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OF HIGHWAYS AND
PUBLIC TRANSPORTATION

COOPERATIVE
RESEARCH

SELECTION OF WORK ZONE CHANNELIZING DEVICES USING THE VALUE ENGINEERING APPROACH

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 292-3
STUDY 2-18-81-292
TRAFFIC AT WORK ZONES

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16. Abstract

This report investigates the use of Value Engineering for selecting work zone channelizing devices. Presented first is a State-of-the-Art review of available channelizing devices and their relative performance. Next, an overview of the Value Engineering problem-solving approach is presented. The paper then demonstrates how the Value Engineering approach can be applied to select work zone channelizing devices. For illustration, the approach is used to select devices for a lane closure taper at a rural freeway work zone.

Based on the results of the investigation, Value Engineering appears to be a useful and practical work zone traffic management tool. It provides an objective means of evaluating any number of alternative channelizing devices using whatever performance and cost data are available. Most important, it encourages the selection of low cost devices which are safe and effective under the prevailing work zone conditions.

The investigation further suggests that the Value Engineering approach is most appropriate for use at the Division level. It is an effective analytical tool which can be used in developing standards and for resource planning and allocation.

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Research Report 292-3
Research Study Number 2-18-81-292
Handling Traffic in Work Zones

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INTRODUCTION

There are a wide variety of channelizing devices currently available for use in highway work zones. The Manual on Uniform Traffic Control Devices (MUTCD) presents basic design standards for these devices and general guidelines for their use (1). However, it is left up to the highway agency to decide where and when to use particular devices or sets of devices. As a result, the application of work zone channelizing devices varies widely between agencies and between projects (2).

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

1. Select the device with the lowest initial cost.
2. Select a device which is normally used by the agency.
3. Select a device already in stock.
4. Select the very "best" device just in case.

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

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

Presented first is a State-of-the-Art review of work zone channelizing devices. The available channelizing devices and their relative performance are discussed. Next, a general overview of the Value Engineering concept is presented. It will then be demonstrated how the Value Engineering approach can be applied to selecting work zone channelizing devices. For illustration, the approach will be used to select devices for a lane closure taper at a freeway work zone.

STATE-OF-THE-ART

Table 1 identifies the work zone channelizing devices currently in use in this country. With the exception of the Horizontal Panel developed by the Utah DOT, all of the devices are recognized in the MUTCD. The table summarizes the current standard usage of each device, including relevant MUTCD design standards.

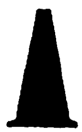
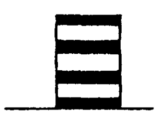
Device Performance Based on NCHRP Report 236

NCHRP Report 236 represents the most comprehensive evaluation of work zone channelizing devices undertaken to date (2). This report details the performance of all the primary devices including cones and tubes (with and without reflective collars for night visibility), barricades, drums, and panels. The performance findings are based on laboratory studies, closed-highway field studies, and field studies at "real-world" freeway work zones.

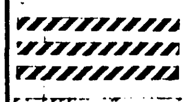
According to NCHRP Report 236, the function of work zone channelizing devices is to alert drivers to potential hazards and provide path guidance approaching and through a work zone. Motorists respond to the path defined by an array of channelizing devices, rather than to individual devices.

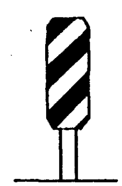
The NCHRP studies found that all of the primary channelizing devices, when designed and used properly, adequately perform the function of channelization, both day and night. Furthermore, none of the common devices elicit unique or particularly hazardous driver responses. In fact, drivers generally cannot tell which types of devices are in an array when they first sight it. From a distance, all arrays appear to be patterns or lines of color and light.

TABLE 1. AVAILABLE WORK ZONE CHANNELIZING DEVICES

Device	Current Standard Usage					
	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
	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
DRUM 	MUTCD	18" diameter	36"	Orange and white horizontal circumferential	4–8"	Must have at least 2 orange and 2 white stripes. During dark, lights should be placed on drums

Adapted from Reference 2.

Device	Current Standard Usage						
	Source	Minimum Height	Rail Width	Length (Min.)	Color(s)/ Configuration	Stripe Width	Visibility Requirements
TYPE I BARRICADE 	MUTCD	3'	8" min.- 12" max.	2'	Orange and white sloping at 45°	8" (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
	Others in use	–	6"–12"	6'	Black and white	4"	Minimum brightness orange 25-70 candelas white–70-250 candelas
TYPE II BARRICADE 	MUTCD	3'	8" min.- 12" max.	2'	Same as MUTCD above	8" (4" for rails less than 3')	Same as MUTCD above. Lights on option after dark
	Others in use	–	6"–12"	–	Black and white	–	
TYPE III BARRICADE 	MUTCD	5'	8" min.- 12" max.	4'	Same as MUTCD above	8" (4" for rails less than 3')	Same as MUTCD above. Lights on option after dark
	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"	

Device	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	4–8"	Entire area shall be reflectorized with a material that has a smooth sealed outer surface Should place lights on panel after dark
	Others in use		48" from ground	Horizontal stripes & chevron stripes		Minimum brightness white 70-75 candelas orange 25-70 candelas

As part of the NCHRP studies, the various channelizing devices were evaluated in single-device taper arrays at simulated freeway work zones. A single-device array is one which contains only one type of device (i.e., devices are not mixed). For the studies, MUTCD taper lengths and device spacings were used. Table 2 shows the day and night mean detection distances for the various device arrays. From the table it is apparent that most of the arrays were detected by drivers at very long distances under the simulated work zone conditions. The most effective arrays within each device category were detected at distances ranging from 1,450 feet up to 4,400 feet.

In addition to detection distance, the studies evaluated lane change location upstream of the various taper arrays. The results of the evaluation are presented in Table 3. Shown in the table are the mean lane change distances, relative to the beginning of the taper, for each device array under day and night conditions. The mean lane change locations ranged from only 200 feet upstream of the taper (for 28-inch cones at night) to approximately 800 feet (for 3-foot X 12-inch Type II Barricades).

The NCHRP studies attempted to rate the overall performance of the various device arrays. Table 4 presents the resulting rankings of the taper arrays based on detection distance, lane change location, lateral positioning of vehicles, speed effects and driver preference. The most effective arrays within each of the device categories (i.e., those individual arrays with high day and night combined ratings) are underlined. The table shows that, within each device category, there are highly rated (i.e., acceptable) alternatives.

Based on the overall study findings, recommendations for the design and use of channelizing devices applicable to freeway work zones were developed.

TABLE 2. MEAN ARRAY DETECTION DISTANCES FOR SELECTED WORK ZONE CHANNELIZING DEVICES

Device Type		Mean Array Detection Distance in Feet	
		Day	Night
3' X 12"	Type I Barricades	4250	3150
2' X 8"	Type I Barricades	3950	2200
3' X 12"	Type II Barricades	4100	2800
2' X 8"	Type II Barricades	3200	3400
8" X 24"	Vertical Panels	3300	2100
12" X 24"	Vertical Panels	3100	3700
12" X 36"	Vertical Panels	4400	3300
28"	Tubes[a]	3250	2300
42"	Tubes[a]	3200	1900
28"	Cones[a]	4250	1600
36"	Cones[a]	4400	1450
	Drums	4200	N.A.

Source Reference 2

[a] Equipped with reflective collars.

TABLE 3. MEAN LANE CHANGE LOCATIONS RELATIVE TO THE TAPER FOR SELECTED WORK ZONE CHANNELIZING DEVICES

Device Type		Mean Array Detection Distance in Feet	
		Day	Night
3' X 12"	Type I Barricades	640	660
2' X 8"	Type I Barricades	550	630
3' X 12"	Type II Barricades	400	810
2' X 8"	Type II Barricades	330	550
8" X 24"	Vertical Panels	420	370
12" X 24"	Vertical Panels	N.A.	N.A.
12" X 36"	Vertical Panels	370	500
28"	Tubes[a]	600	380
42"	Tubes[a]	620	350
28"	Cones[a]	400	200
36"	Cones[a]	460	250
	Drums	540	560

Source Reference 2

[a] Equipped with reflective collars.

TABLE 4. RANKING OF TAPER ARRAY PERFORMANCE

Device	Array Detection Day		Array Detection Night		Point of Lane Change		Lateral Placement	Speed		Driver Preference	Overall Rating								
	Mean Detection Distance	DSD Criterion	Mean Detection Distance	DSD Criterion	Mean Distance – Day	Mean Distance – Night	Path Consistency	Speed Reduction – Day	Speed Reduction – Night	Easiest to See	**(Total possible = 6)						**(Total possible = 10)		
											Day			Night			Combined		
											H	M	L	H	M	L	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
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
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
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)[a]																			
28" post	H	H	H	H	H	H	L	L	L	L	3	0	3	3	0	3	6	0	6
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)	H	H	N/A	N/A	M	M	M	H	H	H	4	2	0	2	2	0	5	3	0

*High, Medium, Low number.

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

Source: Reference 2

[a] Devices "optimized" by adding a reflective collar.

These are presented in Table 5. Note from the table that all of the primary device types (i.e., cones, tubes, drums, barricades and panels) are applicable for all work zone situations. However, it is left up to the agency to decide which type of device to use for a given set of conditions.

The studies revealed there is no driver behavior rationale for using more than one type of channelizing device in an array (i.e., mixed arrays perform no better than single-device arrays). In fact, there appear to be economical and logistical advantages to stocking the smallest possible number of device types.

Detection Distance for Freeway Lane Closures

The previous section presented the mean detection distances for various single-device taper arrays at freeway lane closures. A recent study evaluated the minimum required detection distance for freeway lane closures. The findings of this study supplement and generally support the conclusions of NCHRP Report 236.

Richards and Dudek (3) conducted field studies at 17 lane closure work zones on freeways in Texas. Based on the data shown in Figure 1, they concluded that a lane closure must be visible (i.e., detectable) to motorists at least 1000 feet from the beginning of the taper, and a distance of 1500 feet is desirable. If the detection distance is less than 1000 feet, the number of motorists who get "trapped" in the closed lane at the taper increases very rapidly.

TABLE 5. RECOMMENDED GUIDELINES FOR CHANNELIZING DEVICES FOR USE AT FREEWAY WORK ZONES

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

Source: Reference 2

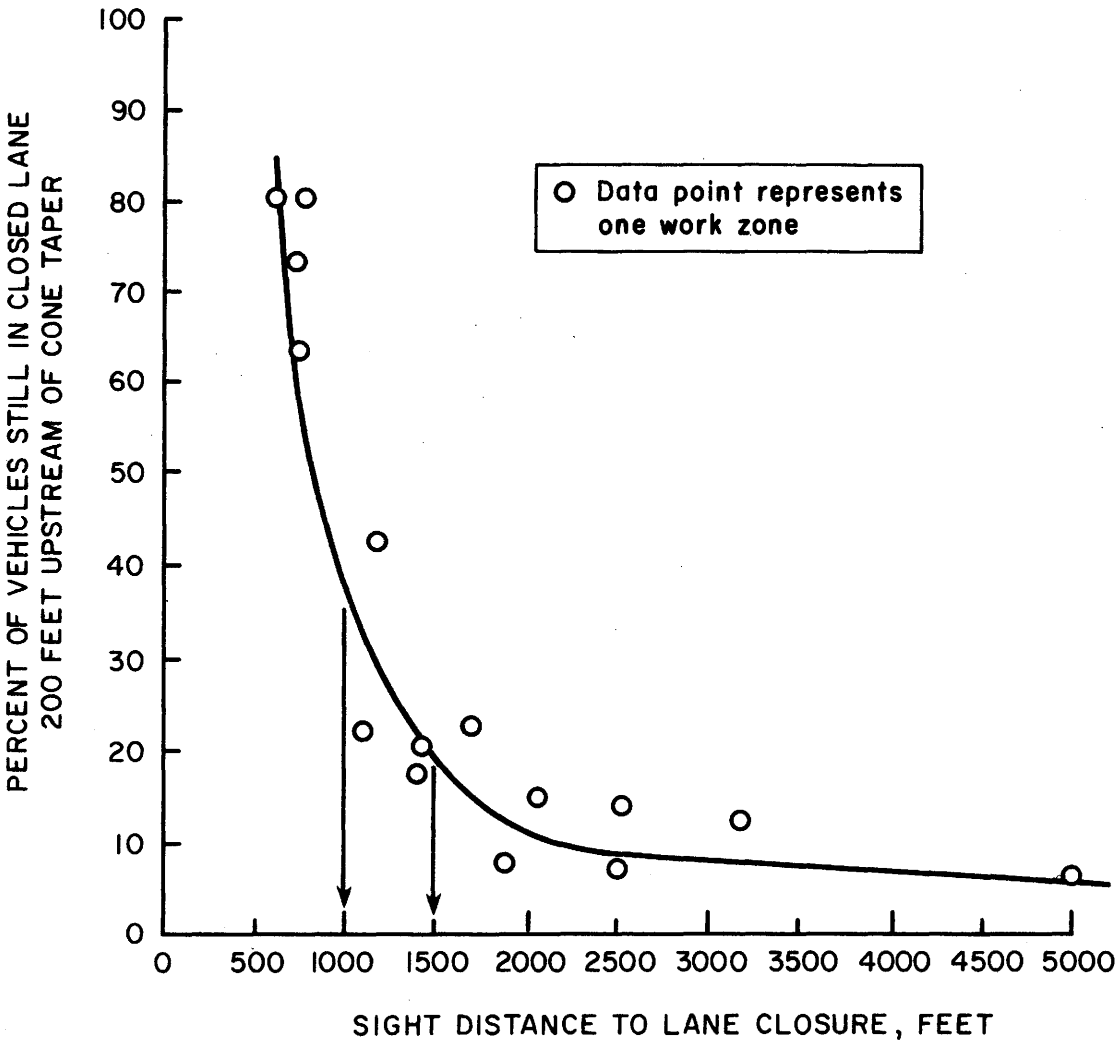


Figure 1. The Effects of Sight Distance to a Closed Lane on Occupancy of the Closed Lane

Device Selection

It should be apparent that many common channelizing devices are acceptable for most work zone uses. However, because there are so many available alternatives, the selection of the most appropriate one is very difficult. It requires an objective consideration of several factors including cost, safety, maintainability, availability, uniformity, project life and work zone conditions.

Currently, there is no widely accepted, objective means for selecting work zone channelizing devices. Thus, the need for a proven approach like Value Engineering is well founded.

THE VALUE ENGINEERING APPROACH

Value Engineering is a formalized approach to problem solving. Lawrence D. Miles, who first coined the phrase, provided the following definition (4):

> "Value Analysis [Engineering] is a philosophy implemented by the use of a specific set of techniques, a body of knowledge, and a group of learned skills. It is an organized, creative approach which has as its purpose the efficient identification of unnecessary cost . . . Unnecessary costs are those costs which provide neither quality, nor use, nor appearance, nor customer features."

Miles went on to say that Value Engineering focuses attention on the essential function of a product or service and emphasizes meeting the essential function at the lowest total cost (4).

The United States Defense Department embodied Miles' original concepts into the following definition:

> Value Engineering is an organized effort directed at analyzing the function of an item with the purpose of achieving the required function at the lowest overall cost. (5)

Two features of Value Engineering set it apart from other formal problem-solving techniques. First, it is concerned with function (i.e., identifying the desired function of an item or service). Second, it attempts to establish the relative value of alternatives in accomplishing function. Value is the possession of appropriate performance and cost for a particular function.

The relationship between value (or worth as it is often called) and function is expressed in the following equation (6):

$$\text{VALUE} = \frac{\text{FUNCTIONAL PERFORMANCE}}{\text{COST}}$$

From this equation, it is seen that value may be increased in either of two ways:

1. Value is increased by reducing costs, if performance is maintained.
2. Value is increased by increasing performance but only if increased performance is needed and wanted, and the user is willing to pay for it.

Objectives of Value Engineering

The intent of Value Engineering is to find solutions which achieve the required function at the lowest overall cost. **Value Engineering does not strive to save dollars, rather dollar savings are automatic and maximum** (4).

In emphasizing function, Value Engineering lessens the chance that existing hardware limitations or established practices will confine creative thinking. Thus, Value Engineering promotes objective and innovative problem solutions (5).

Development and Use of Value Engineering

Value Engineering was developed and first applied by Miles in the 1940s. Miles worked for General Electric during World War II and, as a production engineer, had to find ways to compensate for scarce resources and reduced budgets during the war years. In searching for substitute resources and cost saving techniques, he combined and refined existing problem-solving principles and practices into a new methodology he called "Value Analysis."

Miles first applied his new methodology to analyze existing products and production techniques, hence he used the term "Value Analysis." However, the approach was quickly adapted to the planning and design functions under the name of "Value Engineering." Today, the two terms are used synonymously.

In the 1950s and 60s, Value Engineering became popular in the United States and Europe. For example, the United States Defense Department adopted the concept for purchasing materials at its Naval shipyards. As experience with Value Engineering grew, tremendous benefits were realized. Applied properly, Value Engineering removes 15 to 20% of the cost of an item or service (5). Generally, it results in total cost savings ranging from 2 to 20 times the investment (5).

In 1975, the Federal Highway Administration established a Value Engineering unit and offered workshops around the country (7). A survey conducted in 1982 revealed that at least 15 state highway departments had adopted Value Engineering programs. Most of these programs address large construction projects (7). In addition, approximately 25 states provide monetary incentives to contractors who reduce project costs through their own Value Engineering studies.

NCHRP Synthesis of Practice 78 discusses the usefulness of Value Engineering in highway construction (8). This publication emphasizes the need for a team approach and notes that Value Engineering is most effective when applied in the pre-construction phase.

Penn DOT has one of the more aggressive Value Engineering programs in the country. Between 1980-1982, this agency estimates that it saved $35 million on highway construction and rehabilitation projects through its program. This represents a cost savings of $100 for every $1 spent on the program (7).

At least 2 states have applied Value Engineering to traffic-related problems. Caltrans used the approach to evaluate guide markers for highway tangents. The resulting modifications to the State's standards have saved an estimated $100,000 per year (7). The Mississippi Highway Department used the Value Engineering concept to evaluate alternative detour schemes for a work zone. The agency estimated that it saved $16,300 as a result (7).

Value Engineering Studies

It is not possible to give a detailed description of a Value Engineering study. In fact, each Value Engineering study needs to be tailored to meet the particular needs and conditions. Nevertheless, most studies take on a basic form which can be discussed in general terms.

Information Gathering

In the Information Phase, the existing conditions and deficiencies are identified. All available factual and subjective data on known alternative solutions are gathered for later use, including pertinent cost data. Normally a literature review is conducted and persons with practical experience are consulted.

Functional Analysis

The Functional Analysis Phase is generally considered the most critical aspect of any Value Engineering study. In this phase, the desired functions of the item or service under study are identified and categorized according to type (e.g., basic vs. secondary functions). An effective technique for determining function, called a FAST diagram, will be discussed in the next section.

Speculation and Evaluation

In the Speculation and Evaluation Phases, alternative solutions are developed, analyzed and refined. The "value" of each alternative is determined and compared. Value is a relative quantity and depends on the State-of-the-Art, study thoroughness and accuracy of information (5). Value determination involves both objective and subjective decisions and is usually an iterative process.

Implementation

The Implementation Phase consists of feasibility and economic analyses of the most "valued" alternative(s). This phase answers the questions: Can we implement the results and what will it take?

Presentation

The Presentation Phase "sells" the results of the Value Engineering study to the sponsor and/or user. This phase involves summarizing and documenting the study findings, and informing and training those who will implement the findings.

Assessing Function

As noted above, a critical step in any Value Engineering study is to identify and assess the basic function(s) of the item or service under study. In fact, the concern over function is the main difference that distinguishes Value Engineering from other cost reducing techniques (5).

Functional analysis involves several tasks. First, an attempt is made to identify all of the functions which the item or service provides. Then, the various functions are classified as basic or secondary functions. Basic functions are those which are absolutely essential in order for the item or service to perform its purpose. Secondary functions are those related to esteem, appearance or convenience. After the functions have been appropriately categorized, the basic functions are organized into a logical, hierarchical sequence. This makes it possible to identify the principle function(s) of the item or service, thus establishing a basis to judge value.

To assist in identifying and organizing the basic functions, a Functional Analysis System Technique (FAST) diagram is commonly developed. A FAST diagram is a simple type of flow chart. The basic functions are stated in two-word descriptors (i.e., verb-noun combinations), and then organized sequentially from higher-order functions to the most basic function. For illustration, a FAST diagram for a fire alarm is shown in Figure 2.

The functional evaluation phase involves judgment and is best performed as a team effort (5). The team approach provides maximum technical input into the process and encourages objective and comprehensive results.

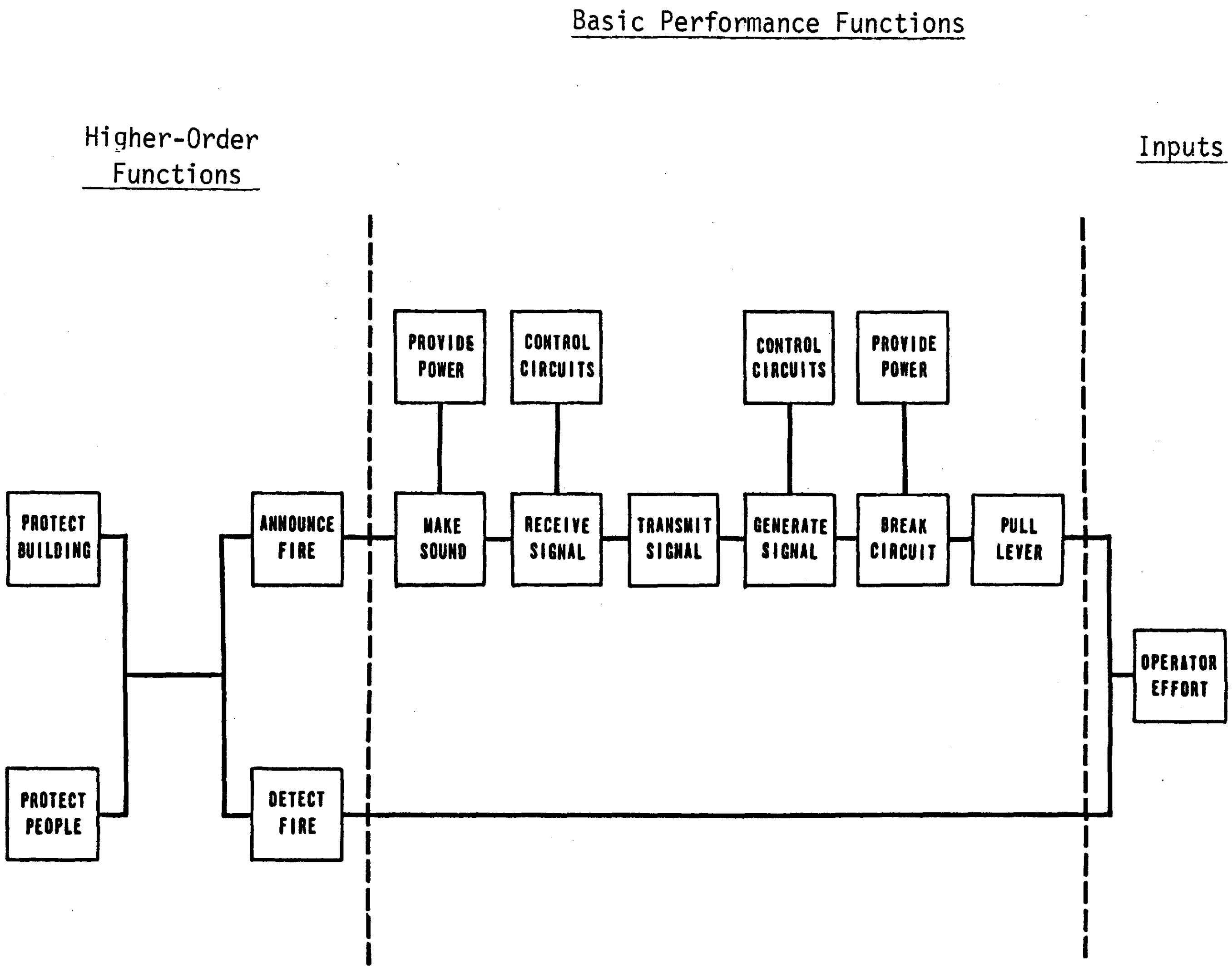


Figure 2. Example of FAST Diagram for a Fire Alarm

APPLICATION OF VALUE ENGINEERING

The Value Engineering approach can be used to select work zone channelizing devices which offer the greatest value (i.e., those devices which serve their intended purpose at the lowest overall cost). In fact, Value Engineering is particularly appropriate since it reduces costs without reducing safety below an acceptable level (5).

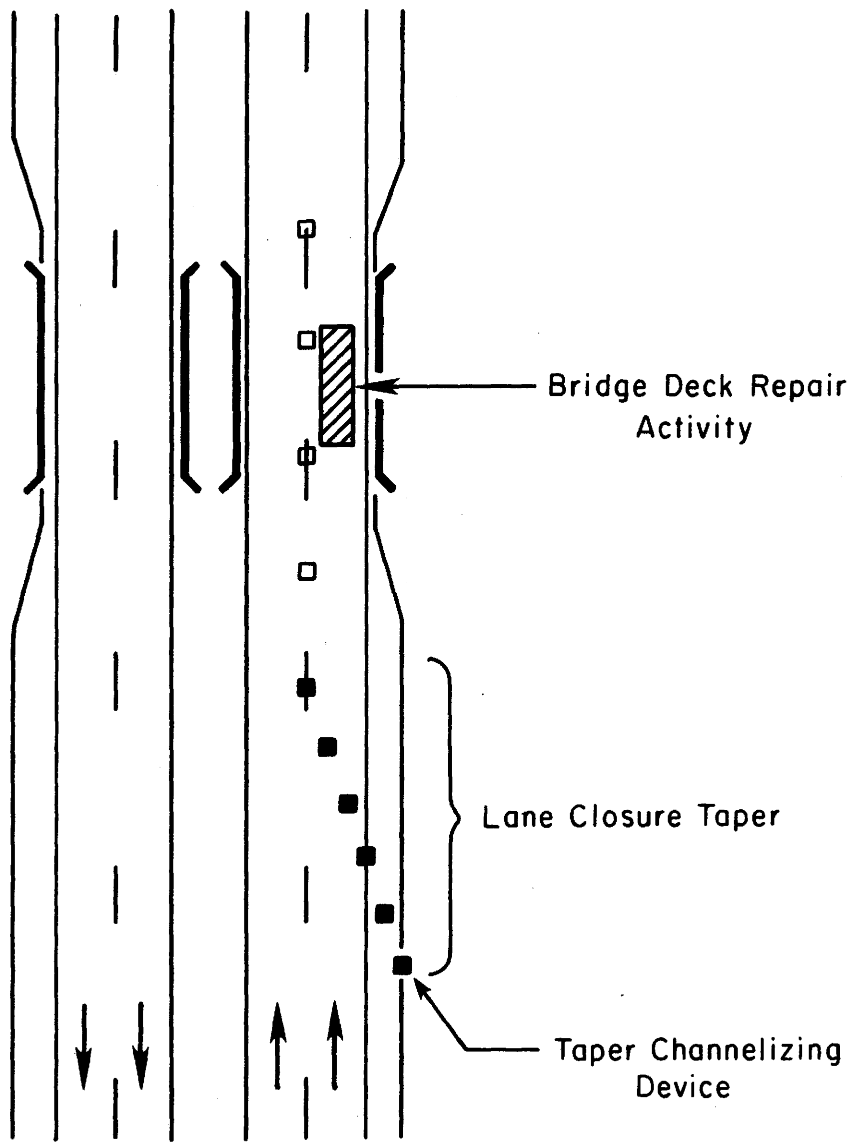
The selection of work zone channelizing devices using the Value Engineering approach involves 7 steps:

1. Determine the intended purpose (function) of the devices.
2. Identify available alternative devices.
3. Select appropriate measures of device performance (i.e., a means of evaluating how well a device performs its intended function).
4. Determine the performance of the alternative devices based on the selected performance measures. (If it has not already been done, alternatives which do not meet minimum performance criteria should be excluded.)
5. Estimate the total cost of each acceptable alternative.
6. Calculate the relative value of each acceptable alternative, where value = performance/cost.
7. Select the alternative with the greatest value.

Rather than describing each of these steps, the following sections will demonstrate how they are performed in selecting taper devices for a lane closure work zone. The Value Engineering approach may be applied similarly to select channelizing devices for any work zone situation.

Work Zone Scenario

Bridge-deck repair work is planned for the northbound, right-hand lane of a rural freeway (see Figure 3). The four-lane divided freeway carries low to



Note: MUTCD taper length and device spacing are assumed for evaluating all alternative taper devices.

Figure 3. Freeway Work Zone Site Layout

moderate traffic volumes, and speeds are generally high (e.g., 55 mph). In the area of the work, sight distance is excellent and there are no ramps.

The Value Engineering approach will be used to select the channelizing devices for the lane closure taper. It is anticipated that the right lane will be closed, day and night, for approximately two weeks. It is also assumed that the minimum taper length and maximum device spacings recommended in the MUTCD will be used, and that a single-device array will be used.

Function of the Lane Closure Taper

The first step in the Value Engineering analysis is to identify function. To accomplish this, a functional analysis of the channelizing devices used in a freeway lane closure taper was performed by a team consisting of 5 traffic engineers and 1 industrial (Human Factors) engineer. The team first identified the various functions performed by channelizing devices in a lane closure taper and then categorized them as either basic or secondary functions. A listing of these functions by type is presented in the Appendix.

Based on the team input, a FAST diagram for taper devices was developed. The FAST diagram, shown in Figure 4, indicates that the most basic function of channelizing devices in a lane closure taper is to display color and/or light to approaching motorists. The pattern of color/light **identifies the closure, defines the workspace** and **identifies the travel path.**

There was some disagreement among team members as to whether the taper devices should indicate the required direction of movement. After much debate, it was agreed that the entire taper, plus any supplemental devices (e.g., an arrowboard), should indicate direction. It is not essential, therefore, for individual channelizing devices to convey a directional message.

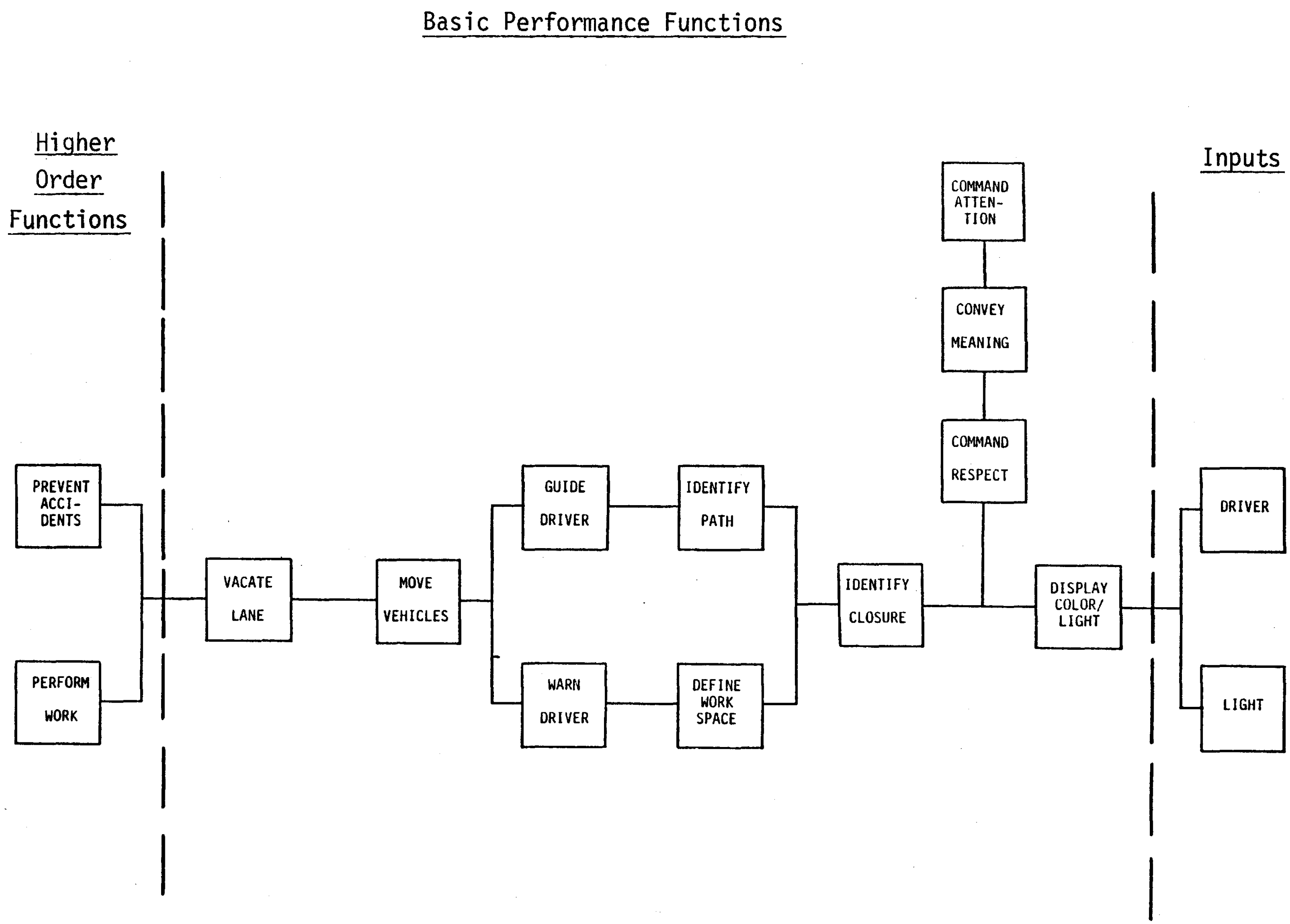


Figure 4. FAST Diagram Illustrating the Basic Functions of Lane Closure Taper Channelizing Devices

In addition, the team did not necessarily believe that taper devices should be used as a means of encouraging reduced speeds. Team members did not cite speed control as a function of taper devices.

Available Devices

After assessing device function, the next step in the Value Engineering analysis is to identify alternative channelizing devices which perform the required functions. The data in NCHRP Report 236 provide a basis for selecting appropriate candidate devices. From Table 4, the following 6 types of channelizing devices were selected as viable alternatives for a freeway lane closure taper:

1. 3-foot X 12-inch Type I Barricades
2. 3-foot X 12-inch Type II Barricades
3. 12-inch X 36-inch Vertical Panels
4. 36-inch Cones with Reflective Strips
5. 42-inch Tubes with Reflective Strips
6. 55-Gallon Drums with Reflective Strips

As seen in Table 4, each of these devices generally was the best performing device within its respective category. Also, all 6 candidate devices received high day and night overall performance ratings.

Measure of Performance

The FAST diagram (see Figure 4) reveals that taper channelizing devices, through the display of color and light, should **identify the closure, define the work space** and**identify the travel path.** After reviewing NCHRP Report 236, two measures of performance were selected for determining how well the alternative devices perform these basic functions:

1. Mean array (taper) detection distance.
2. Mean location of lane change relative to the beginning of the taper.

These performance measures were selected because they correlate to the basic functions of taper channelizing devices, and because there are corresponding performance data available for each alternative device. With respect to the detection distance measure, there also are data available which provide a basis to establish a minimum level of performance (3).

In addition to performing the basic channelization functions, it is essential that the alternatives perform required secondary functions. Secondary functions might include maintainability, durability, ease in placement and removal, sign support, etc. It is assumed that the 6 alternative devices satisfy all the desired secondary functions at the freeway lane closure site. At another site where different secondary functions are required, some of the alternatives might have to be excluded from consideration.

Device Performance

Having selected appropriate measures of performance, the next step is to determine device performance based on the established measures. Table 6 shows the mean array detection distance and the mean lane change location for each of the candidate device arrays under day and night conditions. These performance data are extracted from Tables 2 and 3 and are based on the NCHRP studies.

With respect to array detection distance, research by Richards and Dudek (3) suggests that the minimum detection distance for a freeway lane closure

TABLE 6. MEAN DETECTION DISTANCES AND LANE CLOSURE LOCATIONS FOR ALTERNATIVE CHANNELIZING DEVICES

Device Type	Mean Array Detection Distance in Feet		Mean Lane Change Location Relative to Taper in Feet	
	Day	Night	Day	Night
Type I Barricades	4250	3150	640	660
Type II Barricades	4100	2800	400	810
Vertical Panels	4400	3300	370	500
Cones	4400	1450	460	250
Tubes	3200	1900	620	350
Drums	4200	3000[a]	540	560

Source: Reference 2

[a] Estimate based on supplemental research by TTI.

taper should be 1000 feet. Type I and II barricades, vertical panels and drums provide detection distances greatly exceeding this minimum value. However, cones and tubes may not fully satisfy the minimum detection distance requirement. Table 7 shows the nighttime mean detection distance and mean detection distance minus one standard deviation for cones and tubes. (Mean detection distance minus one standard deviation approximates the 85th percentile distance, i.e., the distance from which 85% of the drivers can detect the array, but the remaining 15% cannot yet detect it.) Based on the data in the table, at least 15% of the drivers would not be able to detect a taper of cones or tubes at night from a 1000-foot distance. Thus, cones and tubes are, at best, only marginally acceptable for overnight use at freeway work zones. This limitation should be recognized and considered in selecting an appropriate channelizing device for the 2-week freeway work zone.

Another important consideration in the selection of devices is that when using cones and tubes, there is a potential problem of displacement by traffic. Two things occur with displacement: 1) loss of effectiveness of lane taper, and 2) cost increases if proper maintenance is performed to replace the devices.

A basic assumption in this Value Engineering analysis is that channelizing device performance has no upper limiting values. In other words, all of the detection distance and lane change distance provided by a device is useful and therefore has value. At other work zones (e.g., on a minor city street or where sight distance is physically limited by geometric features), it might be desirable to establish upper performance limits. For example,

TABLE 7. VISIBILITY OF CONES AND TUBES AT NIGHT

Device Type	Mean Nighttime Array Detection Distance in Feet	Mean Nighttime Detection Distance Minus 1 Standard Deviation in Feet[a]
Cones	1450	850
Tubes	1900	910

Source: Reference 2

[a] Mean nighttime array detection distance minus 1 standard deviation approximates the 85th - percentile response.

devices on a city street may only need to be detected from a distance of 1000 feet. Any detection distance above 1000 feet provided by a device would not be used and should not be considered in computing value.

Device Costs

Cost data for the alternative devices were obtained from a traffic control device supplier in Texas. The cost data were used to generate the relative device costs presented in Table 8. The following assumptions were made in the cost evaluations:

1. New devices will be purchased and used.
2. 50% of the cones and tubes would have to be replaced during the 2-week duration, and none of the other devices would have to be replaced.
3. The cost to install and remove each of the devices is approximately the same.

In reality, total device cost depends on a number of factors including: device availability, geographic location, duration of work, replacement rate, salvage value, etc.

Device Value

Table 9 presents a value summary for the alternative devices. The table shows the relative value of each alternative device based on its ability to provide detection distance and encourage early lane changes under day and night conditions. The values in Table 9 were computed based on the performance data in Table 6 and cost data in Table 8 using the basic equation: value = performance/cost. However, the values are expressed in inverse form in the table (i.e., device cost per unit of performance).

TABLE 8. DEVICE COST

Device Type	Cost Per Device in Dollars
Type I Barricades	40
Type II Barricades	45
Vertical Panels[a]	22
Cones[b]	18[d]
Tubes[c]	22[d]
Drums[c]	25

[a] Portable vertical panel mounted on stand.

[b] 4-inch reflective collar added.

[c] Two 4-inch reflective collars added.

[d] Cost based on 50% replacement during 2-week duration.

TABLE 9. RELATIVE VALUE OF ALTERNATIVE DEVICES

Device Type	Device Cost Per 100 Feet of Array Detection Distance				Device Cost Per 100 Feet of Lane Change Distance			
	Day		Night		Day		Night	
Type I Barricades	$0.94[a]	(5)[b]	$1.27	(5)	$ 6.25	(5)	$6.06	(4)
Type II Barricades	1.10	(6)	1.61	(6)	11.25	(6)	5.56	(3)
Vertical Panels	0.50	(2)	0.67	(1)	5.95	(4)	4.40	(1)
Cones	0.41	(1)	1.24	(4)	3.91	(2)	7.20	(6)
Tubes	0.69	(4)	1.16	(3)	3.55	(1)	6.29	(5)
Drums	0.60	(3)	0.83	(2)	4.63	(3)	4.46	(2)

[a] Example calculation:

$$\text{Device Cost per Foot of Array Detection Distance} = \frac{\text{Device Cost from Table 8}}{\text{Array Detection Distance from Table 6}} = \frac{\$40}{4250\text{ ft.}} = \$0.0094/\text{ft.}$$

$$\text{Device Cost per 100 Feet of Array Detection Distance} = \$0.0094/\text{ft.} \times 100 = \underline{\$0.94}$$

[b] Ranking with respect to other devices (1 = best value).

It should be noted again that the minimum taper length and maximum device spacing recommended in the MUTCD were assumed for all the alternatives. Thus, each alternative array would contain the same number of devices. For this reason, the values in Table 9 are expressed in device cost rather than array cost. If the alternatives had included mixed device arrays or arrays with varying numbers of devices, it would be necessary to express value as cost per array.

Device Selection

From Table 9, vertical panels and drums are "good values" for combined day and night use at the freeway work zone, and vertical panels by a slight margin are the best value. From the table, a vertical panel costs only 67 cents for every 100 feet of nighttime detection distance it provides. This cost is slightly lower than drums which cost 83 cents per 100 feet of nighttime detection distance.

Vertical panels also are the best value for encouraging early lane changes at night. For each 100 feet of lane change distance, they cost $4.40. Drums also are a good value costing $4.46 per 100 feet of lane change distance.

Both vertical panels and drums also have relatively good value in the daytime. In fact, only cones and tubes represent a better daytime value.

Thus, based on the Value Engineering analysis, vertical panels mounted on portable stands are recommended for the freeway work zone. Drums could be used as an alternate. Both of these devices are relatively low cost ($22 and $25 respectively), and they provide adequate performance, day and night.

CONCLUSIONS AND RECOMMENDATIONS

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

It is anticipated that the Value Engineering approach can be used by the Department at the Division level as an aid in establishing work zone traffic control standards and for planning and allocating hardware resources. In order to fully utilize Value Engineering in the selection of work zone channelizing devices, more information is needed on device performance and cost. In particular, the following issues need to be addressed:

1. Effects of device spacing and number on performance.
2. Performance of mixed arrays and combined devices.
3. Costs of installing, maintaining and removing different types of devices.
4. Identification of performance measures for various channelizing device uses.
5. Establishment of minimum performance criteria and upper performance limits for various types of work zones.

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APPENDIX - FUNCTIONS OF CHANNELIZING DEVICES

Basic Performance Functions

1. Provide work space
2. Promote safety
3. Prevent accidents
4. Eliminate conflicts
5. Prevent encroachments
6. Vacate lane
7. Move vehicles
8. Guide drivers
9. Identify path
10. Define workspace
11. Indicate direction (merge direction)
12. Identify closure
13. Provide response time
14. Command respect
15. Command attention
16. Convey meaning
17. Display color (message)
18. Display symbol (message)

Secondary Functions

1. Support lights
2. Support signs
3. Withstand wind
4. Withstand (minor) impact
5. Withstand environment (weathering)

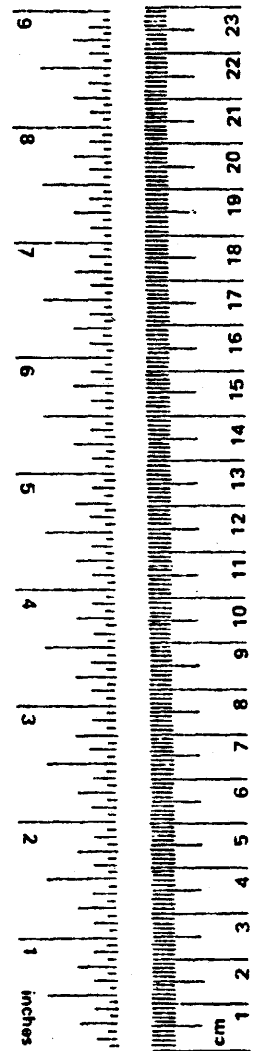
(Assumption: Devices used for 2-week freeway lane closure.)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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



Approximate Conversions from Metric Measures

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