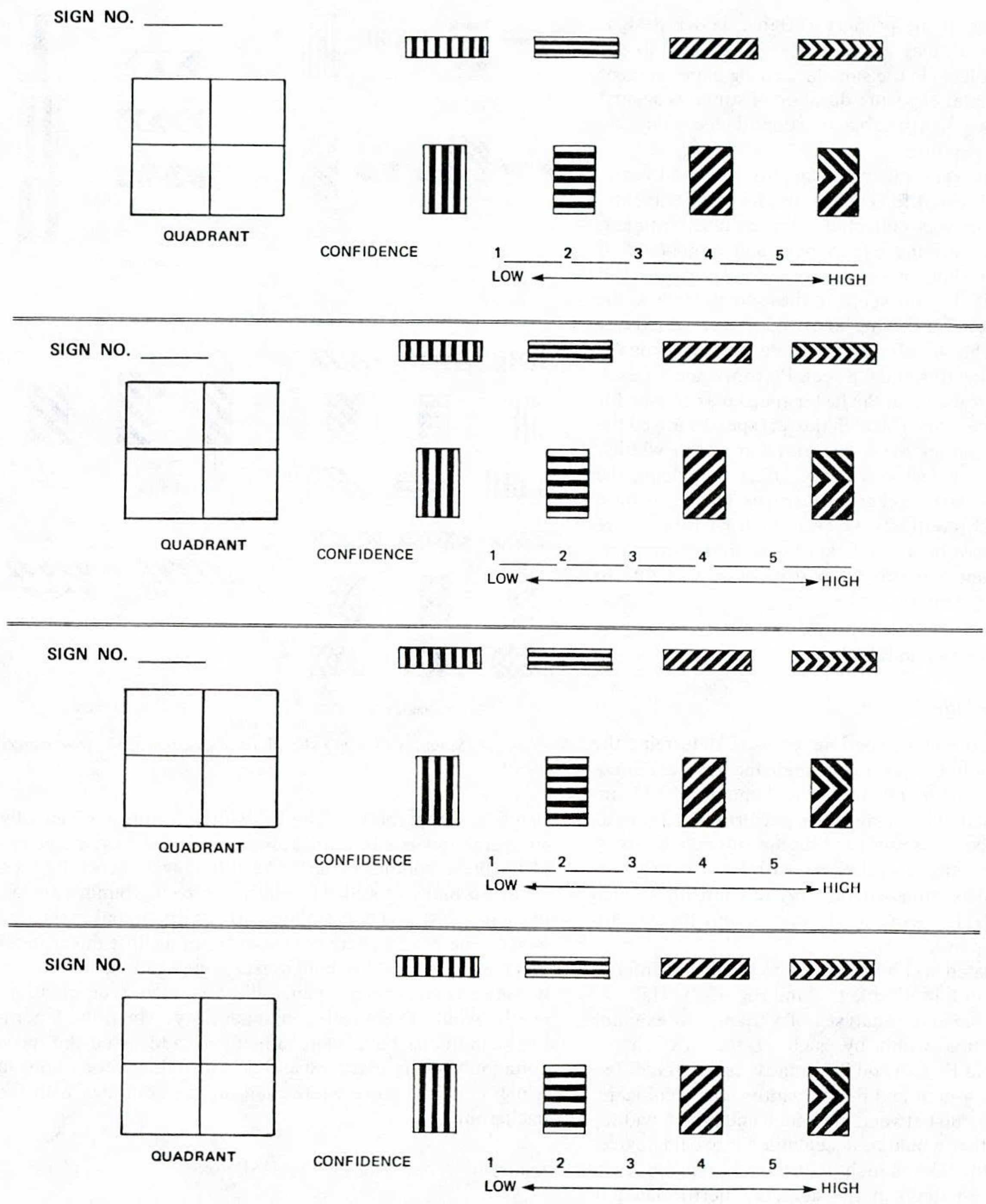


Figure 5. Sample subject response/data sheet for Task 3 laboratory studies.

four standard configurations were placed, one by one, in the center lane, and a photograph taken. The slides of the slanted and chevron configurations were made with the pattern pointing to the left and to the right. This allowed for control of possible driver bias to consistently choose one lane over the other.

Subjects were instructed to think of this situation as if they were driving down the middle lane and suddenly came upon the barricade. A slide showing just the roadway was on continuously before the stimulus slide appeared. Subjects were to assume that there was no traffic behind, and were asked which way they would go around the barricade. The configurations were shown in random order, each one being shown twice. Stimulus slides were shown for 1 sec, and the subject had 8 sec to check Left or Right Lane on the response sheet. Thirty subjects participated in this phase of the experiment.

In this task, 24 devices were presented twice in a random order. Therefore, two trials were obtained for each stimulus.

Simple frequency counts of the number choosing right lane versus number choosing left lane were accumulated, and "z" scores computed to see whether these proportions differed significantly from chance. Table 6 presents the 24 devices and the proportions and z-scores obtained for each.

The significant z-scores are marked with asterisks. Three basic trends may be seen in these data:

1. The chevron effectively indicates a direction on bars and panels, without question.
2. The "new" shape device, with one side pointing left instead of being straight, clearly indicates a direction to the left regardless of the design.
3. The diagonal, and even the horizontal and vertical, lines seem to indicate a direction to many drivers in the bar shape but not the panel.

These points are easily explained as follows. The chevron, viewed in isolation against a reasonably uncluttered background (as was the case here), looks exactly like a series of arrowheads indicating a direction to the right or left. In fact, this is exactly how responses occurred; in one case a chevron bar pointing to the left elicited an unambiguous left-lane choice on both stimulus trials.

The shape or form of the "new" device induced many drivers to select the left lane because its point's edge indicates this direction. This shows the stronger impact of sign forms, even when the design configuration within the form did actually point to the right (i.e., slant right design). In this case, the *power* of the chevron configuration was diminished by the power of the shape of this *form*, because as many drivers selected a left lane as did a right lane when right-pointing chevrons appeared on the new form. This, incidentally, is in accordance with the basic perceptual principles stating that form perception and response are more basic than design symbology, which, in turn, is more basic than verbal message.

The bar shape sitting in the center lane is apparently a more realistic-looking channelizing device (looking like an actual barricade) than the panel shape appears as a panel or drum. Many drivers selected a right-lane choice on seeing a vertical or horizontal bar. This may well indicate the natural tendency to avoid obstacles to the right rather than to the left. A single barricade is a fairly common urban arterial sight, and a lot of drivers may be fairly used to circumventing it around to the right rather than risk oncoming traffic to the left.

It is noted that the foregoing conclusions are based on choice and common sense data rather than on actual performance data, as in the preceding portion of the experiment and the previous two experiments. The detection and identification of the chevrons and diagonal patterns were, in general, poorer than that of the horizontal and vertical designs. This trend has followed throughout the first three experiments. However, chevrons consistently convey directional meaning.

Table 2. Correlation coefficients total index score X confidence level.

Configuration		Horizontal		Vertical		Slant		Chevron	
Contrast		Dark	Light	Dark	Light	Dark	Light	Dark	Light
Shape	Width								
PANEL	4	.63	.59	.60	.12*	.81	.88	.62	.21*
	6	.59	.45	.59	.64	.44	.63	.48	.66
	8	.60	.30	.49	.19*	.52	.40	.66	.81
BAR	4	.43	.10*	.30	.57	.58	.70	.58	.35
	6	.73	.16*	.54	.60	.55	.78	.78	.50
	8	.74	.47	.40	.23*	.54	.63	.64	.41

below 0.25

Effective Height-to-Width Ratios of Devices

The fourth experiment was designed to determine the most effective height-to-width ratio of barricades and vertical panels. The design configuration was held constant, using the traditional diagonal stripes, so that the only detection parameters were stimulus location (quadrant) and shape (Type I barricade, Type II barricade, or vertical panel). (Throughout this discussion and also in the detailed reporting in Appendix C, the terms Type I and Type II are used to mean one-rail barricades and two-rail barricades respectively. This is not to assume the exact size and area differences often

Table 3. Experiment 1 summary of ANOVA stripe width vs. panel.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Width (A)	2	31.1302	15.5651	9.1297
Configuration (B)	3	158.9453	52.9818	30.5782*
Subjects (C)	31	240.7891	7.7674	
AB	6	27.0156	4.5026	2.4194**
AC	62	105.7031	1.7049	
BC	93	161.1380	1.7327	
ABC	186	346.1510	1.8610	
Total	383	1070.8724		

*Significant at .01 level

Table 4. Experiment 1 summary of ANOVA stripe width vs. bar.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-Ratio
Width (A)	2	72.2500	36.1250	22.4912*
Configuration (B)	3	74.6536	24.8845	14.2624*
Subjects (C)	31	292.5182	9.4361	
AB	6	96.1667	16.0278	9.1822*
AC	62	99.5833	1.6062	
BC	93	162.2630	1.7448	
ABC	186	324.6667	1.7455	
Total	383	1122.1016		

*Significant at .01 level

found in actual Type I and Type II barricades.) Illustrations of these stimuli are shown in Figure 4.

The data were subjected to two analyses of variance, subjects by width by barricade type, or, for panels, height, using the index score. Tables 7 and 8 and Figures 10 and 11 present the results of these analyses.

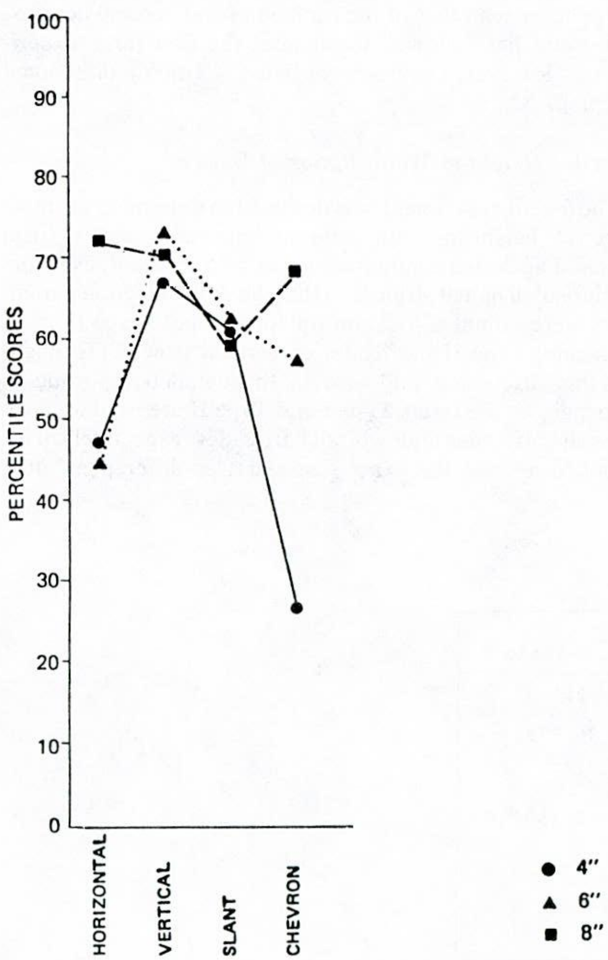


Figure 6. Configuration vs. stripe width—bars.

Table 7 gives F ratios for the Type I and Type II barricades in conjunction with increasing rail width. A glance at Figure 10 immediately reveals that the main effects are not significant. A divergence occurs between rail width and number of rails beginning with width number 2. This suggests that there is some type of interaction occurring between these parameters and, in fact, the F ratios for these are significant. The nature of this function is not entirely clear from the data. Therefore, no simple principle can be derived stating that increasing area of display should be separated from one into two rails of a given visual area for optimal detection, since it appears that there are too few data points to define the exact function. A fairly simple conclusion from the data is evident, however; with very small areas or very large areas, one-rail or two-rail displays are reasonably interchangeable. Within the medium range of areas (widths 2 and 3), a breakdown does occur. To test these conclusions, t-tests were performed comparing the various rail and width combinations as pairs. These ratios are given in Table 9. As can be seen, the two extreme widths (1 and 4) do not significantly differentiate between Type I or Type II barricades. The divergence occurs in the middle, as previously suggested. At first a one-rail, Type I barricade is significantly better at width 2; then, this reverses at width 3. The suggestion here is that the individual rails must be at a minimum width before they are fairly detectable; *then*, if there are two instead of one, a larger total image is presented which is easily detectable. This is supported by noting the significant t-ratio between the two-rail widths (2 versus 4 and 2 versus 3 comparisons), which are highly significant; yet, the one-rail width (3 versus 4) is significant at $p = 0.05$ only. With a two-rail after a minimal area is achieved, two rails containing this area are optimal, while one rail is only adequate in one certain case. The very smallest width (1) seems to present a problem in detection for both one and two rails.

It is fairly obvious that a more complex set of factors than simple area of display as seen in one or two rails is operating here. Apparently, the total image projected by the barricade with bars and stripes that slice up the visual background is related to the way this is embedded in the background, where it is against the background, etc. A simple height-to-width function does not adequately describe all of the factors operating in this situation.

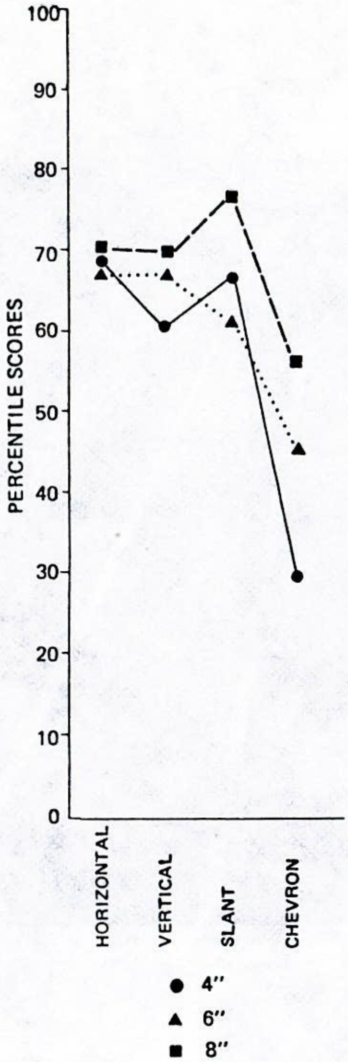


Figure 7. Configuration vs. stripe width—panels.

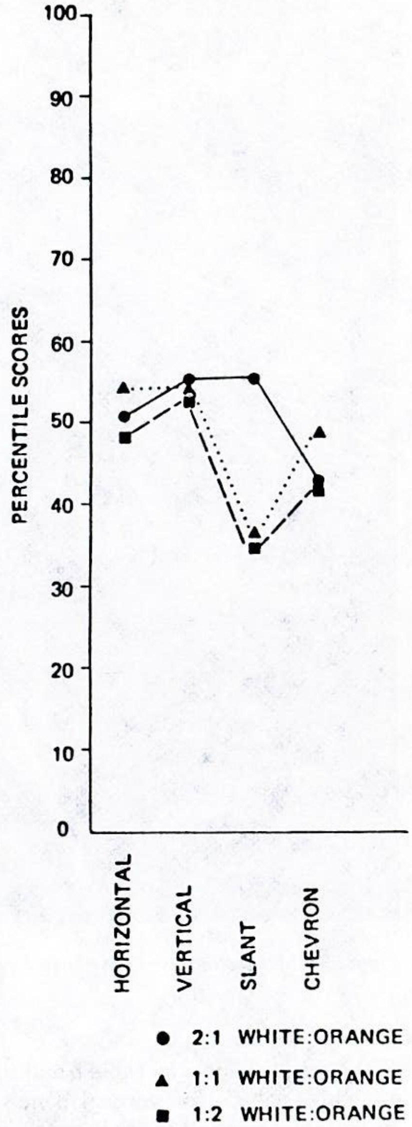


Figure 8. Configuration vs. white-to-orange color ratio.

Table 5. Experiment 2 summary of ANOVA subject vs. confidence vs. color ratio.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Configuration (A)	5	336.7795	67.3559	21.9871*
Color Ratio (B)	2	80.4306	40.2153	7.8983*
Subjects (C)	31	896.4288	28.9171	
AB	10	184.4444	18.4444	4.5351*
AC	155	474.8316	3.0634	
BC	62	315.6806	5.0916	
ABC	310	1260.7778	4.0670	
Total	575	3549.3733		

*Significant at .01 level

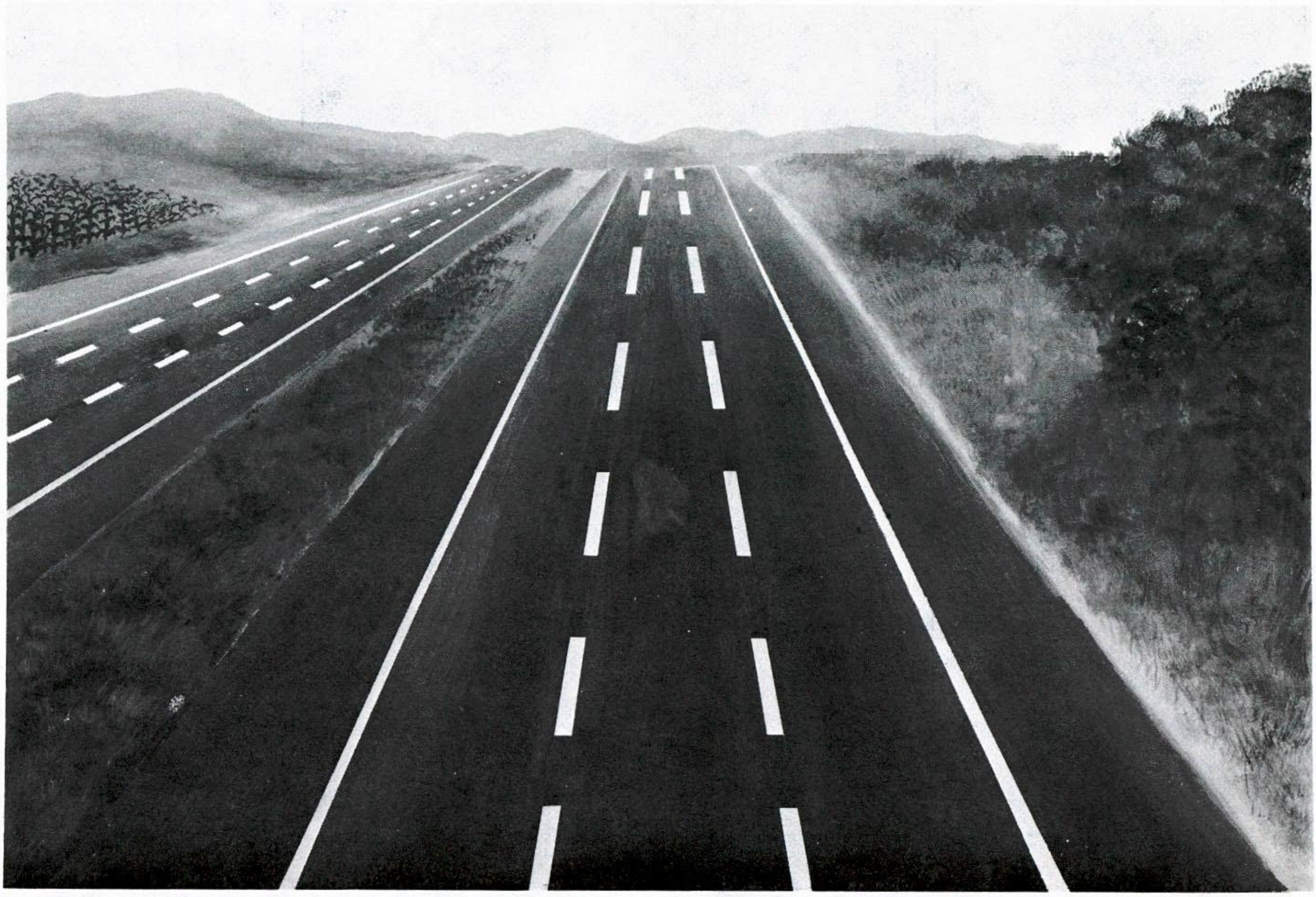


Figure 9. Background used for phase 2 of experiment 3.

The results shown in Table 8 and Figure 11 for the height-to-width analysis for vertical panels indicate that a more narrow image, whether short or tall, is more easily detected and identified. There is no significant interaction between factors of height and width. This finding is in harmony with data from the previous laboratory studies indicating the slight superiority of the vertical panel as a detection stimulus. Apparently, the eye best detects a clear vertical image against the cluttered, dim background of the display. Those targets with more width than height not only within the design but in their forms seem to be generally less effective in detectability.

Summary of Findings and Selection for Field Tests in Task 4

Within the limited scope of these experiments (i.e., a search, detection, and recognition task in the laboratory), the results allowed some preliminary findings regarding channelizing device design to be made:

1. Optimal stripe width is 6 in. or 8 in.
2. Desirable ratio of white-to-orange coloring favors equal white-to-orange or more white.
3. Optimal stripe design configurations are first vertical, then horizontal; detection and recognition performance decrement occurs for diagonal stripes and, most notably, for chevrons.
4. As a configuration, chevrons best connote directional meaning to drivers.
5. Vertical panels elicit better performance than horizontal bars or trapezoid shapes.
6. There was little useful difference between Type I (one-rail) and Type II (two-rail) barricades in terms of detection and recognition.
7. Tall, narrow, vertical panel-type images are recommended over shorter, wider devices.

The preceding results, discussion, and recommendations have been based on four short laboratory experiments of rather limited scope and purpose. As with most research, more questions seem to be uncovered in the process of conducting the investigations than are answered. A larger problem of greater scope than simple discernments of stripe widths, shapes, and configurations seems to underlie the data. The perception of lines, angles, and edges as they geometrically increase in size is not, apparently, a straight line function perfectly correlated with increased detectability. Rather, the actual image configuration achieved as these

Table 6. Directional decision proportions and z-scores obtained for channelizing devices.

Directional Decision Proportions and
Z - Scores Obtained for Channelizing Devices

Description	Trial #1 Proportion			Trial #2 Proportion		
	L	R	Z	L	R	Z
25 1 Horizontal Panel	.42	.58	1.00	.37	.63	1.53
26 2 Vertical Panel	.27	.73	2.63**	.39	.61	1.34
27 3 Slant Right Panel	.41	.59	0.96	.23	.77	2.96**
28 4 Slant Left Panel	.53	.47	0.32	.58	.42	0.89
29 5 Chevron Right Panel	.06	.94	4.98**	.06	.94	4.92**
30 6 Chevron Left Panel	.97	.03	5.14**	.97	.03	5.14**
31 7 Dbl. Chevron Panel	.40	.60	1.09	.33	.67	1.86
32 8 X Panel	.34	.66	1.72	.29	.71	2.32*
33 9 Horizontal Bar	.27	.73	2.63**	.37	.63	1.53
34 10 Vertical Bar	.26	.74	2.79**	.32	.68	2.01*
35 11 Slant Right Bar***	.23	.77	3.13**	.26	.74	2.79**
36 12 Slant Left Bar****	.52	.48	0.11	.37	.63	1.53
37 13 Chevron Right Bar	.09	.91	4.64**	.06	.94	4.92**
38 14 Chevron Left Bar	1.00	.00	5.66**	1.00	.00	5.59**
39 15 Dbl. Chevron Bar	.38	.62	1.53	.45	.55	0.55
40 16 X Bar	.39	.61	1.34	.33	.64	1.86
41 17 Horizontal New	.97	.03	5.20**	.94	.06	4.80**
42 18 Vertical New	.88	.12	4.19**	.97	.03	5.20**
43 19 Slant Right New	.91	.09	4.53**	.84	.16	3.69**
44 20 Slant Left New	.84	.16	3.85**	.94	.06	4.80**
45 21 Chevron Right New	.53	.47	0.36	.48	.52	0.22
46 22 Chevron Left New	.47	.53	0.45	.48	.52	0.22
47 23 Dbl. Chevron New	.60	.40	1.09	.84	.16	3.69**
48 24 X New	.78	.22	2.83**	.81	.19	3.35**

Significance:

* α = .05 (Z > 1.96)

**α = .01 (Z > 2.58)

***Stripes slant from lower left to upper right corner.

****Stripes slant from lower right to upper left corner.

Table 7. Experiment 4 summary of ANOVA subject vs. height vs. barricade type.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Rails (A) Type I or Type II	1	0.1856	0.1856	0.2589
Rail Size (B)	3	5.0720	1.6907	2.6261
Subjects (C)	32	52.1667	1.6302	
AB	3	49.6477	16.5492	20.7062*
AC	32	22.9394	0.7169	
BC	96	61.8030	0.6438	
ABC	96	76.7273	0.7992	
Total	263	268.5417		

*Significant at .01 level

Table 8. Experiment 4 summary of ANOVA subject vs. panel width vs. panel height.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Panel Height (A)	1	0.0076	0.0076	0.0111
Panel Width (B)	1	10.3712	10.3712	20.2627*
Subjects (C)	32	33.5606	1.0488	
AB	1	0.0682	0.0682	0.1486
AC	32	21.7424	0.6795	
BC	32	16.3788	0.5118	
ABC	32	14.6818	0.4588	
Total	131	96.8106		

*Significant at .01 level

Table 9. t-Ratios—number of barricade rails vs. rail height.

Pair of Conditions	t	df	Significance
Type I vs. Type II Ratio 1	0	32	n.s.
Type I vs. Type II Ratio 2	6.95	32	.01
Type I vs. Type II Ratio 3	4.05	32	.01
Type I vs. Type II Ratio 4	1.50	32	n.s.
Ratio 1 vs. Ratio 2 Type I	4.51	32	.01
Ratio 1 vs. Ratio 2 Type II	2.60	32	.05 only
Ratio 1 vs. Ratio 3 Type I	3.73	32	.01
Ratio 1 vs. Ratio 3 Type II	1.29	32	n.s.
Ratio 1 vs. Ratio 4 Type I	0.14	32	n.s.
Ratio 1 vs. Ratio 4 Type II	1.60	32	n.s.
Ratio 2 vs. Ratio 3 Type I	5.96	32	.01
Ratio 2 vs. Ratio 3 Type II	4.37	32	.01
Ratio 2 vs. Ratio 4 Type I	3.81	32	.01
Ratio 2 vs. Ratio 4 Type II	4.54	32	.01
Ratio 3 vs. Ratio 4 Type I	2.41	32	.05 only
Ratio 3 vs. Ratio 4 Type II	0.36	32	n.s.

n.s. = not significant

lines and forms interact with the display background draw upon basic perceptual organizational principles which deserve further investigation. Quite simply, more data points are needed to describe and model the functions of optimal detectability as the parameters of size, height, width, design stripe width, angularity of design, appearance against varying ambient backgrounds, position within the entire visual field, and so on, are altered. The search for a "figurally good" image for detection necessitates the testing of many display sizes and configurations to better detection as a function of perceptual stimulus elements. Apparently, a certain arrangement of the design elements against a certain type of background produces optimal detectability. Specification of these parameters based on present data, however, is not possible unless it can be augmented by further study.

A final word may be said regarding the purpose of this study. The determination of optimal stripe widths, color ratios, and height-to-width ratios for barricades, panels, and drums was executed as the driver detected and identified these device simulations in isolation, against a background of visual clutter designed to simulate real informational load-

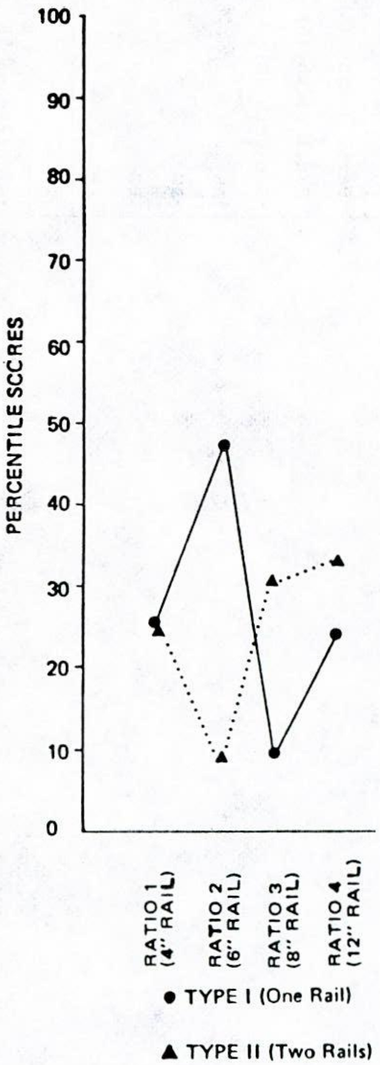


Figure 10. Rail height vs. Types I and II barricades.

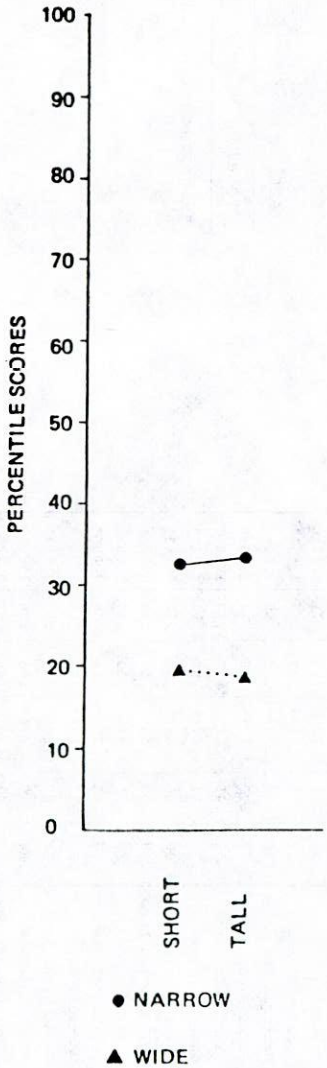


Figure 11. Panel height vs. panel width.

ings. In reality, these devices are not generally perceived standing alone, but as a cluster or array protecting and channelizing traffic away from hazardous zones. Therefore the design recommendations and findings are "inputs" to field tests which examine these individual devices in combination rather than alone. As noted earlier, the purpose here was not to generate the optimally detectable single channelizing device, but rather to select for field testing those design elements most conducive to detection and identification, and eliminate those elements soliciting consistently poor performance. (Specifically, further testing in controlled and real world settings was performed as Tasks 4 and 5.) These laboratory studies suggest the best and the worst to be tried in the field under real driving conditions to evaluate their ability to effectively display the hazard situation and channelize drivers around it with the least perturbation of their normal driving.

a. View looking toward array 1

b. View looking toward array 2

Figure 12. Overall view of the sites where arrays were located.

Figure 13. Single device detection site.

EFFECTIVENESS OF CHANNELIZATION DEVICES (CONTROLLED FIELD STUDIES)

General

In Task 4 six experiments were conducted to verify the results of the laboratory study and examine variables (i.e., size, brightness, spacing, arrays) which were not amenable to laboratory study techniques.

The same methodology was used for all the experiments. An instrumented vehicle (DPMAS) loaned to the project by the National Highway Traffic Safety Administration was driven by subjects on a 6-mile test course. The course was an unopened, but almost completed, section of a by-pass near State College, Pennsylvania. This four-lane divided road conforms to interstate standards. At two sites with over 5,000-ft sight distances, a one-lane closure was set up using only channelizing devices. No other signing was present. At two other points, single devices were placed on the right shoulder of the roadway. Figures 12, 13, and 14 show the sites and the slight grades involved. At other points along the route, drivers were required to stop suddenly, cross the median to turn around, and obey stop signs. Thus, some diversity was introduced into the test drive. Subjects were given an orientation prior to entering the car. The experimenter riding in the car gave more specific instructions, and after several hundred feet of practice drive, gave instructions on the test course. Additional instructions were given throughout the test drive. Following the 10-min drive, subjects completed a short questionnaire and were thanked and paid.

A factorial experimental design was used, with each treatment seen by a different group of 10 subjects. In fact, each subject drove by two arrays, but these were changed and counter-balanced so that all 10 drivers in a group did not see the same two devices in the same order. Later examination of the data verified that the 3 miles of driving between arrays, other maneuvers, and counterbalancing prevented any order effects. Separate driver groups were used day and night. An attempt was made to have each group of subjects divided by age and sex in the same proportion as the general (licensed) driving population. This was not precisely achieved for each treatment group, but was attained for the experiments overall.

The dependent variables included speed, lateral placement in the daytime and night (for nighttime only treatments), point of lane change, array detection distance, and driver preference. Other measures collected, but found insensitive

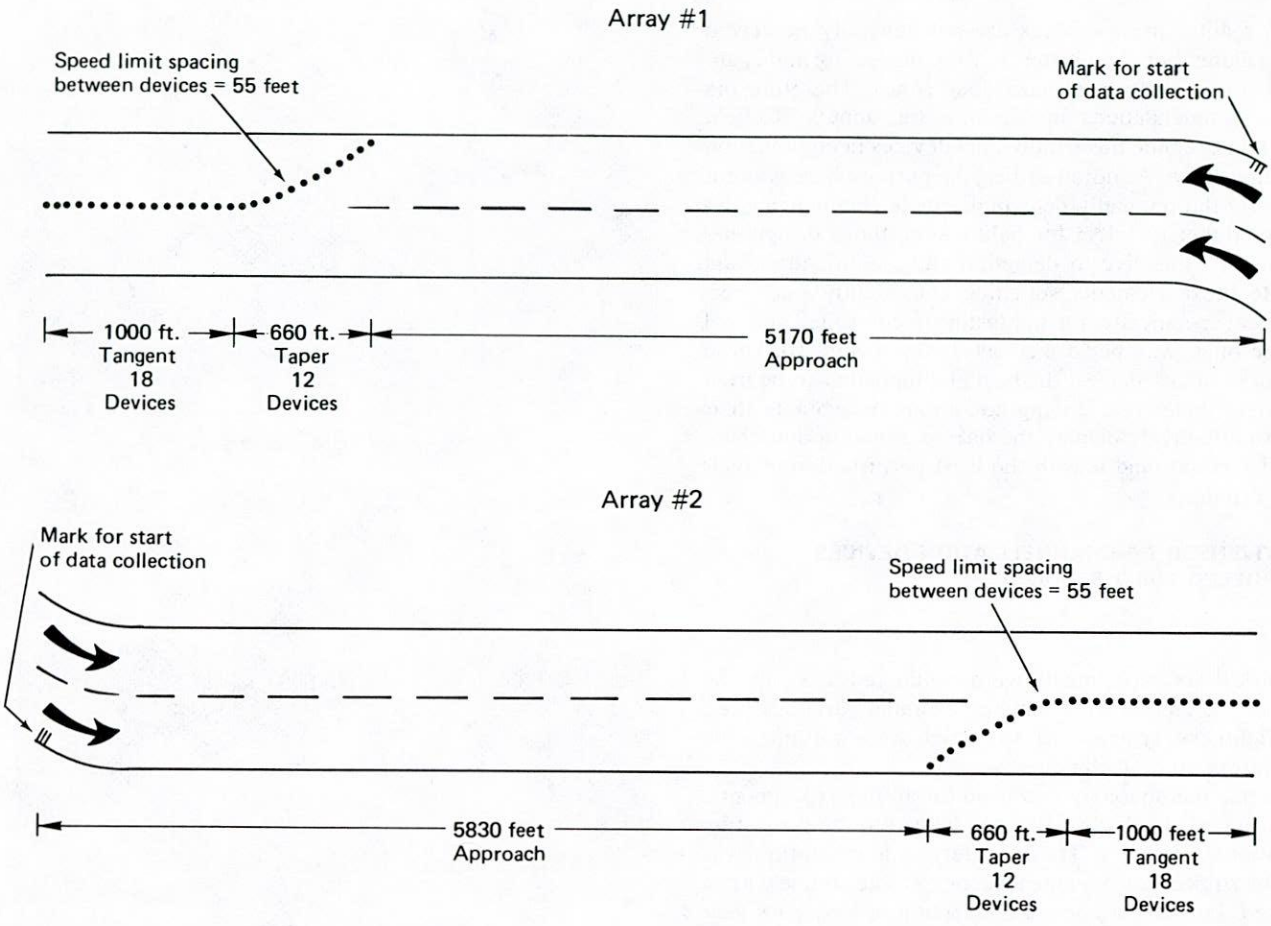


Figure 14. Layout of array sites.

or unusable, were throttle pedal position, steering wheel position and rate, and brake applications.

A massive amount of data is collected by the DPMAS (e.g., 2 samples per second). This was reduced by first dividing each array site into four distance groups: (1) 4100–5100 ft before the taper, (2) 0–800 ft before the taper, (3) 660-ft taper, and (4) the first 800 ft of the tangent section. Then a mean for each dependent variable in each distance group was computed. The means serves as the score for that driver in each distance group. Analysis of variance with a repeated measure was applied to these scores. Comparisons between specific treatments were analyzed with t-test or Sandler's A statistics. For cases where the data were shown to be heterogeneous via an F_{max} test, the nonparametric chi-square and Kruskal-Wallis tests were applied. The 99 percent or 0.01 level was the criterion of significance for all experiments.

The treatments compared are given by experiment in Table 10.

The results of each experiment are discussed in detail in Appendix D. The devices are described and shown in Exhibit D-1. The findings presented in the following are a synthesis of the results. This synthesis was accomplished by categorizing each device into high, middle, and low groups on each of eight measures, and then summing across categories. This was done for experiment 2. These basic findings were then qualified or expanded as required by the results of the remaining experiments.

Experiment 1—Device Detection

Each device was seen singly. Drivers indicated when they first detected the device. Note that detection does not necessarily imply recognition of type of device or stripe configuration on the device. The means and standard deviations of detection distance day and night are given in Table 11, and statistical test results are given in Table 12.

Statistically, the 36-in. × 12-in. Type I barricade, cones, 42-in. post, and drum are superior in the daytime. At night, the 12-in. × 36-in. panel is the best detected device, followed by the drum, then the remaining barricades and panels. Cones and posts have the shortest detection distance at night.

A particularly interesting finding is that single device detection is not consistently predictive of array detection distances, as shown in Figures 15 and 16. Determining how far away a single device can be seen is not an adequate method of evaluating likely performance in an array setting. Given this finding, the experiment data are useful mainly in selecting devices to be used singly or in very small numbers as hazard warning/alerting devices.

Table 10. Independent variables for the six closed field experiments.

Experiment 1:	all the devices listed under the next five experiments
Experiment 2:	(all devices have 6" diagonal stripes and Type II retroreflective sheeting) Barricades / Panels / Cones/Posts / Drum 3'x12" Type I / 8"x24" / 28" Cone / plastic 3'x12" Type II / 12"x24" / 36" Cone / 55 gallon 2'x8" Type I / 12"x36" / 28" Cone / 8" horizontal stripe) 2'x8" Type II / / 42" Post* /
Experiment 3:	2'x8" Type I Barricades with: • Engineering grade (Type II per Fp-74-7) retroreflective sheeting • High intensity grade (Type III) retroreflective sheeting (narrow, .2°, divergence or observation angle) • Steady-burn lights on every device • Steady-burn lights on the taper device only • Steady-burn lights on alternate devices
Experiment 4:	2'x8" Type I Barricades and 8"x24" panel at: • Speed limit spacing (55 feet) • Half spacing (27.5 feet) • Double spacing (110 feet)
Experiment 5:	Taper / Tangent 1. 2'x8" Type I Barricade / 36" Cone 2. 8"x24" Panel / 42" Post 3. Each device in a "pure" array
Experiment 6:	2'x8" Type Barricades with: • Diagonal stripe • Vertical stripe • Chevron stripe (4" stripe)

*6" of Type III reflective material

Table 11. Mean and standard deviation of device detection data for experiment 1.

Device	Detection Distances			
	Night		Day	
	Mean (FT)	SD (FT)	Mean (FT)	SD (FT)
Barricades:				
3'x12" Type I	2311.1	814.81	2543.00	1284.28
3'x12" Type II	2048.25	979.05	1986.20	639.26
2'x8" Type I	2097.50	853.50	2178.70	900.71
2'x8" Type II	Not avail	Not avail	1438.70	821.55
Panels:				
8"x24"	2019.23	674.56	1037.13	630.49
12"x24"	1343.29	414.24	1633.89	854.80
12"x36"	2874.80	291.34	1667.40	460.75
Posts:				
28"	1223.78	261.21	1781.75	748.97
42"	Not avail	Not avail.	2521.20	668.18
Cones:				
28"	520.28	297.08	2543.19	445.80
36"	1045.94	638.12	2490.31	640.92
Drum:	2700.22	645.50	2448.73	822.73
Combinations:				
2'x8" Type I + Steady burn light	2151.50	292.82	1857.00	815.66
2'x8" Type I + High intensity sheeting	1616.13	708.41	Not avail	Not avail
8"x24" Panel + Horizontal stripe	2378.14	721.11	549.11	476.79
8"x24" Panel + Chevron stripe	2407.00	591.84	1048.57	532.86
2'x8" Type I + Vertical stripe	2288.00	894.78	Not avail	Not avail
2'x8" Type I + Chevron stripe	1977.50	1148.66	1525.00	1144.39

Experiment 2—Comparison of Devices

Each of the devices was used in a lane closure array with a 660-ft taper and 100-ft tangent section both day and night. Results for each measure are detailed in Appendix D. Table 13 summarizes the synthesized results, including the data on optimized cones and tubes. In the table, results are ranked high, medium, or low for each measure and device. The total H, M, and L are summed for day, night, and day plus night conditions. Finally, H, M, and L are summed for day, night, and day plus night conditions for each device category.

There are no major differences overall between the device categories in the daytime. At night, barricades, panels, drums, cones, and tubes are also equivalent if the optimized cone and tube reflectorization is used. Posts and cones with 6 in. of collar did not elicit an equivalent level of driver behavior, particularly at night.

Two types of device rankings were prepared based on Table 13. The first (Table 14A) uses all eight MOEs and assumes that speed reduction from taper to tangent is desirable. The second part (B) of Table 14 gives rankings without that assumption (e.g., speed data are not included). In both parts of Table 14 a less controversial assumption was that the least weaving in the tangent section was safest.

In general, the major difference between the two types of rankings reflects the finding that the optimized cones and tubes have less impact on speed than the other device types. This must be interpreted rather carefully because a test site difference (two- vs. three-lane road) could account for loss of speed reduction impact. This is supported by the result that barricades and panels had an impact on taper-to-tangent speed only in the two-lane situation. The underlying principle is that perceived narrowing or road constriction interacts with device size/visible area in eliciting speed change.

A second use of Table 13 would be to determine the particular driver behaviors desired at a particular work zone, then choose the device most closely eliciting the desired behaviors.

In addition to the foregoing general synthesis, there were more specific findings addressing questions posed in this

Table 12. Summary of differences in detection distance between channelizing devices.*

	Night \ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
3′ x 12″ Type I Barricade	1				**	**	**	**							X	**	**	X	**
3′ x 12″ Type II	2														X	**		X	
2′ x 8″ Type I Barricade	3	X	X	X		**									X	**	**	X	
2′ x 8″ Type I Barricade	4									**	**	**	**		X			X	
8″ x 24″ panel	5									**	**	**	**		X			X	
12″ x 24″ panel	6	**									**	**	**		X	**		X	
12″ x 36″ panel	7						**				**	**			X			X	
28″ post	8	**		**		**		**		**					X	**		X	
42″ post	9	X	X	X	X	X	X	X	X						X	**	**	X	**
28″ cone	10	**	**	**		**	**	**						**	X	**		X	**
36″ cone	11	**	**	**		**		**							X	**	**	X	**
drum	12						**		**		**	**			X	**	**	X	**
Steady burn light on 2′ x 8″ Type I	13						**		**		**	**			X	**	*	X	
High intensity sheeting on 2′ x 8″ Type I	14										**	**	**					X	
8″ x 24″ panel w/horizontal stripe	15						**		**		**	**						X	**
8″ x 24″ panel w/chevron	16						**		**		**	**						X	
2′ x 8″ Type I w/vertical stripe	17							**			**		**						
2′ x 8″ Type I w/chevron stripes	18										**	**							

* Based on the least squared difference (LSD) test (3)
** Sig α .01
X No data

experiment. These are stated followed by the findings which answer those questions.

1. *What effects do various categories of channelizing devices have on driver behavior?* There were no differences between the four major device categories. This is true when the optimized posts and cones are used. The standard cones and tubes (6-in. collar) do not function as well as other devices at night. In terms of specific behavioral effects, none of the channelizing devices elicited unique or particularly hazardous behaviors. The effects found include:

a. Long array detection distances (3,100–5,000 ft) in the day and somewhat shorter at night (2,050–4,000 ft).
b. Considerable variability in array detection distance between drivers for most devices.
c. For barricades, panels, and drums, the mean point of lane change is farther away from the array at night than in daylight. However, for cones and posts, there was little difference or the reverse was found.
d. Extensive variability in point of lane change among drivers was evident, particularly at night for larger devices.
e. In every group, regardless of device, one to four subjects drove to within 20–300 ft of the taper before changing lanes.
f. All devices elicited a shift in lateral placement towards the left edge of the lane away from the devices.
g. There were differences in displacement (weaving or path consistency) elicited by devices. The 3-ft × 12-in. Type II, 8-in. × 24-in. panel, and 36-in. cone showed the least weaving.
h. There were no significant differences in speed distributions between the devices tested.
i. In the daytime, larger devices in each category elicited a statistically significant speed reduction (around 2 mph) from taper to tangent section. At night, barricades, panels, and drums (but not posts or cones) elicited the speed reduction (around 2 mph).
j. Driver rankings of device pictures indicated people think the larger devices (3-ft × 12-in. barricades, drum) are easiest to see.

2. *Are channelizing device effects on driver behavior different under day and night visibility conditions?* The following differences were prominent:

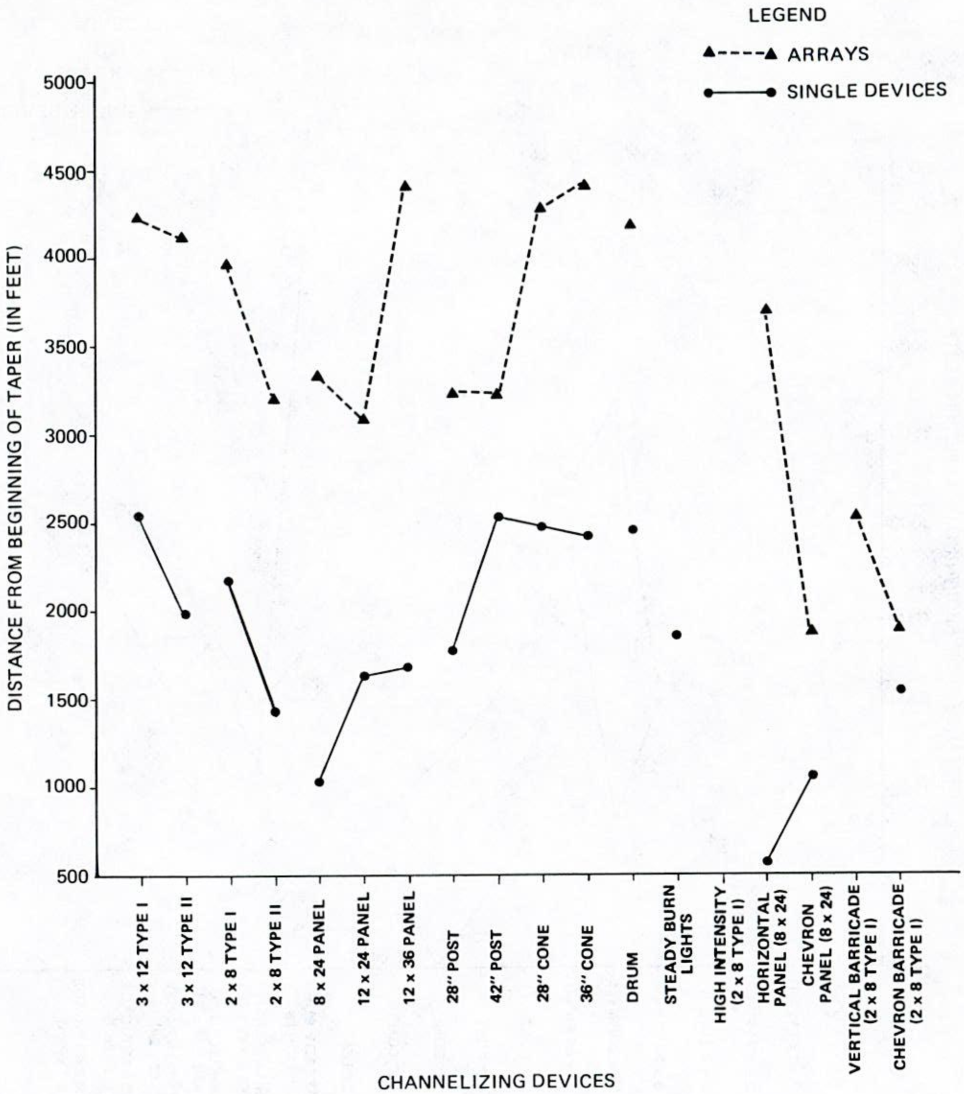


Figure 15. Mean detection distance—single devices vs. arrays (day).

a. Array detection distance was less at night.
b. Array detection variability was greater at night.
c. Point of lane change was farther away from the taper at night except for posts and cones which were the same or closer at night than in the day.
d. Speed reduction at night from taper to tangent was controlled by device type (barricade, panel, drum), not by device size.
e. During day and night, drivers' perception of the array was one of a pattern or line of color (day) or light (night). Drivers could not tell what type of device or what pattern was used on the device when they first detected the array.

3. *What effect does device size have on driver behavior?* Device size appears to have a more powerful impact on behavior than the laboratory experiments suggested. This is partially because device arrays are not simply an additive of single device characteristics. Specifically:

a. Speed reduction in daytime is controlled by device size. The largest devices in each category resulted in speed reduction.
b. Device size appears to control driver perception or ease of device detection in the daytime.
c. At night, visible reflectorized area appears to be critical in controlling point of lane change, speed reduction, and detection distance.

3a. *No difference was postulated between the 8-in. × 24-in., 12-in. × 24-in., and 12-in. × 36-in. panels.*

a. The 8-in. × 24-in. panel performed consistently poorer than the two larger panels.

3b. *No difference was hypothesized between one- and two-rail or large and small barricades.*

a. The data indicated that the larger devices (3 ft × 12 in.) are quite superior to the smaller (2 ft × 8 in.) barricades in every respect.
b. Differences between one- and two-rail barricades were mixed and a second test was run (see App. F). There the one-rail device had no lower cross bar or brace between legs. The two-rail was superior. It therefore appears that two-rail devices are preferable, particularly for the smaller barricades.

4. *Does device shape have an impact on driver behavior?* This was stated in the null form as: There will be no differences between bar and panel shaped devices.

a. This experiment supports the laboratory study in that overall bar and panel shapes are highly comparable.

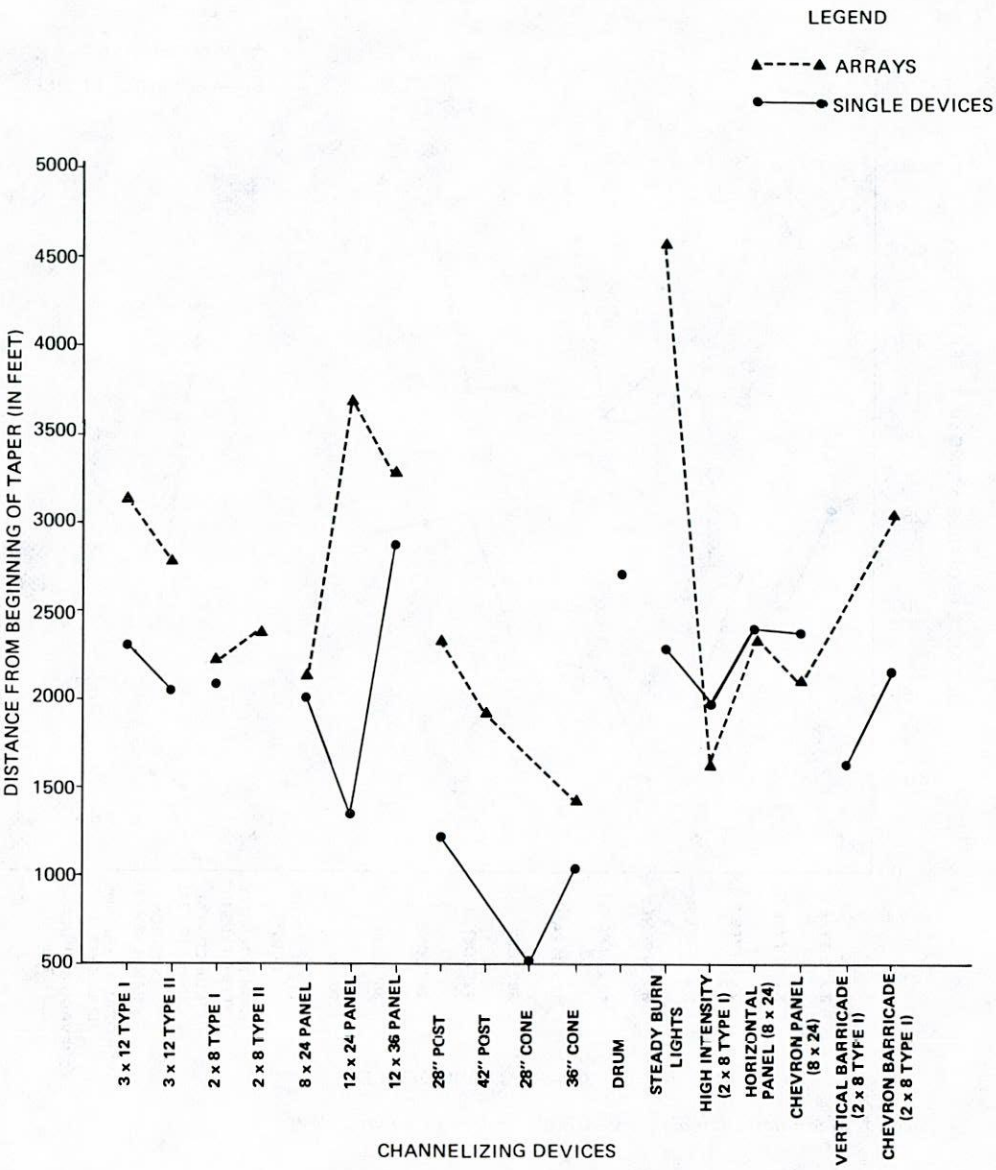


Figure 16. Mean detection distance—single devices vs. arrays (night).

Size appeared to control behavior more than shape.

b. The larger barricades were more consistent across measures and did not have some of the rather large vacillations in measures associated with the larger panels.

c. The roundness of the drum was apparently not perceived at great distance so it, in essence, functioned more like a large panel.

d. The triangular shape of the cone apparently provides attention-getting geometric contrast in daylight.

From the results of this experiment there is evidence that size and visible area control driver behavior more than shape. Specific design recommendations supported by the data are:

1. Barricades should be the 12 in. × 24 in. size with 12 in. × 36 in. used where space permits.

2. There appears to be little advantage gained from two rails except for the smaller size (8 in. × 24 in.) barricade. Then the two-rail has a distinct advantage.

3. Panels should be a minimum of 12 in. wide and no less than 24 in. long.

4. Triangular cone shapes provide good geometric contrast but need to be relatively large for maximum effect (e.g., 28–36 in.).

5. Tubes also should be no less than 28-in. high (3.5–4 in. diameter minimum).

Operationally, there appears to be no driver-behavior-related rationale for having more than one type of channelizing device available. Economically and logistically there are advantages to having the smallest possible numbers of device types inventoried. In the daytime, any of the large devices from all four categories are relatively equivalent. At night, the same devices are also equivalent. Table 13 gives the specific variations among these devices.

Table 13. Synthesis of experiment 2 results (includes Phase II).

	Array Detection Day: Mean Detection Distance	Array Detection Day: DSD Criterion	Array Detection Night: Mean Detection Distance	Array Detection Night: DSD Criterion	Point of Lane Change: Mean Distance – Day	Point of Lane Change: Mean Distance – Night	Lateral Placement: Path Consistency	Speed: Speed Reduction – Day	Speed: Speed Reduction – Night	Driver Preference: Easiest to See	Individual Devices **(Total possible = 6) Day H	Day M	Day L	Night H	Night M	Night L	**(Total possible = 10) Combined H	Combined M	Combined L	Device Groupings (Total number/percent)*** Combined H	Combined M	Combined L
Barricades																						
3' x 12" Type I	H*	H	H	H	H	H	M	H	H	M	4	2	0	4	2	0	8	2	0	21/52	9/23	10/25
3' x 12" Type II	H	H	M	L	L	H	H	H	H	H	5	0	1	4	1	1	7	1	2			
2' x 8" Type I	M	H	L	L	M	H	M	L	H	L	1	3	2	2	1	3	3	3	4			
2' x 8" Type II	L	L	H	H	L	M	M	L	H	M	0	2	4	3	3	0	3	3	4			
Panels																						
8" x 24"	L	H	L	L	M	L	H	L	H	L	2	1	3	2	0	4	3	1	6	17/57	3/10	10/33
12" x 24"	L	H	H	H	H	H	L	H	H	M	3	1	2	4	1	1	7	1	2			
12" x 36"	H	H	H	H	L	M	L	H	H	H	4	0	2	4	1	1	7	1	2			
Posts and Cones (MUTCD Standard)																						
28" post	L	H	L	L	M	L	L	L	L	L	1	1	4	0	0	6	1	1	8	11/28	4/10	25/62
42" post	L	H	L	L	H	L	L	H	L	L	3	0	3	0	0	6	3	0	7			
28" cone	H	H	L	L	L	L	M	L	L	M	2	2	2	0	2	4	2	2	6			
36" cone	H	H	L	L	M	L	H	H	L	H	5	1	0	2	0	4	5	1	4			
Posts and Cones (Optimized)																						
28" post	H	H	H	H	H	H	(L)	L	L	(L)	3	0	3	3	0	3	6	0	6	23/57	4/10	13/33
42" post	H	H	H	H	H	H	(L)	L	L	(L)	3	0	3	3	0	3	6	0	6			
28" cone	H	H	H	H	H	H	(M)	L	L	(M)	3	2	1	3	2	1	6	4	2			
36" cone	Data for optimal condition not available																					
Illuminated cone	H	L	H	H	H	H	(M)	L	L	(M)	2	2	2	3	2	1	5	4	3			
Drum (55 gallon plastic)	H	H	N/A	N/A	M	M	M	H	H	H	4	2	0	2 [4]	2	0	5 [7]	3	0	5/63	3/37	0/0

*<u>H</u>igh, <u>M</u>edium, <u>L</u>ow number.

**Refers to total of H, M, or L's possible for each device.

***Refers to total number of H, M, or L's in each cateogyr and corresponding %.

( ) Category assumed from MUTCD standard condition.

Experiment 3—Steady-Burn Lights and Reflectance

At night, the impact of steady-burn lights on driver behavior was compared to the same devices with Types II and III retroreflective sheeting. The steady-burn lights add considerable detection distance to devices with Type II sheeting. They also more than triple the distance or zone in which lane changing occurs before the taper. Lights on each or alternate devices are equally effective. Steady-burn lights in the taper only are statistically no different from lights on every device and on alternating devices in the taper and tangent, but they do not spread out the lane change zone to the same degree.

The comparison of Type III sheeting (high intensity) with lights and Type II sheeting (engineering grade) demonstrated the importance of angularity. Narrow angle sheeting, even though high brightness, is not effective under certain site geometric characteristics (i.e., hills, curves).

In the cone and tube optimization test of Type II vs. Type III sheeting, the Type III was significantly better at night. This was achieved on a flat straight road.

Even though the Type III sheeting and steady-burn lights are comparable in terms of point of lane change and array detection distance, the effect of vertical or horizontal curvature on any reflective sheeting must be considered.

Definition of High, Medium and Low Categories

High	Medium	Low
	<u>Speed Change</u>	
Significant reduction in speed from taper to tangent section—2 to 3 mph.	Not used	No significant change
	<u>Lateral Placement</u>	
Most consistent path or guidance behavior. Taken from Table D-7	From Table D-7	Greatest amount of displacement or weaving. From Table D-7
	<u>Array Detection</u>	
Day 4000 plus feet Night 3000 plus feet	3501-3999 2501-2999	3500 under 2500 or less
	<u>DSD (Decision Sight Distance)</u>	
Mean minus two standard deviations equals 1000 feet or more	Not used	Equals less than 1000 feet
	<u>Point of Lane Change</u>	
600 or more feet	401-599 feet	400 or less
	<u>Preference</u>	
Top third of Table D-11	Middle third of Table D-11	Lower third of Table D-11

Table 14. Rank order of devices based on eight synthesized dependent variables. (Note: This table represents a method of combining multifaceted measures. It is a tool to aid in selection of devices for further testing and should not be construed as a recommendation for device use.)

A. Assuming speed reduction desirable between taper and tangent

Day	Rank Order	Night	Rank Order	Combined	Rank Order
36" cone-std	1	3' x 12" Type I	1.5	3' x 12" Type I	1
3' x 12" Type II	2	Drum	1.5	Drum	2
→					
3' x 12" Type I	3.5	3' x 12" Type II	4	3' x 12" Type II	4
Drum	3.5	12" x 24" panel	4	12" x 24" panel	4
12" x 36" panel	5	12" x 36" panel	4	12" x 36" panel	4
→		→		→	
28" cone-opt	6	2' x 8" Type I	6	28" cone-opt	6
12" x 24" panel	7	28" x cone-opt	7.5	42" tube-opt	7.5
42" post-opt	8	Ill. cone	7.5	28" tube-opt	7.5
42" post-std	9	42" post-opt	9.5	Ill. cone	9
				→	
28" post-opt	10	28" post-opt	9.5	36" cone-opt	10
→		→			
Ill. cone***	11.5	2' x 8" Type II	11	2' x 8" Type I	11.5
28" cone-std	11.5	8" x 24" panel	12.5	2' x 8" Type II	11.5
8" x 24" panel	13	36" cone-std	12.5	8" x 24" panel	13
		→			
2' x 8" Type I	14	28" cone-std	14	42" post-std	14
				→	
28" post-std	15	42" post-std	15	28" cone-std	15
2' x 8" Type I	16	28" post-std	16	28" post-std	16

B. Assuming *NO* speed change between taper and tangent is desirable

Day	Rank Order	Night	Rank Order	Combined	Rank Order
36" cone-std	1	3' x 12" Type I	2.5	3' x 12" Type I	1.5
3' x 12" Type II	2	28" cone-opt	2.5	28" cone-opt	1.5
3' x 12" Type I	4	(Drum)**	2.5	42" post-opt.	3.5
Drum	4	Ill. cone	2.5	28" post-opt	3.5
		→		→	
28" cone-opt	4	12" x 24" panel	6	(Drum)**	5
12" x 36" panel	7	12" x 36 panel	6	Ill. cone	6
42" post-opt	7	3' x 12" Type II	6	12" x 24" panel	8
28" post-opt	7	42" post opt	8.5	12" x 36" panel	8
→					
Ill. cone	9.5	28" post-opt	8.5	3' x 12" Type II	8
28" cone-std	9.5	2' x 8" Type II	10	36" cone-std	10
				→	
12" x 24" panel	11.5	36" cone-std	11	2' x 8" Type I	11.5
		→			
8" x 24" panel	11.5	2' x 8" Type I	12	2' x 8" Type II	11.5
42" post-std	13	8" x 24" panel	13	28" cone-std	13
→					
2' x 8" Type I	14	28" cone-std	14	8" x 24" panel	14
28" post-std	15	42" post-std	15.5	42" post-std	15
2" x 8 Type II	16	28" post-std	15.5	28" post-std	16

* std = 6" cone collar (MUTCD standard) opt = optimized design (see Phase II findings).

→ indicates "natural" break points in the distribution.

** placed here tentatively because night array detection data not available – rationale for assuming "high" performance in text.

*** ill cone - illuminated cone.

Experiment 4—Device Spacing

Regular speed limit (SL) spacing (55 ft in this test) was compared to half (27.5 ft) and double (110 ft) SL spacing. Tests were run with 2-ft × 8-in. Type I barricades and 8-in. × 24 in. panels. The results indicate that changes in spacing have little impact on driver behavior. There were no speed or lateral placement differences between half, regular, and double SL spacing. A nonsignificant trend suggests that point of lane change and array detection increase with shorter spacings and vice versa. Spacing combinations such as half SL in the taper and double SL in the tangent have promise for optimizing driver behavior and reducing logistic and maintenance cost.

Experiment 5—Mixed Devices

Two mixed device arrays were tested day and night. The 2-ft × 8-in. Type I barricade in the taper plus 36-in. cone in the tangent and 8-in. × 24-in. panel (taper) plus 42-in. post (tangent) were compared with arrays composed only of each device type. In the daytime, there were few differences between mixed and single device arrays. Any advantages to this type operation will stem from logistic or cost (not driver behavior) considerations. At night, the effect of mixing devices appears to be a compromise in driver behavior between the characteristics of the two devices used. Therefore, the types of devices used and behavioral consequences must be carefully considered. Only two device combinations were tested here and further research on other combinations is desirable. However, behaviorally, there does not appear to be any particular advantage to mixing devices.

Experiment 6—Best/Worst Validation of Task 3 Markings

In this experiment, the effect of diagonal and chevron stripes on barricades and panels was tested. Also tested were a horizontal stripe on the panels and a vertical stripe on the barricades. The particular chevron design used here was not as detectable in the daytime as the other patterns. The diminished performance may be because a 4-in. stripe, not 6 in. as used on the panels and barricades, was used. At night, the chevron was equivalent to the other patterns. A vertical stripe on barricades did not perform well, most likely because it did not form a satisfactory pattern of contrast with light or dark backgrounds. The horizontal stripe on panels appears equal to, and perhaps better than, the diagonal stripe. Thus, a horizontal pattern can be used on panels; chevrons as well as diagonal stripes can be used at night on barricades and panels.

Evaluation of Dependent Variables

Three types of dependent variables were used in the experiments: detection, vehicle control, and preference. Of the 13 measures used, the following are recommended as sensitive to different channelizing devices and, therefore, are probably useful for work zone measurements in general: speed change from taper to tangent sections; point of lane change (mean and variance), array detection (mean and variance), the derived decision sight distance criteria (see Table 13 for brief explanation), and displacement (weaving) in the tangent.

Comparison of Task3 and Task 4 Results

The purpose of Task 4 was to verify and extend the Task 3 laboratory work. Given the Task 4 results, the following statements summarize the comparisons of the two tasks:

1. *Stripe Width*—The laboratory tests indicated 6- or 8-in. stripes were optimal.

2. *Shape*—There was little difference between bar and panel shapes in the laboratory. In the closed-field experiments, the large one-rail barricade had a slight advantage over the larger panels. However, the laboratory finding that bar and panel shapes are generally equivalent was verified.

3. *Configuration*—The laboratory data suggested horizontal and vertical stripes could be more detectable than the diagonal. In Task 4, the horizontal stripe on a panel was equal to, and perhaps superior to, the diagonal configuration. The vertical stripe on barricades was definitely inferior to the diagonal stripe. Chevrons were equal to other configurations at night, but were not as detectable in the daytime. This confirms the laboratory finding.

The chevron is unique among the configurations tested in that it is the only one to consistently and reliably convey directional information on a channelizing device; the chevron is the only acceptable configuration of the four tested for that purpose.

4. *Color Ratio*—Again, this was not directly tested in the closed-field study. From the laboratory findings, a 1:1 ratio and no more than a 2:1 white-to-orange ratio were recommended. The ability of devices with the 1:1 ratio to provide adequate contrast both day and night was evident from the Task 4 data. The success of devices in being detectable appeared to be more than a simple matter of color ratio. A single color on a device might suffice against a very simple bright background; however, against multicolored, variegated backgrounds, some type of pattern greatly aids a driver in discriminating the device from the background. The angles, colors, shape, and contrast formed by a device pattern serve to break up and standout from the visual complexity of most backgrounds. The most effective devices are those which, when placed in an array, enhance and extend the pattern throughout the array. Drastically increasing either white or orange would probably alter the overall pattern perception and hamper constrast under light or dark visibility conditions.

5. *Height-to-Width Ratio*—According to the laboratory studies, this parameter did not have a profound impact on detectability. Thus, shorter or narrower devices should be equally as effective as wider or longer devices. The closed-field experiments included this variable only to a limited degree. However, the pattern of differences in Task 4 indicated that size is the controlling variable. The height-to-width ratio is much less important than assuring a sufficient visible area. Thus, the laboratory studies were verified.

As part of this parameter, one- versus two-rail devices were studied in the laboratory. Findings were not clear, but one-rail devices were recommended for additional study. One closed-field study finding supported that recommendation; a second did not. The data show that there is little difference between a Type I barricade which has a lower rail that is not reflectorized and a Type II barricade. However, there is a significant difference between a Type I barricade with only one rail and a Type II barricade. Also, the Type I and Type II difference is evident for the smaller barricade (8 in. × 24 in.). For the larger size barricade 12 in. × 24 in., or greater, one-rail appears adequate.

In summary, the laboratory findings were generally verified. Task 4 did, however, demonstrate the importance of the effects of arrays as opposed to single devices, the important contribution of device size, and (at night) the value of device brightness. This simply indicates that laboratory studies can be useful, but they are severely limited in the scope of contributing variables that can be studied.

Task 4 Cone and Tube Optimization Studies

This effort was to gather experimental data to determine the effects of size, spacing, reflectorization, etc. on drivers' ability to perceive and negotiate the cone or tube image and arrays. Task 4 testing had shown cones and tubes to be as effective as other channelizing devices in the daytime, but a performance decrement was found at night. Therefore, the goal of the work reported here and detailed in Appendix F was to optimize nighttime performance characteristics of cones and tubes without sacrificing daytime effectiveness.

Selecting Cone and Tube Configurations for Study

Two sources of information were used to guide selection of device treatments: a literature search and results of operational practices surveys. Two survey forms, one for state traffic engineers and one for American Traffic Services Association Members, provided information on cone and tube designs. Complete results are given in Tables F-1 and F-2. In summary, 28-in. cones predominate, with 36 in. and 18 in. also used. Various forms of reflective collars are used at night, but cone use at night is quite limited. About one-third of the respondants used 36-in., 39-in., or 42-in. tubes primarily in the day. Smaller tubes were used in one state for separation of two-way traffic but not for lane closures. In general, tubes are used for long-term operations somewhat more than cones.

Using these sources plus project panel and ATSA Cone Committee comments the cone/tube treatments listed as follows were selected for further testing:

Cones	Tubes
5 areas of reflectorization (69, 138, 207, 276, and 345 sq. in. corresponding to single bands of 6, 10.4, 14, 17, and 19.7 in.)	5 areas of reflectorization (14, 28, 43, 57, and 71% of area covered corresponding to bands of 6, 12, 18, 24, and 38 in.)
Number of bands of reflectorized material (1, 2, 3)	1, 2, 4, 6, or 8 bands
High versus low mounting position	High versus low mounting position
4 types of reflectorization plus internal illumination	4 types of reflectorization
2 colors (white and amber)	2 colors
3 sizes (18-, 28-, 36-in.)	3 sizes (18-, 28-, 42-in.)
3 device spacings (half, regular, and double speed limit spacing)	3 device spacings

Experimental Method

Two test procedures, both in a closed field setting, were used to conduct 10 experiments. In the first set (4 experiments), 4 or 5 subjects at a time were driven by lane closures with a different cone/tube design at each pass. Subjects pushed a button when they first saw something in the lane ahead (detection distance) and again when they could tell the lane was closed and they would have to change lanes (recognition distance). The second set of 6 experiments verified and expanded the first set. The method was as close a replication of the Task 4 closed-field study as possible. The major differences were:

1. A different test site had to be used because the original test site was now open to the public. Figure F-1 shows two views of the new site. The 7-mile drive had an array in each direction on a straight flat road section three lanes wide. Thus the new site was 1 mile longer, was flatter, and had an additional lane in each direction compared to the earlier site.
2. A 1981 Escort station wagon was instrumented to collect array detection distance, point of lane change, and speed instead of NHTSA DPMAS (a 1974 Chevrolet).

Step 1 Testing. The purpose of this series of experiments was to determine the optimal values for several cone and tube design parameters. From the variables listed earlier, the reflective area, number of bands, mounting position, reflective material, and device size were selected. Four experiments (see Table F-4) were designed and tested.

The various treatment configurations are shown for cones in Figure F-3 and for tubes in Figure F-4. The device sizes tested were 18-in., 28-in., and 36-in. cones and 18-in., 28-in., and 42-in. posts. Reflective material tested included 3M "High Intensity" in white and yellow, Reflexite vinyl in white, and polycarbonate in white and yellow. In addition, ½ vinyl/½ polycarbonate and internally illuminated cone treatments were tested.

The findings in terms of the various tube and cone design characteristics are summarized in Table F-8. The last column of that table also indicates parameters of values that needed to be verified or studied further in the Step 2 tests.

Step 2 Tests. In this step, a factorial design was used in which each treatment was seen by 8 subjects and tested day and night. For analytic and interpretation purposes the treatments were grouped to form experiments testing specific hypotheses. Need for the various experiments was identified in Step 1 testing. Table F-9 summarizes the 8 experiments. To establish comparability between the closed-field Task 4 tests and the follow-on optimization study, an empirical "bridge" was created by testing several devices from the original experiments in the cone and tube optimization setting.

On the basis of the preceding experiments, several design suggestions for cones and tubes can be offered. By incorporating these suggestions in cone/tube design, driver response to these devices can be substantially improved at night without daytime decrement. Tables F-16 and F-17 summarize the various findings and state design and use guidelines based on the findings.

Several qualifying factors should be noted about these results. First, only cars were used in the closed-field testing. The effect of truck/bus eye height on these findings is not known. Second, unique designs or modifications to tubes and cones can be readily designed (e.g., wider tubes, flat reflective panels inserted in cone or tube tops at night, light mounts, cones or tubes with one side flat) but were not within the scope of this study. Third, not all problems noted in the user survey were addressed by this project. Stability, durability, storage (stacking), and vandalism, although obviously important, were not considered.

Data from experiment 7 indicate that there was moderate comparability between the original Task 4 tests and the follow-on optimization tests. Panels, cones, and tubes, particularly on the array detection measure, were similar. Barricades were discrepant for the point of lange change and array detection measures. This limited comparison of barricades with devices from the earlier tests.

In experiment 8(a), the Type III sheeting was superior to the Type II at night, but not in the day. Nighttime array detection was in the 4500-ft and lane change in the 1500-ft range. For experiment 8(b), the two-rail 2-ft × 8-in. barricade was clearly superior to the one-rail. Details of these results are given in Appendix F.

In conclusion, the result of the Steps 1 and 2 testing is a set of design guidelines which produce cone and tube configurations that are detectable at least 3000–4000 ft away at night and 4000–5000 ft away in the day, meet the decision sight distance criterion, elicit lane changing 800–1600 ft before the taper, and after eliciting an initial speed reduction (≅ 2.5–3.5 percent) have minimal effects on speed from 1100 ft prior to the taper through the tangent section.

Summary of Findings and Selection for Field Tests in Task 5

Although the closed field studies were a step closer to reality than the laboratory, they still represented a very simple "pure" situation. The next task was to validate these findings in an operational setting. One concern about the next step is measurement sensitivity. The measures used in the closed-field situation were relatively "fine-grained"; yet there were no large, dramatic differences. This was particularly true of measures which are typically used in full field settings (e.g., speed). When channelizing devices are buried within the context of a full work zone information system, the relatively small differences found in the closed-field situation may be washed out or masked by overriding responses to other components of the work zone. With that possibility in mind, the findings that are recommended for verification in the field evaluation include:

1. Large devices elicit speed reduction to a significantly greater extent than small devices.
2. Drivers change lanes further away from the taper at night than in the day.
3. Panels and barricades are equivalent in their impact on drivers.
4. Steady-burn lights are highly detectable and increase the mean and the overall zone where lane changes occur.
5. Alternate or taper-only light spacing is as effective as lights on every device.
6. The relationship between steady-burn lights and Type III sheeting needs further investigation.
7. Wider device spacings are equivalent to regular speed limit spacing.
8. Mixed arrays, at least at night, reflect a compromise between the performance elicited by the two devices used.
9. The chevron configuration and horizontal stripe on panels are equivalent to the diagonal stripe.

EFFECTIVENESS OF CHANNELIZATION DEVICES (FIELD EVALUATION STUDY)

General

The final task of this study was to evaluate the effectiveness of selected channelization devices when used collectively under actual field conditions. The purpose of this evaluation was not so much to determine the most effective device, but rather to validate that those devices and designs which were found to be promising from the previous tasks would perform adequately under actual conditions. Performance measures in this case consisted of the traffic flow parameters of speed, speed variance, lane changing, and traffic conflicts. Adequacy was judged by comparing the performance of the selected device against the performance of a standard MUTCD device.

The work zones that were used for testing were as follows:

1. Site 1—a two-lane (one direction) by-pass of a bridge repair project. Both lanes were maintained as they were routed over the median.
2. Site 2—a right lane closure on a two-lane (one direction) highway to provide space for shoulder repairs.
3. Site 3—a left lane closure on a two-lane (one direction) highway to provide space for bridge repair.

Table 15 describes the various devices that were tested at each of the three sites. These devices are grouped as follows:

1. A base condition consisting of a Type I barricade with a 24-in. wide and 12-in. high rail and 6-in. diagonal orange and white stripes.
2. Two devices the same as the base condition but with vertical stripes, and one treatment with devices spaced at 110 ft along the tangent section.
3. Five device combinations using Type I barricades but with 4-in. chevron stripes; and, along the tangent section, two treatments using cones and one with devices spaced at 110-ft intervals.
4. Three device combinations using 12-in. wide by 24-in. high vertical panels and variations of spacing and cones on the tangent section.

These devices were selected with consideration of the results of the previous tasks and the logistical limitations.

The data collection procedure consisted of obtaining traffic flow measurements of vehicles as they approached and passed by the work zone channelization devices. The Traffic Evaluator System (TES), an electronic device which monitors all vehicles in all lanes instrumented with a tapeswitch sensor, was employed to collect data on vehicle speed, acceleration, and lane changing. Because the tapeswitches were placed at several locations, profiles of mean speed and speed variance could be developed. The TES software also identified lane changing between tapeswitch traps in the adjacent lanes. This instrumented data collection procedure was supplemented by manual observation of traffic conflicts and erratic maneuvers of various types. On each data collection day, a new channelization treatment was deployed, and data were collected for a 3- to 4-hour period during the day and, for most cases, the night. Changes were made only to the channelization devices and not to any of the signs, markings, or any other devices present.

The findings of this task are presented in order of the four performance measures used for the evaluation. Appendix E contains complete documentation of the data collection methodology, analysis of the data, and results for the three test sites.

Table 15. List of treatments tested at each site.

Treatment No.	Location	Device Type[1]	Pattern	Spacing	Sites 1 K-10	Sites 2 I-57	Sites 3 I-55/74
1 (Base)	Taper Tangent	24" x 12" Type I Barricade	6" diagonal	55 ft	D, N[2]	D, N	D, N
2A	Taper Tangent	24" x 12" Type I	6" vertical	55 ft	D, N	D	D, N
2B	Taper Tangent	24" x 12" Type I	6" vertical	55 ft 110 ft		D, N	D, N
3A	Taper Tangent	24" x 12" Type I	4" chevron	55 ft		D, N	
3B	Taper Tangent	24" x 12" Type I	4" chevron	110 ft		D	
3C	Taper Tangent	24" x 12" Type I	4" chevron	55 ft 110 ft			D, N
3D	Taper Tangent	24" x 12" Type I 36" cone	4" chevron	55 ft 55 ft	D, N	D	D
3E	Taper Tangent	24" x 12" Type I 42" post cone	4" chevron	55 ft 55 ft			D
4A	Taper Tangent	24" x 12" vertical panel	6" horizontal	55 ft	D, N		D, N
4B	Taper Tangent	24" x 12" vertical panel	6" horizontal	55 ft 110 ft			D
4C	Taper Tangent	24" x 12" vertical panel 36" cones	6" horizontal	55 ft 55 ft			D

[1]Steady-burn lights were placed on all devices except the cones and were operative during the nighttime; for cones, reflective collars were used during the night.

[2]D – tested during day.
N – tested during night.

Mean Speed

Figures 17, 18, and 19 show the daytime and nighttime speed profiles for each lane for sites 1, 2, and 3, respectively. The profiles are those for the base condition (i.e., channelization devices consisting of Type I barricades with a 24-in. × 12-in. rail of diagonal stripes (steady-burn lights were used at night on all barricades). Appendix E shows the profiles for the other experimental treatments. The base condition profiles are presented as examples of the speed profiles for all treatments because none of the treatments varied drastically from the base.

The speed profiles for each site are unique to that site and should not be considered as generalizable to all work zone types. Nonetheless, there are some findings which apply to all three sites.

Day vs. Night

At all three sites, day speeds were generally higher than night speeds. The difference ranged from 2 to 5 mph depending on the site and trap location. The day and night speeds were substantially different at the upstream traps, but the day speeds tended to converge down to the level of the nighttime speeds in the work zone areas. This indicates that motorists do not reduce their speed as much at night as they approach and travel through the work zone as they do during the daytime, mainly because they are already travelling at a lower speed.

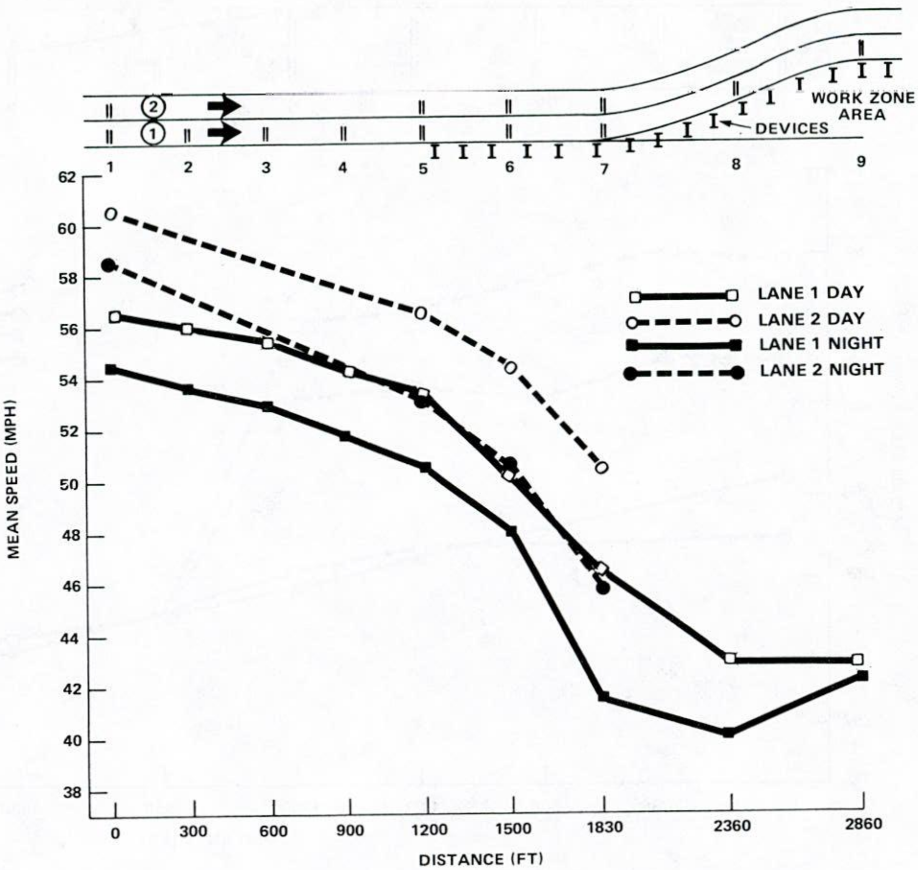


Figure 17. Speed profile for traffic diversion, site 1.

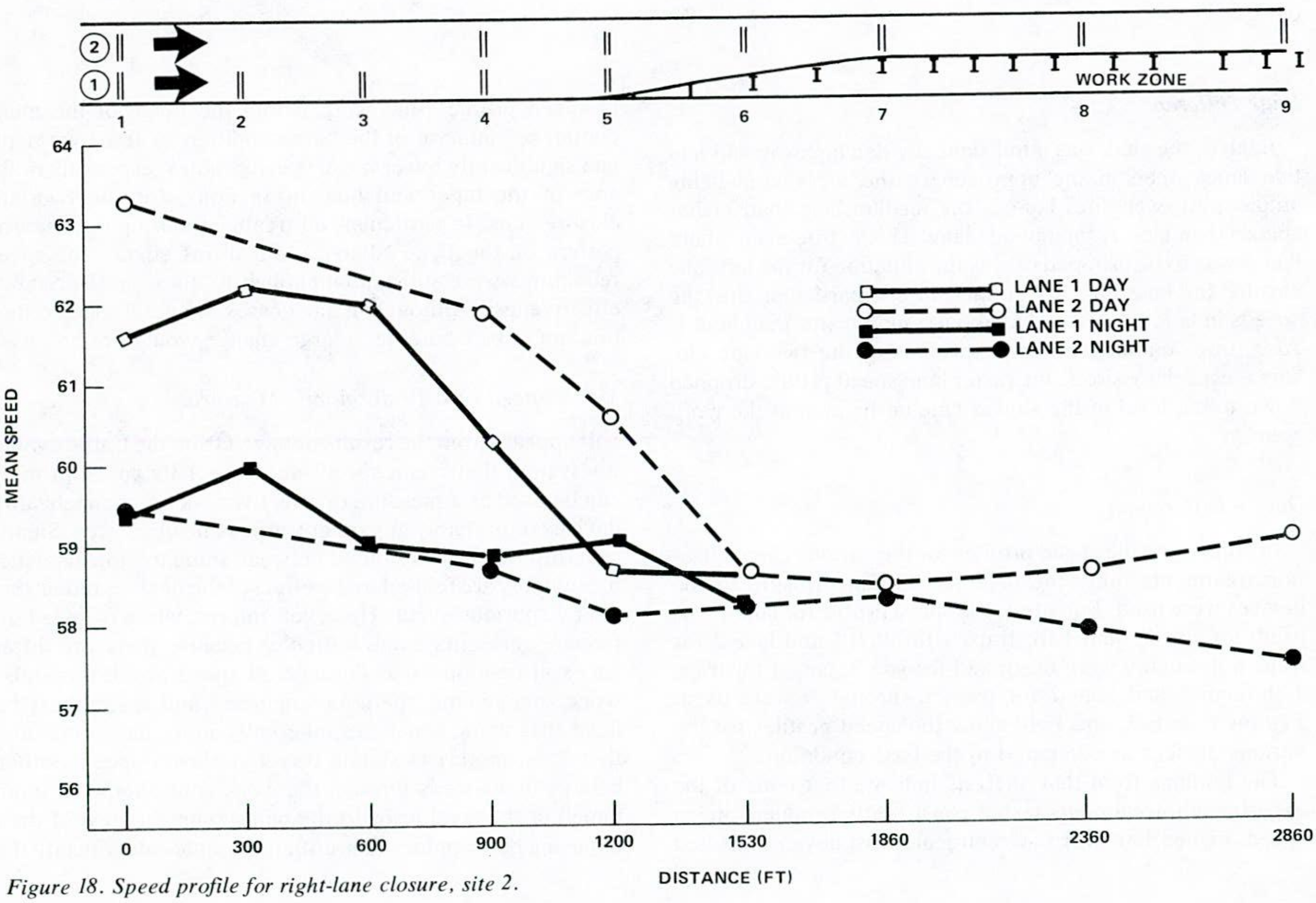


Figure 18. Speed profile for right-lane closure, site 2.

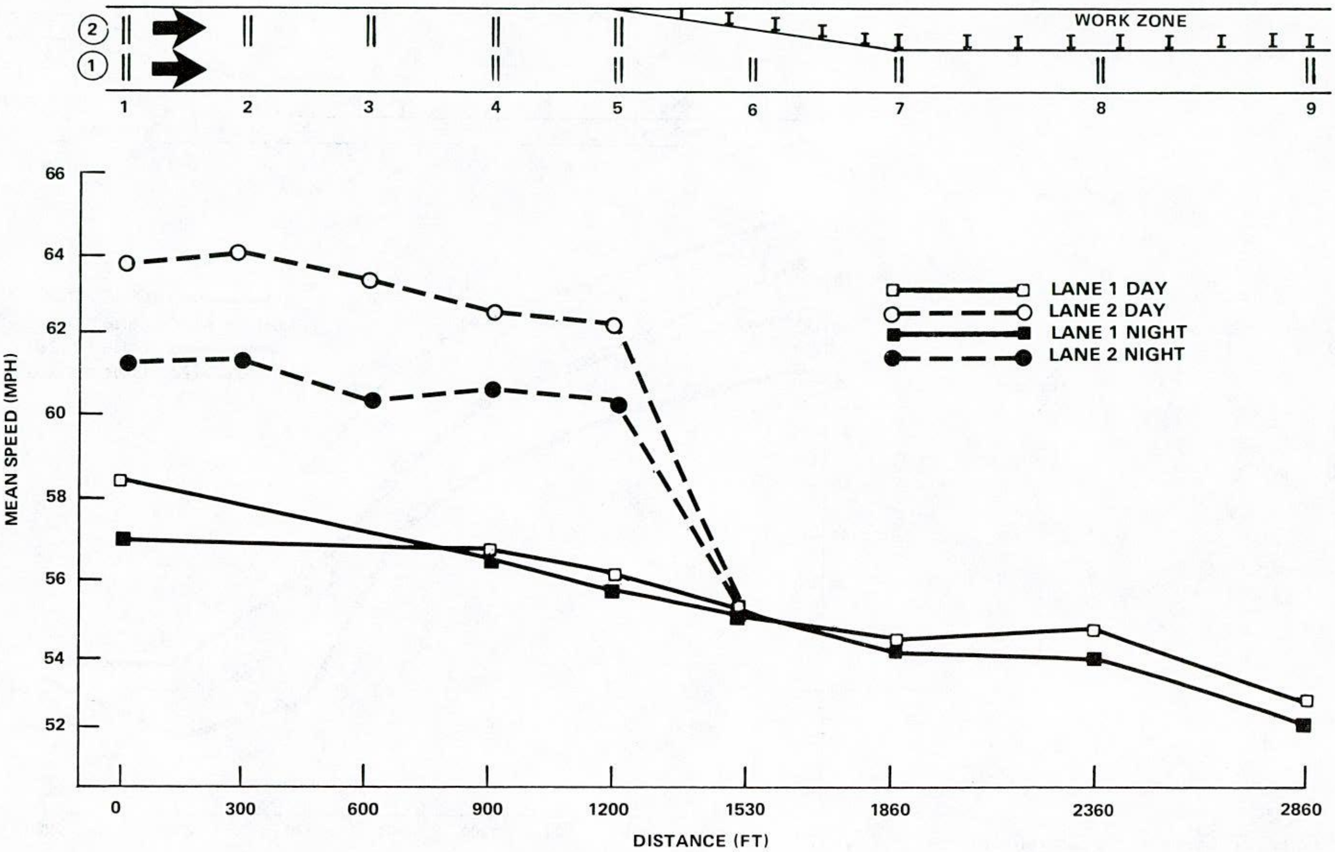


Figure 19. Speed profiles for left-lane closure, site 3.

Lane Differences

Each of the sites was a four-lane divided highway and had two lanes open in the approach to the work area being studied. At each site, lane 2, the median lane, had higher speeds than lane 1, the outside lane. This is true even where lane 2 was to be dropped as was the situation for the left-lane closure site (see Fig. 19). In fact, at this particular site, the speeds in lane 2 remained at about 5 mph faster than lane 1. Also, in examining the speed profiles of the two-lane closures, especially site 3, the faster lane speed profile dropped down to the level of the slower lane in the area of the work zone.

Device Differences

In comparing the speed profiles for the various channelization treatments, only the data for the lane closure to the devices were used. For site 1, the speed profile for lane 1 was used; for site 2, lane 1 for traps 1 through 5 and lane 2 for traps 6 through 9 were used; and for site 3, lane 2 for traps 1 through 5 and lane 1 for traps 6 through 9 were used. Figures E-4, E-7, and E-10 show the speed profiles for the various devices as compared to the base condition.

The findings from that analysis indicate that none of the experimental treatments tested consistently produced mean speeds higher than the base treatment. Most devices resulted in speed profiles that were within the range of the mean confidence interval of the base condition. A few treatments had significantly lower mean speed profiles, especially in the area of the taper and tangent sections, for the two-lane closure sites. In particular, all treatments using the chevron pattern on the Type I barricade had this effect. The speed reductions were substantial enough to question their safety effectiveness. Although in most cases a general speed reduction might be desirable, a large change would not be.

Mean Speed as a Performance Measure

It appears from the results obtained from the traffic evaluator system that mean speed, and especially speed profiles, can be used as a measure of effectiveness for channelization devices or probably any other traffic control devices. Significant differences were found between some treatments which presumably are related to the effect of the devices rather than to any spurious event. However, interpretation of speed differences presents some difficulty because there are differences in opinion as to the desired speed profile through a work zone. Some operating engineers and researchers believe that work zones are inherently more hazardous and, therefore, motorists should travel at slower speeds; others believe that speeds through the work zone should be maintained at the level prior to the work zone. In view of these opposing philosophies, it is difficult to state categorically that a channelization device is more effective if it reduces or increases speed.

Speed Variance

The second measure of effectiveness obtained from the traffic evaluator system was speed variance. This statistic is a measure of the dispersion from the mean and has been related to accident proneness in previous research. At a given mean speed, higher speed variance would indicate a more hazardous situation because more motorists would be travelling at higher and lower speeds than the average speed.

Figures 20, 21, and 22 are speed variance profiles for the three sites. As with the mean speed profiles, they represent the base condition for both lanes, day and night. The findings related to speed variance are discussed in the following.

Day vs. Night

It was noted earlier that day mean speeds were in most cases higher than night speeds, especially in the approach area. This relationship did not hold true for the speed variance profile for all sites. At site 1 (see Fig. 20), speed variances were higher at night at most traps; but, at sites 2 and 3 (see Figs. 21 and 22), they were frequently lower than daytime speed variances. At all sites, however, the speed variance profile is "noisier" (i.e., subject to more fluctuations) than the daytime profile. These fluctuations were particularly noticeable in the taper approach area. This result indicates that although motorists, on the average, tend to drive at slower speeds at night in work zone areas, they do so with more variation, especially as they approach the transition area.

Lane Differences

Mixed results were found with regard to differences in speed variances between lanes. The higher speeds found for the inside lane did not transfer over to speed variance in all cases. There seems to be a trend, although not conclusive, that speed variances are higher in the lane that is to be dropped, lane 1 for site 2 and lane 2 for site 3. This would seem reasonable because motorists had to merge out of their lane and lane changing causes more speed variance.

Device Differences

As with the mean speeds profiles, Figures 20, 21, and 22 show the speed variance profiles only for the base treatment. Figures E-5, E-8, and E-11 show the variance profiles for each of the experimental treatments.

The findings of the treatment comparisons for the three sites indicate that at site 1 only one treatment, Type I barricades with 6-in. vertical stripes, was different from the base condition. At night, this treatment produced a higher speed variance profile, but in the day it was lower than the base treatment.

At site 2, the three channelization treatments using chevron patterns on a Type I barricade had a higher speed variance in the taper approach area. They also produced lower speeds. On the basis of the assumption that the difference in speed variance is attributable solely to the devices, it appears that the chevron pattern causes more speed variation. This is difficult to explain because the results of the earlier tasks indicated that motorists understood the directional symbolism of the chevron better than other patterns.

At site 3, speed variance profiles for most experimental treatments (including a few with chevron patterns) were similar to the base treatment. One notable exception was a treatment consisting of Type I barricades with chevron patterns spaced at 110-ft intervals along the tangent section. Unfortunately, because there were two items different from the base condition, the chevron design and the longer spacing, it cannot be determined if one or both of the factors caused the increase in variance. But, because the differences were more dramatic in the tangent area where the spacing was longer, this result would indicate that long spacing (in this case, twice the original speed limit) produces higher speed variance.

Speed Variance as a Performance Measure

The results obtained from the three study sites indicate that speed variance is a viable performance measure for evaluating the effectiveness of alternative channelization devices. It can be observed from the profile charts that some devices produced similar mean speed profiles but dissimilar speed variance profiles. Where this occurred, an erroneous conclusion regarding the effectiveness of a particular treatment could be made if the only performance criterion was changes in mean speed.

Lane Changing

The third measure of effectiveness used was the occurrence and location of lane changing. The traffic evaluator system software tracks individual vehicles as they travel through the tapeswitch arrays and can, therefore, indicate if a lane change occurred between any two tapeswitch traps in adjacent lanes. The findings with regard to lane changing are given for each site separately because each was a unique situation.

Site 1

This site was a by-pass-type work zone in which both lanes were maintained and diverted around the work site. Lane changing was not required and, in fact, was discouraged with the use of a solid white lane line. Table 16 gives the frequency of lane changes from lane 1 (the outside lane and closest to the channelization devices) to lane 2 (the median lane) and vice versa. The data in the table provide three findings at least with regard to this site. (1) There is a higher occurrence of lane changing from the inside to the outside lane. (2) There is more lane changing at night than during the day. (3) None of the experimental treatments produced significantly more or less lane changes than the base condition.

Site 2

At site 2, all vehicles in the outside or shoulder lane had to merge into the inside or median lane. Figure 23 is a bar chart showing the percentage of vehicles changing lanes at various intervals before the beginning of the taper and along the taper for each treatment studied during the day. The chart indicates that a majority of free-flow vehicles (i.e., those not

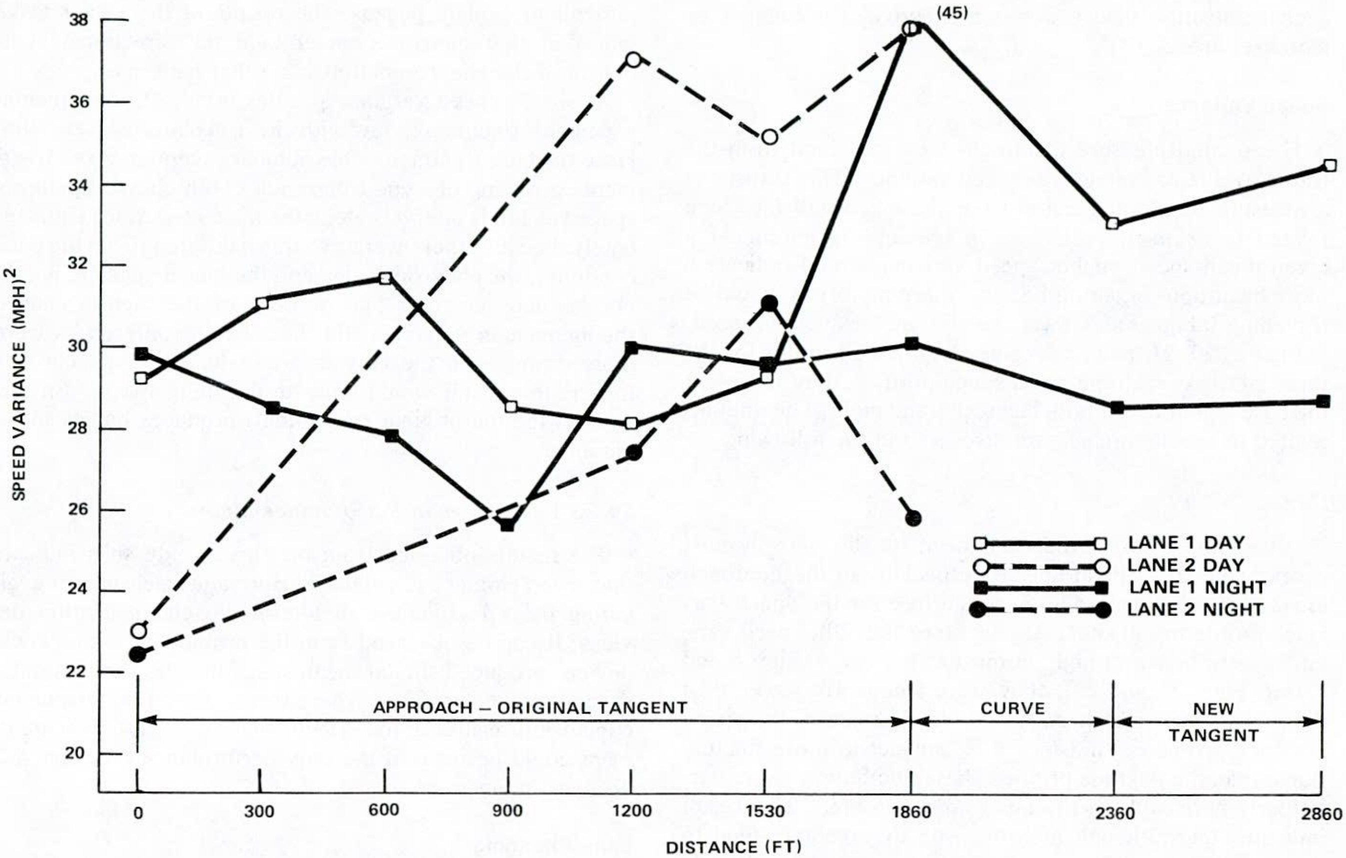


Figure 20. Speed variance profile for traffic diversion, site 1.

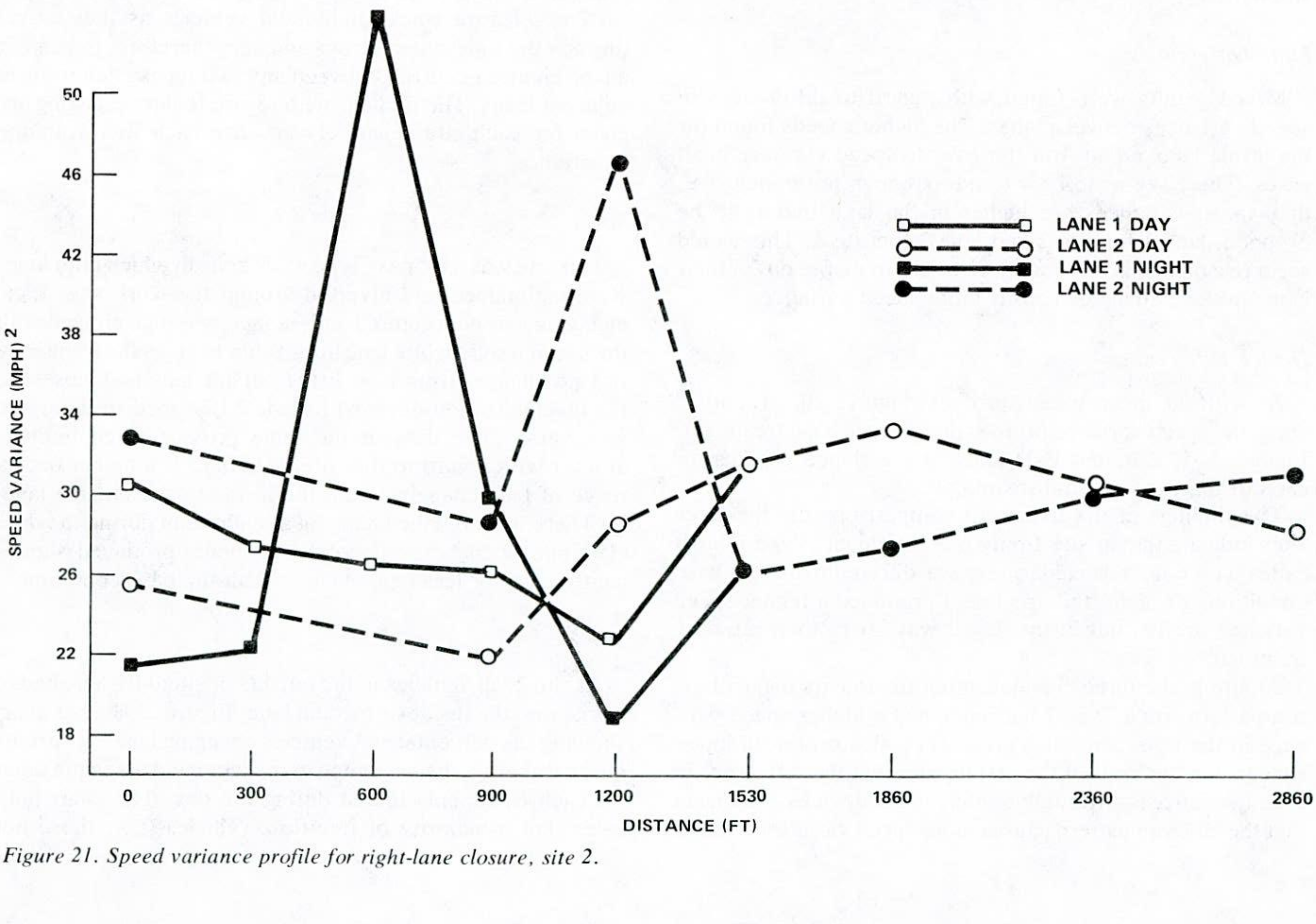


Figure 21. Speed variance profile for right-lane closure, site 2.

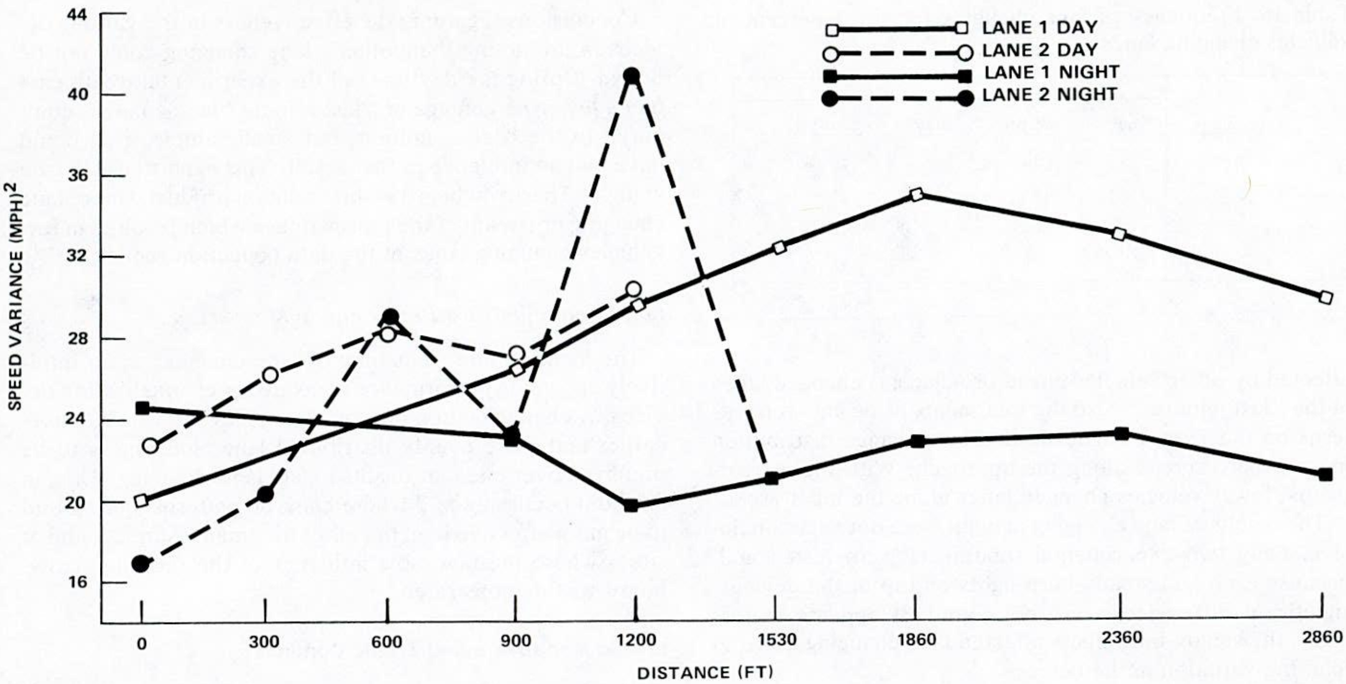


Figure 22. Speed variance profile for left-lane closure, site 3.

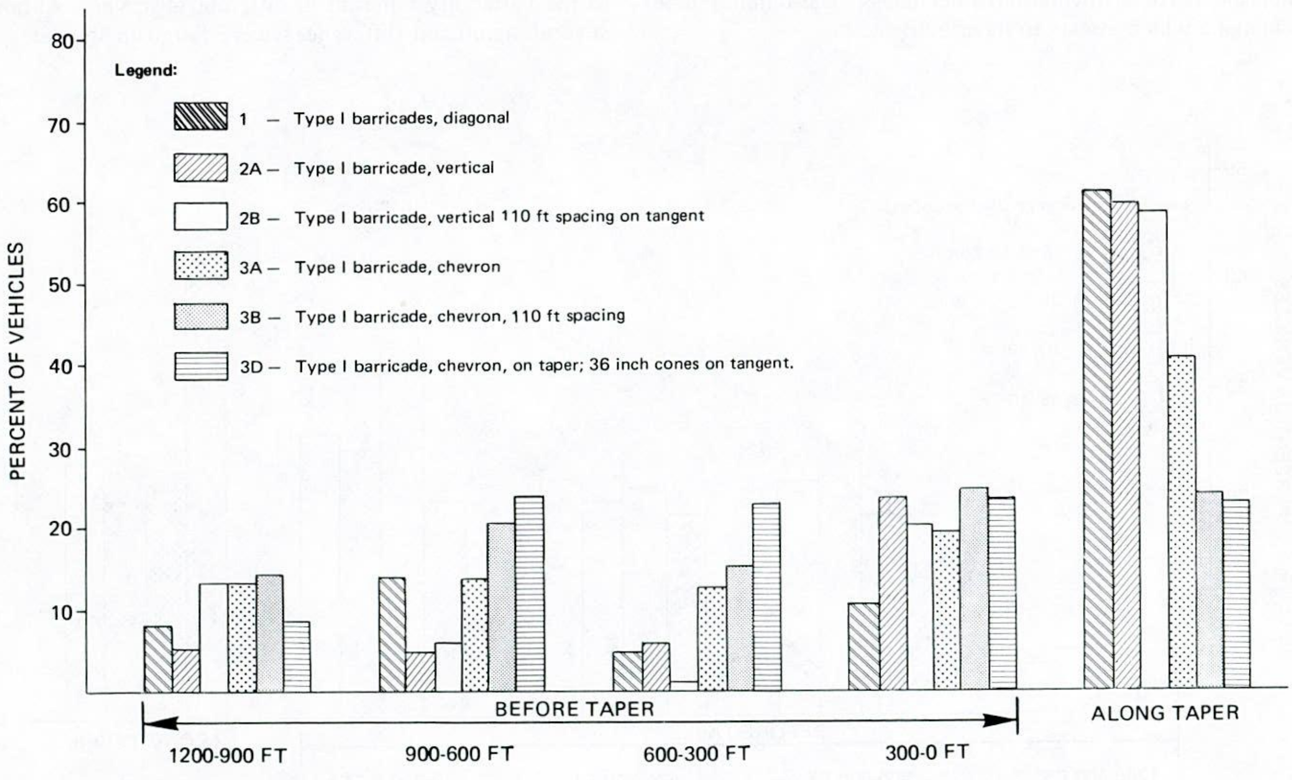


Figure 23. Location and frequency of lane changing for right-lane closure site (day).

Table 16. Frequency of lane changing for site 1 percent of vehicles changing lanes.

Treatment	1 to 2 Day	1 to 2 Night	2 to 1 Day	2 to 1 Night
1 - Base	.7	11	3	37
2A	1	13	3	20
3D	--	--	2	34
4A	2	9	4	35

affected by other vehicles ahead or adjacent) changed lanes at the "last minute." Also the treatments using chevron patterns on the Type I barricade had lane change distribution more evenly spread along the approach. With these treatments, fewer vehicles changed lanes along the taper area.

The results of lane changing at night were not very conclusive. Only two experimental treatments were tested and, because each had steady-burn lights on top of the devices, significant differences were not found. It appears that at night, the steady-burn lights affected lane changing more so than the variation in the devices.

Site 3

Because site 3 had a left-lane closure, vehicles in the faster, median lane had to merge into the slower, shoulder lane. It also should be noted that, at this site, a flashing arrowboard was operating for all test conditions. Its effect on lane changing can be seen in Figure 24 which shows a more even distribution of the location of lane changing along the approach. The arrowboard results in less "last-minute" lane changing which attests to its effectiveness.

Conclusions regarding the effectiveness of the various devices in promoting "smoother" lane changing could not be drawn. During the daytime, all the experimental treatments had a lower percentage of "last-minute" lane changes compared to the base condition, but small sample sizes could have had an influence in that result. This is particularly true at night. The arrowboard in this situation produced more lane changing upstream of the tapeswitches which resulted in few vehicles changing lanes in the data collection section.

Lane Changing as a Performance Measure

The location and frequency of lane changing is an intuitively appealing performance measure for channelization devices. A channelization device, or any device, which causes earlier and more evenly distributed lane changing is to be preferred over one that results in late lane changing. This, in fact, did occur at site 2 where chevron patterns were found to be more effective than the other treatments studied, and at site 3 where the favorable influence of the flashing arrowboard was demonstrated.

Erratic Maneuvers and Traffic Conflicts

The fourth performance measure used in the device evaluation was the rate of erratic maneuvers and traffic conflicts. These events were manually observed and classified into several types for analysis. Appendix E includes a discussion of the analysis which essentially resulted in inconclusive findings regarding the relative effectiveness of the alternative treatments. One of the results uncovered in the analysis was that several differences in the erratic maneuver and traffic conflict rates between treatments could have been attributed to the variability inherent in different observers. Although several significant differences were found in the rates be-

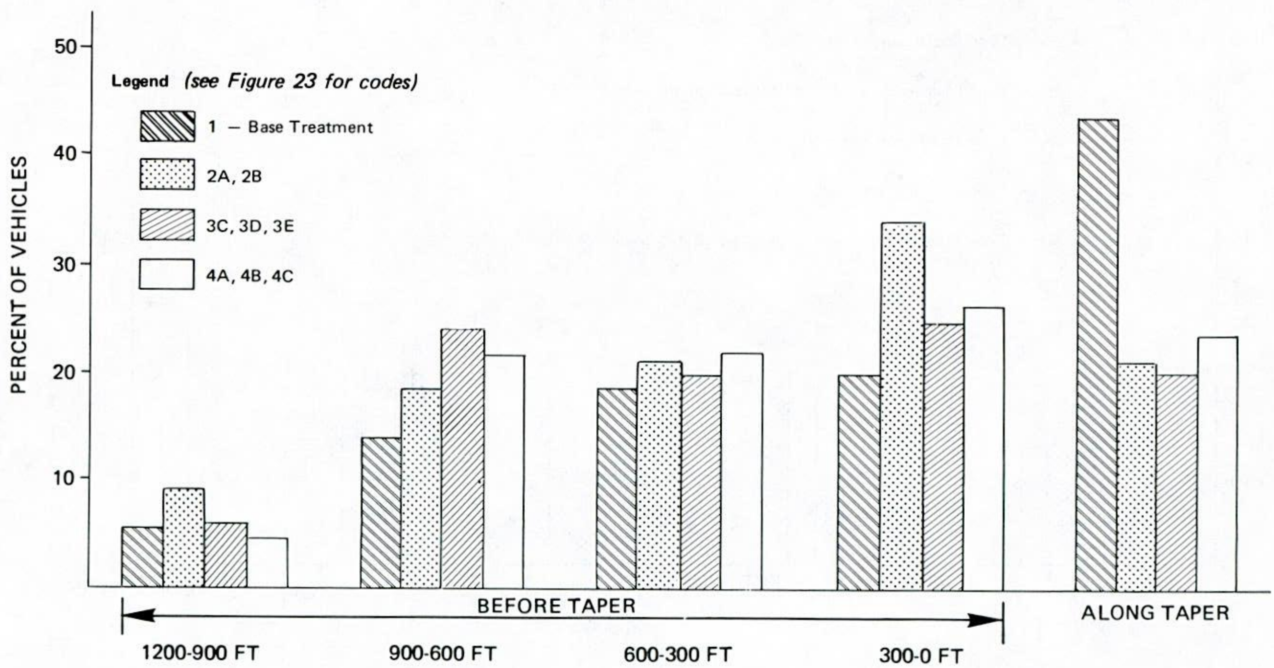


Figure 24. Location and frequency of lane changing for left-lane closure site (day).

tween the base condition and the experimental conditions, both higher and lower, most had to be discounted because of observer differences.

In view of this finding, the usefulness of traffic conflicts and erratic maneuvers as a performance measure for channelization devices is questionable. Even when intercoder variability is controlled, few differences are found between devices. This is not unexpected because minor variations in channelization systems are not likely to produce significantly different erratic maneuver or traffic conflict rates.

CHAPTER THREE

INTERPRETATION AND APPLICATION

In this chapter the findings of the various tasks reported in Chapter Two are synthesized and interpreted for the purpose of providing suggested guidelines for the application of channelizing devices in work zones. The discussion proceeds in the following order. The first section presents the findings related to the effectiveness of the device types and conclusions that can be drawn regarding their applications. The second reviews the findings related to various design parameters including stripe configuration, color, ratio, and spacing. The third section treats the usefulness of the performance measures used.

EFFECTIVENESS OF ALTERNATIVE CHANNELIZATION DEVICES

Cones

Cones have been, and will likely continue to be, the most frequently used channelization device for highway work zones. Because of their compactness, portability, durability, and ease of application, cones are generally preferred over other devices, especially for short-term operations.

During the day, cones (especially larger sizes) appeared to perform as well as, if not better than, other types of devices. With their full orange mass and triangular geometry providing good contrast for daylight conditions, the cones were found to have long detection and adequate lane change distances. The 36-in. cones were generally found to be more effective than the 28-in. cones in the day, and both of these were more effective than the 18-in. cones on a freeway facility.

Cone size had less impact at night. The amount of reflective material on the cone controls driver response. Two or three bands of reflective material totaling 150–200 in.^{2} (roughly the amount in a 12–14-in. collar) provided an effective nighttime target for motorists. Smaller amounts of material (e.g., 6-in. collar) result in diminished nighttime performance and larger amounts show very minor improvements in effectiveness. In general, optimized cones were as effective at night as other devices.

In the field evaluation task, cones were placed along the tangent section only, with the results indicating they affected flow about the same as the other devices.

Taken together, these findings suggest the following application guidelines for the use or nonuse of cones as a channelization device.

To afford maximum effectiveness, cones should be as large as practical. Although 18-in. cones may be suitable for low-speed applications, cones at least 28 in. and preferably 36 in. high should be used on high speed facilities.

During the day, cones are an acceptable channelization device for all types of work zone applications. However, in the taper or approach area of high-speed highways, it is advisable to use either supplemental signing (e.g., the W1-6 sign), a flashing arrowboard, or other types of high mast alerting devices (*24*) (This latter comment really applies to all the channelizing devices.)

Cones should be used at night in taper and tangent sections only if adequately reflectorized. This means two or three bands totaling 150–200 in.^{2} (75–100 in.^{2} visible to driver) of at least SIA = 250 reflective material. Even higher brightness materials (e.g., polycarbonate) enhance driver response characteristics and are preferable. A yellow/amber color with considerable red saturation outperformed the white material. This amount of reflective material can be left on the cones all the time and not adversely affect daytime driver response.

Tubes

Tubes, most frequently referred to as post or tubular cones, are used for day and night operations and especially where space between the travel lane and the work area is a premium.

In this study, 18-in., 28-in., and 42-in. posts were studied in the controlled field experiments and one application of 42-in. tubes was evaluated in the field evaluation task. In the daytime the 28-in. and 42-in. tubes elicited responses similar to cones and other devices. The 18-in. tube had significantly lower performance and is not recommended for lane closures or diversions on high-speed facilities.

A 28-in. or 42-in. tube at night with 12 in. of SIA = 250 or greater reflective material (white or yellow) in a single band mounted high or low performed comparably to cones and as well as, or better than, other device types.

The results of the field evaluation experiment in which 42-in. tubes were used on the tangent section did not indicate that they were any better or worse than the other devices tested.

The results of this study suggest that tubes are generally interchangeable with cones and are particularly useful where space between the work zone and travel lane is limited.

Drums

Drums, especially the 55-gal steel drum variety, are used frequently for long-term work zones. Their large size provides good target value and long visibility distances. Because of their size and shape, they present a formidable obstacle to the motorist. However, when they are hit, they can become dangerous objects themselves, especially to the roadside workers. For this reason, more use is being made of plastic, simulated drums.

The drums that were tested in this project were made of a polyethylene material and were 36 in. high with alternating 8-in. bands of reflectorized orange and white stripes. The results of the controlled field study support the advantages of these devices. They were observed to be highly visible and detectable from long distances, both day and night. They also promoted lane changing further upstream of the channelization system and resulted in speed reductions along the devices.

For these reasons drums should be considered as a suitable channelization device in work zones. However, full surface reflectorization with alternating stripes of orange and white is recommended.

Vertical Panels

Although the MUTCD suggests that panels be used for traffic separation or shoulder barricading where space is at a minimum, they have been used as a substitute for Types I and II barricades in several situations.

In this project, vertical panels were tested in the laboratory in the controlled field study and in the field evaluation study. The results of laboratory experiments revealed that in terms of shape, the vertical panel is somewhat superior to the barricade on the basis of detection and also that the tall narrow shape is better than a shorter, wider device. These findings were not conclusive, however, and it was recommended that further testing be performed using the devices in an array.

The finding of the field evaluation study (which used the 12-in. × 24-in. panel) indicates that the vertical panel was equally effective as the 12-in. × 24-in. Type I barricade and in some instances promoted earlier lane changing.

These findings support the use of the vertical panel as an acceptable channelization device for all situations. However, the findings of the detection study indicate that the minimum width dimensions of the panel should be 12 in. rather than 8 in., especially if used at night and on high speed facilities. Perhaps a standard 12 in. × 24 in. or 12 in. × 36 in. size should be adopted for use in panels and barricades.

Barricades

Barricades, especially the Type I and Type II, rival the cone as the most frequently used channelization devices for work zone traffic control. Many engineers believe it is the primary device because it has good target value both day and night, is easily portable, and provides an easy mount for signs and warning lights.

Different sizes and configurations of barricades were tested in all three experiments—laboratory, field controlled, and field evaluation. The results of the laboratory experiment showed that there was no clear-cut distinction between a Type I and Type II barricade in terms of detectability. This finding led to further testing in the controlled field study which examined both Type I and Type II barricades with 8-in. × 24-in. panels and 12-in. × 36-in. panels. The results of those studies were that the one-rail 12 in. × 36 in. was equivalent to the two-rail. However, the two-rail 8 in. × 24 in. was superior to the one-rail version in that size. This study also found that the 12-in. × 36-in. barricade was far superior to the smaller size 8-in. × 24-in. barricade. It had longer detection distances, earlier lane changing, and reduced speed through the array.

In the field evaluation study, a Type I with 12-in. × 24-in. panel was used. It was used as the base condition against which other treatments were tested; and, on the basis of the results obtained, it served that purpose quite well. In many instances, the performance measures obtained for the Type I barricade were between those for other devices; in no case was the Type I barricade's performance worse.

These findings provide the basis for the following recommendations concerning barricades.

A Type I barricade is an acceptable channelization device for work zones both day and night in the larger sizes (i.e., 12-in. × 24-in. to 12-in. × 36-in. range). There appears to be no advantage gained from using a Type II barricade unless smaller size barricades (i.e., 8 in. × 24 in.) are used; then two rails offer a distinct advantage.

On high-speed facilities, the minimum rail dimension for a Type I barricade should be 12 in. × 24 in. with a preferred length of 36 in. where space permits.

Type III barricades were not studied in this project because they are not considered to be a channelization device; however, they are recommended for road closures and similar situations where entry is restricted or prohibited.

Steady-Burn Lights

One of the specific objectives of this study was to determine the need and applications for use of flashing and steady-burn lights in work zones. The flashing lights were never evaluated in this project because they are not, and should not be, considered as a channelization device. Their use is more appropriate to spot locations off the travel lane (e.g., a culvert repair on the shoulder should have a channelization system which guides the motorist away from the hazard area).

Steady-burn lights provide additional delineation of a channelization system during the night. (It is assumed and recommended that all channelization devices be reflectorized or self-illuminated so that they provide their own nighttime delineation.) Although always thought to be effective delineation devices for work zones, they are subject to battery life and replacement constraints.

Steady-burn lights vs. sheeting was examined in the controlled field portion of this project. Steady-burn lights were used in the field evaluation study, but for all device types during the night, thus no light–sheeting comparison was possible from the operational test.

The findings of the closed-field study emphasize steady-burn light effectiveness. Compared to the other types of devices and retroreflective materials tested, steady-burn lights afforded the longest detection distances. Also, because of their long detection distances, steady-burn lights promoted early lane changing.

Another advantage of the steady-burn lights is that because they are self-illuminated, they are not dependent on the light of the vehicle and the observation angle of the observer as much as retroreflective devices.

Given their effectiveness, it is suggested that steady-burn lights be used at night whenever feasible. Because their main advantage lies in their long detection distance, they are suited for tapers in the transition areas. They are suitable also for tangent sections, but can be spaced at longer distances than the devices on which they are placed (alternate device spacing). Their use does not eliminate the need for reflectorization of the primary channelization devices, however.

DESIGN PARAMETERS

Thus far, this chapter has dealt primarily with the various devices without regard to the design parameters unique to a particular device or for all devices. In this section, the findings related to stripe width, stripe configuration, color ratio, size, reflectance, height-to-width ratio, and device spacing are interpreted to provide application recommendations.

Stripe Width

The investigation of device stripe width was conducted during the laboratory studies. Stripe widths were scaled to the same proportions as 4-in., 6-in., and 8-in. barricade stripes. Each width appeared in all four of the stripe configurations (horizontal, vertical, sloping, chevron) as well as on the bar and panel shapes.

The 4-in simulated width was found to be clearly inferior to the 6 in. and 8 in. The 8 in. was generally the best in terms of detection, although not significantly so from the 6 in. Thus the 6 in. is acceptable for continued use as the standard width, although the change to 8 in. could be advocated wherever feasible.

The only application of 4-in. stripes for field use is on barricades or panels less than 24 in. wide. In the controlled field study findings, the performance of these smaller devices was generally found to be inferior to larger devices. In regard to stripe width, then, because a larger device is advocated for better overall performance, it is recommended that the device be at least large enough to accommodate 6-in. stripes. Cottrell (*24*) independently arrived at a similar result based on operational field tests.

Stripe Configuration

Variations in stripe configuration (horizontal, vertical, diagonal, and chevron) were examined in the laboratory, controlled field, and field evaluation studies for different device types. The conclusions regarding the stripe configuration are dependent, to some extent, on the device type. In general, however, the findings can be interpreted to indicate that there is not much difference between the stripe configurations of horizontal, vertical, or diagonal during the daytime. The direction of the diagonal is irrelevant to device detection and does not convey any directional meaning to the motorist. The chevron pattern is more difficult to detect in daytime, but conveys a directional meaning which other patterns do not. At night the detection of the devices with a chevron is the same as for other devices.

These conclusions provide the following recommendations concerning stripe configuration for each device type.

For cones, two or three bands of white or yellow reflective material totaling 150–200 in.^{2}, 3–4-in. minimum between bands, are optimum at night and do not degrade daytime performance on 28–36-in. cones. For drums, alternating horizontal (circumferential) stripes of orange and white are recommended. With respect to barricades, retain the current diagonal stripes, but further experimentation is warranted for both vertical and chevron stripes. For vertical panels, use either horizontal or diagonal stripes, and further experimentation with the chevron is warranted. A single 12-in. band of white or yellow reflective material is recommended for tubes.

The chevron pattern for both barricades and vertical panels is appealing particularly for taper and transition areas where a direction message needs to be conveyed to the motorist. The proper placement of the devices containing the chevrons is vital because the directional meaning is part of the information being given. However, before widespread use is made of this pattern, further research and development are necessary to improve its detection and recognition qualities.

Color Ratio

The ratio of white-to-orange was studied only in the laboratory setting. It appears that for any given situation of background luminance as construed by varying background contrasts (light and dark) and stripe size and configuration, there is an optimum white-to-orange color ratio. However, the finding of the laboratory experiment tends to support the current standard of equal white-to-orange regardless of the device type. This ratio is simply a result of the tradeoff between better contrast during the day with orange and during the night with white. It is recommended, therefore, that the 1:1 ratio be retained with exceptions allowed only for devices that require a different ratio for optimum detection day and night.

Size and Height-to-Width Ratios

In the laboratory a taller and narrower shape was more detectable than a shorter and wider device. The closed-field study had only two different ratios, but in different sizes. Clearly, size was the controlling parameter. Therefore, height-to-width ratio does not appear to be a useful way of specifying devices.

From the closed-field data, it is evident that size is a controlling factor, particularly in eliciting speed reduction in the daytime. At night, total reflectorized area and brightness (or contrast) were the predominant variables. In light of these findings, minimum height and width specifications are recommended instead of height-to-width ratios. These are: (1) panels—12-in. width minimum, and 24-in. height minimum with MUTCD recommended panel clearance from the ground; (2) barricades—12-in. minimum rail width, and 24-in. rail length with 36 in. preferred on high speed facilities; (3) drums—36-in. high reflectorized (orange and white stripes); (4) cones—28 in. or 36 in. for high-speed facilities; and (5) posts/tubes—28 in. to 42 in. total height for lane closures and diversions.

Reflectance

Although most devices were tested with Type II (engineering grade) sheeting, use of Type III (high intensity—SIA ≥ 250) substantially improved driver response under certain conditions, namely at straight, flat sites. Where vertical or horizontal curvature was present, the impact of the high intensity was greatly diminished. Thus the practice could be to use Type II (engineering grade) sheeting as a minimum at all times. However, the advantages of Type III may be beneficial in certain situations and should be carefully considered. Where there is any curvature, however, steady-burn lights should be used to supplement the reflective material.

Spacing

The final design parameter is the spacing of the devices, which was examined in both the controlled field and field evaluation studies. As with stripe configuration, the optimum spacing is somewhat dependent on device type. What may be suitable spacing for a large drum may not be appropriate for a small cone. Unfortunately, this study was not able to ferret out the optimum spacing for each device type. However, the results of the two studies tend to support the MUTCD standard of speed limit spacing, at least for 55-mph facilities. Although not statistically different, devices placed at 110 ft tended not to perform as well as when they were placed at 55 ft. In the closed-field study, it was observed that when devices were placed at one-half speed limit spacing (27½ ft), they produced a speed reduction at night, apparently from the illusion that the motorist was going faster than he really was.

From these findings it is recommended that all devices be placed at speed limit spacing for most conditions and, in all cases, along the taper or transition section. If there is no construction work or hazards in the closed lane for a substantial length, or traffic delays, the spacing can be increased to no more than twice the speed limit. Shorter spacings may prove to be useful where speed reduction is desired. Variable spacing for curve sections was not examined in this study; however, longer or shorter spacings may be desirable depending on the direction and degree of curvature.

Summary of Design Parameters

To conveniently summarize the design applications, Table 17 presents a matrix of devices by design parameters.

Table 17. Summary of recommendations for use and design of channelization devices for freeway operations.

Device	Application Guidelines	Minimum Dimensions	Stripe Configuration	Color	Minimum Stripe Width	Spacing
Cone	• Interchangeable with other devices • Applicable for all work zone situations	• 28" or greater for high speed facilities	• 2 or 3 bands totaling 150-200 in^2 of SIA-250 (preferably higher) reflective material*	All orange cone yellow or white reflectorization	N/A	MUTCD
Tubular Cone	• Interchangeable with other devices • Applicable for all work zone situations	• 28" or greater for lane closures or diversions • 4" diameter	• 1 band—high or low mounting of same material as cones	All orange tube yellow or white reflectorization	12"	MUTCD
Barricades	• Applicable for all work zone situations • Type 1 suitable for all channelization situations	• Rail—12" wide 24" long • Height—MUTCD	• Diagonal, but not to be used to convey direction • Consider chevron to convey direction	1 orange to 1 white	6"	• MUTCD • ½ SL in taper and double speed limit acceptable in tangent area where no work activity or traffic delays
Vertical Panels	• Interchangeable with other devices • Applicable for all work zone situations	• 12" wide • 24" height • Ground clearance—MUTCD	• Diagonal or horizontal • Consider chevron to convey directional change	1 orange to 1 white	6"	Same as barricade
Drums	• Interchangeable with other devices • Applicable for all work zone situations	• Same as MUTCD	• Horizontal	1 orange to 1 white	6"	Same as barricade
Steady-Burn	• Should be used at night whenever feasible • Especially effective for tapers and approach ends • Use in visually noisy environment 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

*75-100 in^2 visible to the driver.

The specific design and use recommendations indicated by the research findings of this project comprise the entries in the matrix cells.

PERFORMANCE MEASURES

The three types of experimental work conducted in this project used a variety of dependent variables. This section discusses the usefulness of those measures.

In the laboratory studies the combination of search and detection tasks resulted in location, shape, and pattern identification accuracy measures. These were sensitive to the design parameters tested.

A total of 13 dependent measures were taken in the closed-field experiments. Those found to discriminate between devices while having some operational meaning were: speed change from taper to tangent sections, point of lane change (mean and variance), array detection distance (mean and variance), displacement (weaving) in the tangent, derived measure, decision sight distance criteria (see Table 13 for brief explanation), and driver performance.

Measures such as steering wheel position and rate, brake applications, absolute speed, and throttle–pedal position did not discriminate between devices.

Four measures were used in the field evaluation study. Speed profiles did show differences between treatments. Speed variance was a useful adjunct to mean speed profiles. Two profiles could be virtually identical but could have very different speed variance characteristics which change the meaning of the findings. Lane changing was as effective a measure in the field as it was in the closed-field setting. Erratic maneuvers and traffic conflicts appeared to be of questionable value. Coder variability could account for the differences found in the data collected, and analytically there is little reason to suspect that relatively minor variations in channelizing devices would result in major swings in conflicts.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Channelization devices are just one item, although a very critical one, of several types of traffic control devices which collectively are used to alert drivers of impending conditions, warn them of hazards, and guide them through the proper path. Channelization devices are a particularly critical component because they should serve several functions. First, they should help to alert the driver of a potential hazard or an unexpected change in roadway alignment ahead. Although signing and other devices are primarily used for this purpose, the initial channelization devices should serve this function as well. Second, they should provide both near and far delineation of the path which the motorist should take to avoid the work zone hazards. Motorists should be provided with as much advance information as possible as to "where the road is going" so they can adjust their speed and path accordingly. Once into the work zone, motorists need near delineation of the travel lane, also provided by channelization devices, for maintaining safe speed and path and for delineation of the travel way further downstream.

Third, channelization devices should provide protection for the workers in the construction zone. Most channelizing devices cannot keep an errant vehicle from penetrating into the work zone and possibly hitting workers or machinery. However, when they perform their primary functions properly (i.e. alerting and defining the path for vehicles) they can serve the function of a protective device.

Because channelization is so critical to a safe and efficient traffic control plan for work zones, it is imperative that the devices used are those which provide the best guidance for the driver and protection for the worker. There are many types of channelization devices and design variations that are being used (and misused) throughout the country. This project was aimed at providing data to support principles regarding the design and use of channelization devices which would lead to better standardization and maximum effectiveness. The general conclusions obtained from this research are set forth in the following.

1. In general, there is no one type of channelization device or design which provides maximum effectiveness for both day and night conditions. In fact, some devices are equally effective and should be considered interchangeable. Barricades, drums, vertical panels, cones, and tubes, when designed properly, all perform the function of channelization adequately both day and night.

2. There appears to be sufficient equivalence between the larger versions of each device category that only a small variety of device types needs to be available. For example, if panels are used, barricades are not required. Further, diagonal, horizontal, or vertical stripes convey no consistent directional information. There appears no reason to have a diagonal stripe pattern for left and right "sidedness." However, only one direction of diagonal should be allowed in an array so there is always a consistent pattern or image on devices. Standardization of panel and barricade size and configuration would be economically and logistically advantageous.

3. Regardless of the device, each type obtains its maximum effectiveness when properly deployed as a system or array of devices. Motorists do not respond to a single channelization device, but to the path that is defined by the array. Therefore, it is important that care be taken in the layout of these devices as well as the selection of device types.

4. The approach-end taper treatment of a channelization system must be detectable at a distance sufficiently long so that the motorist can adjust his speed and path in a safe and efficient manner. Therefore, devices used along tapers and transition areas should be those which provide maximum conspicuity day and night. Although alternate channelizing devices (barricades, panels, drums, cones, and tubes) can be used to achieve this, they should also be kept clean, be reflectorized, and be properly displayed with regard to taper length and spacing. At night, steady-burn lights, if maintained properly, can enhance the conspicuity considerably, particularly in the presence of horizontal or vertical curvature.

5. The study of channelizing devices as separate entities is relatively unproductive, particularly in an operational setting. The behavioral response differences are generally small. In an operational work zone the other information and traffic inputs mask any differences between channelizing devices. A work zone should be studied as a total information system especially in full field settings.

6. There are behavioral differences drivers bring to work zones (e.g., late lane changes). Current devices do not influence their behavior. Although further work on trying to create guidance systems to modify their behavior is possible, the option is to accept them as a given in the highway system and to design with them in mind.

7. The evaluation of channelizing devices, and probably other work-zone traffic-control devices, cannot be entirely conducted by any one experimental procedure and by any one performance measure. Evaluations must be tailored to specific objectives. Design parameters must be studied in a controlled environment and should include detection, recognition, and preference as well as driving performance measures.

RECOMMENDATIONS FOR FURTHER RESEARCH

With the completion of this project, three general areas emerge as requiring further research.

First, channelization devices are not used as separate entities unaffected by other components within the work zone. The interworking of these various components should be examined from a total information system point of view. Specifically, the following is recommended:

1. Define the information role of all devices or markings used in a work zone.

2. Then determine what role channelizing devices play within that system. For example, if a channelizing device is simply to form a visual path for driver guidance, there is no need to symbolically convey directional information (i.e., with arrows, chevrons, etc.). However, if directional information is to be conveyed, even secondarily, appropriate messages should be included.

3. Consistent meanings should be attached to various symbols or devices and guidelines should be prepared for their use. Different types of work zones have slightly different information requirements. The symbols used to convey these distinctions must be defined and used consistently. Thus, a chevron may be used to convey that a change in direction is required. However, directional change is only required in the taper of a lane closure. A chevron pattern may not be appropriate along the straight tangent section where a straight path guidance is required. In a lane diversion, the directional change may be a fairly long curve across a median. Arrows, chevrons, and so on, may be appropriately used to convey the directional diversion. The point here is to establish a single meaning, especially for symbols, then not violate driver expectancy.

4. Determine the desired behavior profiles through various types of work zones. In this project, assumptions were made that speed reduction along the tangent is a desirable behavior. That may not be totally correct. Issues such as speed profile, lateral placement, and zone of lane changing need to be resolved so existing devices can be selected which foster "correct" behavior, or new devices can be designed which more emphatically elicit these behaviors.

5. Evaluate the interactions of the various information components. What impact does advance signing have on channelizing device effectiveness? To what degree can directional information be provided by advance signing and marking instead of channelizing devices?

A second area which can be further studied is the extension of the design optimization studies performed in this project. Although very specific design specifications were advanced, additional work is recommended. This includes:

1. Recognition of device configurations, if meaning is to be conveyed, must be improved. This is particularly true of chevrons in the daytime and all patterns at night. Array detection as used in this project did not imply recognition. Research on recognition distance and the source of recognition (e.g., from symbols themselves, shape of the device, or alignment of devices in array) is needed.

2. This project was aimed at urban and rural freeway roads. Clearly, verification of findings in this study for urban and suburban high visual noise setting is important. Also, the impact of weather conditions was not part of the scope of this project. Even so, a small number of instrumented car runs were made in the rain. The observed behavioral differences were sufficient to suggest that further verification of device design in poor visibility conditions is warranted.

The third area of research concerns deployment and maintenance. Correctly designing work zones, properly setting them up, and then maintaining them are, currently, most critical needs for improving the safety and efficiency of work zones. Guidelines and/or training which imparts the ability to judge the adequacy of a channel and the importance of device maintenance need to be generated.

CHAPTER FIVE

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APPENDIX A

LITERATURE REVIEW

INTRODUCTION

Appendix A contains the results of Task 1, Literature Review, of NCHRP Project 17-4, "Evaluation of Traffic Controls for Street and Highway Work Zones." This discussion is intended to be used as a reference data source for the remaining tasks of the project.

On the basis of the project objectives, four literature content areas were reviewed: (1) accidents in highway work zones, (2) use of traffic control devices in work zones, (3) effectiveness of traffic control devices in work zones on driver performance, and (4) driver performance measures. For each of these areas, the libraries of BioTechnology, Inc., and the Midwest Research Institute were searched. Where the literature on a topic was not complete, a computer search was done. Three searches were conducted, as follows:

Search	Purpose	Literature Base Searched
Driver perception and information processing	3-year update	TRIS* and APA**
Construction zone traffic control devices	3-year update	TRIS
Traffic hazard and accidents in construction zones	3-year update	TRIS

*Transportation Research Information Service
**American Psychological Association

To supplement the foregoing searches, requests were made for reports from selected Federal, state, and city traffic engineers who had studied traffic control devices in work zones. Finally, as documents were acquired, bibliographies were checked for references as yet uncovered in the search efforts.

The genesis of the study area of the project arose from the recognition that work zones apparently divert the attention of the driver from his normal driving task and thereby constitute a potential hazard. Given this hazard situation, the possibility of roadway accidents exists and, in fact, accident data reveal that many work-zone-related accidents do occur causing injury to motorists, pedestrians, and workers, as well as to machinery and equipment. The emphasis in this project is an examination of the use of certain traffic control devices that warn and channelize traffic about and through these zones. In recognition of the apparent hazard potential of the work zone, the question is how these devices may expedite or hinder the driver's task of successfully negotiating the zone.

In approaching the problem, pertinent literature was reviewed in a step-wise progression, leading to the need to experimentally evaluate the appearances and uses of the devices in controlled and real-world settings. Thus, four topic areas of the literature were analyzed: (1) accident data and studies in work zones, (2) use of traffic controls in work zones, (3) current status of effectiveness of traffic controls in work zones, and (4) driver performance measures to find measures to evaluate the driving task as applied to driving through the work zone.

The first three areas are covered under the heading "Literature Summaries." Here are found, in each subject area, the reference citations (in alphabetical order) and a summary of findings for each. Also included are an accumulation and review of documents concerning accidents in work zones and, more specifically, whether or not these are related to use or effectiveness of traffic control. In some cases, number of accidents is used as a measure of effectiveness. The report summaries detail current use of traffic controls as reported in the literature. This documents current practice out on the roadway today. A compilation of document summaries of findings about the effectiveness of various traffic controls on driver performance consists of research studies or observational study of traffic related to work zones and/or traffic controls in work zones. The fourth area of the literature research constitutes a broader look at driver performance and the driving task to extract from pertinent documents measures that may be used to experimentally evaluate the effects of traffic controls in work zones. This discussion considers how these measures were located (from what types of sources) and bridges the gap between the literature base presented as the status quo on the zone and the need to further research the problems and gaps encountered (Tasks 2 through 6 of the project). The end product of the search for performance measures is a table listing (Table A-1) of candidate measures and their projected suitability for laboratory or field study.

The next section presents all of the documents reviewed for the topic areas presented earlier in a Subject By Reference Matrix (Table A-2). The format and use of this matrix is discussed immediately preceding its presentation.

The final section of this appendix lists the manuals on uniform traffic control devices which were reviewed. The information derived is presented in the body of this report in which the literature findings are synthesized.

The complete references of the works cited in the following pages of this appendix are given in the bibliography included in Chapter Five of the report.

LITERATURE SUMMARIES

Accidents in Work Zones

Andrews, J. F. (1967). In this work four fatal accidents in maintenance crews within one year caused a special investigation of each accident. In three of the accidents the passing traffic, for reasons unknown, left the traveled way and plowed into the work areas. Negligence of maintenance employees was a major factor in two of the accidents.

Biggs (1975). This study indicates that incidents (accidents and stalls) should be planned for to allow rapid removal and recovery of traffic flow. Consideration should be given to organizing a special group with the major activity of providing for traffic handling around maintenance activities on urban freeways.

Byrd, Tallamy, MacDonald, & Lewis (1975). National Safety Council (1972) work injury data includes a rate of 17.5 work injuries per million man-hours for state highway employees, a rate of 15.0 work injuries per million man-hours for construction employees and an all industry rate of 10.1 injuries per million man-hours. Work injury data for municipal employees includes a rate of 53 work injuries per million man-hours for street and highway maintenance work and a rate for all functions of 31 work injuries per million man-hours.

Center for Auto Safety (1977). As FHWA has noted, "accident statistics consistently show an increase when traffic is maintained through construction zones." This increase is generally associated directly with problems peculiar to construction areas.

Frick (1972). New standards in Illinois for traffic control for work areas resulted in a 33 percent decrease in accidents per job site in the first year.

G.A.O. (1977). General Accounting Office's review of construction zone safety in seven states—Louisiana, Mississippi, Missouri, New York, Ohio, Texas, and Washington—revealed widely varying safety deficiencies at the 26 sites visited.

Graham, Paulsen, and Glennon (1977). This study shows that in both the before-during construction accident number analysis and the before-during construction accident rate analysis there was a slight shift in accident severity toward property damage only accidents. The proportion of night accidents to the total number of accidents remained relatively constant in both the accident number and accident rate analysis.

Multiple regression analysis indicated a strong correlation between types of traffic control devices and construction fixed object accidents.

Accident rate increases for the construction zone control status categories of Stationery (12 projects), Temporary—moving weekly or monthly (45 projects), and Temporary (moving hourly or daily) (18 projects) were +18.0 percent, +10.0 percent, and +0.6 percent.

The before-during construction accident number increased by 7.5 percent but the number of fixed object accidents increased by 38.9 percent.

The number of barricades should be minimized to reduce fixed object accidents.

Hatton (1970). In 1969, Arizona experienced 278 accidents of a construction and maintenance nature involving 18 fatalities. Various spacings for traffic control devices are specified as a minimum standard for construction and maintenance work.

Juergens (1972). A 1965 study of construction zone accidents in California revealed a 21.4 percent accident rate increase during construction and a fatal accident rate increase of 132.4 percent.

In 1970, after many new principles for construction zone traffic control were put into practice, the total accident rate increased only 7 percent and the fatal accident rate increased only 1.6 percent.

Barricades are inherently fixed object hazards. Therefore, they should not be used unless the construction hazard the motorist may encounter is greater than the hazard of striking the barricades. They should not be used as primary delineation to guide traffic.

Kahm (1974). In 1973, there were 579 traffic accidents in construction areas and detour routes on the Colorado State Highway System. In 1972, there were 659 accidents in similar areas. Seven persons were killed in the 1973 accidents, and 17 were killed in the accidents occurring in 1972.

Lee (1969). Analyses of accident records in District 7 California Division of Highways reveal that fewer accidents occur during night construction periods than during ordinary nights. Success in lowering night accidents was attributable to 2,000 ft tapers versus 1,000 ft normally used and illuminated traffic cones.

Lisle, Reilly, and Beale (1976). With due consideration of the effects of the energy crisis, the frequency of accident occurrence on I-495 during construction was 119 percent higher than the frequency during a preconstruction baseline period. Although the increased frequency of accident occurrence was experienced along the entire length of I-495 during construction, high concentrations of accidents were noted at interchanges and transition zones.

The amount of estimated property damage per accident during the construction study period increased 41 percent, rising to $1,364, compared to the before construction baseline figure of $965.

There were shifts in crash distributions during construction toward crashes involving property damage only, fixed objects, and impaired drivers. Also there was a greater percentage of accidents during the hours of darkness.

Mason (1970). Accident records from three sites in the San Francisco Bay area indicate that the construction site may divert the attention of the driver.

Migletz (1977). Accident rates increased from before to during construction and decreased from before to after construction.

Single vehicle fixed object accidents contained a significantly high proportion of accidents involving construction equipment, and these accidents primarily involved drums.

For the during construction period, single vehicle fixed-object accidents are less severe than other types of accidents.

Eighty-four percent of the accidents occurred while single lane closure traffic control procedures were in effect. Others occurred under shoulder closure or no closure conditions.

Ohio DOT (1973). Case studies were made of two fatal injuries in a work zone. In one accident a worker was killed by an errant vehicle that did not have functioning brakes. Factors in this accident were stationing of the flagman too near the crew and lack of a device for the flagman to warn the workmen of a dangerous vehicle. In the other accident a worker was backed over by a truck and killed. Factors were poor physical condition of the worker and insufficient care by the truck driver.

Rowe (1975). Studies have shown that in most construction zone accidents, the driver received neither visual stimulation nor sufficient warning and was unable to avoid the accident.

Construction zone safety may be achieved by improvement of driver visibility, proper illumination of work crews, safer work procedures in and around work sites, and legislation requiring mandatory compliance with various safety precautions.

Russell (1969). This study provides information that in one freeway project it was necessary to shift traffic from one freeway roadway to the other a total of eight times. The only delineating devices used were combinations of rubber tubes and rubber cones, with and without reflective assemblies. During the life of the project the roadway had a lower accident, injury, and fatality rate than it did the year before construction started.

Transportation Research Board (1974). Although accidents to maintenance workers are comparatively infrequent, occasions do arise when vehicles in lanes adjacent to the work areas go out of control and hit construction equipment and workers, despite warning signs and traffic cones placed before and around the work site.

Use of the new crash cushion trailer developed by the Texas Transportation Institute has resulted in doubled productivity by maintenance crews because they can concentrate on their work without having to watch for traffic.

Traffic Safety (1974), "California Takes Steps to Reduce Its Road Worker-Motorist Accidents." From 1971 to 1973, the California Department of Transportation had five of its highway maintenance men and ten construction workers killed in motorist-related accidents.

A task force studying this problem recommended that CALTRANS develop a safety information system that would allow the department to quickly retrieve accident data and alert it to problem areas.

The Use of Traffic Control Devices in Work Zones

Armour (Undated). This manual outlines the traffic control measures to be employed by public and private organizations when temporary disruptions of traffic are necessary for street repairs, public utility work, or similar projects. Details are given on the use of cones, lamps, signs, signals, and road layouts for the control of traffic under these circumstances.

The use of paint or asphaltic liquids was not found to be effective as a means of pavement marking obliteration on all highway construction projects, and their use was discouraged. Where mechanical means of marking removal were employed to completely remove the marking and its reflectivity, paint of a color matching the pavement surface or used crankcase oil may be used, if necessary, as a means of covering contrasting pavement texture.

Where pavement markings have been obliterated, nighttime inspections are needed to verify the continued effectiveness of the pavement marking pattern.

Where temporary pavement strips are required, a product such as removable tape may be used in lieu of paint, where appropriate.

Beecroft (1977). This study is an evaluation of the use of raised pavement markers as a means of controlling traffic through construction areas.

Biggs (1975). A check of traffic volumes on Houston's freeways revealed that very few selections were capable of handling the excess demand created by lane closures needed for maintenance operations. Two methods were used to reduce the demand through the work zone; upstream entrance ramps were closed and traffic in the outside lane was removed to a frontage road prior to the work zone.

In this maintenance operation, where the two inside lanes were closed, traffic on the outside lane was routed over a temporary ramp to a frontage road. The other two lanes of traffic were merged to the shoulder and outside lane until past the work zone.

Policemen, especially dressed flagmen, standard warning signs, special message signs, cones and arrow boards were used to direct traffic around and through the work zone.

The author believes that special, creative signs are needed to capture drivers' attention because of visual interference about them.

The use of mobile signs should be required to minimize the time needed to set up traffic control devices.

Brunner (1977). The objective of this study was to evaluate the use of raised day/night relfective pavement markers as a means of providing improved delineation in construction zones.

Byrd, Tallamy, MacDonald & Lewis (1975). Example problem areas in traffic control include inadequate delineation/guidance and ambiguous pavement markings. A need exists for improvement in devices and uniformity: (1) use of cones and tubes (to guide motorists through hazardous areas, cause a minor impedance to traffic flow); (2) use of drums (at sites of longer length, generally used to delineate a zone, give the appearance of a more formidable obstacle); (3) use of barricades (present a more formidable obstruction than cones or drums, give a good target value, close off work area, can be used to mount signs and warning lights); (4) use of vertical panels (where space is at a minimum, for traffic separation, shoulder barriers); (5) use of delineators (to guide motorists through hazardous areas, to indicate horizontal and vertical alignment of roadway, to outline intended vehicle path during hours of darkness); (6) use of pavement markings (to guide motorists through hazardous areas, markings which no longer apply must be covered, obliterated, or removed); and (7) spacing of channelizing devices in feet should equal speed in mph.

Crumpton (1977). This study is an evaluation of the use of raised pavement markers as a means of controlling traffic through construction.

Chipps, Doyle, Franklin, and Kuykendall (1976). This study provides information that may be useful to governmental jurisdictions and other agencies in implementing uniform control and safety measures at construction and maintenance sites. Its application is directed toward both urban and rural worksites. Special attention is devoted to urban operations. Suggested traffic control procedures are presented for general and specific traffic conditions. The necessary traffic control devices are described. Twenty-one typical worksite setups depicting common conditions are illustrated. Information on such areas as advance planning, public information needs, project management, training, and recordkeeping are covered.

This study developed three separate volumes. Volume I, Project Report, is a presentation of the stewardship of the data, and information collection and development phases of the study. It describes the data collection methodology and the general findings.

Volume II, Office Functions, contains information that will be useful for "office" personnel engaged in determining traffic controls at construction and maintenance worksites.

Volume III, Field Functions, contains information that has been written and produced in an innovative and informal style to readily assist "field" personnel in their objectives of providing adequate traffic controls and safety in the general work area.

Federal Highway Administration (1974). In maintaining two-way traffic on an interstate bridge structure in Ohio, the contractor was required to install tubular-type traffic cones at 100-foot intervals along the bridge deck. After opening the bridge to traffic, the tubular cones were also added to both approaches to the bridge.

On the Dan Ryan and Calument Expressways in Chicago, 3,500 to 4,000 Type II barricades were used to separate traffic from work areas. The barricades were spaced 100 ft center-to-center, except that lane tapers and lane transition barricades were spaced at 50 ft. All median crossover barricades were spaced at 10 ft center-to-center. Seventy to one hundred barricades per day were destroyed in this project. Plastic barricades did not remain upright in warm weather.

The use of 55-gal drums as traffic control devices proved to be very effective in guiding traffic through construction areas in Ohio. In one resurfacing project, drums used in conjunction with barricades with attached steadily burning lights, signs, and flagmen were used to delineate the roadway from the construction area.

Federal Highway Administration (1975). This notice from FHWA creates an awareness of hazardous highway conditions that may result from inadequate removal or obliteration of inappropriate pavement markings, and recommends desirable practices. Acceptable methods of pavement marking removal include: sand blasting using air or water; high pressure water; steam or superheated water; mechanical devices such as grinders, sanders, scrapers, scarifiers, and wire brushes; and solvents and chemicals.

Federal Highway Administration (1977). This notice provides guidelines for the use of "Timber Barricade" traffic control devices. "Timber Barricades" are not approved for use on direct Federal or Federal-aid projects as a positive barrier at any speed. The use of these devices should be approved for delineating work areas only on an exception basis, and only for city street types of improvements where operating speeds of 20 mph or less can be expected. When positive barriers are needed to control traffic in construction zones, devices such as concrete safety-shape barriers and metal beam systems are recommended.

Graham, Paulsen, and Glennon (1976). This report contains state-of-the-art information on traffic controls in work zones. It identifies many specific problems and suggests some recommendations for improvement. Standard traffic control devices which are described include: signs, traffic signals, hand signaling devices, channelization devices, vehicle barriers and crash cushions, high level warning devices, lighting devices, and new devices. Maintenance of traffic control devices is also discussed.

Graham, Paulsen, and Glennon (1977). This report contains the results of two studies of construction zone traffic control; traffic accident analysis and speed reduction methods. The results relative to traffic control procedures used in construction zones included: (1) Enforcement patrols and lighted sequential arrow panels decreased vehicle speeds near where they were installed, but their speed reduction effect was only effective over a short length of highway. (2) Based on time-trend analyses, the initial period of construction zone traffic control was not more hazardous than the later periods. (3) Drivers adjusted speed and position based on the environment (geometrics of zone, lateral clearance, and devices) more than on signing. (4) Basic national standards for traffic control layouts in work zones were found to be often violated.

HRB (NCHRP Synthesis No. 1) (1969). Various approaches to the problem of providing proper traffic control devices for work performed by contract provide that they be (1) furnished and retained by the contractor; (2) furnished by the contractor but turned over to the highway agency upon completion of the work; (3) furnished by the highway agency on consignment to the contractor; (4) furnished, placed, maintained, and operated by the highway agency; and (5) furnished by a rental agency at contractor expense or at agency expense.

Where potential conflict with large volumes of freeway traffic is a prime consideration, night work has been employed to meet maintenance needs. This generally is accompanied by additional signing and lighting at the work site, as well as reflectorization of all work site signs. Electric lights placed under translucent plastic traffic cones have been used for additional nighttime delineation of the work zone. Successful emergency traffic control procedures require the ready availability of suitable traffic control devices and the prearrangement for emergency duty of qualified personnel. Electronic equipment and computer coordination offers additional opportunities for emergency planning.

On shoulder work sites, the adjacent lane is sometimes closed or a short cone taper is used to barricade the shoulder and additional cones are placed along the pavement edge to delineate the work area. For recovery area work sites most agencies use a single warning sign immediately ahead of the work. Where work operations are located on the right-of-way outside of the recovery area (such as mowing operations) flags, signs, or flashing or rotating lights are used on the work vehicle. Some agencies also position signs at intervals along the shoulder or near the operation.

Barricades are used to protect the work site from traffic or to protect traffic from hazards within the work site area. Traffic cones are used for closing lanes and channeling traffic around or through work sites. Special sign trailers or trucks, equipped with vehicle-mounted generators, flashing or rotating lights, and storage areas for cones, flags, signs, and ground mounting devices, are frequently employed.

The most commonly used barricade devices usually follow the standards prescribed in the MUTCD with the following major differences: (1) Many agencies use a 1-in. rail instead of the 2-in. rail prescribed in the Manual, and several agencies use a 10 by 10 in. or 12 by 12 in. timber curb as part of the barricade. (Timber curbs have been found to be hazardous and are no longer allowed on Federal-sponsored projects and are not included in the MUTCD.) Unfortunately, the heavy curbed barricade often is used when only delineation is required, and where lighter barricades or cones would be safer. (2) Most agencies use traffic cones for closing lanes and channeling traffic around or through work areas. The knocked-over cone problem has been solved by one highway district by placing a used automobile tire, coated with reflectorized paint, around each cone. Another agency places lights under translucent plastic cones for night delineation of tapers and traffic lanes. The cones are also reflectorized to provide a fail-safe system. Mechanical equipment is also used by several agencies, both to place and to pick up cones at a reasonable rate of speed. Plastic barrier rails have been used with the 36-in. cones to provide light barricades for traffic lane delineation. (3) Pylons are used to replace cones for lane delineation and traffic channeling. The pylon's principal advantage is the small amount of lane space it uses, because its small base usually can be fastened to the pavement with an adhesive. (4) Both painted and adhesive pavement markings are used to designate temporary lanes at long-term work sites. They may replace or supplement traffic cones. Very few agencies elect to use painted temporary lines on finished surfaces because of the differences in pavement texture after the line has been removed. (5) Steel barrels are used on construction projects as both barricades and delineation devices. The maintenance organizations' use of barrels normally is limited to semipermanent lane closures and temporary lane drops. They are also used to channel traffic at points where the pavement ends.

Johnason (1977). The use of raised pavement markers as a means of controlling traffic through construction areas is evaluated in this project.

Juergens (1972). Two studies were made of construction zones to compare the accident rate during construction with the rate for the same portion of highway prior to construction. Results relating to traffic control procedures include the following: (1) Old pavement markings should be completely removed. (2) Where detours of asphaltic concrete paving meet diagonally with portland cement concrete, the longitudinal joint should be covered over with asphaltic concrete to reduce the contrast between the two types of pavement. (3) Barricades should not be used unless the hazard is greater than the hazard of striking the barricade. They should not be used as primary delineation devices to guide traffic. (4) Delineation devices must be maintained or they will become ineffective. (5) Too many signs may cause confusion and inattention.

Kessinger (1977). In this study, the use of raised pavement markers as a means of controlling traffic through construction projects is evaluated.

Lisle, Reilly, & Beale (1976). There is a need for a national standard to provide guidance in designing a system for the safe movement of traffic through construction zones. Functional criteria and guidelines are needed for the appropriate use and placement of cones, pylons, barricades, barrels, barriers, impact attenuators, etc. The choice of the timber barricades for use on I-495 was part of a good faith attempt to provide safety for both motorists and workmen. The use of timber barricades where no roadside hazard justified their use or where no construction activity was in progress was contrary to the principles set forth in the MUTCD.

The high concentration of accidents at interchanges and transition zones identifies those roadway locations where extreme care and meticulous effort must be exercised in the selection, use, and maintenance of the traffic control devices.

The timber barricades did not prove to be effective as positive barriers for the traffic conditions in the I-495 construction zone, inasmuch as 73.5 percent of the vehicles impacting the barricades straddled or penetrated them. Use of the precast concrete traffic barriers in place of the timber barricades on I-495 would reduce each of the traffic lanes by approximately 4 in.

Lynch (1977). The use of raised pavement markers as a means of controlling traffic through a construction project is evaluated in this study.

National Safety Council (1974). Some of the major sources of injuries resulting from the improper use of barricades and warning devices are: collision with construction equipment, collision with other vehicles, pedestrians falling into open excavation work, driving into work areas, driving into contractor personnel, and loss of car control because of minor road repairs.

The horizontal members of Type I barricades should be 8 to 12 in. (20.5 to 30.5 cm). The supports for the rails can be built of lumber, metal, or other suitable materials and shaped in the correct manner. In either case, the support should contain, at the correct height, a notch or loop into which the horizontal members are inserted. Rapid assembly and disassembly of this type is an essential ingredient. This barricade is usually found in 6 to 8 ft (approximately 20 m) lengths.

Type II barricades can be made of wood, metal, or other components and combinations. The supports are of the "A-Frame" type, or hinged to permit easy folding. This is to allow for stacking and convenient transport from location to location. Because this portability is of prime importance, the materials should be as lightweight as possible; yet they should provide the necessary strength and durability. (This type has a high center of gravity and is easily blown over. Sandbags, folded over the lower board, can provide the needed ballast.) The Type II barricades are usually used for a permanent location and, therefore, should be built of substantial material. If they are built on bases instead of ports, consideration should be given to providing additional ballast in the form of sandbags.

Traffic cones and tubular markers are often useful adjuncts to barricades for marking the outer limits of a travelable roadway, which is adjacent to a ditch or an unfinished shoulder. Where lane obstructions occur and adequate advance warning has been provided, cones can also be used to funnel traffic into appropriate lanes.

The predominant color used in cones should be orange. Traffic cones and tubular markers should be a minimum of 18 in. (46 cm) high, with a broad-ended base, and be constructed of materials that will withstand any damage either to design or to vehicles striking them.

Larger sized cones should be used where traffic speeds are tight or where more conspicuous guidance is needed. All cones should be kept clean and bright. When they are used during the night, they should be reflectorized or equipped with lighting devices for maximum visibility.

When cones are used, precautions are necessary to assure that they will not be blown over or displaced. This may be of particular importance when they are adjacent to lanes of moving traffic where there will be a wind created by passing vehicles. Some cones are built with a base that can be filled with ballast. With other types, it may be necessary to double the cones in order to increase the weight, or to fabricate weights that can be added to the cone for extra stability.

Traffic cones have a greater target value than the tubular-shaped devices. The target value of either device can be increased by the addition of an orange flag in the top end and, at night, by colored delineators or interval lights.

Delineators, as used here, means all types of reflector units that are capable of reflecting light from either the upper or lower beam of automobile headlights. They are used primarily for guidance rather than for warning.

Properly installed, delineators will indicate the horizontal and vertical alignment of the roadway and, thereby, outline the path that vehicles must take. They should be spaced sufficiently close to outline clearly their intended path during night hours. (They should always be used in combination with other traffic control devices.)

Another traffic channelization device is the metal, 30- to 55-gallon (114 to 208 liter) capacity drum. They are set on end, and they are used as an expedient channelization method.

The color and marking should be the same as those for barricades—orange and white or black and white. (The colors should not be intermixed in the same area.) The color should be black or orange with at least two horizontal, circumferential white stripes 4 to 6 in. wide (10.5 to 15 cm).

Drums should be reflectorized for use at night and never be placed in a roadway without advance warning signs. In addition, a flashing warning light should be added when drums are used singly, and steady warning lights should be added when they are used in series.

One application of drums is to show an unusual vehicle path made necessary by construction activity. Another effective application occurs on road-widening projects, where a row of barrels is used at night to mark the edge of pavement and to direct traffic away from an open excavation at the edge. During working hours, the same barrels are moved further onto the pavement to provide working room for construction activities.

These barrels are heavy, bulky, and not easily transported, but they do provide a good visual warning. They give the appearance of being formidable obstacles and, thereby, command the respect of the drivers. However, they do not inflict undue damage to a vehicle in the event they are struck. Barrels may be weighted-down to resist wind forces, but they should not be so heavy as to present a hazard to motorists if struck.

Vertical panels used as channelizing devices should consist of at least one panel, 6 to 8 in. (15.5 to 20 cm) in width and 24 in. (61 cm) in height. They are striped and reflectorized in the same manner as barricades, and they are mounted with the top a minimum of 36 in. above (91.5 cm) the roadway on a single, lightweight post.

These vertical panel devices should be used for traffic separation or shoulder barricading where space is at a minimum.

Tiemann (1976). This report is concerned with deficiencies in construction zones. Some examples are: inadequate planning, coordination, and control of safety features for traffic services; inadequate signing for construction activities; improper use of barricades; failure to adequately remove obsolete pavement lane markings; unprotected storage of construction material and equipment along the roadway; and inadequate taper distances for lane changes.

Transportation Research Board (1974). In establishing traffic controls for rehabilitation work sites, the available alternatives include roadway closures and off-site detours, detours within the right of way, and lane closures or lane constrictions. Lane reversals in conjunction with median crossovers have been successfully employed by a number of agencies, but safety considerations necessitate special design features when this alternative is selected.

In Detroit, comprehensive studies have indicated that the closing of segments of the freeway system during night hours permitted reconditioning work to be performed at the optimum rate and cost. (A 36.1% savings was indicated as compared to work conducted under traffic during daylight hours for a project on the John C. Lodge Expressway in June 1968.)

The Effectiveness of Traffic Control Devices

Bailey & Nail (1977). The objective of the study was to make an initial determination of the advantages and/or disadvantages of the chevron versus the diagonal pattern on the top rail of barricades. Although the diagonal pattern is more "distinct" at a closer distance than the chevron pattern, both are judged the same for target value. It was also concluded that the diagonal pattern conveys no directional message to the driver, whereas the chevron does convey a directional message, but only at distances of 200 ft or less. It is recommended that the current MUTCD guideline using the diagonal pattern be maintained until further research evidence warrants change.

Bates (1976). In this study tests were conducted during a serious traffic congestion at a bridge construction site, where two truck-mounted arrowboards were used at the northbound merge point.

The results show that arrowboard trucks placed near the merge point of two lanes have a profound effect on moving vehicles from the closed to the open lane farther in advance of the detour than without the arrowboard trucks. This produces a more efficient lane merge by moving vehicles into the through lane at a higher speed, and also provides motorists a longer period of time in advance to merge.

It was concluded that arrowboard trucks are a definite aid in the merging of traffic lanes and should be used at other, similar locations. Although this study definitely showed the effectiveness of arrowboard trucks for merging traffic, it did not provide guidelines for when they are needed.

It suggests that arrowboard trucks may be more effective in moving vehicles to the left than to the right.

Brewer (1972). Brewer conducted a study to evaluate the speed control effectiveness and safety of a traffic sign/traffic cone/traffic barricade pattern, developed by the Iowa State Highway Commission, which forces traffic through a weaving pattern in a single lane prior to a lane closure (commonly referred to as the "Iowa Weave"). Three test sites were evaluated. Sites 1 and 2 employed the weave pattern, whereas site 3 used a standard taper, with the following results: (1) Analysis of the speed data showed site 2 to be far superior to sites 1 and 3 in reducing speeds. Construction activity was easily visible at site 2, but not at sites 1 and 3, and is probably the reason for the large difference. (2) Skewness of the distribution of vehicular speeds was examined, and all sites had aproximately normally distributed speeds. (3) Analysis of the rate of merging was conducted at sites 1 and 2 but not at site 3. The only significant difference between the two sites was during a 1,000-ft section within the advance warning sign system which included an exit ramp at site 1. As expected, there were significantly more vehicles in the outside lane for site 1 than for site 2 over this portion of the roadway. (4) Photographic data on 1,363 vehicles showed that only about 0.03 percent of the vehicles were involved in hazardous or unusual maneuvers. Therefore, the weave pattern did not appear to result in unsafe operations.

Enustin (1972). This study was initiated to measure the effectiveness of transverse plastic pavement stripes with gradually decreasing spacing. Speed change was selected as an acceptable indication of the effectiveness of these devices in alerting the driver to an impending danger or maneuvering requirement.

Colored stripes alone resulted in a numerically small reduction in average speeds. Larger reductions in average speeds were caused by rumble bars than by colored stripes. In general, paint stripes are applicable for situations where a hazard cannot be readily eliminated.

Low-profile rumble bars are recommended for use in construction areas as well as at other locations that require maximum driver awareness, provided that special precaution is taken not to damage them during winter maintenance.

Graham, Paulsen, and Glennon (1977). This study evaluates several speed reduction methods employed at two sites, one urban freeway and one rural freeway. Data collected include speeds, erratic maneuvers, and slow-moving conflicts.

Rural freeway results indicate that the presence of enforcement (police) depressed mean speed by 2.77 mph, reduced the erratic maneuver rate by 25 percent, and reduced the slow-moving conflict rate by about 25 percent. The presence of an arrowboard panel reduced mean speed by 0.87 mph, reduced the erratic maneuver rate by 25 percent, and increased the slow-moving conflict rate by about 20 percent. The presence of active warning of speed zoning reduced the erratic maneuver rate by about 30 percent, and increased the slow-moving conflict rate by about 20 percent. The presence of speed zoning (either advisory or regulatory) increased the slow-moving conflict rate by 35 percent as compared to no speed zoning.

Because of a loss of data from one of the four urban freeway experiments, it was not possible to determine the effect of any of the experimental treatments at this site.

Graham & Sharp (1977). This study was a comparison of speeds, erratic maneuvers, slow-moving conflicts, weave or slow-to-weave conflicts, and encroachment rates for the standard taper length formula (shown below, as specified in the MUTCD) and a new proposed taper formula:

Standard Formula: $L = WS$
Proposed Formula: $L = WS^2/60$

where L = minimum length of lane-drop taper, ft; S = speed limit or 85th percentile speed, mph; and W = width of the offset, ft.

In general, speeds were higher for the shorter length taper, but by small amounts (less than 1 mph difference).

No site showed that the shorter proposed taper created more erratic maneuvers than the standard taper length.

Only at one of the four test sites were slow-to-weave conflicts higher under the proposed taper as compared to existing taper lengths (the existing taper was shorter than the proposed taper at this site).

McAllister & Kramer (1974). The California Department of Transportation conducted a study to determine the most effective size and operation for arrowboards. The measure of effectiveness of the arrowboards was the percent of decrease in lane occupancy of the median lane at various distances upstream from the boards. Presumably, more effective arrowboard operation will result in lane changes occurring farther upstream. Significant results included: (1) Larger arrowboards were more effective than smaller boards during the daytime. (2) A sequencing pattern was the most effective during the daytime, but a flashing pattern was recommended for night. (3) Speed measurements revealed a drop in speeds of 5 mph due to the arrowboards.

Seymour, Deen, & Havens (1974). This study examined the effect of standard yellow contractors' signs, new yellow signs, and new orange signs on driver compliance at lane closures in construction zones. The measures used to evaluate driver compliance were spot speeds, traffic conflicts, and merging maneuvers. The study results were as follows: (1) The original contractors' signs were the least effective in reducing speeds. There was no significant difference between the new yellow and the new orange signs. (2) In this study, conflicts were defined as: (a) abnormal brake applications, (b) forced merges, and (c) complete stops. All three types of signs were analyzed for both right and left lane closures. For the right lane closures, the conflict rate with the contractors' signs was significantly higher than the rate with the new yellow or orange signs. Comparing the new orange and the new yellow signs, there was no significant difference, although the new orange signs generally had fewer conflicts. (3) For right lane closures, the contractors' signs had a significantly higher number of merges within 500 ft of the first traffic cone than the yellow or orange signs. For left lane closures, only the new orange signs were significantly lower than the contractors' signs in the number of merges within this distance. There was no significant difference between the yellow and orange signs, although the orange was found to be slightly superior.

Shah and Ray (1976). This report discusses the effect of certain variables, such as sign size, height of installation, and legend, on the driver responses measured by speed, conflict, and queuing parameters.

Speed decrease at two land locations was greater for the 30-in. (0.762 m) signs than for either the 36-in. (0.914 m) or the 48-in. (1.22 m) signs. At interstate locations, the 36-in. signs yielded better overall response than the corresponding 30-in. signs. The height of the sign installation and sign legend did not indicate any statistical difference in the measured responses. Sequencing accumulative bidirectional chevrons greatly enhanced the compliance of the driver to warning signals.

DERIVATION OF DRIVER PERFORMANCE MEASURES FROM LITERATURE RESOURCES

A driver's successful negotiation of a construction work zone is a function of his ability to adjust his speed and path to unexpected roadway conditions. In construction zones, the information concerning the needed adjustments in speed and path are provided through the use of construction signs, arrowboards, and channelizing devices. This section of the literature review concerns the development of a list of driver performance measures that could be used to evaluate the effectiveness of channelization devices in providing drivers with the proper speed and path information.

Two separate bodies of literature were surveyed to obtain a list of candidate performance measures. The first type of literature reviewed was research reports in the area of driver perception of highway guide signs and traffic control devices. Pertinent studies which used drivers in real-world roadways, in controlled roadways, and in laboratory driving situations were examined and then analyzed. Unfortunately, few studies relate directly to work zones. Most are peripheral to this area (i.e., field- and controlled-field tests of the effectiveness of other types of visual displays such as signs, flashing lights, traffic signals, and so on). Inferences about driver performance through work zones are appropriate, however, because the same types of decision-making tasks are involved as in other driving situations. The second approach, human information processing, recognizes that a driver is, first of all, an information processor, and takes into consideration the basic foundations of his perceptual needs. These studies are conducted in a laboratory setting, and generate implications for the general characteristics which various stimulus arrays may have in order to be effectively and efficiently perceived.

The measures of individual performance in the information processing tasks have been extracted from these two sets of documents. The result is a list of candidate performance measures (Table A-1) appropriate for use in evaluating human performance in field, controlled-field, and laboratory settings.

Obviously, every measure cannot be used to empirically research and evaluate channelizing devices as perceived by drivers. Therefore these measures must be reviewed and given careful consideration to determine which measures are the most effective in determining how drivers respond to various configurations of channelizing devices. This is the objective of Task 2 (App. B).

LITERATURE SUBJECT BY REFERENCE MATRIX

Table A-2 contains an alphabetical listing of every document reviewed pertinent to the evaluation of channelizing devices and barricades in construction work zones, and this listing is presented in a matrix format. The matrix consists of the documents on the left side, with 42 subject headings in 16 general areas on the right side. Reading across, left to right for any given document, those subject areas addressed in that document are marked. Thus, at a single glance, a reader can recognize the subject matter of any listing or, conversely, select a certain subject area of interest and find documents relating to that area.

As stated, 16 categories define the documents. The first three categories relate to the context in which the traffic control device (TCD) in work zones was reviewed, current practice, experimental performance evaluation, and operational evaluation. The fourth category contains the driver performance measures. These are measures of effectiveness (MOEs) used in previous research studies in the evaluation of TCD and highway guide signs. Fifth are documents relating to the theoretical principles underlying human perception of information displays and information processing as related to traffic control devices. The sixth category covers specific documents that review work zone procedures relating to the placement of traffic control devices. The seventh category includes type of highway contexts the document reviews.

The eighth category covers variation in design of TCD and lists documents that review TCD other than those specified in the *Manual on Uniform Traffic Control Devices* (MUTCD). The ninth category, application of devices, relates to documents that discuss the planning for traffic control in work zones, procedures to install and remove TCD in work zones, and how TCDs are used in maintenance operations. The tenth, type of channelizing devices, classifies the document into which TCDs were reviewed. The remaining six document classifications refer to subject areas used in the analysis of safety problems in work zones. Finally, a classification of the documents themselves is given so that a reader may know if a particular report is a research study, a general discussion, a status report, and so on. If a particular document is of interest, the reader is referred to the "Literature Summaries" section, which contains the references and an abstract of these documents, again, in alphabetical order. The complete references are given in the bibliography included in the main body of the report (Chapter Five).

REVIEW OF SELECTED STATE, LOCAL, AND UTILITY MANUALS ON UNIFORM TRAFFIC CONTROL DEVICES

The following manuals on uniform traffic control were reviewed:

- Texas A&M University Traffice Control Manual (1977).
- Iowa Traffic Control Handbook (1976).
- California Manual of Traffic Controls (1977).
- Traffic Barricade Manual, Phoenix, Arizona (July 1974).
- Traffic Safety Manual, New York Thruway (April 1976).
- Work Area Protection, Ohio Department of Transportation (July 1975).
- Lousiana Maintenance Traffic Control Handbook (1973).
- Australian Standard MUTCD (1975).
- Canadian MUTCD (1976).
- Nevada Traffic Control Manual (1974).
- Traffic Control Manual, San Diego Chapter, American Public Works Association.
- North Carolina MUTCD (Oct. 1973).
- Omaha, Nebraska Public Works Department, Manual (Sept. 1973).
- Traffic Barricade Manual, Shreveport, Louisiana (1971).
- New Hampshire MUTCD (1972).
- Maintenance and Operations, Traffic Control Handbook, Maine DOT (1977).
- Ohio MUTCD Part VI.
- Tennessee MUTCD Part VI (June 1972).
- Florida MUTCD Part VI (1972).
- Minnesota MUTCD Appendix B Traffic Controls for Temporary Lane Closures, Street and Highway Construction, Maintenance and Public Utility Operations (1974).
- Michigan MUTCD Part VI (1976).
- Traffic Control for Street and Highway Construction and Maintenance Operations, West Virginia Department of Highways.
- Safety Training Program, Work Area Protection, Pennsylvania Power and Light Company (1973).
- Work Area Protection Guide, Philadelphia Electric Company (1972).
- Typical Traffic Control for Work Area Protection, Virginia Department of Highways and Transportation (1975).
- Policy Manual, Maintenance Division, Virginia Department of Highways, Revised (1974).

Table A-1. Candidate performance measures.

Document / Measures	Laboratory Experiment	Controlled Field Experiment	Field Experiment	Used as MOEs to Evaluate TCDs in Work Zones	
				YES	NO
ATSA, 1973				X	
Observer Rating Scale/Judgments		X			
ATSA, 1974				X	
Observer Rating Scale/Judgments		X			
Attneave, 1954					X
Frequency of Responses	X				
Errors or Extrapolation	X				
Banks & Prinzmetal, 1976					X
Reaction Time	X				
Errors	X				
Grouping Measure	X				
Caelli & Umansky, 1976					X
Forced Choice Detection of Alternatives with Feedback	X				
Copple & Milliman, 1966				X	
Detection Distance by Observers - Ranking Scale		X			
DeGreene, 1970					X
Error Types in System Failure	X	X	X		
Dewar & Swanson, 1972					X
Recognition Time	X				
Errors	X				
Dewar & Ells, 1974					X
Verbal Reaction Time	X				
Detection Distance - Classification & Identification		X			
Dewar, 1976					X
Correct Recognition - Glance Legibility (Error Scores)	X				
Dewar, Ells, & Cooper, 1977					X
Lane Choice (Errors)	X				
Reaction Time	X				
Glance Legibility	X				
Frequency of Destination Change		X			
Stops		X			
Reversals		X			
Dewar & Ells, 1977					X
Semantic Differential	X				
Errors in Comprehension	X				
Dietrich & Markowitz, 1972				X	
Confidence Ratings (4 Pt. Scale)	X	X			
Error Scores in Recognizability	X	X			
Questionnaire for - Meaning, Activity, Preference	X	X			
d'	X	X			

Table A-1 Continued

Document / Measures	Laboratory Experiment	Controlled Field Experiment	Field Experiment	Used as MOEs to Evaluate TCDs In Work Zones YES	NO
Graham, Paulsen, & Glennon, 1977				X	
Accident Rate/100 MVM (17 Classifications)			X		
Speed (MPH)			X		
Mean Speed and Variance via Trace Analysis			X		
Erratic Maneuvers			X		
Slow Moving Conflicts - Observer Counts/15 Min. Periods			X		
Previous Conflict Rate			X		
Growney, 1976					X
Rating via Method of Magnitude Estimation	X				
Hanscom & Berger, 1976					X
Mean Speed (MPH)		X	X		
Speed Variance		X	X		
Mean Acceleration (Ft./Sec.)		X	X		
Acceleration Variance		X	X		
Spot Speed (1400-800-200 Ft. Advance)		X	X		
Acceleration (Ft./Sec.)		X	X		
Headway (200-800 Sec. Ft. Advance)		X	X		
Gap, Ft. (200-800 Ft. Advance)		X	X		
Front Closure Speed (200-800 Ft. Advance)		X	X		
Rear Closure Speed (200-800 Ft. Advance)		X	X		
Max Front Accident Potential (ft./Sec.)		X	X		
Max Rear Accident Potential (ft./Sec.)		X	X		
Distance Driving Slowly (300 Ft. Intervals)		X	X		
Distance Driving Fast (300 Ft. Intervals)		X	X		
Two Second Headway Violations		X	X		
One Second Headway Violations		X	X		
Point of Maximum Speed Change		X	X		
Point of Acceleration Maximum Change		X	X		
Point of Maximum Rear Closure Speed		X	X		
Point of Maximum Front Closure Speed		X	X		
Size of Maximum Speed Change Ft./Sec.		X	X		
Size of Maximum Acceleration Change		X	X		
Location of Exit Weave		X	X		
Merge Gap Acceptance Length		X	X		
Acceleration Noise		X	X		
Eye Movements/Eye Fixations & Fixations		X	X		
Lateral Acceleration		X	X		
Brake Pedal Usage		X	X		
Gas Pedal Usage		X	X		
Subject Ratings		X	X		
Erratic Maneuvers		X	X		
Percent Lane Changes		X	X		

Table A-1 Continued

Document / Measures	Laboratory Experiment	Controlled Field Experiment	Field Experiment	Used as MOEs to Evaluate TCDs In Work Zones YES	NO
Hochberg & McAlister, 1953					X
Frequency of Response/Stimulus Sets	X				
Juergens, et al., 1972					X
Accident Rate/100 MVM			X		
Klein, Allen, & Peters, 1976					X
Steering Wheel Position		X	X		
Steering Wheel Rate		X	X		
Throttle Pedal Position		X	X		
Brake System Pressure		X	X		
Forward Velocity		X	X		
Wheel Rotation Velocities		X	X		
Longitudinal Acceleration		X	X		
Lateral Acceleration		X	X		
Vertical Acceleration		X	X		
Pitch Rate		X	X		
Roll Rate		X	X		
Vehicle Lane POsition (Lane Position Tracker)		X	X		
Electrocardiogram (ECG)		X	X		
Electromyógram (EMG)		X	X		
Electroencephalogram (EEG)		X	X		
Galvanic Skin Response (GSR)		X	X		
Vehicle Side Slip		X	X		
Path Angle		X	X		
Eye Point of Regard		X	X		
Yaw Rate		X	X		
Distance Traveled		X	X		
Lateral Position		X	X		
Heading Angle		X	X		
Roll Angle		X	X		
Pitch Angle		X	X		
Steering Error		X	X		
Ladan, Heron, & Nelson, 1974					X
d'		X			
McAlister & Kramer, 1974				X	
Percent Decrease in Volume (Lane Evacuation)			X		
Speeds at Set Distances			X		
Erratic Maneuvers (Score vis Time Lapse Movie Film)			X		
Morton, 1976				X	
Percent Merges at Various Distances			X		
Osaka, 1975					X
Rating Via Method of Magnitude Estimation	X				
Pomerantz & Swaitzberg, 1975					X
Mean Sorting Times	X				
Sorting Errors	X				

Table A-1 Continued

Document / Measures	Laboratory Experiment	Controlled Field Experiment	Field Experiment	Used as MOEs to Evaluate TCDs In Work Zones: YES	NO
Ruden, et al., 1977					X
Recognition of Signal (Errors)	X				
Attention Value of Signal (Preference)	X				
Reaction Time		X			
Head Movement Counts (Via Time Lapse Camera)			X		
Vehicle Deceleration (Via Radar)			X		
Running Vs. Stopping in Obedience to Signal (Vehicle Count)			X		
Observed Braking Maneuvers			X		
Preferences	X				
Shah & Ray, 1976				X	
Average Speed in Critical Zone			X		
Traffic Conflicts - Forced Merge & Complete Stop			X		
Vehicle Count - Properly Queued in Travel Lane Between Last Sign & First Cone Taper			X		
Shepard, 1971				X	
Weave Counts in Various Zones			X		
Speed Changes			X		
Volume in Lanes			X		
Smith & Janson, 1976					X
Field Interviews			X		
Accident Reports			X		
Reaction Time	X				
Error Scores	X				
Reference Rankings (Pair Comparison Method)		X			
Swezey, 1974					X
Recall Scores/Specified Intervals	X				
Tolhurst & Dealy, 1974					
Errors in Detection and Judgment (%)	X				

Table A-2. Subject by reference matrix.

EVALUATION OF TRAFFIC CONTROLS FOR WORK ZONES

Task 1 – Literature Review

Reference	Year				Driver Performance Measures				Human Information Processing			Type of Highway							Application of Devices			Type of Channelizing Devices											Construction Activity						Type of Document				
		Current Practice	Experimental Performance Evaluation	Operational Evaluation	Laboratory	Controlled Roadway	Real World Roadway	Other	Traffic Control Device Related	Theoretical/General	Review of Work Zone Procedures	Rural Interstate	Rural Expressway	Rural Two-Lane	Urban Interstate	Urban Arterial	Urban Residential	Variance in Design of TCD	Planning	Installation/Removal	Maintenance	Barricades	Cones	Delineators	Drums	Panels	Pavement Markings	Warning Lights	Arrow Boards	Other	Legal Considerations	Review of Work Zone Safety	Moving	Temporary	Permanent	Geometric and Roadway Features	Type of Accidents	Statistical Analysis	Research Study	Bibliography	General Discussion	Status Report	Std./Official Ruling/Guideline
Alexander, King & Warskow	1970								•																														•				
Alfonso, Concepcion, Bandeleria & Roa	1974	•									•				•																												
Andrews, J.F.	1967																															•		•			•				•		
Armour, J.	?										•					•	•				•																						•
ASCE	1976																														•										•		
Attneane	1954									•																													•		•		
Bailey & Nail	1977			•					•							•						•												•					•				
Banks & Prinzmetal	1976				•					•																													•				
Bates	1976		•				•						•																•										•				
Beecroft	1977			•																										•									•				
Bender	1972	•									•																														•		
Berger & Hanscom	1974		•			•	•		•																														•		•		
Biggs	1975			•							•									•												•		•					•				
Brevoord, G.	1975										•																														•		
Brewer	1972		•				•		•									•		•			•							•									•				
Brunner, R.	1977			•												•														•									•				
Byrd, Tallamy, MacDonald, Lewis (Tech. for Street. . .)	1975	•									•																					•		•					•				
Byrd, Tallamy, MacDonald, Lewis (Traffic Control for Street. . .)	1975										•								•	•	•																						•
Caelli & Umansky	1976									•																													•		•		

Table A-2 Continued

EVALUATION OF TRAFFIC CONTROLS FOR WORK ZONES

Task 1 — Literature Review

	Current Practice	Experimental Performance Evaluation	Operational Evaluation	Driver Performance Measures: Laboratory	Driver Performance Measures: Controlled Roadway	Driver Performance Measures: Real World Roadway	Driver Performance Measures: Other	Human Information Processing: Traffic Control Device Related	Human Information Processing: Theoretical/General	Review of Work Zone Procedures	Type of Highway: Rural Interstate	Type of Highway: Rural Expressway	Type of Highway: Rural Two-Lane	Type of Highway: Urban Interstate	Type of Highway: Urban Arterial	Type of Highway: Urban Residential	Variance in Design of TCD	Application of Devices: Planning	Application of Devices: Installation/Removal	Application of Devices: Maintenance	Type of Channelizing Devices: Barricades	Type of Channelizing Devices: Cones	Type of Channelizing Devices: Delineators	Type of Channelizing Devices: Drums	Type of Channelizing Devices: Panels	Type of Channelizing Devices: Pavement Markings	Type of Channelizing Devices: Warning Lights	Type of Channelizing Devices: Arrow Boards	Type of Channelizing Devices: Other	Legal Considerations	Review of Work Zone Safety	Construction Activity: Moving	Construction Activity: Temporary	Construction Activity: Permanent	Geometric and Roadway Features	Type of Accidents	Statistical Analysis	Type of Document: Research Study	Type of Document: Bibliography	Type of Document: General Discussion	Type of Document: Status Report	Type of Document: Std./Official Ruling/Guideline
Center for Auto Safety 1976										●																														●		
Center for Auto Safety 1977										●																					●									●		
Chipps, Doyle, Franklin, Kuykendall 1976	●									●								●	●	●																		●				
Copple & Milliman 1966		●				●																					●											●				
Cornette, D. 1972		●	●			●																																●				
Crumpton 1977			●																										●									●				
DeGreene 1970									●																															●		
Dewar & Swanson 1972				●	●				●																													●		●		
Dewar, 1973								●	●																															●		
Dewar & Ells 1974				●				●																														●		●		
Dewar 1976								●																														●		●		
Dewar & Ells 1977								●																														●		●		
Dewar, Ells, & Cooper 1977				●	●			●																														●		●		
Dietrich & Markowitz 1972				●		●		●	●																													●		●		
Doyle 1975	●																	●	●	●																		●				
Enustin 1972		●				●																																●				
FHWA (Change in MUTCD. . .) 1976			●							●																●																●
FHWA (Highway Focus) 1974			●							●							●	●	●	●	●								●											●		
FHWA (Program Manual No. 12) 1974										●																																●
FHWA (Temporary Barriers. . .) 1977			●							●																			●													●

Table A-2 Continued

EVALUATION OF TRAFFIC CONTROLS FOR WORK ZONES

Task 1 — Literature Review

	Year	Current Practice	Experimental Performance Evaluation	Operational Evaluation	Driver Performance Measures: Laboratory	Driver Performance Measures: Controlled Roadway	Driver Performance Measures: Real World Roadway	Driver Performance Measures: Other	Human Information Processing: Traffic Control Device Related	Human Information Processing: Theoretical/General	Review of Work Zone Procedures	Type of Highway: Rural Interstate	Type of Highway: Rural Expressway	Type of Highway: Rural Two-Lane	Type of Highway: Urban Interstate	Type of Highway: Urban Arterial	Type of Highway: Urban Residential	Variance in Design of TCD	Application of Devices: Planning	Application of Devices: Installation/Removal	Application of Devices: Maintenance	Type of Channelizing Devices: Barricades	Type of Channelizing Devices: Cones	Type of Channelizing Devices: Delineators	Type of Channelizing Devices: Drums	Type of Channelizing Devices: Panels	Type of Channelizing Devices: Pavement Markings	Type of Channelizing Devices: Warning Lights	Type of Channelizing Devices: Arrow Boards	Type of Channelizing Devices: Other	Legal Considerations	Review of Work Zone Safety	Construction Activity: Moving	Construction Activity: Temporary	Construction Activity: Permanent	Geometric and Roadway Features	Type of Accidents	Statistical Analysis	Type of Document: Research Study	Type of Document: Bibliography	Type of Document: General Discussion	Type of Document: Status Report	Type of Document: Std./Official Ruling/Guideline
FHWA (The Obliteration. . .)	1975			●							●																●																●
Frick	1972	●		●							●								●																		●	●		●			
Fullerton & McCasland & McCasland	1976			●			●																																●				
Gafarian, Goodwin & Lawrence	?			●			●																																●				
GAO	1977																															●									●		
Goodwin	1976						●																																●		●		
Graham, Paulsen, Glennon	1977	●									●																												●			●	
Graham, Paulsen, Glennon	1977		●				●																						●	●						●	●	●	●				
Growney	1976								●	●																													●				
Hanscom & Berger	1976					●	●		●																														●		●		
Hatton	1970																																	●	●	●	●		●				
Hochberg & McAlister	1953									●																													●		●		
HRB (Traffic Control Control. . .)	1969	●									●																												●				
Johnason	1977			●																										●									●				
Juergens, W.R.	?			●							●								●	●	●			●						●							●	●	●				
Jung & Nyers	1975		●															●			●									●												●	
Kahm	1974										●																					●					●						●
Kessinger	1977			●																										●									●				
Klein, Allen, & Peters	1976					●	●																																		●		

Table A-2 Continued

EVALUATION OF TRAFFIC CONTROLS FOR WORK ZONES
Task 1 – Literature Review

					Driver Performance Measures				Human Information Processing			Type of Highway							Application of Devices			Type of Channelizing Devices											Construction Activity						Type of Document				
		Current Practice	Experimental Performance Evaluation	Operational Evaluation	Laboratory	Controlled Roadway	Real World Roadway	Other	Traffic Control Device Related	Theoretical/General	Review of Work Zone Procedures	Rural Interstate	Rural Expressway	Rural Two-Lane	Urban Interstate	Urban Arterial	Urban Residential	Variance in Design of TCD	Planning	Installation/Removal	Maintenance	Barricades	Cones	Delineators	Drums	Panels	Pavement Markings	Warning Lights	Arrow Boards	Other	Legal Considerations	Review of Work Zone Safety	Moving	Temporary	Permanent	Geometric and Roadway Features	Type of Accidents	Statistical Analysis	Research Study	Bibliography	General Discussion	Status Report	Std./Official Ruling/Guideline
Ladan, Heron, & Nelson	1974									●																													●		●		
Lamb, M.W.	1970																														●										●		
Lee, C.	1969			●								●			●					●			●											●		●	●	●	●				
Lisle, Reilly, Beale	1976			●																		●							●		●								●	●			
Lokken, E.C.	1973	●		●																●	●								●												●		
Lunenfeld	1976	●	●	●	●		●																																●		●		
Lynch	1977			●																										●									●				
Mason, B.	1970												●																						●		●	●	●				
Mathews, MacLean	1976	●									●			●		●																									●		
McAllister, Kramer	1974		●				●								●														●										●				
McLean	1975										●									●																							●
Morton	1976		●				●																					●											●				
Munro & Hvana	1968											●			●	●																●					●	●	●				
National Safety Council	1974	●		●							●							●				●	●	●	●	●		●		●									●				
OECD	1973		●								●							●	●	●	●																		●				
Osaka	1975									●																													●		●		
Pigman & Agent	1974			●			●																																●				
Pomerantz & Swaitzberg	1975									●																													●		●		
Roberts & Kipple	1976		●		●				●																														●				
Rock	1975									●																															●		
Rowe	1975																														●	●									●		
Russell	1969										●																					●					●				●		

EVALUATION OF TRAFFIC CONTROLS FOR WORK ZONES

Task 1 – Literature Review

				Driver Performance Measures				Human Information Processing			Type of Highway							Application of Devices			Type of Channelizing Devices											Construction Activity						Type of Document				
	Current Practice	Experimental Performance Evaluation	Operational Evaluation	Laboratory	Controlled Roadway	Real World Roadway	Other	Traffic Control Device Related	Theoretical/General	Review of Work Zone Procedures	Rural Interstate	Rural Expressway	Rural Two-Lane	Urban Interstate	Urban Arterial	Urban Residential	Variance in Design of TCD	Planning	Installation/Removal	Maintenance	Barricades	Cones	Delineators	Drums	Panels	Pavement Markings	Warning Lights	Arrow Boards	Other	Legal Considerations	Review of Work Zone Safety	Moving	Temporary	Permanent	Geometric and Roadway Features	Type of Accidents	Statistical Analysis	Research Study	Bibliography	General Discussion	Status Report	Std./Official Ruling/Guideline
Seymour, Deen Havens 1974		●				●		●												●									●												●	
Shah, Ray 1976		●	●			●					●		●															●										●				
Smith 1974									●																														●	●		
Suppelt 1971	●																	●																								●
Swezey 1974								●	●																													●		●		
Tannir 1977	●									●																												●				
Thomas 1975																														●			●					●				
Tieman, N.T. 1976										●																																●
Tolhurst & Dealy 1974									●																													●		●		
Toombs 1974			●																					●	●															●		
TRB (Crash Cushion Trailer) 1974			●																										●		●					●				●		
TRB (Maine Facility) 1974						●																																●				
TRB (Re-Conditioning Freeways) 1974	●														●			●	●																			●				
TRRL (Temporary Road Traf. Signals) 1973	●		●																										●											●		●
Unknown (Calif. Takes Steps. . .) 1974										●																					●							●				
Unknown (Roads and Streets) 1970										●																				●									●			
Wojick & Allen 1972		●		●																																		●				

APPENDIX B

DERIVATION OF PERFORMANCE MEASURES

INTRODUCTION

The objective of the second task was to derive appropriate measures of performance that reflect driver response and the relative effectiveness of particular devices. These measures were then to be used in the three subsequent tasks:

1. A laboratory experiment of individual device design (Task 3, App. C).
2. A controlled field experiment testing alternative devices used collectively (Task 4, App. D).
3. An evaluation of selected devices applied to actual work zone situations (Task 5, App. E).

Two activities were pursued to derive the appropriate performance measures. The first was a review of the literature to identify candidate measures. The results of this effort are reported in Appendix A (see Table A-1) and served as "input" to the remainder of the task. The second activity was an analytical assessment of the driving task requirements for a typical work zone situation. By analyzing the driving task it was possible to identify the desired driver and vehicle responses and, in turn, translate these into performance measures for evaluation. This driving task analysis was particularly useful in defining those measures that were relevant to the field evaluation study.

The discussions of the performance measures used for the laboratory experiment (Task 3) and the field controlled testing (Task 4) are best presented in the context of their individual reports. Hence the reader is referred to Appendixes C and D for that information. This appendix will deal chiefly with the driving task analysis and how it was used to develop candidate performance measures.

WORK-ZONE DRIVING TASK AND RELATED MEASURES

The technique followed in deriving performance measures was an adaptation of the information-decision-action (IDA) analysis technique used by Taylor et al. (*1*) in deriving roadway delineation requirements. In that study, delineation devices were considered part of the information requirements which were determined in a sequential fashion by establishing the required actions, identifying the decisions the driver must make to implement these actions, and then identifying the information necessary for the driver to make the decisions.

By applying the IDA analysis to the problem at hand, it is possible to identify appropriate performance measures by first determining the task requirement sequence (i.e., action) as the driver approaches and passes through a construction zone. Then from identifying the information requirements, at least in generic terms, it can be established whether or not any of the devices being studied are a factor in eliciting the appropriate driver response. Finally, the appropriate performance measures can be identified based on driving tasks and whether or not the devices being studied are likely to affect the driving task.

This procedure can be illustrated using a typical work zone situation—a lane closure on a divided highway (as shown in Figure B-1. The first step in this analysis is to establish reference points, areas, or zones where driver actions may be required or are likely to occur.

The areas labeled on the right side of Figure B-1 are those defined by Graham et al. (*2*) as follows.

The term *construction zone* refers to an entire construction project. The beginning and end of the zone are called the *project limits*.

The *warning area* begins with the first information to the driver that he is approaching a work area. On high-speed expressways, the warning area may begin 1 to 2 miles upstream of the work area.

The *approach area* begins with the first information to the driver about the actual condition of the roadway ahead and the actions that will be required to travel through the work area. Although no physical restrictions narrow the roadway in the approach area, there are often slowing and merging maneuvers as drivers adjust their speed and position based on their concept of the safe path through the zone.

The *entering transition* begins at the point where the normal roadway is altered laterally by devices such as cones, barricades, or barriers in order to channelize traffic to the part of the roadway open through the work area. In Figure B-1, traffic must move from the right lane into the median lane. In other types of construction zones, the entering transition may lead traffic onto a temporary bypass road or to an alternate route.

The *work area* is that length of the roadway where work is being done or is going to be done. The work area may be completely closed to traffic, or a portion of the roadway may be open through the work area. If the work area is open to traffic, traffic control should provide for the separation and protection of motorists and construction workers.

The *exiting transition* is the area downstream from the work area where traffic returns to the normal roadway. In Figure B-1, the right lane is reopened in the exit transition. If the work area roadway is closed to traffic the exit transition leads traffic back to the normal roadway. Also in the exit transition area traffic returns to the lanes that were closed and resumes its normal speed. In this area traffic should be informed if no further work areas will be encountered.

To these areas has been added another section which is within the work area—the *activity area* where the actual construction work is being done, as evidenced by workers and machinery moving about. A distinction is made here between the work area and the activity area because: (1) motorists may drive more cautiously (which would be reflected by some performance measures) where there is work activity, and (2) it may be desirable to use a "stronger" barrier system where there is activity for purposes of worker protection.

The labels on the left side of the figure are those from the concept of positive guidance, which is operationally defined as "information presented unequivocally, unambiguously, and conspicuously enough to meet decision sight distance criteria and enhance the probability of appropriate speed and path decisions" (*3*). Decision sight distance is defined as "the distance at which a driver can detect a hazard in an environment of visual noise or clutter, recognize it (or its threat potential), select appropriate speed and path, and perform the required action safely and efficiently" (*4*).

In this study, construction zones can be considered condition-type hazards because they represent a road condition that is unexpected and requires a maneuver. More specifically, in the case illustrated by Figure B-1, the devices along the taper constitute a fixed object hazard for motorists in the outside lane.

One of the activities of the positive guidance procedure is to establish zones corresponding to the nature of the tasks the driver must perform approaching, through, and leaving the site (in this case, the construction zone). These zones, as depicted in Figure B-1 are:

1. Advance zone—where hazards or inefficiencies do not yet affect the driver's task.
2. Approach zone—corresponding to the decision sight distance (DSD) minus the stopping sight distance. (The distances shown in Figure B-1 are based on DSD criteria established by McGee (*5*) for 60 mph.)
3. Nonrecovery zone—begins at the point beyond which there is insufficient space to avoid a system failure (i.e., stopping sight distance).
4. Hazard zone—distance corresponding to the length of the hazard (in this case it starts with the first device at the taper and ends at the last device on the tangent).
5. Downstream zone—area beyond the hazard corresponding to the distance it takes to safely leave and not be affected by or affect opposite direction traffic.

With the various zones of interest having been defined, task and information analysis can be made to arrive at the required performance measures.

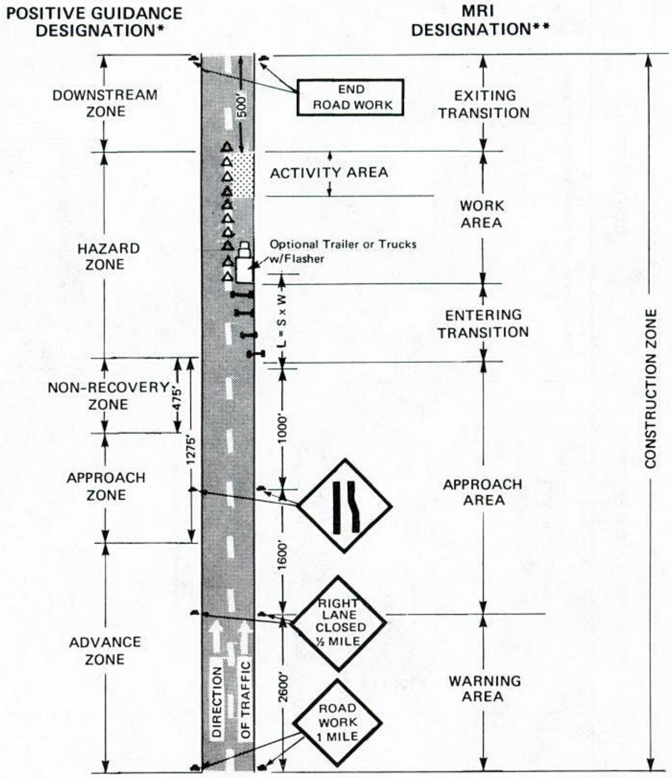


*Figure B-1. Areas within construction zones related to driver action (*Ref. (3); **Ref. (2)).*

Advance or Warning Area

For practical purposes, this area (zone) begins with the first information of a construction zone. In Figure B-2, the ROAD WORK 1 MILE sign is the initial advance point. The area terminates with the beginning of the approach area, which could be defined as either:

1. The point where the signing informs the motorist what action is required (e.g., RIGHT LANE CLOSED) and where it is to take place (e.g., 1/2 MILE).
2. The point of possible first sighting of the hazard (i.e., the taper devices).
3. The decision sight distance—an established distance based on information processing.

In this area there is no special or unusual driving task requirement. The primary task is to maintain a quasi-steady driving state, which simply means maintenance of the desired or required lateral (lane placement) or longitudinal (speed, headway) control. Because the driver usually cannot see the construction area ahead and cannot determine from the advance signing what specific action is required, there is not likely to be a significant change in his quasi-steady driving state, at least none that could be attributed to the devices of interest in this study.

Performance measures to be obtained here, if at all, would include those typical traffic flow measures which could be used as base values to compare with other zones. These include:

1. Speed, all lanes.
   a. Mean.
   b. 85th percentile.
   c. Variance.
2. Headway, all lanes.
3. Placement, outside lane.

LOCATION	ACTION TO BE TAKEN	INFORMATION REQUIREMENT/SOURCES	PERFORMANCE MEASURES	COMMENTS
1. ADVANCE OR WARNING AREA	A. Maintain QUASI-STEADY STATE – No change in speed or path required	**REQUIREMENT** Dr ver needs only to be made aware of construction activity ahead **SOURCES** 1. Advance warning sign(s) e.g. W20-1 2. Driver may have view of channelization devices or flashing arrow board if there is long sight distance	A. VEHICLE 1. Speed • mean, 85th percentile • variance	– Base value for comparison with other areas
			2. Headway – all lanes	– Not directly comparable to other areas unless number of lanes is continued thru zone
			3. Placement • mean • variance	– Difficult to compare with other areas
			4. Conflicts/Erratic Maneuvers a. sudden speed reduction b. brake light application c. swerving, weaving d. slow moving	
			5. Volume (by lane)	
			B. DRIVER 1. Recognition of Signal – • reaction time • head/eye movements • recall 2. Preference 3. Understanding	– Requires instrumented vehicle, test subjects

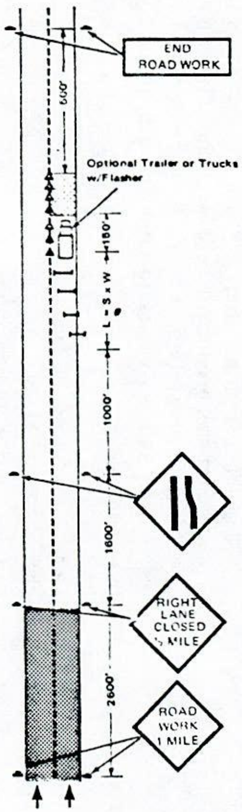


Figure B-2. Task analysis for advance area.

a. Outside lane with respect to edge line.
b. Inside lane with respect to median edge line.

4. Conflict (multiple vehicle) and/or erratic maneuvers (single vehicle). (NOTE: none are expected to occur.)
a. Sudden deceleration, brake light application.
b. Slow moving, below one standard deviation.
c. Lane changing

5. Volume, all lanes

Approach Area

Figure B-3 shows the task analysis for this area. Several tasks are required of the driver, depending on the lane in which he is positioned. The first task, which is required of all motorists but especially those in the lane to be closed, is one of information processing and decision-making. At the upstream boundary, or very shortly thereafter, the motorist should be able to detect and recognize the upcoming hazard (i.e., the taper). After recognition, the driver will go through a decision process. For the driver in the outside lane, this means deciding when to change lanes. For the inside lane driver it will be either to maintain speed and path or to adjust his speed to accommodate those changing lanes. Motorists in the outside lanes will scan the adjacent lanes for gaps and merge when an acceptable gap becomes available. The initiation of the lane change could vary from 420 to 700 ft (120 m to 214 m) (based on the 5.7 to 9.5 sec until response at 50 mph) downstream of the beginning of the approach area to nearly the beginning of the entering transition area.

The information sources available to the driver to aid him in the driving task are the signs as shown in Figure B-3 (RIGHT LANE CLOSED 1/2 MILE), the pavement width transition sign (W4-2), and the view of the taper devices, including the flashing arrowboard, if used. Because the taper devices will be an information source at this point, any modifications in the quasi-steady driving state may be attributable to those devices, and, therefore, any performance measures which describe these modifications are candidate measures of effectiveness. These include:

1. Speed, all lanes.
   a. Mean and/or 85th percentile—as discussed earlier, motorists, after recognizing the devices, may begin to adjust their speed. If so, this should be detected by a difference in the mean or 85th percentile speed when compared to the base value in the advance area. Speed is also likely to be influenced by the traffic flow itself. Therefore, this measure should be obtained during "free flow" conditions where the drivers are responding to the devices and not to traffic conditions.
   b. Variance—smaller speed variance is related to a safer condition. As drivers approach the taper area, greater speed variation can be expected, and this measure by itself can be used to evaluate effectiveness of devices.
   c. Change (mean or variance) from the advance area—the difference between the mean or variance obtained at the advance and the approach zone can be used as a measure of "noise" or change.

2. Headway—at this point, headway is not likely to be affected by the devices being studied. It is more likely to be affected by vehicle density as some of the vehicles in the outside lane merge into the inside. Although listed as a performance measure, it may not be appropriate for this area.

3. Placement—lane placement for vehicles in the outside lane is likely to change in the approach area. However, it may not be appropriate in this area because it will be biased by those vehicles changing lanes.

4. Conflicts/erratic maneuvers—in the approach area, especially near the downstream end, conflicts or erratic maneuvers may occur as drivers change lanes. The frequency of these measures will be related to traffic volume, average point of lane changing, and signing, as well as the devices being examined.

5. Volume—counts by lane can be used to determine lane distribution and as a gross indicator of merge location.

6. Merge point—one of the most meaningful measures related to the taper design is how it affects where drivers in the outside lane merge with the adjacent lane. This measure is best defined as the distance upstream from the beginning of the taper to where the vehicle's left wheels cross the lane line.

There are other measures related to driver information processing, such as recognition, understanding (comprehension), and preference. Although these may be valid measures for evaluation of the devices, they require the use of a driver survey and/or an instrumented vehicle.

Entering the Transition Area

Figure B-4 shows the task analysis for this area, where motorists should be making final adjustments in speed, path, and headway prior to the actual work area. Ideally, all motorists in the outside lane should have already merged into the open, adjacent lane prior to the taper. If not, there will be lane changing as the motorist follows the taper into the adjacent lane. Other drivers may adjust their speed to the new speed limit if they have not already done so, positioning their vehicles in the lane in response to the delineation provided by the markings and channelization devices, and adjusting their headway in response to vehicles ahead of them.

The only information requirement in this area is the need for a clearly delineated path. This is normally provided by the channelization devices, which are of primary interest in this study. Other sources of information include other vehicles and the construction area itself.

The anticipated performance measures relating to the driving task are shown in Figure B-4. Some additional comments concerning these are:

1. Speed—same comments as noted for the approach area.

2. Headway—although the motorist is directly influenced by the channelization devices, headway may not be a good measure because it is likely to be affected by lane merging and by traffic density.

3. Placement—this measure may also be inappropriate here because of lane merging and the continuously changing reference line (i.e., the taper).

4. Conflict/erratic maneuvers—this area should have the highest incidence of these measures as motorists attempt late lane changes.

5. Volume—all traffic counted in two lanes in the upstream areas should be in the single open lane, but it may be

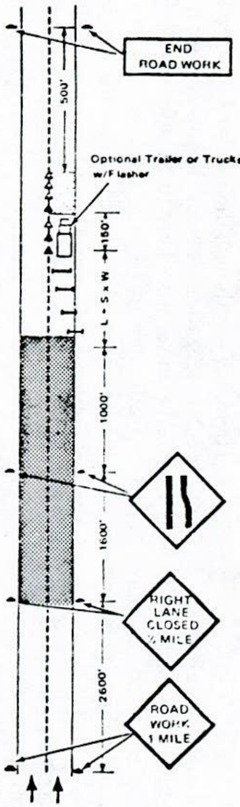
LOCATION	ACTION TO BE TAKEN	INFORMATION REQUIREMENT/SOURCES	PERFORMANCE MEASURES	COMMENTS
2. APPROACH AREA 	A. Information Processing by Driver: – detection, recognition, decision making – scanning for gaps in adjacent lane B. Possible Speed Reduction — all lanes C. Lane Changing — for outside lane	REQUIREMENT Driver needs information indicating situation ahead (e.g., Right Lane Closed Ahead), location (½ mile, 500 ft., etc.) and action required. Within the decision sight distance should be able to see the hazard (channelization devices) SOURCES 1. WARNING Signs e.g. W20-5, W4-2 2. Possibly Flashing Arrow Board 3. View of construction area/channelizing devices 4. Other traffic	A. VEHICLE 1. Speed (all lanes) a. mean, 85th percentile b. variance c. change from advance area	– MOE only under free-flow conditions (LOS A, B); otherwise a function of capacity
			2. Headway (all lanes)	– See comment under advance area, also comment above holds true
			3. Placement (also variance a. mean b. variance c. placement "noise" – change in mean or variance from advance zone	– See comment for advance area
			4. Conflicts	– Same as for advance area
			5. Volume (by lane)	
			6. Merge Point – distance upstream from begin of taper where vehicle merges	
			B. DRIVER 1. Recognition of Signal 2. Preference 3. Understanding	– Same comments as for advance; however, if in this zone, driver can see initial channelization devices, these measures may be relevant

Figure B-3. Task analysis for approach area.

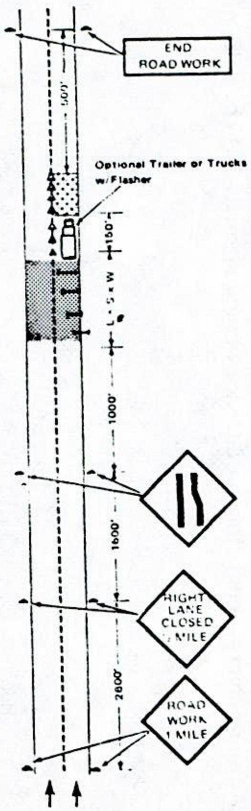
LOCATION	ACTION TO BE TAKEN	INFORMATION REQUIREMENT/SOURCE	PERFORMANCE MEASURES	COMMENTS
3. ENTERING TRANSITION AREA  	A. Late Lane Changing – outside lane B. Adjusting Speed, lane position and headway	REQUIREMENT No new information is needed since driver is making final adjustments to enter the work area. Needs only path guidance (delineation). SOURCES 1. Channelization Device(s) – cones, drums, barriers, etc. – markings 2. Construction Area – – equipment, activity 3. Other Vehicles	A. VEHICLE 1. Speed a. mean b. variance c. change from approach area 2. Headway 3. Placement a. mean b. variance c. placement noise 4. Conflicts/Erratic Maneuvers a to d – defined earlier 5. Volume (by lane) 6. Merge Point	– Same comment as before – See previous comment; difficult to measure at this area due to merging – Changing reference point for lane being closed – Use to determine lane distribution compared to advance area – Distance upstream from begin of taper where vehicle merges

Figure B-4. Task analysis for entering transition area.

necessary to count those vehicles that still have not merged by the beginning of the transition area.

6. Merge point—as previously noted, lane changing should have occurred prior to the taper, but again, this measure should be obtained for late lane changes.

Work Area and Activity area

The task analysis for the work area and activity area is shown in Figure B-5. By this time, the motorists should have established a new quasi-steady driving state, although there is likely to be more variation in speed and placement because of possible flow perturbations. For example, the driver may feel the need for more cautious driving in the areas where work is actually being performed. Also, because there are more situational cues (construction activity, barriers, etc.) to monitor, there is likely to be more speed and placement adjustment.

The driver's information requirements consist of a continuous reminder of the lane closure (or in more positive terms, delineation of the lane which is open) and the speed limit. Within the work area there may be specific situations (e.g., trucks crossing, use of flagmen, etc.) which will require special signing. It may also be advisable to provide information in areas where there is activity, especially if these are spaced between long sections of nonactivity areas.

Because the driving task is similar to that described for the advance area, the performance measures are also similar. In this case, the measures are influenced by the barriers and, therefore, are appropriate measures for their evaluation.

Exiting Transition Area

The final area of the construction zone is the exiting transition area, where the driver returns to the original highway condition. Because the channelization devices being evaluated in this project are not employed in this area, a task analysis is not presented.

SUMMARY OF PERFORMANCE MEASURES

Figure B-6 summarizes the previous analysis and specifies where the appropriate performance measurements can be collected. Again only one case, the lane closure on a divided highway, is illustrated; but this time a three-lane, one-direction case is used.

From the previous discussion, several potential data collection points can be identified along with the appropriate measures. These include:

A. Advance point—at or before the advance warning sign advising motorists of construction ahead. Should be a "normal" driving condition; therefore, no data collection requirements are anticipated here.

B. Control point—at or just before the beginning of the approach area. The measures noted in Figure B-6 should be used as control values to compare with other points.

C. Approach point—can be arbitrarily established as the midpoint between the beginning of the approach area and the transition area. In this general area, motorists are likely to be involved in speed changes and lane changes. Measures that should be collected include speed (lanes 1 and 2), volume by lane, merge point, and conflicts or erratic maneuvers.

D. Transition point—same measures collected for the approach point should be collected at the beginning of the transition area.

E. Entry point—defined as the end of the transition area. All of the measures noted in Figure B-6 should be collected here.

F. Activity point—at some locations where there is construction activity, the measures noted in Figure B-6 should be collected to determine if they differ from those in a nonactivity area.

G. Nonactivity point—can be any point between E and H where there is no construction activity. The same measures as listed in E should be collected. It is possible that measures for E could be used for this point.

The other data collection points, H and I, are shown in Figure B-6 for completeness but not for locations for data collection, at least in this situation.

REFERENCES

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2. Graham, J. L., Paulsen, R. J., and Glennon, J. C., "Accident and Speed Studies in Construction Zones." *FHWA-RD-77-80,* Midwest Research Institute (June 1977) p. 230.
3. Post, T. J., Robertson, H. D., Price, H. E., Alexander, G. J., and Lunenfeld, H., "A Users' Guide to Positive Guidance." BioTechnology, Inc., and Federal Highway Administration (June 1977) p. 167.
4. Alexander, G. J., and Lunenfeld, H., "Positive Guidance in Traffic Control." Federal Highway Administration (Apr. 1975) p. 57.
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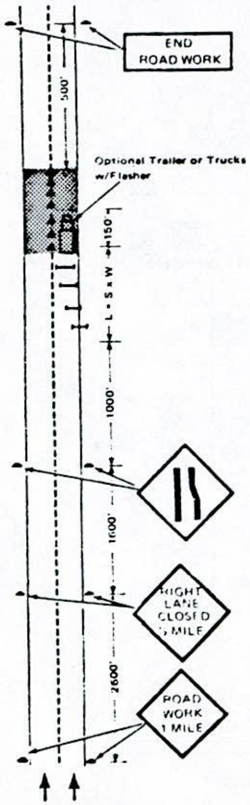
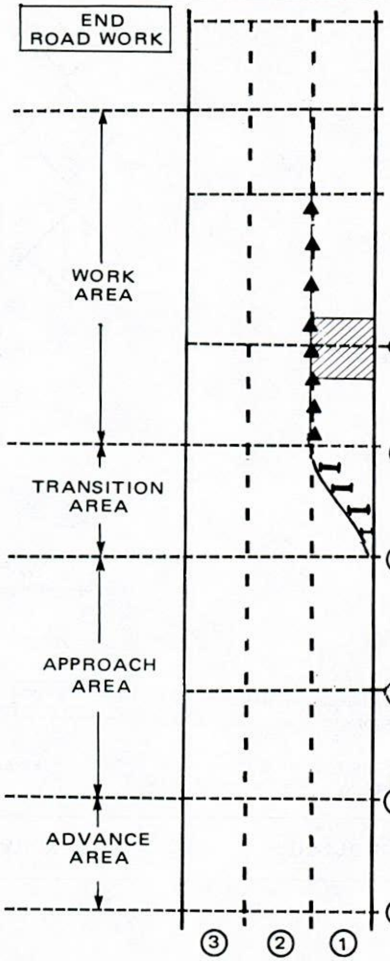
LOCATION	ACTION TO BE TAKEN	INFORMATION REQUIREMENT/SOURCE	PERFORMED MEASURES	COMMENTS
4. WORK AREA (including ACTIVITY AREA) 	A. Maintain new QUASI-STEADY STATE – Speed, placement, headway B. Monitor traffic construction activity for possible speed/placement adjustments	REQUIREMENT Unless there is a change in alinement (curve, cross-Over, etc.) driver needs only to be reminded of lane closure and speed limit. Driver should be made aware of areas where ther is construction activity. SOURCES 1. Barriers, cones, channelization devices 2. Lane markings 3. Construction activity 4. Other traffic	A. VEHICLE 1. Speed a. mean, 85th percentile b. variance c. change from approach area	
			2. Headway	– Compare to headway in advance area
			3. Placement a. mean, also centrality index b. variance c. noise	– Use barrier as reference point
			4. Conflicts – a thru e as defined previously	
			5. Volume (by lane)	– For more than one lane, determine percent in lane nearest to construction area.
			B. DRIVER 1. Preference 2. Anxiety, comfort	

Figure B-5. Task analysis for work area.



Possible Data Collection Points	Measurements					
	Speed	Lateral Placement	Headway	Volume	Merge Point	Conflicts/ Erratic Maneuvers
Ⓘ *Downstream Point* — area of return to pre-construction normal driving.	N/A	N/A	N/A	N/A	N/A	N/A
Ⓗ *End Construction Point* — end of construction and therefore end of device.	N/A	N/A	N/A	N/A	N/A	N/A
Ⓖ *Non Activity Point* — any area between E and H where there is no construction activity and represents "normal" speed/path thru construction.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
Ⓕ *Activity Point* — area(s) of construction activity where drivers may make further modifications in speed/path.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
Ⓔ *Entry Point* — end of transition where drivers have stabilized their speed position, influenced by devices.	Lane 2	Lane 2	Lane 2	Lanes 2 & 3	N/A	Lane 2
Ⓓ *Transition Point* — Begin of taper, final opportunity for merge — highest incidence of transitions, conflicts; directly influenced by channelization devices	Lanes 1 & 2	—	—	All lanes	Lane 1 to 2 and Lane 2 to 3 Measure Over Entire Area	Lanes 1 & 2
Ⓒ *Approach Point* — area where change in speed/path occur and are influenced by channelization devices	Lanes 1 & 2	—	—	All lanes		Lanes 1 & 2
Ⓑ *Control Point* — used for base values which reflect measures prior to influence of channelization.	Lanes 1 & 2	Lane 1, maybe 2	Lane 1	All lanes		Lanes 1 & 2
Ⓐ *Advance Point* — represents "normal" flow measures un-influenced by construction area.	N/A	N/A	N/A	N/A	N/A	N/A

Figure B-6. Data collection points and measures.

APPENDIX C

OPTIMIZATION OF DESIGN CHARACTERISTICS

INTRODUCTION

This research consists of four laboratory studies to examine the design and marking configuration of orange and white stripes as displayed on a number of panel and barricade type forms. The objective was to provide a quantitative evaluation to recommend optimal designs for use on actual work-zone traffic-control devices. The purpose here was not to generate the optimally detectable single channelizing device, but rather to select for field testing those design elements most conducive to detection and identification and eliminate those soliciting consistently poor performance. This was believed to serve a need to standardize and make uniform the displays on traffic controls through and around construction zones, inasmuch as the safe and efficacious movement of traffic through these zones is a crucial issue today.

A primary driver activity is acquiring visual information about the highway and its immediate environs. A wide variety of visual configurations confront the driver, who must constantly search the roadway for appropriate guidance and navigation cues. This search and detection process is particularly important in a work/construction zone setting, where there are unexpected changes in the roadway and often there are many distracting visual cues.

A laboratory setting was used to investigate construction-zone traffic-control device markings. Although a laboratory experiment is not intended to be a direct simulation of the driving task, it can be made more relevant if the subjects' tasks are similar and the information load is similar to that of driving. To accomplish this, a general experimental method emphasizing search and detection performance was designed, and four experiments were performed. The experimental method, analyses, and results are discussed in the following.

EXPERIMENTAL METHOD

A visually noisy and fairly abstract background picture was created. Four of these pictures were placed together to form a square, each quadrant of the square being the same picture. Small stimuli (e.g., bar or panel of a particular stripe width), orange-to-white color ratio, height-to-width ratio, and stripe design (horizontal, vertical, 45° slant, chevron) were placed on one quadrant of the square, and another picture taken. The resultant slide was then projected tachistoscopically at a fast speed (0.4 or 0.8 sec). The subject's task was to search the four quadrants, identify the type of design (horizontal, etc.), and identify the shape (bar or panel). Figure C-1 is a substantially photoreduced copy of the stimulus background (the original is in full color), and Figure C-2 presents selected samples of the device stimuli used for each of the four studies. The blotches of gray on Figure C-1 are different colors on the actual slides. This presents a total image of geometric lines overlaid with color visual noise. In making the stimulus slides, the placement of device stimuli was completely random, both for choice of quadrant and placement within the quadrant.

The construction and projection of each stimulus on the screen were accomplished in such a way as to simulate experience should the actual channelizing devices with 4-in., 6-in., or 8-in. (10.15-cm, 15.3-cm, or 20.35-cm) stripe widths be encountered. This was accomplished by computing the approximate visual angle for each stimulus as it appeared on the screen, then having respondents sit at distances approximating perception of these stimuli at 100 to 150 ft (31 to 46 m). In the four experiments performed, the respondents were seated at 10 to 15 ft (3.1 m to 4.6 m) to simulate this perceptual condition (figures are approximate).

The measures of performance by subjects responding to these stimuli were, thus, a Q score (quadrant detection), a C score (configuration identification), and an S score (shape identification). A subject scored "1" for correct response in each, or zero if incorrect. These three were then summed for each stimulus for each subject to obtain a combined index score for performance for each stimulus. All subjects in each experiment saw all stimuli; therefore, the same basic subjects-by-treatments analysis of variance (ANOVA) could be applied to the performance data obtained. This basic model prevails in all four studies.

In addition, subjects were asked to indicate how confident they were of their responses on a scale of 1 (low) to 5 (high). All of these measures were collected on a response sheet, samples of which may be seen in Figure C-3.

Thirty licensed drivers, ranging in age from 17 to 60 years, were obtained and tested for each of the four experiments. Subject information was collected after each experiment, including age, sex, driving experience, and comments (if any). The stimulus slides were shown and subjects marked the response sheets.

EXPERIMENTAL ANALYSES AND RESULTS

Experiment 1

The purpose of the first experiment was to determine the optimum stripe width for use on channelizing devices. Simulated 4-in., 6-in., and 8-in. (10.15-cm, 15.3-cm and 20.35-cm) stripes were studied. The mean index performance score, as previously described, was analyzed by the subjects by treatments ANOVA.

Before proceeding to the actual findings regarding stripe width, a secondary purpose of this first laboratory study

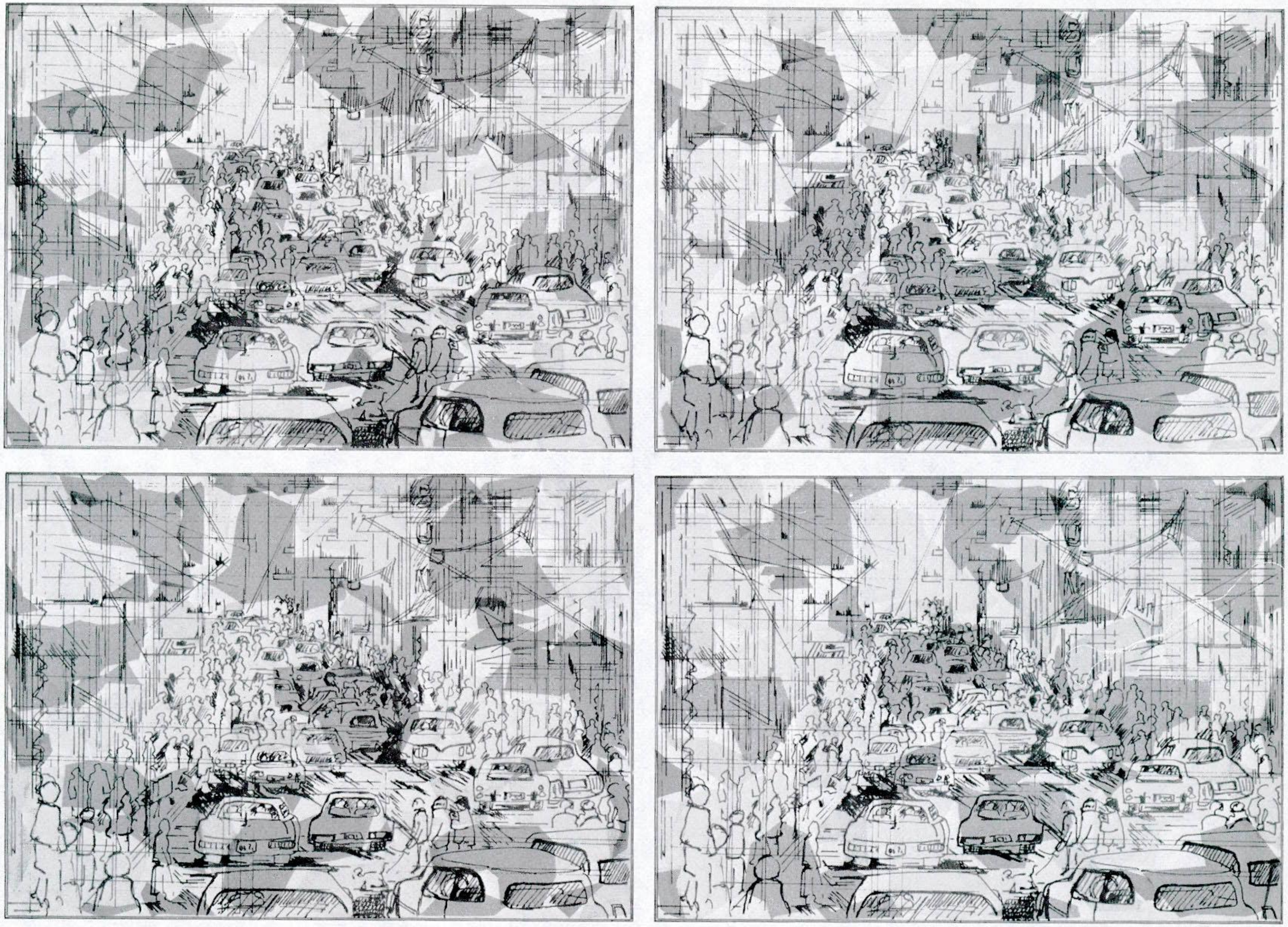


Figure C-1. Background used for experiments.

must be discussed. In a sense this initial study was a proving ground for the studies to follow, in that it examined some of the potential effects of demographic and conditional environmental variables impinging upon the primary factor (e.g., stimulus design). The following are these secondary factors:

1. Males versus females in the sample.
2. Ages of subjects in the sample.
3. Driving experience of subjects in the sample.
4. Exposure duration of stimulus slides.
5. Contrast of stimulus against background—dark versus light.
6. Shape of stimulus device—bar versus panel.
7. Subjective confidence ratings by subjects for each response.

Sex

Contingency tables were drawn up relating sex of respondent to response scores for each slide. Table C-1 shows that z-test scores achieved from both groups are significantly higher than chance in only a few cases. Therefore, the male/female factor for this task was deemed relatively inconsequential. In fact, these empirical data support the findings of most researchers (Eriksen (*1*), who used students to study location of objects in a visual display as a function of various stimulus dimensions and found no evidence of sex difference on performance.

Age and Driving Experience

The effects of age and driving experience followed a similar trend. The sample used consisted of 30 subjects with the following characteristics:

1. Fifteen males and 18 females.
2. Twenty one subjects under 25 years of age and 12 subjects over 25 years of age.
3. Twelve subjects with 1 to 3 years of driving experience and 21 subjects with over 3 years of driving experience.

For the purpose of this study, the sample of the general driving population used was adequately representative to account for any age, sex, or driving-experience-related differences.

Exposure Duration

To examine stimulus exposure duration, the stimulus slides were shown at two speeds, one high (0.4 sec) and one low (0.8 sec). An analysis of variance (subjects by exposure, speed by stripe width) was performed using the mean index scores to determine if the speed of presentation interacted significantly with the design characteristics being tested. The results are given in Table C-2 (F ratios) and Figure C-4 (plot of performance score means). Figure C-4 shows performance scores on a scale of 0 to 100. This is a transformation of the actual raw index score to achieve uniformity for this and succeeding graphs so that they are comparable.

The F ratios indicated significance at the $\alpha 0.001$ level for the exposure speed factor. The rationale behind speed controlled presentations was to induce enough errors to discriminate between stimuli. Therefore, the higher speed (0.4 sec) was chosen for subsequent tests because it showed more clearly the difference between the three conditions of the primary variable (in this case 4-in., 6-in., or 8-in. (10.15-cm; 15.3-cm; or 20.35-cm) stripe width). Table C-3 documents this with the results of t-tests performed between the 4-in., 6-in., and 8-in. (10.15-cm, 15.3-cm, and 20.35-cm) width combinations and shows definite discrimination between performance on 8 in. (20.35 cm) versus 4 in. (10.15 cm) at the faster speed.

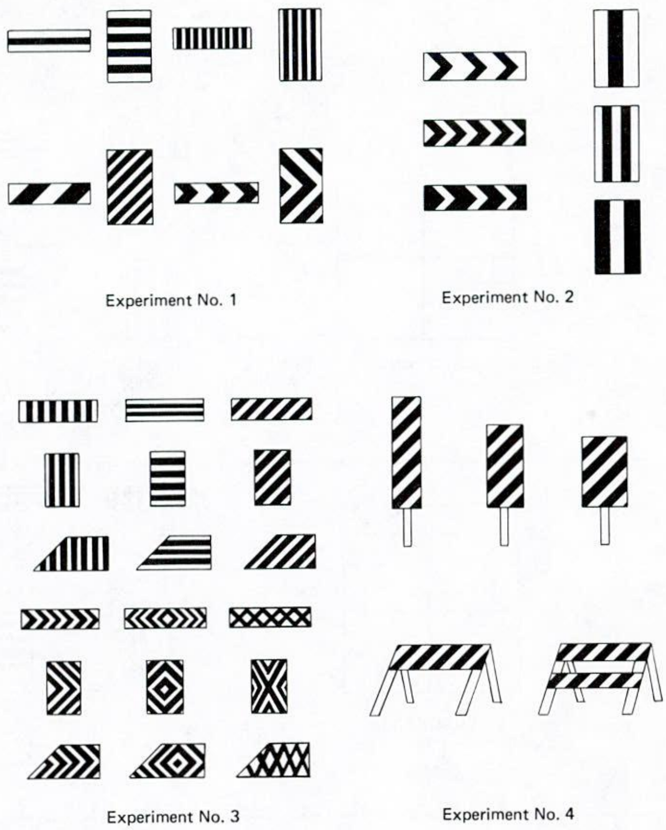


Figure C-2. Samples of some stimuli used in each of the four experiments.

Contrast

Another secondary factor under consideration was the effect of placing the stimulus against a dark background versus placing it on a lighter background. An analysis of variance (subjects by design configuration by background (dark/light)) was performed. Overall contrast was not a significant factor in stimulus detectability (see Table C-4). Most of the variance in subject performance was due to differences in configuration (see Fig. C-5). There was a significant interaction between contrast and configuration, but this has little operational implication because the differences between dark and light backgrounds were not significant.

Shape of Stimulus

An analysis of variance (subjects by design configuration by shape) was performed to determine whether the de-

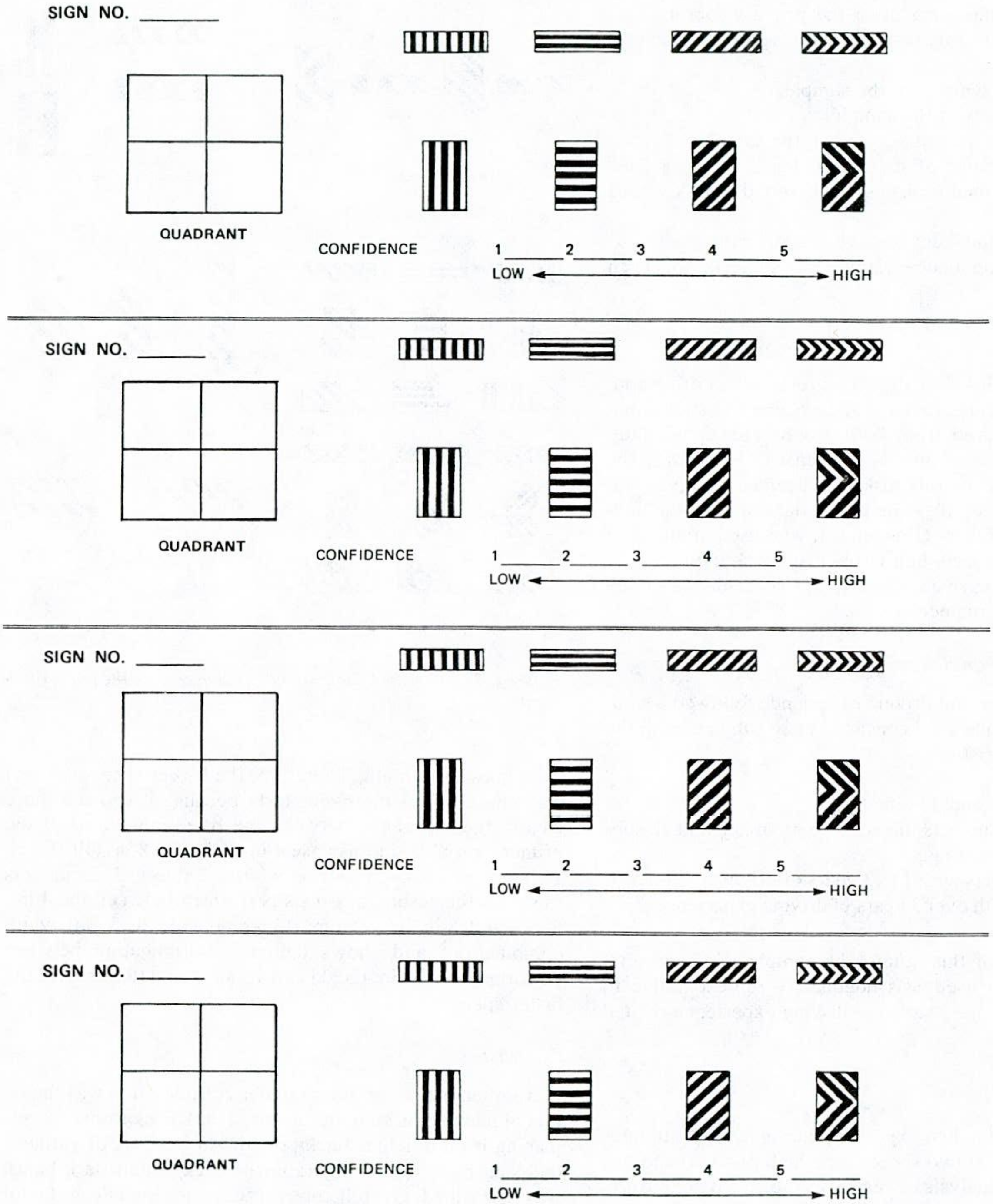


Figure C-3. Sample subject response/data sheet for Task 3 laboratory studies.

vice shape (bar or panel) would play a significant role in detectability.

It was found that device shape was not a significant factor overall (Table C-5 and Fig. C-6). The differences seen in Figure C-5 were not significant, excepting that for the horizontal configuration, a t-test performed between the horizontal bar and horizontal panel produced a t-ratio of 5.34 (df =31), significant at $\alpha = 0.001$.

Because of this significant difference, it was decided to use both bars and panels in the experiments.

As with the previous analysis, the F ratios showed a general disparity in performance among the device configurations (horizontal, vertical, slant, and chevron) with a smaller, but significant, interaction between shape and configuration.

Subjective Confidence Ratings

A table of correlation coefficients was generated to determine whether any relationship existed between the subjects' actual performance (index score) and their confidence in their response (confidence rating) (see Table C-6). Generally,

Table C-1. Comparison of male–female performance in experiment 1.

Stimulus	Source of Score	Female a. Number Subjects	Female b. Number Correct	Female c. Percent Correct	Male a.	Male b.	Male c.	z Value
1	Q[1]	18	8	44.4	16	11	68.8	-1.4249
	C	18	8	44.4	15	8	53.3	-0.5088
	S	18	9	50.0	15	12	80.0	-1.7843
2	Q	18	11	61.1	16	7	43.8	1.0125
	C	18	9	50.0	16	8	50.0	0.0
	S	18	10	55.6	16	13	81.3	-1.5988
3	Q	18	4	22.2	15	5	33.3	-0.7138
	C	18	2	11.1	15	2	13.3	-0.1948
	S	18	5	27.8	15	5	33.3	-0.3458
4	Q	18	10	55.6	16	10	62.5	-0.4108
	C	18	2	11.1	16	8	50.0	-2.4846*
	S	18	12	66.7	16	13	81.3	-0.9623
5	Q	18	15	83.3	17	12	70.6	0.8977
	C	18	11	61.1	17	11	64.7	-0.2199
	S	18	13	72.2	17	14	82.4	-0.7135
6	Q	19	12	63.2	15	11	73.3	-0.6299
	C	18	17	94.4	15	11	73.3	1.6844
	S	18	16	88.9	15	15	100.0	-1.3330
7	Q	17	14	82.4	16	9	56.3	1.6308
	C	17	14	82.4	16	13	81.3	0.0820
	S	19	15	78.9	16	15	93.8	-1.2471
8	Q	18	6	33.3	16	4	25.0	0.5324
	C	18	13	72.2	16	14	87.5	-1.1001
	S	18	15	83.3	16	12	75.0	0.6000
9	Q	18	11	61.1	17	13	76.5	-0.9785
	C	17	6	35.3	17	13	76.5	-2.4180*
	S	17	12	70.6	17	15	88.2	-1.2726
10	Q	17	9	52.9	16	13	81.3	-1.7245
	C	17	11	64.7	16	12	75.0	-0.6432
	S	17	6	35.3	16	9	56.3	-1.2085
11	Q	16	12	75.0	16	13	81.3	-0.4276
	C	16	12	75.0	16	14	87.5	-0.9059
	S	16	2	12.5	16	1	6.3	0.6065
12	Q	17	14	82.4	15	12	80.0	0.1702
	C	17	8	47.1	16	6	40.0	0.4017
	S	17	13	76.5	15	9	60.0	1.0033
13	Q	17	10	58.8	15	7	46.7	0.6878
	C	17	11	64.7	15	7	46.7	1.0268
	S	17	11	64.7	15	8	53.3	0.6538
14	Q	17	10	58.8	15	7	46.7	0.6878
	C	17	8	47.1	15	8	53.3	-0.3543
	S	17	11	64.7	15	13	86.7	-1.4320
15	Q	17	9	52.9	15	8	53.3	-0.0222
	C	17	10	58.8	15	10	66.7	-0.4574
	S	17	15	88.2	15	14	93.3	-0.4938
16	Q	17	9	52.9	15	13	86.7	-2.0544*
	C	16	12	75.0	15	11	73.3	0.1060
	S	16	10	62.5	15	13	86.7	-1.5371
17	Q	15	2	13.3	14	4	28.6	-1.0126
	C	14	9	64.3	15	5	33.3	1.6671
	S	14	5	35.7	15	12	80.0	-2.4200
18	Q	16	2	12.5	15	7	46.7	-2.0945*
	C	15	5	33.3	15	6	40.0	-0.3790
	S	15	9	60.0	15	5	33.3	1.4640
19	Q	17	9	52.9	15	12	80.0	-1.6085
	C	17	9	52.9	15	8	53.3	-0.0222
	S	17	12	70.6	15	10	66.7	0.2389
20	Q	17	10	58.8	15	5	33.3	1.4422
	C	17	9	52.9	15	10	66.7	-0.7890
	S	16	12	75.0	15	12	80.0	-0.3328

[1] Q = Quadrant detection score
C = Configuration detection score
S = Shape detection score
*Significance at .05 level (two-tailed)

Table C-2. Analysis of variance comparing exposure speed and stripe width.

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio
Subjects	6919.6458	31	-	-
Speed	1575.5208	1	1525.5208	136.7545*
Stripe Width (size)	806.1563	2	403.0782	32.2666*
Speed x Size	161.9479	2	80.9740	7.6836*
Error Speed	357.1459	31	11.5208	-
Error Size	774.5104	62	12.4921	-
Error Speed & Size	653.3854	62	10.5385	-
Total	11248.3125	191	-	-

*Significance at the .001 level.

Table C-3. t-Ratios—4-in. vs. 6-in. vs. 8-in. widths.

Exposure Speed	Width (in.)	Sample Size	Mean	Standard Deviation	t-value*	
High	4	32	25.56	6.45555	1.8631	
	6	32	28.81	7.4636	2.3626**	4.6976***
	8	32	32.75	5.7698		
Low	4	32	33.13	7.0058	1.1836	
	6	32	35.22	7.1199	0.4221	
	8	32	35.97	7.0960		

* t-tests for non-independent groups were used here and in subsequent analyses (2).

** Significant at the .05 level between 4 in. and 8 in. and 6 in. and 8 in. for the fast speed.

*** Significant at the .01 level between 4 in. and 8 in. only for the fast speed.

Table C-4. Experiment 1 summary of ANOVA subject vs. design configuration vs. background.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Contrast (A)	1	3.5156	3.5156	0.8720
Configuration (B)	3	551.5469	183.8490	32.8205*
Subjects (C)	31	1192.9844	38.4834	
AB	3	107.0469	35.6823	6.5138*
AC	31	124.9844	4.0318	
BC	93	520.9531	5.6016	
ABC	93	509.4531	5.4780	
Total	255	3010.4844		

*Significant at .01 level

subjects with correct answers showed more confidence in their decision, with most coefficients being 0.45 or above. A few exceptions to this were notable. Twelve percent (6 coefficients) were below 0.25, as shown by asterisks in the table. These were all for stimuli shown against a light background. This could be contradictory to the background versus configuration results in Figure C-5, or it could simply point to a guessing phenomenon. An examination of the placement of these 6 stimuli on the slides revealed that 5 out of 6 of these were located at the very periphery of the quadrants, 4 out of the 6 along the bottom edge. This is an entirely new dimension of the consideration, namely, peripheral versus central fixation and target search behavior. Detailed examination of this phenomenon is outside the scope of this

Table C-5. Experiment 1 summary of ANOVA subject vs. design configuration vs. shape.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Shape (A)	1	7.5625	7.5625	0.5761
Configuration (B)	3	551.5469	183.8490	32.8205*
Subjects (C)	31	1192.9844	38.4834	
AB	3	149.2500	49.7500	10.2988*
AC	31	406.9375	13.1270	
BC	93	520.9531	5.6016	
ABC	93	449.2500	4.8306	
Total	255	3278.4844		

*Significant at .01 level

Table C-6. Correlation coefficients total index score × confidence level.

Configuration		Horizontal		Vertical		Slant		Chevron	
Contrast		Dark	Light	Dark	Light	Dark	Light	Dark	Light
Shape	Width								
PANEL	4	.63	.59	.60	.12*	.81	.88	.62	.21*
	6	.59	.45	.59	.64	.44	.63	.48	.66
	8	.60	.30	.49	.19*	.52	.40	.66	.81
BAR	4	.43	.10*	.30	.57	.58	.70	.58	.35
	6	.73	.16*	.54	.60	.55	.78	.78	.50
	8	.74	.47	.40	.23*	.54	.63	.64	.41

below 0.25

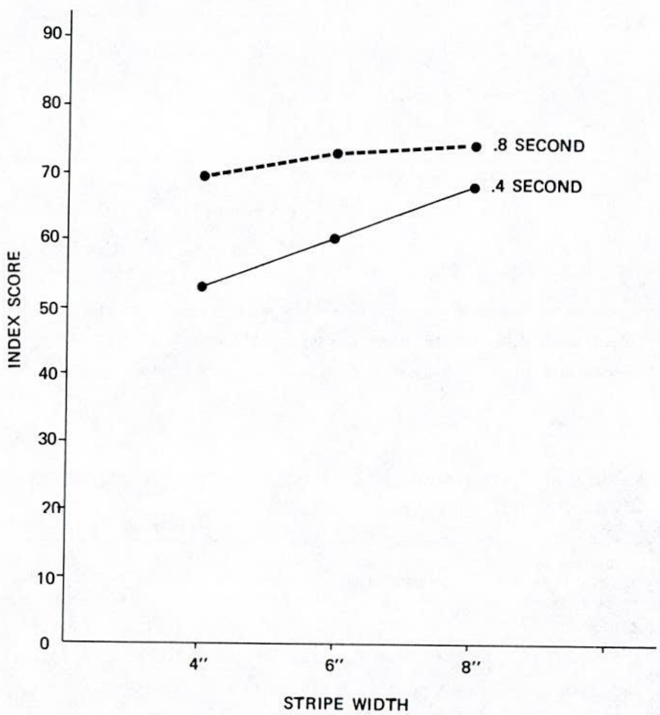


Figure C-4. Speed of exposure vs. stripe width. (Figure C-4 graphically presents performance scores on a scale of 0 to 100. This is a transformation of the actual raw index score to achieve uniformity for this and succeeding graphs to be presented so that they are comparable.)

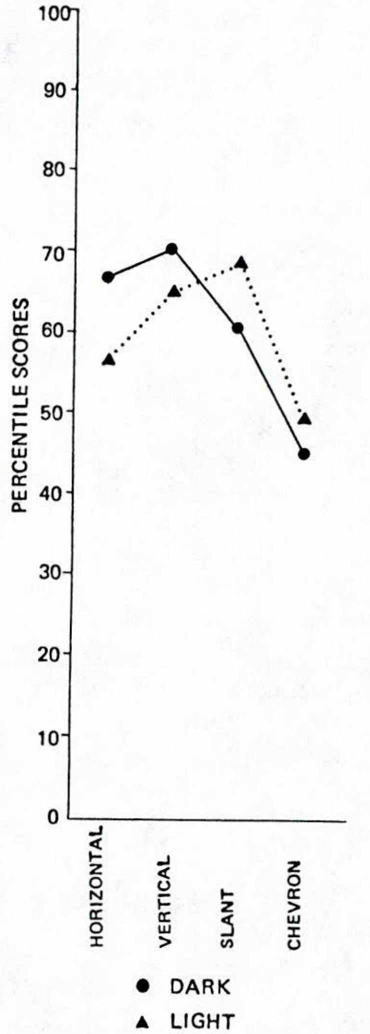


Figure C-5. Contrast vs. configuration.

task. However, it does offer the explanation for low scores and low confidence simply because of missed targets or, conversely, some spuriously good scores due to chance guessing.

With respect to the primary findings of the experiment, the investigation of device stripe width, because there was a question of interaction between stripe width and device shape (bar or panel) separate ANOVAs were performed for each. Tables C-7 and C-8 and Figures C-7 and C-8 present the results obtained. The primary finding in each of these sets of data is that the 4-in. simulated width is clearly inferior to the 6 in. and the 8 in. widths; in most cases, there is statistical significance between the 4 in. and the 8 in. widths. Discriminability between the 6 in. and the 8 in. widths is not as clear nor is it significant, suggesting that either would be acceptable for use on devices in the real world. The 8 in. would seemingly be preferable (especially for larger size devices), because, particularly in the case of the panels, the 8-in scores are all superior to the 6 in. and 4 in. However, the 8-in. stripe is not consistently or significantly so superior to the 6 in. to justify discarding the latter.

The general superiority of the 8 in. width with the concurrent acceptability of the 6 in. does not address smaller issues, such as the discrepancy between horizontal bar versus panel detection, and the emerging inferiority of the slanted, and more apparently, the chevron configurations. Even though performance in 8-in. detection is clearly superior or at least equivalent in all cases, the general poor detectability of the chevron, and to a lesser extent, the slanted design, as well as the horizontal bar with 4-in. and 6-in. stripes is apparent. These underlying trends that surface as a subset of the primary finding account for the significant interactions between width and configuration. Although they do not discount the impact of the basic finding of 8-in. superiority, they do suggest the need for a more detailed analysis of the data, an invitation to hypothesize in a more complex, factorial fashion about the elements actually operating in the perceptual stimulus characteristics of these designs. This was beyond the scope of this study, but its implications are discussed in the concluding sections of this appendix.

Experiment 2

The purpose of the second experiment was to determine the optimal color ratio (white to orange) to be used on barricades, panels, and drums. Each design configuration examined in experiment 1 (horizontal, vertical, slant, chevron) was prepared in a simulated 6-in. stripe width using white-to-orange color coverage of 1:2, 1:1, and 2:1. Because many demographic and methodological variables were considered and mollified in experiment 1, one high-speed stimulus exposure was used (0.4 sec) for all of the slides in this study, and the responses were analyzed directly relating to the primary objective, color ratio. The analysis of variance (subjects by configuration by color ratio) was performed, again using the total index score achieved for each stimulus presentation. Table C-9 and Figure C-9 present the results of this analysis. Clearly, the significant F ratio for color ratio indicates sufficient performance differences due to this factor. In general, the 2:1 white to orange is slightly advantageous although not generally significant from the 1:1. The 1:2 white to orange, essentially an overabundance of orange, is in general inferior, although again, in most cases, not significantly. Logic explains these findings in part. The stimuli were generally seen against a multicolored, visually noisy background, simulating some cluttered construction areas to be found in the real world. The bright white best stands out against this general dim melange of background noise. Were the bright orange to be viewed in a cleaner, open white pavement type situation, results would surely reflect a superiority. Thus, the laboratory conditions have more effectively addressed the more common, visually cluttered and/or dim ambient condition in which equal or more white than orange contrasts with the background.

The general trend wherein the horizontal and vertical configurations effect higher performance scores than the slant and chevron patterns continues as in experiment 1. Notably, however, the traditional slanted pattern in current use does emerge as superior in the 1:1 ratio. In fact, t-tests performed between various parts of designs reveal the significant superiority of the vertical and horizontal patterns over the chevron design. Although this is not the primary problem at hand, the small but significant F ratio for the interaction between color ratio and configuration again emphasizes an invitation to examine more complex issues not within the scope of this study.

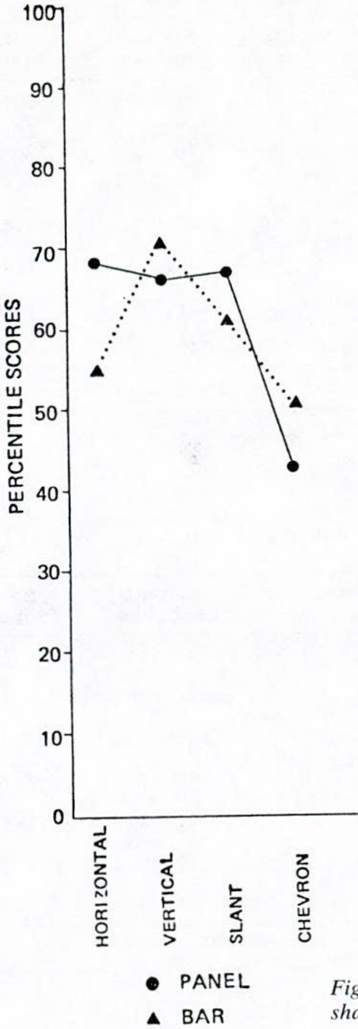


Figure C-6. Configuration vs. shape.

Experiment 3

This experiment had as its purpose the close examination of the actual effectiveness and possible inherent meanings of these device configurations. The first part of the experiment looked at effective detection of some new and old designs, and the second part searched for some meanings within these designs.

Part 1

Here, each of the four standard configurations (horizontal, vertical, slant, chevron) and two shapes were tested, but two distractor configurations (double chevrons and X's) and one distractor shape were tested. Figure C-2 shows examples of these distractor stimuli. The detection and identification procedures for these stimuli were identical to that for experiments 1 and 2. Therefore, an analysis of variance (subjects by configuration by shape) was performed. Table C-10 and Figure C-10 present the results of this analysis. F ratios for

Table C-7. Experiment 1 summary of ANOVA stripe width vs. panel.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Width (A)	2	31.1302	15.5651	9.1297
Configuration (B)	3	158.9453	52.9818	30.5782*
Subjects (C)	31	240.7891	7.7674	
AB	6	27.0156	4.5026	2.4194**
AC	62	105.7031	1.7049	
BC	93	161.1380	1.7327	
ABC	186	346.1510	1.8610	
Total	383	1070.8724		

*Significant at .01 level

Table C-8. Experiment 1 summary of ANOVA stripe width vs. bar.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-Ratio
Width (A)	2	72.2500	36.1250	22.4912*
Configuration (B)	3	74.6536	24.8845	14.2624*
Subjects (C)	31	292.5182	9.4361	
AB	6	96.1667	16.0278	9.1822*
AC	62	99.5833	1.6062	
BC	93	162.2630	1.7448	
ABC	186	324.6667	1.7455	
Total	383	1122.1016		

*Significant at .01 level

the main effects, namely configuration and shape, are significant, but not nearly so as in previous analyses. The interactive effects of configuration by shape also produce a significant F, again underscoring the persistence of underlying factors operating in a complex way rather than in simple incremental levels of one dimension, shown in Figure C-10. Although the horizontal and vertical configurations still exhibit a certain amount of superiority, they also fall below the average scores in certain cases. The chevron design reaches two high peaks on panel and bar shapes, but falls dramatically when placed on the new shape. The new shape, in fact, is the more stable operator within the study because it favors horizontal, vertical, and slanted configurations and declines sharply in performance when containing all the chevron or new designs. The panels and bars are inconsistent in performance as compared to the findings in the previous studies. The general superiority of the horizontal, and particularly the vertical, panel is still established, however.

This task essentially shows performance degradation due to subject confusion by virtue of these distractor stimuli. The basic perceptions of the up-and-down and side-by-side of the horizontals and verticals have effectively been interfered with such that performance has strayed across various dimensions. The distraction elements, in fact, add the touch of realism to the laboratory setting, inasmuch as the real world usually consists of many distractors impinging on any given primary task at hand. The addition of the distractor elements seems to have made the task more difficult for the subjects and resulted in guessing. The findings of Part 1 do not confirm or refute the results of the configuration versus shape study of experiment 1.

Part 2

The second part of this experiment was conducted to determine what, if any, inherent meaning was conveyed by the stimuli presented in Part 1. For example, do the chevrons and stripes indicate a particular direction or path to follow if a driver encounters them in the real world? The test of this question was a forced lane choice, left or right divergence from the center lane of travel on encountering one of the devices in the center lane ahead.

To do this, the subjects were shown a slide of a roadway containing a barricade in the center lane and necessitating a move to the right or left. In this experiment, the background consisted of a drawing of a 6-lane (3 in each direction) freeway. An artist's rendering of this (shown as a substantially reduced black and white picture—the original is in color) is shown in Figure C-11. Models of barricades of the four standard configurations were placed, one by one, in the center lane, and a photograph taken. The slides of the slanted and chevron configurations were made with the pattern pointing to the left and to the right. This allowed for control of possible driver bias to consistently choose one lane over the other.

Subjects were instructed to think of this situation as if they were driving down the middle lane and suddenly came upon the barricade. A slide showing just the roadway was on continuously before the stimulus slide appeared. Subjects were to assume that there was no traffic behind, and were asked which way they would go around the barricade. The configurations were shown in random order, each one being shown twice. Stimulus slides were shown for 1 sec, and the subject had 8 sec to check Left or Right Lane on the response sheet. Thirty subjects participated in this phase of the experiment.

In this task, 24 devices were presented twice in a random order. Therefore, two trials were obtained for each stimulus. Simple frequency counts of the number choosing the right lane versus the number choosing the left lane were accumulated. Then z-test scores were computed to see whether these proportions differed significantly from the chance expectation, 50-50, that no particular lane bias exists given any particular stimulus design. Table C-11 gives the 24 devices shown and the proportions and z-scores obtained for each.

The significant z scores are marked as shown with asterisks. Three basic trends may be seen in these data: (1) the chevron effectively indicates a direction on bars and panels, without question; (2) the "new" shape device with one side pointing left instead of being straight, clearly indicates a direction to the left regardless of the design; and (3) the slanted and even horizontal and vertical lines seem to indicate a direction to many drivers in the bar shape but not in the panel.

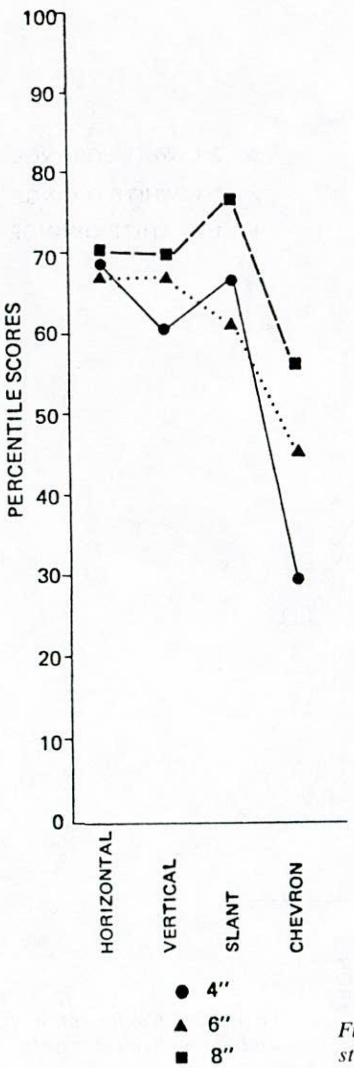


Figure C-7. Configuration vs. stripe width—panels.

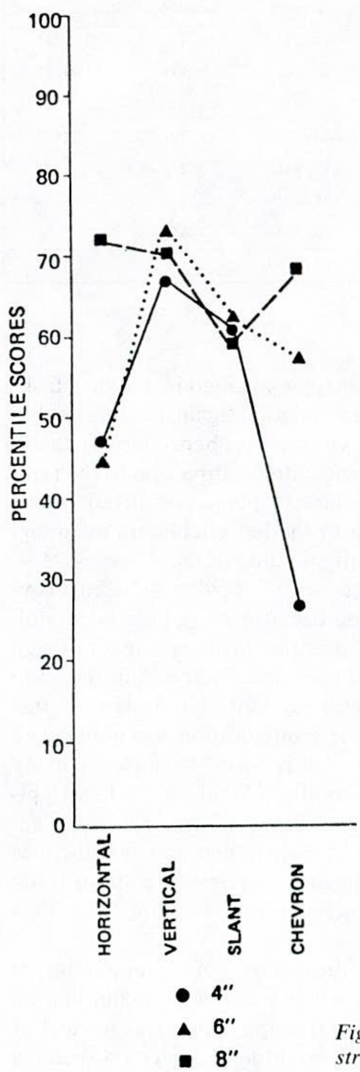


Figure C-8. Configuration vs. stripe width—bars.

Table C-9. Experiment 2 summary of ANOVA subject vs. configuration vs. color ratio.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Configuration (A)	5	336.7795	67.3559	21.9871*
Color Ratio (B)	2	80.4306	40.2153	7.8983*
Subjects (C)	31	896.4288	28.9171	
AB	10	184.4444	18.4444	4.5351*
AC	155	474.8316	3.0634	
BC	62	315.6806	5.0916	
ABC	310	1260.7778	4.0670	
Total	575	3549.3733		

*Significant at .01 level

Table C-10. Experiment 3 summary of ANOVA subject vs. configuration vs. shape.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio Model Three
Shape (A)	2	51.5035	25.7517	7.3259*
Configuration (B)	5	83.2431	16.6486	8.6537*
Subjects (C)	31	446.2153	14.3940	
AB	10	212.2674	21.2267	11.1350*
AC	62	217.9410	3.5152	
BC	155	298.2014	1.9239	
ABC	310	590.9549	1.9063	
Total	575	1900.3264		

*Significant at .01 level

The foregoing points are easily explained in a logical fashion. The chevron, viewed in isolation against a reasonably uncluttered background (as was the case here), looks exactly like a series of arrow heads indicating a direction to the right or left. In fact, this is exactly how responses occurred: in one case a chevron bar pointing to the left elicited an unambiguous left lane choice on both stimulus trials.

The shape or form of the "new" device induced many drivers to select the left lane because its point's edge indicated this direction. This shows the stronger impact of sign forms, even when the design configuration within the form did actually point to the right (i.e., slant right design). In this case, the power of the chevron configuration was diminished by the power of the shape of this form, because as many drivers selected a left lane as did a right lane when right-pointing chevrons appeared on the new form. This, incidentally, is in accordance with the basic perceptual principles stating that form perception and response are more basic than design symbology, which, in turn, is more basic than verbal message.

The bar shape sitting in the center lane is apparently a more realistic-looking channelizing device (looking like an actual barricade) than the panel shape appears as a panel or drum. Many drivers selected a right lane choice on seeing a vertical or horizontal bar. This may well indicate the natural tendency to avoid obstacles to the right rather than the left. The single barricade is a fairly common urban arterial sight, and many drivers may be fairly used to circumventing it around to the right rather than risk oncoming traffic to the left.

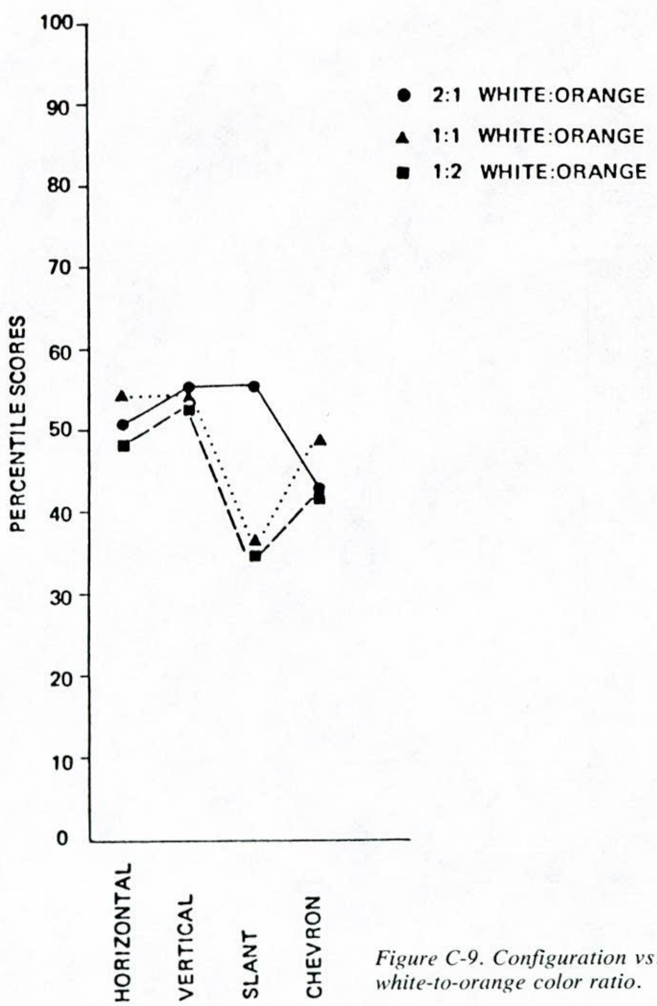


Figure C-9. Configuration vs. white-to-orange color ratio.

Note that these conclusions are based on choice and common sense data rather than on actual performance data as in the preceding portion of the experiment and the previous two experiments.

The detection and identification of the chevrons and slanted patterns were, in general, poorer than that of the horizontal and vertical designs. However, chevrons (and to some extent, slanted lines) seem to convey some directional meaning. The vertical and horizontal designs seem to evoke meaning only when couched in a fairly realistic form recognizable as a barricade. The fact that a chevron carries a strong meaning, but is not as easily detectable as some other patterns which apparently have no meaning, is not discouraging, however, because the ultimate fate of these channelizing devices is not generally to stand alone and be detected as a single unit, but rather to stand as one small part of an entire device array. It is likely that a big enough, bright enough chevron barricade would be highly detectable, but this is not a cost-effective approach. The larger question is the effective detection of these device elements as a part of a larger array.

It is noteworthy that some manufacturers have made de-

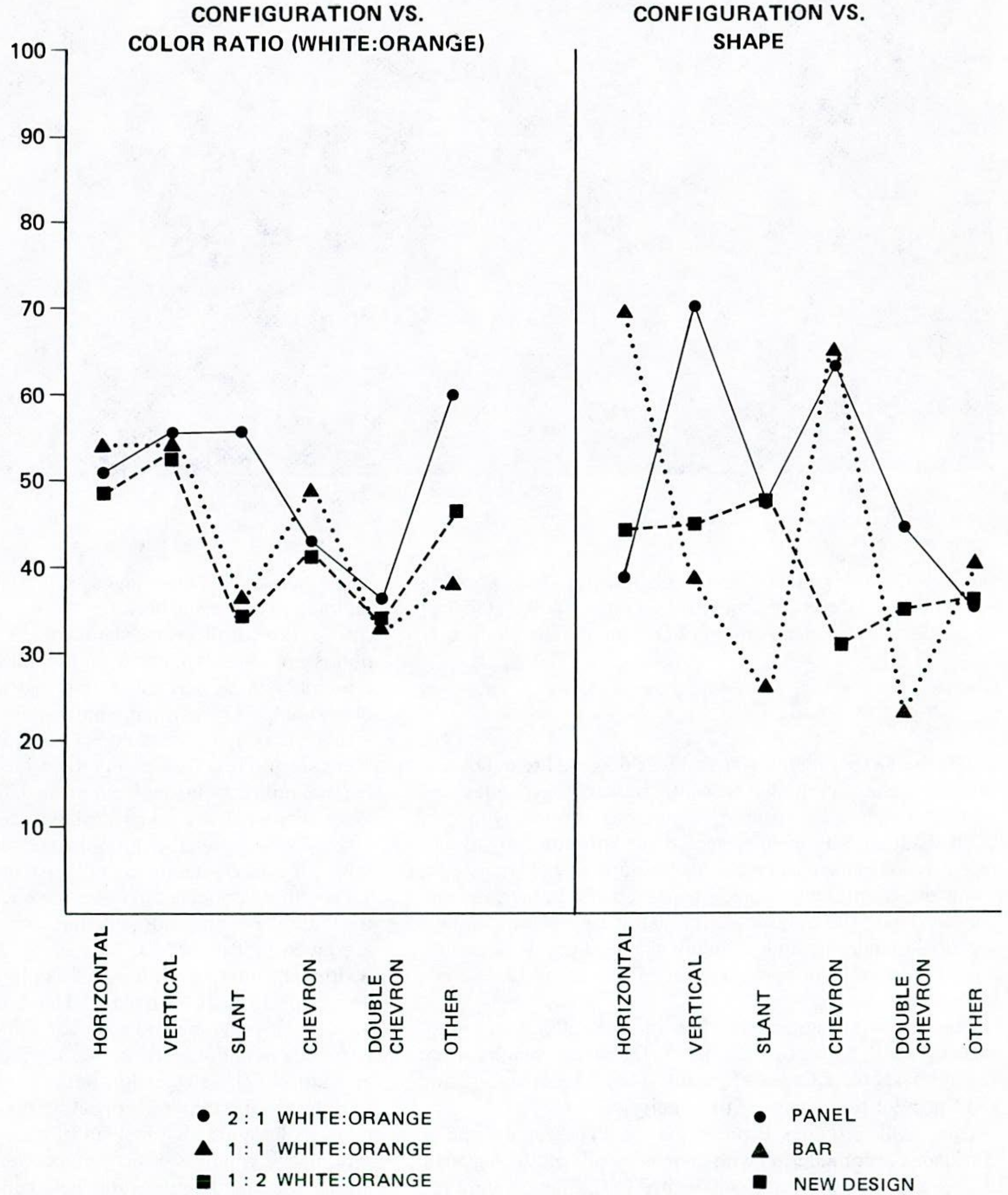


Figure C-10. Summary of ANOVAS, experiment 3.

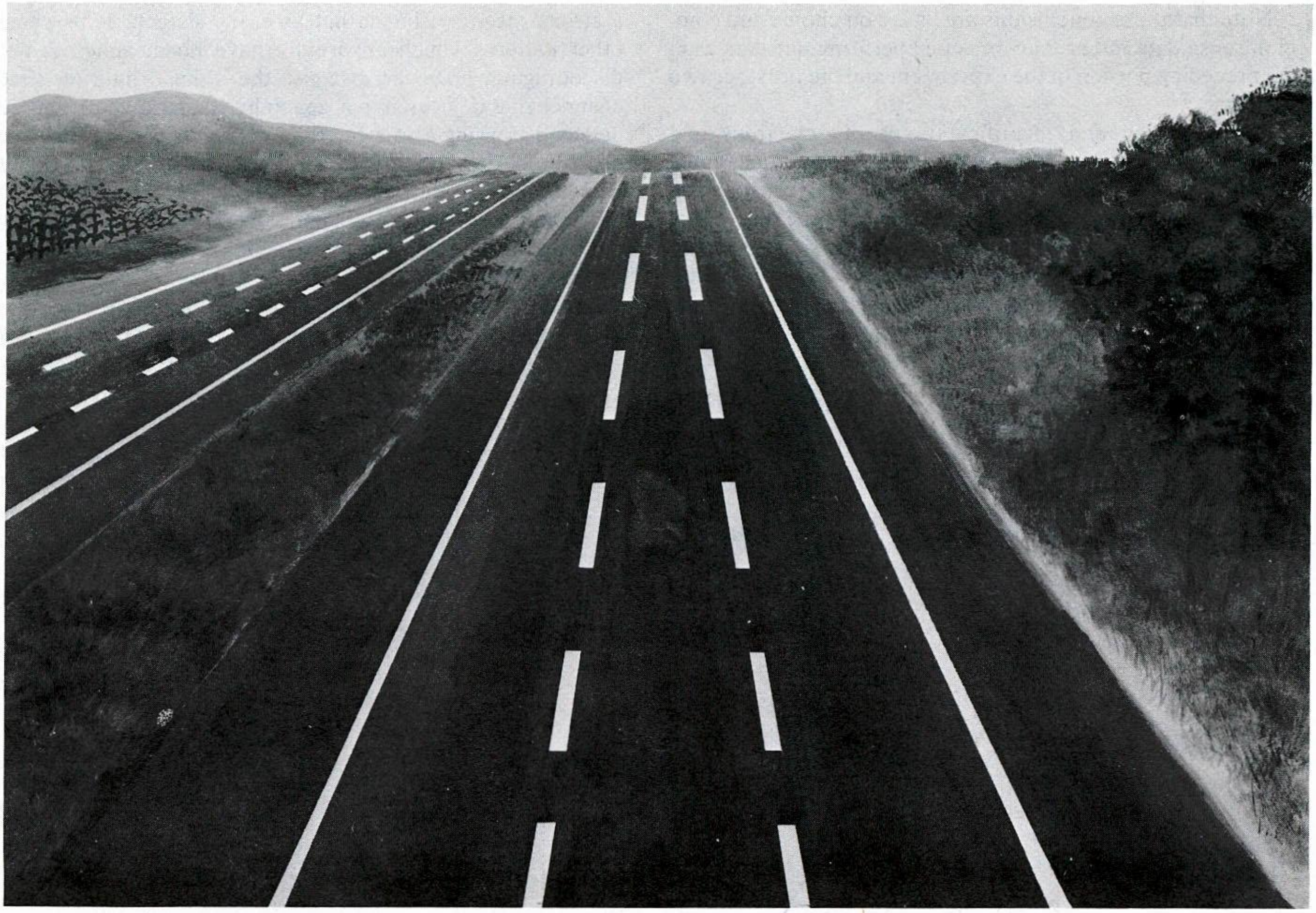


Figure C-11. Background used for phase 2 of experiment 3.

sign modifications to the chevron display (i.e., incorporating black outlines of the arrowheads) for enhanced detectability. These new devices have not yet been empirically evaluated.

Experiment 4

The final experiment of Task 3 was designed to determine the most effective height-to-width ratio of barricades and vertical panels. The four quadrant background with embedded stimuli was again projected tachistoscopically to subject drivers. The design configuration was held constant, using the traditional slanted stripes on the barricades and panels. Thus, the only detection parameters were stimulus location (quadrant) and stimulus shape (Type I barricade, Type II barricade, or vertical panel). These stimuli are shown in Figure C-2.

The data were subjected to two analyses of variance, subjects by width by barricade type or, for panels, height, using the index score. Tables C-12 and C-14 and Figures C-12 and C-13 present the results of this analysis.

Table C-12 provides F ratios for the Type I and Type II barricades in conjunction with increasing rail width. A glance at the graphic representation, Figure C-12, immediately reveals that the main effects are not significant. A divergence occurs between rail width and number of rails beginning with width number 2. This suggests that there is some type of interaction occurring between these parameters, and, in fact, the F ratios for these are significant. The nature of this function is not entirely clear from the data; however, no simple principle can be derived stating that increasing area of display should be separated from one into two rails of a given visual area for optimal detection, because it appears that there are too few data points to define the exact function. A fairly simple conclusion from those data is evident, however. With very small area, or very large area, one-rail or two-rail displays are reasonably interchangeable. Within the medium range of areas—widths 2 and 3—a breakdown does occur. To test these conclusions, t-tests were performed comparing the various rail and width combinations as pairs. These ratios are given in Table C-13. As can be seen, the two extreme widths (1 and 4) do not significantly differentiate between Type I or Type II barricades. The divergence occurs in the middle, as previously suggested. At first a one-rail Type I barricade is significantly better at width 2, then this reverses at width 3. The suggestion here is that the individual rails must be at a minimum width before they are fairly detectable; then, if there are two instead of one, this presents a larger total image which is easily detectable. This is supported by noting the significant t-ratio between the two rail widths, 2 versus 4 and 2 versus 3 comparisons that are highly significant; yet, the one-rail width, 3 versus 4, is significant at

Table C-11. Directional decision proportions and z-scores obtained for channelizing devices.

Description	Trial #1 Proportion L	Trial #1 Proportion R	Trial #1 Z	Trial #2 Proportion L	Trial #2 Proportion R	Trial #2 Z
25 1 Horizontal Panel	.42	.58	1.00	.37	.63	1.53
26 2 Vertical Panel	.27	.73	2.63**	.39	.61	1.34
27 3 Slant Right Panel	.41	.59	0.96	.23	.77	2.96**
28 4 Slant Left Panel	.53	.47	0.32	.58	.42	0.89
29 5 Chevron Right Panel	.06	.94	4.98**	.06	.94	4.92**
30 6 Chevron Left Panel	.97	.03	5.14**	.97	.03	5.14**
31 7 Dbl. Chevron Panel	.40	.60	1.09	.33	.67	1.86
32 8 X Panel	.34	.66	1.72	.29	.71	2.32*
33 9 Horizontal Bar	.27	.73	2.63**	.37	.63	1.53
34 10 Vertical Bar	.26	.74	2.79**	.32	.68	2.01*
35 11 Slant Right Bar***	.23	.77	3.13**	.26	.74	2.79**
36 12 Slant Left Bar****	.52	.48	0.11	.37	.63	1.53
37 13 Chevron Right Bar	.09	.91	4.64**	.06	.94	4.92**
38 14 Chevron Left Bar	1.00	.00	5.66**	1.00	.00	5.59**
39 15 Dbl. Chevron Bar	.38	.62	1.53	.45	.55	0.55
40 16 X Bar	.39	.61	1.34	.33	.64	1.86
41 17 Horizontal New	.97	.03	5.20**	.94	.06	4.80**
42 18 Vertical New	.88	.12	4.19**	.97	.03	5.20**
43 19 Slant Right New	.91	.09	4.53**	.84	.16	3.69**
44 20 Slant Left New	.84	.16	3.85**	.94	.06	4.80**
45 21 Chevron Right New	.53	.47	0.36	.48	.52	0.22
46 22 Chevron Left New	.47	.53	0.45	.48	.52	0.22
47 23 Dbl. Chevron New	.60	.40	1.09	.84	.16	3.69**
48 24 X New	.78	.22	2.83**	.81	.19	3.35**

Significance:
* α = .05 (Z > 1.96)
**α = .01 (Z > 2.58)
***Stripes slant from lower left to upper right corner.
****Stripes slant from lower right to upper left corner.

Table C-12. Experiment 4 summary of ANOVA subject vs. height vs. barricade types.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Rails (A) Type I or Type II	1	0.1856	0.1856	0.2589
Rail Size (B)	3	5.0720	1.6907	2.6261
Subjects (C)	32	52.1667	1.6302	
AB	3	49.6477	16.5492	20.7062*
AC	32	22.9394	0.7169	
BC	96	61.8030	0.6438	
ABC	96	76.7273	0.7992	
Total	263	268.5417		

*Significant at .01 level

Table C-13. t-Ratios—number of barricade rails vs. rail height.

Pair of Conditions	t	df	Significance
Type I vs. Type II Ratio 1	0	32	n.s.
Type I vs. Type II Ratio 2	6.95	32	.01
Type I vs. Type II Ratio 3	4.05	32	.01
Type I vs. Type II Ratio 4	1.50	32	n.s.
Ratio 1 vs. Ratio 2 Type I	4.51	32	.01
Ratio 1 vs. Ratio 2 Type II	2.60	32	.05 only
Ratio 1 vs. Ratio 3 Type I	3.73	32	.01
Ratio 1 vs. Ratio 3 Type II	1.29	32	n.s.
Ratio 1 vs. Ratio 4 Type I	0.14	32	n.s.
Ratio 1 vs. Ratio 4 Type II	1.60	32	n.s.
Ratio 2 vs. Ratio 3 Type I	5.96	32	.01
Ratio 2 vs. Ratio 3 Type II	4.37	32	.01
Ratio 2 vs. Ratio 4 Type I	3.81	32	.01
Ratio 2 vs. Ratio 4 Type II	4.54	32	.01
Ratio 3 vs. Ratio 4 Type I	2.41	32	.05 only
Ratio 3 vs. Ratio 4 Type II	0.36	32	n.s.

n.s. = not significant

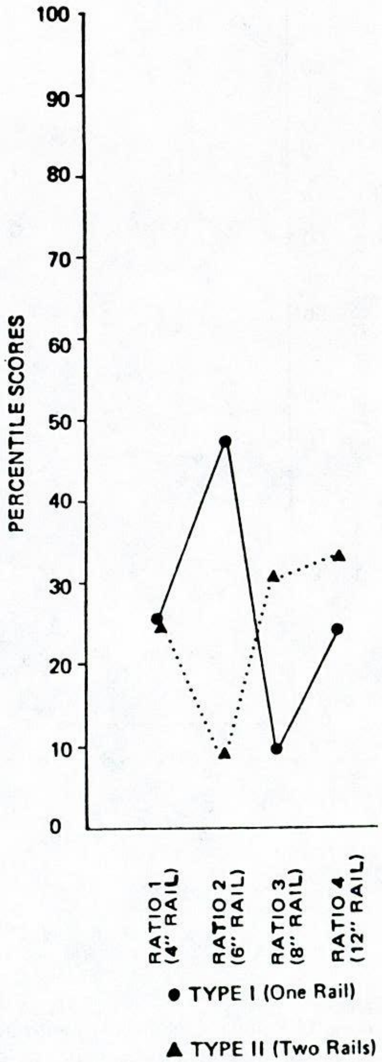


Figure C-12. Rail height vs. Types I and II barricades.

Table C-14. Experiment 4 summary of ANOVA subject vs. panel width vs. panel height.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Panel Height (A)	1	0.0076	0.0076	0.0111
Panel Width (B)	1	10.3712	10.3712	20.2627*
Subjects (C)	32	33.5606	1.0488	
AB	1	0.0682	0.0682	0.1486
AC	32	21.7424	0.6795	
BC	32	16.3788	0.5118	
ABC	32	14.6818	0.4588	
Total	131	96.8106		

*Significant at .01 level

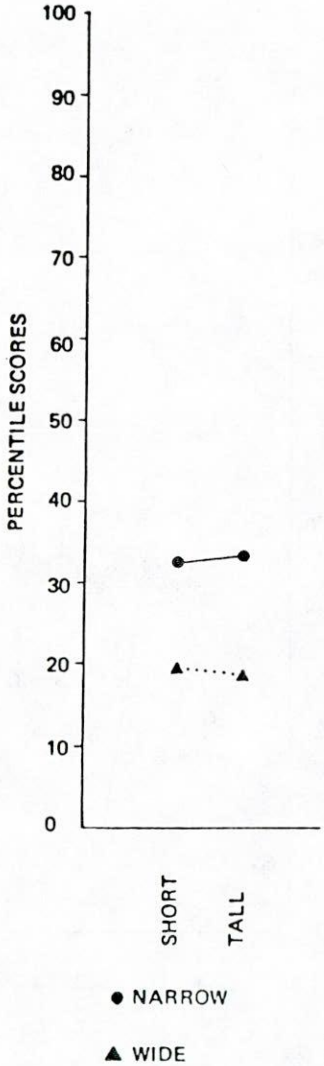


Figure C-13. Panel height vs. panel width.

α = 0.05 only. Essentially, with a two-rail, after a minimal area is achieved, two rails containing this area are optimal, whereas one rail is only adequate in one certain case. The very smallest width (1) seems to present a problem in detection for both one and two rails.

It is fairly obvious that a more complex set of factors, besides simple area of display as seen in one or two rails, is operating here. Apparently, the total image projected by the barricade with bars and stripes that slice up the visual background is related to the way this is embedded in the background, where it is against the background, etc. A simple height-to-width function does not adequately describe all of the factors operating in this situation.

Table C-14 and Figure C-13 provide the results for the height-to-width analysis for vertical panels. Here the findings are clear. A narrow image, whether short or tall, is more easily detected and identified. There is no significant interaction between factors of height and width. This finding is in harmony with data from the previous laboratory studies indicating the overall superiority of the vertical panel as a detection stimulus. Apparently the eye best detects a clear vertical image against the cluttered, dim background of the display. Those targets with more width than height not only within the design but in their forms seem to be generally less effective in detectability.

RECOMMENDATIONS FOR APPLICATION AND FURTHER RESEARCH

On the basis of the laboratory studies reported herein, several conclusions applicable to channelizing devices and recommendations for further testing them in field studies are presented.

1. In terms of shape, the vertical panel is somewhat superior to the barricade on the basis of detection. Because the differences were not extensive, field testing is highly recommended. This testing should consider the effect of a long array of devices as opposed to the single devices seen in the laboratory studies.
2. For vertical panels a tall narrow shape is recommended over a shorter, wider device. This clear-cut laboratory result should be tested further in the field, with the device located in an array and also in a visually cluttered work zone situation in the real world.
3. No clear-cut distinction between Type I and Type II horizontal barricades was found in the laboratory. Both types seem equally detectable. It is recommended that field testing be carried out using Type I barricades. Manufacturing cost and logistical convenience were important considerations underlying this recommendation. (*Qualifications*: Stimuli were only seen against a dim background with high visual noise. Another background may produce somewhat different results.)
4. No one stripe pattern was clearly optimal in the laboratory test; however, the chevron was consistently the least detectable. It is recommended that further study in the field be carried out with all the stripe configurations. If this is not possible, it is suggested that field studies compare the most detectable combinations of stripe pattern and shape (horizontal stripes on a vertical panel and vertical stripes on a horizontal bar) versus the least detectable patterns (chevrons on either shape).
5. For denoting direction the optimal stripe pattern of the six tested is the chevron. No other pattern gave directional meaning consistently enough to be considered a source of directional information. Because these configurations have only been tested singly, it is recommended that they be studied when arranged in device arrays in the field. (*Qualifications*: The general detection and identification of

the chevron was poor. Unless the strong directional image can be more successfully projected, the use of chevrons on barricades and panels of the size simulated in the laboratory is not recommended.)

6. The unusual design used (double chevrons and "X" configurations) was either ineffective or spurious and is not recommended for further consideration.

7. The optimal stripe width is an 8-in. or 6-in. stripe. (*Qualifications*: The 8-in. stripe is preferable, particularly on larger devices, but the 6 in. width is currently used and the evidence is not strong enough to warrant a costly changeover.)

8. The desirable ratio of white to orange on horizontal bars, vertical panels, or drums is equal white to orange (1:1). The results were not highly significant, but this is the ratio in current use, and the cost and logistics of change would not be warranted according to these findings. Use of more orange than white is discouraged. (*Qualifications*: This recommendation is in the context of somewhat dim, visually noisy background as opposed to an open, white concrete pavement, which could optimize a higher ratio of orange. One exception to the foregoing finding is that the stripes in current use today (slanted) are more easily detected when in a white-to-orange ratio of 2:1.)

CONCLUDING REMARKS

The preceding results, discussions, and recommendations have been based on four short laboratory experiments of rather limited scope and purpose. As with most research, more questions seem to be uncovered in the process of conducting the investigations than are answered. A larger problem of greater scope than simple discernments of stripe widths, shapes, and configurations seems to underlie the data. The perception of lines, angles, and edges as they geometrically increase in size is not, apparently, a straight line function perfectly correlated with increased detectability. Rather, the actual image configurations achieved as these lines and forms interact with the display background draw on basic perceptual organizational principles that deserve further investigation. Quite simply, more data points are needed to describe and model the functions of optimal detectability as the parameters of size, height, width, design stripe widths, angularity of designs, appearance against varying ambient backgrounds, position within the entire visual field, and so on, are altered. The search for a "figurally good" image for detection necessitates the testing of many display sizes and configurations to better approximate the continuum of better detection as a function of perceptual stimulus elements. Apparently, a certain arrangement of the design elements against a certain type of background produces optimal detectability. Specification of these parameters based on present data, however, is not possible unless it can be augmented by further study.

A final word may be said regarding the purpose of this study. The determination of optimal stripe widths, color ratios, and height-to-width ratios for barricades, panels and drums, was executed as the driver detected and identified these device simulations in isolation, against a background of visual clutter designed to simulate real world informational loadings. In reality, these devices are not generally perceived standing alone, but as a cluster or array protecting and channelizing traffic away from hazardous zones. Therefore, the design recommendations and findings are "inputs" to field tests which examine these individual devices in combination rather than alone. To reiterate, the purpose here was not to generate the optimally detectable single channelizing device, but rather to select for field testing those design elements most conducive to detection and identification, and eliminate those elements soliciting consistently poor performance. (Specifically, further testing in controlled and real-world settings was performed as Tasks 4 and 5.) These laboratory studies suggest the best and the worst to be tried in the field under real driving conditions to evaluate their ability to effectively display the hazard situation and channelize drivers around it with the least perturbation of their normal driving.

REFERENCES

1. Eriksen, C. W., "Location of Objects in a Visual Display as a Function of the Number of Dimensions on Which the Objects Differ." *J. Experimental Psychology,* No. 44 (1952) pp. 56–60.
2. Runyon, R. P., and Haber, A., *Fundamental of Behavioral Statistics*. Addison-Wesley Publishing Company, Reading (1967).

APPENDIX D

CONTROLLED FIELD STUDIES

INTRODUCTION

The objective of Task 4 was to study parameters of channelizing devices which could not be studied in a laboratory setting (e.g., reflectance, device size, and device spacing). This task also was to further validate certain findings from the Task 3 laboratory studies and to incorporate testing of steady-burn lights.

This task was conducted in two phases. During both phases, a device detection study (experiment 1) was conducted. The purpose of this was to determine maximum detection distance day and night while driving, for each of the devices used in the other experiments. In Phase I experiment 2 was conducted to test 12 channelizing devices set in a standard one-lane closure array. No other signs or markings were used in conjunction with the array. The purpose of the experiment was to examine driver responses in the presence of a particular set of channelizing devices. Phase II consisted of a series of four experiments (numbers 3 through 6) testing device combinations, use of steady-burn lights, and variations on device spacings and design.

METHODOLOGY

Experimental Treatments

In Phase I (experiment 2) 12 devices were compared. These were:

Barricades

1. 3′ × 12″ Type I
2. 3′ × 12″ Type II
3. 2′ × 8″ Type I
4. 2′ × 8″ Type II

} All with 6 in. diagonal stripes and engineering grade retroreflective sheeting

Panels

5. 8″ × 24″ with 4 in.
6. 12″ × 24″ } with 6 in.
7. 12″ × 36″

} diagonal stripes and engineering grade retroflective sheeting

Cones

8. 28″ post
9. 42″ post } with reflective collars
10. 28″ regular
11. 36″ regular } with reflective collars at night

Drums

12. plastic—with horizontal stripes, engineering grade retroreflective sheeting

In Phase II, several comparisons were made, each comparison representing a separate experiment. The following are the treatment conditions tested:

Experiment 3—Steady-Burn Lights and Reflectance

Steady-burn lights on 2′ × 8″ Type I barricades.
Steady-burn lights on alternate barricades.
Steady-burn lights only in the taper.
High intensity reflective sheeting on 2′ × 8″ Type I barricades.
These conditions are also compared with the 2′ × 8″ Type I barricades with no lights and engineering grade retroreflective sheeting from experiment 2.

Experiment 4—Device Spacing

Half the speed limit spacing (*1*).
Double the speed limit spacing. } 8″ × 24″ panels
Half and double the speed limit spacing 2′ × 8″ Type I barricades.
These conditions are also compared with experiment 2 data from the same devices at speed limit spacing.

Experiment 5—Mixed Devices

2′ × 8″ Type I barricades in taper and 36″ cones in tangent.
8″ × 24″ panel in taper and 42″ post cones in tangent.
These conditions are compared with the corresponding single device arrays from experiment 2.

Experiment 6—Best/Worst Validation of Task 3 Markings

Chevrons on 2′ × 8″ Type I barricades.
Chevron on 8″ × 24″ panels.
} This marking was successful in the Task 3 test

Panel (8″ × 24″) with horizontal stripe.
Barricade (2′ × 8″ Type I) with vertical stripe.
} These represented the optimal markings from Task 3

Each of these devices is shown in Exhibit D-1.

A factorial design was used as the basic experimental plan. In this, a group of ten subjects were exposed to one array. Each subject drove a 6-mile test course and was exposed to two arrays. The arrays were separated by 3 miles of driving and several other driving maneuvers (e.g., stop at a stop sign, turn around, etc.). Because of this separation, the assumption was made that exposure to one array had an inconsequential impact on responses to the second array. In addition, devices and array sites were counterbalanced. Thus, about half the subjects exposed to a particular device saw it in array 1 and the other half in array 2. A completely new group of subjects were exposed to the same device arrays at night.

A discussion of the technique used to collect the data in this controlled field test follows.

Data Collection Techniques

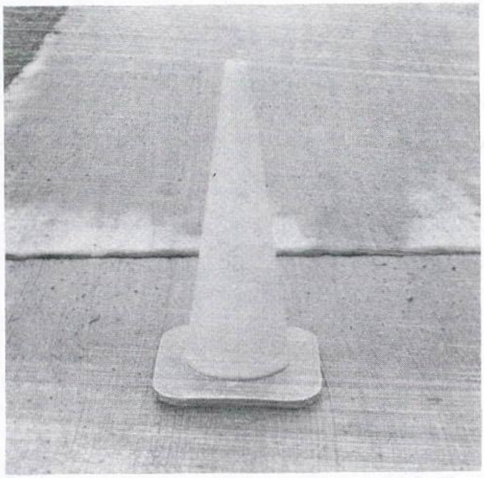
Each subject drove an instrumented car around the closed highway used as the test site. (This car is part of the Driver Performance Measurement and Analysis System (DPMAS) developed by the National Highway Traffic Safety Administration and loaned for use on this project.)

Existing literature fully describes the DPMAS (*2*). In summary, the car is a 1974 Chevrolet Impala with automatic transmission, power brakes, power steering, radio, and air conditioning. A wide variety of driver behavioral and physiological responses, vehicle characteristics, and vehicle motion/position parameters can be measured and recorded. These measures, along with distance and time measures and subject/run identifying information, are digitized and multiplexed onto a magnetic tape mounted on a tape drive in the car's trunk.

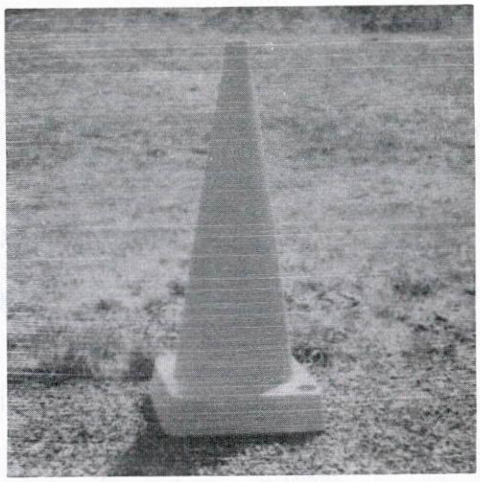
Each subject was tested individually. When the subjects arrived at the test site, they were given a short introduction to the test course, the instrumented car, and their roles as subjects. After entering the car, a subject was briefed on the car and driver tasks during the 6-mile drive. The experimenter rode with the subject and gave more specific directions as required. The experimenter operated the data acquisition system (sensors and magnetic tape unit) and lane tracker video recorder; made keyboard entries; and noted any unusual conditions, subjects' comments, etc. The exact instructions given, plus the experimenter routine, are shown in Exhibit D-2.

At the end of the test course, the subject was given a questionnaire, signed a receipt, and was paid and thanked. Twenty to thirty minutes were required to cycle one subject.

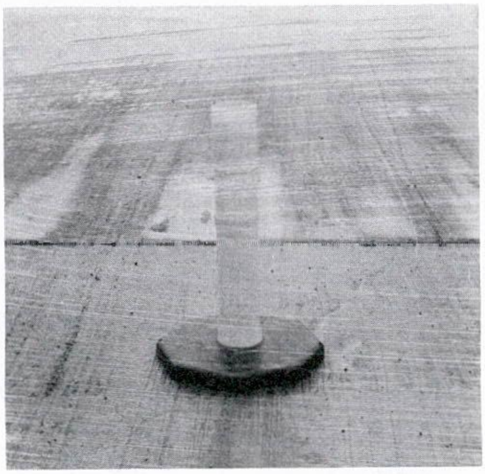
EXHIBIT D-1—Devices Used as Treatments in Task 4



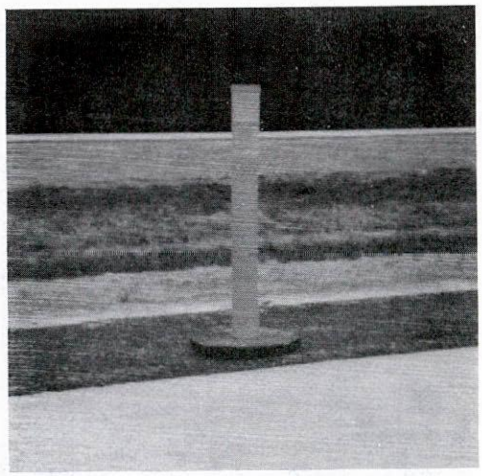
28" Cone – Day Glo Orange



36" Cone – Day Glo Orange



28" Post Cone with Two 4" Reflective Bands



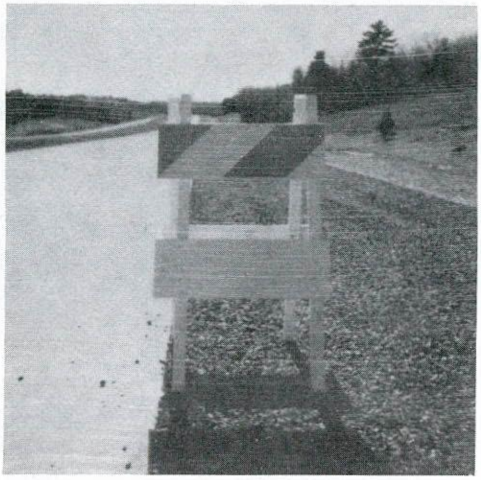
42" Post Cone with Two 4" Reflective Bands

Daytime subjects were run between 10 a.m. and 2 p.m.; early morning and late afternoon hours were not used because the rising and setting sun created unique lighting conditions. Evening sessions began at 7:40 p.m. in experiment 2 and 8:40 p.m. for experiments 3–6, and ran until 11:00 p.m. and 11:40 p.m., respectively.

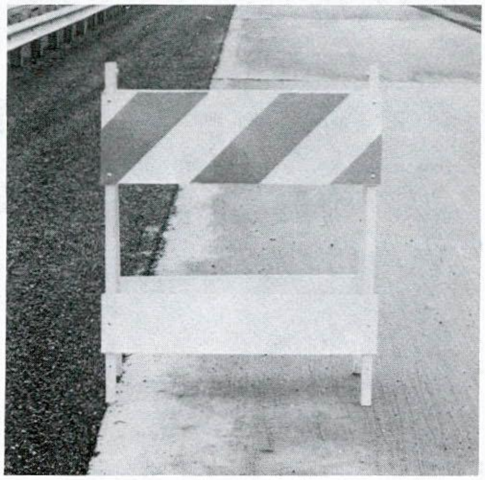
Subjects

Each group of ten subjects exposed to a treatment (device) condition was theoretically composed of two young (16–24 years), two elderly (60 plus years), and four midrange (25–59 years) age people. Half of each group was male, and half female. In fact, scheduling difficulties (e.g., males during the day, females during the later evening hours) did not permit strict adherence to the subject mix for each group of ten. The desired proportions were adequately approximated when each experiment was taken as a whole. Exhibit D-3 gives a more detailed account of the subjects. Each group of ten did have a mix of age and sex groups, but not always in the desired proportions. Because of rain or car failure, 300 subjects were run to obtain the desired sample of 240. After editing and checking data, 10 complete data sets were not available for every condition. However, adequate data were obtained to conduct the planned statistical analyses. Testing could not be extended further because the test course was opened to public use, the DPMAS had to be returned, and the

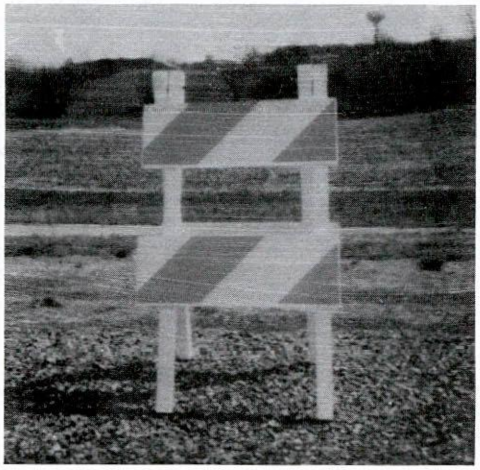
EXHIBIT D-1 Continued



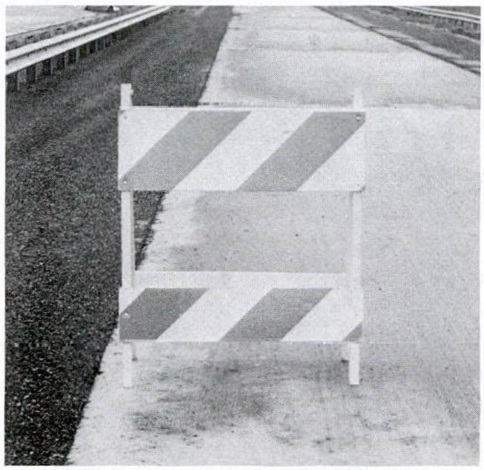
8" x 24" Type I Barricade
with 6" Reflective Diagonal Stripes



12" x 36" Type I Barricade
with 6" Reflective Diagonal Stripes



8" x 24" Type II Barricade
with 6" Reflective Diagonal Stripes



12" x 36" Type II Barricade
with 6" Reflective Diagonal Stripes

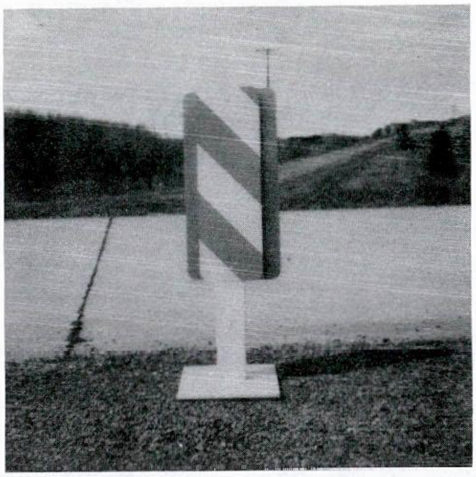
task would have severely exceeded its time and dollar budget.

Measures

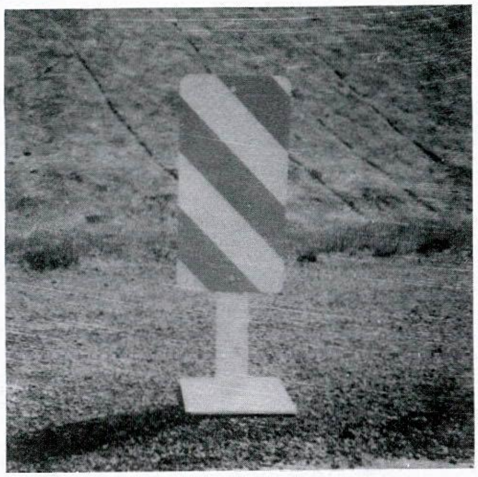
The following measures were taken during the field experiments:

1. Speed—actual vehicle speed; sample rate = 2/sec.
2. Throttle pedal position—excursion, in inches, of accelerator pedal; sample rate = 2/sec.
3. Steering wheel position—location, in degrees, of steering wheel; sample rate = 20/sec.
4. Steering wheel rate—rate of movement in degrees per second of the steering wheel; sample rate = 20/sec.
5. Lateral lane placement—position of vehicle relative to centerline or pavement edge; sample rate = continuous in the daytime and four per array for selected night trials.
6. Brake applications—number of times brake was applied; sample rate = 1/sec.
7. Distance—distance in 1-ft increments the vehicle travelled; sample rate = continuous.
8. Point of lane change—the distance from the first device in the taper to where the left front wheel crossed the centerline while moving from right to left lane.
9. Array detection—distance from the first device in the taper that the subject reported seeing the array.
10. Device detection—distance from a single device placed on the shoulder of the road that subjects first reported seeing the device.

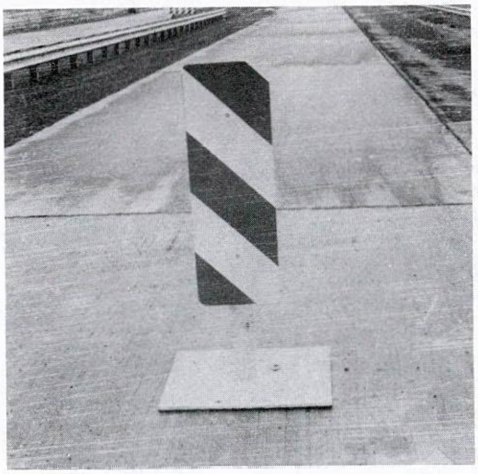
EXHIBIT D-1 Continued



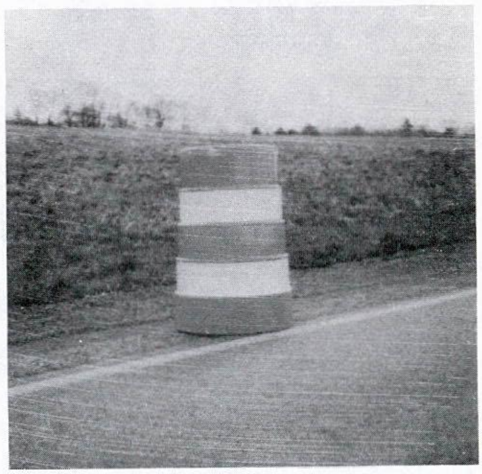
8" x 24" Panel
with 6" Reflective Diagonal Stripes



12" x 24" Panel
with 6" Reflective Diagonal Stripes



12" x 36" Panel
with 6" Reflective Diagonal Stripes



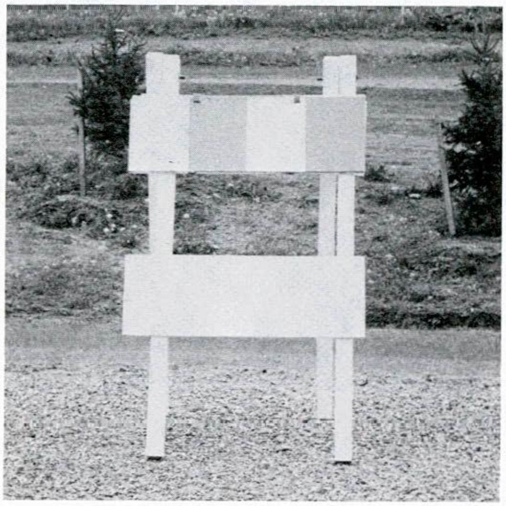
55 Gallon Drum (simulated)
with 8" Reflective Horizontal Stripes

These measures were collected for every subject beginning 5,200 ft before the start of the taper. A note about the lateral placement data: the lane tracker instrument on the DPMAS was not readily usable, therefore a videocamera measuring stick system was attached to the car to gather these data. Lateral placement (in inches from centerline or edge line) was manually coded from the videotape at three set distances prior to the taper, and at four points along the array. The night-only conditions (i.e., steady-burn lights) required a different technique, therefore thin strips (3 ft long) of tape were placed on the road. The distance from the edge of the tire tread to the concrete edge was measured and recorded and the tape replaced after each subject drove past the array.

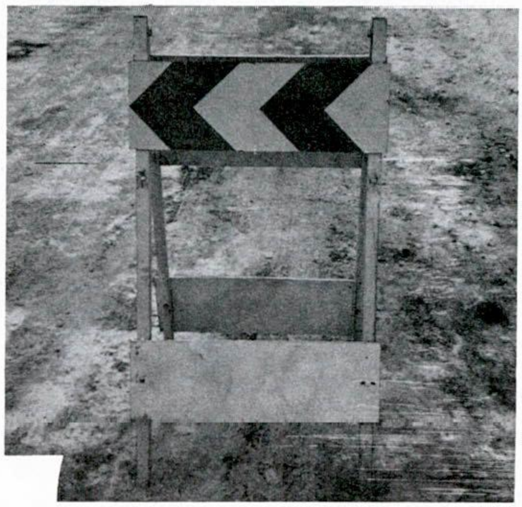
The point of lane change was manually entered by the experimenter via a hand-held keyboard. To reliably detect when the left front wheel hit the centerline, a small "sight" was attached to the hood of the car. When the centerline was visible in the sight, the left wheel was touching the centerline. Array detection was also recorded by the experimenter through the keyboard in response to the subject's indication that the array was sighted. Distance to the taper or tangent could be calculated readily because total distance measurement always began at the same marked point.

Finally, each subject completed a short questionnaire after driving the test course. There was a slight difference between the survey instruments used in experiment 2 and experi-

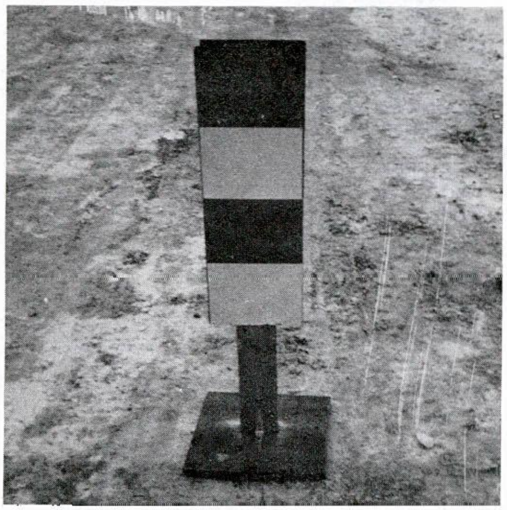
EXHIBIT D-1 Continued



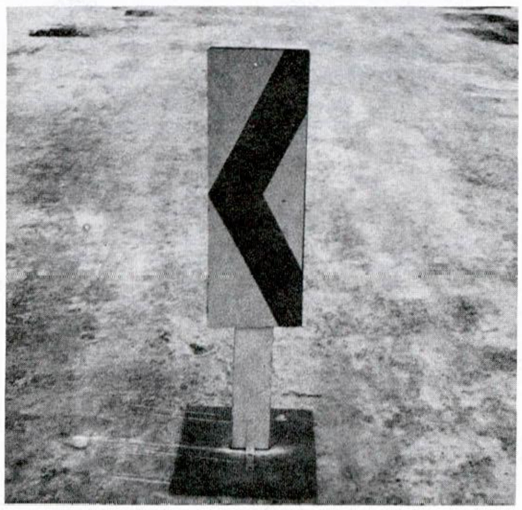
8″ x 24″ Type I Vertical Barricade
with 6″ Vertical Reflective Stripes



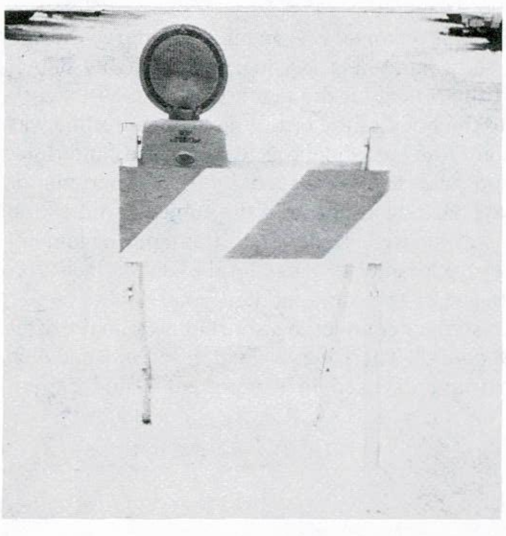
8″ x 24″ Type I Chevron Barricade
with 4″ Reflective Chevron Stripes



8″ x 24″ Type I Horizontal Panel
with 6″ Reflective Horizontal Stripes



8″ x 24″ Chevron Panel
with 4″ Reflective Chevron Stripes



8″ x 24″ Type I Barricade
with 6″ Diagonal Reflective Stripes
Shown with Steady Burn Light

EXHIBIT D-2

INSTRUCTIONS TO SUBJECT DRIVERS

I. Welcome to instrumented vehicle. Drive this car as you would any other. Please:

✓ Buckle seat belt

✓ Check mirrors

✓ Adjust seat and test brake pedal

Let's drive a little for practice so you can get used to the car. Practice accelerating and braking around here. (Point to ramp)

Ready to begin test drive?

II. Ready to Begin

Drive through this course as you normally would drive out on the open highway. This means that you will generally stay in the right lane and maintain a speed of about 50-55 mph. As you go along, you will see various ordinary highway signs and devices such as stop signs, cones, barricades, barrels, etc.

You will need to do three types of things during the drive-through:

(1) At times, apply the brakes and come to a full stop at a stop sign or if I direct you to stop.

(2) Tell me at once - immediately - whenever you first see any signs or traffic devices ahead of you. This is very important.

(3) Finally, drive as you normally would whenever you encounter any signs or devices ahead. You may be forced to change lanes.

Specific instructions and reminders will be given to you all along the way so that you will know what to do. It is important to generally maintain a speed of about 50-55 mph unless you are engaged in a specific maneuver.

Specific Instructions for Each Site Type

I. Rural Stop

Here I would like you to accelerate so that you are driving at normal speed, 50-55 mph. When you hear this tone (beep), apply the brakes and stop, as fast as you can without losing control or skidding.

II. Negotiate Array of Devices

The very first time you see a traffic sign or device ahead, please tell me at once. Continue driving and maneuvering as you would on an open highway.

III. Device Detection

Remember to tell me at once the point at which you see any sign or device ahead. This is the very first time it appears to you on the horizon, even if you cannot tell what kind of device it is.

IV. Set Stop at Stop Line

Be sure to keep up your speed. As we approach these cones ahead, apply your brakes and come to a full stop at the stop line as fast as you can without losing control or skidding.

EXHIBIT D-3

Subject Characteristics Summary

	Phase I (177 subjects)	Phase II (111 subjects)
Age:		
25 or under	68	41
25 - 55	82	60
56 or over	27	10
Sex:		
Female	70	53
Male	107	58
Number of Years Driving Experience:		
0 - 6	56	27
6.1 or more	121	84
Vision:		
Wear glasses	82	59
Bifocals	6	2
Contact lenses	15	5
Miles driven per year:		
Under 2,000	18	13
2,001 - 4,000	32	11
4,001 - 6,000	23	17
6,001 - 8,000	15	10
8,001 - 10,000	18	20
10,001 - 12,000	26	18
Over 12,000	45	22

ments 3–6. The questionnaires used in Phase I and Phase II of Task 4 are shown in Exhibit D-4.

As mentioned earlier, a device detection study was conducted concurrenty with experiments 2–6 during the 6-mile drive. The purpose of the study was to record detection distances for each of the devices used in the other five experiments. Subjects were instructed to tell the experimenter as soon as they saw any kind of roadway sign, marker, or device. The experimenter noted the report with a keyboard entry onto the magnetic tape. A similar entry was made as the car went by the device. Thus, simply subtracting the distance (point seen from point of passing) gave the detection distance measure (in feet). These data were taken day and night.

Test Site

To perform the six experiments, a site was required which had long sight distances (over 5,000 ft), was a realistic freeway-type setting, and was not open to the general public. Pennsylvania State Route 322 by-pass, near State College, a four-lane, divided, limited access facility was complete except for signing and had the required sight distance at two points. It was in a rural setting, therefore there were no major competing light sources.

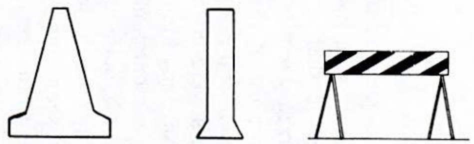
Figure D-1(a) is a photograph of the array 1 site taken over

EXHIBIT D-4— Questionnaires Used in Task 4

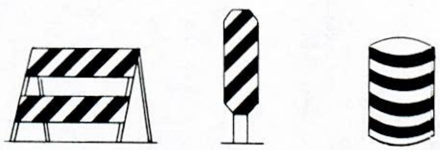
SUBJECT INFORMATION & QUESTIONNAIRE

1. SUBJECT # ____________________
2. MALE _____ FEMALE _____
3. DATE ________________________
4. AGE ________________
5. NUMBER OF YEARS DRIVING EXPERIENCE __________

6. Which of these devices did you see on the road? Check where appropriate.



S	easily			
E E	with moderate ease			
N	with difficulty			



S	easily			
E E	with moderate ease			
N	with difficulty			

7. Why do you think such devices are used? Check all those that are correct.

To indicate to the driver:

_____to change lanes

_____that there was a hazard present

_____to slow down

_____ to stop

_____ to speed up

_____ to continue driving at the same speed

Other. Please specify: ______________________________________

____

8. How many miles do you typically drive in a year?

_____Under 2,000

_____2,001 to 4,000

_____4,001 to 6,000

_____6,001 to 8,000

_____8,001 to 10,000

_____10,001 to 12,000

_____Over 12,000

9. Do you wear glasses?_____ Bifocals?_____ Contact Lenses?_____

10. You will be given a set of photos of construction zone marking devices. Please rank the devices in the order in which you think they are most easily seen.

		Daytime
Easy to see	1	
	2	
	3	
	4	
	5	
Difficult to see	6	

11. Please repeat the same procedure with the second set of photos.

		Nighttime
Easy to see	1	
	2	
	3	
	4	
	5	
Difficult to see	6	

12. Have you any comments about any of the construction zone marking devices shown?

Thank you for participating in the experiment.
We appreciate your help

EXHIBIT D-4 Continued

SUBJECT INFORMATION & QUESTIONNAIRE

1. SUBJECT #________________ 4. AGE________________________

2. MALE_______ FEMALE_______ 5. NUMBER OF YEARS DRIVING EXPERIENCE__________

3. DATE___________________

6. How many miles do you typically drive in a year?

______Under 2,000 ______6,001 to 8,000

______2,001 to 4,000 ______8,001 to 10,000

______4,001 to 6,000 ______10,001 to 12,000

______Over 12,000

7. Do you wear glasses?_____ Bifocals?_____ Contact Lenses?_____

8. You will recall seeing some traffic control markers our on the test drive such as barricades, orange cones, and so on.

Did you have any problems seeing these? Yes_____ No_____

If yes, what? ______________________________

____

Did you have any problems getting around these? Yes_____ No _____

If yes, why? ______________________________

____

____

____

____

9. You will be given a set of photos of construction zone marking devices. Please rank the devices in the order in which you think they are most easily seen.

Easy to see 1. _____
2. _____
3. _____
4. _____
5. _____
Moderately easy to see 6. _____
7. _____
8. _____
9. _____
10. _____
11. _____
Difficult to see 12. _____

10. Do you have any comments or complaints about construction/ work zone set-ups and markers that you see as you ordinarily drive around streets and highways?

____

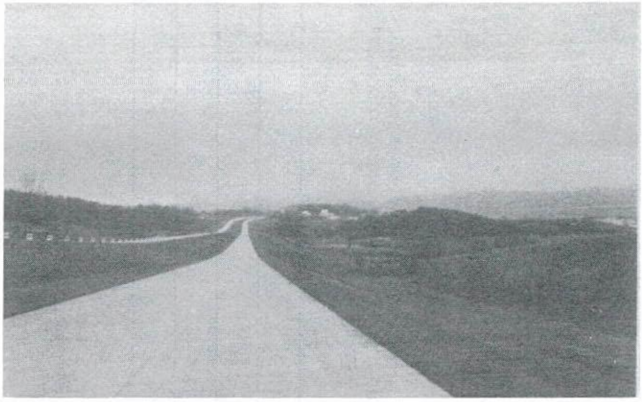
____

____

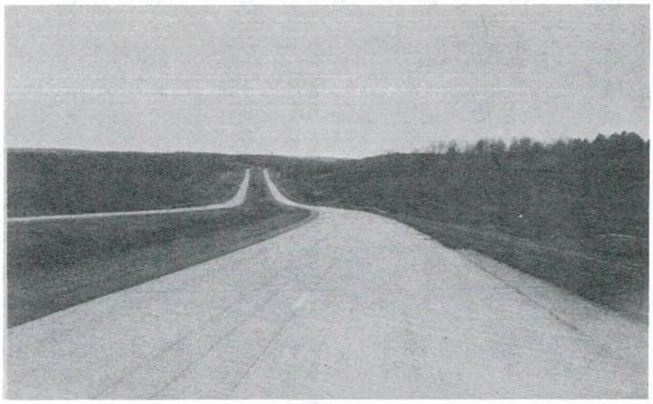
____

____

Thank you for participating in the experiment.
We appreciate your help.



a. View looking toward array 1



b. View looking toward array 2

Figure D-1. Overall view of the sites where arrays were located.

5,000 ft from the beginning of the taper. Figure D-1(b) is a photograph of the array 2 site from a similar distance. These figures show that the geometry is virtually identical for each array site. Figure D-2 is a photograph of the layout about half way through a device detection site.

Figure D-3 shows the layout of each array site. The device detection site was in the first mile of the test drive. Array 1 was approximately 2 miles from the start of the test drive. After passing array 1, subjects drove another mile before coming to the end of the road. The median was crossed on a gravel strip and subjects drove back on the other side of the road about a mile before encountering array 2. The second device detection site was in the sixth (and last) mile of the test drive. Stopping maneuvers were performed after device detection site 1, array 1, array 2, and device detection site 2. These maneuvers, although not performed near the arrays, were included to provide a somewhat more varied test drive.

Finally, Figure D-4 (a through d) shows a device array from each of the major types tested set in "speed limit" (55 ft) spacing arrays (*1*).

Data Reduction

The data were multiplexed and packed on magnetic tape in the DPMAS car. The software available to unpack the tapes was designed for very small sample sizes (i.e., all data channels for one file for one subject were unpacked). Because there were 288 subjects, each with eight or nine files but only five relevant data channels, the time and dollar costs to use the existing software were considerable. Therefore, a new program had to be written and debugged to unpack only the data of interest to this project.

After the data were unpacked, various parametric, nonparametric, and graphical analyses of the data were performed and/or prepared. The following section presents the analyses performed and the interpretation and discussion of the results. Because of the rather large sample sizes and the relatively large number of treatments tested, the 99 percent (0.01) level was used throughout this task as the criterion for a significant difference.

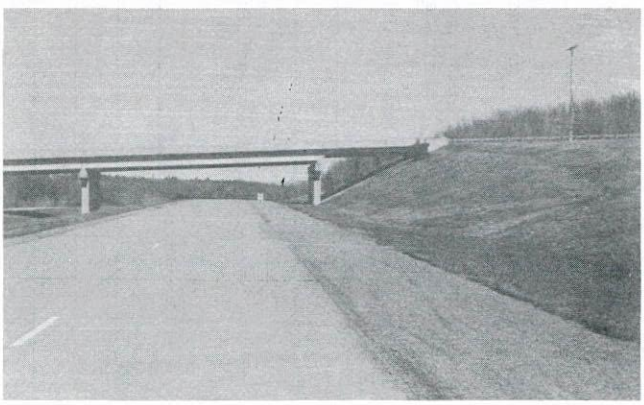


Figure D-2. Single device detection site.

RESULTS AND DISCUSSION OF INDIVIDUAL EXPERIMENTS

Experiment 1

The single device detection experiment was designed to answer the question: Is there any difference in the detection distance of single channelizing devices? Detection distance in this case refers to point of first seeing a device but not necessarily recognizing the pattern on, or type of, device. All the devices tested in the other experiments were also tested in this experiment both day and night.

As subjects drove the test course, they were to tell the experimenter as soon as they saw any signs, markings, or traffic control devices along the test route. The experimenter coded the response through the small keyboard and entered the point the car passed the device. Spurious responses such as, "Oh, I forgot to tell you I could see it," were noted in the log and the data eliminated from the analysis.

Data reduction was simply taking the distance, as measured by the DPMAS, at the two code entry points and subtracting. This gave actual detection distance in feet.

Several statistical comparisons were performed. One-way analysis of variance was applied to the day and again to the night area. The outcome, given in Table D-1, indicates

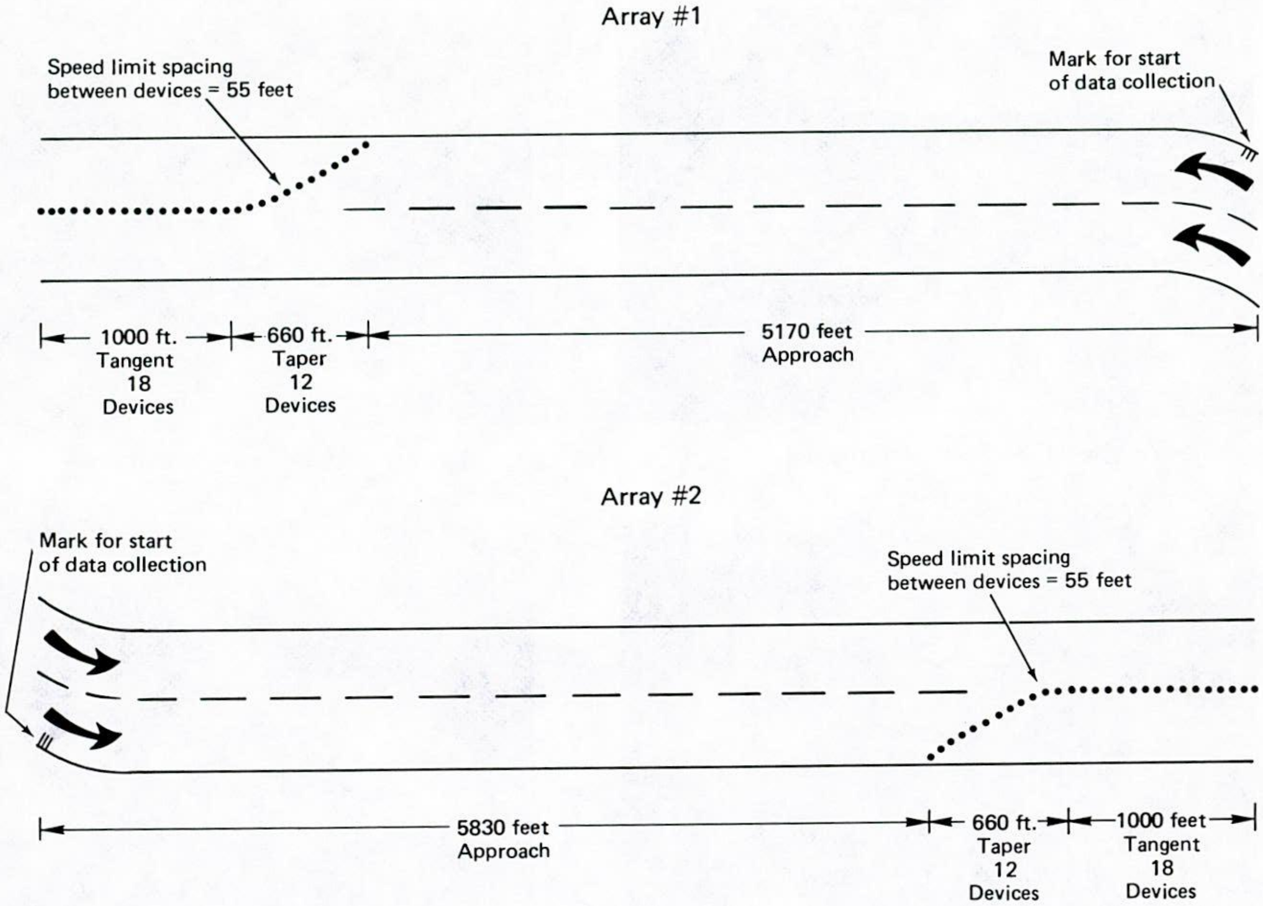


Figure D-3. Layout of array sites.

significant differences between devices both day and night. A t-test comparing day and night data was not significant (t = 0.5, 30 df); however, the performance of specific devices shifted dramatically. To ferret out specific differences between devices, least squared differences (LSD) tests (*3*) were performed. Table D-2 gives the results. The differences are best visualized by referring to Figures D-5 and D-6 which plot the mean detection distance for each device day and night. Several points can be made about these findings.

Daytime Results

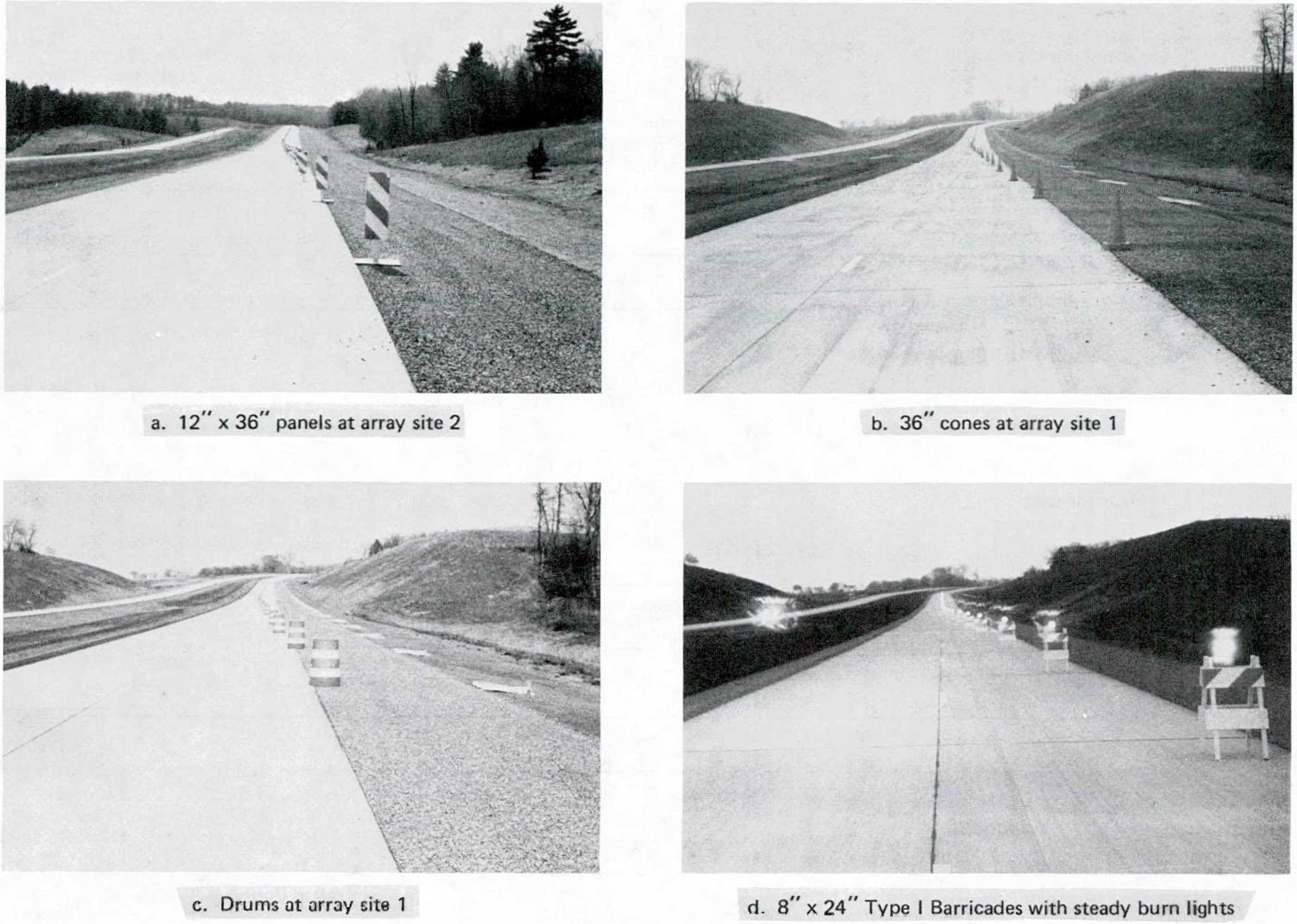
Of the barricade devices, the 2′ × 8″ Type II barricade has significantly shorter detection distances than the 3′ × 12″ Type I. For vertical panel devices, size appears related to detection distance in that the two larger panels are seen further away than the 8″ × 24″ panel. The size or visible area factor was not significant in the laboratory studies of Task 3. However, when real distance and detection, not detection plus recognition, are involved, size does have an impact. Also, the laboratory results did not result in differences between the panel and barricade shape. In terms of detection distance, the panels as a group are clearly the least satisfactory.

Cones, except for the 28″ post, and the drum, perform similarly to the 3′ × 12″ Type I barricade. These devices are significantly better than the panels.

The devices used in experiments 3 through 6 had different patterns but were of identical size as the experiment 2 devices. A comparison of the 8″ × 24″ panel with the chevron and horizontal panels, both also 8″ × 24″, indicates that the three panels are not significantly different from each other and are clearly the least detectable devices in daytime. A similar comparison between the 2′ × 8″ Type I, with nonoperating light on it, and 2′ × 8″ Type I with chevron pattern reveals no significant differences, suggesting that the distances reported herein are replicable and reliable.

Table D-1. ANOVA results for device detection experiment.

	df	F-ratio	p
Day	15/142	10.47	.01
Night	15/180	7.00	.01



a. 12″ x 36″ panels at array site 2

b. 36″ cones at array site 1

c. Drums at array site 1

d. 8″ x 24″ Type I Barricades with steady burn lights

Figure D-4. Sample device arrays.

Nighttime Results

At night there are no statistical differences between the barricades. The 12″ × 24″ panel is detected significantly closer than the 12″ × 36″ panel and 3′ × 12″ Type I barricade. The 12″ × 36″ panel appears, in Figure D-6, very detectable, but it is not statistically different from the barricades or 8″ × 24″ panel. The comparison between the 8″ × 24″ diagonal, horizontal, and chevron pattern panels revealed no statistical differences. This was also true for the 2′ × 8″ Type I diagonal, vertical, chevron, high intensity diagonal and the 2′ × 8″ Type I with steady-burn light. Again, the detection distances appear highly replicable and consistent.

The major, and statistically significant, difference between day and night is in the detection distance of posts and cones. All four posts and cones dropped in detectability at night. As a device group, they were the least effective at night, even with their reflective collars.

Subject Variability

Mean detection distance, although an interesting and useful measure, does not provide a complete picture of driver detection behavior. Variability around the mean is equally important. Two devices may have the same mean detection distance, but the variability (or spread) of the scores around that mean could be very different. An extreme example is shown by the following two sets of scores which have the same mean: (1) 45 50 55; (2) 10 50 90.

On the basis of the Task 2 information analysis of work zones, the optimum performance for detection is maximum distance with the least variation. This is the case because increasing variability may lead to driver uncertainty about what to expect from other drivers relative to the devices; inadequate time to detect, decide on an action, and execute a response; and therefore last minute slow downs, weaving, or other flow perturbations or hazardous maneuvers by drivers close to the device.

Operationally, the decision sight distance concept (*4*) provides guidance as to the minimum distance at various speeds a hazard must be detected to allow adequate recognition, decision, and response execution time and distance. When this concept is specifically applied to work-zone traffic-control devices (*5*), a minimum detection distance at 55 to 60 mph is approximately 1,000 ft. Thus, 1,000 ft is the minimum

Table D-2. Summary of differences in detection distance between channelizing devices.

	Night \ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
3′ x 12″ Type I Barricade	1				**	**	**	**							X	**	**	X	**
3′ x 12″ Type II	2														X	**		X	
2′ x 8″ Type I Barricade	3	X	X	X		**									X	**	**	X	
2′ x 8″ Type I Barricade	4									**	**	**	**		X			X	
8″ x 24″ panel	5									**	**	**	**		X			X	
12″ x 24″ panel	6	**									**	**	**		X	**		X	
12″ x 36″ panel	7						**				**	**			X			X	
28″ post	8	**		**		**		**		**					X	**		X	
42″ post	9	X	X	X	X	X	X	X	X						X	**	**	X	**
28″ cone	10	**	**	**		**	**	**						**	X	**		X	**
36″ cone	11	**	**	**		**		**							X	**	**	X	**
drum	12						**		**		**	**			X	**	**	X	**
Steady burn light on 2′ x 8″ Type I	13						**		**		**	**			X	**	*	X	
High intensity sheeting on 2′ x 8″ Type I	14										**	**	**					X	
8″ x 24″ panel w/horizontal stripe	15						**		**		**	**						X	**
8″ x 24″ panel w/chevron	16						**		**		**	**						X	
2′ x 8″ Type I w/vertical stripe	17							**			**		**						
2′ x 8″ Type I w/chevron stripes	18										**	**							

* Based on the least squared difference (LSD) test (3)
** Sig α .01
X No data

desirable detection distance for devices used on 55-mph highway facilities. This distance decreases for lower speeds.

Now the variability of detection, calculated as a standard deviation, can be subtracted from the mean to determine what percentage of drivers will be able to detect a particular device above or below 1,000 ft. The mean minus 1 standard deviation (SD) encompasses 84 percent of the drivers (all distances above the mean are included in this percent), and minus 2 SD encompasses 97.59 percent of the drivers. Because 1,000 ft is a minimum, all (100 percent) drivers would be a desirable criterion. That is not a realistic goal, however, because many driver factors are not under the highway engineers' control. Therefore, 2 SD or 97.59 percent might serve as a goal.

Applying this criterion—97 percent of the drivers can detect the device at 1,000 ft—to the experiment 1 data results (Table D-3 gives means and SD), only four devices at night (12″ × 36″ panel, drum, steady-burn light, and 8″ × 24″ panel with chevron) and three in the day (42″ post, 36″ cone, and 28″ cone) were successful. An interesting point here is that no device meets the criteria both day and night. Cone detection variability remains relatively low at night, but detection distance is also low. The successful nighttime devices have relatively high mean detection distances in the day, but they suffer from high standard deviations. In terms of detection distance, no device is an unqualified success. However, the major concern in work zones is not with individual devices, but with arrays. A question of particular interest is, What changes in detectability are wrought by placing devices in arrays?

Array Detection

This measure will be discussed as one of several measures used in each of the experiments. However, the comparison with device detection is covered here.

The dashed lines of Figures D-5 and D-6 show the mean array detection distance for each device used in experiments 2–6. An F_{max} test showed the means and SD's of the night data to be heterogeneous, therefore parametric statistics comparing all devices were not warranted. A chi-square test (χ^2 = 3,825 with 10 df, $p < 0.001$) indicated a significant difference between day and night distributions of mean scores. A similar result occurred using the medians as scores. Generally, arrays at night were not seen as far away

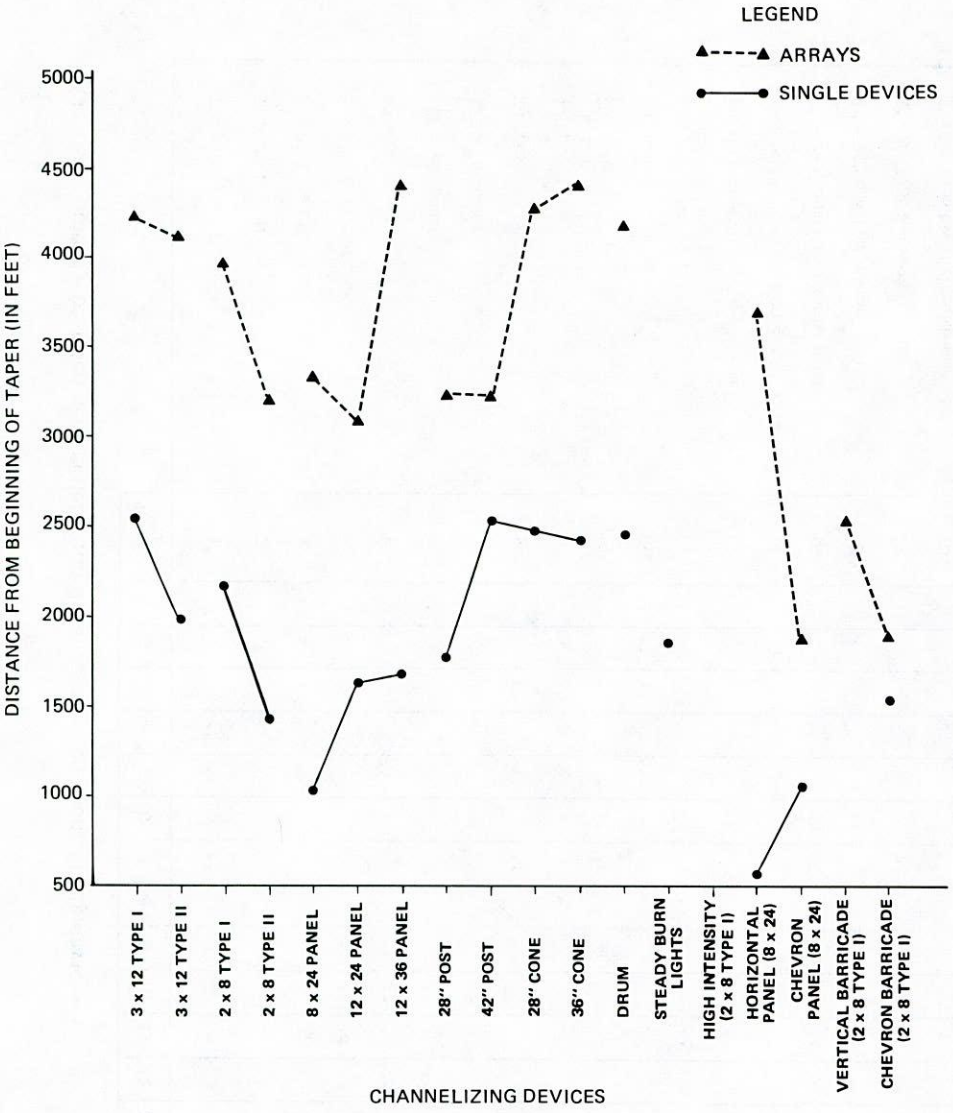


Figure D-5. Mean detection distance—single devices vs. arrays (day).

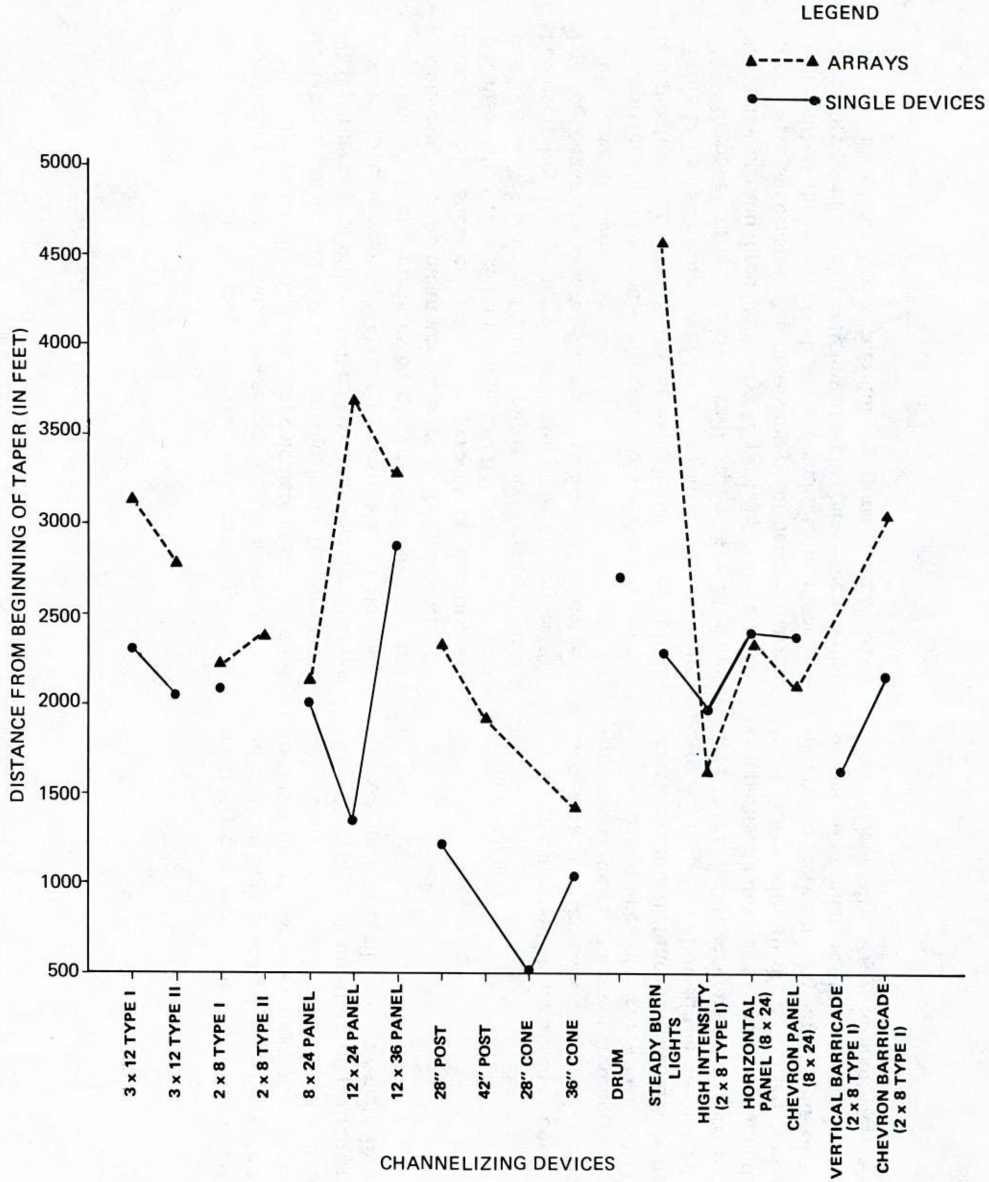


Figure D-6. Mean detection distance—single devices vs. arrays (night).

as arrays in daylight. The major exception was the steady-burn light array at night which was seen farther than any other device, day or night ($\overline{X}$ = 4,565 ft).

At least one device array in each category was detected over 4,000 ft away in the daytime. Generally, these were the larger devices—3′ × 12″ barricades, 12″ × 36″, 28″ × 36″ cones and drums. The point of this finding is that not all devices performed in arrays as would be expected from the single device detection data. This was true of the two smaller panels and the 42″ post.

The device size and array detection relationship was not as clear at night. As in the single device detection situation, the cones reversed their position at night and, as a category, had the lowest array detection distance.

The impact of white reflectorization at night is apparent from the post and cone data. Although these devices had reflective collars, this did not compensate for the smaller visual area. The orange in the daytime provided the needed contrast against a light, bright pavement, but there was insufficient contrast area at night to be seen at great distances. This interpretation is further confirmed by the relatively low standard deviations for the posts and cones at night. Cone SD's were under 700 ft at night; the other device SD's ranged from 750 to 1,250 ft. Such a finding lends credence to the laboratory finding that a 1:1 (white-to-orange) color ratio is optimum when a device must function day and night.

Note that all of the foregoing data refer to detection, not recognition distances. The number of subject comments reflecting the perception of images, specks of light, or patterns of orange or silver lines ahead indicated subjects' detection, but it was not until they were much closer to the array that they could recognize devices, markings on devices, and the fact that the lane was closed. This will be evidenced in experiments 2–6 by the point of lane change which is much closer to the devices than one would expect given the array detection distances.

Summary of Experiment 1 Findings

The findings of this experiment can be summarized as follows:

1. *Day*—Seven of the devices have mean detection distances of 2,000 ft or better. The remaining devices vary from 550 to 1,750-ft mean distances.

2. *Night*—There was no significant difference between day and night mean detection distances for single devices in general (i.e., all devices pooled together). However, there are changes for specific devices between day and night. Cones and the 42″ post, although detected from 2,400 to 2,500 ft in the day and similar in performance to drums and the Type I barricades, shifted to the least detectable device category at night (520 to 1,250 ft) even with reflective collars.

3. *Arrays*—Array detection distance was significantly higher in the daytime than single device detection. Array detection distance at night was significantly higher than single device detection only for certain devices (3′ × 12″ barricades, 12″ × 24″ panel, 28″ post and cone, steady-burn light, 2′ × 8″ Type I with chevron stripe). Array detection in the day was significantly farther than at night. Single device detection scores were not necessarily predictive of array detection distances.

Table D-3. Mean and standard deviation of device detection data for experiment 1.

	Detection Distances			
	Night		Day	
Device	Mean (FT)	SD (FT)	Mean (FT)	SD (FT)
Barricades:				
3'x12" Type I	2311.1	814.81	2543.00	1284.28
3'x12" Type II	2048.25	979.05	1986.20	639.26
2'x8" Type I	2097.50	853.50	2178.70	900.71
2'x8" Type II	Not avail	Not avail	1438.70	821.55
Panels:				
8"x24"	2019.23	674.56	1037.13	630.49
12"x24"	1343.29	414.24	1633.89	854.80
12"x36"	2874.80	291.34	1667.40	460.75
Posts:				
28"	1223.78	261.21	1781.75	748.97
42"	Not avail	Not avail.	2521.20	668.18
Cones:				
28"	520.28	297.08	2543.19	445.80
36"	1045.94	638.12	2490.31	640.92
Drum:	2700.22	645.50	2448.73	822.73
Combinations:				
2'x8" Type I + Steady burn light	2151.50	292.82	1857.00	815.66
2'x8" Type I + High intensity sheeting	1616.13	708.41	Not avail	Not avail
8"x24" Panel + Horizontal stripe	2378.14	721.11	549.11	476.79
8"x24" Panel + Chevron stripe	2407.00	591.84	1048.57	532.86
2'x8" Type I + Vertical stripe	2288.00	894.78	Not avail	Not avail
2'x8" Type I + Chevron stripe	1977.50	1148.66	1525.00	1144.39

4. *Variability in Detection*—Considerable variability around the mean detection scores was evident. Using a 1,000-ft detection distance as a minimum, the 12″ × 36″ panel, drum, steady-burn light, and 8″ × 24″ panel with chevron could meet the criterion of 97 percent (2 SD's) of drivers at night. In the day only the 42″ post, 36″ cone, and 28″ cone met the criterion for 97 percent of drivers.

Experiment 2

Several questions were addressed by this experiment including: (1) What effects do various categories of channelizing devices have on driver behavior? (2) Are channelizing device effects on driver behavior different under day and night visibility conditions? (3) What effect does device size have on driver behavior? (4) Does device shape have an impact on driver behavior?

To verify the laboratory findings of Task 3, specific hypotheses were generated that are related to the four general questions. With respect to question 4, in the laboratory findings there were no consistent differences between the bar and panel shape. *Hypothesis*: There will be no difference between barricade and panel shaped devices.

With reference to question 3, the laboratory results indicated no differences between narrower, shorter, and longer wider panels. *Hypothesis*: There will be no driver performance differences between the 8″ × 24″, 12″ × 24″, and 12″ × 36″ panels. Differences between larger and smaller barricades with one or two rails were not clear-cut in the laboratory and smaller one-rail barricades were recommended over two-rail, mainly for logistic and cost reasons. *Hypothesis*: There will be no differences in driver behavior elicited by one-vs. two-rail or large (3′ × 12″ rails) vs. small (2′ × 8″ rails) barricades.

One hundred seventy-seven subjects participated in the experiment and it was conducted as described in the "Methodology" section. The treatments used were the 12 devices noted earlier and described in Exhibit D-1.

The DPMAS generated continuous and vast amounts of data per subject. To reduce the data for further statistical analysis and to gain insight into the effect of the channelizing devices, each array site was divided into four distance groups defined as:

- Distance group 1= 1,000 ft beginning at the start of the array site (see Fig. D-2).
- Distance group 2 = 800 ft from the point of the taper upstream.
- Distance group 3 = 660 ft from the beginning to the end of the taper.
- Distance group 4 = 800 ft from the beginning of the tangent and extending downstream.

Data for each subject were summed and divided by the total number of data points to arrive at a mean for each distance group. The mean for each driver was used as a performance score and served as the input to further data analysis. This same procedure was followed for experiments 2–6 analyses.

Speed Data

A three-way analysis of variance (ANOVA) for repeated measures (*6, 7*) was applied to the speed data. The three variables tested were day vs. night, the 12 devices, and the repeated measure, distance groups. Table D-4 summarizes the results. The significant differences were between distance groups, the day/night by distance group interaction, and the interaction of the three variables. Thus there are no general differences in speed elicited by the channelizing devices. Neither is there any difference between driver speed performance in the day and at night. Figures D-7 and D-8 are useful in assessing these findings.

To determine the elements contributing to the effect of distance, Sandler's A statistic (*8*), a test of differences between correlated samples, was used. There were no significant differences in speed between distance groups 1 and 2 (A = 1.4, 23 df) or 2 and 3 (A = 0.57, 23 df) day, night, or combined. The significant difference between distance groups is attributable to the significant decrease in speed from the taper to the tangent (A = 0.05, 23 df, $p < 0.001$) both day and night. As drivers came closer, particularly in a lateral direction, to channelizing, they reduced speed.

The two significant interactions suggest that devices elicit different behavior in the day and night between the two distance groups. Again, Sandler's-A was used to elicit specific effects. In the daytime, there were no differences between categories of devices. However, when the devices were separated into large and small categories (see Table D-5), there was a significant decrease in speed (A = 0.199, 5 df, $p < 0.01$) between distance group 3 and 4 only for the large group. Thus, size of device is the predominant factor in eliciting speed reduction as the driver approaches and enters the tangent section of a work-zone lane-closure device array.

At night both large (A = 0.189, 5 df, $p < 0.01$) and small (A = 0.209, 5 df, $p < 0.01$) devices induced significant speed reduction. See Table D-6 for mean speeds. A parameter other than size was affecting behavior. Tests of device categories showed that barricades (A = 0.27, 3 df, $p < 0.01$) and panels and drum (A = 0.25, 3 df, $p < 0.01$) elicited significant speed reduction, but cones (A = 0.4, 3 df, $p > 0.05$) did not. Such a differential effect of devices in day and night illumination explains the two significant ANOVA interactions.

In summary, the channelizing devices tested have little impact on driver speed behavior until the driver reaches the tangent section of a lane closure work zone (i.e., next to the devices). During daylight, the larger devices, regardless of device category (cone, panel, barricade, drum), elicit a significant reduction in average speed (approximately 2 mph), whereas smaller devices do not have such an effect. At night, size is not a controlling variable; rather, barricades, panels, and drums (but not cones and posts) cause speed reductions averaging 2.5 mph from drivers.

Lateral Placement

These data were manually reduced from the videotapes of the measuring stick extending perpendicular from the side of the car. Readings were taken at three points along the approach to each array; 5,000 ft, 2,500 ft, and 800 ft prior to the start of the taper. Five equidistant readings were taken along the tangent section, beginning with the first device in the tangent. All data reported here were taken as part of the daylight tests.

A one-way analysis of variance showed that there were no significant differences in mean lateral placement between the 12 devices along the tangent (F = 1.09, 11/128 df). The spread of mean scores for the 12 devices was under 5 in. However, devices have a distinct impact on lane placement. Figure D-9 shows the mean (across all devices) lane placement at each measurement point. Before the array placement averaged 21 to 24 in. from the centerline, but in the tangent section, placement was 49 to 52 in. from the centerline. Channelizing devices had the effect of shifting vehicle placement in the lane by 28 in.

Means do not give a complete picture of driver performance. Equally important is the distribution of individual driver data around the group mean for each device. Such variance is an indication of the consistency of the effect by a channelizing device on lane placement. First, a Sandler's A test showed there was a significant decrease (A = 0.124, 11 df, $p < 0.01$) in the size of the standard deviations (6.5 to 4.12) from the approach to the tangent section of the array. The range or spread of standard deviations reflects this effect. Standard deviations (SD's) in the approach were 4.98 to 10.12 in., while in the tangent they were 3.23 to 5.55 in.

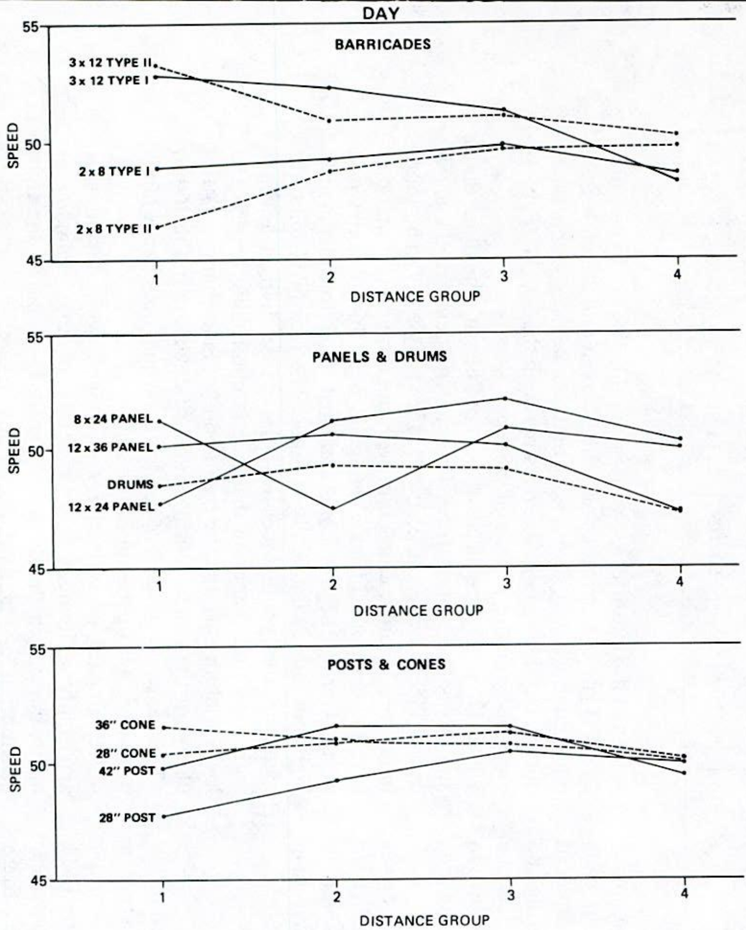


Figure D-7. Mean speeds for devices in experiment 2 (day).

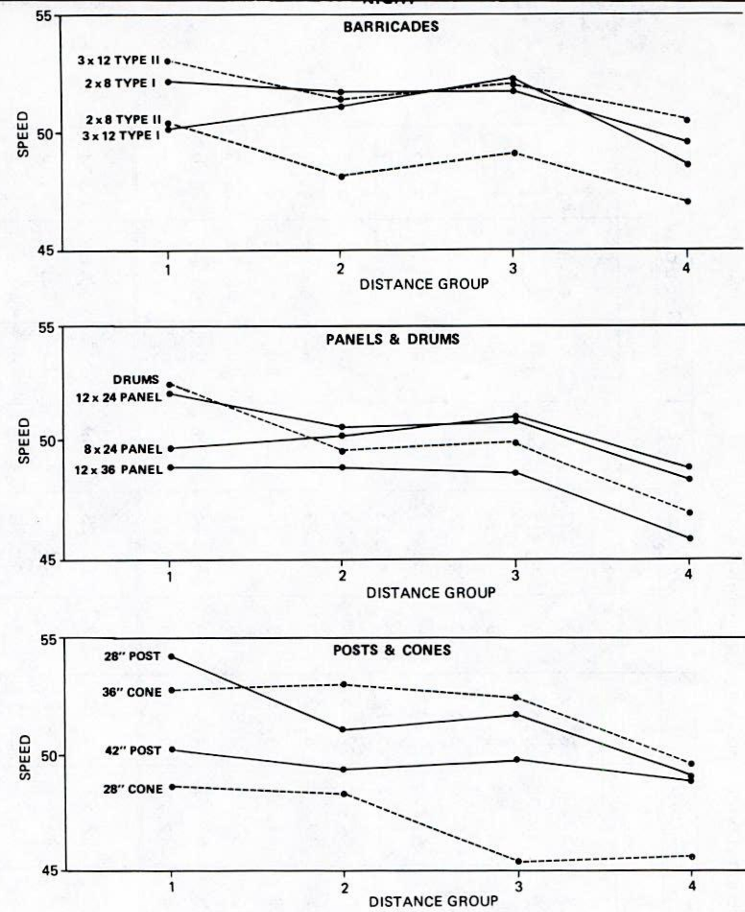


Figure D-8. Mean speeds for devices in experiment 2 (night).

Table D-4. Summary of experiment 2 ANOVA for speed data.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Between Subjects	217	12708.0243		
Day/Night (A)	1	.3657	.3657	.0062
Device Groups (B)	11	810.4445	73.6768	1.2590
AB	11	544.5486	49.5044	.8460
Subjects within Groups	194	11352.6655	58.5189	
Within Subjects	654	5390.1584		
Distance Groups (C)	3	478.8101	159.6034	22.9274**
AC	3	176.3380	58.7793	8.4438**
BC	33	275.3802	8.3449	1.1988
ABC	33	408.1812	12.3691	1.7769**
C Subjects within Groups	582	4051.4489	6.9613	

**significant at p <.01

Table D-5. Devices classified into large and small size groups.

Large	Small
3'x12" Type I barricade	2'x8" Type I barricade
3'x12" Type II barricade	2'x8" Type II barricade
12"x36" Panel	12"x24" Panel
Drum	8"x24" Panel
42" Post	28" Post
36" Cone	28" Cone

Table D-6. Mean speed and standard deviations for each device and distance group.

	Group 1			Group 2			Group 3			Group 4		
	N	$\overline{X}$	σ	N	$\overline{X}$	σ	N	$\overline{X}$	σ	N	$\overline{X}$	σ
Day												
3x12 Type I	7	52.80	2.65	7	52.26	2.29	7	51.27	1.67	7	48.34	1.23
3x12 Type II	10	53.20	4.23	10	50.92	9.02	10	51.13	5.89	10	50.30	4.40
2x8 Type I	8	48.80	9.69	8	49.34	3.62	8	49.82	4.03	8	48.59	3.22
2x8 Type II	10	46.36	7.62	10	48.78	3.47	10	49.72	2.86	10	49.83	2.40
8x24 Panel	9	51.40	2.46	9	47.50	12.37	9	51.03	3.90	9	50.11	3.49
12x24 Panel	7	47.80	7.94	7	51.45	5.78	7	52.15	3.80	7	50.43	4.14
12x36 Panel	10	50.15	2.43	10	50.71	2.55	10	50.20	4.39	10	47.45	4.65
28" Post	9	47.85	5.86	9	49.32	4.99	9	50.49	5.09	9	49.96	4.07
42" Post	10	49.89	3.78	10	51.59	4.55	10	51.36	3.87	10	49.45	4.01
28" Cone	10	50.39	3.62	10	50.94	2.97	10	51.31	2.67	10	50.12	2.52
36" Cone	9	51.62	2.42	9	51.01	4.62	9	50.84	4.28	9	50.06	4.49
Drum	10	48.63	3.02	10	49.36	2.61	10	49.27	4.05	10	47.43	4.54
Night												
3x12 Type I	7	50.18	2.78	7	51.21	4.02	7	52.28	3.09	7	48.65	3.74
3x12 Type II	10	53.10	1.67	10	51.41	2.90	10	52.07	2.72	10	50.46	2.58
2x8 Type I	8	52.32	3.31	8	51.68	3.71	8	51.76	3.63	8	49.53	3.66
2x8 Type II	10	50.36	6.61	10	48.07	4.7	10	49.07	5.67	10	46.95	6.39
8x24 Panel	9	49.94	4.31	9	50.44	4.27	9	51.22	3.85	9	48.96	4.59
12x24 Panel	7	52.16	2.71	7	50.70	2.53	7	50.98	1.60	7	48.52	1.54
12x36 Panel	10	49.03	2.98	10	48.95	4.32	10	48.80	5.48	10	45.98	7.18
28" Post	9	54.21	2.34	9	50.98	3.40	9	51.66	2.63	9	48.97	3.28
42" Post	10	50.16	2.47	10	49.42	3.18	10	48.83	2.92	10	48.87	2.52
28" Cone	10	48.61	4.72	10	48.33	5.23	10	45.38	6.77	10	45.59	5.68
36" Cone	9	52.69	1.80	9	53.04	2.65	9	52.40	4.20	9	49.50	6.03
Drum	10	52.62	2.02	10	49.70	3.81	10	50.05	4.11	10	47.00	6.96

Another indication of device impact is driver weaving or wandering around some point. The displacement of each vehicle from lane centerline was calculated for each driver at each measurement point along the tangent. By squaring and summing the displacements for each device, an index of the magnitude of weaving was developed. The result is shown in Figure D-10. The devices clearly fall into three groups, as given in Table D-7.

In summary, channelizing devices effect a shift in driver lane placement, but there is no difference between devices in the magnitude of the shift. The devices reduce variability in lane placement and certain devices are more effective than others in reducing in-lane weaving or wander.

Point of Lane Change

Figure D-11 shows the mean point of lane change data. A chi-square test of the mean scores indicates that there is a significant difference between the day and night distribution ($\chi^2 = 563$, 11 df, $p < 0.001$). An examination of Figure D-11 reveals the difference is due to the two Type II barricades, 12″ × 24″ panel, and the posts and cones. In the day there were significant differences between the 3′ × 12″ Type I and 2′ × 8″ Type II barricades and the 42″ post and 28″ cones. At night there were no differences between devices within categories, but there are differences between the 3′ × 12″ Type II barricade and the posts and cones.

The 12″ × 24″ panel is clearly out of line with the other data and this is because of three subjects who detected the array over 4,000 ft away and changed lanes very early. The more interesting finding, consistent with the array detection data, is the lower point of lane change at night for all cones and posts. During the day cone and post detection distance is high, but falls dramatically at night. The lack of visibility at night apparently influences the point of lane change. Another indication that detection distance is controlling here is the low variability around the mean point of lane change, particularly for the cones. With a standard deviation in the 160 to 170-ft range, 97 percent of the drivers would not change lanes beyond 550 ft upstream of the array.

The impact of reflectivity combined with device size apparently influences the variability of lane changing at night, but not in the daytime. Figure D-12 shows the tight distribution of standard deviations in the day versus the

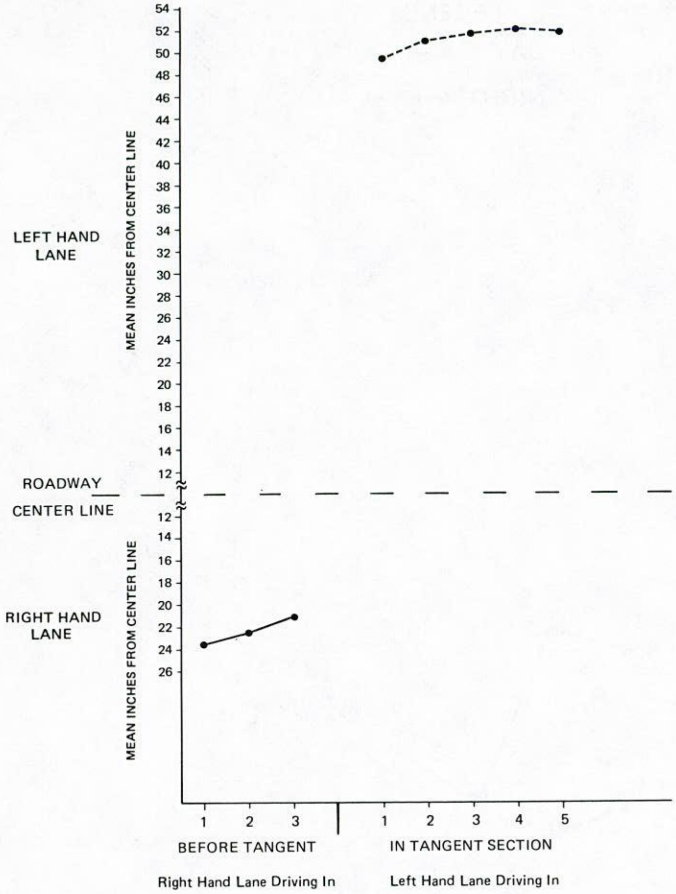


Figure D-9. Mean lateral placement scores before the array and along the tangent section.

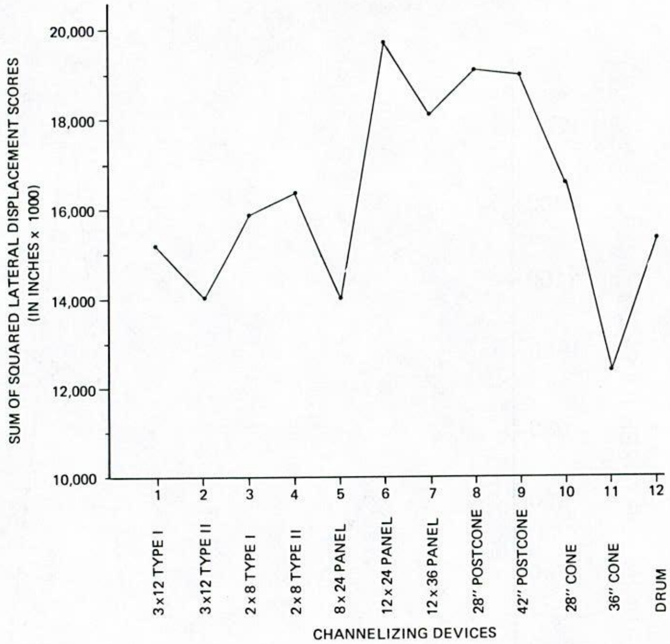


Figure D-10. Sum of squares of lateral displacement along tangent.

Table D-7. Devices ranked by sum of squares lateral displacement score.

High	Middle	Low
12"x24" Panel	28" Cone	3'x12" Type II
28" Post	2'x8" Type II	8"x24" Panel
42" Post	2'x8" Type I	36" Cone
12"x36" Panel	Drum	
	3'x12" Type I	

greater spread of SD's at night. The larger devices, panels and barricades, reflect the higher variance.

Another type of variability not reflected in Figure D-12 is the range of scores within each group of subjects that saw a particular device type. With only one exception (12″ × 24″ panel at night), there were one, two, three, or four subjects in all of the other 23 subject groups that waited until the last minute to make a lane change (i.e., were within 0–300 ft of the taper). Table D-8 gives the score ranges. This phenomenon has been observed around operational work zones (*9*), where traffic flow and volume create small or infrequent gaps. Under traffic congestion it seems reasonable to interpret rushing up to the taper before merging as being in a hurry or a reaction to congestion or delay. In the closed field test there was no traffic pressure of any kind. The wait-till-the-last-minute behavior was apparently not a function of the highway environment. Rather, such behavior is generated internally by the driver. Correlations of point of lane change with sex and age of driver were low ($r = 0.20 - 0.25$ range) and, although significant because of large sample sizes, only accounted for roughly 5 percent of the variance in the data. Because no other data on the drivers were available, no causative conclusions could be drawn. However, two hypotheses were considered. First, visual functions such as depth perception or dynamic visual acuity might be related to point of lane change. However, because age, which is more strongly related to visual functioning, does not explain the behavior, it seems unlikely that vision will prove to be the major factor. The second hypothesis is that changing lanes close to the taper is related to individual cognitive style and personality factors. Some drivers, regardless of what devices or obstructions they detect in their path ahead, are simply "late lane changers" or "high risk takers" and some other drivers are not. Some researchers have attempted to relate this to the concept of field dependence/field independence as a cognitive style in driving behavior, demonstrating that individual personality characteristics can account for the wide variability in driver responses to certain stimuli (*10*). Current research does not suggest any obvious ways highway design, and specifically work zone channelizing devices, can modify this type of behavior. Clearly this is an area warranting further research.

In summary, point of lane change occurs farther away from the array at night compared to day for barricades, drums, and panels. However, distance and variability are greatly decreased for cones and posts. Variance around the mean point of lane change increases substantially at night for larger devices. Few other differences were found between devices.

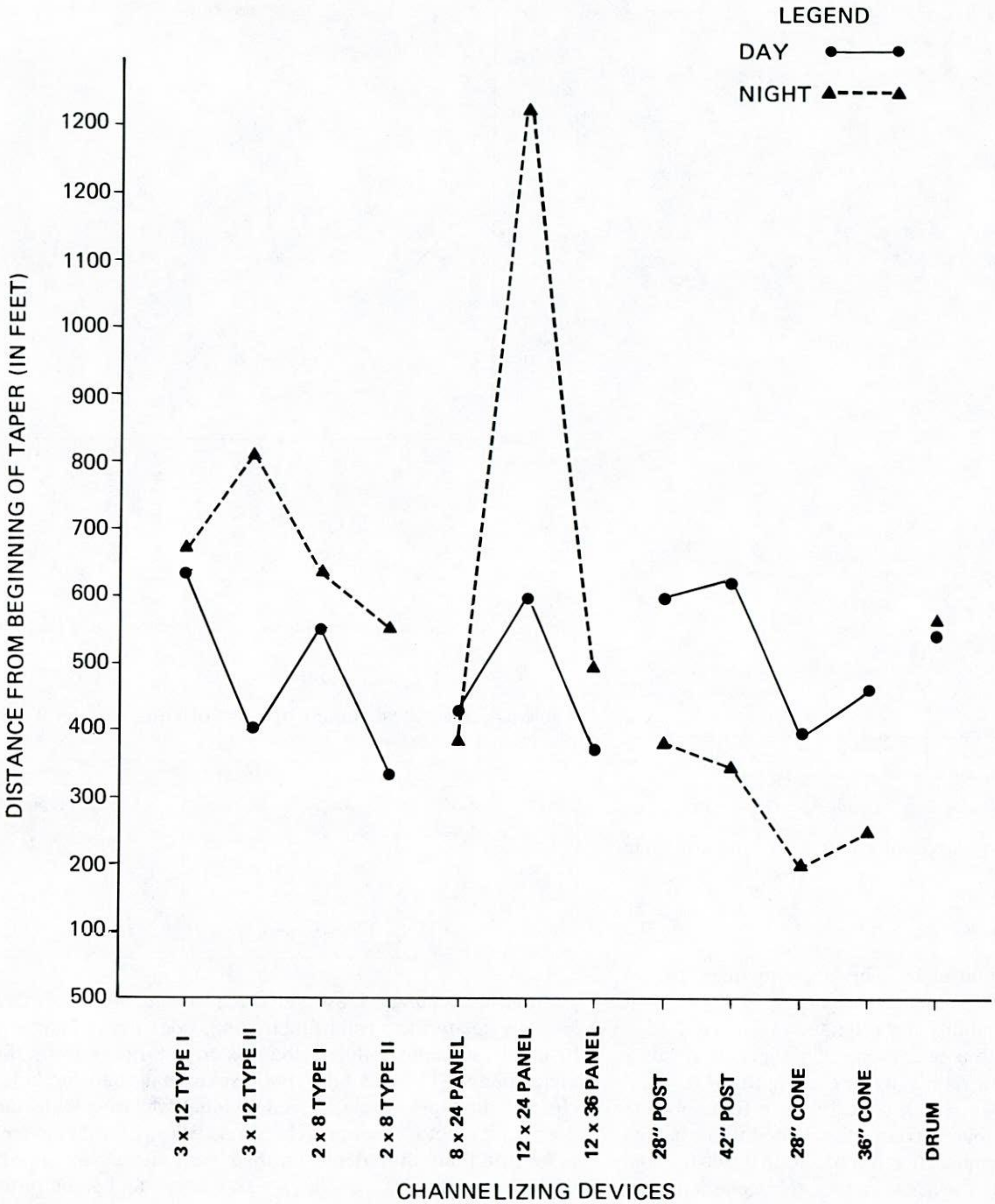


Figure D-11. Mean point of lane change.

Array Detection

These data were introduced in experiment 1 and will be briefly reiterated here. There was a significant increase in array detection distance for 9 of the 12 devices when day was compared to nighttime data. This is somewhat surprising in light of the fact that point of lane change is somewhat farther away from devices (except posts and cones) at night compared to daytime. The impact of reflectorized light from the larger visible surfaces seems to elicit a response at night that is somewhat different from seeing those same devices in the daytime.

Without directly querying subjects, a definitive answer cannot be given here. However, one explanatory hypothesis is that drivers have greater uncertainty at night about what to expect around or before the array. In other words, all they can see are the devices and they do not know what other equipment, holes, etc. are present. Therefore, the uncertainty leads them to change lanes relatively soon after they detect the array. During daylight such uncertainty is not present because drivers can see what is around and behind the devices. In this experiment there was nothing behind the array so the ''hazard value'' of the work zone was very low, particularly in the daytime. This may be one of the few situa-

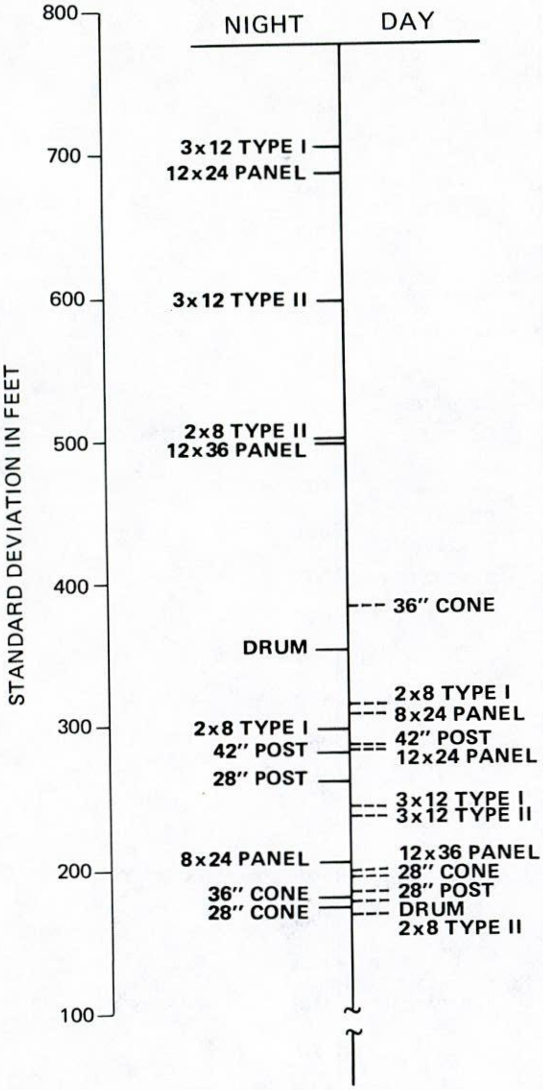


Figure D-12. Distribution of standard deviations for point of lane change (day and night).

tions where driver uncertainty may be considered to have a beneficial result.

In the daytime array, detection is controlled by device size. The arrays of larger devices in all categories were seen further away than the smaller devices. At night, where the controlling factor was device type and not size, the amount of reflectorized area was apparently important. The cones deteriorated the most compared to daytime detection.

As in the case of point of lane change, subject variability was noticeably high (e.g. SD's ranged from 480 to 1,250 ft at night and 270 to 1,360 ft in daylight). Figures D-13(a) and D-13(b) plot the distribution of SD's and means. Examination of these figures reveals that very few devices result in consistently far array detection distance but low SD's—the most desirable type of performance. Applying the concept of decision sight distance and the 1,000-ft criterion as explained in experiment 1, only four devices meet or exceed the criterion both day and night; these are given in Table D-9. Drums were included in Table D-9 even though night data are not available because performance on other measures remained so

Table D-8. Point of lane change—range of scores for the measure (in feet from beginning of taper).

Device	Day	Night
3'x12" Type I	203-927	100-2046
3'x12" Type II	102-739	136-1968
2'x8" Type I	273-1255	275-987
2'x8" Type II	120-540	22-1578
8"x24" Panel	70-1062	169-748
12"x24" Panel	213-1050	692-2234
12"x36" Panel	73-716	41-1404
28" Post	283-845	40-844
42" Post	185-1005	51-679
28" Cone	172-771	17-431
36" Cone	114-1009	20-481
Drum	169-761	194-1228

consistent day and night. Thus it is safe to assume that drums will be consistent on this measure and meet the 1,000-ft criterion at night.

The final point to be made concerning array detection is that single device detection data do not predict array detection nor are daytime findings predictive of nighttime results, particularly for smaller devices.

Driver Preference Data

The questions asked in the Phase I and Phase II questionnaires dealt with drivers' reactions to various device categories, specific devices, and the purpose of such devices (see Exhibit D-2 for complete questionnaires). In the first questionnaire, drivers were asked to rate any of the devices pictured that they had seen on the road. Outline drawings of a cone, post, Type I barricade, Type II barricade, panel, and drum were shown. Table D-10 gives the pictures and percent responses. Size and visible area appear to be controlling driver responses.

A question in Phase II asked drivers to rank each of 12 devices on a scale from "Easy to See" to "Difficult to See." Drivers had pictures of the 12 devices used in experiment 2 before them when responding to this question. The data were converted to proportions of drivers ranking each device in each of the 12 possible scale positions. These proportions were multiplied by the scale number ("1" being easiest and "12" most difficult to see), summed, and the mean deter-

Table D-9. Arrays detected by 97 percent of drivers at the 1,000-ft criterion (day and night).

Device Array	Mean Detection Distance minus 2 SD's (in feet)	
	Night	Day
12"x24" panel	2727	1968
3'x12" Type I barricade	1580	2992
12"x36" panel	1163	2888
Drum	Not avail.	3160

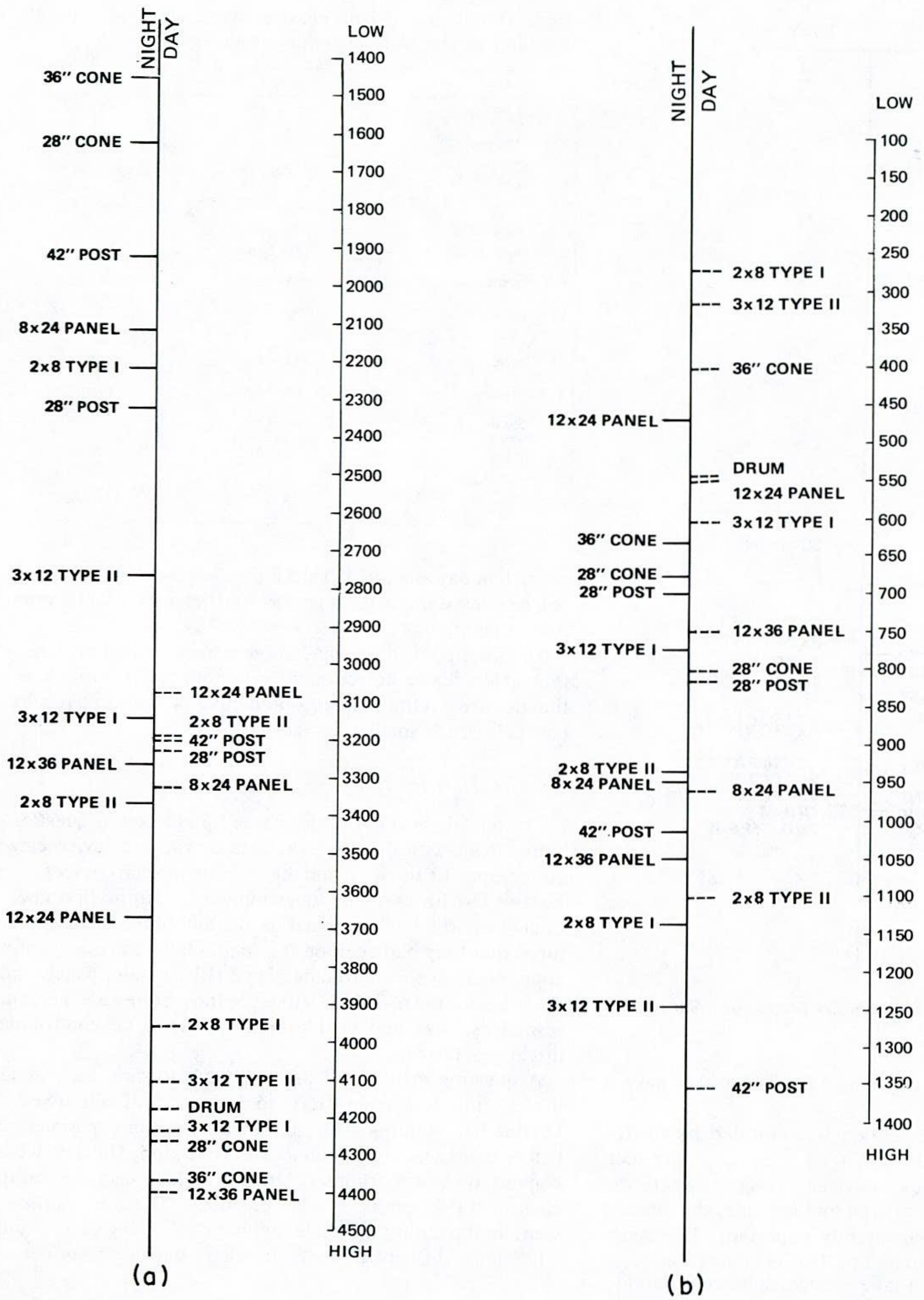
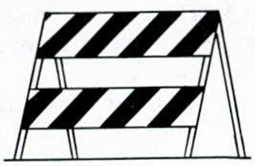
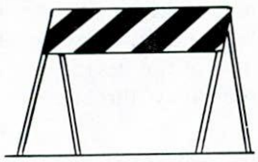
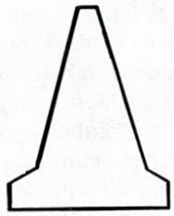
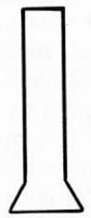


Figure D-13. (a) Distribution of mean array detection distances (in feet); (b) distribution of standard deviations (in feet from beginning of taper) for array detection.

mined. Devices were then ordered from lowest to highest mean. Table D-11 gives the final ordering. Again, the physically largest devices were considered most easily seen. As in the device and array detection data, the largest device from each of the four categories was among the top four devices. Within the first four devices, they are ordered from physically largest visible surface to smallest. Although size of visible area is the major factor, drivers were responding to shape as well. Shape appears to play a secondary role in that cones, although relatively small in visible area, ranked higher than other barricades (e.g. 2′ × 8″ Type I or II), which are larger.

A final question asked drivers concerned what they thought was the purpose of channelizing devices. Table D-12

Table D-10. Device category preference data (percent responses).

			
Seen			
Easily	76%	71%	67%
With moderate ease	20%	20%	21%
With difficulty	4%	9%	12%
	1*	2	3.5
			
Seen			
Easily	67%	64%	49%
With moderate ease	22%	29%	38%
With difficulty	11%	7%	13%
	3.5	5	6

*Devices are ordered from most to least preferred.

Table D-11. Ease-of-seeing ranking of devices by drivers.

Ranking	Device (Weighted Means)
easiest to see	Drum (299)
↓	12"x36" panel (370)
	3'x12" Type II barricade (392)
	36" cone (465)
	12"x24" panel (487)
	3'x12" Type I barricade (493)
	2'x8" Type II barricade (567)
	28" cone (604)
	8"x24" panel (658)
	2'x8" Type I barricade (668)
	42" post (723)
most difficult to see	28" post (799)

Table D-12. Driver understanding of device purpose.

Why do you think such devices are used?
Check all those that are correct.

To indicate to the driver:

165 to change lanes	31 to stop
174 that there was a hazard present	0 to speed up
150 to slow down	10 to continue driving at the same speed

gives the results. The total responses sum to more than the number of respondents because more than one category could be checked by each driver. Clearly, devices are associated with a hazard and a need to slow down. Somewhat surprising was the high number of drivers who thought "change lanes" was implied by the devices. This is likely to be spuriously high because drivers had just finished a test where devices were used to close a lane and they associated the tests. A disturbing number of responses were given to the "stop" alternative. Although there are work zone situations where stopping may be required, this is not the information function of any of the channelizing devices used in this study. This finding again exemplifies the importance of defining the purpose of a traffic control device, establishing a driver expectancy for that device through proper use of the device, and not violating or eroding driver expectancy through misapplication of the device.

Drivers were asked for comments about work zones and channelizing devices. One hundred seventy-three comments were offered, whereas 120 drivers made no comment. Of the comments made, 45 percent were positive, 48 percent were negative or a complaint, and 7 percent made suggestions. A content analysis of the responses revealed that the majority of negative comments revolved around two themes. The first was that drivers are not given enough advance information about the existence and type of work zone they are approaching. Second was a complaint about the condition of devices and work zones. Drivers felt that device maintenance was critical and that trying to keep the roadway through a work zone as neat and uncomplicated as possible was important for safe driving. The positive comments primarily concerned drivers' satisfaction with the brightness of devices (reflective and steady-burn light arrays) and the resulting ease of negotiating a work zone at night.

In summary, drivers felt the largest devices from each category were easiest to see and to associate with hazards and slowing. Problems with work zones are not enough advance information and poor device/array maintenance. Drivers find the levels of reflectance and brightness at night quite helpful.

Other Measures

Several of the measures collected were found insensitive or insufficiently discriminating. Brake applications may be used where more rapid speed adjustments are required in actual traffic, but in the relatively "pure" environment of this experiment, brakes were never applied around the array sites. Throttle pedal position reflects speed to only a limited degree. Throttle pedal position was highly sensitive to terrain (hills and curves) characteristics. Because hills were involved in the test drive, any impact of devices was hidden in the more potent effect of hills on this measure. Steering wheel position was collected at the most sensitive setting. Analysis of variance with these data showed all treatments and interactions to be significant. However, the greatest range of difference in position was less than 30 deg (20 deg to right and 10 deg to the left of center position). Given the car used and the power steering, such differences do not represent interpretable or major steering results; rather, these are within the range of fine steering adjustments normally used to guide the vehicle. Also, this measure did not relate to lateral lane placement which is the outcome performance of concern. Finally, steering wheel rate was not used, essentially for the same reasons just noted. The purpose of using the steering wheel measures was to find a reliable and consistent substitute for lateral lane placement which is relatively difficult to measure. Unfortunately, neither variable, as measured in this experiment, proved to be that substitute.

Synthesis of Results

Several parameters reflecting the impact of channelizing devices on driver behavior were used in this experiment. The results from each measure do not unanimously point to one device or even category of devices as best according to all the measures. Therefore, a more convenient way of organizing the findings to develop an overall assessment of the devices is necessary.

The technique used essentially divides performance of the devices into three categories for each measure. The criteria used for the division are explained as part of Table D-13. These can then be summed for day, night, or the combination. Table D-13 presents the synthesis. Several conclusions are evident when the table is examined. Device detection was not included because it is irrelevant to the array situation. No simple device category is superior to another in the daytime. At night, the categories are similar except for posts and cones which clearly do not perform as well as other types of devices. The real differences impacting driver behavior occur within device categories.

Table D-13 is useful only after considering the assumptions that have been made. First, reducing speed along the tangent section is a desired behavior. There is no definitive research specifying the safest or most efficient speed profile through a work zone. Maintaining speed through the tangent may be desirable to help minimize a slowing wave which eventually induces congestion in the approach and taper sections. Second, it is assumed that the straightest, least wavering path through the tangent was the safest. Third, variability in point of lane change may be desirable. The mean, however, should be as far away from the devices as possible and the distribution should be skewed upstream from the mean. This, in effect, is spreading lane changing out over the longest possible distance and as far away from the taper as possible. Analytically, this seems desirable; however, research is needed to empirically define the best safety/efficiency behavior profile.

Given these assumptions, Table D-13 can be used in two ways. First, individual devices can be ranked for day, night, and combined performance. The results, as given in Table D-14, demonstrate that the largest devices from each category are the most successful in the daytime and at night with the exception of posts and cones. A second use of the table is to select devices that elicit behaviors most suitable to a particular work zone or situation where the assumptions previously noted are not suitable. For example, if a work zone at night was created where traffic flow was critical (i.e., speed maintenance was important), a 2′ × 8″ Type I or II barricade would come closer to eliciting such behavior than the larger devices.

Experiment 2 Conclusions

The conclusions can best be addressed as answers to the questions posed at the beginning of the experiment:

1. What effects do various categories of channelizing devices have on driver behavior? The only difference between the four major categories is that posts and cones do not function as well as other devices at night. In terms of specific behavioral effects, none of the channelizing devices elicited unique or particularly hazardous behaviors. The effects found include:
   a. Long array detection distances (3,100–4,400 ft) in the day and somewhat shorter at night (2,050–3,650 ft).

Table D-13. Synthesis of experiment 2 results.

	Array Detection Day: Mean Detection Distance	Array Detection Day: DSD Criterion	Array Detection Night: Mean Detection Distance	Array Detection Night: DSD Criterion	Point of Lane Change: Mean Distance – Day	Point of Lane Change: Mean Distance – Night	Lateral Placement: Path Consistency	Speed: Speed Reduction – Day	Speed: Speed Reduction – Night	Driver Preference: Easiest to See	Summaries – Individual Devices – **(Total possible = 6) – Day: H	M	L	Night: H	M	L	**(Total possible = 10) – Combined: H	M	L	Device Groupings (Total number/percent)*** – Combined: H	M	L
Barricades																						
3' x 12" Type I	H*	H	H	H	H	H	M	H	H	M	4	2	0	4	2	0	8	2	0	21/52	9/23	10/25
3' x 12" Type II	H	H	M	L	L	H	H	H	H	H	5	0	1	4	1	1	7	1	2			
2' x 8" Type I	M	H	L	L	M	H	M	L	H	L	1	3	2	2	1	3	3	3	4			
2' x 8" Type II	L	L	H	H	L	M	M	L	H	M	0	2	4	3	3	0	3	3	4			
Panels																						
8" x 24"	L	H	L	L	M	L	H	L	H	L	2	1	3	2	0	4	3	1	6	17/57	3/10	10/33
12" x 24"	L	H	H	H	H	H	L	H	H	M	3	1	2	4	1	1	7	1	2			
12" x 36"	H	H	H	H	L	M	L	H	H	H	4	0	2	4	1	1	7	1	2			
Posts and Cones (MUTCD Standard)																						
28" post	L	H	L	L	M	L	L	L	L	L	1	1	4	0	0	6	1	1	8	11/28	4/10	25/62
42" post	L	H	L	L	H	L	L	H	L	L	3	0	3	0	0	6	3	0	7			
28" cone	H	H	L	L	L	L	M	L	L	M	2	2	2	0	2	4	2	2	6			
36" cone	H	H	L	L	M	L	H	H	L	H	5	1	0	2	0	4	5	1	4			
Posts and Cones (Optimized)																						
28" post	H	H	H	H	H	H	(L)	L	L	(L)	3	0	3	3	0	3	6	0	6	23/57	4/10	13/33
42" post	H	H	H	H	H	H	(L)	L	L	(L)	3	0	3	3	0	3	6	0	6			
28" cone	H	H	H	H	H	H	(M)	L	L	(M)	3	2	1	3	2	1	6	4	2			
36" cone	Data for optimal condition not available																					
Illuminated cone	H	L	H	H	H	H	(M)	L	L	(M)	2	2	2	3	2	1	5	4	3			
Drum (55 gallon plastic)	H	H	N/A	N/A	M	M	M	H	H	H	4	2	0	2 [4]	2	0	5 [7]	3	0	5/63	3/37	0/0

*High, Medium, Low number.

**Refers to total of H, M, or L's possible for each device.

***Refers to total number of H, M, or L's in each cateogyr and corresponding %.

( ) Category assumed from MUTCD standard condition.

b. Considerable variability in array detection distance between drivers for most devices.
c. For barricades, panels, and drums, the mean point of lane change at night is farther away from the array than in daylight. However, for cones and posts, the reverse was found.
d. Extensive variability in point of lane change among drivers was evident, particularly at night for larger devices.
e. In every group, regardless of device, one to four subjects drove to within 20–300 ft of the taper before changing lanes.
f. All devices elicited a shift in lateral placement towards the left edge of the lane.
g. There were differences in displacement (weaving or path consistency) elicited by devices. The 3′ × 12″ Type II, 8″ × 24″ panel, and 36″ cone showed the least weaving.
h. There were no significant differences in speed distributions between the devices tested.
i. In the daytime, larger devices in each category elicited a significant speed reduction (around 2 mph) from taper to tangent section. At night, barricades,

Definition of High, Medium and Low Categories

High	Medium	Low
	Speed Change	
Significant reduction in speed from taper to tangent section—2 to 3 mph.	Not used	No significant change
	Lateral Placement	
Most consistent path or guidance behavior. Taken from Table D-7	From Table D-7	Greatest amount of displacement or weaving. From Table D-7
	Array Detection	
Day 4000 plus feet Night 3000 plus feet	3501-3999 2501-2999	3500 under 2500 or less
	DSD (Decision Sight Distance)	
Mean minus two standard deviations equals 1000 feet or more	Not used	Equals less than 1000 feet
	Point of Lane Change	
600 or more feet	401-599 feet	400 or less
	Preference	
Top third of Table D-11	Middle third of Table D-11	Lower third of Table D-11

Table D-14. Rank order of devices based on eight synthesized dependent variables.

A. Assuming speed reduction desirable between taper and tangent

Day	Rank Order	Night	Rank Order	Combined	Rank Order
36" cone-std	1	3' x 12" Type I	1.5	3' x 12" Type I	1
3' x 12" Type II	2	Drum	1.5	Drum	2
→					
3' x 12" Type I	3.5	3' x 12" Type II	4	3' x 12" Type II	4
Drum	3.5	12" x 24" panel	4	12" x 24" panel	4
12" x 36" panel	5	12" x 36" panel	4	12" x 36" panel	4
→		→		→	
28" cone-opt	6	2' x 8" Type I	6	28" cone-opt	6
12" x 24" panel	7	28" x cone-opt	7.5	42" tube-opt	7.5
42" post-opt	8	Ill. cone	7.5	28" tube-opt	7.5
42" post-std	9	42" post-opt	9.5	Ill. cone	9
				→	
28" post-opt	10	28" post-opt	9.5	36" cone-opt	10
→		→			
Ill. cone***	11.5	2' x 8" Type II	11	2' x 8" Type I	11.5
28" cone-std	11.5	8" x 24" panel	12.5	2' x 8' Type II	11.5
8" x 24" panel	13	36" cone-std	12.5	8" x 24" panel	13
		→			
2' x 8" Type I	14	28" cone-std	14	42" post-std	14
				→	
28" post-std	15	42" post-std	15	28" cone-std	15
2' x 8" Type I	16	28" post-std	16	28" post-std	16

B. Assuming *NO* speed change between taper and tangent is desirable

Day	Rank Order	Night	Rank Order	Combined	Rank Order
36" cone-std	1	3' x 12" Type I	2.5	3' x 12" Type I	1.5
3' x 12" Type II	2	28" cone-opt	2.5	28" cone-opt	1.5
3' x 12" Type I	4	(Drum)**	2.5	42" post-opt.	3.5
Drum	4	Ill. cone	2.5	28" post-opt	3.5
		→		→	
28" cone-opt	4	12" x 24" panel	6	(Drum)**	5
12" x 36" panel	7	12" x 36 panel	6	Ill. cone	6
42" post-opt	7	3' x 12" Type II	6	12" x 24" panel	8
28" post-opt	7	42" post opt	8.5	12" x 36" panel	8
→					
Ill. cone	9.5	28" post-opt	8.5	3' x 12" Type II	8
28" cone-std	9.5	2' x 8" Type II	10	36" cone-std	10
				→	
12" x 24" panel	11.5	36" cone-std	11	2' x 8" Type I	11.5
		→			
8" x 24" panel	11.5	2' x 8" Type I	12	2' x 8" Type II	11.5
42" post-std	13	8" x 24" panel	13	28" cone-std	13
→					
2' x 8" Type I	14	28" cone-std	14	8" x 24" panel	14
28" post-std	15	42" post-std	15.5	42" post-std	15
2" x 8 Type II	16	28" post-std	15.5	28" post-std	16

* std = 6" cone collar (MUTCD standard) opt = optimized design (see Phase II findings).

→ indicates "natural" break points in the distribution.

** placed here tentatively because night array detection data not available — rationale for assuming "high" performance in text.

*** ill cone - illuminated cone.

panels, and drums—but not posts or cones—elicited the speed reduction (around 2.5 mph).

j. Driver rankings of device pictures indicated people think the larger devices (3′ × 12″ barricades, drum) are easiest to see.

2. Are channelizing device effects on driver behavior different under day and night visibility conditions? The following differences were prominent:

a. Array detection distance was less at night.
b. Array detection variability was greater at night.
c. Point of lane change was farther away from the taper at night except for posts and cones that were closer at night than in the day.
d. Speed reduction at night from taper to tangent was controlled by device type (barricades, panels, drum), not by device size.
e. During day and night, drivers' perception of the array was one of a pattern or line of color (day) or light (night). Drivers could not tell what type of device or what pattern was used on the device when they detected the array.

3. What effect does device size have on driver behavior? Device size appears to have a more powerful impact on behavior than the laboratory experiments suggested. This is partially because device arrays are not simply an additive of single device characteristics. Specifically,

a. Speed reduction in daytime is controlled by device size. The largest devices in each category resulted in speed reduction.
b. Device size appears to control driver perception of ease of device detection.
c. At night, visible reflectorized area appears to be critical in controlling point of lane change and speed reduction.
d. Question 3 postulated no differences between the 8″ × 24″, 12″ × 24″, and 12″ × 36″ panels. The 8″ × 24″ panel performed consistently poorer than the two larger panels.
e. Question 3 hypothesized no difference between one and two-rail or large and small barricades. (1) The data indicate the larger devices (3′ × 12″) are quite superior to the smaller (2′ × 8″) barricades in every respect. (2) Differences between one- and two-rail devices were generally in favor of one-rail barricades. From a driver behavior perspective, there is no reason to use a two-rail device.

4. Does device shape have an impact on driver behavior? This is stated in the null form because there will be no differences between bar and panel shaped devices.

a. This experiment supports the laboratory study in that overall bar and panel shapes are highly comparable. Size appeared to control behavior more than shape.
b. The larger barricades were more consistent across measures and did not have some of the rather large vascillations associated with the larger panels.
c. The round shape of the drum was apparently not perceived at great distance so it, in essence, functioned more like a large panel.
d. The triangular shape of the cone apparently provides attention-getting geometric contrast in daylight.

From the results of this experiment there is evidence that size and visible area control driver behavior more than shape. Specific design recommendations supported by the data are:

1. Barricades should be the larger 3′ × 12″ size.
2. One rail is generally more effective than two rails.
3. Panels should be a minimum of 12 in. wide and no less than 24 in. long.
4. Triangular cone shapes provide good geometric contrast but need to be relatively large for maximum effect (e.g., 36 in.).

Operationally, there appears to be no driver behavior-related rationale for having more than one type of channelizing device available. In the daytime, any of the large devices from all four categories are relatively equivalent. At night, the same devices (but not cones or posts) are also equivalent. Table D-13 gives the specific variations among these devices.

Experiment 3

This experiment specifically addressed the use of steady-burn lights as part of the work zone device configuration at night. The specific questions tested were: (1) Is there a difference in driver performance when steady-burn lights are added to channelizing devices? (2) Do different configurations of steady-burn lights impact driver behavior? (3) Do differences between steady-burn lights and different levels of reflectance affect driver behavior?

The experimental treatments used to test the three questions were:

Question	Treatments and Comparisons
1.	Steady-burn lights mounted on the 2′ × 8″ Type I barricades. Comparison treatment is the 2′ × 8″ Type I barricade.
2.	Steady-burn lights mounted on every barricade (55-ft spacing), only on barricades in the taper and on alternate barricades (taper and tangent).
3.	2′ × 8″ Type I barricades with high intensity retroreflective sheeting compared to all of the foregoing treatments.

The experimental method and procedure were the same as previously described. This experiment was conducted only at night. To gather lateral placement data, strips of tape were stretched across the road at five points in the taper and tangent. After the DPMAS drove over the tape, the distance from tire mark outer edge to pavement edge was measured.

Results

Table D-15 summarizes the data for each of the treatments. A two-way ANOVA (devices by distance groups) for a repeated measure showed there was no speed difference between treatments ($F = 0.59$, 4/30 df). Because the two-way interaction was not significant ($F = 0.81$, 12/90 df), but distance group was ($F = 16.7$, 12/90 df, $p < 0.01$), the devices are equally effective in eliciting a speed reduction from taper to tangent sections.

Table D-15. Experiment 3 summary of results.

	Steady-Burn Reg. Spacing	Steady-Burn Taper Only	Steady-Burn Alternate	High Intensity Sheeting	Engineering Sheeting
Array Detection (feet)					
Mean	4565	3835	4369	1615	2229
Point of Lane Change (feet)					
Mean	1352	846	1280	474	637
Median	627	643	796	595	753
SD	1355	713	1440	268	297
Lateral Placement (inches)	Tr** Tg**	Tr Tg	Tr Tg	Tr Tg	Tr Tg
Mean	40.5 13.87	35.57 17.2	no data	42.37 14.49	*** 13.55
Speed in tangent (mph)					
Mean	45.45	45.81	45.3	45.85	48.84

* ⌐——┘ indicates a statistical difference p.<.01

**Tr=Taper; Tg=Tangent

***Data available for approach zone only - not comparable to taper data used here.

Another two-way ANOVA (treatment by taper/tangent) using lateral placement data showed no difference between treatments ($F = 0.096$, 2/126 df), but a significant difference ($F = 0.98$, 1/126 df, $p < 0.001$) in placement between taper and tangent sections. Even though drivers are in the open (left) lane in the taper, they are about 35 to 45 in. from the pavement edge. By the time drivers enter the tangent, they are 13 to 17 in. from the pavement edge. Driver response in the taper is clearly to begin moving left as the devices come closer and closer to the centerline.

Point of lane change data were heterogeneous, therefore both parametric (t-test) and nonparametric (Kruskal-Wallis) statistical tests were used. No significant differences between treatments were found with either test. However, examination of the mean, median, and SD for each device (given in Table D-15) reveals some practically useful differences. First, the median point of lane change is relatively close together for all devices. The mean and SD show the distributions of lane change scores for two of the steady-burn light conditions to be very skewed. Several subjects in each group are changing lanes quite far away from the devices. This is possible because array detection is equally far away (4,565 and 4,369 ft). But even the powerful stimulus of the steady-burn lights did not deter a few drivers from waiting to change lanes in the last 100–200 ft before the taper.

The significant differences between devices for array detection are given in Table D-15. Again, because of the skewed distributions, the nonparametric Kruskal-Wallis test was used. In this experiment, retroreflective sheeting was not seen as far away as the steady-burn lights. However, sight characteristics probably play an important role in this finding. Both array sites go slightly downhill at the beginning, level, and begin to rise during the taper. This creates a situation where headlights, particularly low beams, do not directly "hit" the reflectorized material. Also, the high intensity sheeting used had a narrow focus and, therefore, was not particularly bright when viewed from an angle. For this reason, the high intensity sheeting was not seen as far away as the broader beam engineering grade sheeting. The steady-burn light with the 5° × 9° radius of light spread was particularly effective in this setting. This leads to the operational implication that the geometric characteristics of a work zone site must be carefully considered before deciding to use retroreflective sheeting instead of steady-burn lights.

Conclusions

In response to the questions posed for this experiment, the data indicate:

1. There are no speed or lateral placement differences related to steady-burn lights. Point of lane change and array detection occur further away in general. Some (but not over half) drivers begin changing lanes much earlier in the presence of the steady-burn lights. This has the effect of spreading lane changing maneuvers over a longer distance.

2. Again, there were no speed or lateral placement differences between steady-burn lights on every barricade, every other barricade, or taper only barricades. Although the differences in array detection between the three steady-burn light treatments were not significant, they did correlate with the total number of lights visible. The differences in point of lane change were not significant, but again followed the number of visible lights. In essence, any of the three steady-burn light treatments are viable alternatives for work zones.

3. The differences in array detection and point of lane change between steady-burn lights and retroreflective sheeting previously reported appear related to angularity of the high brightness sheeting and site geometrics. This was not an adequate test of high angularity Type III sheeting. However, the problems associated with narrow angularity of sheeting were clearly demonstrated. Operationally, great care must be taken in matching angularity and site geometric characteristics when designing work zones. The steady-burn light was seen further away than Type II sheeting, but there were no speed, lateral placement, or point of lane change differences.

Experiment 4

The question posed in this experiment was: Is there a difference in driver behavior when devices are spaced at double or half the speed limit? Day and night tests using the DPMAS as described earlier were run for the 8″ × 24″ panels and 2′ × 8″ Type I barricades at 27.5-, 55-, and 110-ft spacings.

Results

Figures D-14 and 15 show the mean speeds for all treatment groups, day and night. Analysis of variance with a repeated measure (distance groups) indicated no speed differences between any of the spacing treatments. However, the barricades day and night ($F = 4.8$, 3/120 df, $p < 0.01$) and panels at night only ($F = 7.9$, 3/63 df, $p < 0.01$) elicited a significant reduction in speed from taper to tangent sections. Panels in the daytime did not have any speed reduction effect ($F = 1.29$, 3/48 df). This is consistent with the experiment 2 findings that the smaller devices did not elicit speed reduction. An interesting trend appears comparing day to night. The 110-ft spacing resulted in lowest speed in the day, but changed position with 27.5-ft spacing at night. When driving by devices at night in an otherwise dark environment, an illusion is likely to be created in that suddenly a bright and significant visual source is flashing by quite often. This has a tendency to make the driver think he is going faster and he tends to slow down. A similar illusion does not occur in daylight because there are so many other visual anchors. The British have used appropriately spaced lines across the road before "round-abouts" to create this illusion and effect a speed reduction (*11*).

Lateral placement did not vary significantly in the tangent section between the spacings. All treatments resulted in the now familiar shift towards the lane edge (away from the devices) from approach to tangent.

Point of lane change exhibited only one significant difference. At night, drivers changed lanes significantly closer to the barricade at 27.5-ft spacing than at 55-ft spacing. Table D-16 gives the means, SD's, and median for each treatment. No other differences were significant. Because of heterogeneous variance, the Kruskal-Wallis test was used with this measure. Although there was only one significant difference, a trend was evident. Generally, double spacing reduced mean point of lane change, whereas half spacing increased the average distance. This suggests that half-speed limit spacing in the taper only may increase point of lane change distance. Combined with regular or double spacing in the tangent, this would not increase the number of devices deployed.

Array detection data (Table D-17) are also heavily skewed with a few responses occurring very far from the array. Again, because the data are heterogeneous, the Kruskal-Wallis test was used. The only significant difference was between the regular and double-spaced barricades. As with point of lane change, array detection shows a trend. Generally, the closer the spacing, the farther away the array is detected. This trend was particularly evident at night.

Conclusions

In answer to the question posed for this experiment, the data indicate that the different spacings do not impact speed or lateral placement behavior. There was a nonsignificant trend for device spacing to be positively related to point of lane change and array detection. Thus, device spacing does not appear to heavily influence driver behavior. Given such a finding, consideration in future research could be given to improving detection and lane change behavior through closer spacing in the taper but then widening spacing in the tangent. This might be particularly effective if an appropriate edge line were used along the tangent.

Table D-16. Means, medians, and standard deviations for point of lane change.

	8"x24" Panels			2'x8" Type I Barricades		
	Spacing (in feet)			Spacing (in feet)		
	27.5	55	110	27.5	55	110
DAY						
Mean	692.6	425.5	Unusable	647.2	559.5	462.1
Median	539	387	Data	570	494	530
SD	626.5	311.18		271	321	324
NIGHT						
Mean	622.6	385.3		247.5	637.7	499.5
Median	633	279		221	753	525
SD	451	212.4		61.1	297.9	216.9

Table D-17. Means, medians, and standard deviations for array detection.

	8"x24" Panels			2'x8" Type I Barricades		
	Spacing (in feet)			Spacing (in feet)		
	27.5	55	110	27.5	55	110
DAY						
Mean	3650	3328		2936	3946	2726
Median	3869	3764	Unusable	3265	4026	2559
SD	894	960	Data	1101	272	880
NIGHT						
Mean	1824	2128	1861	2330	2229	1504
Median	1887	1842	1294	2616	1994	1581
SD	968	954	1744	1245	1147	615

Experiment 5

The experiments so far considered only arrays made up of one channelizing device. There are economic and logistic savings possible by mixing device types in an array. Another possible benefit may stem from combining devices to achieve a particular driver behavior effect. For example, a large device could be used in the taper to obtain optimum array detection and point of lane change distance, whereas small cones could be used in the tangent to keep speed reduction at a minimum (attempt to maximize flow through the tangent). The question of this experiment addresses this issue. Specifically stated, the null hypothesis was: there is no driver behavior difference between arrays of mixed devices and arrays composed of only one device.

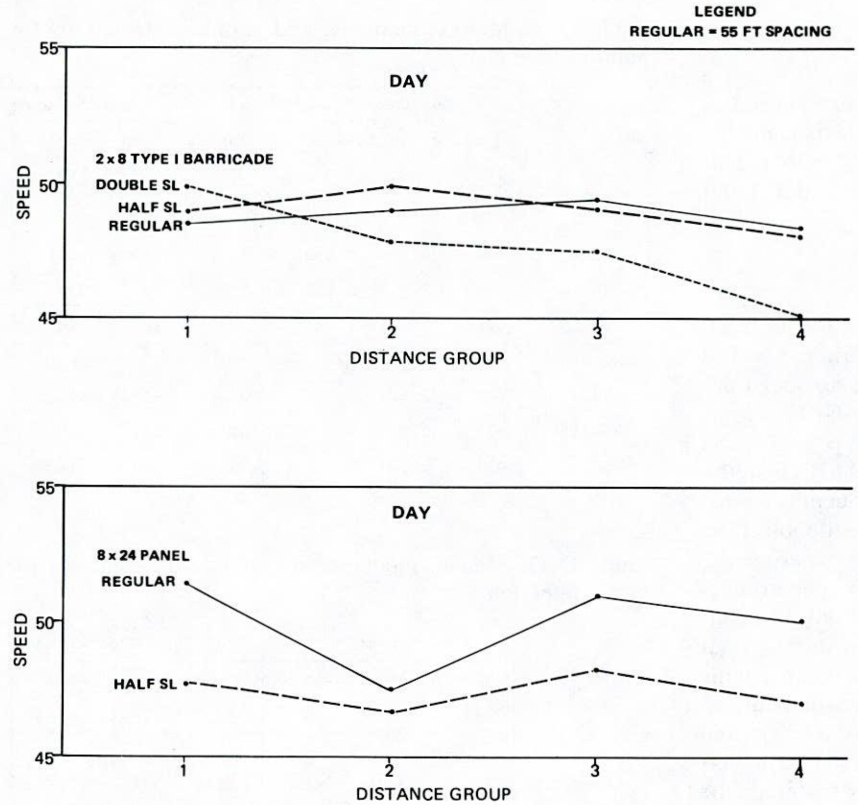


Figure D-14. Mean speeds for devices at different spacings (day).

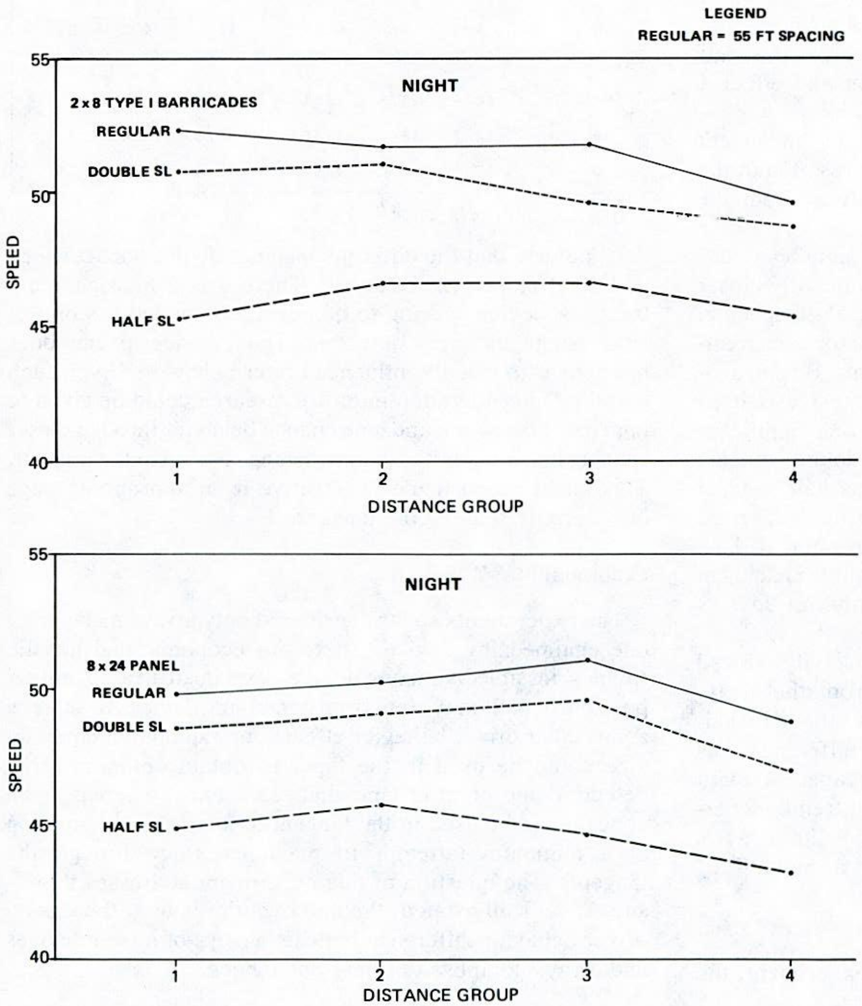


Figure D-15. Mean speeds for devices at different spacings (night).

This experiment was conducted exactly as described for the previous experiments. Here the treatments were an array of 2′ × 8″ Type I barricades in the taper and 36″ cones along the tangent and another array of 8″ × 25″ panels in the taper with 42″ posts in the tangent. These combinations were compared with the "pure" arrays for each of the four devices involved.

Results

The data for all measures are summarized and given in Tables D-18 (day) and D-19 (night). Two ANOVAs with repeated measure were applied to the speed data. The Kruskal-Wallis and/or t-tests were applied to point of lane change and array detection data. In the daytime there were no significant speed differences overall. However, the panel-post array resulted in a particularly low mean speed in the tangent and, according to t-tests, was significantly ($t = 3.01$, 14 df, $p < 0.01$) lower than panel or post alone. Although there were no other significant differences between the three panel-post treatments, the trend of the data suggests a combination effect of the two devices together. Performance variability was generally higher than the panel alone.

The only difference between the barricade–cone treatments was in array detection where the mixed device array was seen at significantly less distance than the 36″ cones alone. This did not affect point of lane change. In all other respects, the mixed and "pure" arrays were the same.

At night, there was a significant speed difference between distance groups ($F = 20.8$, 3/120 df, $p < 0.01$). The device by distance group interaction was also significant ($F = 2.9$, 12/120 df, $p < 0.01$). The barricade–cone array elicited a particularly low speed in the taper and tangent sections (distance groups 3 and 4). Four of the five devices tested resulted in a speed reduction in the tangent section. Because of a malfunction of the DPMAS, no data are available for the panel–post combination. At night, the speed reduction is large, but the other two measures indicate combining devices created a compromise. Barricades evoked greater array detection and point of lane change distances than cones. The devices, when combined, produced distances in between the two extremes.

The results, particularly in light of results from experiment 2, suggest that array detection and point of lane change and array detection are controlled by the total perceptual pattern and contrast provided in the taper and tangent. Using the relatively ineffective cone at night definitely detracted from the overall array performance. In essence, a larger, brighter device in the taper does not totally compensate for less effective devices in the tangent in terms of advance detection.

Although dramatic speed reduction is suggested, the data are not consistent enough to conclude that mixed device arrays will always produce such an effect. Until further evidence is produced, great care should be taken in mixing devices where considerable speed reduction might create hazardous or otherwise undesirable traffic conditions.

Conclusions

In the daytime, there are few differences between mixed and one-type device arrays. The possibility of extensive speed reduction is present, but further testing is necessary to

Table D-18. Summarized data for experiment 5 (night).

	2'x8" Type I Barricade-Taper with 36" Cone-Tangent	2'x8" Type I Barricade	36" Cone	8"x24" Panel-Taper with 42" Post-Tangent	2'x24" Panel	42" Post
Array Detection (feet)						
Mean	1699	2229	1441	Unusable	2123	1920
Median	1430	1994	1632	Data	1843	1916
SD	655	1147	643		954	1020
Point of Lane Change (feet)						
Mean	399	637	251		385	347
Median	371	753	271		279	365
SD	282	297	170		212	270
Speed (mph)						
Mean in tangent	44.2	49.2	49.5		48.9	48.8

Table D-19. Summarized data for experiment 5 (day).

	2'x8" Type I Barricade-Taper with 36" Cone-Tangent	2'x8" Type I Barricade	36" Cone	8"x24" Panel-Taper with 42" Post-Tangent	2'x24" Panel	42" Post
Array Detection	*					
Mean	2907	3946	4352	3798	3328	3201
Median	2977	4026	4617	4019	3764	3697
SD	1118	272	417	1 66	960	1360
Point of Lane Change						
Mean	573	559	462	896	425	627
Median	528	494	386	371	387	604
SD	213	321	376	991	311	287
Lateral Placement	A** T**	A T	A T	A T	A T	A T
	27.2 13.0	21.4 13.5	26.3 15.8	24.1 13.9	17.2 14.2	22.4 13.3
Speed	48.8	48.5	48.9	40.8	49.1	48.5

* (bracket arrow) indicates significance at p <.01

**A=Approach; T=Tangent.

adequately delimit this effect. At night, the same dramatic speed reduction may occur and, again, further testing is warranted. One effect of mixing devices appears to be that the resulting performance is a compromise between the behavior elicited by the two devices in one-device-only arrays.

Because some data were lost and the effects were not consistent, the results of this experiment must be considered suggestive and in need of further experimental verification.

Experiment 6

The final experiment of Task 4 was designed to verify the laboratory findings regarding the pattern or configuration used on channelizing devices. Because all combinations of devices and configurations could not be tested in this experiment, the best and worst were chosen for testing. The relationships found in the laboratory would, hopefully, be predictive of the closed-field test results. Specific predictions tested were: (1) on barricades, a vertical stripe would outperform and a chevron would not perform as well as a diagonal stripe; and (2) on panels, a horizontal stripe would outperform and a chevron would not perform as well as a diagonal stripe.

The experiment was conducted exactly the same as the previous experiments. The treatments are given in Exhibit D-1. In building these treatments, one compromise with constant size had to be made. The configurations were made with 6-in. stripe widths except for the chevrons. Given the 8″ × 24″ display size, a chevron pattern could not be accommodated. Therefore, a decision was made to keep display size constant and use the narrower 4-in. stripe width.

Results

Table D-20 summarizes the data for all the dependent variables. Analysis of variance applied to the speed data revealed two significant differences. The chevron panel elicited a significantly lower speed than the diagonal stripe panel. This difference occurred only in the tangent section. The change in speed for all the panels at night from taper to tangent was significant ($F = 10.8$, 3/54 df, $p < 0.01$) and the more rapid decrease in speed through distance groups 2, 3, and 4 resulted in a significant device by distance group interaction ($r = 43$, 6/54 df, $p < 0.01$).

At night, there were no other differences between the various configurations for point of lane change or array detection.

Daytime differences between treatments all occur in array detection. No other measures showed any significant differences. The chevron and vertical stripe in daylight were detected at significantly (Kruskal-Wallis test) shorter distances than the other patterns.

Conclusions

As predicted by the laboratory results, the chevron used here was not as detectable as the other configurations in daylight. This must be qualified by the fact that a 4-in. stripe was used for the chevron and 6 in. for the remaining stimuli. Because point of lane change was minimally affected and lateral placement or speed not at all, it is equally likely that the poorer performance was due to stripe width, not configuration. At night, the chevron performed as well as the other devices. This suggests that brightness or contrast characteristics, not configuration, control driver behavior at night. Such an interpretation is supported by the experiment 2 results.

The vertical stripe on the barricade does not appear promising because it was seen at significantly less distance than the diagonal stripe. However, the horizontal stripe on the panel appears to have potential. The trend of the data, although not significant, suggests that the panel was seen further, and variability in point of lane change and speed were reduced in daytime. At night, detection distance and point of lane change were above the other two panels.

In general, more definitive research with the chevron is necessary. This is particularly true because it is the only one of the configurations tested in this project which consistently conveys directional meaning. The horizontal stripe on panels appears equally as good as, and perhaps superior to, the diagonal pattern. Further testing with larger panels may produce more definitive results. On the basis of the results at hand from this experiment, there is no conclusive evidence for considering the diagonal inferior to the other configurations tested.

COMPARISON OF TASK 3 AND TASK 4 RESULTS

The purpose of Task 4 was to verify and extend the Task 3 laboratory work. Given the Task 4 results, the following statements summarize the comparison of the two tasks.

Stripe Width

The laboratory tests indicated 6- or 8-in. stripes were optimal. This was not directly tested in the field, but the results of the 4-in. stripe for the chevron tends to confirm this conclusion.

Shape

There was little difference between bar and panel shapes in the laboratory. In the closed-field experiments, the large one-rail barricade had a slight advantage over the larger panels. However, the laboratory finding that bar and panel shapes are generally equivalent was verified.

Configuration

The laboratory data suggested that horizontal and vertical stripes could be more detectable than the diagonal. In Task 4, the horizontal stripe on a panel was equal, and perhaps superior, to the diagonal configuration. The vertical stripe on barricades was definitely inferior to the diagonal stripe. Chevrons were equal to other configurations at night, but were not as detectable in the daytime. This confirms the laboratory finding.

The chevron is unique among the configurations tested in that it is the only one to consistently and reliably convey directional information. If there is need to convey directional information on a channelizing device, the chevron is the only acceptable configuration of the four tested for that purpose. Thus, further design work to improve daytime detectability appears warranted.

Table D-20. Summarized data for experiment 6.

DAY/	2'x8" Type I Barricade with			8"x24" Panels with		
	Chevron	Vertical Stripe	Diagonal Stripe	Chevron	Horizontal Stripe	Diagonal Stripe
Array Detection (feet)						
Mean	1888	2520	3946	1864	3696	3328
Median	2151	1815	4026	1956	3964	3764
SD	920	877	272	1196	836	960
Point of Lane Change (feet)						
Mean	408	535	559	Unusable	467	425
SD	258	135	321	Data	164	311
Lateral Placement (inches)	A* T*	A T	A T	A T	A T	A T
	24.0 11.6	22.2 11.1	21.4 13.5	26.1 12.4	17.7 13.9	17.2 14.2
Speed (mph)						
Mean	43.86	Unusable Data	48.59	47.93	45.08	50.11

NIGHT/	2'x8" Type I Barricade with			8"x24" Panels with		
	Chevron	Vertical Stripe	Diagonal Stripe	Chevron	Horizontal Stripe	Diagonal Stripe
Array Detection (feet)						
Mean	3015	Unusable	2229	2108	2349	2123
Median	3418	Data	1994	2442	2360	1842
SD	1301		1147	1009	1118	954
Point of Lane Change (feet)						
Mean	714		637	527	647	385
SD	528		297	446	582	212
Speed (mph)						
Mean	50.67		49.58	42.82	45.56	47.99

*A=Approach; T=Tangent

Color Ratio

Again, this was not directly tested in the closed-field study. From the laboratory findings, a 1:1 ratio and no more than a 2:1 white-to-orange ratio were recommended. The ability of devices with the 1:1 ratio to provide adequate contrast both day and night was evident from the Task 4 data. The success of devices in being detectable appeared to be more than a simple matter of color ratio. A single color on a device might suffice against a very simple bright background; however, against multicolored, variegated backgrounds, some type of pattern greatly aids a driver in discriminating the device from the background. The angles, colors, shape, and contrast formed by a device pattern serve to break up and stand out from the visual complexity of most backgrounds. The most effective devices are those which, when placed in an array, enhance and extend the pattern throughout the array. This perceptually forms a line or path for the driver to follow. Figure D-16 attempts to show this effect. The photographs in column A are the larger, more successful devices. Notice the clarity of the path established. The column B devices were not as successful. In the case of the vertical stripe on the barricades, the pattern simply does not provide sufficient visible contrast and the barricades are "lost" in the background.

Drastically increasing either white or orange would probably alter the overall pattern perception and hamper contrast under light or dark visibility conditions.

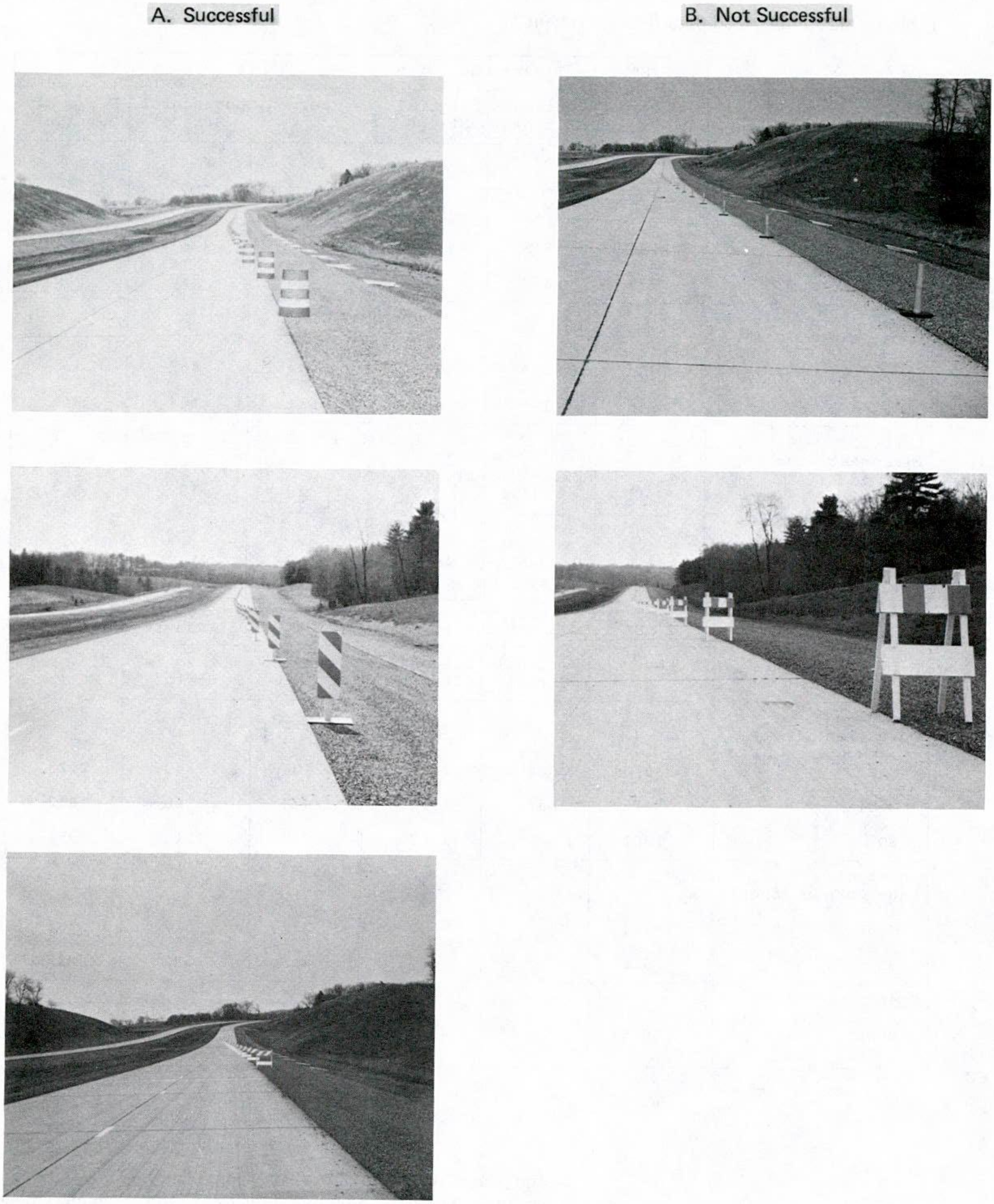


Figure D-16. Effect of device pattern on path clarity.

Height-to-Width Ratio

According to the laboratory studies, this parameter did not have a profound impact on detectability. Thus, shorter or narrower devices should be equally as effective as wider or longer devices. The closed field experiments included this variable to a limited degree. The height-to-width ratio of two panels was different and the same for two panels. Thus: 8″ × 24″ = 0.333; 12″ × 24″ = 0.500; and 12″ × 36″ = 0.333. Also, all barricades were the 0.333 ratio, although two different sizes were used. As the Task 4 results clearly show, there are very significant differences between the 8″ × 24″ panel and larger panels, but no major differences between the larger panels. There was a clear difference between the 2′ × 8″ and 3′ × 12″ barricades. Obviously, the pattern of difference suggests that size is the controlling variable. The height-to-width ratio is much less important than assuring a sufficient visible area. Thus, the laboratory studies were verified.

As part of this parameter, one-versus two-rail devices were studied in the laboratory. Findings were not clear, but one-rail devices were suggested as superior. The closed-field study supports that conclusion. The data suggest there is little reason to use a two-rail device.

In summary, the laboratory findings were generally verified. Task 4 did, however, demonstrate the importance of the effect of arrays as opposed to single devices, the important contribution of device size, and, at night, the value of device brightness. This simply indicates that laboratory studies can be useful, but they are severely limited in the scope of contributing variables.

Evaluation of Dependent Variables

Three types of dependent variables were used in the experiments: detection, vehicle control, and preference. Although it is clear from the results sections of the various experiments which measures were most useful, a brief summary commentary on each measure is provided here.

Speed

There were virtually no significant differences in speed distributions between devices. The greatest mean differences were around 5 mph. The majority of those differences were present at the beginning of the site before devices were detected. Thus, it would be difficult to argue that the devices had an impact. The most useful measure was speed change between taper and tangent sections. Certain devices were more powerful than others in eliciting speed reduction from devices. So speed change appears to be a useful measure for studying channelizing devices.

Lateral Placement

Again, there were no differences in mean lateral placement between devices. All devices had the effect of moving drivers away from the devices. This shift took place in the taper in that as the devices came closer to the centerline, the driver moved closer to the pavement edge.

A more sensitive measure proved to be displacement or the amount of weaving around in the lane through the tangent section. The sum of the squares of displacement gave an index of the amount of swing to both sides of a reference point. This, then, was a useful measure.

Steering Wheel Position

This measure was very sensitive and discriminated between light conditions, devices, and distance groups, but there was no apparent relationship of this measure to any device or geometric characteristic. When the actual degrees of steering wheel movement were examined, the maximum was around 30. Given the type of car, this was well within normal straight-line path steering and, apparently, not a reflection of device effects. Additional manipulations or derivations of this measure might reveal a more useful measure; however, such effort was beyond the resources of this project and this measure was abandoned.

Steering Wheel Rate

This measure suffered from the same problems as steering wheel position and was also abandoned early in the data analysis process. Again, additional development work might produce a useful measure, but that was not possible on this project.

Throttle Pedal Position

Instead of being sensitive to devices, this measure was an excellent reflection of the roadway elevation. Throttle pedal position mirrored grades and little else except for stopping situations.

Brake Applications

In the free flow situation used for this task, brakes were never applied around a work zone. With other traffic present, this should be a more useful measure (e.g. conflicts).

Point of Lane Change

There were differences in mean distance, variability, and spread or range of distributions. Thus, this was one of the most sensitive and discriminating measures used.

Array Detection

This was a sensitive and useful measure, but one of the more difficult to collect. People are prone to vary in certainty before announcing detection and sometimes forget to say anything. In spite of these problems, array detection clearly discriminates between various devices. One would predict some relationship between point of lane change and array detection. In fact, the relationship is evident, but does not appear linear or of the same magnitude in different light conditions. In other words, the two measures are not interchangeable. As in point of lane change, subject variability, range, and form of the response distributions were all informative dimensions of this measure.

A useful derivative of array detection is application of the decision sight distance (DSD) criteria. By subtracting standard deviations from the mean, an indication of the percentage of the driving population detecting the array at various points, specifically at or above the DSD criterion, is possible. This is one way of achieving an indication of the impact of response variability on detection.

Device Detection

As the comparison of array and single device detection data showed, arrays are perceptually more detectable than the effect of single devices added together. Therefore, single device detection is not an adequate indication of performance in an array situation. This measure is useful for selecting a device which will be standing alone or in small numbers (2–4) around a specific hazard.

Driver Preference

Drivers do have relatively clear preferences among the devices. The preferences are almost perfectly correlated with device size and are consistent with the array detection measure.

The comments on work zones are surprisingly consistent and centered around a small number of themes (e.g., advance information, brightness, device maintenance). This type of comment, plus more systematic queuing of drivers as they traverse work zones, appears to be a useful source of information.

Summary

On the basis of the experience and findings in this task, the following measures are recommended as being sensitive to differences in channelizing devices and probably to work zones in general: speed change in the taper-tangent areas; point of lane change; array detection, and displacement (weaving).

SYNTHESIS OF TASK 4 RESULTS

The basic results were synthesized to Tables D-13 and D-14 as part of experiment 2. The remaining discussion concerns how the results of experiments 3 through 6 contribute to those findings.

Steady-Burn Lights

The steady-burn lights add considerable detection distance to devices with Type II sheeting. They also more than triple the distance or zone in which lane changing occurs before the taper. Lights on each or alternate devices are equally effective. Steady-burn lights in the taper are statistically no different from the other light treatments, but they do not spread out the lane change zone to the same degree.

The comparison of Type III sheeting with lights and Type II sheeting demonstrated the importance of angularity. Narrow angle sheeting, even though high brightness, is not effective under certain site geometric characteristics (i.e., hills, curves). Wide angle Type III may be effective, but data to test that premise were not generated.

Device Spacing

The findings suggest that changes in spacing have little impact on driver behavior. There were no speed or lateral placement differences between half, regular, and double speed limit spacing. A nonsignificant trend suggests that point of lane change and array detection increase with shorter spacings, and vice versa. Spacing combinations such as half-speed limit in the taper and double-speed limit in the tangent have promise for optimizing device behavior and reducing logistics and maintenance cost.

Mixed Device Arrays

In the daytime, there were few differences between mixed and single device arrays. Any advantages to this type operation will stem from logistic or cost, not driving behavior, considerations. At night, the effect of mixing devices appears to be a compromise in driver behavior between the characteristics of the two devices used. The types of devices used and behavioral consequences must be carefully considered. Only two device combinations were tested here and further research on other combinations is desirable. However, behaviorally, there does not appear to be any particular advantage to mixing devices.

Device Configurations

The particular chevron design used here was not as detectable in the daytime as the other patterns. However, a 4-in. stripe, not 6-in., was used, and this could account for the diminished performance. At night, the chevron was equivalent to the other patterns. A vertical stripe on barricades did not perform well, most likely because it did not form a satisfactory pattern of contrast with light or dark backgrounds. The horizontal stripe on panels appears equal to, and perhaps better than, the diagonal stripe. Thus, a horizontal pattern can be used on panels and chevrons can be used at night on barricades and panels. Further design improvements appear necessary to make the chevron more detectable for daytime use.

SUMMARY OF FINDINGS AND SELECTION FOR FIELD TESTS IN TASK 5

Although the closed-field studies were a step closer to reality than the laboratory, they still represented a very simple "pure" situation. The next step is to validate these findings in an operational setting. One concern about the next step is measurement sensitivity. The measures used in the closed-field situation were relatively fine grained; yet there were no large, dramatic differences. This was particularly true of measures which are typically used in full field settings (e.g., speed). When channelizing devices are buried within the context of a full work zone information system, the relatively small differences found in the closed-field situation may be washed out or masked by overriding responses to other components of the work zone. With that possibility in mind, the findings recommended or verification in the field evaluation include:

1. Large devices elicit speed reduction to a significantly greater extent than small devices.
2. Drivers change lanes farther away from the taper at night than in the day.
3. Panels and barricades are equivalent in their impact on drivers.
4. Steady-burn lights are highly detectable and increase the mean and the overall zone when lane changes occur.
5. Alternate or taper-only light spacing is equivalent to lights on every device.
6. The relationship between steady-burn lights and Type III sheeting needs further investigation.
7. Wider device spacings are equivalent to regular speed limit spacng.
8. Mixed arrays, at least at night, reflect a compromise between the performance elicited by the two devices used.
9. The chevron configuration and horizontal stripe on panels are equivalent or better than the diagonal stripe.

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APPENDIX E

FIELD EVALUATION STUDY

INTRODUCTION

The final effort of this study (Task 5) was to evaluate the effectiveness of selected channelization devices when used collectively under actual field conditions. The results of the previous tasks were to be used in selecting alternate devices for testing and the experimental plan. These devices were to be tested at work situations similar to those depicted in the typical MUTCD layouts, and include different highway types.

METHODOLOGY

To develop an experimental plan conforming to available time and monetary resources, the number of treatments (channelization device configurations) and the number of applicable work zone situations had to be logically constrained. At the outset, the task was to narrow down to some manageable number of test situations the scope of the field studies from a possible combination of 96 test situations defined by the following:

1. Five major device types—barricades, drums, panels, and cones; with and without steady-burn lights (without considering variations in sizes for each).
2. Four work zone types—lane closure, by-pass, detour, and cross-over.
3. Three highway types—rural two-lane, rural expressway, and urban freeway (without considering number of lanes for the last two types).

In consideration of the types of channelizing devices presented in the MUTCD and the number of options tested in Task 4, it was decided that at least four treatments would be candidates for field testing. A standard MUTCD application would serve as the base condition against which three experimental treatments would be compared. The MUTCD standard used was a Type I barricade with a 12-in. high and 24-in. wide panel and 6-in. diagonal stripes. Three experimental devices were selected with consideration of the results of the previous tasks and the logistical limitations. They were: Type I barricade (24 in. × 12 in.; 6-in. vertical stripes); vertical panel (24 in. × 12 in.; 6-in. horizontal stripes); and combination of Type I barricade (24 in. × 12 in.; 4-in. chevron stripes) on the taper section and cones (36 in. high) on the tangent section.

As explained later, additional treatments were tested when it became obvious that the number of sites available was severely limited.

It was felt that the specific work zone type and highway type situations to which each channelizing device system was to be applied should reflect its hazardousness and frequency of exposure at work zones. Lane closures are the most frequently occurring type of work zone situation in which channelizing devices are used. On rural two-lane roads, however, lane closures generally involve the use of flagmen, a situation which would confound and minimize the measurable effect of channelizing devices. Therefore, the lane closure situation was not considered for field evaluation at a two-lane rural site.

Experience indicated that the most frequent and critical situations are represented by rural expressway and urban freeway one-lane closures. Therefore, two test work zone sites were selected for each of the foregoing roadway conditions and given highest priority.

Traffic diversion is a less frequently occurring situation in which channelizing devices are used. On rural two-lane highways, traffic diversion is accomplished by closing the existing roadway and constructing a detour on a new roadway alignment. Channelizing devices are used to indicate the alignment of the new roadway and to barricade off the existing roadway. In addition, traffic diversion is not frequently used on urban freeways because of the high volume of traffic and long vehicle delay that would occur. Therefore, the traffic diversion for the rural expressway was assigned the next highest priority.

The closing of two lanes on a multilane highway is an infrequently occurring type of traffic pattern. Nonetheless, it can be a particularly hazardous situation. Drivers do not expect to see a second lane closure just after experiencing a previous lane closure. The paths a driver may take to reach the through lane has increased greatly. Therefore, a clear delineation of the two-lane closure using channelizing devices becomes an extremely important factor to guide a driver safely and smoothly through the work zone. Therefore, the additional delineation requirement of a two-lane closure was also considered.

Because of the need for a comprehensive data collection procedure, and to stay within the budget of the project, six test situations were selected for the proposed experimental paradigm shown in Figure E-1. The selected experimental approach is a 4 × 6 factorial design with one treatment serving as the control or base condition. (A factorial design is the application of different experimental treatments to the same situation and analyzing the changes in dependent variables across treatments.)

Several unforseen difficulties arose that made it unfeasible to follow the experimental paradigm as proposed. The urban freeway one-lane closure sites (4 and 5) initially selected for study had to be dropped from consideration because it was obvious on inspection that the traffic volumes were so high that volume itself would influence driver performance (i.e., speed, lane changing, etc.) more so than the channelization devices. If any differences were to be found between the four device treatments, it was believed necessary to have near free-flow volume conditions (level-of-service A or B) whereby drivers would be reacting to the traffic control devices rather than to leading vehicles. Another problem with the urban sites was the use of the flashing arrowboards which, it was assumed, would influence driver behavior more than the test treatments.

The urban freeway two-lane closure site (site 6) was not investigated for yet another reason. The construction project for the preselected site did not materialize during the course of the project schedule and there was no readily available alternative site.

Because there were only three sites left for testing purposes, a decision was made to increase the number of test treatments as compensation for fewer sites. The additional treatments selected included combinations of devices and different spacings. Table E-1 gives the final experimental devices tested at the three available sites.

DATA COLLECTION PROCEDURES

It was assumed that the presence of advanced construction signing, arrowboards, and other informational cues would make it difficult to observe differences in driver action due to channelizing device schemes alone. For the same reason,

Site/Work Zone Type	Site No.	Base	Experimental		
		1	2	3	4
Rural Expressway 1 Lane Closure	1				
	2				
Rural Expressway Traffic Diversion	3				
Urban Freeway 1 Lane Closure	4				
	5				
Urban Freeway 2 Lane Closure	6				

Figure E-1. Proposed experimental paradigm for field evaluation of selected channelizing devices.

one would expect the variation in driver reaction to various channelizing device systems to be small. Therefore, to maximize the number of performance measures, sample size, and the probability of finding significant differences, the Traffic Evaluator System (TES) was employed as the principal data collection technique. It was supplemented by manual observation of traffic conflicts and erratic maneuvers.

Traffic Evaluator System Data Collection

The TES is an electronic device that monitors all vehicles in all lanes instrumented with tapeswitch sensors. In operation, the system continuously records switch identification and exact time of activation whenever switch closure is sensed. Data points are collected and read out at each sensor pair in the array. The full description of the TES is provided by Sanders et al. (*1*).

On each data collection day a new treatment was deployed and then data were collected during both day and night periods. When possible, changes were made only to the channelization devices and not to any of the signs or other devices present. The project schedule did not permit a driver acclimation period for each device; but this did not create an experimental problem in this case. In fact, it was of interest to obtain "first exposure" effects inasmuch as motorists frequently encounter a particular work zone only once because either the motorist or the work zone is transitory.

Erratic Maneuver and Traffic Conflict Data Collection

The effectiveness of the channelization treatments was also determined by using erratic maneuvers and traffic conflict measures. The various types of erratic maneuvers and conflicts that were counted and analyzed are defined as follows:

1. An *erratic maneuver* occurs when an unimpeded vehicle brakes or suddenly swerves while approaching the transition (taper) area. Unimpeded means there are no vehicles directly ahead or rapidly overtaking in an adjacent lane).
2. In general, *a conflict* is a situation in which a vehicle is required to take evasive action, to brake or swerve to avoid an impending collision with another vehicle ahead or alongside. A brake light indication, obvious braking, and swerving by the offended vehicle are indicators of a conflict.
3. A *lane-change erratic maneuver* occurs when an unimpeded vehicle makes a lane change in the transition or work zone area. This type is unique to the traffic diversion site where vehicles were to maintain their lane position.
4. A *lane-change conflict* is a situation in which a vehicle changes lanes into the path of another vehicle, causing the offended vehicle to brake or swerve to avoid collision.
5. A *slow-to-merge erratic maneuver* occurs when an unimpeded vehicle slows or stops during its merge into an open lane.
6. A *slow-to-merge-conflict* occurs when a vehicle slows or stops during its merge into the open lane, causing a vehicle in the open lane to brake or weave.
7. A *wrong-way lane-change erratic maneuver* occurs when an unimpeded vehicle, in approaching the transition area in an open lane, crosses over into a closed lane.
8. A *wrong-way lane-change conflict* occurs when a

Table E-1. List of treatments tested at each site.

Treatment No.	Location	Device Type[1]	Pattern	Spacing	Sites 1 K-10	Sites 2 I-57	Sites 3 I-55/74
1 (Base)	Taper Tangent	24" x 12" Type I Barricade	6" diagonal	55 ft	D, N	D, N	D, N
2A	Taper Tangent	24" x 12" Type I	6" vertical	55 ft	D, N	D	D, N
2B	Taper Tangent	24" x 12" Type I	6" vertical	55 ft 110 ft			D, N
3A	Taper Tangent	24" x 12" Type I	4" chevron	55 ft 110 ft			D, N
3B	Taper Tangent	24" x 12" Type I	4" chevron	110 ft			D
3C	Taper Tangent	24" x 12" Type I	4" chevron	55 ft 110 ft			D, N
3D	Taper Tangent	24" x 12" Type I 36" cone	4" chevron	55 ft 55 ft	D, N	D,N	D
3E	Taper Tangent	24" x 12" Type I 42" post cone	4" chevron	55 ft 55 ft			D
4A	Taper Tangent	24" x 12" vertical panel	6" horizontal	55 ft	D, N		D, N
4B	Taper Tangent	24" x 12" vertical panel	6" horizontal	55 ft. 110 ft			D
4C	Taper Tangent	24" x 12" vertical panel 36" cones	6" horizontal	55 ft 55 ft			D

[1] Steady-burn lights used at night for all devices except cones; reflective collars put on cones.

vehicle, approaching the transition area in an open lane, enters into a closed lane, and an offended vehicle brakes or takes evasive action to avoid collision with the wrong-way lane-change vehicle.

9. A *slow-moving vehicle conflict* occurs when a vehicle swerves or brakes to avoid a slower vehicle in front.

10. A *stop-in-closed-lane conflict* occurs when a vehicle approaching the transition area is confronted with a stopped vehicle. The offended vehicle slows, stops, or swerves to avoid the stopped vehicle.

The procedure used to collect the erratic maneuver and traffic conflict data was to position an observer upstream of the start of the taper or point of diversion where he could observe traffic approach and proceed through the test section. Manual counts of each type of erratic maneuver or conflicts were made at 15-min intervals during the complete 2-to-3-hr data collection period.

DATA REDUCTION

Traffic Evaluator System Data Reduction

For the TES collected data, two utility computer programs and two analysis programs were used to prepare the data for analysis and interpretation. The utility programs translate time and switch codes into vehicles and traffic flow characteristics, reproducing the conditions actually experienced on the roadway. The initial utility program edits data stored on magnetic tape. It checks for data reliability and completeness and arranges the data in a form more readily reviewed by the researcher.

The next utility program reproduces vehicles at each pair of switches. The program assigns a unique identification number to each vehicle entering the array and tracks this vehicle through the entire array of switches on the roadway. For each vehicle at each switch pair crossed, the following 15 elements are recorded: vehicle number, lane number, switch pair number, vehicle type, wheelbase, number of axles, mean speed of all axles, time of day, manual codes associated with this vehicle, time gap to lead vehicle, space gap to lead vehicle, type of lead vehicle, time gap to following vehicle, space gap to following vehicle, and speed of following vehicle.

After the editing programs are completed and vehicle records are made, several computer analysis programs can be used to extract the measures desired. For this project, the first of these was to calculate some 20 vehicle flow measures for each vehicle as it proceeded through the switch trap array. An example output of this program showing the calculated measures for one vehicle is provided in Figure E-2.

The example in Figure E-2 shows that vehicle 15 was a Type 5 (truck) with five axles and a wheelbase of 51 ft. Its mean speed over all traps was 52.34 mph. It was initially detected in lane 2 (inside lane), but the truck moved into lane 1 (outside lane which is being closed) by the next trap and then returned to lane 2 after the fifth trap. Other statistics regarding its flow characteristics are as noted on the figure.

The next analysis program was to generate summary statistics for all vehicles and only for the measures that were of interest. The measures selected for analysis were mean speed, speed variance, acceleration, acceleration variance, and lane changing.

Prior to completing the final analysis program, a sample of the speed data was analyzed to determine if vehicle headway affected mean speed. Originally it was hypothesized that the differences in channelization devices could only be detected for free-flow vehicles. In nonfree-flow conditions, motorists approaching the work zone area would respond to vehicles ahead and vehicles in the adjacent lane rather than to low-profile channelization devices. To test the validity of the assumption, the mean speed and speed variance for one base condition were compared. Vehicles were grouped in 1.5-sec increments of vehicle headway from 1.5 to 10.0 sec. The analysis revealed that the mean speed for all groups was practically the same, but that the speed variances were notably different with longer headways having higher variances. Based on this result, it was decided to use 7.5-sec headway as the criterion for defining a "free-flow" vehicle. This headway criterion applied to vehicles ahead in the same lane and to vehicles in the adjacent lane. At 55 mph, this is a distance of 605 ft. Although lead vehicles are certainly in view of the following motorist at 605 ft, this seems like a reasonable distance where the influence of the lead vehicle is minimal.

The final analysis program provided the summary statistics for each test condition as follows: sample size at each trap, mean speed at each trap, speed variance, mean acceleration, and acceleration variance.

These statistics were calculated for both free-flow vehicles (headway of equal to or greater than 7.5 sec) and nonfree-flow vehicles (headway less than 7.5 sec). All vehicles except trucks were included in the output.

The analysis program also provided a listing of lane changing from a trap in one lane to a trap in another lane (in either direction). These lane changing data included all vehicles.

Erratic Maneuver and Traffic Conflict Data Reduction

The data reduction for the erratic maneuver and traffic conflict phase merely consisted of tabulating the counts for the 15-min intervals and summing for the entire study period. From the counts and the volume data, erratic maneuver and traffic conflict rate expressed as a proportion to the total volume were calculated for each type and then for all types combined.

RESULTS

The results of the studies are presented site by site and then synthesized to arrive at findings that can be generalized for all sites and device types, if possible. The discussion of each site includes a description of the site, what devices were tested, and the results of four evaluation measures—mean speed, speed variance, lane changing, and erratic maneuver/traffic conflict rates.

Site I

The first site used for testing was a work zone located on Kansas State Highway K-10, a four-lane divided highway just southwest of Kansas City, where a bridge was being reconstructed. The 60-ft median between the opposing lanes was used as a by-pass around the construction area. Both lanes were maintained through the by-pass. Figure E-3 is a schematic drawing of the site and indicates the location of the TES tapeswitch traps.

The following channelization treatments were tested:

No.	Treatment
1	24″ × 12″ Type I barricade; 6″ diagonal stripes; 55-ft spacing.
2A	24″ × 12″ Type I barricade; 6″ vertical stripes; 55-ft spacing.
3D	24″ × 12″ Type I barricade; 6″ chevron stripes; from traps 5 to 7; 55-ft spacing and 36″ cone (7″ cone collars) from traps 7 through end of zone; 55-ft spacing.
4A	24″ × 12″ vertical panel; 6″ horizontal stripes; 55-ft spacing.

Steady-burn lights were used at night for all treatments except the cones that were reflectorized with 7-in. white collars of reflectorized material. Data were collected both day and night for all treatments.

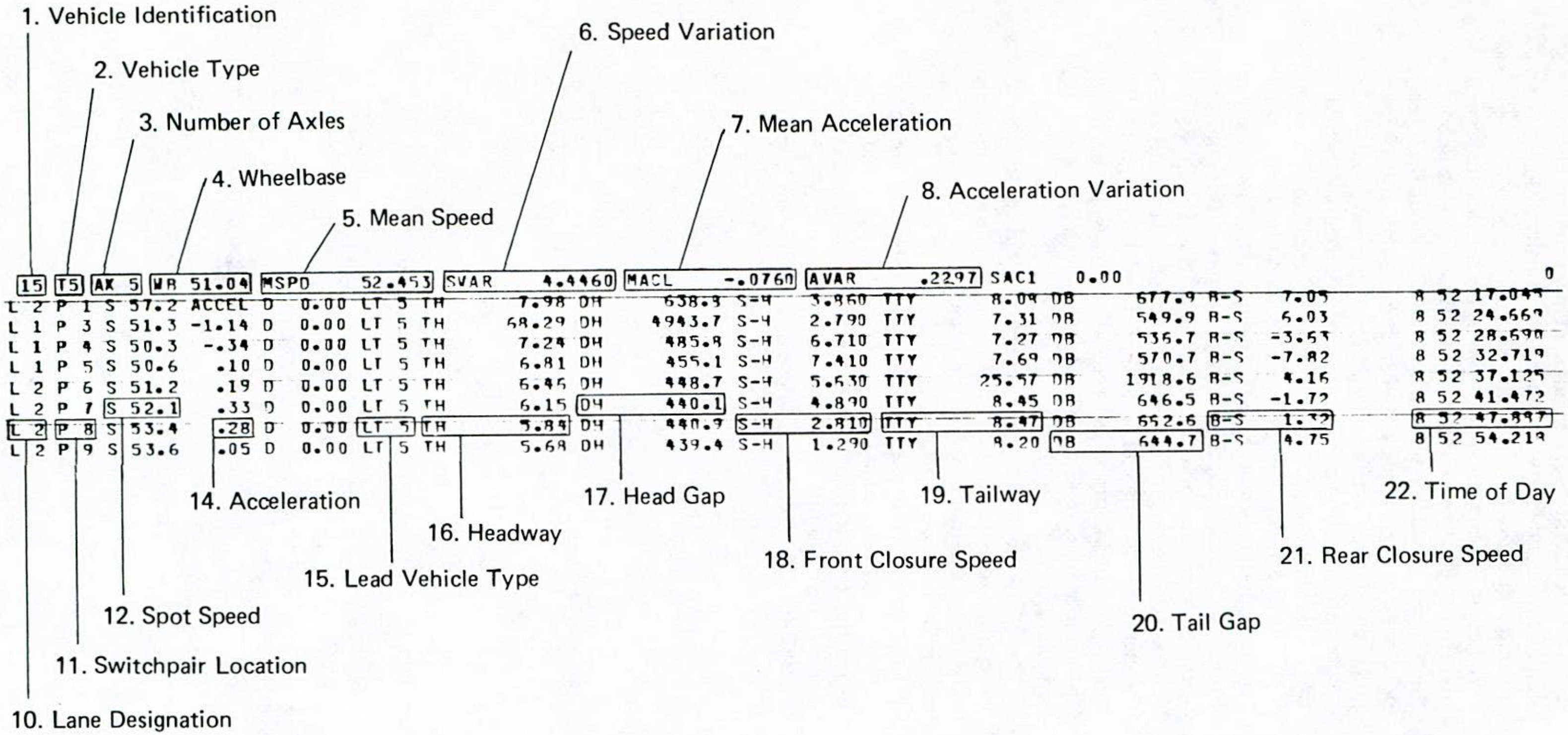

Figure E-2. Example computer output from Traffic Evaluator System.

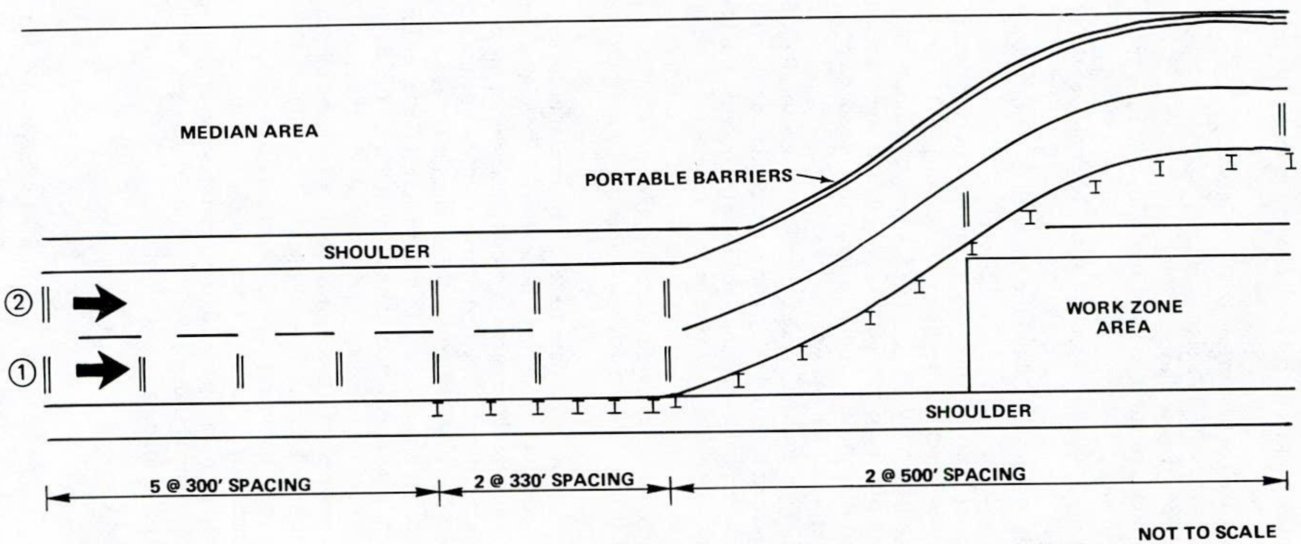

Figure E-3. Schematic drawing of site 1.

Other traffic control devices were in the following order:

1. ROAD CONSTRUCTION 1500 FT sign.
2. DETOUR 1000 FT sign.
3. DO NOT PASS sign at 750 ft.
4. Reverse curve symbol sign with a 45 mph speed advisory plate at 500 ft.
5. 45-mph regulatory sign at the beginning of the reverse curve.
6. DETOUR sign behind the channelization devices.

Speed Profile. The TES traffic flow data for each treatment are given in the tables in Exhibit E-1. Unfortunately, data are not available for one of the test conditions (treatment 3D) during the day. The data on the field tape were unreadable during the initial edit routine and consequently could not be extracted for analysis.

The first analysis conducted was to plot a speed profile for each treatment, both day and night conditions. For this site only lane 1 data were analyzed in detail because the vehicles in this lane are closer to the devices and, therefore, should be affected more. (A cursory observation of the mean speed data shows that for all situations the speeds in lane 2, the median lane, are consistently higher at all traps than lane 1 by 3–4 mph.)

The mean speed data for the experimental devices were adjusted prior to plotting. The reason for the adjustment was to account for differences in speeds observed at the first trap for the treatments. The first trap was sufficiently upstream of the devices (1860 ft) that vehicles should not have been influenced by the devices. Therefore, any differences found at this trap were assumed to be attributable to the day of the week because devices were tested on different days. (Previous research has shown that there is some minor variation in speed during days of the week (*2*).) The ratio of the differences between the base treatment and the experimental treatment to the base treatment for the first trap was used as a constant factor applied to the mean speed at other traps for the experimental devices. This ratio is mathematically expressed as follows:

$$1 \pm \frac{\overline{X}_{B1} - \overline{X}_{T1}}{\overline{X}_{B1}}$$

where $\overline{X}_{B1}$ = mean speed at trap 1 for base condition; and
$\overline{X}_{T1}$ = mean speed at trap 1 for any experimental treatment.

Figure E-4 shows two plots of the mean speed profiles for test treatments. The top plot is for nighttime and the bottom is for daytime. The background pattern represents the 95 percent confidence interval for the base treatment. The confidence interval was derived as follows:

$$\text{C.I.} = \overline{X}_i \pm t \, \frac{\sigma_i^2}{n_i}$$

where $\overline{X}$ = mean speed for each trap;
t = t-statistic at 95 percent confidence level for degrees of freedom = $n - 1$ (for most cases t = 1.96);
σ_i^2 = speed variance for each trap; and
n_i = sample size for each trap.

This confidence interval is significant in that any value for the treatments outside the envelope is statistically different from the corresponding base condition value.

In general, the mean speed profiles for the daytime condition (lower plot) show that the free-flow vehicles decrease their speed gradually from traps 1 to 3 (about 0.23 fps^2), decelerate at higher rate between 3 and 5 (about 0.44 fps^2), and even a higher rate (about 1.11 fps^2) between 5 and 7. The devices started at trap 5 and the transition curve started at trap 7. Between traps 7 and 8, vehicles decelerate at about 0.50 fps^2 and then taper off their deceleration between the last two traps at about 0.25 fps^2. The sharp decrease in speed from traps 5 through 8 indicates that the motorist is adjusting speed to negotiate the curve transition. The site did have a 45-mph speed advisory sign located about 500 ft upstream of the curve transition and a 45-mph regulatory sign at the curve. The maximum speed reduction was from the initial 56.5 mph to a low of 43.0 mph at trap 8, which is a 24 percent reduction.

The nighttime speed profile is nearly identical to the day except that the speeds at all traps are slightly lower and there was an unexplainable trend for vehicles to accelerate between the last two traps.

The mean speed profiles for all three treatments during the day are practically identical. The only difference found between the base treatment and the two experimental treatments is that slightly higher mean speeds were observed in traps 7 through 9 when vertical panels (4A) were in place.

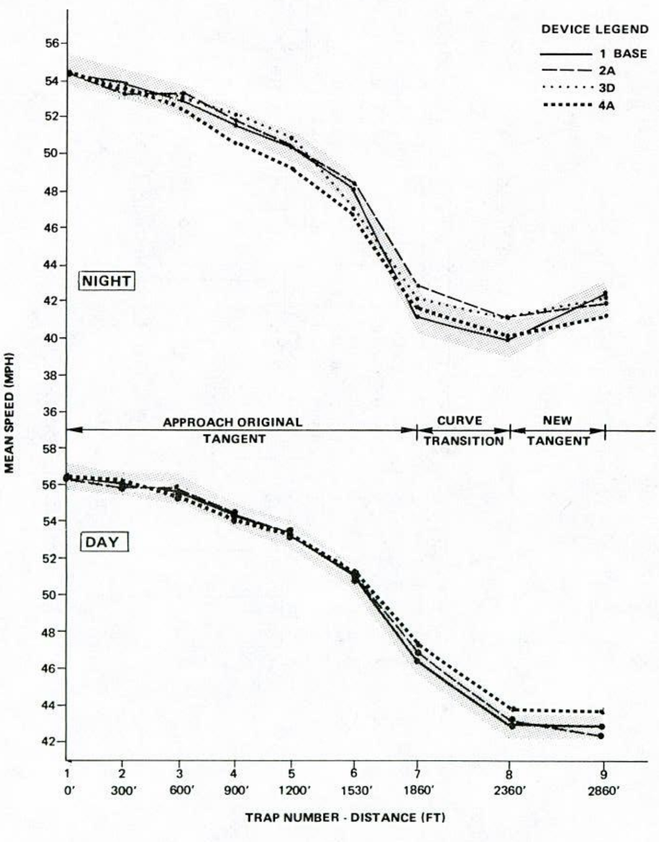

Figure E-4. Day and night mean speed profiles for site 1.

EXHIBIT E-1

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 1 Channelization Treatment 1

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	244	110	236	0	239	0	245	0	248	113	248	114	240	119	205	0	272	0
		Mean Speed (MPH)	56.5	60.6	56.1	-	55.5	-	54.3	-	53.4	56.5	51.0	54.4	46.4	50.4	42.9	-	42.8	-
		Speed Variance $(MPH)^2$	29.8	22.6	28.6	-	27.9	-	25.7	-	30.0	27.3	29.6	31.1	30.1	25.9	28.6	-	28.8	-
		Mean Acceleration (FPS)	-	-	-.2	-	-.3	-	-.5	-	-.4	-	-.8	-.7	-1.4	-1.4	-.5	-	-.3	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.1	-	.2	-	.4	-	.4	.4	.6	1.1	.2	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	392	178	391	0	401	0	413	0	415	170	413	168	363	217	327	0	496	0
		Mean Speed (MPH)	56.6	60.6	56.1	-	55.2	-	53.9	-	52.8	56.5	50.6	54.0	45.9	49.1	42.6	-	43.0	-
		Speed Variance $(MPH)^2$	21.4	18.3	19.8	-	23.4	-	22.3	-	25.2	24.6	29.7	25.1	30.2	30.5	27.2	-	30.0	-
		Mean Acceleration (FPS)	-	-	-.2	-	-.3	-	-.6	-	-.4	-	-.8	-.8	-1.4	-1.7	-.5	-	-.2	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.4	-	.4	-	.4	.5	.7	1.1	.3	-	.2	-
NIGHT	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	170	44	169	0	169	0	169	0	173	54	169	56	114	68	122	0	191	0
		Mean Speed (MPH)	54.6	58.5	53.9	-	53.0	-	51.8	-	50.6	53.2	48.0	50.6	41.3	45.7	40.0	-	42.4	-
		Speed Variance $(MPH)^2$	29.3	23.0	31.2	-	31.8	-	28.7	-	28.1	37.3	29.4	35.1	45.4	37.9	33.1	-	34.4	-
		Mean Acceleration (FPS)	-	-	-.3	-	-.3	-	-.5	-	-.4	-	-.9	-.8	-1.7	-1.6	-.1	-	.0	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.3	-	.3	-	.4	-	.4	.5	.8	1.1	.3	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	136	53	138	0	142	0	148	0	147	47	138	55	93	89	85	0	169	0
		Mean Speed MPH	55.2	58.5	54.5	-	53.8	-	52.6	-	51.6	53.3	49.0	51.2	42.1	46.8	40.9	-	43.3	-
		Speed Variance $(MPH)^2$	22.2	26.3	23.4	-	25.1	-	24.5	-	24.7	36.8	27.1	31.0	55.1	28.9	29.2		32.2	-
		Mean Acceleration (FPS)	-	-	-.3	-	-.2	-	-.5	-	-.4	-	-.8	-.7	-1.6	-1.6	-.2	-	-.0	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.3	-	.5	-	.4	-	.5	.5	1.0	.6	.2	-	.2	-

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 1 Channelization Treatment 2A

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	241	135	239	0	239	0	241	0	245	138	249	136	241	143	197	0	270	0
		Mean Speed (MPH)	56.5	60.7	56.4	-	55.8	-	54.4	-	53.4	56.6	51.1	54.5	46.9	49.9	43.2	-	42.2	-
		Speed Variance $(MPH)^2$	21.0	19.0	26.0	-	23.5	-	26.2	-	27.3	23.7	33.1	25.0	32.0	26.3	33.4	-	37.3	-
		Mean Acceleration (FPS)	-	-	-.0	-	-.2	-	-.5	-	-.4	-	-.8	-.8	-1.3	-1.6	-.6	-	-.3	-
		Acceleration Variance $(FPS)^2$	-	-	1.4	-	.2	-	.2	-	.6	-	.4	.5	.8	.9	.3	-	.3	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	473	181	466	0	478	0	494	0	496	169	491	172	452	200	394	0	568	0
		Mean Speed (MPH)	57.2	62.0	56.8	-	56.1	-	55.0	-	54.1	57.9	52.0	55.7	47.4	51.6	43.5	-	43.2	-
		Speed Variance $(MPH)^2$	24.8	23.5	25.8	-	28.2	-	27.7	-	30.9	25.4	29.5	26.6	25.6	28.7	26.1	-	37.0	-
		Mean Acceleration (FPS)	-	-	-.2	-	-.3	-	-.5	-	-.3	-	-.7	-.8	-1.4	-1.6	-.7	-	-.3	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.4	-	.3	-	.5	.4	.8	1.0	.4	-	.3	-
NIGHT	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	145	34	139	0	137	0	139	0	140	38	140	38	131	46	98	0	147	0
		Mean Speed (MPH)	54.4	57.4	53.4	-	53.3	-	52.0	-	50.6	51.7	48.3	49.8	42.8	44.9	41.1	-	42.0	-
		Speed Variance $(MPH)^2$	30.2	37.1	36.1	-	31.7	-	31.8	-	33.0	37.2	31.7	30.4	26.4	26.4	24.1	-	22.4	-
		Mean Acceleration (FPS)	-	-	-.3	-	-.3	-	-.4	-	-.5	-	-.7	-.7	-1.6	-1.6	-.1	-	.0	-
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.3	-	.2	-	.4	-	.4	.4	1.4	1.4	.2	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	135	38	135	0	133	0	131	0	133	38	131	39	100	68	83	0	153	0
		Mean Speed MPH	55.7	59.9	54.9	-	54.2	-	52.7	-	51.7	54.9	49.1	52.8	43.2	47.6	41.3	-	42.9	-
		Speed Variance $(MPH)^2$	27.7	60.7	33.6	-	33.6	-	30.8	-	31.8	37.5	33.6	41.7	32.6	42.1	24.7	-	30.1	-
		Mean Acceleration (FPS)	-	-	-.4	-	-.3	-	-.6	-	-.4	-	-.8	-.7	-1.6	-1.7	-.2	-	-.1	-
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.3	-	.4	-	.4	-	.5	.6	1.1	1.2	.2	-	.2	-

EXHIBIT E-1 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 1 **Channelization Treatment** 3-A

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	269	127	266	0	268	0	268	0	268	140	267	141	249	156	222	0	288	0
		Mean Speed (MPH)	57.1	60.9	56.7	-	56.1	-	54.9	-	54.0	56.1	51.7	53.6	47.8	49.9	44.4	-	44.1	-
		Speed Variance $(MPH)^2$	23.0	17.4	24.5	-	24.6	-	24.9	-	27.2	20.9	28.0	22.8	27.6	25.5	28.6	-	29.4	-
		Mean Acceleration (FPS)	-	-	-.2	-	-.2	-	-.5	-	-.4	-	-.8	-.9	-1.2	-1.3	-.5	-	-.2	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.2	-	.3	-	.4	.5	.7	.8	.3	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	534	223	521	0	518	0	526	0	540	235	538	236	488	282	443	0	670	0
		Mean Speed (MPH)	56.6	60.5	56.0	-	55.4	-	54.2	-	53.2	56.4	51.0	54.6	46.8	51.2	43.6	-	43.8	-
		Speed Variance $(MPH)^2$	24.8	19.7	24.2	-	22.1	-	21.2	-	22.6	27.5	25.8	23.8	24.6	26.2	24.0	-	27.7	-
		Mean Acceleration (FPS)	-	-	-.2	-	-.3	-	-.5	-	-.4	-	-.7	-.7	-1.2	-1.3	-.5	-	-.2	-
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.3	-	.3	-	.4	.5	.6	1.0	.3	-	.2	-
NIGHT	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	208	71	205	0	204	0	203	0	205	77	202	78	178	98	158	0	236	0
		Mean Speed (MPH)	54.5	57.8	53.5	-	52.4	-	50.7	-	49.2	51.7	46.8	49.2	41.6	43.9	40.1	-	41.4	-
		Speed Variance $(MPH)^2$	29.1	32.3	27.6	-	35.2	-	33.6	-	37.4	35.7	42.9	28.5	38.0	35.9	31.1	-	36.5	-
		Mean Acceleration (FPS)	-	-	-.4	-	-.3	-	-.6	-	-.5	-	-.8	-.8	-1.2	-1.7	-.2	-	-.0	-
		Acceleration Variance $(FPS)^2$	-	-	.4	-	.8	-	.4	-	.4	-	.4	1.0	.6	1.6	.2	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	226	67	226	0	229	0	228	0	224	77	213	89	161	137	145	0	260	0
		Mean Speed MPH	54.3	57.1	53.3	-	52.4	-	51.0	-	49.3	51.3	46.7	49.0	41.7	44.8	40.6	-	41.6	-
		Speed Variance $(MPH)^2$	29.9	22.0	33.3	-	32.5	-	32.1	-	39.4	26.8	39.9	29.2	37.7	31.0	29.9	-	37.9	-
		Mean Acceleration (FPS)	-	-	-.4	-	-.4	-	-.5	-	-.6	-	-.8	-.8	-1.2	-1.4	-.1	-	-.1	-
		Acceleration Variance $(FPS)^2$	-	-	.5	-	.4	-	.6	-	.7	-	.4	.7	.7	.9	.3	-	.2	-

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 1 **Channelization Treatment** 4A (Night only)

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
NIGHT	Free Flow Vehicles >7.5 Second Headway	Number of Vehicles	191	66	189	0	189	0	191	0	190	68	186	69	177	78	142	0	217	0
		Mean Speed (MPH)	54.3	57.7	53.6	-	53.2	-	52.3	-	50.8	53.7	47.1	61.2	42.3	45.9	41.1	-	42.2	-
		Speed Variance $(MPH)^2$	39.1	24.2	39.0	-	38.8	-	36.2	-	34.3	28.5	46.2	34.4	37.7	46.4	35.4	-	32.7	-
		Mean Acceleration (FPS)	-	-	-.3	-	-.2	-	-.4	-	-.5	-	-1.0	-.9	-1.5	-1.6	-.1	-	-.0	-
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.2	-	.3	-	.5	-	.4	.6	.8	1.2	.3	-	.2	-
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	169	46	166	0	167	0	173	0	173	44	161	46	133	85	123	0	194	0
		Mean Speed MPH	55.4	58.2	54.6	-	53.9	-	53.0	-	51.8	54.3	48.7	51.8	42.9	47.3	41.4	-	42.8	-
		Speed Variance $(MPH)^2$	25.1	12.3	24.8	-	25.6	-	27.2	-	30.7	17.7	37.1	17.3	40.2	27.0	28.4	-	31.1	-
		Mean Acceleration (FPS)	-	-	-.3	-	-.3	-	-.4	-	-.4	-	-1.0	-.9	-1.4	-1.5	-.2	-	-.0	-
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.3	-	.3	-	.3	-	.5	.6	.7	1.0	.4	-	.2	-

The treatment comparisons for the night also indicate there is practically no mean speed differences between devices. Treatment 4A (vertical panels), which had the highest speeds during the daytime, had the lowest speeds in the approach area. It appears that none of the experimental devices altered mean speeds to any appreciable amount.

Speed Variance. Figure E-5 shows the profiles of speed variance for both day (lower plot) and night (upper plot). In this case, absolute comparisons of speed variances at each trap through standard statistical testing (e.g., F-test) can lead to erroneous conclusions. This is so because the speed variances at the initial trap are different between the devices, which indicates the sample distributions are not from the same population. For the mean speeds this situation was handled by adjusting the distribution of the experimental treatments so that the mean speed coincided with base treatment mean speed at the first trap. Although this is a reasonable approach for the mean, it may not be for the variance. Therefore, interpretation of the variance profile must be oriented toward the general trend differences.

For the day condition all three test treatments result in the same profile. Speed variances tend to be low up through trap 4, but increase as the motorists approach the transition area. Thereafter, the speed variance tends to remain constant for the base treatment (1, barricades with diagonal stripes) and 4A (vertical panels with horizontal stripes), but continues to increase for treatment 2A (barricades with 6-in. vertical stripes). This increase in variance for treatment 2A is unexplainable because the only difference between it and the base treatment is that stripes are vertical rather than horizontal, a subtle difference for the motorist.

For the more critical nighttime period one finds different results. Speed variance is higher at night than in the day, which supports the contention that night driving is more difficult for the motorist. The base and two experimental treatments (3D and 4A) each experienced a sharp rise in speed variation between traps 5 and 7, followed by a steep decline. For treatment 2A (Type I barricade with 6-in. vertical stripes), the speed variance profile is more stable and, in fact, steadily decreased after trap 5. Under the assumption that a smaller speed variance at equal speeds is better, the results indicate that treatment 2A was more effective at night.

Lane Changing Behavior. Lane change data obtained from this site is given in Table E-2. Here is found the total vehicular volume for each device treatment in each lane at tapeswitch (trap) number 1 (refer to Fig. E-3). Then follows a tabulation of the number changing from each lane and the percent, based on this total volume, throughout the course of the entire site. The final column of the table indicates the percent of those vehicles that made the lane change from either lane to the other at the last trap placed in the array. These traps are just before and parallel to the devices. It should be recalled that this site did not require lane changing and, in fact, was discouraged with the presence of a solid white lane line.

Several trends are evident from these data. First, there is a significant difference in lane change behavior between day and night. Second, over 70 percent of the lane changes occur near or parallel to the devices. Third, there seems to be no significant difference in the lane changing as a function of the different channelizing device set-ups. Finally, more changes occur from lane 2 to 1 than from 1 to 2. Although these points seem to be somewhat distinct, they are interrelated. A discussion of each follows.

First, more lane changes occur at night than in the daytime. Chi-square tests performed for both types of lane changes—1 to 2 and 2 to 1—demonstrate this:

Lane Change	χ^2 value contrasting % changing, day/night
1 to 2	13.46 significant at $\alpha = 0.01$, df = 3
2 to 1	39.33 significant at $\alpha = 0.001$, df = 3

One theory explaining this may be that the devices provide an illusory channel directing the driver along a single lane path. The site geometry gives the illusion of a shift first to the left then to the right—a sort of "S" curve. With the reflective devices to the right and New Jersey barriers to the left, these lane changers may have found themselves projected into a tunnel-like effect. Realizing that night driving is characterized by closer seeking, tracking-type eye search behavior, rather than a daytime "farther into the distant horizon" type perception, this would explain the lane changes occurring close to, and parallel to, the arrays. This is the second point previously mentioned, that because the driver is perceiving close to the very immediate field of view, he is not shunted into the channel-like illusion until fairly close to it (traps 6 through 9). Then follows the third point, that no

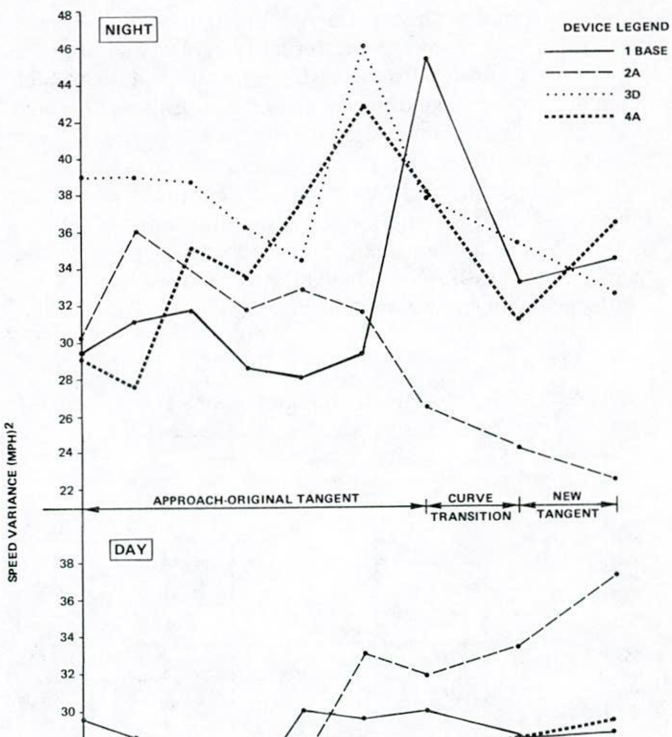

Figure E-5. Day and night speed variance profiles for site 1.

significant difference in this behavior is found specific to any devices. Actually, all of this activity occurs within a 1,300-ft area comprised of just before the taper through the beginning of the tangent. Obviously, the perception of individual stripe variations is secondary to the channel-like effect provided by the devices perceived as a luminous array.

The final point is that more lane changes occur from lane 2 to 1 than 1 to 2. Note that in all cases the majority of those 2 to 1 changes occur from the last trap (trap 7) over to lane 1, which here is beside the tangent. This is again attributable to the channel-like illusion previously discussed because the combination of the devices and roadway geometry seems to draw drivers to the right at this point, the second part of the "S"-like curve. Also, it is conceivable that this is a point at which some drivers traveling in lane 2 realize that the devices are not closing the right lane, as they may have first thought, and can in fact travel in it. Because they are not looking far ahead at night, they may not realize it until this point. This fact, that the device arrays may connote a possible lane closure at first sighting, is documented by many comments from drivers tested and exposed to them in the laboratory and controlled field phases of this project (Tasks 3 and 4).

Erratic Maneuvers and Traffic Conflict Results. Table E-3 provides the erratic maneuver and conflict counts and their respective rates for each type and all types combined by device treatment. Rather than attempt to analyze each E.M./T.C. type, they were grouped together and an overall rate calculated (numbers in last column).

A comparison of the treatments for the daytime is inconclusive for two reasons. A different observer was used for treatments 1 and 2A from that used for 3D and 4A, which accounts for the large differences in the overall number and rate. Also for treatment 3D, the volume counts were not available and therefore a rate could not be calculated.

In reviewing the night data, two observations are made. First, the night rates are fairly high with a range of 39.7 to 45.0 percent of all vehicles committing some type of erratic maneuver or traffic conflict. The predominant type is the "sudden slowing or braking" erratic maneuver. This result is consistent with the mean speed profile TES data which showed that there was an average 20 percent speed reduction for vehicles approaching the taper. The second finding is that there is no statistically significant difference (based on z-test of proportions) among the four treatments. That is, no treatment produced any more or less erratic maneuvers and conflicts than any other.

Site 2

The second site used for the field evaluation was a lane-closure type work zone located on Interstate 57 in Effingham, Illinois. The right or outside lane of this two-lane (in one direction) facility was closed off to accommodate shoulder repair work. Figure E-6 is a schematic drawing of the site indicating the location of the TES tapeswitch traps.

The following channelization treatments were tested:

No.	Treatment
1	24″ × 12″ Type I barricade; 6″ diagonal stripes; 55-ft spacing.
2A	24″ × 12″ Type I barricade; 6″ vertical stripes; 55-ft spacing.
2B	24″ × 12″ Type I barricade; 6″ vertical stripes; 55-ft spacing on taper and 110-ft spacing on tangent.
3A	24″ × 12″ Type I barricade; 4″ chevron stripe; 55-ft spacing.
3B	24″ × 12″ Type I barricade; 4″ chevron stripe; 110-ft spacing.
3D	24″ × 12″ Type I barricade; 4″ chevron stripes; 55-ft spacing on taper and 36″ cones on tangent; 55-ft spacing.

Data were collected for all treatments during the day, but only for 1, 2B, and 3A at night. Steady-burn lights were operating for these treatments at night.

Table E-2. Lane changing behavior for site 1.

	Device Treatment	Lane Number	Total Lane Volume	Vehicles Changing Lanes 1-2 #	1-2 %	2-1 #	2-1 %	Percent Changing in Last Trap[1]
DAY	1	1	690	5	0.7			80
		2	298			33	11	85
	2A	1	763	10	1			60
		2	328			41	13	70
	4A	1	826	16	2			75
		2	358			34	9	95
NIGHT	1	1	315	11	3			72
		2	98			36	37	86
	2A	1	286	9	3			88
		2	74			15	20	93
	3D	1	371	9	2			77
		2	112			39	34	89
	4A	1	441	19	4			84
		2	138			49	35	85

[1] "Last Trap" here refers to, for a change from 1 to 2, traps 6-7; and for a change from lanes 2 to 1, traps 7 to 8 or 9. See diagram, Figure E-3, to which these trap numbers refer.

Table E-3. Erratic maneuver and traffic conflict data for site 1.

	Device Treatment No.	Total Vehicles	Erratic Maneuvers %	Erratic Maneuvers Rate	Slow Vehicle Conflict %	Slow Vehicle Conflict Rate	Right to Left Lane Changing Err. Man. #	Right to Left Lane Changing Err. Man. Rate	Right to Left Lane Changing Conflict #	Right to Left Lane Changing Conflict Rate	Left to Right Lane Changing Err. Man. #	Left to Right Lane Changing Err. Man. Rate	Left to Right Lane Changing Conflict #	Left to Right Lane Changing Conflict Rate	All Types #	All Types Rate
DAY	1	1058	5	.005	13	.012	2	.002	0	0	13	.012	0	0	33	.031
	2A	1165	6	.005	8	.007	9	.008	0	0	41	.035	1	.001	65	.056
	3D	Unk[1]	135	-	41	-	2	-	0	0	10	-	0	0	188	-
	4A	1247	212	.170	60	.048	12	.009	0	0	14	.011	0	0	298	.239
NIGHT	1	468	155	.331	29	.062	6	.013	0	0	4	.009	0	0	194	.415
	2A	378	128	.339	23	.061	5	.013	0	0	4	.011	0	0	160	.423
	3D	534	177	.331	33	.062	0	0	0	0	2	.004	0	0	212	.397
	4A	616	224	.363	46	.075	3	.004	0	0	4	.006	0	0	277	.450

[1]Volume counts not available; therefore, cannot calculate rate.

Other traffic control devices included:

1. ROAD CONSTRUCTION 1 MILE sign.
2. RIGHT LANE CLOSED ½ MILE sign.
3. Pavement width transition symbol sign.
4. RIGHT LANE CLOSED 1000 FT sign.
5. FLAGMAN 500 FT sign (replaced with RIGHT LANE CLOSED 500 FT sign at night).

The flagman required by the traffic control plan was located at the first channelization device and held a SLOW sign in position. He was there during the day only.

Speed Profiles. The TES traffic flow data are shown in Exhibit E-2 for each of the test conditions. Figure E-7 displays the speed profiles for the base and experimental treatments both day and night. The same procedure described under site 1 was followed in plotting the profiles. In this case, the profiles are those vehicles in lane 1 (the lane to be dropped) from trap 1 through 5 (beginning of taper) and then all vehicles in lane 2 from trap 5 through the end of the array.

In reviewing the day mean speed profiles (lower plot), a trend is evident. Free-flow motorists initially increase speed (possibly because of lane changing), decelerate gradually at first, decelerate more rapidly as they approach the taper, hold their speed through the taper (this varied between treatments, however), and finally gradually increase their speed as they become adjusted to the work zone situation.

Keeping in mind that any experimental treatment speed profile outside the gray envelope is considered statistically different from the base condition, all the test treatments experienced lower mean speeds from traps 5 through 7. Treatment 3B, Type I barricade with chevron stripes and 110-ft spacing, produced the most erratic profile. Mean speeds reduced from 60.8 mph at trap 4 to 53.0 mph at trap 5 and then quickly increased ending with the highest observed speed at trap 9. The 110-ft spacing on the taper may not have adequately defined a proper path for the motorists, causing them to decelerate drastically for the approach and then to quickly accelerate to "make-up" for the low speed.

The treatment which most closely paralleled the base treatment was 2A. The only difference in this treatment was that the barricades had 6-in. vertical stripes rather than diagonal stripes. The other three treatments all produced consistently lower speeds than the base condition.

Only two experimental treatments in addition to the base condition were tested at night. All three treatments were Type I barricades varying in their pattern—diagonal, vertical, and chevron stripes. The vertical barricades were spaced at 110-ft intervals on the tangent section.

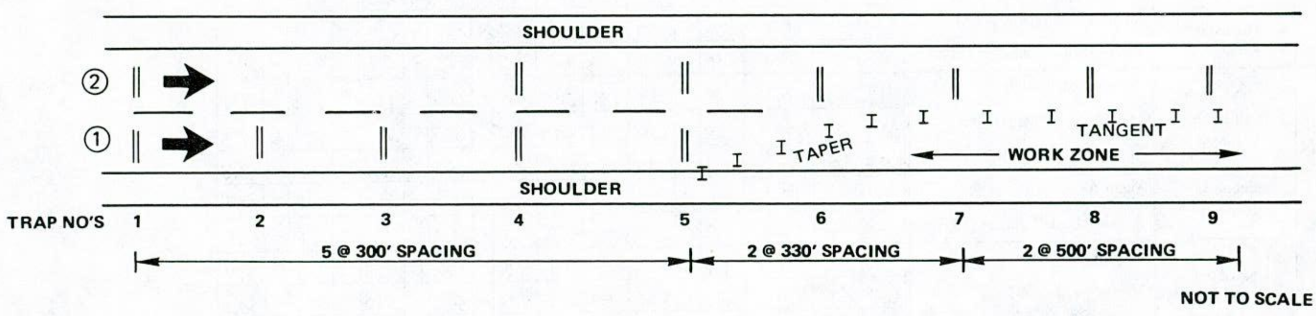

Figure E-6. Schematic drawing of site 2.

EXHIBIT E-2

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 2 Channelization Treatment 1

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles $\geq$7.5 Second Headway	Number of Vehicles	98	138	93	0	75	0	67	163	54	177	0	226	0	234	0	237	0	238
		Mean Speed (MPH)	61.6	63.3	62.2	-	62.0	-	60.3	61.8	58.7	60.6	-	58.6	-	58.4	-	58.7	-	59.2
		Speed Variance $(MPH)^2$	30.4	25.5	27.7	-	26.5	-	26.2	22.0	22.5	28.7	-	31.7	-	33.7	-	30.8	-	28.3
		Mean Acceleration (FPS)	-	-	.3	-	-.0	-	-.8	-	-.6	-.6	-	-.6	-	-.0	-	.1	-	.1
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.4	-	.8	.5	-	.6	-	.3	-	.1	-	.1
	Restricted Vehicles $<$7.5 Second Headway	Number of Vehicles	507	696	432	0	372	0	318	950	250	1031	0	1253	0	1289	0	1285	0	1288
		Mean Speed (MPH)	61.6	62.2	62.0	-	62.0	-	60.3	60.4	58.9	59.0	-	57.6	-	57.2	-	57.4	-	57.8
		Speed Variance $(MPH)^2$	26.3	26.4	25.6	-	25.6	-	29.3	22.2	45.0	26.1	-	28.5	-	28.8	-	27.1	-	26.0
		Mean Acceleration (FPS)	-	-	.2	-	-.0	-	-.8	-	-.5	-.6	-	-.5	-	-.1	-	.0	-	.1
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.3	-	.4	-	1.0	.6	-	.6	-	.4	-	.3	-	.2
NIGHT	Free Flow Vehicles $\geq$7.5 Second Headway	Number of Vehicles	80	137	71	0	61	0	54	173	33	190	0	221	0	227	0	228	0	229
		Mean Speed (MPH)	59.4	59.5	60.1	-	59.1	-	58.9	58.8	59.1	58.1	-	58.3	-	58.3	-	57.9	-	57.5
		Speed Variance $(MPH)^2$	21.6	32.5	22.3	-	58.7	-	29.8	28.4	18.5	46.4	-	26.3	-	27.8	-	30.1	-	31.2
		Mean Acceleration (FPS)	-	-	.3	-	.1	-	-.5	-	-.1	-.2	-	-.0	-	.0	-	-.1	-	-.1
		Acceleration Variance $(FPS)^2$	-	-	.1	-	.1	-	.4	-	.2	.8	-	.2	-	.2	-	.1	-	.1
	Restricted Vehicles $<$7.5 Second Headway	Number of Vehicles	163	257	134	0	106	0	97	340	79	361	0	427	0	444	0	442	0	440
		Mean Speed MPH	59.2	59.4	59.7	-	60.2	-	59.1	58.9	59.0	58.4	-	58.0	-	57.9	-	57.2	-	56.5
		Speed Variance $(MPH)^2$	35.3	24.9	37.3	-	37.0	-	35.5	22.3	39.8	21.8	-	25.6	-	28.2	-	30.9	-	36.0
		Mean Acceleration (FPS)	-	-	.2	-	.1	-	-.5	-	-.0	-.2	-	-.2	-	-.0	-	-.2	-	-.2
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.3	-	.3	-	.4	.3	-	.3	-	.3	-	.2	-	.2

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 2 Channelization Treatment 3A

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles $\geq$7.5 Second Headway	Number of Vehicles	102	114	91	0	80	0	67	151	44	167	0	203	0	214	0	215	0	216
		Mean Speed (MPH)	59.3	59.8	59.6	-	59.4	-	57.1	56.2	54.1	53.6	-	54.3	-	54.8	-	55.0	-	55.2
		Speed Variance $(MPH)^2$	30.8	30.6	33.4	-	30.4	-	39.8	41.1	73.2	91.0	-	49.1	-	48.5	-	45.8	-	41.9
		Mean Acceleration (FPS)	-	-	.1	-	-.2	-	-1.1	-	-1.0	-.9	-	-.2	-	.3	-	.0	-	.0
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.3	-	.5	-	2.6	1.4	-	.4	-	.2	-	.2	-	.1
	Restricted Vehicles $<$7.5 Second Headway	Number of Vehicles	230	227	204	0	168	0	136	320	86	374	0	442	0	463	0	464	0	467
		Mean Speed (MPH)	59.2	59.7	59.7	-	59.4	-	57.5	56.1	55.8	53.7	-	54.2	-	54.5	-	54.2	-	54.2
		Speed Variance $(MPH)^2$	32.7	31.6	35.6	-	37.7	-	45.3	33.1	74.7	64.6	-	39.0	-	42.1	-	41.0	-	37.5
		Mean Acceleration (FPS)	-	-	.1	-	-.2	-	-.9	-	-.6	-.8	-	-.2	-	.2	-	-.0	-	-.0
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.4	-	.6	-	1.0	1.2	-	.5	-	.4	-	.3	-	.3
NIGHT	Free Flow Vehicles $\geq$7.5 Second Headway	Number of Vehicles	49	61	39	0	35	0	33	78	24	86	0	106	0	110	0	112	0	111
		Mean Speed (MPH)	61.4	59.4	61.9	-	62.4	-	60.6	59.1	59.9	58.5	-	58.3	-	58.2	-	57.4	-	57.0
		Speed Variance $(MPH)^2$	24.6	38.2	25.0	-	20.7	-	19.7	28.0	26.1	30.5	-	36.6	-	40.2	-	44.5	-	40.3
		Mean Acceleration (FPS)	-	-	.2	-	-.0	-	-.7	-	-.2	-.3	-	-.2	-	-.0	-	-.2	-	-.1
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.2	-	.2	-	.2	.3	-	.2	-	.2	-	.1	-	.1
	Restricted Vehicles $<$7.5 Second Headway	Number of Vehicles	58	51	52	0	43	0	40	70	35	77	0	106	0	113	0	113	0	114
		Mean Speed MPH	60.7	61.8	61.9	-	62.7	-	61.5	59.9	60.5	60.0	-	59.8	-	59.2	-	58.5	-	57.6
		Speed Variance $(MPH)^2$	49.5	36.0	51.6	-	54.6	-	51.8	29.3	58.9	33.0	-	39.2	-	49.2	-	49.0	-	49.0
		Mean Acceleration (FPS)	-	-	.3	-	.0	-	-.6	-	-.1	-.2	-	-.2	-	-.0	-	-.2	-	-.2
		Acceleration Variance $(FPS)^2$	-	-	.1	-	.2	-	.3	-	.3	.5	-	.4	-	.3	-	.2	-	.1

EXHIBIT E-2 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 2

Channelization Treatment 3 B (Day only)

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	76	127	67	0	53	0	40	164	23	181	0	197	0	202	0	205	0	202
		Mean Speed (MPH)	58.4	58.4	59.0	-	59.0	-	57.8	54.5	47.9	52.9	-	54.1	-	55.3	-	55.9	-	56.2
		Speed Variance $(MPH)^2$	33.2	47.4	28.5	-	28.3	-	21.1	45.3	224.6	76.5	-	41.4	-	36.4	-	35.9	-	33.5
		Mean Acceleration (FPS)	-	-	.0	-	-.3	-	-1.1	-	-1.1	-.6	-	.2	-	.4	-	.2	-	.0
		Acceleration Variance $(FPS)^2$	-	-	.2	-	.5	-	.7	-	1.5	.9	-	.5	-	.4	-	.2	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	200	271	163	0	126	0	105	373	62	415	0	472	0	482	0	484	0	482
		Mean Speed (MPH)	58.0	58.6	58.3	-	57.8	-	54.5	54.7	50.4	53.0	-	53.0	-	53.9	-	54.3	-	54.4
		Speed Variance $(MPH)^2$	41.0	37.1	40.0	-	39.3	-	46.7	40.6	54.2	54.5	-	40.4	-	33.9	-	31.3	-	29.8
		Mean Acceleration (FPS)	-	-	-.0	-	-.3	-	-1.2	-	-1.2	-.6	-	.0	-	.3	-	.1	-	.0
		Acceleration Variance $(FPS)^2$	-	-	.4	-	.6	-	1.3	-	2.1	.7	-	.7	-	.4	-	.2	-	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 2

Channelization Treatment 3 D (Day only)

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	71	96	66	0	49	0	34	133	17	150	0	166	0	167	0	168	0	168
		Mean Speed (MPH)	59.5	60.7	59.7	-	58.1	-	56.7	56.2	54.7	54.1	-	54.7	-	55.4	-	56.2	-	56.6
		Speed Variance $(MPH)^2$	54.6	29.7	42.7	-	71.2	-	28.8	44.5	34.4	79.7	-	49.4	-	48.6	-	43.8	-	38.8
		Mean Acceleration (FPS)	-	-	-.0	-	-.4	-	-1.0	-	-.5	-.7	-	-	-	.3	-	.1	-	.1
		Acceleration Variance $(FPS)^2$	-	-	.5	-	.6	-	1.0	-	1.0	.7	-	.2	-	.3	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	176	164	148	0	110	0	85	259	44	296	0	332	0	341	0	340	0	341
		Mean Speed (MPH)	58.8	60.6	59.7	-	58.7	-	56.7	55.2	53.2	53.2	-	53.4	-	54.2	-	54.4	-	54.8
		Speed Variance $(MPH)^2$	50.5	49.5	47.1	-	50.9	-	47.0	41.6	49.7	70.5	-	39.3	-	33.4	-	31.8	-	31.2
		Mean Acceleration (FPS)	-	-	.1	-	-.4	-	-1.2	-	-.9	-.9	-	-.1	-	.3	-	.1	-	.1
		Acceleration Variance $(FPS)^2$	-	-	.3	-	.7	-	.7	-	1.1	1.1	-	.5	-	.4	-	.2	-	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		

EXHIBIT E-2 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 2 Channelization Treatment 2B

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	97	142	86	0	80	0	77	172	55	192	0	246	0	251	0	250	0	251
		Mean Speed (MPH)	59.2	60.1	59.5	–	59.5	–	57.4	58.0	55.0	56.0	–	54.6	–	54.7	–	55.6	–	56.3
		Speed Variance $(MPH)^2$	41.8	31.6	38.7	–	37.6	–	38.5	39.4	42.0	57.8	–	44.2	–	45.6	–	42.3	–	40.4
		Mean Acceleration (FPS)	–	–	.2	–	-.0	–	-.8	–	-.9	-.8	–	-.6	–	.1	–	.2	–	.2
		Acceleration Variance $(FPS)^2$	–	–	.1	–	.3	–	.8	–	1.4	.8	–	.6	–	.3	–	.1	–	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	284	195	245	0	193	0	165	323	118	375	0	493	0	500	0	501	0	503
		Mean Speed (MPH)	59.6	60.0	60.4	–	60.5	–	58.8	58.0	57.9	56.7	–	55.8	–	55.8	–	56.0	–	56.3
		Speed Variance $(MPH)^2$	23.2	27.7	23.7	–	25.5	–	25.5	25.2	39.4	28.3	–	30.1	–	29.6	–	28.8	–	28.1
		Mean Acceleration (FPS)	–	–	.2	–	-.0	–	-.7	–	-.5	-.6	–	-.4	–	-.0	–	.1	–	.1
		Acceleration Variance $(FPS)^2$	–	–	.2	–	.2	–	.4	–	1.1	.5	–	.5	–	.4	–	.3	–	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	69	121	63	0	55	0	47	146	42	152	0	180	0	193	0	194	0	194
		Mean Speed (MPH)	58.3	59.9	59.0	–	59.3	–	58.3	59.2	58.2	58.3	–	58.5	–	58.2	–	57.6	–	57.3
		Speed Variance $(MPH)^2$	32.4	41.7	32.9	–	26.3	–	24.0	33.8	26.9	58.8	–	34.1	–	35.9	–	37.0	–	36.4
		Mean Acceleration (FPS)	–	–	.3	–	.2	–	-.4	–	-.1	-.3	–	-.1	–	-.1	–	-.1	–	-.1
		Acceleration Variance $(FPS)^2$	–	–	.1	–	.1	–	.2	–	.2	1.1	–	.3	–	.2	–	.1	–	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	86	77	72	0	60	0	51	114	39	128	0	156	0	166	0	166	0	166
		Mean Speed MPH	56.9	58.7	57.9	–	58.2	–	57.7	56.9	57.3	56.1	–	56.8	–	56.1	–	56.1	–	55.6
		Speed Variance $(MPH)^2$	48.6	25.5	44.9	–	34.8	–	30.3	36.6	41.7	69.3	–	29.8	–	37.0	–	37.0	–	36.8
		Mean Acceleration (FPS)	–	–	.3	–	.1	–	-.5	–	-.0	-.3	–	-.0	–	-.0	–	-.1	–	-.1
		Acceleration Variance $(FPS)^2$	–	–	.3	–	.1	–	.2	–	.1	1.6	–	.7	–	.3	–	.1	–	.1

The mean speed profiles for the night were consistently different from the day profiles. As usual, all speeds were lower at night and maybe because of this, the speed reductions on the approach to the taper were not as drastic as those during the day. Also, for all test conditions, a continuous decrease in speed was observed from trap 7 (end of taper) through the end of the tapeswitch array.

The two experimental treatments produced opposite effects. Treatment 2B, barricades with 6-in. vertical stripes and 110-ft spacing on the tangent, had higher speeds than the base condition, while treatment 3A, barricades with chevron stripes and 55-ft spacing, had significantly lower speeds compared to the base. This result did not hold true for the daytime.

Speed Variance. Figure E-8 shows the speed variance profiles for both day and night test conditions. Although there are some exceptions, the variance profile for the day test indicates an initial decrease in speed variance in the upstream approach area (mean speeds generally increased in this area) followed by a substantial increase in variance (for some treatments, a very drastic increase) through the taper area and then ending with a gradual decrease in variance in the tangent section.

Comparisons between treatments is difficult to make because three treatments had significantly different variances at trap 1. However, close examination of the profiles reveals that treatment 2B, Type I barricade with 6-in. vertical stripes had the least erratic variance profile, although somewhat higher than the base treatment. The two treatments using chevron barricades, 3A and 3B, produced extremely high variances just prior to the taper area. Treatment 2A, barricades with 6-in. vertical stripes, had variances nearly equal to the base condition.

Lane Changes. The lane change data for this right lane closure are given in Table E-4. Here is a record of the number of vehicles merging from the right lane to the left lane at each switch pair trap along the site. For each device array is found the actual number that merged at the various traps and then the percent of the total merges each number represents. Refer to the site diagram, Figure E-6, for layout and trap numbers.

The data analysis was predicated on comparing the point of lane change behavior under the baseline standard diagonally striped barricade condition (treatment 1) with the other various treatments. Also, both baseline conditions were compared for their operations for day versus nighttime effects. The chi-square (χ^2) test was used to compare the proportions merging at the various traps for each treatment against the base. Given this rationale, no differences in point of lane change would be expected between devices or with night operation. The following are the χ^2 values obtained:

Treatment Comparisons				χ^2 value	df	significance
Day	vs.	Night		22.87	4	.001
1	vs.	2A	Day	9.00	4	n.s.
1	vs.	2B	Day	7.55	4	n.s.
1	vs.	3A	Day	11.68	4	n.s.
1	vs.	3B	Day	32.54	4	.001
1	vs.	3D	Day	36.77	4	.001
1	vs.	2B	Night	14.88	4	.01
1	vs.	3A	Night	25.66	4	.001

The baseline trend evident in the data found in Table E-4 is that, given the standard 24″ × 12″ Type I barricades with the conventional striping, most drivers (54 percent) tend to make their merge very late, almost at the taper, near trap 5. The significant χ^2 value in the day/night comparison indicates that, at night, this tendency is somewhat altered, and drivers make their merges somewhat earlier, upstream of the array. Apparently, the steady-burn lights attached to the devices aid in presenting the clear image needed to indicate the merge ahead, so that drivers more cautiously make their maneuver earlier in the nighttime restricted visibility environment.

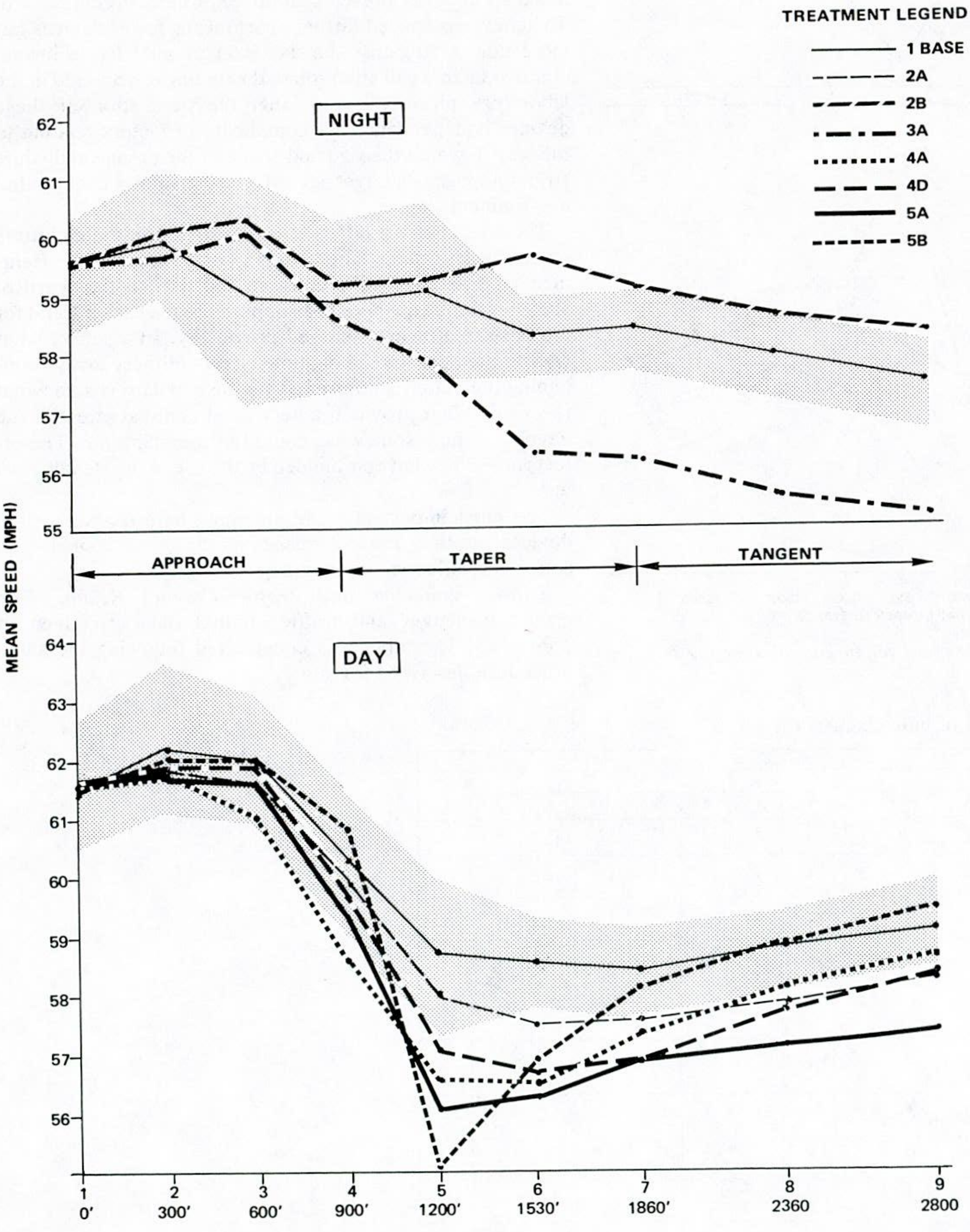

Figure E-7. Day and night mean speed profiles for site 2.

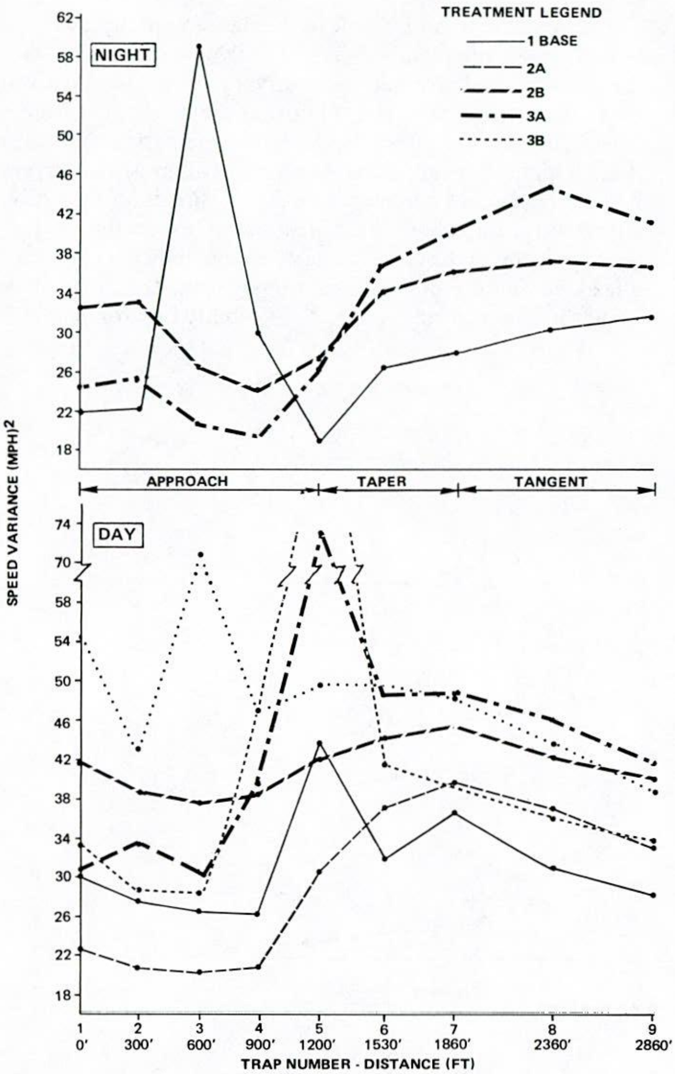

Figure E-8. Day and night speed variance profiles for site 2.

In evaluating the effects of different device arrays compared to the base trend, first the daytime changes will be examined. The device arrays that significantly differ from the standard barricades are the two arrays containing the 4-in. chevron striped barricades, one just in the taper-only with cones on the tangent, the other with 110-ft spacing, all chevron barricades. These two treatments apparently present an image indicating the need to merge in a more urgent fashion than do the standard diagonally striped barricades with conventional spacing. This is not to imply that the chevrons, especially being only 4 in. wide, are detectable as such indicating directionality from far back, but that their combined image as an array presents an image of more urgent hazard. The chevrons spaced farther apart means fewer devices but more contrast against the day background. These image/contrast factors call attention to the findings uncovered in the laboratory phase (Task 3) that the perception of these devices is dependent on a complexity of factors relating to the way in which the size and shape of the orange and white stripes appear as a target against a visually noisy background environment.

The effects of the different device arrays in the nighttime revert back to later lane changing occurring for the treatments 2B and 3A (differently striped barricades—vertical and chevron, respectively) as opposed to the earlier trend for the base treatment discussed previously. In a sense, what was pointed out for the daytime effects of these arrays containing the patterns differing from the standard is somewhat reversed. What provided a very good contrast effect in the daytime is now somewhat diluted in the nighttime. The effects are somewhat confounded by the use of the steady-burn lights.

The most important trend emerging here is that certain devices, as they present images as arrays, not singly, do somewhat influence the merging behavior.

Erratic Maneuver and Traffic Conflict Results. The erratic maneuver and traffic conflict data are given in Table E-5. The table was constructed following the same procedure described for site 1.

Table E-4. Distribution of lane changes for site 2.

	Trap Numbers	Device Treatments											
		1		2A		2B		3A		3B		3D	
		#	%	#	%	#	%	#	%	#	%	#	%
DAY	1-4	6	7	5	5	11	13	11	13	10	14	6	8
	2-4	11	14	5	5	6	7	11	13	15	21	17	24
	3-4	4	5	7	7	2	2	11	13	11	16	16	23
	4-5	9	12	23	24	18	20	16	19	18	26	16	23
	5-6	46	62	54	59	51	58	36	42	16	23	15	22
NIGHT	1-4	10	14			7	13	9	20				
	2-4	12	17			7	13	5	11				
	3-4	6	9			8	15	4	9				
	4-5	16	23			3	6	8	18				
	5-6	26	37			28	53	19	42				

Table E-5. Erratic maneuver and traffic conflict data for site 2.

	Device Treatment No.	Total Vehicles	Erratic Maneuvers		Lane Changing Conflict		Slow Vehicle Conflict		Slow To Merge				Wrong Way Lane Change				All Types	
									Err. Man.		Conflict		Err. Man.		Conflict			
			#	Rate	#	Rate	#	Rate	#	Rate	#	Rate	#	Rate	#	Rate	#	Rate
DAY	1	1712	33	.019	6	.004	41	.024	24	.014	0	0	3	.002	1	.001	108	.063
	2A	1065	28	.026	5	.005	29	.027	20	.019	3	.003	1	.014	0	0	86	.081
	2B	865	16	.018	1	.001	14	.016	16	.018	0	0	0	0	0	0	47	.054
	3A	934	35	.037	1	.001	27	.029	33	.035	6	.006	0	0	0	0	102	.109*
	3B	992	19	.019	0	0	24	.024	20	.020	3	.003	0	0	0	0	66	.066
	3D	834	22	.026	5	.006	34	.041	18	.022	0	0	0	0	0	0	79	.095*
NIGHT	1	750	18	.024	0	0	15	.020	3	.004	3	.004	0	0	0	0	39	.052
	2B	431	21	.049	0	0	15	.035	2	.005	0	0	0	0	0	0	38	.088*
	3A	373	8	.021	1	.003	4	.011	1	.003	1	.003	1	.003	0	0	16	.043

*Indicates a statistical difference compared to base condition.

In examining the data for the daytime conditions, it is noted that three E.M./T.C. types are prevalent: erratic maneuvers; slow vehicle conflicts; and slow-to-merge conflicts. When all types are grouped, the observed rates range from a low of 5.4 percent of the vehicles to a high of 10.9 percent. Using the z-test for proportions, the experimental treatments were compared against the base condition with the result that only two treatments (3A, Type I barricade with 4-in. chevron stripes; and 3D, same barricade with cones on tangent) were found to have significantly higher rates. The difference found for 3A has to be discounted because a different observer was used for this treatment from that used for the others. The higher rate found for 3B is attributable to the higher frequency of slow vehicle conflicts. It is noted that the main difference of this treatment from the others is the use of 36-in. cones on the tangent.

The nighttime erratic maneuver and conflict rates were, on the average, about equal to the daytime rates. The conflict rates were generally lower than the day because of lower volumes and hence lower chance of having a conflict situation. One of the two experimental treatments, 2B, Type I barricade with 6-in. vertical stripes and a combination of 55-ft spacing on the taper and 110-ft spacing on tangent, was found to be significantly higher than the base treatment. This increase could be related to the wider spacing on the tangent which provided a less dramatic delineation of the work zone.

Site 3

The third and final site used for the field evaluation was a section of State Routes 55 and 74, a four-lane rural expressway. The work zone, located near Bloomington, Ill., consisted of bridge repair work with the left or median lane closed to traffic. Figure E-9 is a schematic drawing of the location showing the tapeswitch layout.

Because this was the last site that was available for testing, several channelization treatments were tested:

No.	Treatment
1	24″ × 12″ Type I barricade with 6-in. diagonal stripes; 55-ft spacing.
2A	24″ × 12″ Type I barricade with 6-in. vertical stripes; 55-ft spacing.
2B	Same as 2A with 110-ft spacing on tangent section.
3C	24″ × 12″ Type I barricade with 4-in. chevron stripes; 55-ft spacing on taper, 110-ft spacing on tangent.
3D	24″ × 12″ Type I barricade with 4-in. chevron stripes on taper; 36″ cones on tangent; 55-ft spacing.
3E	Same as 3D with 42″ post cones replacing 36″ cones.
4A	24″ × 12″ vertical panel with 6-in. horizontal stripes; 55-ft spacing.
4B	Same as 4A with 110-ft spacing on tangent section.
4C	24″ × 12″ vertical panel with 6-in. horizontal stripes on taper; 36″ cones on tangent; 55-ft spacing.

All treatments were tested during the day but only 1, 2A, 2B, 3C, and 4A were tested at night. During the night studies, steady-burn lights were used.

Other traffic control devices included:

1. ROAD CONSTRUCTION 1 MILE sign.
2. LEFT LANE CLOSED ½ MILE sign.
3. Pavement width transition symbol sign.
4. LEFT LANE CLOSED 1000 FT sign.
5. LEFT LANE CLOSED 500 FT sign.
6. Flashing arrowboard at end of taper.

The flashing arrowboard was required by the state-approved traffic control plan and could not be removed for this study. It was operative for all test conditions.

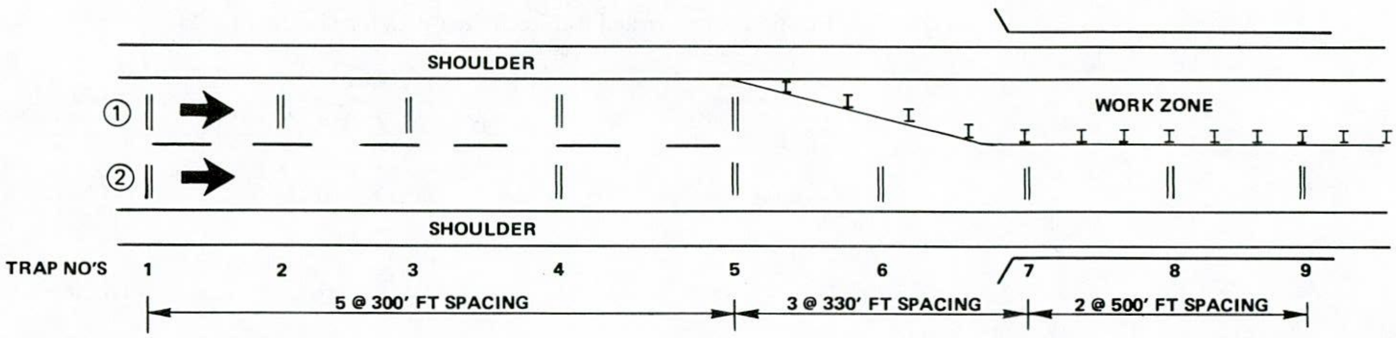

Figure E-9. Schematic drawing of site 3.

Speed Profiles. Exhibit E-3 provides the TES traffic flow data for this site. The analysis focused on vehicles in the inside lane (lane to be closed) as they approached the taper area and then for all vehicles from the taper through the end of the array.

A review of the data in the tables shows that there were very few free-flow vehicles in lane 1, the inside lane. Even when the 7.5-sec headway free-flow criterion was relaxed to 5.0 sec, there still were too few vehicles in lane 1 for statistical analysis. This situation resulted from the high volumes experienced during testing and, consequently, the low probability of having a free-flow vehicle. Keep in mind that the 7.5-sec headway applied to vehicles in the same and adjacent lane.

In view of the low sample size for free-flow vehicles, the much larger sample of restricted vehicles, all those vehicles with headways of 7.5 sec or less, was used for analysis. In using this sample, greater care must be taken in the interpretation of results because any effects found may be confounded by the effects of volume itself. This caveat holds for the remainder of the mean speed, speed variance, and lane changing results discussions.

Figure E-10 shows the day (lower plot) and night (upper plot) mean speed profiles for the various treatments. As with the other two sites, the mean speeds for the experimental treatment were adjusted for any differences found at trap 1.

Referring to the base condition, the speed profile trend was as follows: acceleration from trap 1 to 2, possibly because of the faster cars in the outside lane, speeding up to merge into the through lane; increasing acceleration from trap 2 to trap 4; steady deceleration from trap 4 through trap 7; and a slight acceleration once into the tangent, followed by deceleration between the last two traps. The steep decline from traps 5 and 6 (the first half of the taper) results from combining vehicles in lane 1 with those in lane 2, the open lane. The vehicles in lane 1 were, on the average, traveling about 4 to 5 mph faster than those in lane 2. The deceleration in the last trap may be a result of two factors: (1) the last two traps were on the crest of a slight grade, and (2) there was another active work zone downstream and within the drivers' view.

Treatment comparisons for the daytime conditions reveal several results. Treatments 3C (Type I barricade with chevrons stripes and 110-ft spacing on tangent), 3D (Type I barricade with chevron stripes on taper and 36-in. cones on tangent), 3E (same as 3D but with 42-in. post cones), and 2B (Type I barricade with vertical stripes and 110-ft spacing) resulted in speeds significantly lower than the base treatment at several traps. Treatment 3C was substantially lower and significantly different from the other experimental treatments.

The treatments that most closely matched the base condition were 4A, vertical panels with 6-in. horizontal stripes, and 4B, same panels with 110-ft spacing on tangent.

The nighttime speeds were, on the average, 2 to 3 mph higher than the daytime speeds. Treatment comparisons for the nighttime condition revealed some of the same results found for the daytime. Treatment 3C again produced the lowest mean speed in the work zone area. This treatment had chevron barricades and steady-burn lights on 110-ft spacing in the tangent. This same effect, lower speeds with higher spacing, was found in the Task 4 experimentation. Also, treatment 4A (vertical panels) had the speed most similar to the base condition.

Speed Variance. Figure E-11 shows the speed variance profiles for both day and night. For the daytime, the following results are presented.

All treatments, except the base condition, produced a high increase in speed variance at trap 5, the beginning of the taper. This was preceded by a gradual speed variance increase in the approach and followed by a substantial speed variance decline and then finally, a leveling off in the tangent section.

The base treatment resulted in the smoothest speed variance profile. The treatment that had the lowest mean speed—Type 1 barricade with chevron stripes and 110-ft spacing on tangent (3C)—had the highest speed variance. Although this treatment brought about lower speeds, it also caused a higher speed variance, a less desirable effect.

Except for treatment 3C, all experimental treatments had speed variances in the same range as the base treatments for traps 6 through 9.

The nighttime speed variance profiles do not reveal significantly different results. For the first three traps, the speed variance profiles are erratic and inconsistent between devices. All devices produced the same effect between traps 4 and 5 that was found for the daytime. The same leveling-off phenomenon along the tangent section was observed at night.

Lane Changing Behavior. The data for the point of lane changes for this left lane closure are given in Table E-6. As explained for site 2, the number changing for each switch pair

EXHIBIT E-3

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3

Channelization Treatment 1

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	8	212	8	0	6	0	5	218	4	219	0	219	0	222	0	223	0	223
		Mean Speed (MPH)	61.6	58.8	62.5	-	61.5	-	61.9	58.0	57.0	57.4	-	57.2	-	57.2	-	57.3	-	55.8
		Speed Variance $(MPH)^2$	12.6	16.4	15.5	-	12.9	-	4.4	19.7	33.2	19.0	-	20.2	-	21.7	-	21.8	-	19.8
		Mean Acceleration (FPS)	–	–	.6	-	–.4	-	–.2	–	-2.0	–.2	-	–.1	–	–.0	–	.1	–	–.4
		Acceleration Variance $(FPS)^2$	–	–	.4	-	.2	-	.4	–	5.8	.1	-	.1	-	.1	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	172	753	161	0	134	0	105	831	61	879	0	916	0	946	0	952	0	942
		Mean Speed (MPH)	63.9	58.5	64.2	-	63.6	-	62.7	56.7	62.5	55.8	-	55.2	-	54.6	-	54.8	-	53.0
		Speed Variance $(MPH)^2$	22.3	20.0	26.2	-	28.5	-	27.2	26.5	30.0	29.7	-	32.5	-	34.8	-	32.8	-	29.8
		Mean Acceleration (FPS)	–	–	.2	-	–.5	-	–.7	–	–.3	–.4	-	–.3	-	–.3	-	.0	-	–.4
		Acceleration Variance $(FPS)^2$	–	–	.8	-	1.4	-	1.3	–	1.0	.4	-	.4	-	.4	-	.2	-	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	2	211	2	0	2	0	1	215	1	215	0	216	0	217	0	216	0	217
		Mean Speed (MPH)	64.2	57.6	65.4	-	63.4	-	62.3	57.8	63.1	57.1	-	56.8	-	56.1	-	56.4	-	55.0
		Speed Variance $(MPH)^2$	7.1	22.4	7.7	-	–	-	–	23.0	–	23.2	-	25.2	-	28.8	-	29.0	-	25.5
		Mean Acceleration (FPS)	–	–	.5	-	–1.0	-	–.5	–	.3	–.3	-	–.1	-	–.2	-	.1	-	–.3
		Acceleration Variance $(FPS)^2$	–	–	–	-	1.9	-	–	–	–	.1	-	.1	-	.2	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	34	248	30	0	24	0	20	268	15	272	0	281	0	289	0	298	0	289
		Mean Speed MPH	61.3	57.0	61.5	-	60.5	-	60.8	56.9	60.6	56.1	-	55.2	-	54.3	-	54.1	-	52.6
		Speed Variance $(MPH)^2$	17.0	24.4	20.6	-	28.7	-	23.2	23.1	41.0	19.8	-	21.1	-	22.7	-	22.9	-	21.0
		Mean Acceleration (FPS)	–	–	.1	-	–.3	-	–.4	–	–.1	–.4	-	–.4	-	–.3	-	–.0	-	–.4
		Acceleration Variance $(FPS)^2$	–	–	.4	-	.3	-	.4	–	1.5	.4	-	.3	-	.2	-	.2	-	.2

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3

Channelization Treatment 2-A

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	2	254	2	0	2	0	1	260	1	261	0	261	0	264	0	263	0	263
		Mean Speed (MPH)	69.1	61.0	66.9	-	63.7	-	57.1	60.4	59.0	60.7	-	59.9	-	59.8	-	59.3	-	59.7
		Speed Variance $(MPH)^2$	1.5	20.0	1.4	-	11.7	-	-	24.0	–	22.1	-	21.5	-	23.6	-	23.0	-	23.0
		Mean Acceleration (FPS)	–	–	-1.0	-	-1.6	-	-1.8	–	.8	.1	-	–.3	-	–.0	-	–.1	-	.1
		Acceleration Variance $(FPS)^2$	–	–	1.3	-	1.1	-	3.2	–	.6	.2	-	.2	-	.2	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	243	912	228	0	191	0	134	1029	67	1100	0	1157	0	1171	0	1168	0	1170
		Mean Speed (MPH)	66.9	60.7	65.9	-	65.4	-	63.7	59.6	62.2	59.4	-	58.1	-	57.4	-	56.8	-	56.8
		Speed Variance $(MPH)^2$	37.5	25.0	39.6		42.4	-	44.6	28.2	55.6	31.3	-	32.7	-	36.3	-	35.0	-	34.5
		Mean Acceleration (FPS)	-	-	–.4	-	–.5	-	–.9	–	–.7	–.2	-	–.6	-	–.3	-	–.2	-	.0
		Acceleration Variance $(FPS)^2$	–	–	.7	-	.9	-	1.4	–	1.0	.5	-	.4	-	.3	-	.2	-	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	7	258	7	0	8	0	9	259	6	261	0	264	0	267	0	267	0	266
		Mean Speed (MPH)	64.1	57.3	64.2	-	62.6	-	59.1	56.9	62.2	57.1	-	56.2	-	55.6	-	55.0	-	55.4
		Speed Variance $(MPH)^2$	9.1	23.1	9.7	-	36.7	-	146.9	22.4	34.2	24.8	-	25.2	-	30.2	-	31.2	-	32.2
		Mean Acceleration (FPS)	–	–	.0	-	.1	-	.0	–	–.1	.1	-	–.4	-	–.2	-	–.1	-	.1
		Acceleration Variance $(FPS)^2$	–	–	.8	-	.5	-	.1	–	1.0	.1	-	.2	-	.2	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	52	364	49	0	40	0	35	388	22	401	0	416	0	428	0	428	0	428
		Mean Speed MPH	62.5	57.3	62.0	-	61.4	-	61.1	56.6	61.0	56.2	-	54.7	-	53.9	-	53.0	-	52.9
		Speed Variance $(MPH)^2$	35.8	24.9	36.6	-	37.5	-	37.2	24.1	50.7	24.7	-	26.8	-	31.8	-	30.7	-	33.9
		Mean Acceleration (FPS)	–	–	–.2	-	–.4	-	–.4	–	–.4	–.2	-	–.6	-	–.3	-	–.2	-	–.0
		Acceleration Variance $(FPS)^2$	–	–	.4	-	.5	-	.4	–	.6	.4	-	.6	-	.3	-	.3	-	.2

EXHIBIT E-3 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3 **Channelization Treatment** 2-B

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	2	235	1	0	1	0	1	240	1	239	0	240	0	240	0	240	0	240
		Mean Speed (MPH)	67.8	59.2	68.2	-	67.8	-	66.5	58.8	66.9	58.9	-	58.1	-	58.1	-	57.5	-	57.8
		Speed Variance $(MPH)^2$	1.4	17.2	–	-	–	-	–	18.8	–	18.7	-	19.3	-	19.8	–	19.8	-	21.0
		Mean Acceleration (FPS)	–	–	–.2	-	–.2	-	–.6	–	.2	.0	–	–.3	-	–.0	–	–.1	–	.1
		Acceleration Variance $(FPS)^2$	–	–	.0	-	.0	-	.4	–	.0	.1	–	.1	–	.1	–	.1	–	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	363	1526	338	0	266	0	190	1727	104	1809	0	1901	0	1924	0	1928	0	1930
		Mean Speed (MPH)	64.8	58.7	63.8	-	63.2	-	61.0	57.4	59.8	57.0	-	55.6	-	54.7	-	54.0	-	54.0
		Speed Variance $(MPH)^2$	23.9	20.2	26.9	-	27.4	-	32.8	23.6	43.9	26.9	-	31.6	-	37.9	–	36.0	-	32.9
		Mean Acceleration (FPS)	–	–	–.5	-	–.7	-	–1.2	-	–.7	–.2	-	–.6	-	–.3	-	–.2	–	.0
		Acceleration Variance $(FPS)^2$	–	–	.8	-	1.3	-	2.1	–	1.5	.4	-	.4	-	.4	–	.2	-	.3
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	3	239	3	0	1	0	1	246	1	246	0	245	0	248	0	249	0	249
		Mean Speed (MPH)	63.7	57.0	63.6	-	65.7	-	64.2	56.8	64.6	56.8	-	56.1	–	55.6	-	55.0	-	55.4
		Speed Variance $(MPH)^2$	4.4	18.4	4.9	-	–	-	–	20.7	–	26.9	-	21.8	-	23.8	-	24.7	-	24.0
		Mean Acceleration (FPS)	–	–	–.0	-	–.2	-	–.7	–	.2	.1	-	–.3	-	–.2	-	–.1	-	.1
		Acceleration Variance $(FPS)^2$	–	–	.0	-	.0	-	.5	–	.0	.1	-	.2	-	.3	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	108	769	96	0	74	0	64	824	48	841	0	879	0	895	0	899	0	898
		Mean Speed MPH	61.8	56.2	61.0	-	61.4	-	60.3	55.6	59.4	55.2	-	53.8	-	53.1	-	52.5	-	52.5
		Speed Variance $(MPH)^2$	29.3	20.8	31.2	-	23.2	-	17.8	23.4	37.9	23.6	-	25.8	-	30.3	-	27.4	-	29.3
		Mean Acceleration (FPS)	–	–	–.3	-	–.2	-	–.5	–	–.5	–.2	-	–.5	-	–.2	-	–.1	-	.0
		Acceleration Variance $(FPS)^2$	–	–	.4	-	.8	-	.9	–	2.7	.4	-	.4	-	.4	-	.2	-	.2

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3 **Channelization Treatment** 3C

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	4	136	4	0	4	0	4	136	6	137	0	139	0	140	0	140	0	142
		Mean Speed (MPH)	66.6	59.2	64.8	-	60.0	-	59.0	58.5	49.6	58.4	-	57.6	-	57.7	-	57.4	-	57.1
		Speed Variance $(MPH)^2$	21.1	19.9	6.4	-	50.3	-	25.1	19.2	244	20.8	-	20.7	-	22.8	-	21.0	-	27.3
		Mean Acceleration (FPS)	–	–	–.9	-	–2.0	-	–.5	–	.0	–.0	-	–.3	-	.1	–	–.1	-	–.0
		Acceleration Variance $(FPS)^2$	–	–	2.0	-	7.7	-	2.1	–	.2	.2	-	.1	-	.1	–	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	477	1548	423	0	353	0	255	1811	148	1914	0	2039	0	2070	0	2075	0	2079
		Mean Speed (MPH)	65.0	58.0	64.4	-	63.5	-	61.2	55.3	58.0	54.7	-	52.8	-	52.0	-	51.9	-	51.2
		Speed Variance $(MPH)^2$	28.5	26.1	33.3	-	41.6	-	50.4	42.2	65.0	47.4	-	51.7	-	55.0	–	47.6	-	48.6
		Mean Acceleration (FPS)	–	–	–.4	-	–.7	-	–1.4	–	–1.4	–.4	-	–.7	-	–.2	-	–.0	-	–.2
		Acceleration Variance $(FPS)^2$	–	–	.9	-	1.2	-	1.8	–	2.7	.7	-	.7	-	.5	–	.3	-	.4
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	1	230	1	0	1	0	1	234	1	235	0	236	0	236	0	238	0	239
		Mean Speed (MPH)	64.6	58.7	65.3	-	64.2	-	64.2	58.4	63.4	58.3	-	57.3	-	56.8	–	56.2	-	56.6
		Speed Variance $(MPH)^2$	–	21.2	–	-	–	-	–	20.8	–	22.0	-	21.6	-	23.5	-	23.9	-	25.9
		Mean Acceleration (FPS)	–	–	.4	-	–.6	-	–	–	–.4	–.0	-	–.4	-	–.2	-	–.1	-	.1
		Acceleration Variance $(FPS)^2$	–	–	.1	-	.3	-	–	–	.1	.2	-	.1	-	.2	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	160	800	145	0	124	0	107	865	80	895	0	957	0	979	0	979	0	981
		Mean Speed MPH	63.6	57.2	63.3	-	62.9	-	60.9	56.5	59.6	55.9	-	54.6	-	53.8	-	53.1	-	53.2
		Speed Variance $(MPH)^2$	31.6	23.6	32.8	-	32.8	-	40.6	24.3	53.4	26.2	-	28.5	-	31.8	-	29.4	-	29.5
		Mean Acceleration (FPS)	–	–	–.3	-	–.4	-	–.9	–	–.7	–.3	-	–.6	-	–.3	-	–.2	-	.0
		Acceleration Variance $(FPS)^2$	–	–	.6	-	.9	-	1.2	–	1.8	.4	-	.3	-	.4	-	.3	-	.2

EXHIBIT E-3 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3

Channelization Treatment 3D (Day only)

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles	4	181	5	0	3	0	3	186	4	186	0	188	0	191	0	192	0	191
		Mean Speed (MPH)	66.2	61.2	66.5	-	66.8	-	66.0	60.2	63.9	60.2	-	59.2	-	59.1	-	58.5	-	58.8
		Speed Variance $(MPH)^2$	3.1	17.0	5.0	-	2.8	-	2.0	16.8	10.8	16.8	-	17.0	-	20.1	-	22.2	-	24.5
		Mean Acceleration (FPS)	–	–	-.1	-	-.1	-	-.4	–	-.2	-.0	-	-.4	-	-.0	-	-.1	-	.1
		Acceleration Variance $(FPS)^2$	–	–	.1	-	.0	-	.3	–	.0	.2	-	.1	-	.2	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	258	1067	232	0	196	0	144	1191	92	1250	0	1327	0	1342	0	1343	0	1343
		Mean Speed (MPH)	66.7	60.7	66.1	-	65.3	-	63.3	58.8	62.1	58.4	-	57.0	-	56.4	-	55.7	-	55.5
		Speed Variance $(MPH)^2$	26.6	23.4	26.1	-	30.2	-	38.8	31.5	55.6	33.2	-	34.6	-	35.5	-	32.5	-	35.2
		Mean Acceleration (FPS)	–	–	-.4	-	-.6	-	-1.1	–	-.9	.2	-	-.6	-	-.3	-	-.2	-	-.0
		Acceleration Variance $(FPS)^2$	–	–	.7	-	1.0	-	1.5	–	2.3	1.0	-	.4	-	.5	-	.2	-	.3
NIGHT	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3

Channelization Treatment 3E (Day only)

			Switch Pair No. 1		2		3		4		5		6		7		8		9	
	Type Vehicle	Statistic	Lane No. 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles	1	129	1	0	1	0	1	130	0	131	0	132	0	134	0	134	0	133
		Mean Speed (MPH)	67.8	59.9	67.8	-	67.8	-	67.3	59.0	-	58.8	-	57.9	-	57.9	-	56.9	-	56.2
		Speed Variance $(MPH)^2$	-	29.8	-	-	-	-	-	27.1	-	32.0	-	32.3	-	33.9	-	33.1	-	36.1
		Mean Acceleration (FPS)	-	-	-	-	-	-	-.2	-	-	-.0	-	-.4	-	.0	-	-.2	-	-.2
		Acceleration Variance $(FPS)^2$	-	-	-	-	-	-	.0	-	-	.2	-	.1	-	.2	-	.1	-	.3
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	138	588	124	0	103	0	83	655	52	689	0	721	0	739	0	738	0	734
		Mean Speed (MPH)	65.4	59.0	65.1	-	65.0	-	64.1	57.5	63.4	57.1	-	55.5	-	54.9	-	53.7	-	52.5
		Speed Variance $(MPH)^2$	28.5	23.5	29.0	-	34.9	-	36.0	28.1	52.5	30.8	-	39.5	-	41.6	-	35.2	-	37.8
		Mean Acceleration (FPS)	-	-	-.2	-	-.3	-	-.6	-	-.7	-.3	-	-.7	-	-.3	-	-.3	-	-.3
		Acceleration Variance $(FPS)^2$	-	-	.4	-	1.0	-	1.5	-	3.4	.5	-	.5	-	.4	-	.3	-	.4
NIGHT	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		

EXHIBIT E-3 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3 Channelization Treatment 4-A

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles	1	161	2	0	1	0	1	185	1	185	0	186	0	186	0	188	0	188
		Mean Speed (MPH)	71.3	60.9	64.6	–	71.8	–	71.3	60.4	70.8	59.6	–	59.5	–	59.3	–	59.4	–	57.8
		Speed Variance (MPH)^2	–	23.3	131	–	–	–	–	26.0	–	25.0	–	28.5	–	29.7	–	31.8	–	32.8
		Mean Acceleration (FPS)	–	–	.7	–	–.5	–	–.2	–	–.2	–.4	–	–.0	–	–.1	–	.0	–	–.4
		Acceleration Variance (FPS)^2	–	–	.5	–	.3	–	.1	–	.1	.1	–	.1	–	.1	–	.1	–	.4
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	147	707	144	0	121	0	93	833	54	865	0	906	0	923	0	940	0	928
		Mean Speed (MPH)	65.4	59.7	65.4	–	64.5	–	63.3	58.1	62.1	57.1	–	56.8	–	56.0	–	56.1	–	54.4
		Speed Variance (MPH)^2	33.0	21.6	38.6	–	40.7	–	42.7	31.3	48.3	28.7	–	32.1	–	33.4	–	32.3	–	34.1
		Mean Acceleration (FPS)	–	–	.0	–	–.6	–	–.9	–	–.9	–.5	–	–.2	–	–.3	–	.0	–	–.4
		Acceleration Variance (FPS)^2	–	–	.9	–	.9	–	1.6	–	2.3	.4	–	.3	–	.4	–	.2	–	.4
NIGHT	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles	8	178	8	0	7	0	5	185	5	185	0	190	0	191	0	191	0	190
		Mean Speed (MPH)	61.3	58.0	61.8	–	61.3	–	59.4	57.5	60.0	57.6	–	57.0	–	56.7	–	56.0	–	56.4
		Speed Variance (MPH)^2	41.8	24.5	37.0	–	32.5	–	35.1	35.8	42.5	33.2	–	27.4	–	30.8	–	34.4	–	33.9
		Mean Acceleration (FPS)	–	–	.2	–	.2	–	–.3	–	.3	.1	–	–.4	–	–.1	–	–.1	–	.1
		Acceleration Variance (FPS)^2	–	–	.4	–	.3	–	.1	–	.2	.1	–	.2	–	.2	–	.1	–	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	28	241	30	0	24	0	22	260	17	262	0	273	0	280	0	279	0	280
		Mean Speed MPH	61.0	57.3	59.8	–	59.4	–	57.3	56.7	55.8	56.9	–	55.6	–	54.8	–	53.8	–	53.8
		Speed Variance (MPH)^2	47.0	24.3	57.1	–	42.3	–	37.9	24.3	55.7	23.0	–	24.9	–	28.9	–	30.8	–	29.7
		Mean Acceleration (FPS)	–	–	–.4	–	–.1	–	–1.0	–	–.5	–.0	–	–.5	–	–.2	–	–.2	–	–.0
		Acceleration Variance (FPS)^2	–	–	.7	–	.6	–	4.8	–	2.8	.3	–	.2	–	.3	–	.2	–	.2

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3 Channelization Treatment 4-B (Day only)

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles	10	157	10	0	10	0	5	167	1	169	0	170	0	172	0	171	0	171
		Mean Speed (MPH)	62.7	59.1	62.1	–	56.6	–	46.6	58.6	65.7	58.7	–	57.8	–	57.7	–	57.2	–	57.3
		Speed Variance (MPH)^2	42.4	13.9	39.6	–	174.	–	273	17.8	–	16.0	–	16.3	–	21.6	–	21.0	–	23.7
		Mean Acceleration (FPS)	–	–	–.3	–	–.3	–	–2.2	–	–.4	.0	–	–.4	–	.0	–	–.1	–	.0
		Acceleration Variance (FPS)^2	–	–	.4	–	.9	–	5.4	–	.2	.2	–	.1	–	.2	–	.1	–	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	180	589	167	0	129	0	89	703	50	739	0	781	0	785	0	791	0	790
		Mean Speed (MPH)	64.2	59.2	63.8	–	63.4	–	61.9	58.1	60.7	57.6	–	55.9	–	55.3	–	54.9	–	54.5
		Speed Variance (MPH)^2	32.8	22.6	34.3	–	31.0	–	29.1	25.7	41.7	27.8	–	31.8	–	31.8	–	27.8	–	29.9
		Mean Acceleration (FPS)	–	–	–.2	–	–.6	–	–.8	–	–.8	–.3	–	–.7	–	–.2	–	–.1	–	–.1
		Acceleration Variance (FPS)^2	–	–	.6	–	1.5	–	1.4	–	3.4	.5	–	.6	–	.4	–	.2	–	.3
NIGHT	Free Flow Vehicles ≥7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance (MPH)^2																		
		Mean Acceleration (FPS)																		
		Acceleration Variance (FPS)^2																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance (MPH)^2																		
		Mean Acceleration (FPS)																		
		Acceleration Variance (FPS)^2																		

EXHIBIT E-3 Continued

TRAFFIC FLOW DATA FROM TRAFFIC EVALUATOR SYSTEM

Site No. 3 **Channelization Treatment** 4-C (Day only)

	Type Vehicle	Statistic	Switch Pair No. 1		2		3		4		5		6		7		8		9	
		Lane No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
DAY	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles	2	232	2	0	1	0	1	236	1	237	0	239	0	239	0	238	0	240
		Mean Speed (MPH)	64.4	59.0	61.8	-	60.6	-	60.9	58.4	62.7	58.5	-	57.6	-	57.7	-	57.3	-	57.4
		Speed Variance $(MPH)^2$	1.8	17.2	3.0	-	-	-	-	19.0	-	19.0	-	21.0	-	20.8	-	20.2	-	22.5
		Mean Acceleration (FPS)	-	-	-1.1	-	-	-	.2	-	.8	.0	-	-.3	-	.0	-	-.1	-	.1
		Acceleration Variance $(FPS)^2$	-	-	.0	-	-	-	.0	-	.6	.1	-	.1	-	.1	-	.1	-	.1
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles	178	815	167	0	139	0	98	907	54	956	0	1002	0	1007	0	1007	0	1008
		Mean Speed (MPH)	64.6	59.3	64.3	-	63.9	-	61.8	58.3	60.4	58.0	-	56.6	-	56.0	-	55.2	-	54.8
		Speed Variance $(MPH)^2$	21.1	21.3	24.0	-	26.2	-	32.2	23.8	46.0	25.6	-	28.2	-	31.0	-	28.9	-	30.0
		Mean Acceleration (FPS)	-	-	-.2	-	-.4	-	-1.2	-	-.9	-.2	-	-.6	-	-.2	-	-.2	-	-.1
		Acceleration Variance $(FPS)^2$	-	-	.4	-	.6	-	1.7	-	1.2	.4	-	.4	-	.3	-	.2	-	.2
NIGHT	Free Flow Vehicles ⩾7.5 Second Headway	Number of Vehicles																		
		Mean Speed (MPH)																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		
	Restricted Vehicles <7.5 Second Headway	Number of Vehicles																		
		Mean Speed MPH																		
		Speed Variance $(MPH)^2$																		
		Mean Acceleration (FPS)																		
		Acceleration Variance $(FPS)^2$																		

Table E-6. Site 3 left-lane closure lane-changing behavior.

	Switch Pair Number	Device Treatment 1		2A		2B		3C		3D		3E		4A		4B		4C	
		#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
DAY	1-4	3	6	5	7	13	12	8	10	2	3	6	15	2	4	2	6	3	6
	2-4	6	13	10	15	24	21	20	24	12	21	11	28	10	20	9	27	10	19
	3-4	8	18	14	21	27	24	13	15	16	27.5	9	23	12	24	6	18	14	27
	4-5	9	20	21	32	27	24	18	21	12	21	13	32	14	27	10	31	12	23
	5-6	19	43	17	25	21	19	25	30	16	27.5	1	2	13	25	6	18	13	25
NIGHT	1-4	4	45	2	10	5	24	9	21			0	0						
	2-4	1	11	4	20	5	24	7	16			2	17						
	3-4	1	11	5	25	1	5	6	14			1	8						
	4-5	2	22	6	30	3	14	4	11			4	33						
	5-6	1	11	3	15	7	33	16	38			5	42						

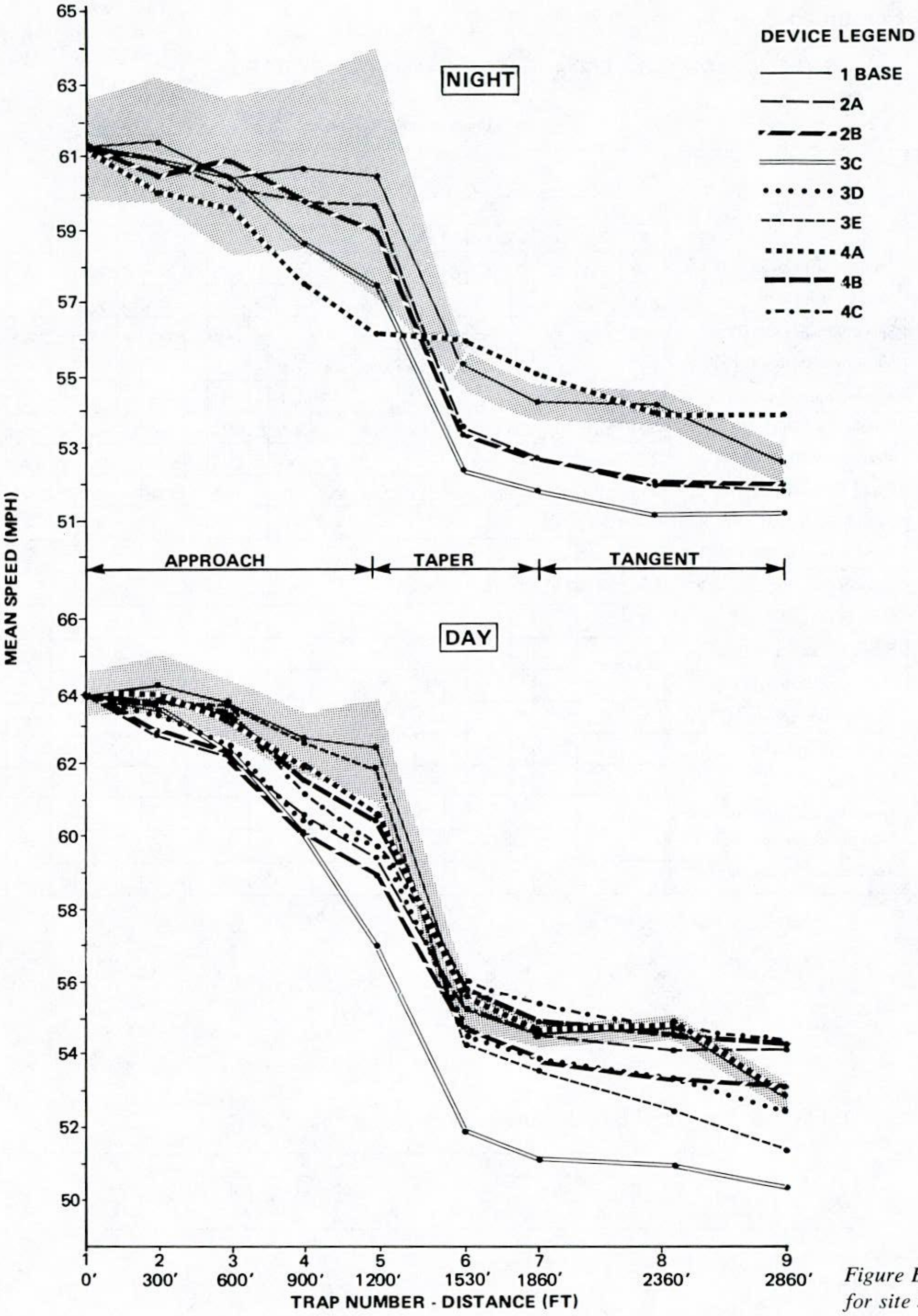

Figure E-10. Day and night mean speed profiles for site 3.

trap is given followed by what percent this is of the total. Lane changes are given for each of the device arrays tested.

The analysis is again predicated on a comparison of each device treatment with the baseline standard 24" × 12" barricade set-up (treatment 1), and looking at day and night operations separately. Chi-square (χ^2) values were computed on the proportions changing in each trap for the base vs. for each device treatment. A χ^2 was also obtained comparing the baseline treatment, day versus night. The following are these values:

Treatment Comparisons				χ^2 value	df	significance
Day	vs.	Night		50.74	4	.001
1	vs.	2A	Day	7.98	4	n.s.
1	vs.	2B	Day	14.39	4	.01
1	vs.	3C	Day	6.88	4	n.s.
1	vs.	3D	Day	8.30	4	n.s.
1	vs.	3E	Day	50.08	4	.001
1	vs.	4A	Day	8.55	4	n.s.
1	vs.	4B	Day	17.52	4	.01
1	vs.	4C	Day	7.90	4	n.s.
1	vs.	2A	Night	32.18	4	.001
1	vs.	2B	Night	26.25	4	.001
1	vs.	3C	Night	28.56	4	.001
1	vs.	4A	Night	67.09	4	.001

Interpretation of these data is subject to recognition of the qualifications discussed in the introductory statements regarding this site; namely, the use of restricted vehicle data rather than free-flow, and acknowledging the presence of the arrowboard placed to augment the channelizing devices.

Given the foregoing constraints, a few conclusions regarding the effects of the devices on point of lane change may be made. First, the marked disparity between day versus night operations continues here as shown with the very significant χ^2 value of 50.74. Drivers tend to make the lane shift very early, not so many waiting until close to the taper as in the daytime. This holds true uniformly for the base condition (24″ × 12″ barricades with diagonal striping), then is a little less so under differing device treatments. Note that, in the nighttime, even though the χ^2 values are showing significant deviation from the baseline, these values are really based on very little data. This obviously suggests that the majority of the vehicles had made the necessary lane change upstream, even in advance of the first trap. The overwhelming directional influence of the bright flashing arrowboard at night surely has somewhat diluted the effects of the channelizing devices.

The daytime operations are a little more interpretable in terms of device effects, with the general trend to wait until close to the taper before merging for the standard barricades (treatment 1). This continues the trend established in site 2, which effected the same phenomenon. χ^2 values obtained contrasting differing device set-ups with the base reveal only three that differ significantly—2B (110-ft spacing for vertically striped barricades on tangent), 3E (combination treatment: chevron barricades with post cones in tangent), and 4B (110-ft spacing for horizontally striped vertical panels). This is somewhat difficult to interpret, however, because other treatments bore no significant difference from the base, yet their only difference from each other was spacing. The treatment 3E—chevron barricade/post cone combination set-up—contains a lot of orange to provide a highly detectable image from afar. This is in support of findings from the Task 4 controlled field study wherein orange cones are a very effective display in the daytime, conveying the lane closure message clearly. The treatments 2B and 4B are arrays that deviate from standard set-up by virtue of a wider spacing. Apparently, some perceptual characteristic of this image provides a positive alerting message to the driver, causing him to merge early as compared to the base treatment. Exactly how this perceptual process is operating in response to this image is a subject for further study.

Erratic Maneuver and Traffic Conflict Results. Table E-7 summarizes the erratic maneuver and traffic conflict counts and rates (counts divided by the total vehicles) for each of the treatments, day and night.

When all types of erratic maneuvers and conflicts are combined, the day rates ranged from a low of 4.2 percent for the base treatment to a high of 11.6 percent for treatment 2A, Type I barricades with 6-in. vertical stripes. The slow vehicle conflict and the slow-to-merge erratic maneuver were the most prevalent types observed.

Statistical comparisons were made of the experimental treatments against the base condition. All but two treatments had significantly higher rates than the base condition. But unfortunately, this difference can be equally attributable to inter-observer differences. The observer for the base condi-

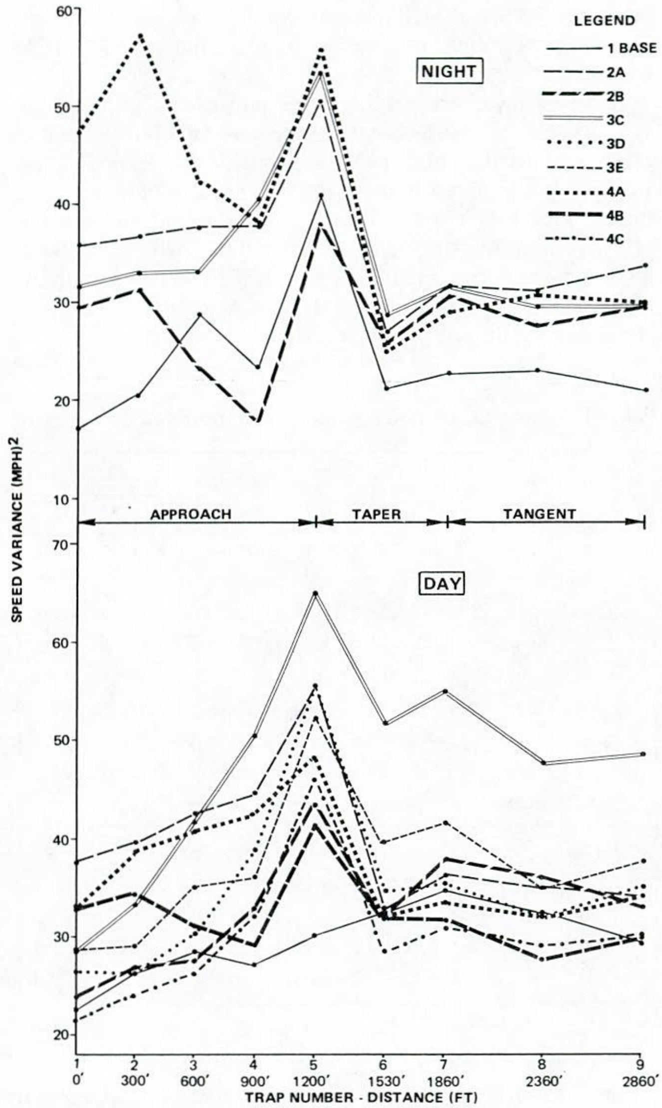

Figure E-11. Day and night speed variance profile for site 3.

tion was different from the observer for the other treatments. Of those treatments which had the same observer, there were no statistical differences among the treatments.

Unfortunately, the same situation regarding different observers occurred at night. The base condition, which had the lowest rate, was observed by someone different from the observer for the other treatments. The rates for the four experimental treatments were fairly consistent.

Synthesis of Results

Up to this point, the results of the four evaluation measures have been presented for each study site separately without drawing any general conclusions regarding the overall effectiveness of any particular device. Indeed, the purpose of this field evaluation task was not to identify the most effective device but rather to validate, so to speak, those alternative devices and designs that were found to be promising from the previous tasks. Still, it is necessary to synthesize the results of the three sites so that some findings can be presented which will indicate whether any particular device is appreciably better or worse than the base MUTCD treatment.

Table E-8 was prepared for this purpose. The table is a synthesis of the results for the three sites. Each treatment is given a zero (0), plus (+), or minus (−), depending on whether it compared equally (0), better than (+), or worse than (−) the base treatment for each of the four measures of effectiveness. Missing cells are a result of one of the following conditions: treatment was not studied at the site; treatment was not studied for a day or a night condition; if studied, data do not permit a conclusive result.

Before the results of the table are discussed, several assumptions must be understood. First, all treatments were compared to the base treatment—24″ × 12″ Type I barricade with 6-in. diagonal stripes. In essence, the assumption is made that this device causes the best performance against which all other devices should be compared. Obviously, this assumption can be questioned because there are no data to support it. In reviewing the speed data, however, it appears that the base treatment, in most cases, did serve as a good baseline condition. Its mean speeds were generally between the high and low values, and the speed variances were on the low side and not very erratic. Also, again it should be empha-

Table E-7. Erratic maneuver and traffic conflict data for site 3.

	Device Treatment No.	Total Vehicles	Erratic Maneuvers #	Erratic Maneuvers Rate	Lane Changing Conflict #	Lane Changing Conflict Rate	Slow Vehicle Conflict #	Slow Vehicle Conflict Rate	Slow to Merge Err. Man. #	Slow to Merge Err. Man. Rate	Slow to Merge Conflict #	Slow to Merge Conflict Rate	Wrong Way Lane Change Opp. #	Wrong Way Lane Change Opp. Rate	Wrong Way Lane Change Conflict #	Wrong Way Lane Change Conflict Rate	All Types #	All Types Rate
DAY	1	1685	7	.0042	4	.0024	34	.0202	21	.0125	4	.0024	1	.0006	0	0	71	.042*
	2A	1743	26	.0149	54	.0309	69	.0395	49	.0280	0	0	5	.0029	0	0	203	.116*
	2B	2407	6	.0025	7	.0030	73	.0300	49	.0200	22	.0090	2	.0008	0	0	159	.066*
	3C	2863	6	.0021	7	.0024	66	.0230	57	.0199	28	.0098	2	.0007	0	0	166	.058*
	3D	1863	4	.0021	6	.0032	53	.0284	33	.0177	6	.0032	0	0	0	0	102	.055*
	3E	1235	3	.0024	33	.0260	50	.0400	30	.0240	12	.0090	2	.0016	0	0	120	.097*
	4A	1516	4	.0026	0	0	43	.0280	42	.0277	11	.0073	1	.0007	0	0	101	.066*
	4B	1414	2	.0014	6	.0042	36	.0250	21	.0148	7	.0050	3	.0021	0	0	75	.053*
	4C	1437	2	.0014	34	.0237	45	.0313	35	.0243	16	.0111	0	0	0	0	122	.085*
NIGHT	1	912	3	.0033	0	0	15	.0164	0	0	0	0	0	0	0	0	20	.022
	2A	800	2	.0025	2	.0025	15	.0180	6	.0075	2	.0025	1	.0012	0	0	28	.035
	2B	1221	3	.0020	2	.0016	33	.0270	11	.0090	3	.0020	2	.0016	0	0	54	.044*
	3C	1608	5	.0031	2	.0012	40	.0250	20	.0124	5	.0031	4	.0025	0	0	76	.047*
	4A	893	8	.0090	0	0	23	.0250	5	.0050	0	0	1	.0010	0	0	37	.041*

* Indicates significantly different rates.

Table E-8. MOE comparisons of experimental treatments for 3 sites.

Site No.	Measures of Effectiveness	2A D	2A N	2B D	2B N	3A D	3A N	3B D	3B N	3C D	3C N	3D D	3D N	3E D	3E N	4A D	4A N	4B D	4B N	4C D	4C N
1	Mean Speed	0	0										0			0	0				
	Speed Variance	-	+										0			0	0				
	Lane Changing	0	0										0			0	0				
	Erratic Maneuver/Traffic Conflicts		0										0				0				
2	Mean Speed	0		-	0	-	-	-				-									
	Speed Variance	0		0	0	-	-	-				-									
	Lane Changing	0		0		0		+				+									
	Erratic Maneuver/Traffic Conflicts	0		0	-			0				-									
3	Mean Speed	0	-	-	-					-	-	-		-		0	0	0		0	
	Speed Variance	0	-	0	0					-	0	0		0		0	0	0		0	
	Lane Changing	0		+	+					0		0		+	+	0		+	+	0	
	Erratic Maneuver/Traffic Conflicts																				

D = Day
N = Night

0 = No difference from base treatment
\+ = Positive difference (better) from base treatment
\- = Negative difference (worse) from base treatment

sized that because the objective was not to identify the most effective (or ineffective) device, absolute values are not as important in the overall evaluation as relative values, and it seems logical to use the base MUTCD treatment as the reference point.

The remaining assumptions relate to the criteria used for assigning a zero, plus, or minus to the treatments for each measure of effectiveness. The most difficult assumption was with regard to mean speed. There still is no widespread agreement as to whether speeds should be maintained or reduced through construction zones. One school of thought holds that speeds in the work zone area should be similar to those on highways before the work zone and that large changes in speed are hazardous. The other school contends that construction zones are hazardous and, therefore, speeds should be reduced accordingly. In view of these opposing philosophies, the following criteria were used for mean speeds: (1) a zero value was assigned to any treatment that had a mean speed profile within the confidence interval of the base treatment; (2) a plus value was assigned to any treatment that lowered the speeds without any resulting large speed changes between traps; and (3) a minus value was assigned to any treatment that significantly increased or decreased mean speed compared to the base, but did so with large speed changes between traps.

For speed variance, a plus was assigned to a treatment if it produced a variance profile that was smoother and/or lower than the base condition. This is a reasonable assumption since increased speed variance has been related to a more hazardous situation. Following this logic, a minus value would be given to a treatment that had a higher and more erratic speed variance profile.

For lane changing, a distinction had to be made between site 1 and sites 2 and 3. For the former site, lane changing was not required nor desired; therefore, any treatment that resulted in fewer lane changes was assigned a positive value. For sites 2 and 3, a positive value was assigned to any treatment that resulted in lane changing further upstream of the taper or, in other words, produced less lane changing at the last trap before the taper. There is no consensus of opinion regarding where the motorist should change lanes in a lane-drop situation, but most would agree that the earlier, the better.

Finally, for the erratic maneuver and traffic conflict rates, the assumption was obvious. A treatment resulting in a lower rate was assigned a positive value. A higher rate was assigned a negative value.

There are a few problems in interpreting the results given in Table E-8. First, all treatments were not tested at all sites. Even if they had been, it would still be difficult because the sites are different types and it is possible that a treatment may be more or less effective at any particular site type. Another problem is that at any one site and treatment, there are mixed results for the four measures and for both day and night. What does it mean if a device produces higher speed variance in the day but lower speed variance at night or vice versa? Also, what does it mean if a device promotes earlier lane changing but at the expense of higher speed variance? These questions are not easily answered.

Given these constraints and assumptions, only one overall conclusion can be drawn from the results given in Table E-8. Of the channelization devices tested, none consistently affected the four MOE's that would indicate it was either better or worse than the base device—24″ × 12″ Type I barricade with 6-in. diagonal stripes. It can be inferred from this that all the treatments would be interchangeable and equally effective as the base treatment.

A discussion of each device type is warranted to elaborate on this conclusion and to highlight any specific exceptions to the conclusion that treatments 2A and 2B were similar to the base treatment except that 6-in. vertical stripes were used instead of diagonal stripes. Treatment 2B varied from 2A in that the spacing was increased to 110 ft on tangent. Both devices compared negatively to the base treatment in several instances, but the results are mixed. It is not conclusive but it appears that the longer spacing with treatment 2B is not as desirable as the 55-ft spacing.

Treatments 3A through 3E all used 4-in. chevron stripes on the Type I barricade. At sites 2 and 3, they compared negatively with regard to mean speed and speed variance but produced improved lane changing. The improved lane changing with the chevron pattern is consistent with the laboratory finding that motorists more quickly identify the need for lane changing and direction with a chevron pattern. The negative mean speed and speed variance performance is unexplainable, however.

The last three treatments—4A, 4B, and 4C—were all 24″ × 12″ vertical panels except that 4C had 36″ cones on the tangent section. They all seemed to perform as well as the base condition. The vertical panels spaced at 110 ft did not produce any negative results, but they were tested only at one site and only during the day.

REFERENCES

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APPENDIX F

CONE AND TUBE OPTIMIZATION STUDIES

INTRODUCTION

The traffic cone (and tube) has been, and likely will be, one of the most frequently used channelizing devices for street and highway work zones. Its compactness, durability, and portability make it one of the most preferred devices for work zone applications. Also, recent laboratory research on the associative meanings of various roadway delineation systems indicates that drivers most often connote an array of traffic cones to mean a delineation for or near work zone activity (*1*).

However, the results from Appendix D, closed-field study, suggest that the cone and tube performance at night was not satisfactory in comparison with other devices. In that test the MUTCD recommended reflectorization configuration was used, and there is no empirical evidence to suggest it is an optimal treatment.

In order to make statements concerning the detectability and channelizing effectiveness of cones and tubes, a representative sampling of the many types must be evaluated empirically under various spacing, reflectivity, and size conditions. NCHRP follow-on project (17-4(2)) to the work reported in the preceding appendixes was initiated in response to this need.

Clearly, the objective of this continuation project (17-4(2)) was to gather experimental data to determine the effects of size, spacing, reflectorization, etc. on drivers' ability to perceive and negotiate the cone or tube image and arrays. As previously noted, earlier testing had shown cones and tubes to be as effective as other channelizing devices in the daytime. The performance decrement was found at night. Therefore, the goal of the work reported in this appendix was to optimize nighttime performance characteristics (in terms of driver response) of cones and tubes without sacrificing daytime effectiveness.

In order to accomplish testing of so many different device configurations, set-up in a controlled field site was most efficacious. Here the driver was posed with a real driving situation and real lane closure, yet in the situation where many types of cones and tubes under varying conditions were easily evaluated and controlled by the experimenters. Therefore the work and results of Project 17-4(2) are most meaningfully considered in terms of the experiments conducted—not the task structure of the project.

SELECTING CONE AND TUBE CONFIGURATIONS FOR STUDY

Two sources of information were used to guide selection of device treatments: literature search and operational practices surveys.

Literature Search

NCHRP Project 17-4 (Phase I) literature search was updated with emphasis on cones and tubes. Sources reviewed included traffic control manuals (Federal, state, local, and private sector); accident/safety studies of work zones; traffic control device effectiveness studies; driver information need analyses; and theoretical work on image perception (detection, recognition, and response).

The extent to which each source contributes valuable information for design of the current evaluation is largely dependent on the point of view adopted. No specific report focuses on cones and tubes as an independent entity.

Traffic control manuals and specifications are somewhat divided on the deployment of the cones. The *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*) purports that the function of cones (as well as other channelizing devices) is "to warn and alert drivers of hazards . . . in or near the traveled way, and to guide and direct drivers safely past the hazards." Yet, other widely respected manuals, for example, that developed by Texas A&M University (*3*), state that the primary function of cones and tubes is the channelization of traffic. They are a useful adjunct to the more highly detectable barricades, but never to be used in a high speed setting without the complement of advanced warning devices such as signs, flashing arrowboards, flagpersons, and so on.

Given the prevailing confusion as to whether cones are to serve as highly detectable advance warning images of the work area or simply channelize drivers when they are closer to the zone, somehow optimizing their performance from the driver's point of view is still quite justified. First, drivers do not find signs and other advance controls all that credible as denoting a work zone ahead (*4*), only responding to the hazard on sighting the control devices. Second, an array of cones has been positively shown to carry the associative meaning of a work zone to the driver upon first flash of this image (*5*). The power of the orange image to mean "caution—work zone" is a well-learned concept in the driver's experiential set of expectancies. Finally, cones and tubes are ubiquitous and destined to remain so (*6*). Their portability and soft material make-up make them easy to work with, and incidents involving impact are not harmful to car or driver.

Accident investigators report that safety problems around work zones may be largely due to driver error (*7*). The problem seems to center around inadequate communication of the need for increased caution by the motorist. The U.S. Government Accounting Office in a recent survey (*8*) found that unsafe conditions prevailed in a sample of 26 construction sites visited nationwide. Numerous authors have written about the need to have a systems plan for traffic control and device set-up (*9, 10, 11, 12, 13*), as a matter of ethics and safety, but these thoughts have just begun to engender the kind of research needed to specify drivers' needs for information when encountering the work zone and the required performance response to it.

Prior to the pursuit of understanding driver needs for information concerning the work zone, highway research groups concentrated on evaluation of devices based on accident reduction or traffic operational measurement criteria. Particular emphasis was given to various sorts of barricades and barriers (*14, 15*), as being able to withstand crash impacts while safely repelling errant vehicles. The Louisiana Department of Highways has been notable in its studies (*16*) on advance traffic control warning systems for maintenance operations. Measures taken in evaluation of various signs and other devices included speed and conflict in the traffic flow.

Yet these reports are still peripheral to specifying standards of performance for specific devices such as the cones and tubes. More general research emerging and at the same time addressing driver needs in work zones seems more relevant to performance aspects of a given device. Design concepts for visual information display devices has emerged from principles of positive guidance, and more specifically, decision sight distance (DSD) (*17, 18, 19*) as a means to promote optimum communicative properties of a visual image to interface with the driver's perception. Here the cone or tube is seen as a specific component in a total system to effectively warn the driver of a violation in normal driving expectancies. The DSD concept for placement of traffic control devices is defined as:

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

Some research activity has occurred to attempt to employ the DSD concept for driver detection, recognition, and responses to specific devices. Flashing warning lights, steady-burn beacons, roadway delineators, and flashing arrowboards have all been the subject of recent study emphasizing driver detection and recognition responses to the device meanings and desired driving behaviors that should ensue (*20, 21, 22, 23, 24*). This emphasis toward driver perceptions of the devices and their meanings attacks problems of communication between the driver and the visual environment. For example, in evaluating the flashing arrowboard (*23*) as a high target value warning device, laboratory tests of arrow symbol design and meaning were followed by collection of flow parameters in the field. Placement was then governed by the DSD concept, and certain desirable behaviors such as early merging and shorter queues at the beginning of lane closures were recorded.

Evaluation of cones and tubular markers has completely achieved the shift toward driver intrusive performance evaluation in research activity. This has begun, as described in Appendixes D and E, but specific emphasis had not been given to cones and tubes. Other recent research addresses currently unresolved issues as to whether channelizing devices should be highly detectable advance warning devices, or serve to strictly channelize drivers through the hazard zone.

In one experiment (*25*) TTI kept advance signing constant but varied the work zone devices (i.e., devices were present or absent); and lane changing behavior was measured.

A second experiment varied the sight distance to the lane closure (taper). Advance signing and channelizing devices used were the same. They measured the number and percent of vehicles remaining in the closed lane 750 ft before the taper. With the longer sight distances, 25 percent of the vehicles remained in the closed lane; but for the shorter sight distance, 41 percent of the vehicles were still in the closed lane at the point of measurement. The conclusions from these experiments relevant to cone and tube study were: (1) advance signing has little credibility for drivers; they generally wait to see the lane closure before merging; and (2) the minimum recommended sight distance for 50 to 60 mph facilities is 900 ft.

Conclusion (2) was derived from traffic operational data and is a different type of verification of the experimentally obtained decision sight distance (DSD) criterion of 900 to 1,000 ft for 50- to 60-mph speeds. Given this type of empirical replication, the DSD criterion seems all the more justified for this project.

Conclusion (1) empirically verifies one of the results of the Appendix B information analysis: that drivers need definitive information on the start of a lane closure. One of the arguments for using visual detection/recognition/point of lane change measures throughout this project has been that cones, tubes, and other devices are channelizing devices for providing path or guidance information. However, channelizing devices must also serve as a hazard warning. The devices in a lane closure, particularly the taper, confirm the advance signing and show the driver in real terms—not abstract feet or mile designations—where the lane ends. The TTI (*25*) finding empirically supports this argument. Given the DSD of 1,000 ft and the variability associated with device detection and recognition, emphasis on optimizing visibility characteristics of channelizing devices, including cones and tubes, is indeed a necessary operational and safety endeavor.

Operational Practice Survey

There are any number of cone and tube sizes, colors, reflectorization, and use options. This project could not accommodate all of the treatment possibilities. The main emphasis of Project 17-4(2) in general was on optimizing and evaluating commonly accepted and used devices, not creating new ones. To determine what is most commonly used, two surveys and a literature request were devised and mailed out.

A survey form was sent to the eight states represented by the project panel. All forms were returned and the results are given in Table F-1. A slightly different survey form was sent to the 131 full members of the American Traffic Services Association. Many members had no dealings with cones or tubes. The 27 forms returned, although a small number, included responses from 17 states; 6 western, 6 midwestern, and 5 eastern. Survey results are given in Table F-2. It should be noted that the results given in Tables F-1 and F-2 are from rather small samples and may not be representative of the entire country.

The results among states and between the two surveys were quite consistent. In general, cones are valued for their portability and ease of use, and are considered an effective channelizing device in the daytime. The typical problems cited (e.g., they are easily blown over or stolen and have diminished nighttime visibility) are reflected in low night and long-term (over 24 hours) use of cones.

Cone size and reflectorization were potential variables in this project, and are therefore of particular interest. The

Table F-1. State questionnaire summary.

BioTechnology, Inc.

3027 ROSEMARY LANE • FALLS CHURCH, VIRGINIA 22042

(703) 573-3700

10 responses
8 use devices
8 different states represented

May 1980

Dear Project 17-4 (2) Panel Member:

If you would take a few minutes to complete the following questions, the information will be of considerable help to us in developing the final test plans for 17-4 (2). Anything you wish to add, not covered by the following questions, will be most welcome.

Please return the questionnarie *within two weeks* so that we can use your response.

Thank you in advance for your help and support.

Richard F. Pain, Ph.D.
Principal Investigator

The following questions refer to 4-lane (or more) highways or freeways.

1. Does your organization use cones or tubes for highway (4-lane or more/freeway) construction/maintenance work zones?

 8 Yes (go to question =2)   2 No (go to question =5)

2.a. What type of *cones* do you use in various situations? Please check the appropriate categories and fill in the requested information.

Situations	Day Use	Night Use	Cone Sizes Used 18"	28"	36"	Cone Colors
8 lane closure	8 day	4 night	3	7	3	7 orange/1 O+W
8 shoulder work	7 day	4 night	3	7	3	7 orange/ 1 O+W
6 median crossover or diversion	6 day	4 night	2	5	2	6 orange
2 other (please specify)	2 day	2 night	0	1	1	2 orange
denotes center/lane lines/	___ day	___ night				
low shoulders/temp. hazard	___ day	___ night				

___ Do not use cones (go to question =3)

b. Do you use cones for:

Short-term (less than 24 hours) operations? 8 Yes ___ No
Long-term (more than 24 hours) operations? 5 Yes 3 No
Taper sections? 8 Yes ___ No
Tangent sections? 8 Yes ___ No

c. Are the cones reflectorized or illuminated at night?

 5 Yes   3 No (go to question #3) (Do not use cones at night)

If yes, please specify how (e.g., specific collar type and size, refelective button size, color, etc.).

3 – 6"-7" white collar
1 – 4" white collar (changing to 6" in 1981)
1 – 13" orange collar
1 – Internal illumination
1 – 13" white collar

d. Do you leave reflective collars on cones during the daytime?

 3 Yes   3 (one state leaves glued collars on – removes others)

(over)

Table F-1 Continued

BioTechnology, Inc.

3.a. What type of *tubes* do you use in various situations?

Situations	Day/Night Use		Tube Sizes Used 28'	36"	42"	Tube Colors
3 lane closure	3 day	2 night	1	1	2	orange
2 shoulder work	2 day	2 night	1		2	orange
3 median crossover or diversion	3 day	2 night	1	1	2	orange
1 other (please specify)	1 day	1 night		?		yellow
Separate 2 way traffic and	___ day	___ night				
for bus lanes	___ day	___ night				

4 Do not use tubes (go to question #4) (In one state, contractors use tubes, but not state)

b. Do you use tubes for:

Short-term (less than 24 hours) operations? 2 Yes ___ No

Long-term (more than 24 hours) operations? 3 Yes ___ No

Taper sections 2 Yes 1 No (one state uses ½ spacing for tubes)

Tangent sections 3 Yes ___ No

c. Are the tubes reflectorized or illuminated at night?

3 Yes ___ No (go to question #4)

If yes, please specify how (i.e., amount and type of reflectorization or illumination).

1 – 6" band of white or yellow reflectorization

1 – 2 3" bands of reflectorized material

1 – 1 or 2 4" bands – made of flexible material with enclosed lens

4. What are the major problems and/or benefits you experience with:

Cones — Problems	Easily knocked over by wind, traffic or stolen	7
	Less visible at night (especially non-reflectorized)	3
	Collars easily lost if not permanently attached	1
	Drivers disregard – 1/Tend to space too far apart	1
Cones — Benefits	Easy to stack, move, store	7
	Less or no damage to vehicle when struck	4
	Good target valve	3
Tubes — Problems	Unstable – blown over by trucks	1
	Bulkier – more difficult to stack, store, move	1
	Low conspicuity	4
Tubes — Benefits	Can be fastened to road surface	1
	More stable	1

Other Comments:

Cones: Can be internally illuminated/use dividers and barricades to supplement target value/use cones as advance taper-lead-in to concrete barricades.

Tubes: Cannot be internally illuminated/useful for lane closure/shift on high speed and volume roadways.

Table F-2. ATSA member survey summary.

131 sent
27 returned = 21%

BioTechnology, Inc.

3027 ROSEMARY LANE • FALLS CHURCH, VIRGINIA 22042 (703) 573-3700

May 1980

Dear ATSA Member:

A second study on work zones funded by the National Cooperative Highway Research Program (NCHRP) is underway. This project focuses on cones and tubes. To help us determine what types of cone and tube devices are available and how they are used, we are asking you to answer the following questions. Please return the questionnaire as soon as possible so your response can be used.

Thank you in advance for your help and support.

Richard F. Pain, Ph.D.
Principal Investigator

1.a. If you manufacture or deal in cones or tubes or relevant accessories (e.g., reflective collars, internal illumination, etc.) for them, please send us any catalog or descriptive materials about your products in addition to completing this questionnaire.

b. Please indicate the approximate percentage of your cones and/or tubes sold/supplied represented by each cone size.

Cone/Tube Description	Size	Numer Dealers/ Suppliers	Percentage of Sales or Demand	Distribution	
			Range %		
cone	12'	3	7- 10%	0-24-3 25-49-	50- 74- 75-100-
cone	18"	18	10- 90%	0-24-5 25-49-5	50- 74-5 75-100-3
cone	28"	20	1-100%	0-24-5 25-49-6	50- 74-5 75-100-4
cone	36"	6	2- 50%	0-24-3 25-49-2	50- 74-1 75-100
tube	18"	1	5%	–	
tube	26-28"	3	2- 28%	0-24-2 25-49-1	
tube	36-39"	3	5- 70%	0-24-2	50- 74-1
tube	42"	7	1- 20	0-24-7	
tubes	no size given	1	1%	–	

2. Does your organization set-up cones or tubes for highway (4-lane or freeway) construction/maintenance work zones?

18 Yes (go to question #3) 9 No (go to question #6)

(over)

Table F-2 Continued

3.a. What type of *cones* do you use in various situations? Please check the appropriate categories and fill in the requested information.

Situations on 4 Lane Highway or Freeway	Day/Night Use		Cone Sizes Used 18"	28"	36"	Cone Colors
18 lane closure	18 day	4 night	3	13	3	orange
13 shoulder work	13 day	3 night	3	8	1	orange
10 median crossover or road diversion	10 day	1 night	2	6	1	orange
___ other (please specify)	2 day	1 night		4		orange
	___ day	___ night				
	___ day	___ night				

___ Do not use cones (go to question #4)

b. Do you use cones for:

	Yes	No
Short-term (less than 24 hours) operations?	17 Yes	1 No
Long-term (more than 24 hours) operations?	3 Yes	15 No
Tangent sections of the work zone?	13 Yes	5 No
Taper sections of the work zone?	15 Yes	3 No

c. Are the cones reflectorized or illuminated at night?

6 Yes 12 No (go to question #4) Not used at night

If yes, please specify how (e.g., amount and type of reflectorization or illumination)

1 — 6" or 7" band
1 — 1 stripe of engineer grade, applied vertically — 5 per cones
1 — internal illumination
1 — 2 stripes of reflective sheeting
1 — 4" white collar
1 — 13" orange collar
1 — 12v steady burn light

d. Do you leave reflective collars on cones during the daytime?

1 Yes 3 No

4.a. What type of *tubes* do you use in various situations?

Situations	Day/Night Use		Tube Sizes Used	Tube Colors
5 lane closure	3 day	4 night	39/42"	orange
4 shoulder work	2 day	3 night	39/42"	orange
5 median crossover or diversion	3 day	4 night	39/42"	orange
2 other (please specify)	3 day	1 night	39/42"	orange
	___ day	___ night		
	___ day	___ night		

12 Do not use tubes (go to question #5) Number using tubes = 6 or 33%

b. Do you uses tubes for:

	Yes	No
Short-term (less than 24 hours) operations?	3 Yes	4 No
Long-term (more than 24 hours) operations?	5 Yes	2 No
Taper sections of the work zone?	3 Yes	2 No
Tangent sections of the work zone?	4 Yes	1 No

c. Are the tubes reflectorized or illuminated at night?

5 Yes 1 No (Go to question #5) Not used at night

If yes, please specify how (e.g., amount and type of reflectorization or illumination)

1 — 2-3" bands amber
4 — 2-4" amber bands

Table F-2 Continued

BioTechnology, Inc.

5. What are the major problems and/or benefits you experience with:

	Problems		Benefits	
Cones	Easily knocked over by wind/traffic or stolen	15	Easy to stack, move, store	9
	Less visible at night	6	Less damage to vehicles if struck	1
	Drivers disregard/less intimadating	4	Good visibility (day)	3
	Discoloration	1		
Tubes	Difficult to stack, move, store	4	Good visibility/taller	4
	Blown/broken/unstable	4	More intimadating	2
			More stable than cones	2
	When hit, tend to roll out into traffic	1	Easier to handle then barricades	1

6. Do you know of any four lane freeway sites, fairly flat, and 2 miles or longer, that are closed to traffic and that might be candidates for closed field testing this summer and fall. Please list them.

Name of Facility	Location	Is it Illuminated?

7. Name and address of your organization ____________

8. Telephone = ( ) ____________

9. Person to contact for further information: ____________

The time you have taken to assist us is greatly appreciated.

17 states represented

West – 6
Midwest – 6
East – 5

sales/demand figures indicate 18- and 28-in. cones comprise the bulk of the market. However, larger (28- and 36-in.) cone use predominates on four-lane facilities. Note that 18-in. cones are used on the high-speed facilities and, because of their continued use, were tested.

Those using cones at night all in some way enhance cone visibility. One state uses the internally illuminated cone; the other respondents use a wide variety of reflective treatments. These range from three sizes of reflective collars to vertical stripes of Type II sheeting.

Approximately one-third of the respondents use tubes. Even though the absolute number is small, these respondents were very positive about the usefulness of tubes as channelizing devices.

Tubes are used slightly more at night than in the day. Smaller tubes (28 in.) are used and sold/rented, but primarily for lower speed facilities. Only the larger (39- and 42-in.) tubes are used on the high-speed highways. In Pennsylvania, 18-in. tubes are used on a turnpike as lane dividers, but not for lane closures. Reflectorization appears more standardized (i.e., two 3- or 4-in. bands in amber color). Tubes are also used relatively more than cones for long-term operations.

The comments summarized in Tables F-1 and F-2 most often refer to handling and stability characteristics of cones and tubes. Driver response and visibility characteristics of these devices were mentioned and took the form of:

1. Cones have diminished visibility at night, but high conspicuity in the daytime.
2. Tubes are thought to have poor visibility by four respondents, and four others commented on their good visibility.

From these surveys, the device factors that commonly varied and/or were controversial were:

1. Cone size: 18-, 28-, 36-in.
2. Cone visibility at night and methods of enhancing conspicuity: amount and type of reflectorization or internal illumination.
3. Tube size: 36- or 42-in.
4. Effect of increasing reflectorization.

Finally, cone, tube, and reflectorization manufacturers were asked to send product literature to BioTechnology. This confirmed the survey findings as to device size, shape, color, and reflectorization availability.

Candidate Device Treatments

A comprehensive but logistically overwhelming list of device treatments was generated. Using the survey results, comments from the project panel and ATSA Cone Committee, and findings from a pilot study on amount of reflectorization, a workable number of cone/tube treatments were selected. Table F-3 gives the final list.

Table F-3. Device treatments selected for testing.

Cones	Tubes
5 areas of reflectorization (69, 138, 207, 276, and 345 $in.^2$ corresponding to single bands of 6, 10.4, 14, 17, and 19.7 inches)	5 areas of reflectorization (14, 28, 43, 57 and 71% of area covered corresponding to 6-, 12-, 18-, 24-, and 30-inch bands)
Number of bands of reflectorized material (1,2,3)	1, 2, 4, 6, or 8 bands
High versus low mounting position	High versus low mounting position
4 types of reflectorization plus internal illumination	4 types of reflectorization
2 colors (white and amber)	2 colors
3 sizes (18-, 28-, 36-inch)	3 sizes (18-, 28-, 42-inch)
3 device spacings (half, regular, and double speed limit spacing)	3 device spacings

EXPERIMENTAL STRATEGY

Because the intent of the optimization studies was to produce data compatible with the Task 4 closed-field studies, the experimental methodology had to replicate the earlier study to the greatest possible degree. However, even a small sample of the variables relevant to cone and tube design given in Table F-3 could not be logistically included in a complete factorial design. The problem was resolved by studying cone and tube design optimization in an initial series of four experiments, hereafter referred to as Step 1 testing. The most promising treatments were used in Step 2 testing, which attempted to fully replicate the closed-field studies.

Test Site

Replicating the closed-field methodology was complicated by the fact that the closed roadway originally used was now open to the public. Following a nationwide search in which three usable test sites were located, the I-295 by-pass near Richmond, Va., was selected. Figure F-1 shows the 5,000-ft sight distance available at this site. Additional benefits were little construction equipment interference, an adequate source of subjects, and excellent logistics support.

In both the west- and eastbound lanes, a lane closure with 660-ft taper and 1,000-ft tangent was laid out with 5,000- and 5,200-ft sight distances, respectively. A circuit drive of 7 miles, compared to 6 at the Task 4 site, was achieved using a graded median crossover. The roadway had no illumination, and no light sources were visible within 1,000 ft of the lane closures.

Because the site was east/west oriented, care was taken to conduct all daytime tests between 10 a.m. and 2 p.m. to minimize sun angle effects. Night testing commenced only after there was total dark.

During the course of Step 2 testing the roadway signing was installed. All delineators and small signs were covered so there was no visual change at the work zone. However, each approach to the work zone had a large green guide sign with exit route and destination information erected midway through testing. A t-test of detection distance across treatments between before-and-after sign installation showed no difference. Subject comments and overt responding did not noticeably change. This suggests that the signs did not materially change subject responding to the cone/tube arrays.

Test Subjects

To obtain a sample of the general driving population similar to that used in Project 17-4, the same recruitment techniques were employed. Newspaper ads and announcements to nonprofit organizations and major employment centers were circulated throughout the northern Richmond area.

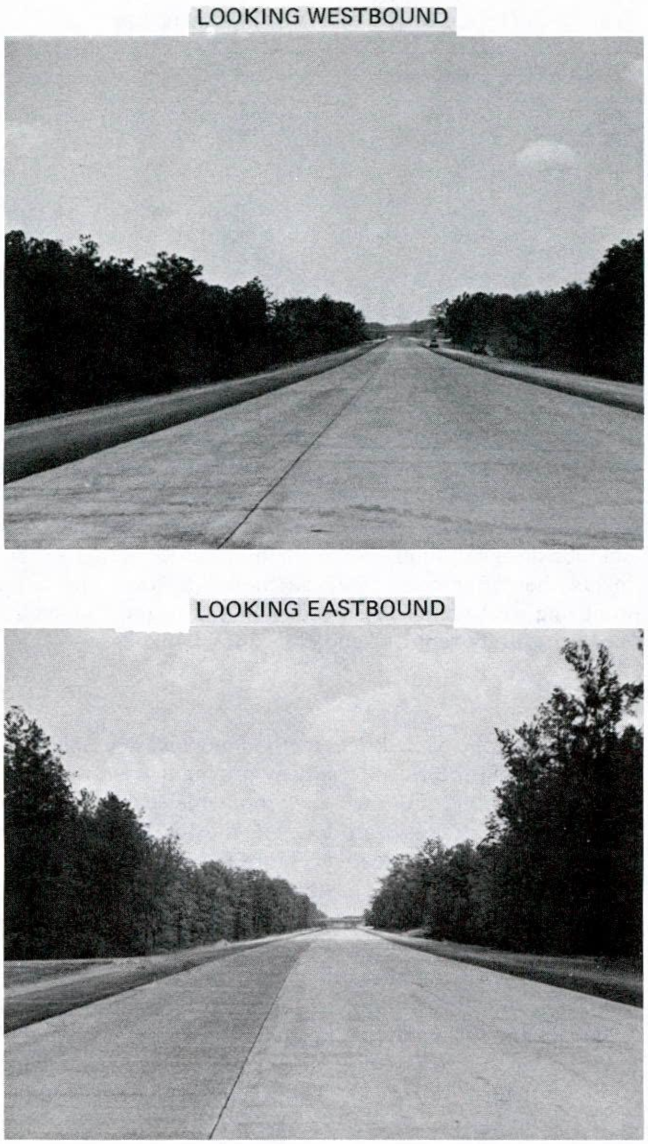


Figure F-1. Pictures of the test site I-295 near Richmond, Va.

A central-number answering service took calls. The research team returned each call and made a specific test appointment. The spectrum of age and sex characteristics found in the driving population was well represented in the subject pool.

Sample size was determined by assuming that the minimum difference in lane change or detection distance to be of interest was 300 ft. Using variance from the Project 17-4 studies, the t-test was solved for number of subjects (N) required. The result was six subjects per group. To be conservative, an N of eight was selected as the sample size for all groups.

Instrumented Car

A data collection system was required which could function in both Step 1 and Step 2 testing. A portable instrumentation package based on a programmable microcard data processor and a small printing calculator was developed, pretested, and calibrated. Distance was measured by counting the number of speedometer cable revolutions. Because distance was measured by noting start and end points along the test course, it was important that the experimenter could accurately and reliably push the appropriate button. To test this, a 1-mile course was walked off with a measuring wheel on a local street. The instrumented car was driven up and down the check mile three times (a total of six runs). The experimenter pushed a start and stop button as the end points were passed. The results of the runs were that the number of revolutions per mile was identical for all runs; therefore, the measurements were accurate and reliable.

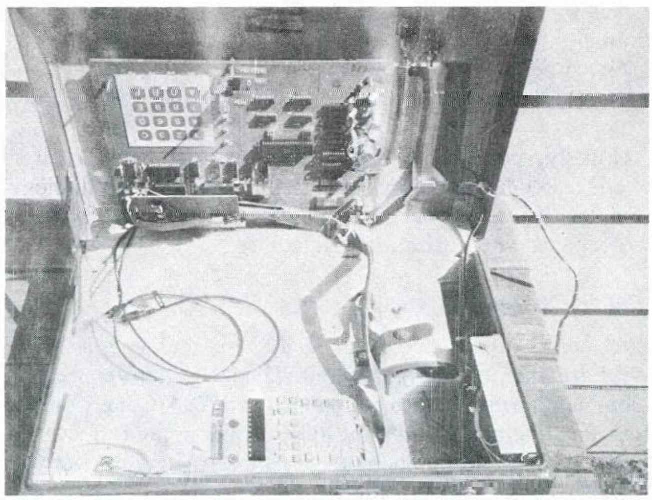
The instrumentation package shown in Figure F-2 was installed in a 1979 Ford LTD station wagon for the first three experiments, and in a 1981 Ford Escort station wagon for the remaining tests. In Step 1, the instrumentation recorded two button pushes for up to six subjects per test run. The experimenter pushed a button at the first device of the taper so detection and recognition distances could be calculated.

For Step 2 testing the data processor was modified to record speed in addition to button pushes. Recalibration tests were conducted after the reprogramming. All testing was conducted with low beam headlights.

Given this general background, the method and results for Step 1 and Step 2 testing can be discussed.

STEP 1 TESTING

The purpose of this series of experiments was to determine the optimum values for several cone and tube design parameters. From the variables given in Table F-3, the reflective area, number of bands, mounting position, reflective material, and device size were selected. Four experiments (Table F-4) were designed and conducted. Specification of treatment values for each succeeding experiment was decided on the basis of results from the prior experiment. In the case of experiment 1, pilot testing suggested the values.



NOTE: Case is standard attaché case

Figure F-2. Data collection instrumentation package.

Methodology

For each experiment, between 7 and 10 subjects were driven by a 1,660-ft lane closure (660-ft taper, 1,000-ft tangent) in an instrumented car. The subjects had a push-button which they were instructed to push first when they saw something in the lane ahead. This is detection distance and does not imply that the subjects knew what they saw or if any information was conveyed. A second push indicated they could see that their travel lane was closed and they would have to change lanes. This recognition distance was the point at which subjects could decipher the lane closure information from the array.

Each push was converted to a distance, in feet, from the first device of the taper. The data were printed on paper tape after all subjects had seen one treatment.

From pretesting it was evident that there were some practice effects, therefore each group of subjects was given two practice runs. On the first drive-by, subjects looked for a sign mounted at the beginning of the taper. They pushed their buttons when they first saw the sign and again when they could read the sign. This legibility distance measure was taken for all subjects. It gives a gross indication of the comparability of subjects in terms of a standard visual task. For the second drive-by, a lane closure with cones or tubes was used.

Each experiment was conducted by driving a group of 3 or 4 subjects past an array, changing subjects, and driving the second group of 3 or 4 by the same array; and then printing the data from those two runs. As soon as the second run passsed the array, 5 helpers came from off the road and changed treatments (i.e., put on a different set of cone/tube collars or changed the size or type of device). Between runs, subjects sat in a van and were provided with coffee; between the last two runs they filled out a short questionnaire.

Fatigue and boredom began to tell on subject responses after 2 hours of testing. This meant that only 9 or 10 treatments could be tested at one time. Because most of the experiments required 18 to 20 treatments, testing was broken into two sessions on consecutive days or nights for experiments 1, 2, and 4; and weekends, for experiment 3. Subjects were not paid until an experiment was completed.

Subjects sat in the same assigned seat in the instrumented car for all trials. Data were collected and printed by seat position so that differences in responding because of seat position could be analyzed; none were found.

Subjects were distributed by age and sex within each experiment. The only category underrepresented was the 60-years-old or older group. This was a function of the subject pool available, plus the fact that the effort of constant climbing in and out of vans and cars would have been difficult for some people in this age group.

In summary, Step 1 testing took the approach of in-depth testing of a small number of subjects. Basically, subject characteristics were held relatively constant over treatments.

Experiment 1—Area of Reflectorization, Number of Bands, and Mounting Position

Treatments

A pilot study was performed that suggested there were subject response differences to five reflective collar areas on cones. Table F-5 gives the areas used and the amount of cone area covered for different size cones. Holding area constant while dividing it into two or three bands was complicated by the truncated cone shape. The derivation of band size under low and high mounting conditions is summarized in Exhibit F-1.

Table F-4. Step 1 experiment sequence.

Experiment 1
- Amount of reflectorization
- 1, 2, or 3 bands of reflectorized material
- High vs. low collar mounting position
- 28" cones, 42" tubes at night

Experiment 2
- Selected values from Experiment 1 of reflectorization, number of bands, and mounting position
- 18-, 28-, and 36-inch cones
- 18-, 28-, and 42-inch tubes
- Daytime

Experiment 3
- 3 types of reflective material
- Internally illuminated cones
- 2 colors
- Day and night
- 28-inch cones and 42-inch tubes

Experiment 4
- Verification of unanticipated findings from Experiments 1, 2, and 3
- Cones and tubes
- Night & Day

EXHIBIT F-1

DERIVATION OF COLLAR SIZES FOR MULTIPLE BANDS

Creating multiple bands while holding area constant is not a simple matter of cutting collars in halves or thirds. As you descend a cone, the girth increases and the width of the band has to shrink to maintain a constant area. Starting with the basic formula for area of a truncated cone,

$$\pi (r_1 + r_2) \sqrt{h^2 + (r_1 - r_2)^2}$$

where r_1 = radius of the base, r_2 = radius at the top, and h = vertical height, we derived the formula:

$$\text{area} = \frac{\text{top circumference + bottom circumference}}{2} \times H^1$$

where H^1 = slant side height. This was readily usable in a computer program which could take any desired reflective collar area and calculate the dimensions of one, two, or three bands of equal area. Constraints on where the collar began, e.g., 3 inches from cone top, and how far it should be from the bottom of the cone, were included in the program. Finally, the area of spaces between bands was calculated and could be controlled with the program. The program can be used with any size cone if the cone dimensions are placed in the program.

Table F-5. Percentage of cone covered by five sizes of reflective collars.

Collar Area (In.^{2})	Equivalent Single Band Collar Size in Inches	Cone Size 18"	28"	36"
69	6	26	14	10
138	10.4	53	29	20
207	14	80	43	30
276	17	-	57	40
345	19.7	-	72	50

Varying the three parameters resulted in the 18 cone treatments shown in Figure F-3. Figure F-4 shows the final 18 tube treatments. The cylindrical nature of tubes makes collar sizing a simpler process. With one exception, all bands are some multiple of a 3-in. collar. These treatments were presented in random order.

Measures

Step 1 was a form of group testing. The experimenter was driving, therefore speed was held constant. Array detection distance was the primary measure. It was supplemented by recognition distance. This is the point at which subjects could tell that the lane ahead was closed.

Results

The mean detection and recognition distances across the seven subjects are shown in Figures F-5 through F-8.

Figures F-5 and F-6 deal with cones. The one-band cone collar size, rounded to the nearest inch, is shown across the top of the first plot on each figure to serve as a referent to gauge the differences in the five areas. The most striking results are the low detection and recognition distances associated with the 6-in. collar.

These data suggest one reason the night performance of the cones in Appendix D compared unfavorably with all other devices tested: 6 in. of reflective area is far from optimum in terms of human perceptual performance.

For the other parameters varied in this experiment, high versus low mounting appeared to impact detection and recognition more as an interaction between reflective area and number of bands. Multiple bands improve performance, but only for the three larger reflective areas. This phenomenon does not appear to be a simple linear relationship; rather, a cut-off or threshold principle is evident from the data. In Figure F-5, detection distance increases rather dramatically from area 1 to area 2 to area 3, but then changes little for the larger areas in the multiple band conditions. For recognition distance a similar trend is evident. The general design concept emerging from these data appears to be that simple increases in reflective area do not guarantee increased vis-

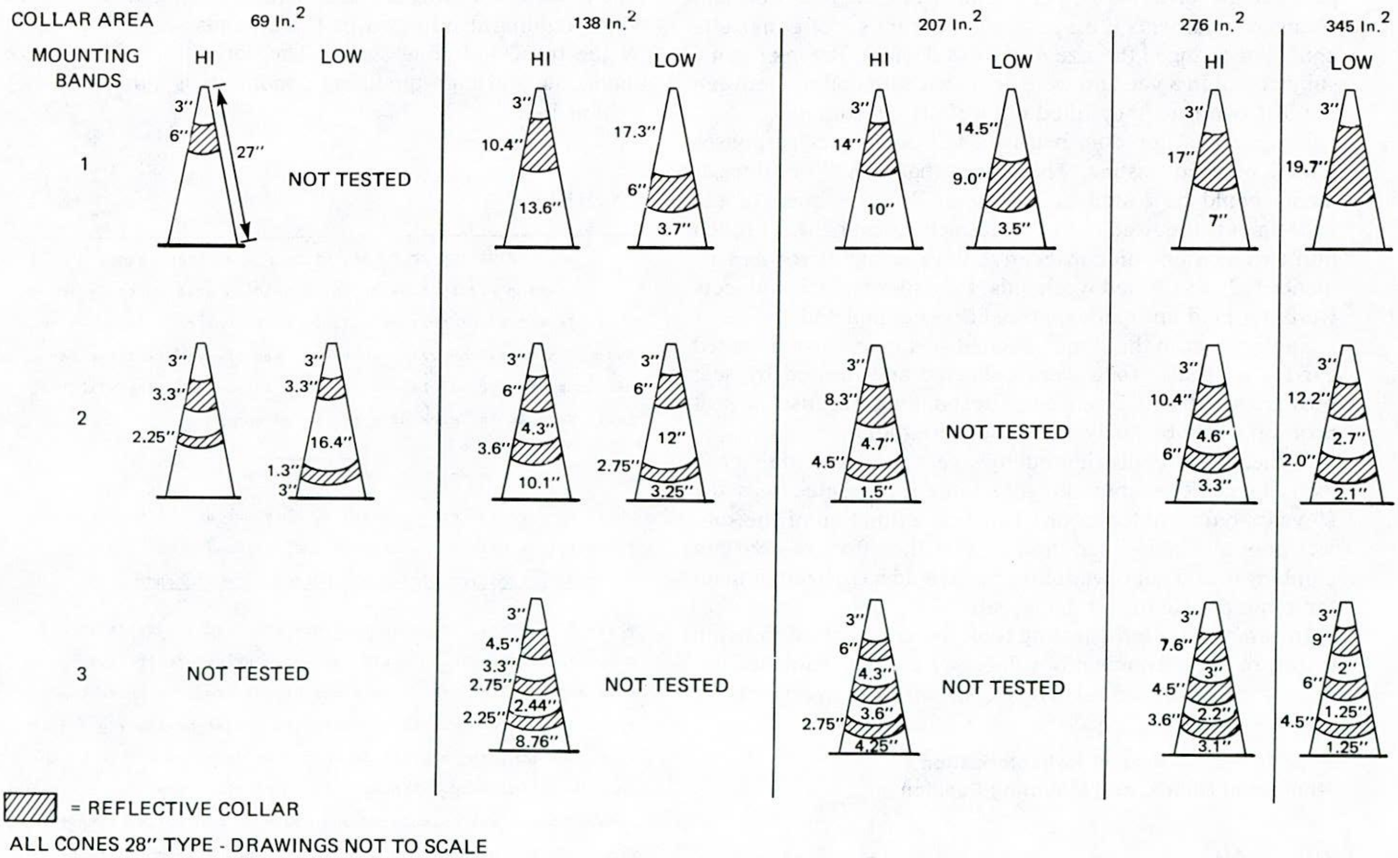


Figure F-3. Experiment 1 cone treatment conditions.

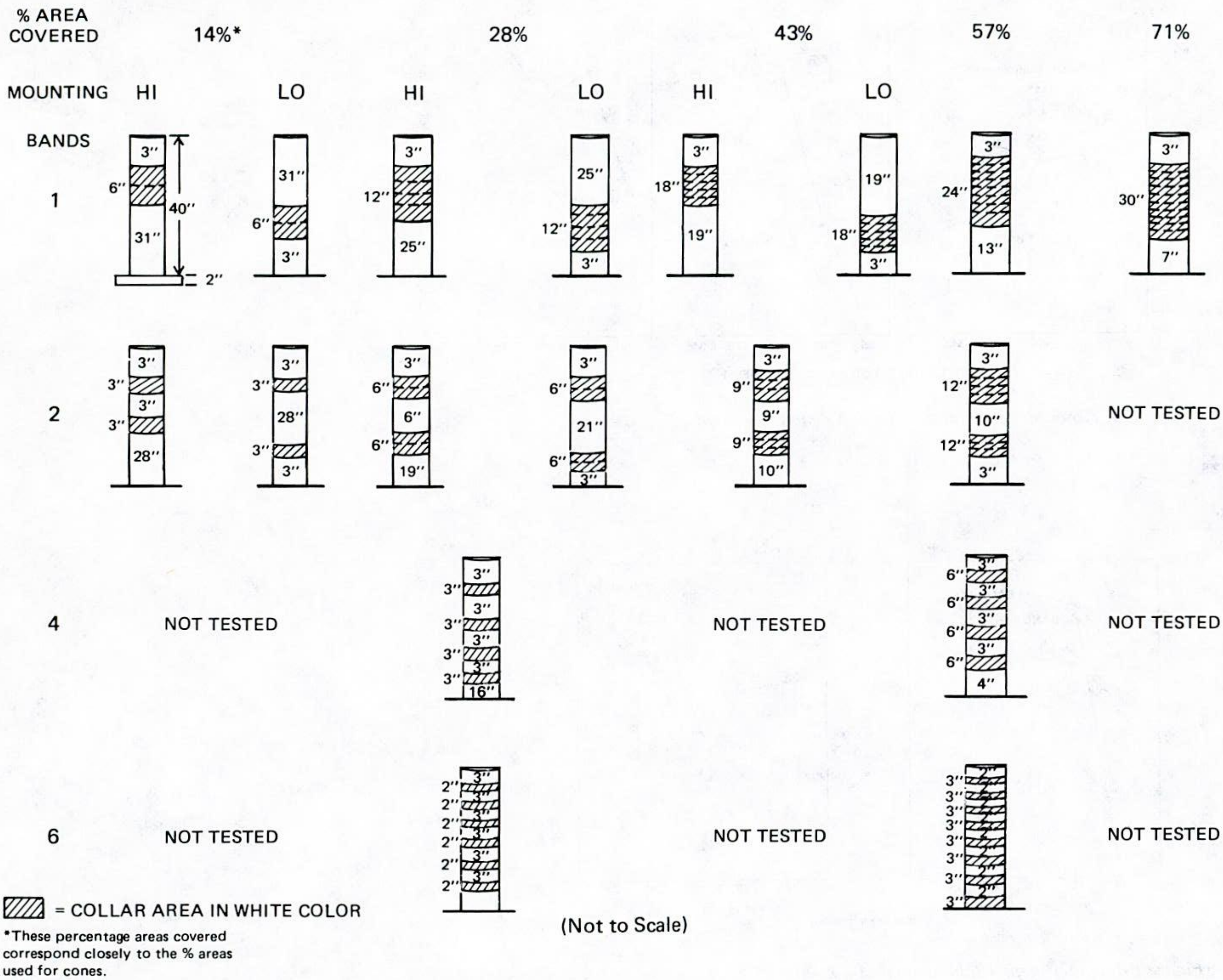


Figure F-4. Experiment 1 tube treatment conditions.

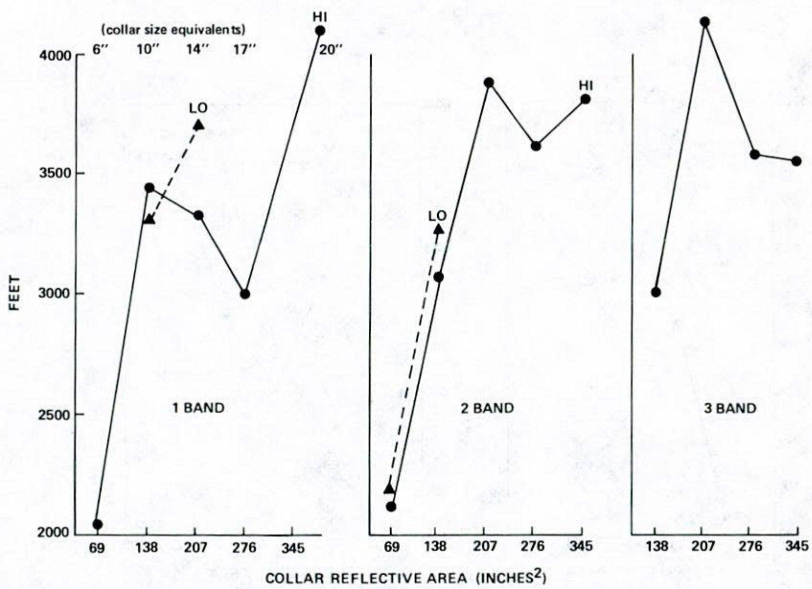


Figure F-5. Experiment 1 cone detection distance —night.

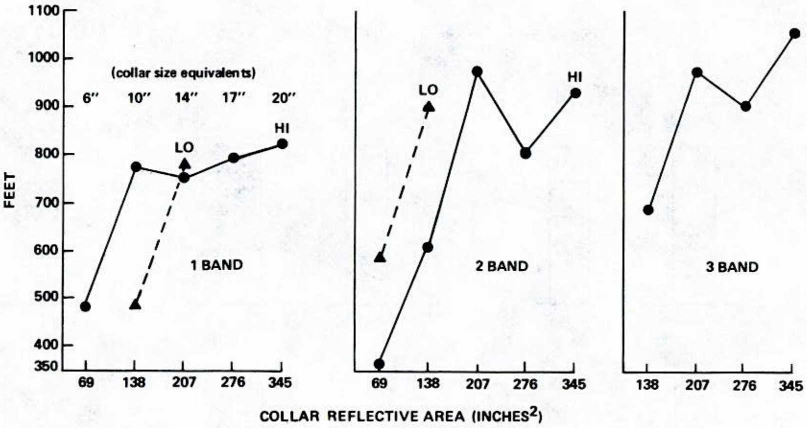


Figure F-6. Experiment 1 cone recognition distance—night.

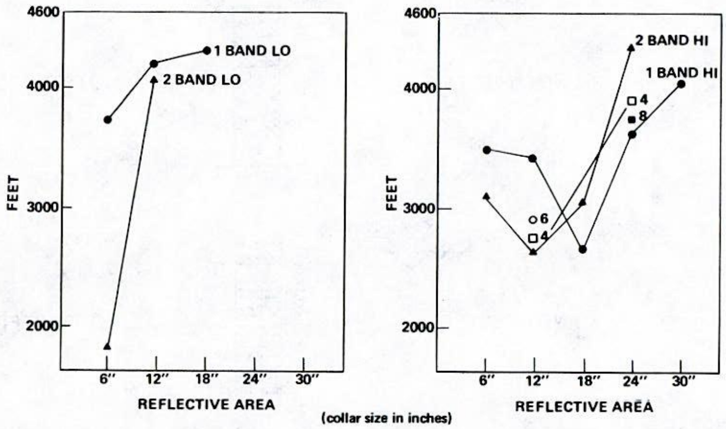


Figure F-7. Experiment 1 tube detection—night.

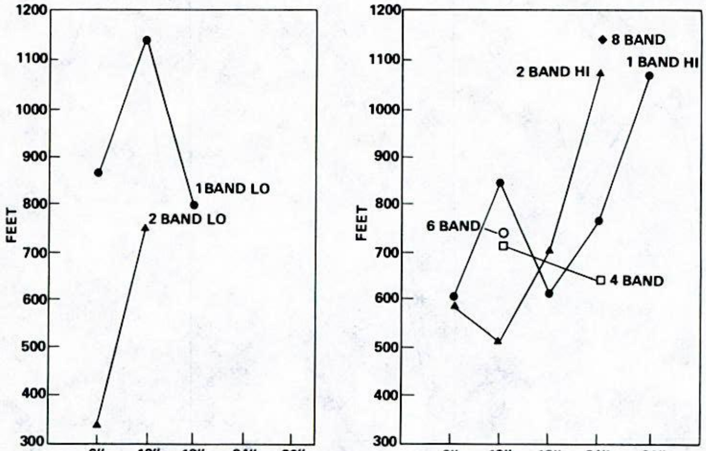


Figure F-8. Experiment 1 tube recognition—night.

ibility. Instead, only if the larger three areas are configured to spread the reflected light across the device are detection and recognition improved.

These results suggest that there are several cone collar configurations that optimize detection and recognition distance performance. Selecting those for further testing becomes a question of logistic and economic concern. Generally, the larger the reflective area and the more bands used, the greater the cost; thus, the point at which detection and recognition asymptote is probably going to be logistically optimum. Given the Figure F-5 and Figure F-6 data, this would be the area 3 (equivalent of a 14-in. collar) in 2 or 3-band configuration collars.

The data for tubes shown in Figures F-7 and F-8 are quite different. These two figures demonstrate that number of bands beyond 2 contributes little to detection or recognition. However, low versus high mounting on the 42-in. tube plays a substantial role in visibility for 6-, 12-, and 18-in. width bands. The low mounting (starting 3 in. from the bottom of the tube and extending upwards) increases the detection distance of tubes by 500 to 1,000 ft, and recognition distance by roughly 300 ft, or 25 to 33 percent.

The smaller, low-mounted collars are equally as effective as the larger, high-mounted or 6- to 8-band area collars. Economically, the smaller collars would be considered more desirable. One point should be noted about low mounting on tubes or cones: very rapid dirt accumulation may minimize any visibility benefits gained from low mounting. Research addressing this point is not within the scope of this project, but the concern should not be overlooked.

Experiment 2—Effect of Reflectorized Area, Number of Bands, and Mounting Position on Daytime Visibility

Treatments

A major design concern relative to cones and tubes was the question as to what would happen to the excellent daytime visibility characteristics of these devices when enough reflective material covered the orange to optimize nighttime visibility. To find the answer, the most effective nighttime reflectorization designs were tested in daytime conditions. The treatments used on three device sizes are given in Table F-6. The 18-in. tube condition merits some explanation. The original work plan suggested using a 60-in. tube. The survey found such a device unused on a scale to warrant consideration. In the meantime, correspondence received from Pennsylvania indicated adoption of an 18-in. tube as a divider for construction zones where two lanes are closed and the remaining two lanes operate as one lane in each direction. Although this is very different from the lane closure application, there was considerable interest in testing the 18-in. tube for a different application.

Measures

The detection and recognition distance measures were used. Eight subjects, aged 23 to 52, responded to the 20 treatments, 10 per day, over a 2-day test period.

Results

Figures F-9 and F-10 show the results of experiment 2.

Table F-6. Experiment 2 treatment summary.

Cone				Tube			
Condition	18"	28"	36"	Condition	18"	28"	42"
Baseline: no collar	✓	✓	✓	Baseline: 2 3" collars	✓	✓	✓
10" 1-band	✓	✓	✓	12" 1-band low mount	✓	✓	✓
10" 2-band low mount	✓	✓	✓	24" 2-band			✓
14" 2-band		✓	✓				
14" 3-band		✓	✓				

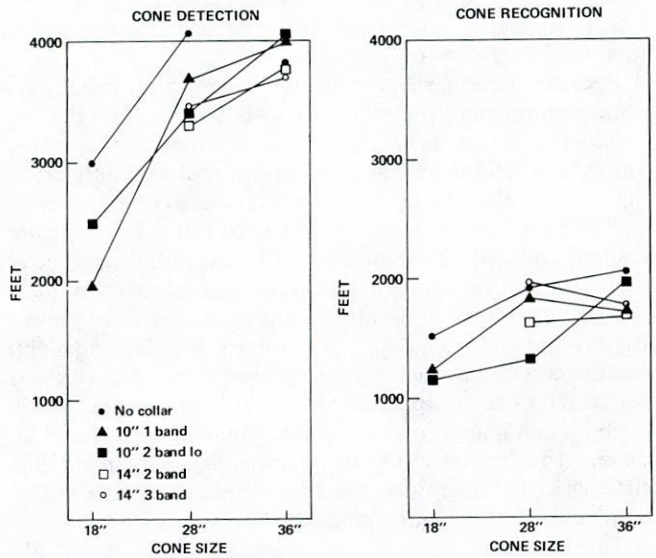


Figure F-9. Experiment 2 cones—day.

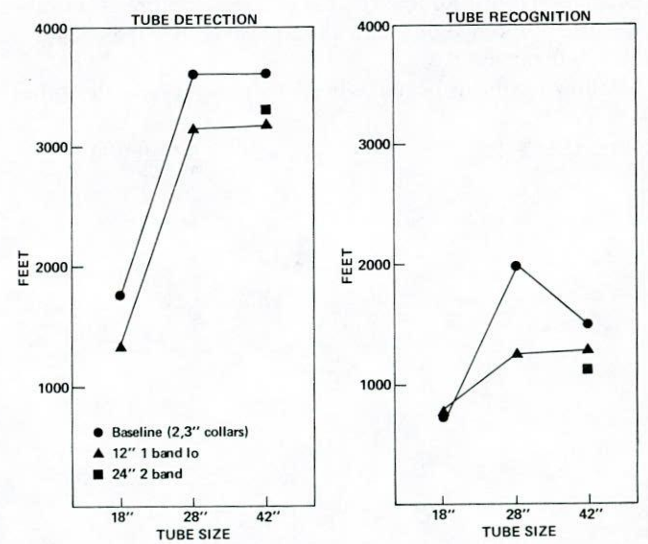


Figure F-10. Experiment 2 tubes—day.

Daytime cone detection is not affected by the collars tested on the 36-in. devices; is reduced 350 to 750 ft on the 28-in. cones; and is shortened 500 to 1,000 ft on the 18-in. cones. Obviously, the percentage of orange covered impacts daytime detection distance. Just as the impact curve reached an asymptote for amount of reflective material at night, a similar phenomenon occurs for amount of orange area in the daytime. The asymptote begins around the 28-in. cone for the collar areas used. In general, the mean detection distance differences between collar areas and configurations are quite small, 350 to 400 ft, suggesting that for the two larger cones any of the treatments tested provide relatively comparable results.

A similar finding is also true for recognition distance. Except for the 10-in., 2-band, low-mounted collar on 18-in. cones, all treatments fall within 400 ft of each other for the 28-in. and 36-in. cones. The baseline or no collar condition is not particularly superior for either the 28- or 36-in. cone. The smallest cone (18-in.) is most adversely affected by the collars, as expected, and is generally recognized 400 ft closer than the larger cones.

Because there is relatively little difference in mean daytime performance, the main decision criteria for selecting collars for further testing are mean nighttime performance, variance around the mean, and percent of data points meeting or exceeding the decision sight distance (DSD) criteria.

To select devices from experiments 1 and 2 for further testing, a procedure was devised to use mean and variance of detection and recognition measures. In essence, the mean and standard deviation (50) of each treatment were ranked for day and night conditions. The (mean, SD, day and night) treatment with the highest ranking in all four categories was selected for use in experiment 3: 207 in.^{2} of reflective area in a 3-band configuration on a 28- and 36-in. cone. For the 18-in. cone, a smaller reflective area is necessary to maintain daytime visibility, therefore 138 in.^{2} of reflective area (10-in. equivalent) in a 2-band configuration was selected.

Turning to the tube data of experiment 2 (see Fig. F-10), there is clearly no benefit from the larger collar area and no major difference between the two larger tubes in detection distance. The 18-in. tube is less visible by over 1,200 ft. Tube recognition is less affected by the different treatments or tube size, the difference between 18- and 28/42-in. tubes being in the 400-ft range.

Following the procedure used to rank cones, the tubes were also ranked. The 12-in. collar mounted low on 18-, 28-, and 42-in. tubes was selected for further use in experiment 3.

Experiment 3—Type and Color of Reflectorization

Treatments

Four treatments were tested:

1. Polycarbonate Reflexite: reflective intensity of over 2,000 at entrance angle = −4° and observation angle to = 0.1°. Using an observation angle of +0.2°, reflective intensity is 800+ up to = 16° entrance angle.
2. High Intensity Grade Scotchlite (3M): for respective measurement angles, reflective intensities are 300 and 250.
3. Combination of polycarbonate Reflexite with vinyl Reflexite used in earlier experiments. The polycarbonate was mounted high, vinyl low, on cones and tubes.
4. The foregoing materials in a yellow/amber color. Note that for the poly/vinyl combination only the poly was amber.
5. The Calspan 28-in. illuminated cone with a 6-in. reflective collar 3 in. from the top of the cone.

These treatments were used on 28-in. cones and 42-in. tubes. The white treatments were also applied to 18-in. cones and tubes.

Measures

As before, array detection and recognition were measured. Tests were conducted day and night using 8 different subjects for each illumination condition.

Results

Mean detection and recognition distances for day and night are shown in Figures F-11 and F-12. Comparing the two figures reveals much clearer evidence for one of the findings implied in Appendix D. There is little decrement in

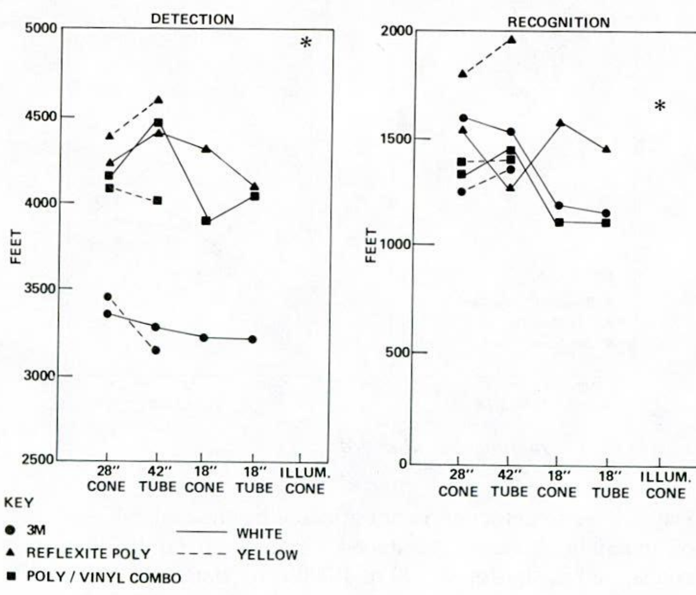


Figure F-11. Experiment 3—night.

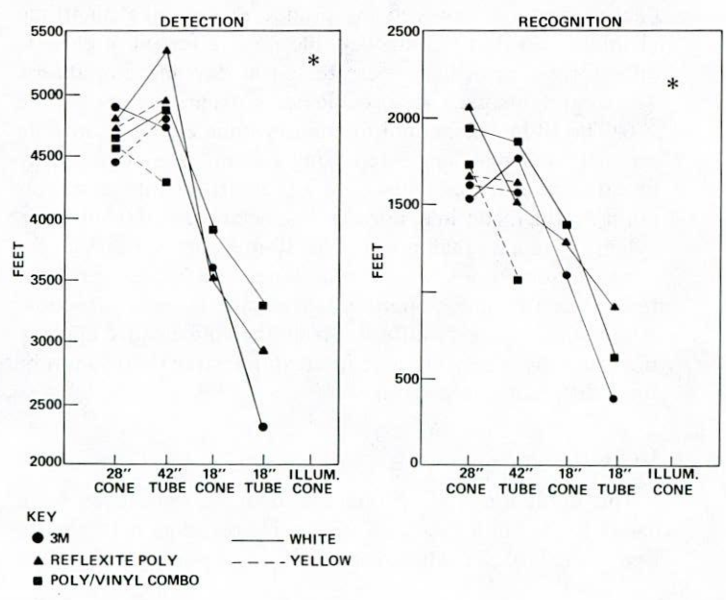


Figure F-12. Experiment 3—day.

nighttime visibility performance across device sizes shown in Figure F-11. However, there is a dramatic change in visibility as a function of device size in the daytime, as shown in Figure F-12. A similar result can be seen by comparing Figures F-5 and F-6 with Figures F-7 and F-8. The principle this illustrates is that at night, device size (and from App. D, shape) has minimal effect on visibility. The amount and type of reflective area control driver perception of channelizing devices. From experiments 1 and 2, this must be qualified by noting that configuration of the reflective material and percent of the cone or tube covered interact with reflective area.

As shown in Figure F-11, there is not more than 400 ft separating the various Reflexite collars and colors at night. There is also a very small difference between the 3M colors. However, there are differences in the 600- to 1,000-ft range between the High Intensity Scotchlite and polycarbonate and poly/vinyl collars for detection distance. When considering recognition distance, these differences disappear.

Comparing these results with the cones in experiment 1 where the Reflexite vinyl collar was used, the Reflexite poly carbonate or the poly/vinyl combination gives mean detection in the 4,000- to 4,500-ft range, while the vinyl only (see Fig. F-5) in the 4,000-ft vicinity. Recognition distance with the vinyl material (see Fig. F-6) is no better than 950 ft, but improved to the 1,500- to 1,800-ft area using 3M and polycarbonate and poly/vinyl combination collars.

The nighttime differences for tubes were less dramatic in terms of detection distance, going from 4,300 ft (see Fig. F-7) to 4,400-4,500 ft. Recognition did improve, going from 1,200 (see Fig. F-8) to the 1,500- to 1,900-ft range.

Finally, mean detection distance for the illuminated cone was around 4,900 ft, or in the same neighbrohood as the steady-burn light and approximately 400 ft above reflectorized tubes and cones. However, the mean recognition distance of 1,683 ft is not substantially different from reflectorized cone and tube recognition distances.

Daytime detection and recognition data (Fig. F-12) indicate that there are few major differences in detection or recognition distance between the various materials on the larger devices. There are greater differences for the 18-in. tubes. The illuminated cone was expected to be more visible in the daytime than the 28-in. cone with 207 in.^{2} of reflective material. This is because there was only a 6-in. "backup" collar on the illuminated cone.

Experiment 4—Unresolved Questions

Treatments

Questions posed by the experiment 3 daytime data concerned the increased magnitude of both detection and recognition distance compared to the experiment 2 data. Was it possible that the "exotic" reflective materials impact daytime visibility? Or was it possible that the two subject groups were widely divergent? A check on the second question was to compare the distribution of legibility (sign reading) scores. Experiment 2 subjects had a wider range (401 to 1,114) than experiment 3 subjects (504 to 966), but the means were almost identical: 746.75 versus 746.62. To resolve the dilemma the eight treatments listed under daytime in Table F-7 were tested. These represented replications of treatments tested in earlier experiments.

Table F-7. Experiment 4 treatments.

Day	Night
Cones	
28" 3M yellow (hi intensity), 3 band, 207 in.^{2}	28" 3 band, 207 in.^{2}, poly, yellow
28" Reflexite polycarbonate, 3 band, 207 in.^{2}	28" 2 band, 138 in.^{2}, poly, yellow
28" Reflexite vinyl, 3 band, 207 in.^{2}	28" 2 band, 138 in.^{2}, 3M, white
	28" 2 band, 138 in.^{2}, vinyl, white
Tubes	
42" poly, 12" low mount	42" 12" band, low, poly, yellow
42" poly/vinyl combination, 12" low mount	42" 12" band, high, poly, yellow
42" vinyl, 12" low mount	42" 12" band, high, 3M, white
42" 3M white, 12" high mount,	
42" poly, 12" high mount, yellow	

Measures

Half of the 8 subjects were from experiment 2 and the other half were new. This provided a comparison of subjects across the treatments in question. The same array detection and recognition measures were used day and night.

Results

Turning to the daytime results reveals cone and tube mean detection distances in the 3,100- to 3,600-ft range. Mean recognition distances varied from 1,050 to 1,600 ft. Mean detection and recognition distances were within 300–400 ft for the various treatments. Operationally and statistically there were no significant differences. These data did suggest that the shorter perception distances of experiment 2 are more representative of cone and tube performance than the very long distances of experiment 3.

Subject groups were examined in terms of the legibility measure for the three experiments, and there was no statistical difference (means were 746.75, 746.62, and 748.13, respectively). The most likely explanation of the experiment 3 finding is weather conditions. A cloudy sky tends to improve cone/tube contrast. This is because the fluorescence is converting ultraviolet, and brightness appears enhanced against a gray sky. In fact, device brightness has not changed, but the device-to-background contrast ratio increases on a cloudy day, resulting in longer detection/recognition distances.

The nighttime findings, shown in Figure F-13, suggest that low mounting on tubes is more effective than high mounting, particularly for the detection distance measure. The larger area on cones is not statistically different from the smaller area tested. And there was no difference between the white collars tested.

Step 1 Test Summary and Implications for Step 2 Testing

The findings in terms of the various tube and cone design characteristics are given in Table F-8. The last column of the table also indicates parameters of values that need to be verified or studied further in the Step 2 tests.

STEP 2 TESTING

Step 2 testing was designed to replicate, as closely as pos-

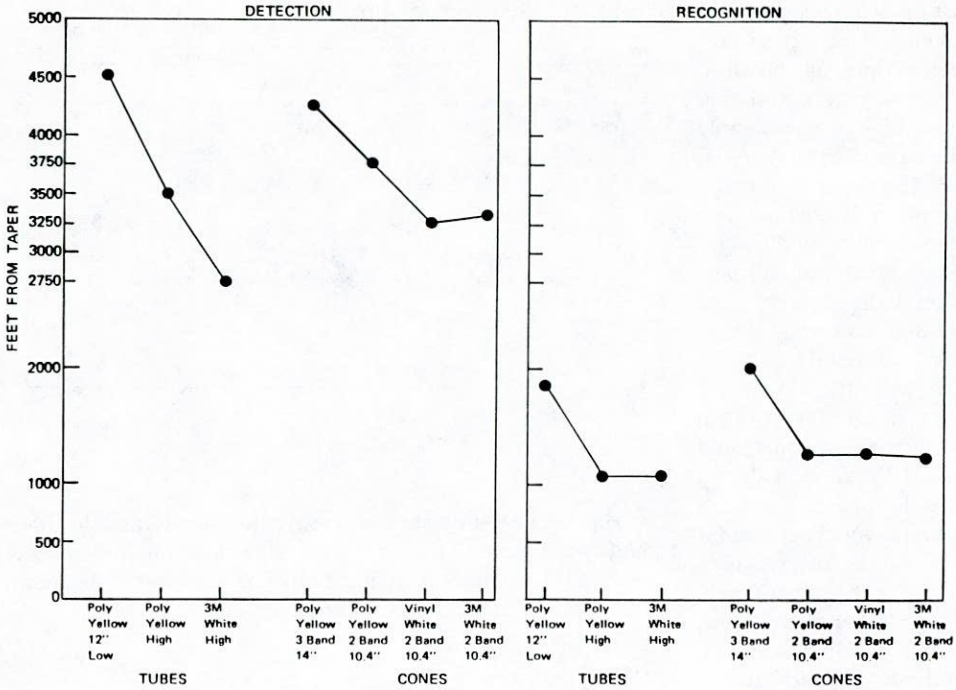


Figure F-13. Experiment 4 results—night.

Table F-8. Step 1 test results summary.

Design Parameter	Cone Result	Tube Result	Step 2 Test Implications
Size of reflective collar	207 in.^{2} consistently better than 138 in.^{2}, but not always statistically different. Either is adequate in daytime.	12" band optimum, also adequate in daytime.	Cone—resolve 138 vs. 207 in.^{2} Tube—confirm that 12" is superior to smaller 6" band.
Number of bands	3 bands appears optimum, but no statistical difference between 2 and 3 bands.	1 band appears optimum.	Cone—resolve if there is a difference between 2 and 3 bands. Tube—confirm that 1 band is superior to 2 bands.
Mounting position	Low mount more effective for 2 band condition only.	Low band optimum.	Cone—confirm interaction of low mount-2 band condition. Tube—confirm that low and high mounting are different.
Reflective material and color	Reflexite Polycarbonate yellow consistently better. No difference between other materials/colors in terms of recognition distance. 3M "high intensity consistently lower detection distance. No daytime differences.	Same as cone.	Cone and Tube—verify yellow vs. white and poly vs. other materials differences.
Device size	Amount of reflective area controls at night—device size has no effect. In daytime 18" devices have significantly lower detection/recognition distances than larger devices. Minor differences between 28" and 36".	Same as cones at night. Daytime—no differences between 28- and 42-inch tube. 18" significantly less than others.	Cone—verify similarity of 28" and 36". Tube—verify similarity of 28" and 36".

sible, the closed-field testing reported in Appendix D. The purpose of this testing was to verify and extend the Step 1 findings with a more realistic test situation and measures of effectiveness.

Methodology

The instrumentation from Step 1 was reprogrammed for use to record:

1. Mean speed through four distinct zones corresponding to the zones used in Appendix D: zone 1—5800–5000 ft prior to taper; zone 2—1100–300 ft; zone 3—660 ft during the taper; zone 4—1000 ft during the tangent.
2. Array detection: the point at which drivers reported to the experimenter that they could see something in the road but not necessarily what it was.
3. Point of lane change: distance from the beginning of the taper where drivers responded to the lane closure by moving to the interior lane (note that this may be analogous to recognition distance).
4. Legibility distance: the distance at which every driver in every experiment could read a standard sign.

A test route of 7 miles was established on I-295 near Richmond. One array was set in the eastbound direction; and another, in the westbound direction. Between the two arrays the driver had to read the standard sign (for the legibility distance measure), negotiate a median crossover, and perform a relatively quick stopping maneuver. Thus, as in the closed-field test (App. D), there were some distractor tasks for the driver. Array layout was identical to all previous closed-field tests.

Instructions from Appendix D were modified to suit the site characteristics, but were in all other respects identical. In summary, the instructional sequence was:

1. Upon subject arrival—very general greeting.
2. Enter instrumented car—general description of task.
3. Warm-up drive—above 1/4 mile, then stop.
4. Specific instructions—more specific instructions on driver task and responses.
5. Reminders and directional information en route.
6. Go to van after test drive to fill out questionnaire.
7. Receive payment ($15) and depart.

A questionnaire was given subjects to fill out after the test drive. A copy is included as Exhibit F-2. Notice that it is different from the questionnaire in Exhibit D-4. Because there were 275 previously collected (App. D) data sets, simply adding numbers would not produce new insights. Therefore, new, more useful, questions were created for this testing. More emphasis was placed on reaction to the devices seen during the drive, reactions to cones and tubes on the highway, and driver risk propensity.

Experimental Design

Like the earlier testing a factorial design was used, in which each treatment was seen by 8 subjects, and was tested day and night. For analysis and interpretation purposes the treatments were grouped to form experiments testing specific hypotheses. Need for the various experiments was identified in Step 1 testing (see Table F-8). Table F-9 summarizes the eight experiments. To establish comparability between

Table F-9. Experiments conducted in step 2 testing.

	Cones	Tubes
1. Reflective area	138 in.^{2} (10 in.) vs.. 207 in.^{2} (14 in.)	6″ vs. 12″
2. Number of bands	2 vs. 3	1 vs. 2
3. Reflective material and color	Vinyl/polycarbonate ½ Vinyl/½ polycarbonate 3M high intensity White vs. yellow/amber	Same as cones
4. Band mounting position	Hi vs. Lo	Hi vs. Lo
5. Spacing	Regular speed limit vs. ½ SL vs. double SL	Same as cones
6. Size	18 vs. 28 vs. 36 inch	28 vs. 42 inch
7. Phase I/Phase II (Bridge) Comparison	Panels, Type II Barricades 17-4 vs. 17-4(2)	
8. Unresolved Questions: a. Type III vs. Type II Sheeting	3M Type III Sheeting vs. Type II—on Type II Barricades	
b. 1 vs. 2 rail barricades	1 rail vs. 2 rail barricades with Type III sheeting	

EXHIBIT F-2

DRIVER QUESTIONNAIRE Phase II

A 1. Subject Number ________

A 2. Male ___ Female ___

A 3. Age

___ Under 21 ___ 40-60

___ 21-40 ___ Over 60

Date	________
Run #	________
Treatment Codes	
Array 1	________
Array 2	________

A 4. Driving Experience

___ Less than 1 year ___ 3-5 years

___ 1-2 years ___ More than 5 years

A 5. Type of Driving you do

___ Mostly city ___ A little city & highway both

___ Mostly highway (high speed) ___ A lot of city & highway

___ Drive infrequently

B 1. In this drive-thru, you have just driven by some sets of traffic control devices that closed off your driving lane and caused you to change your lane. Please rate the overall adequacy of these devices to advise you that your lane was closed ahead and to guide you along.

Set #1

Very Poor	Poor	Borderline	Good	Very Good
1	2	3	4	5

Set #2

Very Poor	Poor	Borderline	Good	Very Good
1	2	3	4	5

B 2. Can you note one feature about each set of devices that you liked?

Set #1 ________

Set #2 ________

B 3. Can you note one feature about each set of devices that you disliked?

Set #1 ________

Set # 2 ________

B 4. What feature about these devices best told you to change lanes?

____

B 5. Consider the devices as you first saw them, rate how easy it was for you to react and know that you had to change to another lane.

Set #1

___ Very easy ___ Not as much time as I would have liked

___ About right for me to react ___ Not enough time to react safely at all

Set #2

___ Very easy ___ Not as much time as I would have liked

___ About right for me to react ___ Not enough time to react safely at all

B 6. Consider the devices as you were driving by them.

Rate how smoothly and easily the devices guided you past the closed lane.

Set #1

___ Very easy path to follow I felt very safe ___ Not as clear as I needed to stay in my lane and pass thru

___ Good path given for me to drive thru ___ Seemed unsafe and hazardous to pass by

Set #1

___ Very easy path to follow I felt very safe ___ Not as clear as I needed to stay in my lane and pass thru

___ Good path given for me to drive thru ___ Seemed unsafe and hazardous to pass by

B 7. What changes would you make in the devices to improve what they are trying to convey?

Overall size: Larger ___ Smaller ___ Neither ___

Color(s): Colors OK ___ Change to ________

Brightness: Too bright ___ Not bright enough ___ OK as is ___

Shape: Leave as is ___ Change to ________

B 8. How do these devices affect your driving when you see them out on the highway protecting a work area?

___ Change lanes earlier

___ Change lanes later

___ Lower my speed until past them

___ Lower my speed at first, then pick it up near them

___ Keep up same speed

B 9. What do you think is the purpose of these devices around work areas? (Check all that apply)

___ Give early warning of lane closed ahead

___ Slow down traffic

___ Speed up traffic

___ Maintain speed

___ Guide traffic around work area only

___ Protect workers in work area and keep cars out

B 10. What do you think is the proper way to maneuver through a work area, regardless of devices used?

___ Be able to maintain speed to get by it quickly

___ Slow down when first sighting the zone, then pick up speed in passing the zone

___ Slow down and proceed with caution until through the area completely

B 11. Do you have any other comments or complaints about the devices you have seen or any others, as well as work zone traffic control in general?

____

____

____

____

Part C

Please respond to these statements expressing your own feelings. Use the following scale:

1. Strongly agree
2. Agree
3. Undecided
4. Disagree
5. Strongly disagree

C 1. I have the ability to control my automobile at high speeds.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 2. Because of the sturdy construction of my vehicle, I feel safe driving at any speed.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 3. I like to drive at relatively high speeds.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 4. I like to pass cars when driving at relatively high speeds on two-lane roads.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 5. When avoiding a hazard, I steer around it rather than use my brakes.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 6. I believe traffic regulations are designed for unskilled drivers.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

C 7. From time to time, I enjoy finding myself in a situation that challenges my driving skills.

1 ___ 2 ___ 3 ___ 4 ___ 5 ___

THANK YOU FOR YOUR HELP

the earlier tests and Steps 1 and 2 tests, an empirical "bridge" was created by testing several devices reported in Appendix D in the current setting.

Treatments

A total of 38 treatments were selected for testing. They were randomly assigned to array 1 or array 2. Each device tested is given in Tables F-10 and F-11.

Problems

Two problems arose during testing which constrained the final data set. The approach to array 1 involved a vertical and horizontal curve approximately 6,000 ft before the taper. Because of the upgrade, drivers rarely accelerated hard enough to get the instrumented car to cruising speed by the time speed zone 1 was entered. The result was that approach speed (zone 1) to array 1 is not representative of highway driving and those data could not be used.

Second, testing was conducted in January and several days were lost to inclement weather. Testing was slightly behind schedule when the roadway was ready to be opened for public use. Therefore, several treatments were not tested in the daytime, and subjects lost because of "no-shows" or instrumentation malfunction could not be made-up. As Table F-10 and F-11 indicate, however, sufficient data were gathered for analysis and interpretation of all experiments.

Subjects

Paid drivers were solicited using the methods described in Step 1 testing. A total of 254 usable subject data sets were collected. Table F-12 gives pertinent subject characteristics. Subjects were distributed among age groups, but the oldest

Table F-10. Step 2 test treatments.

Cones	Size (height in inches)	Reflective Material	Reflective Area (inches^2)	Number Bands	Mounting Position	Spacing	Number Subjects Completed Day	Night
Array 1	28	Illuminated	69	1	H	R	4	8
	28	3M-W	138	2	H	R	2	7
	28	Vinyl-W	138	2	H	R	6	5
	28	Vinyl-W	207	2	N/A	R	7	8
	28	3M-W	207	3	N/A	R	0	8
	28	Vinyl-W	207	3	N/A	D	8	8
	36	Vinyl-W	207	3	N/A	R	8	7
	28	Poly/Vinyl-W	207	3	N/A	R	7	8
	28	Poly-W	207	3	N/A	R	6	7
Array 2	28	Vinyl-W	138	2	L	R	7	6
	28	Vinyl-W	207	3	N/A	R	6	8
	28	Poly-Y	207	3	N/A	R	0	7
	18	Vinyl-W	207	2	N/A	R	0	7
	28	Vinyl-W	207	3	N/A	½	6	8
	36	Vinyl-W	207	3	N/A	R	8	8
	36	Vinyl-W	207	3	N/A	D	7	8
Tubes			(inches)					
Array 1	42	Vinyl-W	12	2	H	R	7	5
	42	Vinyl-W	12	2	L	R	4	8
	42	Vinyl-W	12	1	L	D	7	8
	28	Vinyl-W	12	1	H	R	0	6
	28	Vinyl-W	12	1	L	½	8	6
	28	Vinyl-W	12	2	H	R	0	8
	42	3M-W	12	1	L	R	5	8
	42	Poly-W	12	1	L	R	8	8
	42	Poly-Y	12	1	L	R	7	5
	42	Poly/Vinyl-W	12	1	L	R	7	8
Array 2	42	Poly-Y	12	1	H	R	4	8
	42	Vinyl-W	12	1	H	R	6	5
	42	Vinyl-W	12	1	L	R	7	1
	42	Vinyl-W	6	1	H	R	0	7
	28	Vinyl-W	12	1	L	R	0	8
	42	3M-Y	12	1	L	R	8	8
	28	Vinyl-W	12	1	L	D	7	8
	42	Vinyl-W	12	1	L	½	6	7

Spacing:
R = regular speed limit spacing, i.e., 55' center to center
½ = half speed limit spacing, i.e., 27.5' center to center
D = double speed limit spacing, i.e., 110' center to center

Color:
W = White
Y = Yellow or Amber

Mounting Position:
H = High (3 inches from top)
L = Low (3 inches from bottom)

Reflective Material:
Vinyl = Reflexite (currently used)
3M = 3M type III (high intensity grade)
Poly = Reflexite polycarbonate high intensity

Table F-11. Step 2 "bridge" treatments.

Treatment (All tested in Array 2)	Number Subjects Completed Day	Night
12" x 24" panel – Type II sheeting	7	8
2 rail (8" x 4" rails) – Type II barricade-Type II sheeting	8	7
2 rail barricade – Type III sheeting	7	8
1 rail barricade – Type III sheeting	7	8

Table F-12. Subject characteristics.

Characteristic	Number	Percent
Sex		
Male	132	52
Female	122	48
Age		
Under 21	42	16.5
21-40	147	57.9
40-60	48	18.9
Over 60	17	6.7
Driving Experience		
Less than 1 year	6	2.4
1-2 years	11	4.3
3-5 years	39	15.4
More than 5 years	198	78.0
Type of Driving		
Mostly city	40	15.7
Mostly highway	13	5.1
A little city & highway	84	33.1
A lot of city & highway	114	44.9
Drive infrequently	3	1.2

and youngest categories were approximately 10 percentage points lower than targeted. There is no reason to suspect this confounds results in any way, particularly because there is a standard legibility measure for all subjects. The female–male distribution (48 to 52 percent) is adequately close to the 50-50 percent target. Fewer "new" drivers than desired participated, but more subjects were experienced in city and highway driving.

The legibility distance measure is a very rough gauge of visual functioning among subjects. An analysis of variance (ANOVA) was performed comparing legibility distance across treatments and day vs. night. No differences emerged between treatments. The F-ratio from the ANOVA was 0.97 with 1 and 196 degrees of freedom ($F = 0.97$, 1/196 df). This is statistically insignificant, indicating general equivalence of the subject groups. As expected, daytime was significantly greater (0.001 level) than nighttime legibility distance ($F = 51.15$, 1/196 df).

Experimental Results—Cones

Each experiment is described separately. Only cone data are discussed first so that the continuity of the findings is not interrupted by switching between devices. The numbering and order of experiments follow that in Table F-9.

Experiment 1—Reflective Area

The hypothesis tested was: There is no difference between 138 in.^{2} and 207 in.^{2} of reflective collar area. Figure F-14 depicts the three dependent variables for day and night conditions. ANOVA results indicate:

1. No statistical difference in speed between treatments or between zones, day or night.
2. Lane change—a significant ($F = 10.16$, 1/48 df, $p < 0.01$) difference between day and night, but no statistical difference between collar sizes.
3. Detection distance—a significant day/night difference ($F = 62.9$, 1/48 df, $p < 0.001$), but no treatment difference.
4. Both treatments meet the DSD criterion.

These results indicate that when attending to the total driving task, not just looking for arrays, there is little operational difference between 138 in.^{2} and 207 in.^{2} of reflective collar area day or night. In an area where more roadside (distractor) lighting or oncoming glare is present, the larger size may be more useful; however, this hypothesis was not tested.

Considering Steps 1 and 2 results a reflective cone collar area, no less than 138 in.^{2} appears adequate, but a collar area larger than 207 in.^{2} appears unnecessary. This means the driver should see between 69 and 103.5 in.^{2} of reflective material.

Experiment 2—Number of Collar Bands

Step 1 tests found three bands preferable to two bands, and these distinctly superior to one band for anything over 138 in.^{2} Logistics and economics of collar installation and cost dictate that the smallest number of bands will be the most economical. In this experiment 2-band and 3-band configurations were compared.

Figure F-15 displays the results. ANOVA statistical findings are:

1. There is a significant day-night difference in lane change and detection distance favoring daytime.
2. Lane change—differences are not significant; however, the night difference favoring 2 bands is operationally considerable.
3. Detection distance—2-band cones had significantly greater detection distance day and night ($F = 9.48$, 1/28 df, $p < 0.01$).
4. Two-band cones met the DSD criterion day and night; 3-band cones met it only at night.
5. Speed—no differences, although 2-band cones elicited consistently (albeit slightly) lower speeds.

In day, as expected, but also at night, the 2-band outperformed the 3-band cones. Therefore, two bands appear preferable on cones.

Experiment 3—Reflective Material and Color

Five reflective materials and two colors were compared in this experiment. Figure F-16 shows the results and Table F-10 describes the treatments. All the reflective materials used are high intensity and are minimum reflective 2 or 4 materials as defined in Federal Specification L-S-300C (*26*).

Findings from the ANOVA are:

1. Speed—no difference between speed zones or materials/colors during the day.
2. Speed at night is not different between zones, but there is a difference between materials ($F = 8.18$, 5/126 df, $p < 0.01$). From Figure F-16 it is seen that poly-yellow and poly-white are the high and low extremes accounting for this result.
3. Lane change shows only a significant day–night difference ($F = 19.93$, 1/56 df, $p < 0.01$) but the difference between

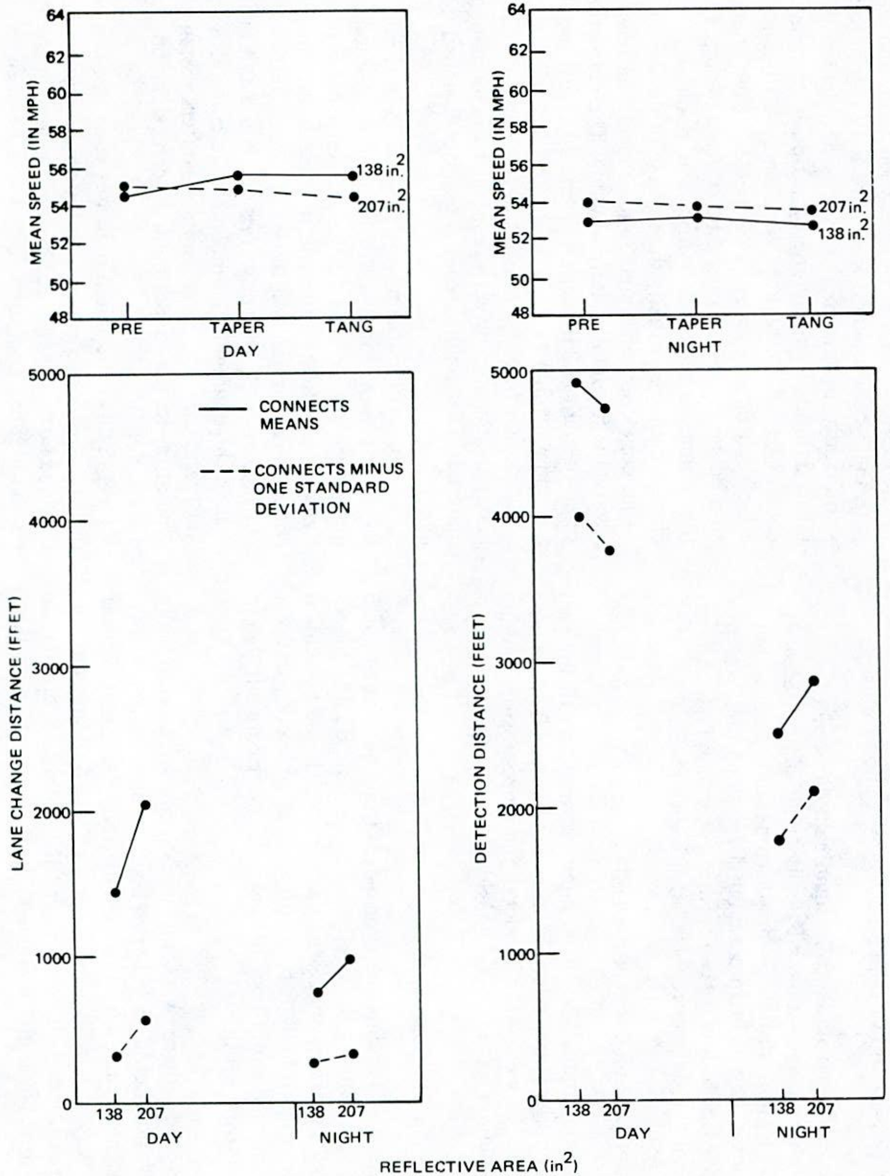


Figure F-14. Experiment 1 reflection area on cones.

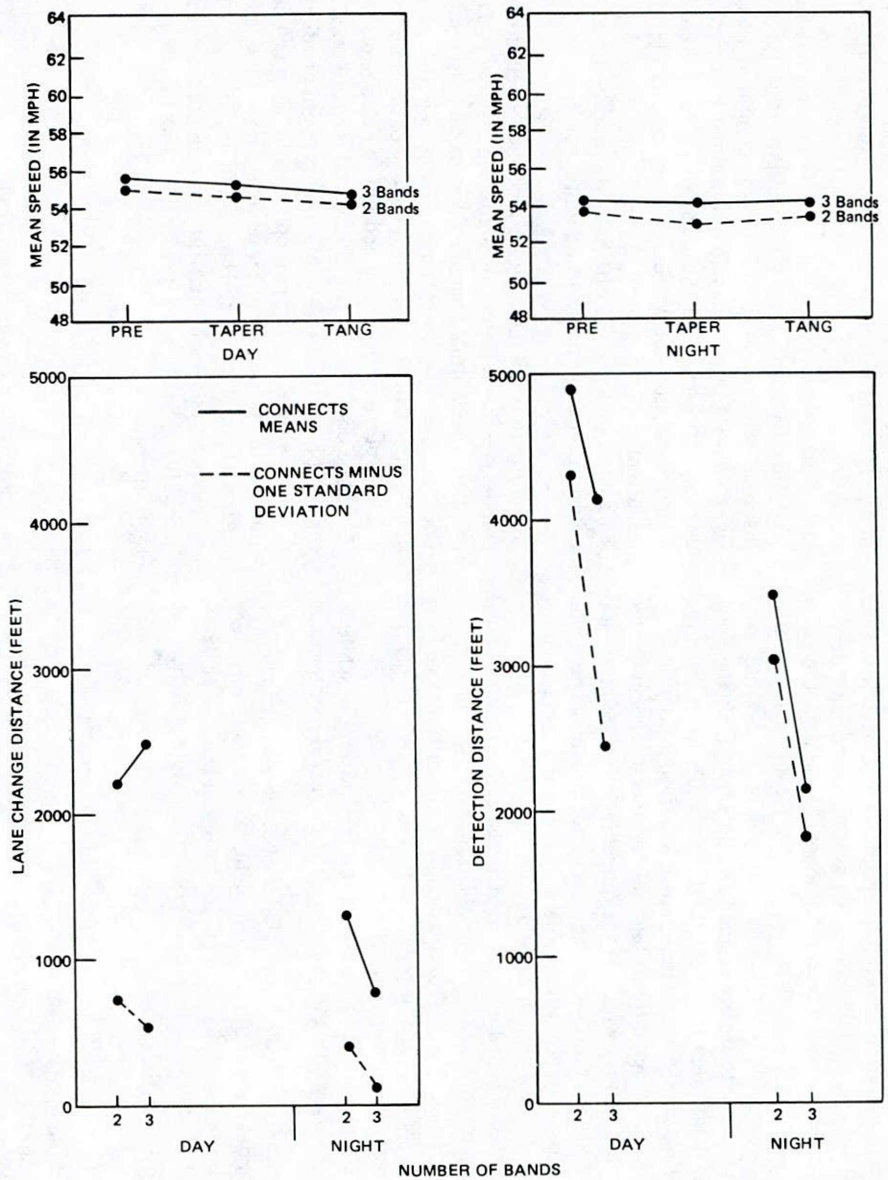


Figure F-15. Experiment 2 number of bands on cones.

reflective materials and the interaction term are both in the $p < 0.10$ and > 0.05 range, suggesting there may be differences between specific treatments. In the day, the poly-white collar is different from the other treatments ($t = 2.04$, 11 df, $p < 0.05$). At night, poly-yellow, 3M-white, and poly/vinyl-white are not statistically different. Only the poly-yellow is different ($t = 1.90$, 13 df, $p < 0.05$) from the three lowest materials; illuminated cone, vinyl, and poly-white.

4. Daytime detection is high, over 4,000 ft, except for the illuminated cone, which is inexplicably low, Legibility and driver characteristics (e.g., age) were not unusual. There was considerable overcast and this may have had a negative effect on the illuminated cone daytime distance.

5. Detection distance at night finds a significant F-ratio between treatments ($F = 6.9$, 5/39 df, $p < 0.001$). The four top materials (see Fig. F-16) are significantly different (e.g., t between 3M-white and poly/vinyl-white = 2.81, 13 df, $p < 0.01$) from the lower two.

6. All treatments at night met the DSD criterion, while in the day poly-white and poly/vinyl/white met the criterion.

In terms of reflective material, the polycarbonate in yellow is the most consistently high at night. All six materials meet the decision sight distance (DSD) criterion (i.e., over 95.44 percent (2 standard deviations) of drivers detect devices at 1,000 ft or greater).

Experiment 4—Band-Mounting Position

Band-mounting position appears to affect perception of cones, but the effect was not overly strong or clear in Step 1 and clarification was desirable.

Figure F-17 shows the data. ANOVA shows that:

1. Speed—no statistically significant differences.
2. Lane change—no statistically significant differences.
3. Detection distance—no daytime differences, but a substantial day-night interaction ($F = 48.45$, 1/20 df, $p < 0.001$). At night low is seen further away than high. A t-test of the night difference was significant ($t = 1.77$, 16 df, $p < 0.05$).
4. Both treatments met the DSD criterion day and night.

Low mounting (3 in. from cone bottom) one of the two bands improves detection distance but has no effect on lane changing. However, the impact of mounting position on dirt accumulation has not been considered in this project.

Experiment 5—Cone Spacing

Appendix D findings of a consistent trend but no statistical significance among the one-half, regular, and double-speed-limit (SL) spacings suggested this variable should be studied further. Figure F-18 displays the data graphically. ANOVA supplemented with t-tests between pairs of treatments led to the following results:

1. Speed—there were no statistically or operationally significant differences between zones or spacing treatments.
2. Lane change—in the overall ANOVA, the day/night factor was marginally significant (i.e., $p > 0.05$ and < 0.10). The greater one-half speed limit (SL) distance accounts for this result. T-test also indicated that the one-half speed limit at night is significantly ($p < 0.05$) greater than the regular SL condition.
3. Both spacing ($F = 10.38$, 2/84 df) and day/night ($F = 95.4$, 1/84 df) factors were significant ($p < 0.001$) for detection distance. The one-half SL at night condition was detected significantly farther away than the other two treatments. In daytime, the one-half and regular speed limits were detection distances significantly greater than the double-speed-limit treatment.
4. At night only the one-half SL condition met the DSD criterion; in daytime all treatments met it.

Here then is statistically stronger and operationally more emphatic evidence than presented in Appendix D that the one-half speed limit spacing does impact driver behavior. Because there is no difference between the regular and double-speed-limit conditions, the use of one-half speed limit in the taper and double-speed-limit spacing in the tangent should be considered. If traffic speed is maintained, the perception of a continuous work zone is maintained. However, if speed slows, driver perception will change because so much time elapses between devices. Hypothetically, weaving in and out of the closed lane could become a problem. The exact speed at which this will occur is not known, but it is probably a function of perception and driver personality (e.g., in a hurry).

Experiment 6—Cone Size

There were few cone size differences in Step 1 and this experiment was to verify that finding.

The first comparison was between 28-in. and 36-in. cones with the 3-band collars. In Figure F-19 day performance is significantly better than night, as anticipated. The 800-ft mean difference in daytime detection is marginally significant (i.e., $t = 1.54$, 12 df, $p > 0.05$ and < 0.10), with the 36-in. cone seen farther away, as expected. Both the 28-in. and 36-in. cone means are over 4,000 ft from the taper; however, the variance around the 36-in. cone is much smaller. The lane change data are virtually the reverse of the detection result: 28-in. cones outperformed 36-in. cones. The reason for this reversal is not immediately obvious. The consistency of results for night and detection distance suggest the reversal is a random artifact.

As shown in Step 1 tests, device size is relatively immaterial at night: drivers respond to amount of reflective material. That phenomenon was also demonstrated in this experiment.

A second comparison was between 18-in. cones with two bands and 28-in. cones with 2-band, low-mounted collars. At night there was no lane change difference between any of the sizes tested. In detection terms the 18-in. and 28-in. low cones were marginally different statistically ($t = 1.67$, 11 df, $p > 0.05$ and < 0.10) but were seen over 800 ft farther away than the high mounted 28-in. and 36-in. cones. Low mounting was found earlier to make a minimal difference; thus the large separation in this experiment is consistent but somewhat unexpected.

Overall this experiment indicates cone size has no bearing on driver response at night. In the daytime the larger cone is detected farther away and has smaller performance variance, but both 28-in. and 36-in. cones can be seen over 4,000 ft

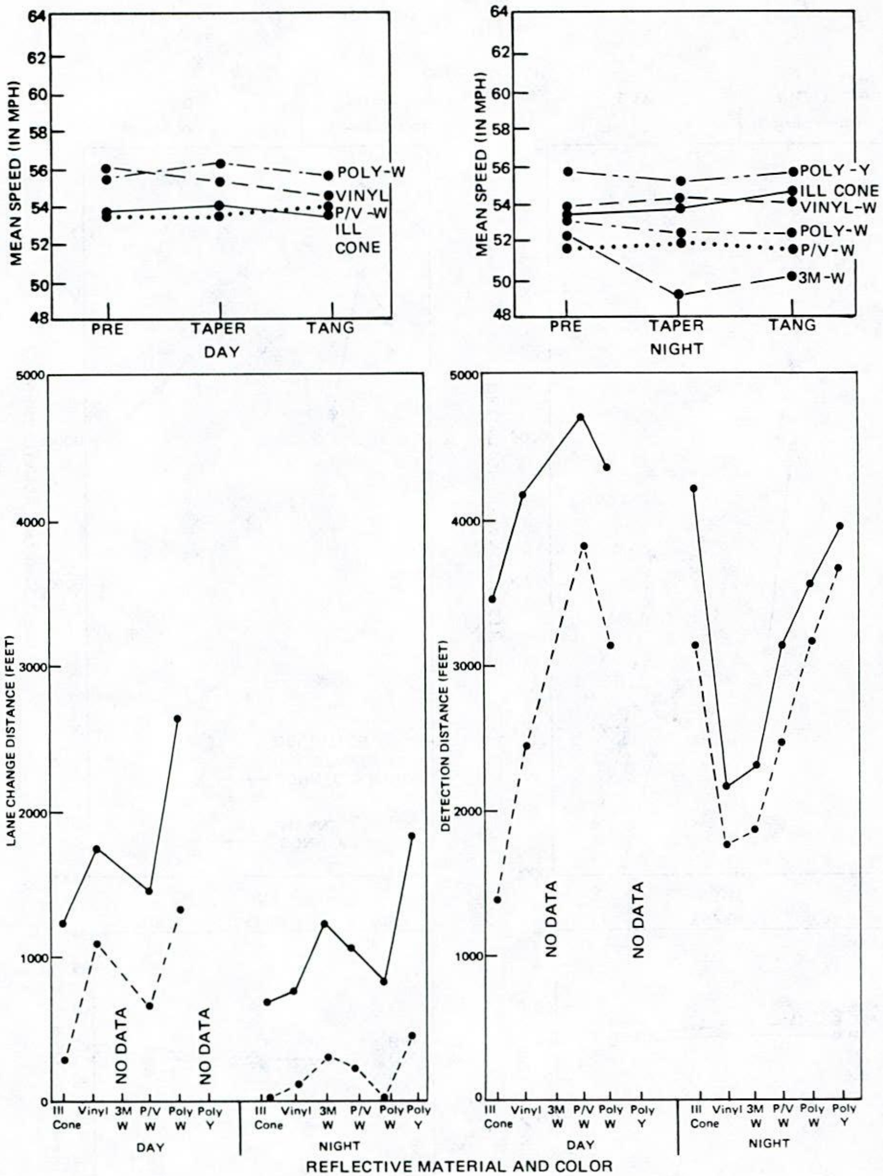


Figure F-16. Experiment 3 reflective material and color on cones.

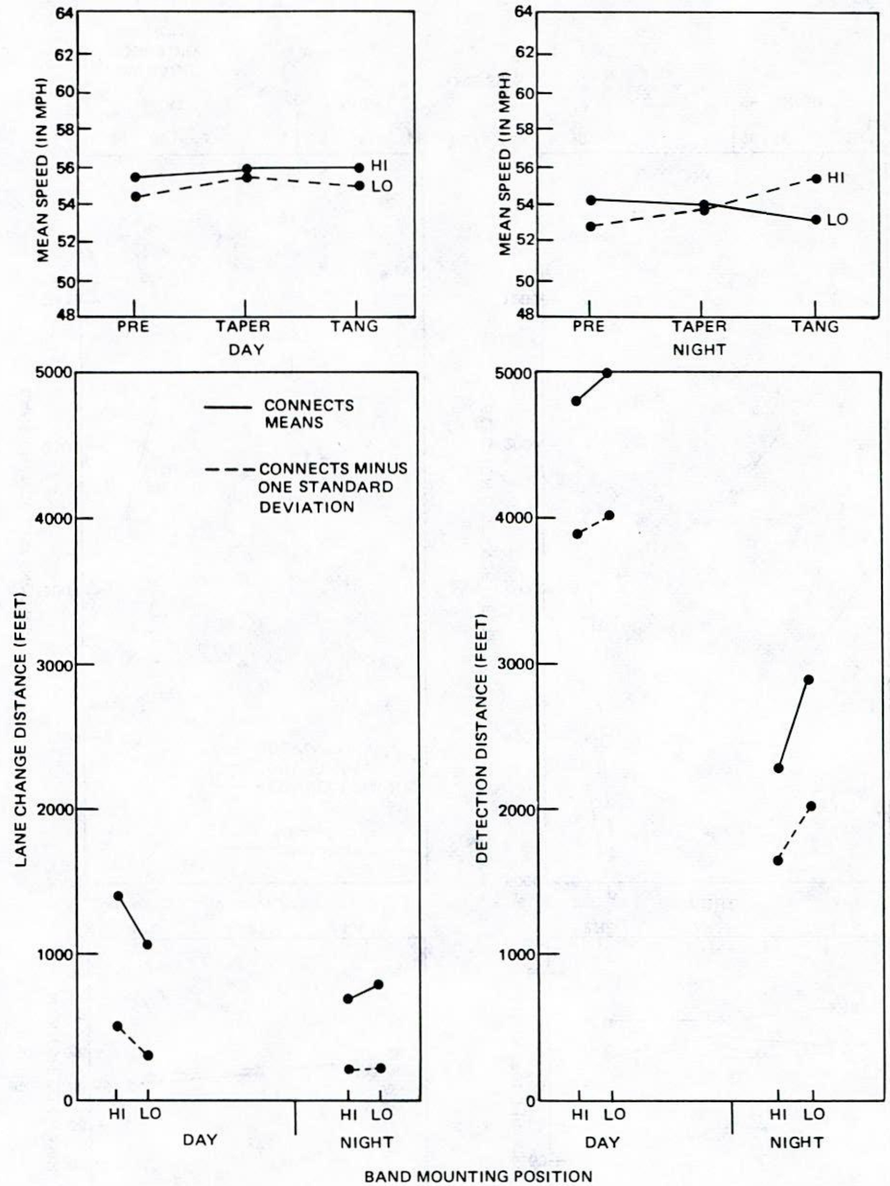


Figure F-17. Experiment 4 band mounting position on cones.

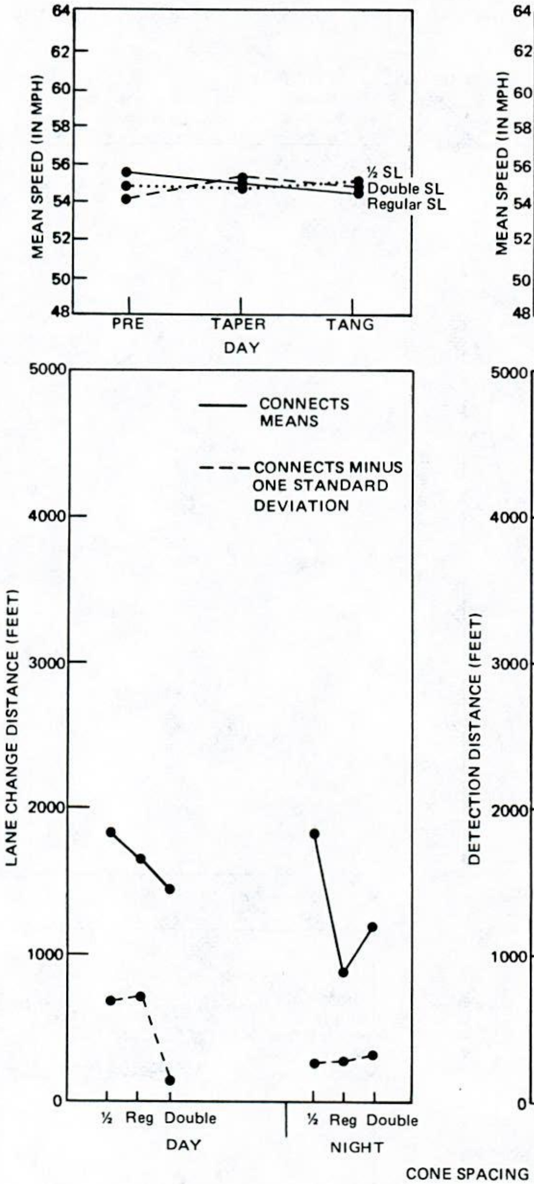


Figure F-18. Experiment 5 cone spacing.

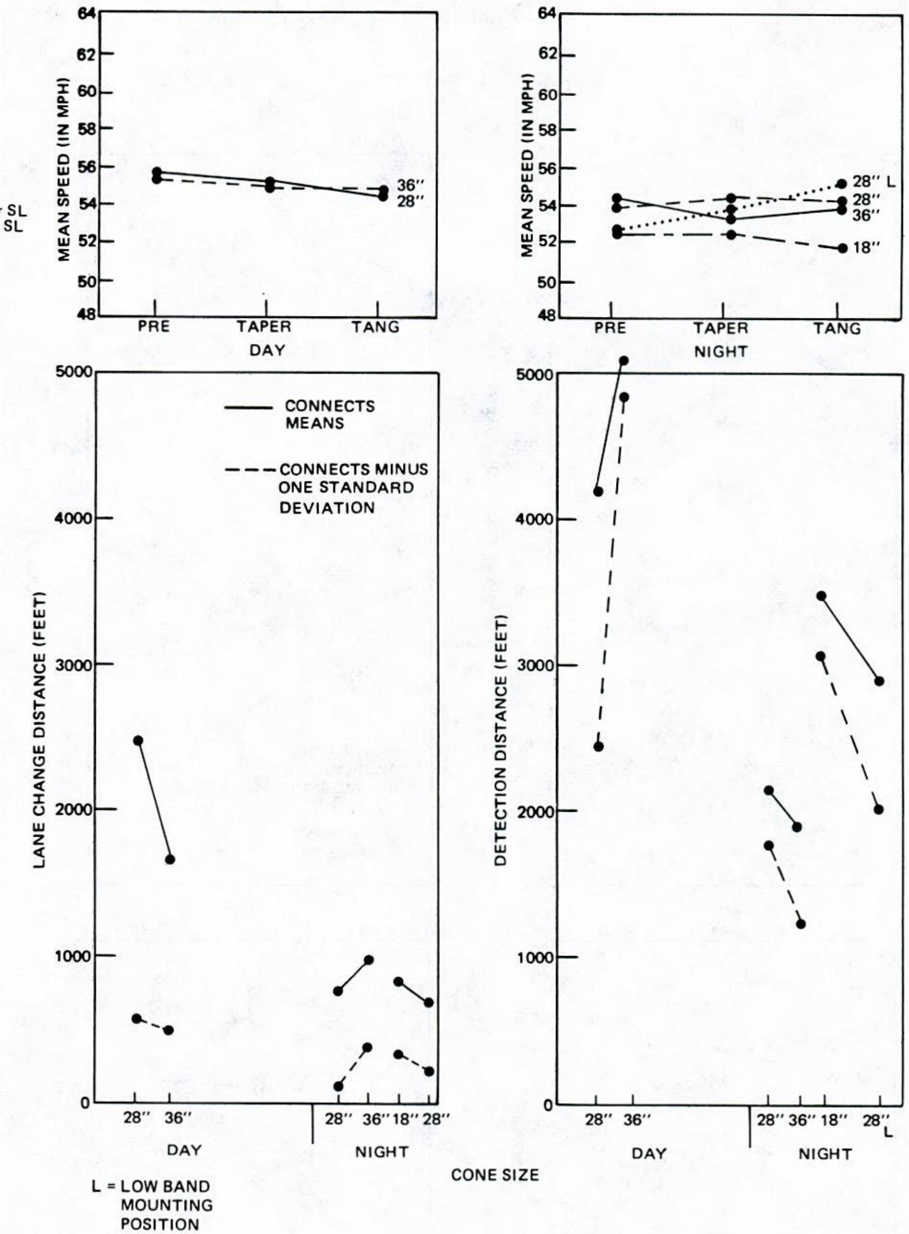


Figure F-19. Experiment 6 cone size.

away. The DSD criterion is met by the 28-, 28 (L)-, and 18-in. cones at night and the 36-in. cone in the day. Lane change is not statistically different but operationally favors the 28-in. cone. Speed differences are again inconsequential.

Experimental Results—Tubes

The data for tubes from the same six experiments are discussed in this section.

Experiment 1—Reflective Area on Tubes

From Step 1 tests it was rather clear that the 12-in. reflective collar was superior to 6-in. reflective collars. Because this represents a change from current practice, the finding was examined in Step 2.

Figure F-20 shows the results for 6-in. versus 12-in. high-mounted reflective collars on 42-in. tubes. There was no diffference in lane change. The 12-in collar was detected significantly ($t = 2.59$, 10 df, $p < 0.025$) farther away than the 6-in. collar. Both treatments met the decision sight distance (DSD) criteria. Where sight distance is over 2,500 ft, the 12-in. collar is superior; under that distance, a 6-in. collar is sufficient.

The nighttime speed difference was marginally significant ($t = 1.48$ and 1.38, 10 df, $p > 0.05$ and < 0.10) with the 6-in. collar resulting in slower speeds in taper and tangent sections.

Experiment 2—Number of Bands on Tubes

The finding that two bands on cones but one band on tubes was most effective was not readily explainable in Step 1. Step 2 attempted to replicate that finding.

Figure F-21 shows the data giving consistent replication for the higher performance of 1-band collars on tubes. Sta-

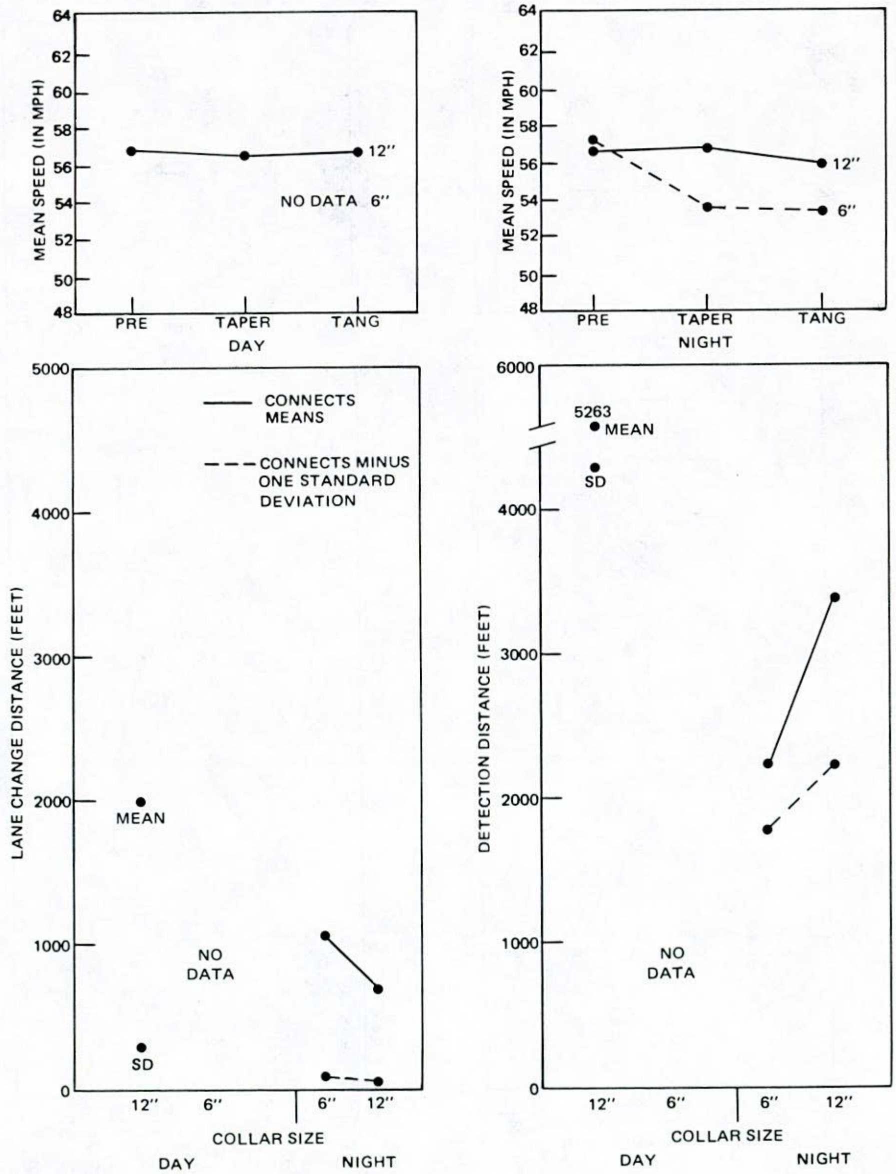


Figure F-20. Experiment 1 reflective area on tubes.

tistically, ANOVA and t-test found that even though there is wider separation in speeds than for most treatments, the overall differences were not significant. The difference between one and two bands is significant ($F = 6.73$, 1/48 df, $p < 0.05$) for point of lane change and detection distance ($F = 8.96$, 1/48 df, $p < 0.01$). Daytime detection distance is significantly greater than nighttime ($F = 67.6$, 1/48 df, $p < 0.001$). The 1-band configuration meets the DSD criterion on the 28-in. tube in the daytime; other treatments do not meet the criterion.

Experiment 3—Reflective Material and Color on Tubes

In Step 1 tests, reflective materials produced somewhat different results on cones and tubes. Further test of the impact of materials and colors, specifically on tubes, was considered important in Step 2. Two colors (white and yellow) were tested in the polycarbonate (Reflexite) and high intensity Scotchlite (3M) materials. In addition, the vinyl (Reflexite) and a combination (6 in. each) of polycarbonate and vinyl were included in the tests for a total of six treatments.

Figure F-22 shows the results. The ANOVA and t-test statistics showed that the vinyl and polycarbonate in white and yellow gave significantly ($F = 13.09$, 1/28 df, $p < 0.01$) better lane change performance during the day, but at night the differences were not significant. Detection distance in the daytime averaged over 4,500 ft for all materials except the 3M white. Those same materials readily met the decision sight distance criteria. No differences appear between materials at night, but the yellow color is significantly better than the white ($F = 21.29$, 1/28 df, $p < 0.001$) in the same material (poly and 3M). Note, however, that there is no statistical difference between the white vinyl and yellow ma-

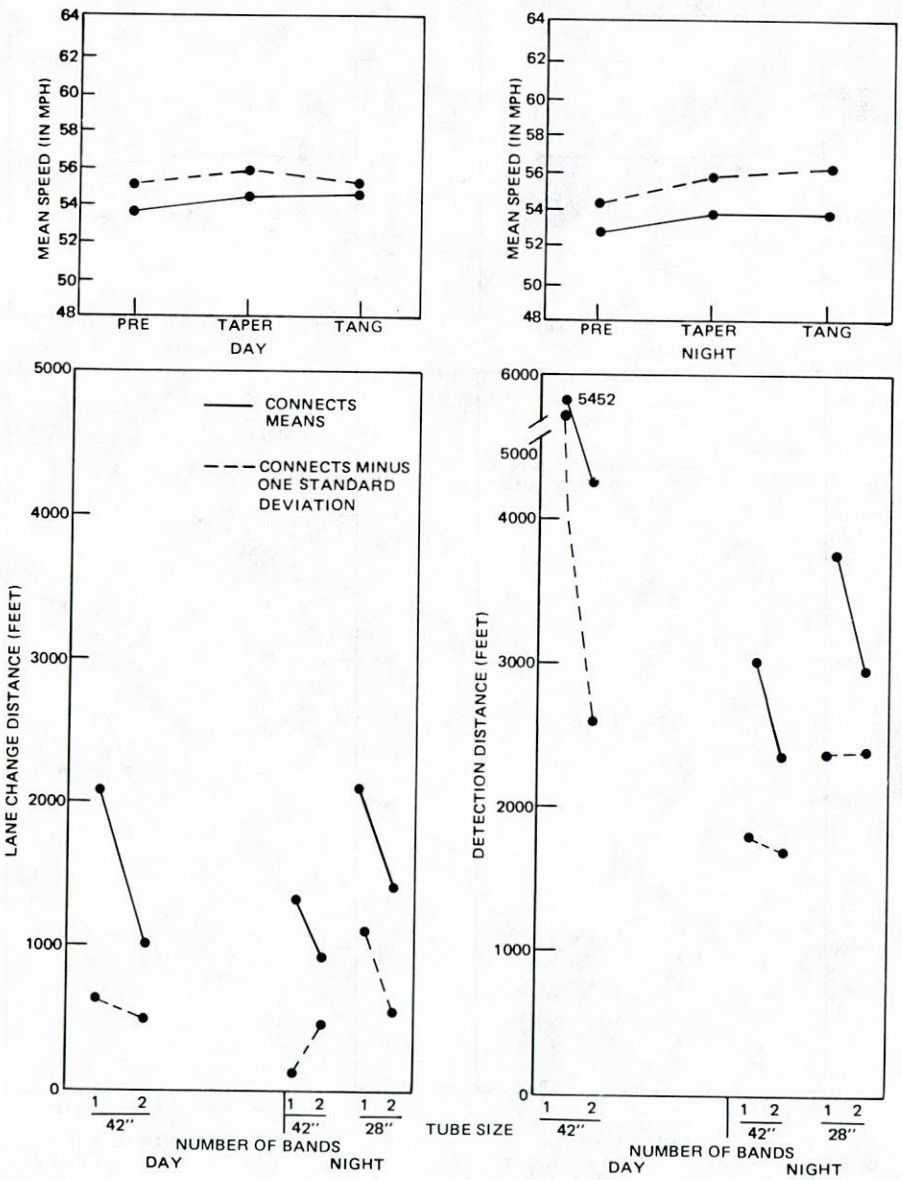


Figure F-21. Experiment 2 number of bands on tubes.

terials. The poly/vinyl combination and poly yellow do not, while the remaining treatments do, meet the DSD criterion. The change in speed across zones was not significant and no difference between colors was evident. There were significant speed differences between the materials day and night. Because the speed changes were slight through the work zone these differences do not seem to be operationally very meaningful.

Generally, the yellow color shows advantages over the white, although not as consistently as in the case of cones. In terms of reflective materials, all three (vinyl polycarbonate, and 3M) have pros and cons; none consistently outperforms the others on all measures day and night.

Experiment 4—Band Mounting Position

The Step 1 result that reflective bands placed low on the tube were superior to high-mounted bands required confirmation.

Statistically, there were no differences in mounting position in the daytime. At night, neither the differences for lane changing (t = 1.11, 38 df) nor detection distance (t = 1.31, 38 df) was significant. The only condition that did not meet the DSD criterion was the low mounting at night. Figure F-23 shows the results. No differences in speed between treatments or zones were found.

Even though the Step 1 tests found the low mounting supe-

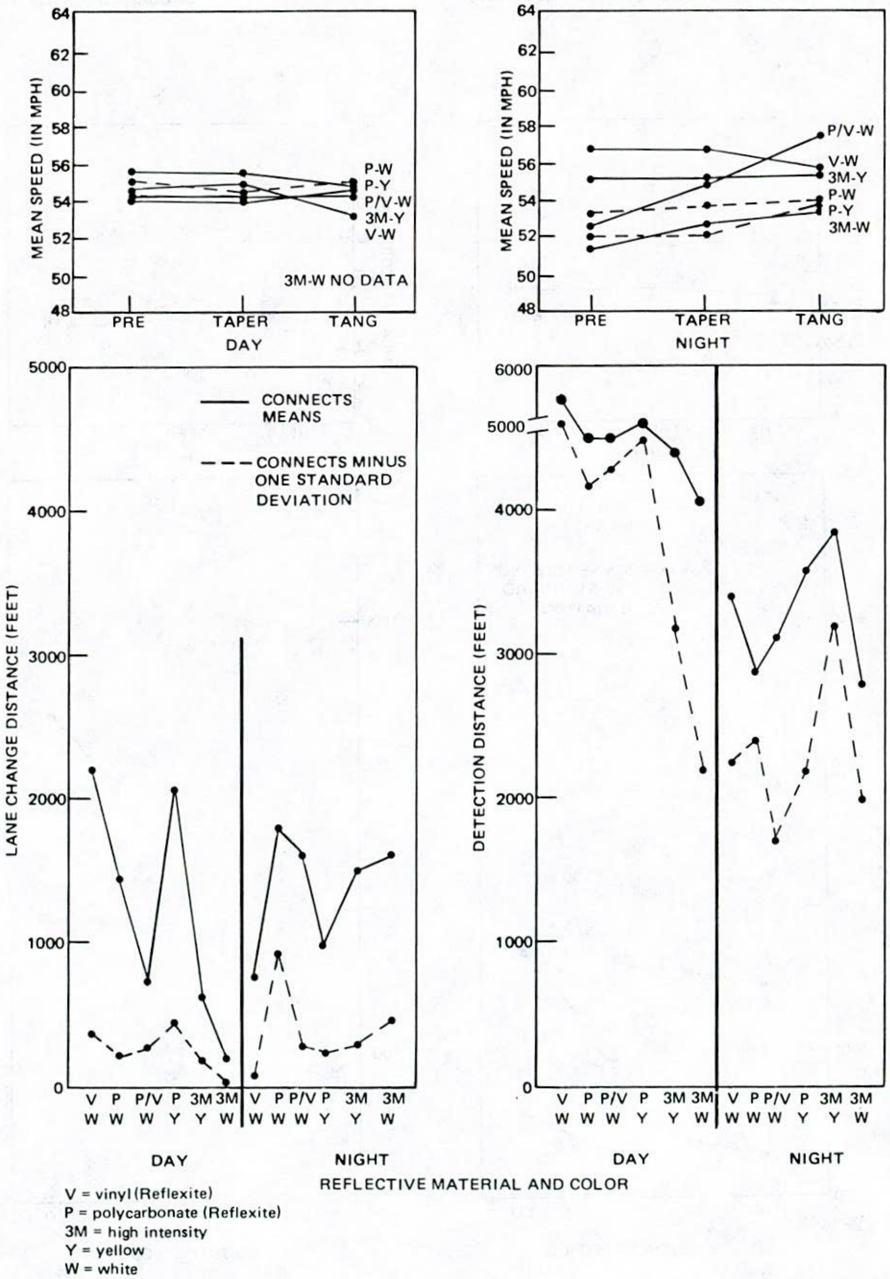


Figure F-22. Experiment 3 reflective material and color on tubes.

rior, adding additional task loading on the subjects appears to have reduced the difference to the point that the high mounting, although not seen quite as far away at night, shows less variability in detection. Thus, the high mounting seems slightly more appealing from a driver response perspective.

The low–high mounting question stems from European findings (discussion between the authors and J. Godthelp of the Institute for Perception, The Netherlands, May 1980) suggesting low mounting as an aid to detecting path curvature. Such curvature is not present in the lane closures used in this project. Further exploration of the low mounting on cones and tubes in lane diversion settings may answer this question more clearly.

Another question beyond the scope of this project is the impact of mounting position on dirt accumulation and corresponding visibility/reflectivity decrement.

Experiment 5—Tube Spacing

Regular, half, and double speed limit (SL) tube spacing (55 ft, 27.5 ft, and 110 ft, center to center) were tested using 28-in. and 42-in. tubes. Figure F-24 shows the data. ANOVA tests confirm the graphic presentation. There are no statistical or operationally significant differences between the three spacings in the daytime. All three met the DSD criterion. The lane change data at night are significantly different ($F = 67.8$, 2/42 df, $p < 0.001$), with the regular spacing being considerably separated from the half and double spacing. At night the detection differences are not statistically different. The half and regular spaced devices meet the DSD criterion, but double spaced devices do not.

In general, results of this experiment are only somewhat consistent with the tests reported in Appendix D. In the

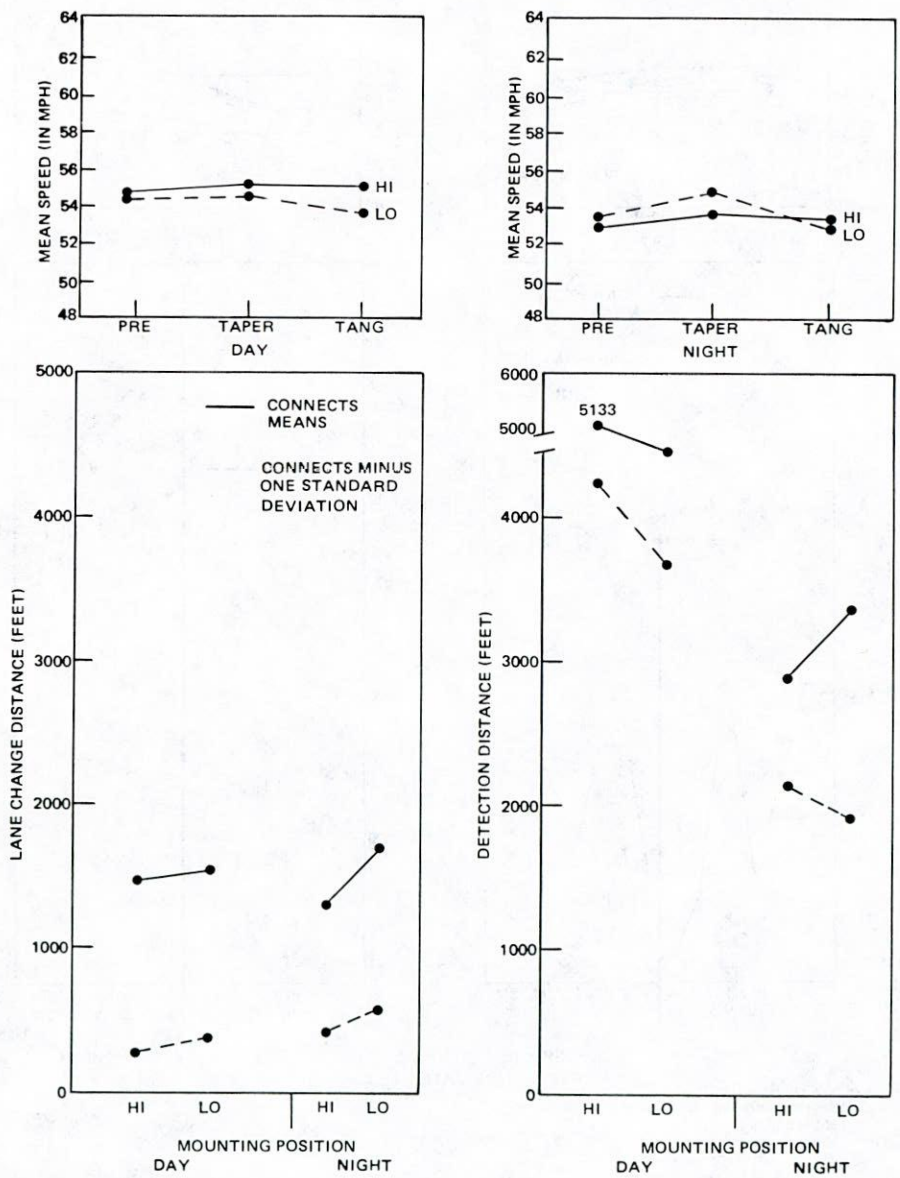


Figure F-23. Experiment 4 band mounting position on tubes.

daytime the spacing has little influence. At night the double spacing is less effective than regular spacing, as expected. The half spacing shows a slight decrement, not the hypothesized increase, compared to the other spacings. These findings are really inconclusive in terms of supporting a half in taper/double in tangent spacing scheme for tubes. However, other results do support the half in taper/double in tangent spacing for cones.

Although double spacing would not be excluded as an operational option by these data, an important constraint should be noted. All drivers had unblocked sight distance (i.e., they could see the entire array) and were travelling quite near a speed limit pace. In a traffic situation where a driver could not see the array ahead and was going much slower, the time between devices would appear long. The result could be a greater probability of drivers thinking the work zone was over and pulling into the closed lane. Even if all drivers immediately recognized the mistake and returned to the through lane, the risk to construction workers and equipment would be substantially (and unnecessarily) increased.

Experiment 6—Tube Size

Step 1 found daytime, but only slight nighttime differences between the 18-in. and 42-in. tubes. This experiment further tested the effect of device size.

Daytime findings are in the expected direction, with 42-in. tubes being seen farther (but not significantly) away and lane change being significantly ($t = 1.87$, 25 df, $p < 0.05$) greater. This is reflected in Figure F-25.

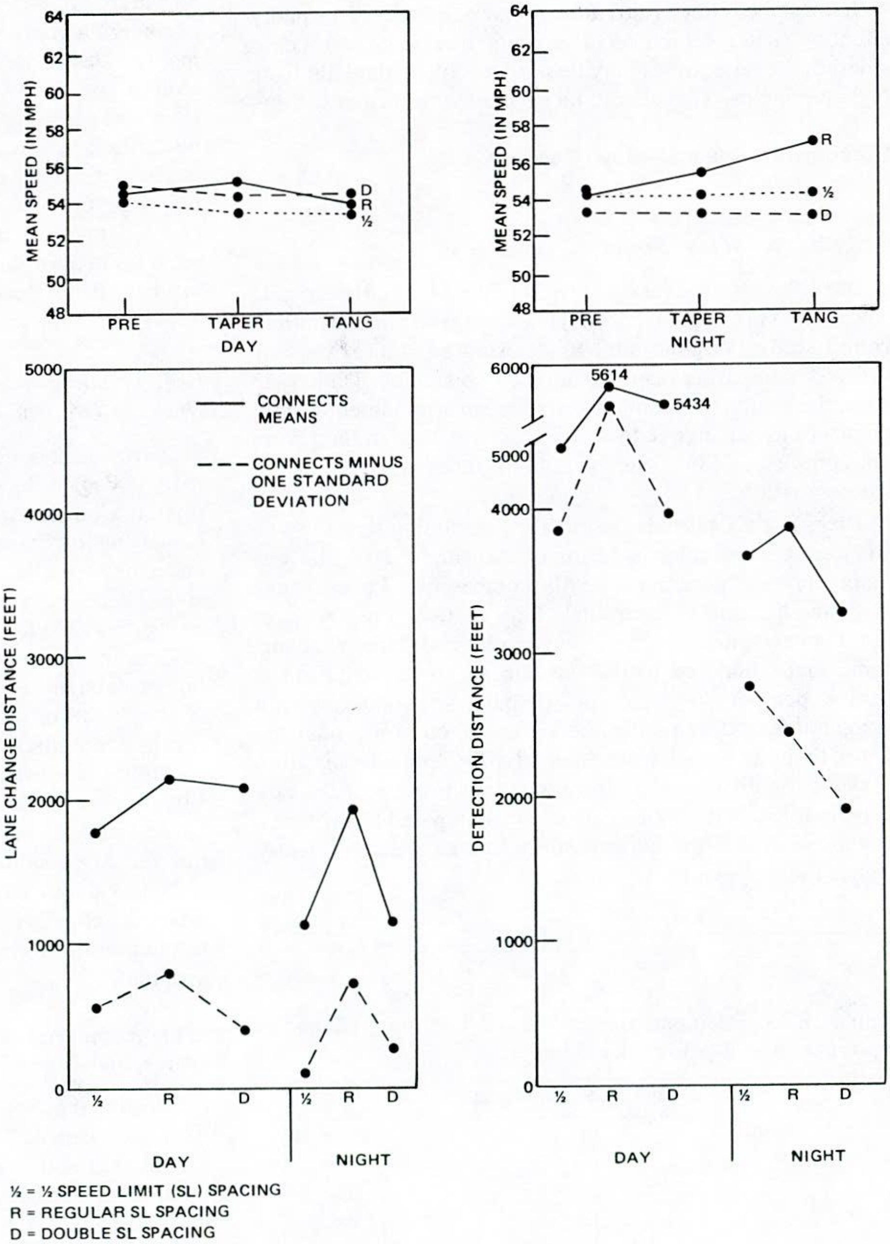


Figure F-24. Experiment 5 tube spacing data.

At night the findings are reversed. The 28-in. tubes were significantly superior to the 42-in. tubes in lane changing ($F = 12.12$, 1/60 df, $p < 0.001$). Detection distance was marginally different statistically ($F = 3.48$, 1/60 df, $p > 0.05$ and < 0.10) with the 28-in. tubes holding the advantage. Both sizes meet the DSD criterion day and night. Earlier results indicated that the reflective material and area, not device size, control driver response at night. This does not contradict that finding, but the 28-in. and 42-in. tubes were not as equal at night as expected.

Reasons for the nighttime differences are not evident. The differences between legibility distance scores were not significant. Anomalies in test subjects, weather, roadway, or device conditions were not a factor judging from the experimental log.

Considering the Step 1 and Step 2 results, the 42-in. tube is somewhat superior in the daytime but at night the two sizes with the same reflective treatment can be considered equally effective. When vehicle mix (i.e., cars, trucks, buses) is considered, the taller tubes may be more visible in daylight from higher vehicles. This should be verified with further testing.

Experimental Results—Other Tests

Experiment 7—Appendix D and Optimization Study (Bridge) Comparison

The 12″ × 24″ panel and 8″ × × 24″ Type II (2 rail) barricade were tested in (App. D) (Pennsylvania site) and in this optimization study (Virginia site) to determine if there was any basis for comparing results from the two studies. Table F-13 gives the results of a comparison of mean array detection and point of lane change data using t-tests. Although data were not complete, 28-in. cones and 42-in. tubes were compared where possible.

There is only partial support for concluding that the two sites are comparable. In terms of measures, detection distance appears more consistently comparable. Lane change is generally not comparable. The vertical curvature of the Pennsylvania site may have inhibited lane changing somewhat compared to the flat Virginia roadway. From a device perspective, theType II barricade data are not comparable and generally the optimization study data are lower than the values from Appendix D (Pennsylvania site).

Detection distance data from the two sites appear directly comparable. Lane change data can be compared but with the qualification that the current study figures are consistently higher than Appendix D values.

Table F-13. Comparison of Task 4 (App. D and optimization) data for selected devices.

	Array Detection		Lane Change	
	Day	Night	Day	Night
12"x24" Panel	✓	✓		✓
8"x24" Type II Barricade				
28" Cone	✓	✓		ND
42" Tube	✓	ND	ND	ND

✓ = No statistical difference.
ND = Non-comparable or unavailable data.

Experiment 8a. Unresolved Questions—Type II vs. Type III Reflective Sheeting

Two issues were unresolved in Appendix D and an opportunity was present to collect additional data in Step 2 testing.

The first was a comparison of Type III reflective sheeting against Type II sheeting on 2-rail 8″ × 24″ barricades. As reported in Appendix D the vertical curvature of the test site affected the outcome of the results. The flat roadway available at the Virginia site allowed a slightly different test of the two materials. The Type II material was Fasign "engineering grade" sheeting (specific intensity per unit area (SIA = 70), and the Type III was 3M high intensity sheeting (SIA = 250).

Figure F-26 shows the results. ANOVA tests indicate that daytime point of lane change and detection is not statistically different. The higher intensity sheeting resulted in lane change ($F = 8.75$, 1/28 df, $p < 0.01$) and detection ($F = 36.7$, 1/28 df, $p < 0.001$) significantly farther from the taper than the engineering grade sheeting. Both types of reflective material met the DSD criterion. There was a significant difference in overall speed day ($F = 4.24$, 1/48 df, $p < 0.05$) and night ($F = 4.61$, 1/56 df, $p < 0.05$) between the two intensities but no difference across speed zones.

These findings show that there is a difference in driver response to the two reflective intensities tested on barricades. However, the flat, straight nature of the Virginia site must be kept in mind when using these results; particularly in view of the decreased performance shown by higher intensity sheeting in Appendix D with vertical curvature.

Experiment 8b. Unresolved Questions—One- vs. Two-Rail Barricades

Barricades of one or two 8″ × 24″ rails having high intensity (SIA = 250) reflective sheeting on them were compared in this experiment. Appendix D experiments made this comparison using lower intensity (SIA = 70) sheeting and the differences between the two types of barricades were not conclusive. Therefore, supplementary data were considered useful.

Figure F-27 plots the data. ANOVA tests confirm what is evident in the graphs. Daytime lane change is the same for both treatments. Daytime detection is marginally different ($t = 1.75$, 13 df, $p < 0.10 > 0.05$). Day vs. night detection results are statistically different ($F = 16.56$ and 5.66, 1/28 df, $p < 0.05$). Two-rail device detection and lane changing are significantly farther from the taper at night. None of the speed comparisons are significantly different. Except for the one-rail day condition, the devices meet the DSD criterion.

The evidence from this experiment suggests that the additional reflective area at night has an impact on performance. However, the daytime impact is much less pronounced.

Experimental Results—Panels, Barricades, Cones, and Tubes Compared

Because the Appendix D and the current study "bridge" data (experiment 7) did not totally agree, a comparison of the most effective cones (poly-yellow, 269 in.^{2}, 3 band) and tubes (poly-yellow, 12-in. band, low mount) with other devices tested in this appendix is instructive. Figure F-28 shows the differences. Analysis of variance showed that lane changing was not different statistically. This is apparent if the

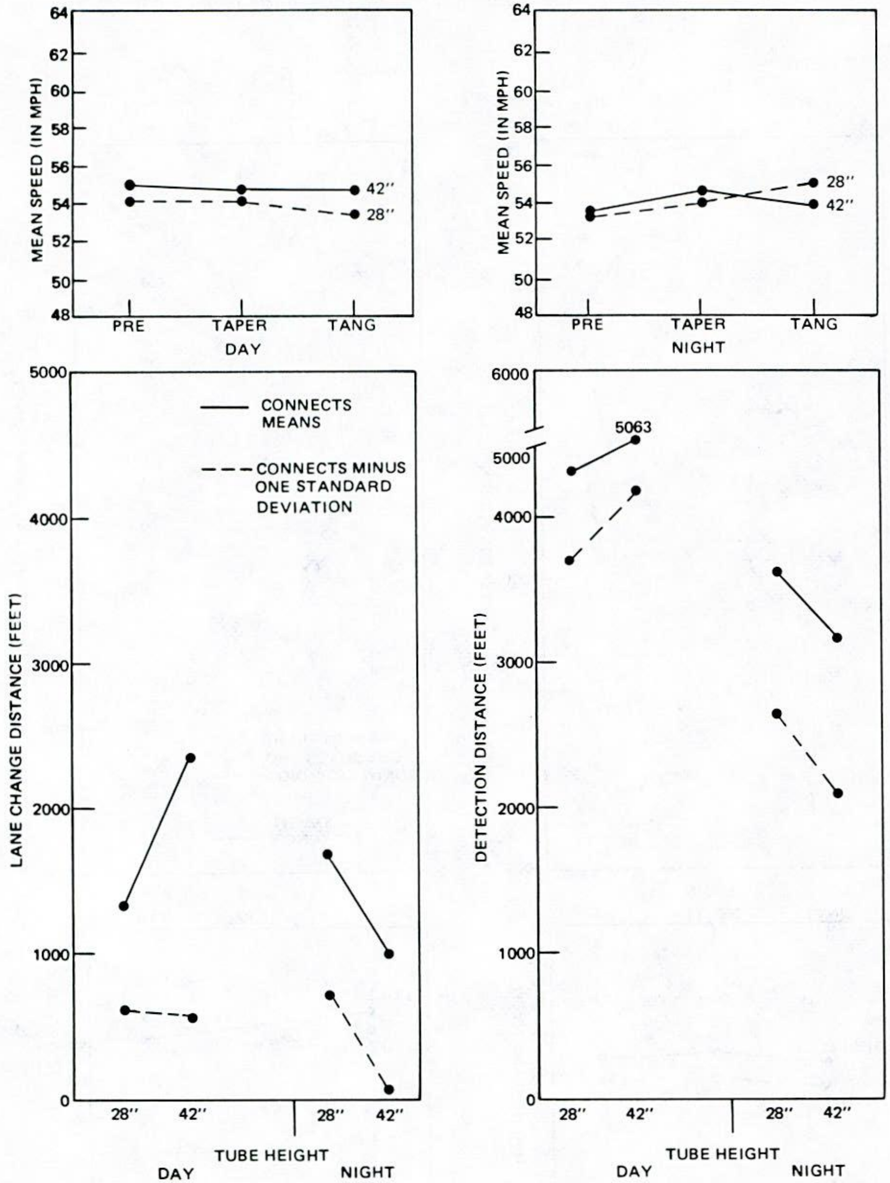


Figure F-25. Experiment 6 tube size.

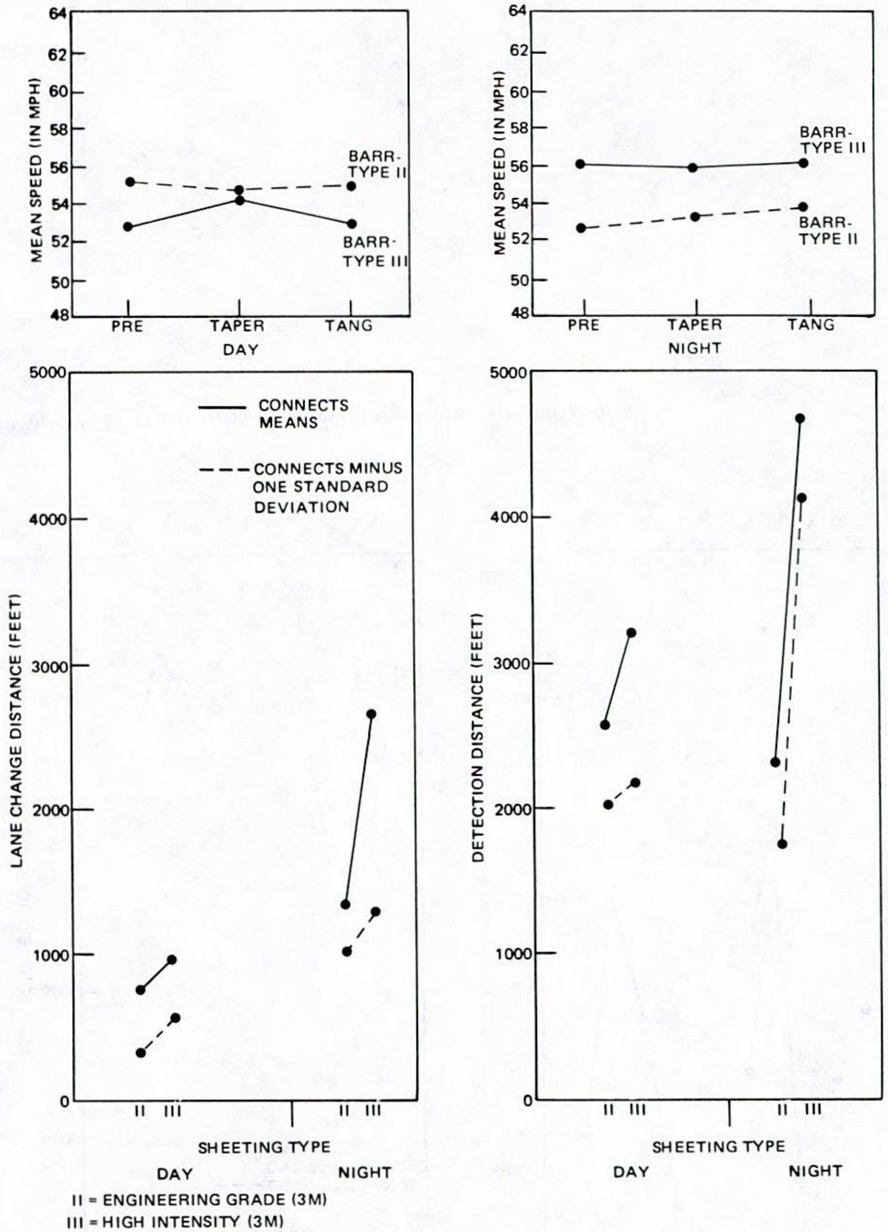


Figure F-26. Experiment 8a high intensity vs. engineering grade sheeting on barricades.

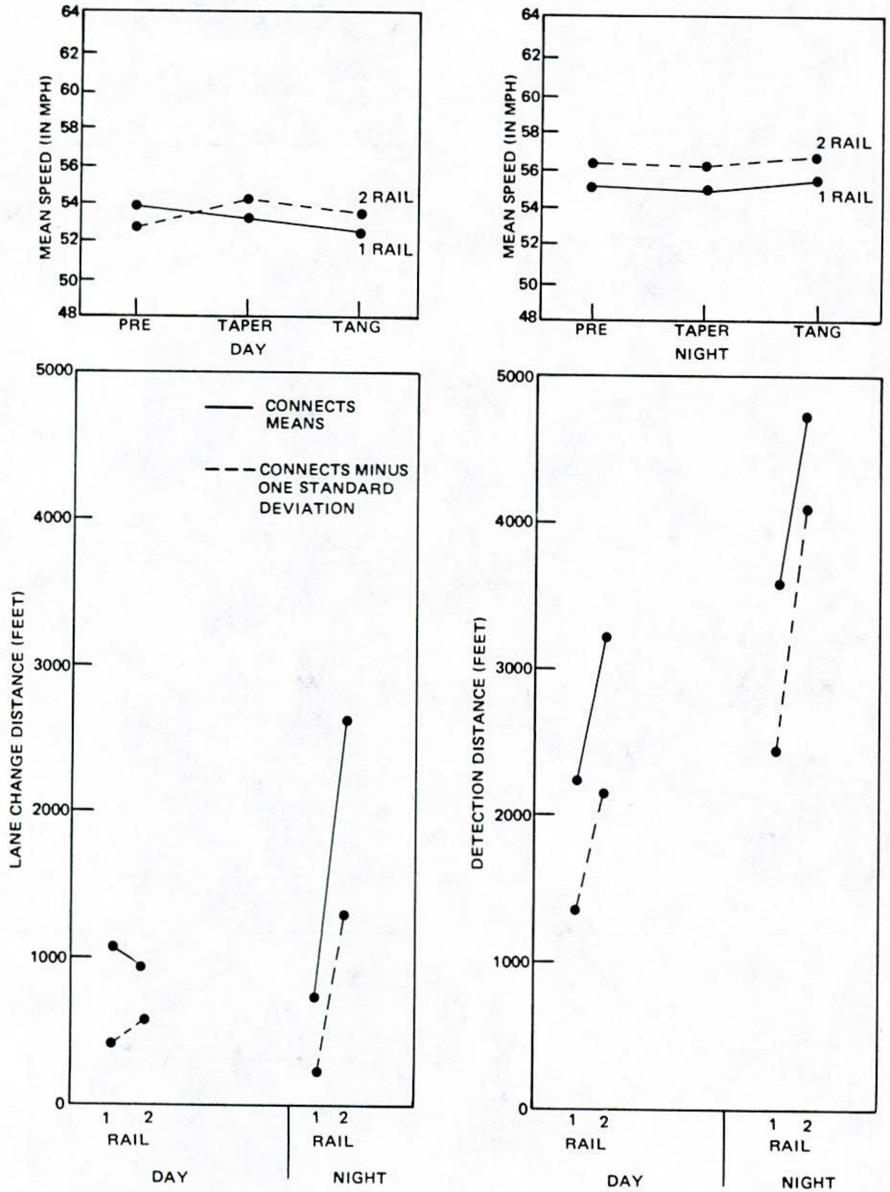


Figure F-27. Experiment 8b one-rail vs. two-rail barricades.

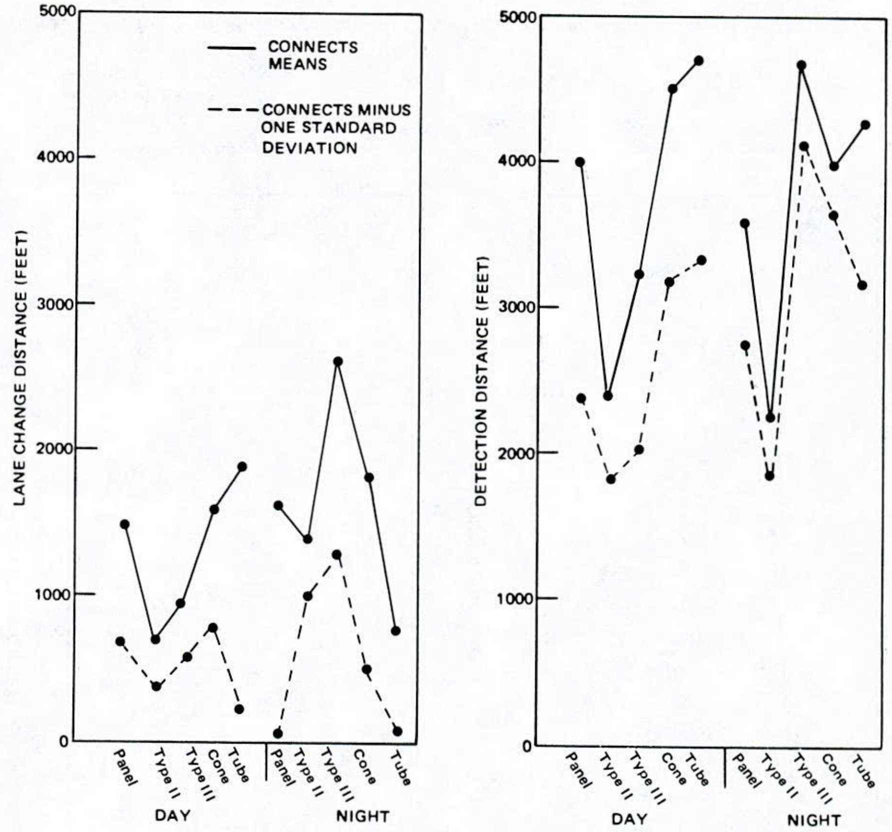


Figure F-28. Comparison of cones, tubes, barricades, and panels.

Type III reflective sheeting barricade is ignored. Then all the values, day and night, cluster.

There was a significant difference in detection distance between devices ($F = 11.65$, 4/70 df, $p < 0.001$). Although there are no day/night differences, the interaction of day/night and devices is significant ($F = 3.08$, 4/70 df, $p < 0.05$). Examining Figure F-28 shows the reason for the interaction. Cone and tube detection is very high (≅ 4,500 ft) in the day, whereas barricade detection is considerably lower. At night the barricade with Type III sheeting improves considerably, while cones and tubes decrease slightly. Panels and Type II sheeting barricades change little. All devices met the DSD criterion at night. In the day only the panels and barricade with Type III sheeting did not meet the DSD criterion.

Relative to the findings described in Appendix D, a most important difference to note is that cones and tubes are highly detectable in the daytime, and their performance remains comparatively high at night. This nighttime performance is quite superior to the cone and tube performance in Appendix D and suggests that the optimization process described in this appendix achieved the intended objective.

The devices had the same general effect on speed as found in Appendix D. Speed was significantly reduced from the before work zone (5,000–5,800 ft from taper) to the pretaper area (300–1,100 ft), but no further change occurred through the work zone. Table F-14 gives the data and t-test results. Thus cone and tube device arrays alone generally reduce mean speed in the vicinity of 1.5 mph. Once the initial speed adjustment is made, further change is slight.

Table F-14. Mean speed (mph) behavior at array 2 (pooled across devices).

Location	Day		Night	
Before (5,000-5,800 feet before taper)	56.2		56.1	
		t = 3.07 198 df p < .01		t = 2.67 198 df p < .01
Pre (300-1,00 feet)	54.7		54.7	
		NS		NS
Taper	54.8		54.1	
		NS		NS
Tangent	53.9		54.2	

NS = Not Significant

Table F-15. Summary of driver treatments ratings, at night (in percent).

Question	Rating	Cones	Tubes	Other
B_1 Overall Device Adequacy	Lo	2.2	1.5	3
	2	2.8	3.6	3
	3	12.2	9.6	8.7
	4	45.2	46.6	51.0
	Hi	37.6	38.7	34.3
B_5 Adequacy for Distant Detection	Lo	.9	0	0
	2	15.1	12.5	6.5
	3	35.3	42.6	43.5
	Hi	48.7	44.9	50
B_6 Adequacy for Guidance Through Array	Lo	.9	.8	0
	2	9.6	14.2	6.2
	3	33.9	33.1	46.9
	Hi	55.6	51.9	46.9

Experimental Results—Driver Questionnaire

Results from the questionnaire shown in Exhibit F-2 served three purposes: (1) determine subjects subjective reactions to the treatments they saw in the test; (2) compare device types; and (3) obtain driver perceptions about work zones in general. Also subject comments and ideas often shed light on quantitative data.

Reactions to Cone/Tube Treatments

Questions B1, B5, and B6 were tallied by treatment. Because the majority of responses were in the two top or "best" categories on all three questions (see Table F-15), only a very crude criterion could be used to discriminate between treatments. Therefore, any treatment which had more than two responses outside the top two ratings in each of the three questions was considered less adequate than other devices. A 28-in. cone with white high intensity sheeting (3M), 28-in. cone with three bands of vinyl sheeting, 42-in. tube with double spacing, and 42-in. tube with poly-yellow sheeting were the only devices so rated. There is no evident pattern or commonality among these devices.

The important finding is the consistently high ratings elicited by the various treatments across all devices tested.

In addition to ratings, written comments were solicited in the questionnaire. The most typical responses are noted for each question:

Question B 2—Can you note one feature about each set of devices that you liked?

Response—Visibility, brightness, reflectorization, clearness, cleanness.

Question B 3—Can you note one feature about each set of devices that you disliked?

Response—Devices placed too close to open lane, couldn't tell how many lanes were blocked; at far distance array seemed to block whole road; the 28-in. cones and tubes not high enough; need advance warning (signs, etc.); too bright, not bright enough.

Question B 4—What feature about these devices best told you to change lanes?

Response—Placement in taper, gradual taper, brightness.

Question B 7—What changes would you make in the devices to improve what they are trying to convey?

Response—Relatively few of the change options were selected.

Compare Device Types

Panels, barricades, tubes, and cones were compared. No major differences in mean rating for these devices day or night in overall adequacy, advance detection, or path guidance adequacy were found. As with the behavioral data cone and tube performance did not change at night as it did in the closed-field (App. D) study. This further confirms that the design optimization process has had a positive effect.

Driver Perceptions of Work Zones in General

In the following the percentage of Step 2 subjects checking each response is given for each question:

Question B 8—How do these devices affect your driving when you see them out on the highway protecting a work area?

Response—

Night	Day	
8.4	11.1	Change lanes earlier
32.3	26.4	Change lanes later
13.2	14.5	Lower my speed until past them
23.0	24.9	Lower my speed at first, then pick it up near them
23.1	23.1	Keep up same speed

Question B 9—What do you think is the purpose of these devices around work areas (Check all that apply)?

Response—

Night	Day	
3.3	3.5	Give early warning of lane closed ahead
15.2	14.1	Slow down traffic
28.2	30.0	Speed up traffic
25.6	25.9	Maintain speed
18.5	15.4	Guide traffic around work area *only*
9.2	11.0	Protect workers in work area and keep cars out

Question B 10—What do you think is the proper way to maneuver through a work area, regardless of devices used?

Response—

Night	Day	
9.6	10.3	Be able to maintain speed and get by it quickly
9.6	6.6	Slow down when first sighting the zone, then pick up speed in passing the zone
80.8	83.1	Slow down and proceed with caution until through the area completely

Perhaps the most interesting outcome from these questions is the divisiveness of the responses. Drivers do not have a "norm" or generally acknowledged behavioral expectation at work zones. Once the traffic engineering community decides what behavior(s) is most desirable it should be communicated to enforcement, driver improvement (licensing), driver educators, and truck/bus operators for dissemination to the driving public.

Question B 11—Do you have any other comments or complaints about the devices you have seen or any others, as well as work zone traffic control in general?

Response—Warn of rough road in construction areas; dislike flashing lights in long work zones, distracting; want more advance warning; taper should have solid barrier to protect workers.

In summary, driver opinions generally confirm the behavioral data: The devices tested in Step 2 are considered adequate by over 80 percent of drivers. In general drivers do not have a standard or generally accepted expectancy for driving behavior through a work zone. This is particularly true for speed control.

SUMMARY AND CONCLUSIONS

On the basis of the preceding experiments, several design suggestions for cones and tubes can be offered. By incorporating these suggestions in cone/tube design, driver response to these devices can be substantially improved at night without daytime decrement. Tables F-16 and F-17 summarize the various findings and state design and use guidelines based on the findings.

Several qualifying factors should be noted about these results. First, only cars were used in the closed-field testing. The effect of truck/bus eye heights on these findings is not known. Second, unique designs or modifications to tubes and cones can be readily designed (e.g., wider tubes, flat reflective panels inserted in cone or tube tops at night, light mounts, cones or tubes with one side flat) but were not within the scope of this project. Third, not all problems noted in the user survey were addressed by this project. Stability, durability, storage (stacking), and vandalism, although obviously important, were not considered.

In conclusion, the result of the Steps 1 and 2 testing is a set of design guidelines which produce cone and tube configurations that are detectable at a distance of 3,000–4,000 ft at night and 4,000–5,000 ft in the day; that meet the decision sight distance criterion; that elicit lane changing 800–1,600 ft before the taper; and after eliciting an initial speed reduction (≅2.5–3.5 percent) have minimal effects on speed from 1,100 ft prior to the taper through the tangent section.

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Table F-16. Summary of findings and design/use guidelines for cones.

Parameter	Findings	Design/Use Guidelines	Comments
Reflective Area	• Decrement in performance below 138 in.^{2} but no significant increase in performance above 207 in.^{2} • The 138 and 207 in.^{2} areas met the Decision Sight Distance (DSD) criterion. • Step 1 tests showed recognition and detection distance significantly higher for 207 in.^{2} • Step 2 test lane change and detection distance differences between 138 and 207 in.^{2} were non-significant but favored the 207 in.^{2}.	An area in the 150-200 in.^{2} range appears optimum.	This is analogous to a current single 12" to 14" cone collar.
Number of Bands	• Step 1 clearly favored 3 bands at night. • Two bands gave significantly better detection results in Step 2, day and night. • Lane change differences were not significant but favored 2 bands at night. • 2 and 3 bands met the DSD criterion. • Less than 2 or more than 3 bands degrade performance.	Two or three bands are acceptable, with two bands preferred.	A minimum of 3 inches should separate the bands.
Band Mounting Position	• Minor differences in Step 1 tests for 2 band configuration. • No lane change differences. • Low mounting was detected further away at night. • Both positions met the DSD criterion day and night.	A top band starting 3 inches from cone top and lower band starting 3-5 inches from the bottom of the cone appears optimum.	
Reflective Material and Color	• Polycarbonate in yellow was the most consistently high material at night. • All six materials tested in Step 2 met the DSD criterion at night. • The illuminated cone and vinyl did not meet DSD in the day. • The illuminated cone was detected far away but showed lowest lane change distance—some drivers confused these devices with car taillights.	Where long (over 3,000') sight distances are available the materials most appropriate are: Polycarbonate-yellow (Reflexite) Poly/vinyl combination (Reflexite) Polycarbonate-white (Reflexite) Illuminated cone For shorter sight distances (under 3,000') the following are equally appropriate: High Intensity (3M) White or Yellow Vinyl (Reflexite)	
Device Spacing	• 1/2 speed limit (SL) spacing was significantly superior to regular or double SL spacing at night for detection and lane change. • Only 1/2 SL met the DSD criterion at night. • All spacings met the DSD criterion in the day. • 1/2 and regular SL spacing were detected further away than double in the daytime. • There was no difference in lane changing during the day.	1/2 SL spacing can be used in the taper to increase detection and lane change behavior at night. Double SL spacing can be considered in tangent applications.	Use of double SL has possible negative safety implications noted but not studied in this project.
Cone Size	• 18" cones show a 25-33% loss in detection when a 10" collar is in place during the day. • The larger the cone, the further away it was detected in the daytime. • Lane change in the day was better for the 28" cone. • There were no lane change or detection differences due to size at night.	At night the cone size is relatively immaterial as long as it can support the suggested reflective area, band, and mounting position values. In the day 28" or 36" cones are suggested for high speed (45 or more mph) operations.	During the day cone size and color control perception; at night amount and type of reflectorization control.

Table F-17. Summary of findings and design/use guidelines for tubes.

Parameter	Findings	Design/Use Guidelines	Comments
Reflective Area	• The 12" collar is significantly better in detection distance than 6" but there is no useful improvement over 12 inches of collar at night. • 6" and 12" collars meet the DSD criterion. • There are no differences in point of lane change between areas. • Daytime detection, recognition, and lane change are not diminished by the 12" collar.	A collar in the 11-13 inch range appears optimum.	
Number of Bands	• One band was consistently significantly superior to two bands on lane change and detection distance measures day and night. • The DSD criterion was met in the day by 1 but not 2 bands. • Only the 2 band on 28" cones at night met the DSD criterion.	One band of reflective material.	
Band Mounting Position	• No differences in the daytime, lane change or detection distance. • No lane change or detection differences statistically at night; however, low mounting had consistently higher values. • DSD criterion met by both positions in the day but only by the high mounting at night.	Use high mounting until additional evidence available.	Low mounting may be more effective in lane diversion or detour settings; however, additional study is necessary for that answer.
Reflective Material and Color	• Of the six treatments tested all except the High Intensity (3M) in white meet the DSD criterion in the daytime. • Yellow was generally superior to white at night. • Differences between materials were not significant. • Two of the six treatments (polycarbonate-yellow and poly/vinyl) did not meet DSD criterion at night.	Use yellow color with High Intensity (3M) Polycarbonate (Reflexite)	Findings were less clear than, but generally consistent with results for cones. Same material and color can be used for cones and tubes.
Device Spacing	• No daytime differences. • DSD criterion met by all three spacings in the day. • Lane changing is significantly further away for regular spacing at night. • Detection at night is not statistically different but the lower distance for double spacing is consistent with earlier results. • 1/2 and regular SL spacing meets the DSD criterion.	There is no benefit for using 1/2 or double spacing with tubes evident in Step 1 or 2 findings.	
Tube Size	• 42" superior in the daytime, especially for lane changing. • 28" superior at night, especially for lane changing. • All devices met the DSD criterion day and night. • 18" tube detection and recognition distance 50% less than 28" tube.	42" preferred in the daytime. At night any height with a minimum 4" diameter which supports the 12" collar should be adequate.	Reflective surface area, not device height/size controls at night. Size is more important in the day.

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