Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-82/117		PB83 158717

4. Title and Subtitle	5. Report Date
DETERMINATION OF DRIVER NEEDS IN WORK ZONES	September 1982
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s) R.S. Hostetter, K.W. Crowley, G.W. Dauber, L.E. Pollack, S. Levine	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Institute For Research, Inc. 257 South Pugh Street State College, PA 16801	31Y1052
	11. Contract or Grant No. DOT-FH-11-9549
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590	Final Report Jan. 1979 - October 1981
	14. Sponsoring Agency Code T-0499

15. Supplementary Notes

1. FHWA Contract Manager: J.G. True (HSR-30)
2. Subcontractor: The Pennsylvania Transportation Institute, Penn State

16. Abstract

The objectives of the study were: (a) to determine what information drivers need to travel through work zones safely and efficiently; (b) to determine how this information can best be conveyed to the drivers; and (c) to determine where improvements to the present system of work zone traffic control are needed. The study began with an analysis of driver tasks for eight major work zone types: lane closure, shoulder closure, roadside, lane diversion, crossover, temporary detour, detour to alternate routes, and reduced lane width. From this effort, a set of information content needs was identified for each work zone type. A further analytic effort using the principles of the Positive Guidance Procedure and the concept of Decision Sight Distance, resulted in the identification of recommended information presentation locations for the various types of information.

These analytic efforts were combined into information requirements which were then evaluated for applicability by exercising each on a series of actual work zones. The requirements were modified where necessary and were then used as the basis for the development of a procedure for the derivation of work zones signing plans.

Another aspect of the project involved the evaluation of individual construction-related signs, in which each device was evaluated with respect to several criteria and problems were identified.

17. Key Words	18. Distribution Statement
Work Zones Information Task Analysis Traffic Control Devices	NO RESTRICTIONS: This document is available to the public through the National Technical Information Service Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	117	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

i.q

* U. S. GOVERNMENT PRINTING OFFICE : 1973 735-504/338

TABLE OF CONTENTS

-- continued --

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. OVERVIEW

The objectives of the study were: (a) to determine what information drivers need to travel through work zones safely and efficiently; (b) to determine how this information can best be conveyed to the drivers; and (3) to determine where improvements to the present system of work zone traffic control are needed. The study began with an analysis of driver tasks for eight major work zone types: lane closure, shoulder closure, roadside, lane diversion, crossover, temporary detour, detour to alternate routes, and reduced lane width. The task analysis served as the means to identify the various types of information that drivers should be provided with as they drive through different types of work zones. The identification of what information should be provided to drivers is referred to as information content needs. An equally important aspect of driver information needs is to identify when the information should be presented with respect to various parts of the work zone. Even if the driver is presented with the appropriate information content, the information may be ineffective if it is not presented in a timely fashion. Driver performance factors such as detection and recognition of the information and the time needed to perform the required maneuvers must be considered in identifying when the driver should receive each type of information. By applying the principles of the Positive Guidance Procedure and the associated driver performance models such as Decision Sight Distance and Stopping Sight Distance, an additional analysis was conducted to identify the locations within a work zone that the various types of information should be presented. Taken together, the analytic efforts resulted in a set of rather detailed information requirements for each work zone type. Since the analyses were based upon ideal layouts for each work zone type, it was necessary to test the derived information requirements against a variety of actual work zone configurations to determine their field applicability. This was accomplished by carefully cataloging the layout and information systems of approximately 250 work zones of various types. The information requirements were then applied to the actual work zones and where problems in application occured the necessary modifications were made. In large part the modifications involved making the requirements less specific and establishing application guidelines such that the necessary range of work zone variations could be accommodated.

In conjunction with applying the information requirements to the field sites, the cataloged work zones were evaluated with respect to informational problems.

One finding from the analysis of field data had a significant effect upon the nature of the output from the project. The original intent was to develop driver information requirements for each of the eight work zone types noted above. However, in evaluating the field catalog data and attempting to apply the original information requirements, it was found that approximately 40% of the work zones failed to fit the existing definitions. In other words these work zones were composite sites which contained features from two or more of the work zones as defined by FHWA for use in this study. For this reason it was decided that the output of the project would be significantly more useful if the information requirements were structured in such a way that they were applicable for composite sites as well as those which fit existing definitions. This was done by identifying the universe of work zone features, i.e. the various geometric components of which all work zones

are comprised. By identifying the information requirements for each feature and providing guidelines for locating the information within and between features, it was possible to develop a procedure to aid in the design of an information system for any combination and sequence of features required for a particular construction or maintenance project.

With respect to the types of informational problems identified from the field catalogs, it was concluded that the information systems could be substantially improved if existing guidelines and standards were to be consistently implemented in the field. While some improvements can be identified, primarily via provision of more specific application/deployment guidelines, the current state-of-the-art is largely adequate with respect to meeting driver needs. The most prevalent problem which is not adequately attended to within the existing guidelines and standards is the provision of adequate warning distance, particularly for the features which are located in the interior (or downstream) portions of a work zone. Hopefully, the procedures developed on this project can aid in reducing the extent of this problem in that identification of information presentation location receives primary attention.

It should be noted that the major emphasis of the study was on the driver information needs fulfilled by signs. This emphasis, however, is not meant to imply that delineation is considered to be of secondary importance in work zones. The overall information system can be maximally effective only if the signing and delineation systems complement each other. The emphasis on signs occurred for several reasons. First, the evalutions of work zone information systems indicated that there were more significant and more frequent problems associated with signs than with delineation. In fact, the most frequent delineation problem was not related to the type or the extent of delineation used, but with failure to adequately remove existing markings, thereby creating confusing situations for drivers. Research relating to this problem is one of identifying improved methods of eradication, and was not within the scope of the project. Other than this, the most frequently asked questions regarding delineation relate to the extent of delineation required, i.e. number and spacing of barricades, RPM's, etc., rather than questions related to the type of devices or markings required. The answers to these questions requires a type of experimental approach that was not consistent with the broader overall objectives of the project from the standpoint of allocation of time and funds.

In summary, it was felt that an emphasis on work zone signing had the potential for producing the greatest improvement in work zone information systems.

CHAPTER II. TECHNICAL APPROACH

A. Introduction

The existence of a work zone typically produces some disruption in traffic flow and imposes unexpected maneuvering requirements on drivers. As such, the work zone can therefore be considered a hazard (or series of hazards) which must be safely negotiated and can be treated as any other hazardous location. The FHWA "Positive Guidance" procedure was developed as a means to identify the most effective driver information treatments for hazardous locations. The premise underlying the development of the "Positive Guidance" procedure is that since all hazards cannot feasibly be removed, drivers must be given information in an appropriate form and at an appropriate time so that the hazard(s) can be avoided. Since the work zone creates a hazard in the sense described above, the principles of the procedure form the underpinnings to the approach used for derivation of work zone information requirements. The derivation process began with an analysis of the driver's tasks for various types of work zones. The task data were translated into generalized information requirements which were then modified, where necessary, on the basis of field data. The field data consisted of catalogs of the layout and information systems of actual work zones of the various types. Each work zone was documented via photography and automatic distance measurement equipment such that each traffic control device and its location, with respect to key geometric features, was known. In other words, the catalog data permitted the implemented traffic control system to be duplicated on paper. The review and evaluation process provided two types of outputs. First, it provided a means for identifying the nature and extent of problems on actual work zones. Secondly, it provided a basis for evaluating and "fine-tuning" the analytically derived requirements to assure that the majority of the situations encountered in actual work zones would be reflected in the final set of requirements. In addition, the field data provided a means for identification of hazards which are not necessarily associated with a specific site type but which generate a requirement for "other" information aimed at hazard avoidance, i.e. construction equipment entrances and exits, sections of rough roadway, bumps, dips, etc.

B. Derivation of "Primary" Information Requirements

The primary information requirements were based upon the application of the IDA (Information-Decision-Action) task analysis model. This particular model was chosen after reviewing a number of different methods of task analysis. The primary advantage of the IDA model over most of the other models is that it is highly flexible, easily applied, and does not require an unnecessary amount of detail. That is, unlike many of the other task analysis models, it does not emphasize structure at the expense of process, thus the degree of thoroughness may be selected for maximum usefulness.

In effect, the IDA approach begins by reversing its own sequence (IDA = ADI). With a general traffic control objective, for example, to close down one lane in the vicinity of a work site, first a point by point correspondence is established between the road situation and the action required of the driver-vehicle unit. Next, the relationship between those actions and the mental processes of judgment, estimation, or decision that guided them is determined along with the relationship between these decisions and the obser-

vations or perceptions on which they are based. The final determination is between those perceptions and the physical characteristics and location of the stimuli that elicited them. By specifying these relationships it is possible to specify the information necessary for negotiating the work zone.

Let us consider a simple example. Suppose that the engineer wishes to close down the right or shoulder lane of the unidirectional half of a divided highway to conduct pavement repairs and desires further to effect a speed reduction to the construction area. Obviously, it would be difficult (if not impossible) even for this relatively uncomplicated situation to specify exhaustively all of the relationships noted above; however, it is feasible to attempt to delimit the problem and focus on information needs. This can be illustrated in the form of the following questions:

1. Regarding the road situation and actions -- at what point(s) must an action or definable part thereof be completed?

2. Regarding actions and decisions -- if an action takes a given time (or distance) to accomplish, what is the latest point in time or space that the decision must be made?

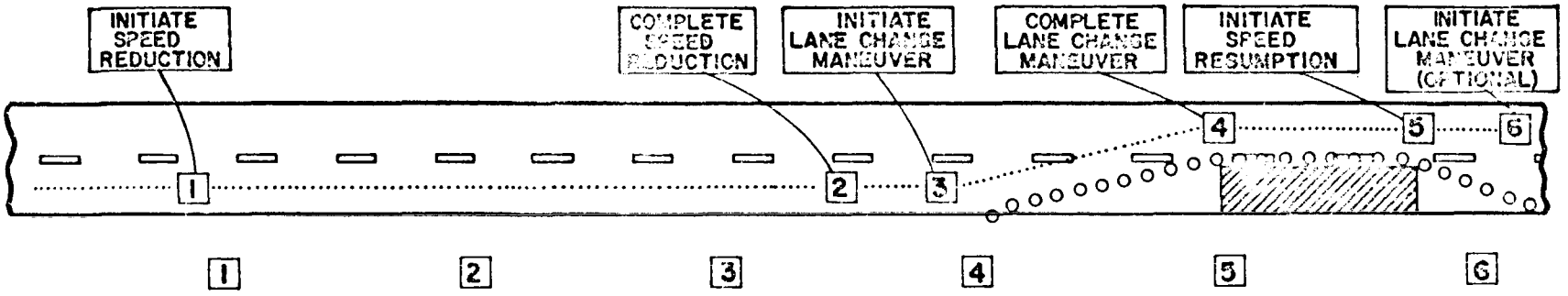
3. Regarding decisions and perceptions -- if a timely decision is to be made correctly (with a high degree of reliability), at what time or at what point must the required observations be made?

4. Regarding perceptions and stimuli -- if certain perceptions (observations) are required, what stimuli have a high probability of detection and sufficient information value to insure that they will be seen and understood at an appropriate point in time and space?

Figure 1 shows the unadulterated version of the hypothetical lane closure. Initiation and completion points of observable actions are shown by the number-keyed boxes. It should be recognized that the keyed requirements sequence represents a starting point, i.e., it refers only to the observable, required, critical actions related to guidance level performance. The translation of these actions to information requirements provides the "primary" requirements.

C. Derivation of "Non-Primary" Information Requirements

Generally speaking, the primary information requirements are related to the work zone features and the associated vehicle maneuvers required to safely negotiate a work zone of a given type. For a given work zone type, the non-primary requirements are those related to confirmatory and/or repeat information. Unfortunately the literature contains no relevant studies from which guidelines for repetition can be derived. While basic human information processing data and/or data on short-term memory capabilities immediately comes to mind as a means of estimating repetition requirements, consideration of the types of tasks which are used in such studies led to the conclusions that the generalization to the work zone driving situation was not warranted. Thus, the non-primary requirements associated with each specific work zone type were developed on the basis of human factors judgment. The judgments are based upon the consideration of factors such as the overall load of primary information, non-sign sampling load, e.g. gap



	1	2	3	4	5	6
ACTION	Initiate Speed Reduction	Complete Speed Reduction	Initiate Lane Change Maneuver	Complete Lane Change Maneuver	Initiate Speed Resumption	Initiate Lane Change (Optional)
DECISION	Begin decel when?	Sufficient deceleration?	When to merge into left lane?	Sufficient lateral adjustment?	Accelerate to posted speed?	Which lane to travel in?
INFORMATION	Sign: reduced speed limit Speedometer: current speed Other traffic Headway/tailway Vehicle feedback	Sign: speed limit Speedometer reading Other traffic Headway/tailway	Sign: lane closure Beginning of taper Lane lines Gap availability	Lane lines Channelizing devices End of taper Work area in sight	Sign: End construction Other traffic Headway	Desired speed Traffic density Termination channel Lane lines

Figure 1. Schematic of critical action points and associated IDA requirements sequence.

selection, high traffic volumes, etc., and the criticality of the information in terms of safety.

Another type of information requirement which may be primary or not, depending upon the situation, is that related to various types of hazards which may occur as a function of a particular operation. These requirements were identified on the basis of observations of hazards made during the collection of work zone field catalogs. Since many of the hazards which generated the requirements occur only during certain stages of an overall construction or maintenance operation, they may not be candidates for inclusion in the initial work zone traffic control plan, but should be considered in the overall planning effort as well as in the periodic inspections.

D. Derivation of Information Reception Location Requirements

As mentioned previously, the information reception location requirements are based upon models which take into consideration the time/distance factors associated with driver detection and recognition and the initiation and completion of the maneuver; e.g., Decision Sight Distance, Stopping Sight Distance, etc.

It should be noted that the recommended information reception locations do not represent the location of traffic control devices. Since devices will vary with respect to legibility characteristics, i.e. due to alternative size signs and/or legend vs. symbol signs, legibility distance must be taken into consideration in actually locating the devices. As such the actual location of signs selected to convey the information will vary as a function of the particular sign design characteristics.

CHAPTER III. FIELD DATA

The field data consisted of carefully documented catalogs of a variety of different types of work zones. The catalogs were used in several ways: (a) to exercise the analytically derived information requirements to determine their applicability over the range of situations encountered in the field; and (b) to identify the types of work zone hazards which are not necessarily associated with a given work zone type but which require that the driver be provided with information regarding the hazards; and (c) to identify the nature and extent of informational problems. The information derived from the field data was used as a basis for "fine tuning" the information requirements and for structuring the traffic control planning procedure.

This section describes the work zone sample, i.e., the number and types of work zones cataloged and encountered; the procedure used to obtain the catalog data; and the assessment procedure used to identify informational problems.

A. Work Zone Sample

The work zone catalogs were collected in eight states in the eastern part of the country, with southern and northern states represented in the sample. Table 1 shows the number of each of the work zone types which was established as a goal for the cataloging effort. The sites were located with the help of state transportation officials, who were asked to recommend routes representing each facility type where various types of work zones were most likely to be represented at the time of data collection. To avoid overrepresentation of the more common work zone types from a given area, several large circuits were made such that a portion of each state was sampled on each circuit. In this way samples of each work zone type were obtained from each state, thereby ensuring that the samples were not unduly biased for any given state and the appropriate range of variations was included in the overall sample. Upon achieving the goal number for each cell shown in Table 1, subsequent work zones encountered for that cell were noted and classified but were not cataloged. Since the work zone sample provided a reasonably unbiased representation of the eastern region, it was felt that a tally of the frequency with which each site type was encountered could be used to estimate the costs or benefits which might be associated with treatment of any given work zone type.

Table 2 shows the number of work zones of each type which were encountered, along with the number cataloged. However, it must be noted that many of the work zones represented in the matrix were "forced" into a classification. As will be discussed in detail later in this chapter, only 63% of the sites cataloged actually fit the existing definitions of the various work zone types established for this study. The remaining 37% were "composite" sites, i.e. work zones which contained features from two or more types. Thus the numbers appearing in Table 2 represent work zones classified according to the site feature that was judged to be most dominant.

B. Cataloging Equipment

Equipment in each cataloging vehicle included a 35 mm camera with power winder, a super 8 movie camera, a radar gun, and a Numetrics, Inc. distance

Table 1. Desired sample of work zones x facility type.

	FACILITY TYPE					
	2 LANE - 2 WAY		MULTI-LANE (NON-FREEWAY)		FREEWAY	
WORK ZONE TYPE	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL
ROADSIDE	5	5	5	5	3	3
SHOULDER CLOSURE	5	5	5	5	3	3
REDUCED LANE WIDTH	5	5	5	5	3	3
LANE CLOSURE	5	5	5	5	3	3
TEMPORARY DETOUR	3	3	3	3	2	2
LANE DIVERSION	3	3	3	3	2	2
DETOUR TO ALT. ROUTES	3	3	3	3	2	2
CROSSOVER	3	3	3	3	5	5

Table 2. Work zone types encountered and cataloged.

	FACILITY TYPE													
	2 LANE - 2 WAY				MULTI-LANE (NON-FREEWAY)				FREEWAY					
	URBAN		RURAL		URBAN		RURAL		URBAN		RURAL		TOTAL	
WORK ZONE TYPE	ENC.	CAT.	ENC.	CAT.	ENC.	CAT.	ENC.	CAT.	ENC.	CAT.	ENC.	CAT.	ENC.	CAT.
ROADSIDE	45	7	44	10	36	8	9	5	8	4	13	4	155	38
SHOULDER CLOSURE	26	7	23	5	19	5	6	6	7	4	13	6	94	33
REDUCED LANE WIDTH	29	8	9	6	12	6	2	2	8	4	2	2	62	28
LANE CLOSURE	24	10	18	10	89	20	21	12	5	4	28	13	185	69
TEMPORARY DETOUR	18	7	24	9	5	4	3	3	1	1	0	0	51	24
LANE DIVERSION	5	3	5	5	6	6	1	1	1	0	3	3	21	18
DETOUR TO ALT. ROUTES	19	4	19	8	16	4	4	4	4	3	5	4	67	27
CROSSOVER	N/A	N/A	N/A	N/A	38	4	10	4	1	1	2	2	51	11
MOVING	N/A	N/A	5	3	2	2	2	2	1	1	2	2	12	10

ENC. = Sites Encountered
CAT. = Sites Cataloged

measurement instrument (DMI), as well as back-up supplies and maintenance equipment.

The DMI is powered by the vehicle battery. A sensor is attached to the turning assembly of one of the front wheels to remain parallel with the inside rim of that wheel. To that inside rim are welded several targets. As the targets pass the sensor, impulses are transmitted to the display unit mounted on the dashboard of the vehicle.

After an initial calibration, several checks showed that the instrumentation read and displayed the distance the vehicle traveled with an accuracy of better than one foot per 1000 feet.

The DMI display can be controlled by off, start, hold, reset, data entry, and memory buttons. The memory button proved particularly useful. It allowed the cataloger to freeze the displayed distance as the driver drove past a device, while the system continued to operate. The operator could record the distance, then release the memory button and return the display to the continuous display mode. Thus the vehicle could catalog device location in a continuous pass under most circumstances. The DMI also had a reverse mode which permitted the vehicle to back up, and back-up distance would be subtracted from the distance of forward progress.

C. Work Zone Cataloging Procedure

Depending upon the complexity and type of work zone, a full catalog of data required four to six passes through the site. The first pass of the cataloging vehicle through any work zone was to allow the driver and cataloger to identify the work zone according to the type or types it resembled -- roadside, shoulder closure, reduced lane width, lane closure, detour to alternate route, temporary detour, lane diversion, crossover, or moving. The work zone was classified according to its dominant type and the other features it contained were noted. As mentioned, many of the sites were composite sites, i.e. where features of one work zone type were mixed with features of another type.

On the second pass through the work zone, after zeroing the DMI at the first warning sign of the work zone, the cataloger recorded the following data on a catalog form:

1) a code for each sign or other traffic control device encountered.

2) the distance of each device from the first warning sign of the work zone.

3) the color of a traffic control device if it was other than the orange and white or black characteristic of construction and maintenance zones.

4) whether the signs were gated, i.e., present on both sides of the road, or the location (left side of the road or right) of single signs on multi-lane roads. The location on two-lane, two-way roads is assumed to be the right side of the road unless otherwise noted on the catalog sheet.

5) details about the device, such as the lane and distance information of a sign that says LEFT LANE CLOSED 1500 FT (the device code refers only to a sign with ____ LANE CLOSED ___ FT), drawings of the symbol contained on a device, speed limit values for speed control devices, descriptions of signs for which no device code was listed, and whether a sign appeared to pre-date the establishment of the work zone, etc.

For continuous information in the form of channelizing devices -- series of drums, barricades, cones, panels, tubes, portable concrete barrier, etc. -- the device code and distance values were listed for the first and last devices of the series, along with the approximate interval between devices in the series, and on which side of the road the series was located.

For the third pass through the work zone, the cataloger started the automatic distance measurement instrument (DMI) when the legend, symbol, or figure on the first traffic control device in the work zone could be comprehended and stopped it at physical location of the device, thereby providing an estimate of legibility distance. Then the DMI was zeroed at the first device, and, as the cataloging vehicle traveled through the work zone, the cataloger activated the DMI memory button at the point he could comprehend the message, symbol, or figure of each device. That distance was recorded along side the already recorded distance of the device from the zero point. The difference between the two distances was a device's legibility distance.

The fourth pass provided information regarding the pavement striping and any changes in striping which occurred, along with the code for the new stripe. Center and right edge lines were recorded for two-lane, two-way roads; left edge line or center line, lane lines, and right edge line were recorded for multi-lane roads.

On the fifth pass through the work zone, the cataloger photographed each device via 35 mm camera. For a series of channelizing devices, the first and last devices were photographed for purpose of identification. In addition, some intermediate photographs were taken to provide a back-up estimate of the spacing. In some cases photographs were taken at regular intervals to provide back-up data as to the overall layout of the work zone. Selected work zones were recorded in super 8 movie film on yet another pass through the work zone. Finally, upstream and just out of sight of the first device, the cataloger obtained a 15 minute sample of approach speeds via a radar gun.

D. Work Zone Assessments and Review

The aspect of the assessment related to "fine tuning" the information requirements was in large part an exercise aimed at determining an appropriate level of specificity for the information content and presentation location requirements. As discussed previously, the initial set of primary information requirements was based upon a task analysis. Additional requirements, e.g. various types of warnings and support information, were based upon other human factors judgment, taking into consideration general knowledge regarding information processing performance, short term memory performance, etc. The information location requirements were based on a theoretical hazard avoidance model as reflected in the concepts of Decision Sight Distance (or some component thereof) and Stopping Sight Distance. Taken together, these analytic efforts resulted in a rather detailed set of

information prescriptions for various work zone types and work zone features. This attempt at highly specific guidelines was, in part, an attempt to merge several existing and widely accepted concepts into a unified approach to identifying driver information needs. It was also, in part, a reaction to a situation which has frequently been assumed to be a problem; namely, the lack of specific guidelines for designing and implementing driver information systems in work zones. To the extent that highly varied interpretations of general guidelines were manifested in inconsistencies in work zone information systems or to the extent that general guidelines involved judgments that ultimately resulted in informational problems, the goal of greater specificity seemed reasonable. However, at the same time it was realized that high specificity and usability (or at least user acceptance) are not always compatible. Also, it was realized that specific guidelines developed on the basis of an analysis of "ideal" work zone geometrics and layout could fail reasonable applicability standards when exercised on actual work zone designs. Thus, one aspect of the work zone assessments was to apply the analytically derived information prescriptions to actual sites so that application problems could be identified and evaluated. This effort resulted in modifications to various aspects of the requirements; primarily modifications to the specificity of the guidelines.

Each of the work zone catalogs was also reviewed in order to identify "other" information needs of drivers, i.e. those which could not be identified via task analysis. These needs are associated primarily with hazards that are contingent upon particular types of operations, stages of operation, etc.

The final element in the assessment and review procedure was to identify informational problems which represented lack of compliance with existing guidelines and standards.

E. Field Results

1. Work Zone Classification

As mentioned in Chapter I, the original intent of the project was to identify driver information requirements for at least the eight major types of work zones. The major types and the definitions established by FHWA for this study are as follows:

- Roadside - Where the work activity is taking place adjacent to the traveled way (i.e., in medians and in the area adjoining the outer edge of the roadway).

- Lane Closure - Where one or more lanes of a unidirectional traveled way are closed to traffic; i.e., the traffic in the lane to be closed ahead must move to an adjacent lane.

- Lane Diversion - Where one or more lanes are diverted from their normal paths. Traffic is not required to change lanes.

- Shoulder Closure - Where the shoulder (either outside or median) is closed to traffic.

- Reduced Lane Width - Where one or more traveled lanes are open to traffic but are reduced from their normal width.

- Crossover - Traffic is channeled into one or more lanes of the roadway normally used for traffic in the opposite direction. On divided highways, a temproary or existing connection between the two directional roadways is used to channel traffic to the opposite side. On undivided roadways, traffic is channeled across the old centerline of the roadway so that both directions of traffic are using the same side of the roadway.

- Temporary Detour - A temporary road is built to carry traffic around the work area. This bypass roadway may be either one-way or two-way.

- Detour to Alternate Routes - Where the roadway is completely closed for either one or both directions and traffic is rerouted onto alternate routes.

While the terms and associated definitions offer a convenient means to categorize work zones, only slightly more than 63% of the actual work zones cataloged fit the existing definitions. The remaining sites, while forced into a classification on the basis of dominant characterictics, were "composites" in that they contained features from two or more of the types as currently defined. Further, based upon the sample of composite sites reviewed, there was no patterning of individual features (in terms of the combinations or sequence of features) such that useful new definitions could be developed. Table 3 shows the percentage of each of the work zone types which actually fit the existing definitions, i.e. the pure types, and the percentage which contained additional features, i.e. composites. It should be noted, however, that the percentages associated with each site type provide only a general estimate in that there were a number of composite sites which were difficult to classify and could have fit one category as well as another. The overall percentage is, however, accurate, and the relatively high percentage of composite work zones dictated the need for "component" information requirements rather than work zone type requirements. In this way, any of the components can be combined in any sequence required.

Table 3. Pure vs. composite work zones.

WORK ZONE TYPE	% PURE	% COMPOSITE
Roadside	81	19
Shoulder Closure	84	16
Reduced Lane Width	69	31
Lane Closure	66	34
Temporary Detour	31	69
Lane Diversion	27	73
Detour to Alt. Route	58	42
Crossover	67	33
OVERALL	63	37

2. Problem Definitions and Examples

A total of 258 work zone sites were cataloged as part of the field data element of the study. Following a review of the set, 133 work zone sites were assessed. The difference in numbers results from the determination that, because of similarity, only a sampling of roadside, shoulder and reduced lane width work zone sites was required. An important component of the assessment effort was the identification of information problems. These problems were characterized as being one of eleven different problems. Operational definitions of the problems, along with examples of each are presented below.

Contradictory information - This is a situation produced by two or more signs. One of the more common occurrences results from a failure to remove or cover existing signs; for example, where a regulatory speed reduction is used in the work zone but where the existing speed signs contradict the reduced speed message. Other examples of contradictory information are:

- A sign indicates ROAD CONSTRUCTION 1000 FT. Downstream 300 feet (91.3 m) is a sign RIGHT LANE ENDS 1000 FT. Because the distances on both these signs should be measured to the same point, i.e. the beginning of the lane-closing taper, and because the RIGHT LANE ENDS sign is correctly placed, the ROAD CONSTRUTION 1000 FT sign is considered contradictory.

- There is a "countdown" sequence of three general warning signs, i.e. ROAD CONSTRUCTION 1/2 MILE, ROAD CONSTRUCTION 1500 FEET, etc. This sequence is followed by a section of roadway on which all work has been completed, at which time a new introductory countdown sequence begins. The failure to remove (or modify the content of) signs as work progresses is a problem which may reduce the credibility of subsequent portions of the information system on a site.

- The sign nearest to the desired position for a warning of a right lane closure indicates LEFT LANE CLOSED 500 FT. This is closely followed by the symbol sign for a right lane closure. This particular situation could also be classified under other problem categories. Because the LEFT LANE CLOSED 500 FT sign does not satisfy the location requirement for warning information at this work zone, it would also be classified as misplaced information even if the lane designation were correct. Further, since the beginning of the lane-closing taper is only 227 feet (69.2 m) from the LEFT LANE CLOSED 500 FT sign, this presentation would also be classified as misleading distance information.

- A sign indicating FLAGMAN 500 FT is located more than 1300 feet (396.2 m) upstream of the flagman. The distance is, of course, noted as misleading information. However, the device is also noted as contradictory because it disagrees with an identical sign (FLAGMAN 500 FT) accurately placed at that distance upstream of the flagman.

Misleading distance - an error category used when a sign identifies a downstream situation but includes an inaccurate distance to it. It should be noted that for purposes of assessing work zone problems, some discrepancy

between the signed distance and the actual distance was permitted. That is, if the actual distance was within 50 feet (15.2 m) shorter or 100 feet (30.5 m) longer than the signed distance no error was reported. Even this was perhaps conservative, particularly at the longer (i.e. 1000 feet (304.8 m) or greater) distances. Drivers have been shown to be poor at estimating distances without some aid, and the only available reference is the one-tenth mile indicator on the odometer. Thus any error less than 300 - 400 feet (91.3 m - 121.9 m) should not produce a significant problem.

- Warning information in a work zone on a multi-lane road indicates RIGHT LANE CLOSED 1/2 MILE, while the device is located only 920 feet (280.4 m) from the beginning of the lane-closing taper.

Misleading content - This problem is indicated when the legend or symbol on a sign is not consistent with downstream conditions.

- There is a BEGIN CONSTRUCTION sign at the end of a general ROAD CONSTRUCTION "X" FT countdown sequence. Evidence of construction does not appear until approximately 1/2 mile (805 m) downstream of the BEGIN CONSTRUCTION sign. Furthermore, the distance on the signs of the general warning countdown referred to the BEGIN CONSTRUCTION sign instead of to the first evidence of construction (misleading distance).

- It should be noted that the following example illustrates the problem category improper positioning, in addition to the category of misleading information: The information ONE LANE ROAD satisfies the warning requirement, i.e., it is properly located upstream of the right-lane closure on a multi-lane road. However, the sign is placed directly behind a telephone pole (improper positioning) so legibility and visibility are reduced. Furthermore, it is misleading (misleading content), because only one of the two lanes is closed in each direction.

- A MERGE LEFT sign serves as warning information for a diversion of two eastbound lanes on a city street. However no merge is required, only the shift left of both lanes of traffic to occupy the westbound two lanes, which are closed to oncoming traffic. The merge sign therefore is classified as misleading content.

Non-specific distance - This refers to a situation where the provision of distance information is advisable but where the sign provides only a general location of a downstream condition.

- A sign located to provide a warning is placed 1000 feet (304.8 m) from the beginning of a lane-closing taper and indicates LEFT LANE CLOSED AHEAD. It should provide the more specific information, e.g., LEFT LANE CLOSED 1000 FT unless the taper location is visible.

- A sign at the beginning of the work area in a work zone indicates ROAD CONSTRUCTION NEXT __ MILES. The space for the distance is left blank.

- A sign at the beginning of an area of shoulder work indicates LOW SHOULDER. It should have provided more specific information, such as, LOW SHOULDER NEXT "X" MILES.

Non-specific content - When the information a sign provides is accurate, but when more detailed information would be useful, the problem was classified under this category.

- A presentation at the beginning of the work area of a shoulder closure work zone indicates ROAD CONSTRUCTION NEXT X MILES. More appropriately the sign should specify SHOULDER CLOSED NEXT "X" MILES.

- A sign on a multi-lane road indicates LEFT LANE CLOSED 1/2 MILE when it should have more appropriately indicated LEFT 2 LANES CLOSED 1/2 MILE.

Improper or non-standard message - A sign may be specific in content, i.e. not really mislead the driver, but still provide a less than adequate message regarding the downstream situation.

- On an interstate, both northbound lanes are closed in a sweeping taper that diverts traffic to the right shoulder on a bridge and beyond. There is a passing prohibition sign in the approach area; however the device indicates NO PASSING ON BRIDGE. The message might lead the driver to assume that passing is permitted beyond the bridge, where it obviously is not intended to be.

- There is a SINGLE LANE AHEAD sign in the approach area of a lane closure on a two-lane, two-way road. It isn't misleading. The content seems specific enough. But it doesn't present quite the right message, because it doesn't identify if the driver's lane is closed to form the single lane, in which case a shift to the left would be required, or whether the oncoming lane is closed, in which case the driver might have to stop at a flagman but wouldn't have to change lanes.

- The symbol for keep right - an arrow curving around an obstruction - is used on channelizing devices in a taper and in the tangent section following the taper at a lane closure work zone on a multi-lane road. While the driver must keep right, the message is inappropriate because no obstruction exists.

Improper or non-standard use - This is a problem that results from using a device that is not designed for the situation, or from using it in less than the required quantity.

- A small black arrow on a white background is used at a lane diversion on a multi-lane road. The device is an inappropriate size for the speeds on the facility. It is also the wrong color (improper or non-standard color).

- A RIGHT LANE CLOSED 500 FT sign is gated with a DETOUR AHEAD presentation. Gated presentations should say the same thing. Each is marked as improperly used.

Improper or non-standard color - This problem results from use of a device that is not the orange and black or orange and white color desirable in construction zones.

- See first example under improper or non-standard use. Also, a flagman who isn't warning any orange clothing such as vest, shirt or jacket exemplifies this problem.

Improper or non-standard condition - When the legibility or visibility of a device is affected by age, dirt, or makeshift additions, this problem exists.

- An inapplicable distance is blacked out on a ONE LANE ROAD 1500 FT sign by covering it with a piece of wood. Doing so puts the device into an improper condition.

Improper or non-standard letters or symbols - When the legend or symbol appearing on a sign is not consistent with the specifications of the MUTCD or with other letters or symbols on the sign, this problem class is used.

- On a warning indicating RIGHT LANE CLOSED 500 FT, the 500 FT is in larger letters and is affixed to the sign.

- A piece of white tape formed into an arrow accompanies the legend on a DETOUR AHEAD sign.

Improper or non-standard positioning - This refers to the lateral position and/or height of a traffic control device.

- A sign is placed on the ground, propped against a barricade. It is not mounted at the height required by the MUTCD.

- A sign is placed off the shoulder so far that it may be missed by a driver. It also is not the distance from the edge of the road prescribed by the MUTCD.

3. Summary of Identified Field Problems

The problem related assessment data was segregated by work zone type. Within work zone type, data were categorized by type of roadway (multi-lane vs. two-lane two-way); work zone configuration (pure vs. composite); work zone duration (short term vs. long term).

Table 4 presents the breakdown by site type and category of the 133 different work zones assessed in the information problem identification effort. Fifty-nine percent of the work zones which were evaluated for informational problems are pure, i.e., they conform to one of the FHWA definitions established for this study. The remaining 41% of the work zones are composite sites. Most sites are long term work zones, i.e., longer than one working day duration. The short term sites are almost exclusively either of the lane closure or roadside/shoulder closure/reduced lane width types.

A glance at Table 4 shows that per cell work zone sample sizes are small; in many cases, zero. In very few instances does the available data permit

Table 4. Breakdown of number of work zones assessed by site type and characteristics.

SITE TYPE	MULTI-LANE				TWO-LANE TWO-WAY				TOTAL BY SITE TYPE	PERCENT BY SITE TYPE
	PURE		COMPOSITE		PURE		COMPOSITE			
	SHORT TERM	LONG TERM	SHORT TERM	LONG TERM	SHORT TERM	LONG TERM	SHORT TERM	LONG TERM		
LANE CLOSURE	6	12	2	4	7	--	--	4	35	26.3
DETOUR TO ALT. ROUTE	--	4	--	9	--	9	--	1	23	17.3
TEMP. DETOUR	--	2	--	3	--	6	--	13	24	18.0
CROSSOVER	--	6	--	3	--	--	--	--	9	6.8
LANE DIVERSION	--	3	--	5	1	--	--	4	13	9.8
SHOULDER CLOSURE, ROADSIDE, RED. LANE WIDTH	4	11	--	3	1	7	--	3	29	21.8
TOTAL BY SUB CATEGORY	10	38	2	27	9	22	--	25	133	100.0

quantitative statistical analysis. Furthermore, the intent of this element of the work zone assessment was to describe how well field implementation conforms to existing MUTCD guidelines and, where possible, to identify any site related effects of interest. Descriptive statistics are adequate to accomplish these objectives.

Work zone types will be examined to the level of detail possible. In most cases, this implies a fairly large amount of aggregation to ensure adequate cell sample sizes. Consider, for example, the most frequently assessed site, Lane Closure. A total of 35 work zones (26.3% of the total sample) were assessed. In evaluating these sites, a total of 130 different information problems were identified. Table 5 presents the frequency of occurrence by roadway types, work zone configuration and duration for each of the eleven identified problem categories. Note that the eleven information problems have been grouped into four major categories.

1. Misleading information
2. Non-specific information
3. Contradictory information
4. Improper or nonstandard application

Problems identified under categories 1 or 2 represent a lack of precision or specificity in the application of the MUTCD guidelines while problems identified under categories 3 and 4 represent an incorrect application with respect to the guidelines.

A glance at Table 5 indicates that the sample sizes do not permit meaningful statistical analysis at the level of detail shown on the table. In order to increase the sample size for purposes of analysis, aggregation of the problem related data is required. It should be noted, however, that data for each site type has been developed and recorded, at the very least, at the degree of detail contained in Table 5.

Table 6 presents summary statistics on the frequency of information problems observed at each work zone site type. Statistics for each site are summarized across all eleven information problems but broken out by roadway type, work zone configuration and duration: A number of interesting factors emerge. First, the vast majority of sites assessed were long term (84%). These sites exhibited nearly all the identified information problems (93%). One work zone type, Lane Closure, accounted for all 37 problems identified on short term sites even though comprising only 15 of the 21 short term work zones assessed. The relatively small amount of data from short term work zones suggests elimination of duration as a variable of concern. A further review of Table 6 reveals other items of interest. On comparing the mean frequency of identified problems per work zone one sees that composite work zone configurations have a mean value twice that of pure configurations. This is not illogical as the composite site is more complex and, thus, has more opportunity for problems to occur.

Furthermore, the percentage breakdown of identified problems as shown in Table 6 is not always consistent with the relative number of assessed work zones in each category (Table 4). For example only 38% of the Roadside/ Shoulder Closure/Reduced Lane Width work zones assessed were on two-lane two-way facilities, yet they accounted for 56% of all identified information

INFORMATION PROBLEM	MULTI-LANE PURE SHORT TERM	MULTI-LANE PURE LONG TERM	MULTI-LANE COMPOSITE SHORT TERM	MULTI-LANE COMPOSITE LONG TERM	TWO-LANE TWO-WAY PURE SHORT TERM	TWO-LANE TWO-WAY PURE LONG TERM	TWO-LANE TWO-WAY COMPOSITE SHORT TERM	TWO-LANE TWO-WAY COMPOSITE LONG TERM	TOTAL ALL SITES	TOTAL BY INFORMATION CATEGORY
MISLEADING										
a. Distance Info.	2	25	1	6	3			4	41	
b. Content	1	3	1	1	--			--	6	47
NON SPECIFIC										
a. Distance Info.	1	5	2	3	3			--	14	
b. Content	--	2	1	1	--			1	5	19
IMPROPER OR NON STANDARD										
a. Use	--	6	--	--	--			--	6	
b. Color	--	2	--	--	3			3	8	
c. Message	--	11	--	1	3			--	15	
d. Condition	2	2	1	2	--			--	7	
e. Letters/symbols	1	1	--	--	--			--	2	
f. Positioning	6	3	--	2	5			5	21	59
CONTRADICTORY INFORMATION	1	3	--	--	--			1	5	5
PROBLEM TOTALS BY SUB-CATEGORY	14	63	6	16	17	--	--	14		130

Table 6. Frequency of problems scanned by site type breakdown.

SITE TYPE	MULTI-LANE					TWO-LANE TWO-WAY					TOTAL ALL SITES
	PURE		COMPOSITE		TOTAL MULTI-LANE	PURE		COMPOSITE		TOTAL TWO-LANE TWO-WAY	
	SHORT TERM	LONG TERM	SHORT TERM	LONG TERM		SHORT TERM	LONG TERM	SHORT TERM	LONG TERM		
LANE CLOSURE	14	63	6	16	99	17	--	--	14	31	130
DETOUR TO ALT. ROUTE	--	12	--	51	63	--	19	--	2	21	84
TEMPORARY DETOUR	--	3	--	34	37	--	12	--	105	117	154
CROSSOVER	--	38	--	15	53	--	--	--	--	--	53
LANE DIVERSION	--	12	--	40	52	--	--	--	16	16	68
SHOULDER CLOS., ETC.	--	10	--	18	28	--	13	--	23	36	64
TOTAL NUMBER OF PROBLEM OCCURRENCES	14	138	6	174	332	17	44	--	160	221	553
TOTAL NO. WORK ZONES IN CATEGORY	10	38	2	27	77	9	22	--	25	56	133
MEAN NO. PROBLEMS IN WORK ZONE CATEGORY	1.4	3.6	3.0	6.4	4.3	1.9	2.0	--	6.4	4.0	4.2

problems. Considering that Roadside/Shoulder Closure/Reduced Lane Width conditions are more likely to have a more adverse safety effect on drivers on two-lane two-way routes, this disproportionate representation is of concern. In general, however, work zones on multi-lane facilities exhibited a greater percentage of information problems than expected based solely on the number of work zones in each roadway category. The most extreme multi-lane variation observed was in the Detour to Alternate Route work zone type where 57% of the work zones accounted for 75% of all identified problems.

Problem Frequency By Information Type

As indicated earlier, identified problems are classified into one of four possible major information categories. Table 7 presents the frequency of ocurrence of observed information problems, by major category for each work zone site type. All problems regardless of roadway type, work zone configuration or duration are aggregated.

Table 8 indicates the percentage distribution of problem occurrence by information category within work zone type. Overall, misleading information, either distance or content related, was the most frequently observed problem. This is true for all work zone types with the exception of Lane Closure where improper and/or non-standard application of information was the most frequently observed problem. Table 8 indicates that the actual occurrence of contradictory information was a comparatively rare event, averaging 4.5% of all work zones assessed and ranging from 0% for Roadside/Shoulder Closure/ Reduced Lane Width sites to 7.5% for crossover sites. Although the relative percentage of contradictory information is low, it is important to note that it was identified as a problem in 12% of all work zones assessed, a not inconsiderable number. Improper and/or non-standard application of traffic control devices, e.g. wrong use, color, message, positioning, accounted for nearly 30% of all problems identified at all work zones assessed. It ranged from a low of 12.5% of the Roadside/Shoulder Closure/Reduced Lane Width problems to a high of 45.5% of all problems identified in Lane Closure work zone sites.

As noted earlier contradictory information and improper/non-standard application represent violations of the guidelines. That is, the actual field use is incorrect in terms of the MUTCD guidelines. Approximately 34% of all problems identified in the field assessment represent incorrect applications of signs in terms of MUTCD guidelines. Rather dramatic work zone type dependent differences exist. Roadside/Shoulder Closure/Reduced Lane Width sites exhibited a low degree of incorrect information or applications of TCD's (12.5%). This is logical as the comparatively simple work zone information requirements both in type and number of devices tend to preclude these forms of errors. At the other extreme, nearly 50% of all Lane Closure work zone related problems represent contradictory information or improper/non-standard application of TCD's. As indicated on Table 5, 56% (36 of 64) of these MUTCD guideline errors had to do with improper/non-standard message and positioning.

Generality of Informational Problems

It is not enough to assess the frequency of problem occurrence as the summary values could represent many problem free sites with only a few

Table 7. Frequency of occurrence of problems by site type and major information category.

INFORMATION PROBLEM CATEGORY	LANE CLOSURE	DETOUR TO ALT. ROUTE	TEMP. DETOUR	CROSS-OVER	LANE DIVERSION	ROADSIDE, ETC.	TOTALS
MISLEADING INFORMATION	47	29	71	27	29	38	241
NON SPECIFIC INFORMATION	19	27	33	13	12	18	122
CONTRADICTORY INFORMATION	5	6	8	9	2	--	25
IMPROPER OR NON STANDARD APPLICATION	59	22	42	4	25	8	165
TOTALS	130	84	154	53	68	64	553

Table 8. Problem frequency (%)
by major category.

INFORMATION PROBLEM CATEGORY	LANE CLOSURE	DETOUR TO ALT. ROUTE	TEMP. DETOUR	CROSS-OVER	LANE DIVERSION	SHOULDER ROADS., ETC.	TOTALS
MISLEADING INFORMATION	36.1	34.5	46.1	50.9	42.7	59.4	43.6
NON SPECIFIC INFORMATION	14.6	32.1	21.4	24.6	17.7	28.1	22.1
CONTRADICTORY INFORMATION	3.8	7.1	5.2	7.5	2.9	--	4.5
IMPROPER/NON STANDARD APPLICATION	45.5	26.3	27.3	17.0	36.7	12.5	29.8

problem sites. Conversely, there could be many sites exhibiting one problem each. Table 9 presents the percentage of sites of each work zone type experiencing each of the eleven types of information problems. Some problems are widespread, e.g., misleading distance information which was observed at 63% of all sites assessed. Others are much more limited, e.g., misleading content observed only in 12% of the sites. Non-specific presentations are generally widespread, over 30% of all sites. Within site variations are worthy of attention. For example, nearly 40% of all Lane Diversion sites exhibited some improper or non-standard positioning problem. Nearly 46% of all Temporary Detour sites had some improper or non-standard message problem.

A Summary Comment

The field assessment effort indicates that information related problems are widespread and varied. A surprisingly large percentage (34%) represent violations of the MUTCD guidelines. The remaining two-thirds represent problems such as distance information at variance with reality or lack of specificity in distance or content information. Composite sites exhibit more problems per site on the average than do pure sites, a not unexpected finding.

The results of this element of the study indicate that a real need exists to (a) ensure better conformance with the MUTCD guidelines and (b) tighten up the guidelines with respect to distance and content specificity.

Table 9. Percent of work zones in which problems occurred.

INFORMATION PROBLEM	LANE CLOSURE	DETOUR TO ALT. ROUTE	TEMP. DETOUR	CROSS-OVER	LANE DIVERSION	ROADSIDE SHOULDER, ETC.	TOTALS
MISLEADING							
a. Distance Info.	51.4	52.2	79.2	100.0	76.9	55.2	63.2
b. Content	14.3	4.3	12.5	--	15.4	17.2	12.0
NON SPECIFIC							
a. Distance Info.	31.4	39.1	37.5	88.9	53.8	17.2	36.8
b. Content	11.4	39.1	50.0	22.2	38.5	27.6	30.1
IMPROPER OR NON STANDARD							
a. Use	5.7	17.4	8.3	11.1	15.4	3.4	9.0
b. Color	17.1	4.3	--	--	15.4	--	6.8
c. Message	28.6	4.3	45.8	22.2	15.4	6.9	21.1
d. Condition	11.4	21.7	8.3	--	15.4	6.9	11.3
e. Letters/symbols	5.7	8.7	16.7	33.3	7.7	--	9.0
f. Positioning	28.6	13.0	20.8	--	38.5	6.9	18.8
CONTRADICTORY INFORMATION	11.4	17.4	16.7	22.2	15.4	--	12.0
NUMBER OF WORK ZONES IN EACH SAMPLE	35	23	24	9	13	29	133

CHAPTER IV: DRIVER INFORMATION NEEDS

A. Introduction

The original intent of the study was, as mentioned previously, to develop driver information requirements for each of the eight work zone types specified. However only about 60% of the work zones encountered during the field data collection effort fit the classification for which these requirements were developed. The remaining 40% of the work zones were of the "composite" variety, i.e., contained features from two or more of the definitions. Further, even the work zones which fit the exisitng definitions exhibited a great deal of within-class variety due to pre- existing geometric and situational conditions which were accommodated within the work zone. For these reasons it was decided that the most reasonable way to deal with the range of unique work zone layouts that existed in the field was to develop a procedure which could be easily applied and would result in site specific or "tailored" information systems.

The procedure includes not only suggestions as to what type of information drivers need (information content), but also guidelines regarding where drivers should receive such information (information reception locations). That reception location requirements are a necessary part of the overall information requirement guidelines is based upon the problems identified from the assessments of work zones. That is, there were more problems associated with the location at which drivers were given information than with the type of information they were given; the primary problem being failure to provide warning information within an adequate time frame. Further, this problem was more prevalent on "composite" sites, where adjacent geometric features were frequently spaced so closely that it was not possible to provide sufficient information for each without mixing the information components. This, of course, sometimes resulted in high information loads and potentially confusing situations for the driver. Problems of this sort may have resulted for several reasons. First, the existing standards, guidelines, and illustrations for work zone traffic control tend to deal with typical situations and contain little specific information regarding how to go about developing a traffic control plan for the sort of composite sites which frequently occur. Hopefully, the procedure will aid in rectifying this problem. The other possible reason is that the development of the traffic control plan may not be a part of the overall construction planning and evaluation process, but may be done after a design and layout has been selected. While a number of geometric features of a work zone may be fixed because of the work required, there is frequently some leeway with regard to the location of features such as temporary detours, lane closure tapers, etc. As such, a traffic control plan evaluation conducted as part of the overall design process, i.e. before the final construction plan is selected, would act to identify adjacent geometric features which could be separated to provide more adequate space for driver information. This would reduce the types of problems which are frequently encountered on composite sites.

Before proceeding into the background and the procedure itself, it is important to note that the procedure is seen as a supplement to the standards and guidelines in Part VI of the MUTCD. While the procedure provides guidelines (or recommendations) which are more specific than the current manual with regard to where drivers should receive information and, in some cases,

the information content which should be provided, it is not in conflict with the MUTCD. Further, as will be obvious, the guidelines are just that; they do not substantially reduce the need for the same engineering judgment and analysis typically employed. This chapter contains a description of the procedure suggested for the development of work zone signing plans. The section following the procedure presents suggestions as to the types of information to be used for various work zone features.

B. Background and Definitions

The procedure described here was developed to serve two major purposes: (1) to provide specific guidelines regarding where to present signing information to drivers in order to avoid problems associated with inadequate warning distances; and (2) to provide general guidelines related to information priorities to aid in resolving information conflicts which would otherwise lead to driver confusion. While the application of the procedure and the associated information requirements will not produce a final traffic control plan, it will hopefully focus the required engineering judgments on the problems noted above and thereby result in more adequate work zone information systems for the driver.

The first step in developing the procedure was to review all the work zone layouts from the field and to identify each work zone feature which was to be treated separately with regard to the information requirements. The rationale underlying the development of requirements for separate features rather than for entire layouts is that the requirements for the individual features can then be combined and the information system can be developed to accommodate any combination and sequence of features and will therefore be applicable to any work zone layout. The features and operational definitions of each are presented in the following subsection. Following the identification of the separate features, the driver maneuver associated with each was identified and the task analysis information was used to identify the driver information needs for each. The maneuvering requirements were also used as a basis for determining where drivers should receive information. Finally, the various types of work zone information were classified and general guidelines for determining information priorities were established.

1. Work Zone Features and Driver Maneuvers

It should be noted that the following discussion of work zone features is restricted to those major features necessitated by the construction activity. The terms used to identify major work zone features correspond to the terms originally established to label the various work zone types. However, the multi-lane crossover as originally defined involves a lane closure in advance of the crossover section. For purposes of applying the procedure, the lane closure and the crossover features are considered separately to identify the information needs and the reception locations for each. The individual work zone features for which information requirements have been derived are described below:

(a) Roadside - This feature involves work for which full use of the shoulder can be maintained and where there is no potential interaction between driver and workers or equipment. As such there is no maneuver required of the driver. This feature is included because it is necessary for

drivers to be made aware of the activity to avoid potential problems of unnecessary speed reductions and/or lane changes which may otherwise occur when the operation is directly observed.

(b) Shoulder Closure - This feature can involve actual activity on the shoulder of the roadway or, during some stages of a project, may involve construction-related conditions such as soft shoulder or shoulder dropoffs which require the shoulder to be closed. Depending upon the severity of the condition, e.g. depth of dropoff, and whether or not a physical separation between the shoulder and lane edge is employed, the only driver maneuver likely to be required is a speed reduction.

(c) Reduced Lane Width - The only maneuver likely to be required for this feature is a speed reduction. This will depend upon the useable pavement width and whether the feature is on a multi-lane or a two-lane/two-way facility.

(d) Lane Closure (Multi-Lane) - The lane closure on a multi-lane facility is a feature involved in many of the more complex work zones. Further it is frequently the first major feature encountered by the driver. As such, the potential for driver expectancy violation to have a negative effect on response time is higher than for many of the other features. The driver maneuver required is a lane change. However, unlike maneuvers associated with many of the other features, where the geometrics dictate that all drivers perform the required maneuver at approximately the same location, it is desirable to have lane change initiation locations well distributed over the approach to the lane-closing taper. The lane closure requires greater visibility distance and greater warning distance than many of the other features so that a desirable distribution of lane changes can be accommodated.

(e) Lane Closure (Two-Lane/Two-Way) - The lane closure on a two-lane/two-way facility requires that the driver be prepared for a full stop, usually at a flagger or signal. On a rural two lane facility, i.e. an open road situation, the requirement to come to a full stop represents a significant violation of driver expectancy when the lane closure is the first feature encountered by the driver. Where the lane closure is located on a section that is normally a passing zone, information regarding prohibition of passing must also be considered.

(f) Crossover, Detour, Temporary Detour, Lane Diversion Turn/Curve Each of these four features, while differing with respect to driver information needs, requires the driver to negotiate a turn or curve. It is the transitional turn/curve which is used to determine the information reception location for each of these features. An additional critical information element for the two-way traffic section of the crossover feature, when designed without positive physical separation of opposing flows, is prohibition of passing maneuvers.

2. Information Classes

The purpose of this section is to describe the various classes of information which drivers may need and to provide a general indication of the suggested information content for the signs in each information class. The specific information requirements suggested for each work zone feature are

presented in Section D of this chapter. Before proceeding, it should be noted that general construction approach warnings are not dealt with here. This is not meant to imply that such information is unnecessary. Rather, the field data indicated that there were few problems associated with this class of information, suggesting that the existing guidelines are adequate.

(a) Feature Warning - This information identifies the work zone feature to be encountered, e.g. lane closure, shoulder closure, etc. Another element of feature warnings is the specific distance to the beginning of the feature. Where the work zone feature requires a major maneuver, i.e. lane change, stop or turning/curve maneuver, the feature warning is supplemented by a maneuver warning (see next class). However, where no maneuver is required or where only a speed reduction is required, the feature warning requires no supplement.

(b) Maneuver Warning - This information identifies what the driver must do to negotiate features that demand lane changes, turns, or stops. An important element of maneuver information is the distance to the desired maneuver initiation point. The maneuver warning "prepares" the driver for a maneuver.

(c) Feature Location - This information identifies the beginning of the feature, which is also the location at which or by which any associated maneuver must be accomplished.

(d) Prohibitory/Restrictive Warning - This class of information identifies downstream restrictions on the types of maneuvers which are permitted, e.g. passing, lane changing, etc.

(e) Prohibitory/Restrictive Location - This information identifies the physical loction where the maneuvering prohibition or restriction begins and/or ends.

(f) Speed Advisory, Speed Change Warning, and Speed Limit - Speed advisory information may be presented to the driver through the use of advisory speed plates. Advisory speed plates may be used in conjunction with any standard warning sign to indicate the maximum recommended speed. Advisroy speeds do not require a speed change warning. However, where the use of a regulatory speed is deemed necessary, the use of a speed change warning sign is recommended. Further, since regulatory speed limit information is presented via separate signs, rather than presented in conjunction with warning signs, the speed limit signs and speed change warnings must be integrated into the overall information system layout.

(g) Route Guidance - This information is required only for detours to alternate routes. When all traffic must leave the roadway at the same location, the presentation of route guidance information within the work zone is not critical. Where the information load related to other aspects of the work zone is already high such information can be presented outside the work zone, i.e. on the roadway, ramp, street, etc. approaching the alternate route.

(h) Confirmation - The need for confirming information depends upon the length of various site features and the risk associated with performing

or failing to perform a given maneuver. For example, a long crossover section where opposing traffic is not positively separated requires confirmation of the passing prohibition and confirmation of the existence of two-way traffic. Also, where a reduced speed is required, the driver should be periodically reminded of the reduced speed limit. Conditions such as soft shoulders or shallow shoulder dropoffs that continue for long distances but are not severe enough to require drums, barricades, etc., also require that drivers be reminded of the hazard. In other words, the need for confirmation of any given type of information must be based upon engineering judgment as do decisions as to the intervals at which the confirmatory signs should be placed. Where confirmation is judged to be sufficiently critical that a constant reminder is necessary, legibility distances associated with the particular devices can be used to determine the interval.

3. Driver Maneuvers and Information Reception Locations

The guidelines as to where drivers should receive various classes of information, referred to as information reception locations, are based upon the range of times required by drivers for: detection and recognition, decision and response initiation, and completion of a maneuver.

All of the values used are derived from two sources: (a) A Policy on Design Standards for Stopping Sight Distances (AASHTO-1971); (b) Decision Sight Distance for Highway Design and Traffic Control Requirements (McGee, et. al.; 1978 - Rept. No. FHWA-RD-78-78). With regard to Decision Sight Distance (DSD), both the total DSD value and the component values are used, depending upon driver requirements. Figure 2 and Table 10 show the Decision Sight Distance components from which some of the values are derived. The specific values recommended are based upon the driver maneuver required in a given situation. The speed/distance tables used to identify information reception locations are given in Section C, which details the procedure for deploying signs in a work zone. Also provided as part of the procedure are the reference points from which the various reception locations are measured. The following discussion details the relationship between driver maneuvers and the values used to determine information reception locations.

(a) Turning Maneuver - For work zone features which require the driver to negotiate a turn or a curve, e.g., crossover, temporary detour, etc., the use of the entire Decision Sight Distance value is recommended for determining the reception location of the maneuver warning. The recommended reception location of the feature warning for these features is based upon the Detection/Recognition component value, measured upstream of the maneuver warning reception point.

(b) Lane Change Maneuver - A lane change maneuver for a single vehicle under low volume conditions uses Decision Sight Distance as a basis for determining the reception location for the maneuver warning, and Detection/Recognition distance for the feature warning. However, from a practical standpoint, the lane change maneuver is most frequently associated with a lane closure on a multi-lane roadway; a feature which is frequently the first encountered. As such, the warning information system must be deployed to allow time for the driver to select a gap before initiating the lane change. Further, the warning system must be deployed such that it results in a favorable distribution of lane changes on the approach to the

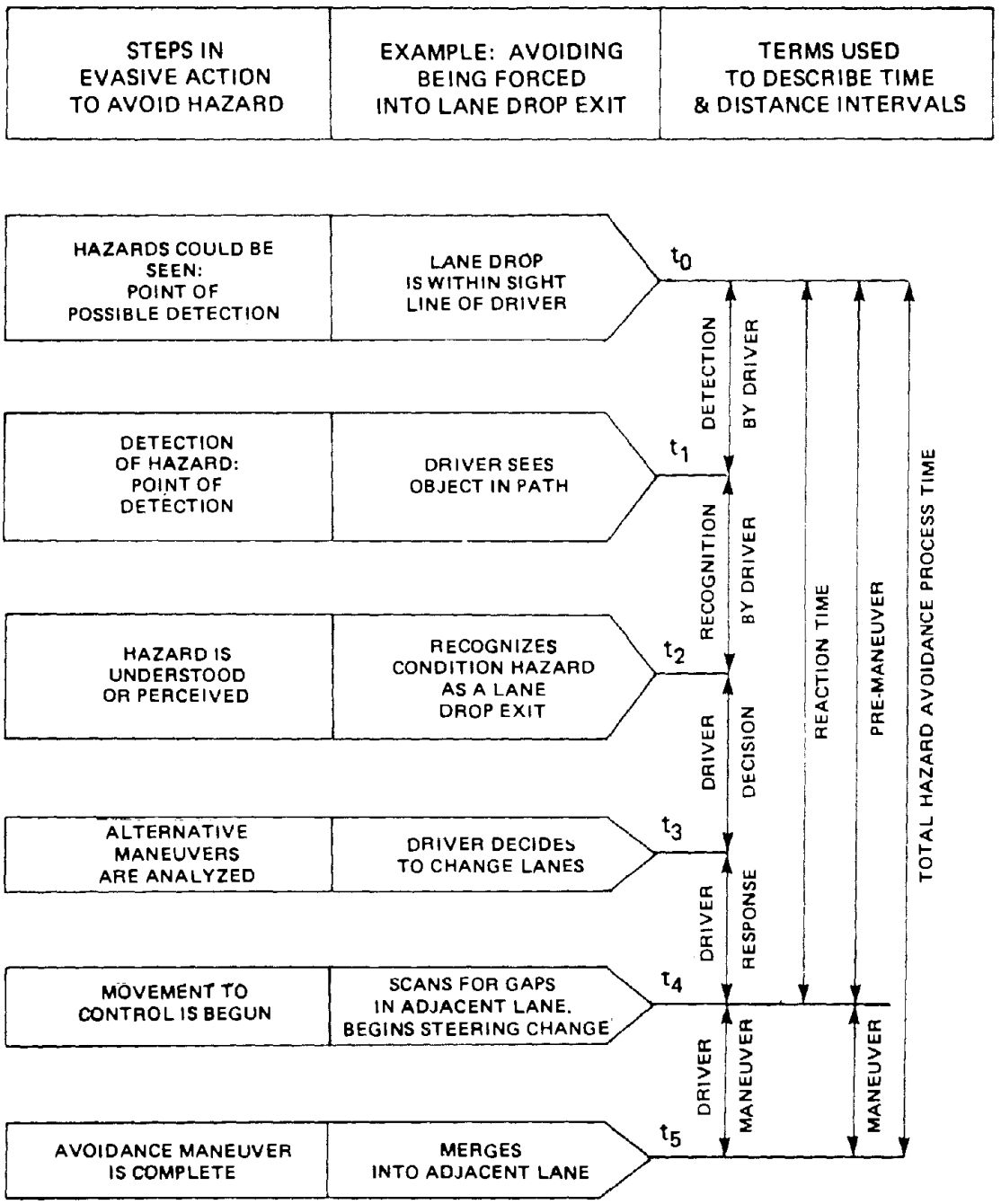


Figure 2. Decision sight distance hazard avoidance process.

Table 10. Decision sight distance components.

Design Speed (mph)	Times (Seconds)				Decision Sight Distance (ft)	
	Pre-Maneuver		Maneuver (Lane Change)	Summation	Computed	Rounded For Design
	Detection & Recognition	Decision & Response Initiation				
30	1.5	4.2 – 6.6	4.5	10.2 – 12.6	449 – 554	450 – 550
40	1.5	4.2 – 6.6	4.5	10.2 – 12.6	559 – 739	575 – 750
50	1.5	4.2 – 6.6	4.0	9.7 – 12.1	711 – 887	725 – 900
60	2.0	4.7 – 7.1	4.0	10.7 – 13.1	942 – 1153	950 – 1150
70	2.0	4.7 – 7.1	3.5	10.2 – 12.6	1057 – 1294	1050 – 1300
80	2.0	4.7 – 7.1	3.5	10.2 – 12.6	1197 – 1478	1200 – 1475

1 mph = 1.609 km/h
1 ft = 0.3048 m

lane closure. For this reason, the warning distances specified in the MUTCD for lane closures on multi-lane roadways are recommended in lieu of Decision Sight Distance.

(c) Stopping Maneuver - Where the work zone feature is such that it is necessary for drivers to stop, the recommended reception location of maneuver warning information is based upon the Stopping Sight Distance value. For situations where the necessity of a stop is uncertain, the recommended reception location is based upon a combination of the Premaneuver component of DSD, plus the braking distance component value of Stopping Sight Distance. The rationale underlying the choice of this combination of components is that the driver must deal with some uncertainty regarding what must be done and the increased distance resulting from the combined values provides greater time for the driver decision process.

(d) No Maneuver Required - Where the driver must simply be made aware of a feature or activity but where there is no actual maneuver required, the reception location of the feature warning is based upon the Detection and Recognition component value of Decision Sight Distance.

Section C of this chapter presents tables for all of the values discussed above and identifies the specific situations under which each is used.

4. Resolving Information Conflicts

In designing the traffic control plan for a work zone layout there are likely to be situations where the recommended information reception locations for adjacent features or conditions are in conflict. That is, there may be situations where sign placement based on these reception points may overlap to produce a confusing situation for the driver. In the planning process these conflicts can be resolved in several ways. Conflict resolution is involved in several steps in the procedure that follows in Section C.

One consideration in resolution is the priority of the conflicting information. Elements comprising any work zone are designated as either Group I or Group II. Features requiring a lateral change of position (e.g. crossover or lane closure -- multi-lane road) or a stop (e.g. lane closure, two-lane, two-way road) are designated as Group I features. Those not requiring a major maneuver or, at most, necessitating a speed change (e.g. shoulder closure, reduced lane width) are designated as Group II.

Information relating to Group I features within the work zone generally has a higher priority than information associated with Group II features. That is, if any information location conflicts occur between Group I features and Group II features in developing the traffic control plan, they will be resolved by giving priority to Group I and making adjustments in the Group II information reception locations.

Another consideration in conflict resolution is whether a feature is fixed or relocatable. That is, some features will be a direct function of the construction/maintenance activity and will be fixed at a given location. The location of others, e.g. a lane closing taper, may be discretionary. Where this is the case, some conflicts can be resolved by relocating the feature upstream or downstream to provide adequate space for the warning

signs required.

C. Procedure for the Development of Work Zone Signing Plans

The initial series of steps indentifies the general layout of the work zone in that it identifies the location and sequence of work zone features.

An illustrative work zone layout is used to provide examples of the application of selected procedural steps (Figures 4 through 8). The work zone used for the illustrations represents an actual layout encountered during the field data collection and is shown in Figure 3. Note that in the illustrative layout the driver traveling on the two-lane, two-way road entering Figure 3 from the left encounters: (a) two lanes, one way in his direction as the roadway becomes multi-lane; (b) a shoulder closure 600 feet long when he is about 1250 feet into the multi-lane roadway; (c) a lane-closing taper of only 250 feet immediately following the shoulder closure; (d) a curve to a crossover section immediately following the lane-closing taper; and (e) a curve to a detour route only 700 feet into the crossover section. Note that the material shown in "boxed" format presents an explanation of the various steps in the procedure as they apply to the illustrative work zone.

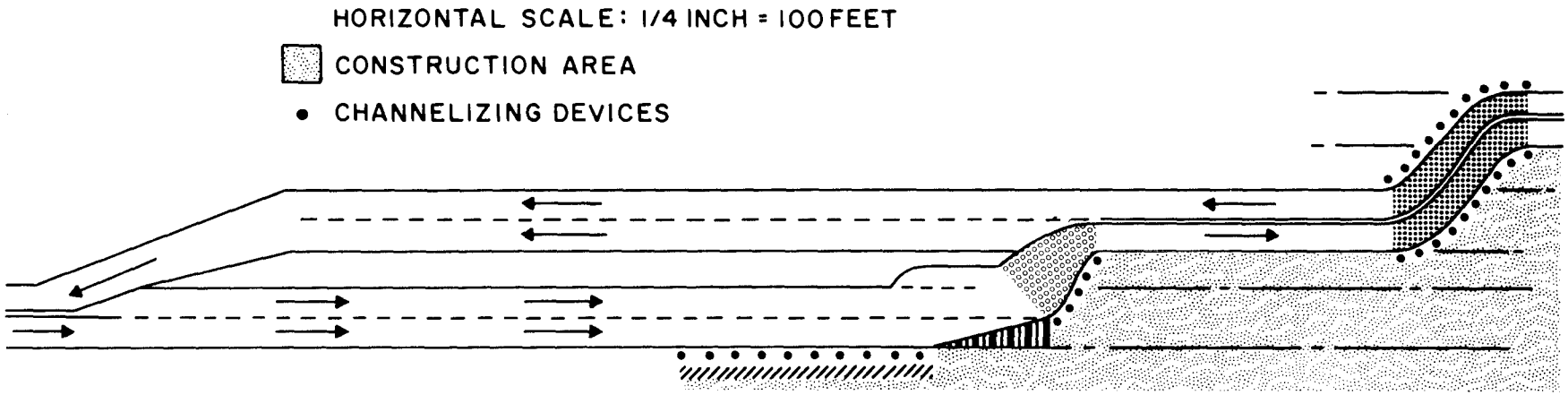
Step 1 - Identify Work Zone Features: Refer to Table 11*, and identify all features projected for the work zone.

Step 2 - Locate Work Zone Features on Plan View: Identify the start points and termination points, i.e. the area covered, for each feature, and tentatively locate each on a plan view of the site. Considering the anticipated traffic volume (particularly volume peaks) and the potential capacity reductions associated with each feature, also identify features at which queues are likely to form. Estimate the maximum queue length expected and modify the "start" points of these features as necessary to accommodate the estimated queue. For example, if heavy volume is expected to cause a 1/4 mile queue (402 m) upstream of the beginning of a lane-closing taper (the normal "start" point of a lane closure feature), the new "start" point (beginning of the feature) will be 1/4 mile (402 m) upstream of the beginning of the lane-closing taper. If the queue is expected to last only for a short period, e.g. 1/2 hour during morning rush hour, consideration should be given to treating the situation via temporary signs such as WATCH FOR STOPPED TRAFFIC or BE PREPARED TO STOP. Figure 3 shows the location of the features being dealt with in each of the subsequent illustrations.

Step 3 - Review Original Signing & Marking Plan: Identify all existing signs and markings that must be covered or removed.

Step 4 - Identify Controlling Maneuvers: With reference to Table 11, note on the site plan the controlling maneuver, i.e. stop, lane change, or curve/turn, associated with each feature. The type of controlling maneuver determines the location of warning

*All referenced tables are presented following the final procedural step.



	FEATURES (L. to R.)
1	SHOULDER CLOSURE
2	LANE CLOSURE
3	CURVE TO CROSSOVER SECTION
4	CURVE TO ALTERNATE ROUTE (DETOUR)

Figure 3. Example work zone layout.

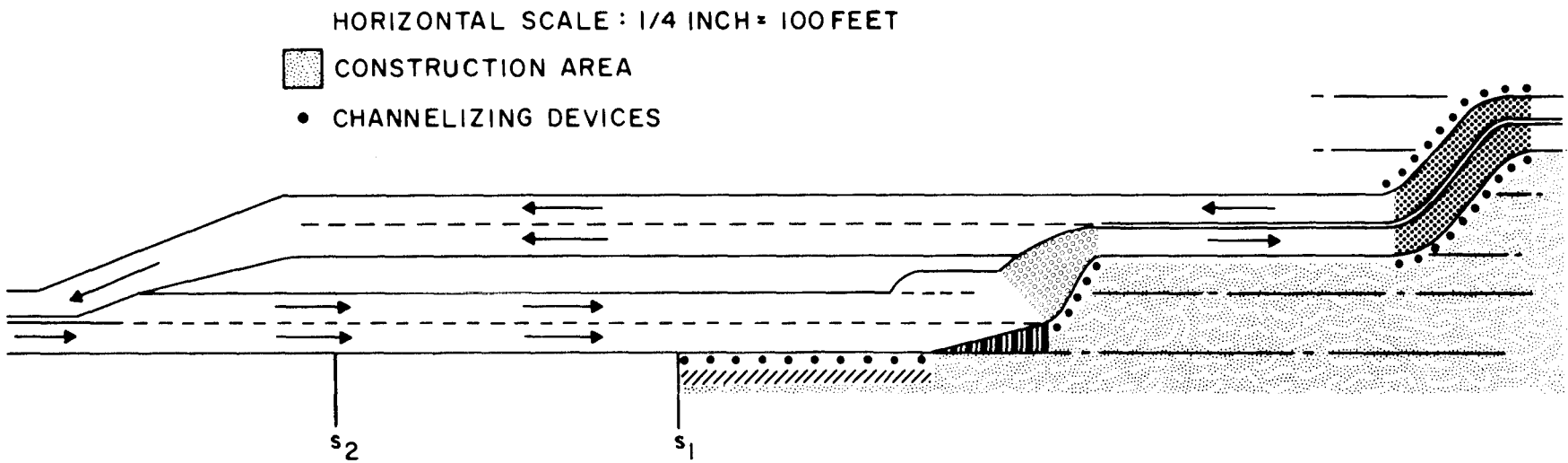
information. For later reference designate features that have a controlling maneuver as Group I and those that demand no maneuver or require only a deceleration as Group II.

Step 5 - Estimate Approach Speeds: This step requires an estimate of driver approach speeds to each feature. Approach speed estimates identify where to enter the tables used for determining the reception location of the feature warning and/or maneuver warning information. Approach speeds may be influenced by work zone geometrics and/or speed signs. Therefore, after evaluating the geometrics of each feature, tentatively locate where the driver should receive speed reduction information, if any, upstream of each feature. Allow sufficient distance for any speed reduction to be stepped down by a maximum increment of 10 mph, as stated in the MUTCD guidelines. Speed reduction information may be in the form of advisory plates or speed limit signs. Based upon the geometrics, the projected location of all speed reductions, and the probable effectiveness of the projected speed reductions, estimate and note on the site plan the estimated approach speed associated for each feature.

> For the illustrative work zone, the curve to the crossover section and the curve to the alternate route that quickly follows, suggested that the speed limit of 55 mph on the approach should be reduced to 35 mph for entry to the crossover curve. Figure 4 shows the tentative locations of the speed information. The approach speed to each of the four features was estimated as shown in Figure 4. Also shown are the controlling maneuvers and the maneuver designations from Step 4.

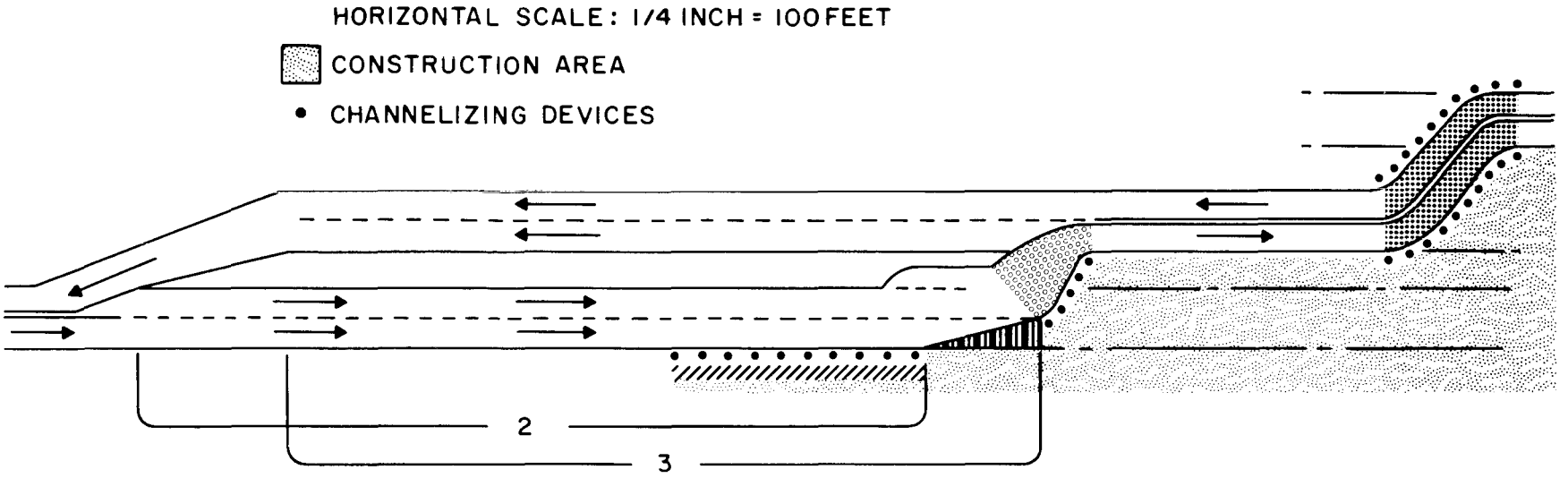
Step 6 - Identify Fixed and Relocatable Features: Note on the site plan which features are fixed in location and which can be relocated upstream or downstream. For those that can be relocated, mark the physical or practical limits of relocation on the site plan. Relocation may be limited by entrance or exit ramps, variations in median, etc. Figure 5 illustrates the notation from Step 6.

> In the illustrative layout, the lane closure and curve to the crossover section are relocatable features but can be moved only upstream. The curve to the crossover section can be relocated upstream as far as there



	FEATURES (L. to R.)	(GROUP)	CONTROL. MANEUVERS	SPEED LIMIT SIGNS (TENTATIVE)	ADVISORY SPEED PLATES	ESTIMATED APPROACH SPEED
1	SHOULDER CLOSURE	(II)	NONE			55
2	LANE CLOSURE	(I)	LANE CHANGE			55
3	CURVE TO CROSSOVER SECTION	(I)	CURVE	s_1 = 35 mph s_2 = 45 mph		45
4	CURVE TO ALTERNATE ROUTE (DETOUR)	(I)	CURVE			45

Figure 4. Procedural steps 1 through 5.



	FEATURES (L. to R.)	LIMITS OF RELOCATION
1	SHOULDER CLOSURE	FIXED
2	LANE CLOSURE	2
3	CURVE TO CROSSOVER SECTION	3
4	CURVE TO ALTERNATE ROUTE (DETOUR)	FIXED

Figure 5. Procedural step 6.

are two opposing travel lanes to accommodate the cross-over section. The lane closure can be relocated upstream only to the beginning of the multi-lane section.

The second series of steps results in determination of the locations where the driver should receive the feature warning and/or maneuver warning information upstream of each feature. Note that the reception location is not the point at which warning signs will be located. Depending upon the size of the signs and the associated legibility characteristics, they may be located 125 feet to 200 feet downstream of the reception location. Sign location is discussed in Step 19. This series of steps also will permit identification of conflicts among information reception locations.

In Table 11, as noted earlier, all work zone maneuvers and non-maneuver situations have been broken into four categories - stop, lane change, curve/turn, and no maneuver - and linked to the feature they characterize. Table 12 links these maneuvers and non-maneuver situations to the tables used for determing the reception location for the warning information. Reception locations for these warnings are measured using the beginning of features (defined in Step 2) as a reference point.

Step 7 - Determine Reception Location of the Maneuver Warning for Group I Fixed Features: Using the controlling maneuver for each Group I fixed feature (Steps 1, 2, 4), first consult Table 12 for the associated reception location value for the maneuver warning, i.e. Decision Sight Distance, Stopping Sight Distance, etc.; this reception location value is accompanied by the number of the table that translates the value into distance. Next enter the appropriate table using the assumed approach speed to the feature (as noted in Step 5) to get a reception distance for that speed. This distance is measured upstream from the beginning of the feature (as determined in Step 2) to provide the reception location of the maneuver warning. Mark the reception location of the maneuver warning for each Group I fixed feature. Note, however, that in line with the definition of the multi-lane lane closure feature, the warning distance as depicted in the MUTCD should be used for determining the actual location of the maneuver warning for a lane closure on a multi-lane road. That is, the maneuver warning should be placed from 1000 to 1500 feet upstream of the beginning of the lane-closing taper, depending upon the road type and geometrics of the site.

Step 8 - Determine Reception Location of the Feature Warning for Group I Fixed Features: As noted in the definition, the feature warning information class also should appear upstream of a feature that demands a maneuver. It precedes the maneuver warning. Use Table 16 (Detection-Recognition Distance) to determine the reception location of the feature warning. Enter Table 16 at the estimated approach speed to the feature (as noted in Step 5) to get the Detection - Recognition Distance. This distance is measured upstream from the maneuver warning reception

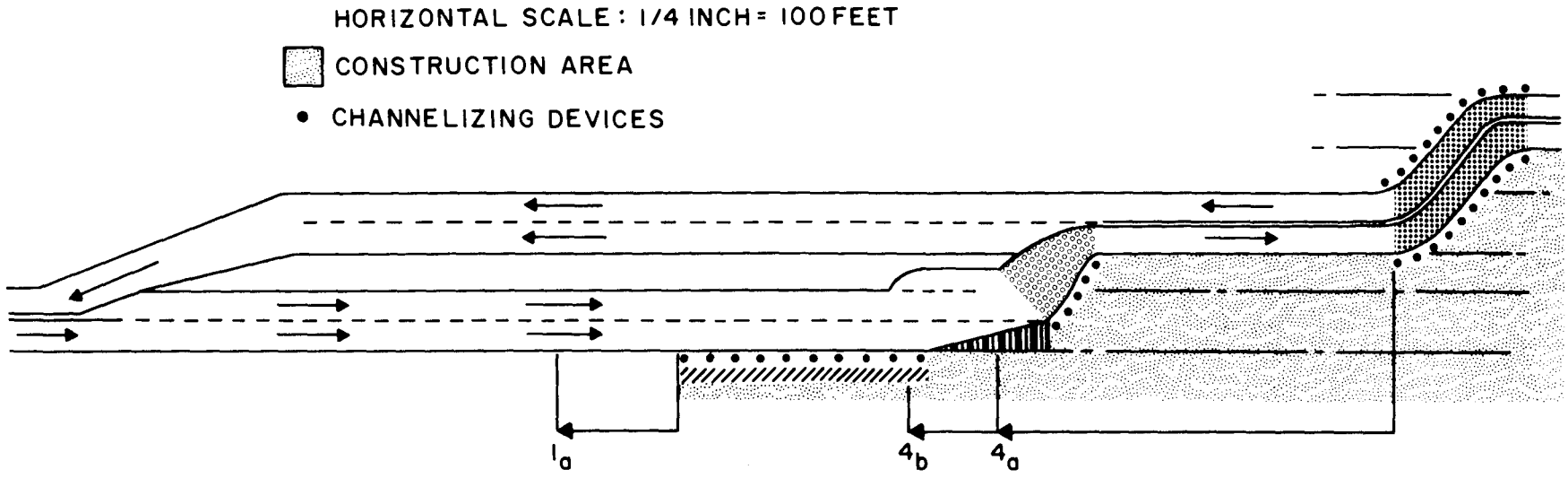
location to provide the reception location of the feature warning for each Group I fixed feature. Recall, however, that for the multi-lane lane closure feature the warning distance as depicted in the MUTCD should be used for determining the location of the feature warning sign. That is, the feature warning should be placed 2500 to 2600 feet upstream of the beginning of the lane-closing taper. Mark the reception location (or actual location for multi-lane lane closures) of the feature warning for each Group I fixed feature.

Step 9 - Determine Reception Location of the Feature Warning for all Group II (Non-Maneuver) Fixed Features: Enter Table 16 (Detection - Recognition Distance) at the assumed approach speed to each Group II fixed feature to obtain a reception distance for that speed. This distance is measured upstream from the begining of the feature to provide the location of the feature warning. Mark the reception location of the feature warning for each Group II fixed feature.

> Figure 6 provides a schematic representation of Steps 7 through 9. Note that the maximum distances were chosen for locating the feature warnings and maneuver warnings. If necessary, these can be reduced later to resolve sign placement conflicts based on these reception locations. There is, for instance, possible conflict evident in Figure 6 where the reception locations of warnings about the curve to the alternate route may put signs conveying these warnings within the preceding lane closure or curve to crossover section; a situation that could confuse the driver.

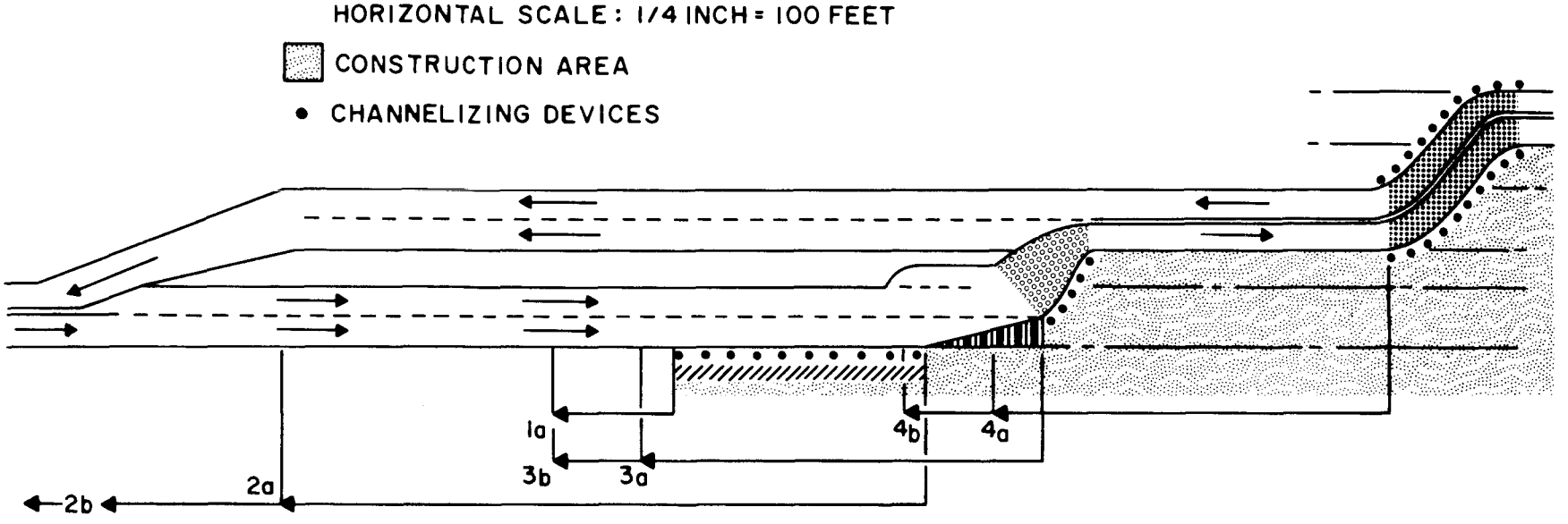
Step 10 - Identify Reception Location of Warnings for Group I and II Relocatable Features: Repeat instructions in Steps 7 through 9 as appropriate. Figure 7 shows the notation from Step 10. The reception locations of feature and maneuver warnings about fixed features from steps 7 through 9 are maintained in this illustration.

> Note that the distances shown for the maneuver warning and feature warning regarding the lane closure feature (2a, and 2b continuing off the illustration at the left) represent the locations where signs conveying these warnings will be placed. They do not represent information reception locations as the other measured distances do. This is because the



	FEATURES (L. to R.)	(GROUP)	WARNING RECEPTION LOCATIONS-FIXED FEATURES	
			MANEUVER WARNING	FEATURE WARNING
1	SHOULDER CLOSURE	(II)		l_a (242 ft. max.)
2	LANE CLOSURE	(I)		
3	CURVE TO CROSSOVER SECTION	(I)		
4	CURVE TO ALTERNATE ROUTE (DETOUR)	(I)	4a (925 ft. max.)	4_b (198 ft. max.)

Figure 6. Procedural steps 7 through 9.



	FEATURES (L. to R.)	(GROUP)	WARNING RECEPTION LOCATIONS– RELOCATABLE AND FIXED FEATURES	
			MANEUVER WARNING	FEATURE WARNING
1	SHOULDER CLOSURE	(II)		1a (242 ft. max.)
2	LANE CLOSURE	(I)	2a (1500 ft. actual location)	2b (1000 ft. actual location)
3	CURVE TO CROSSOVER SECTION	(I)	3a (925 ft. max.)	3b (198 ft. max.)
4	CURVE TO ALTERNATE ROUTE (DETOUR)	(I)	4a (925 ft. max.)	4b (198 ft. max.)

Figure 7. Procedural step 10.

MUTCD calls for placement of information about a lane closure on a multi-lane road at these distances to allow sufficient warning distance for multiple lane changes.

At this point in the procedure it is necessary to review possible conflicts produced by the foregoing assignment of information reception locations. Generally speaking a conflict occurs when (1) there is insufficient distance between the termination of an upstream feature and the beginning of a downstream feature to accommodate the warning information at the recommended locations and (2) warning sign locations regarding different features fall in the same area. However, the severity of the conflict, i.e. the probability of creating confusion, varies with the types of features involved. For example, where a feature requiring a maneuver, e.g. a temporary detour, is downstream of feature which requires only that the driver be aware but does not require a maneuver, e.g. a shoulder closure, placement of information about the feature requiring a maneuver is usually not a problem. That is, warnings regarding the temporary detour can be located within the closed shoulder feature without producing problems for the driver. The same can be said for placing information about a feature not requiring a maneuver within a feature requiring one. On the other hand, if each feature requires a maneuver and warnings about a downstream feature are placed within the upstream feature, confusion could result. Finally, when warning signs about two closely spaced successive features fall within the same area, the overload could cause the driver to miss a warning or be confused about which warning applies first. Again, such a conflict is not severe when one of the warnings concerns a feature that does not require maneuver. In summary, while conflicts may not be significant during daylight for situations where the sight distances are adequate and the layout and sequence of features is obvious, they could produce problems at night or when sight distance is limited.

Obviously, the identification of conflicts and the decision as to need for resolution must be based upon engineering judgment. The most conservative and safest approach is to provide a work zone layout that does not involve informational conflicts. While it is realized that this is impossible in some cases and not practical in others, each conflict produced by the assignment of information reception locations should be carefully reviewed with respect to the potential for producing confusion and misinterpretation. Although it may not be possible to resolve all conflicts, they should all be identified and reviewed.

The considerations and general guidelines for information conflict resolution are:

- If the conflict involves a fixed and non-fixed feature, the non-fixed feature can be relocated upstream or downstream to provide more space between features, thereby providing more leeway to deploy information. However, the relocation must be evaluated to ensure that another conflict has not been created.

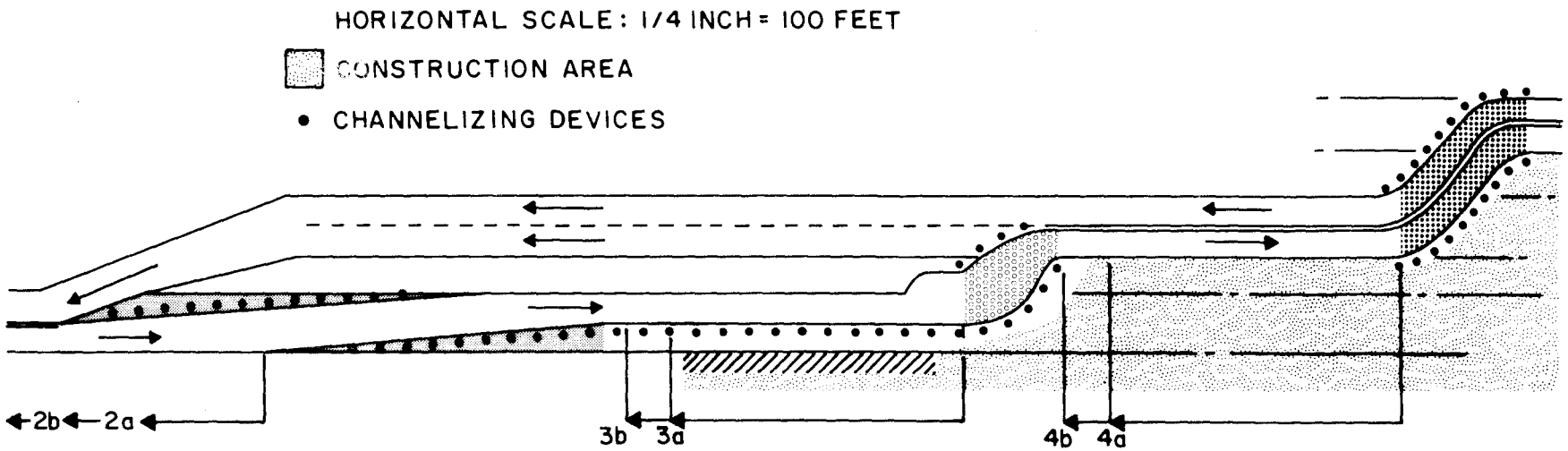
- If relocation is not possible, a judgment must be made as to which information has higher priority in terms of driver and worker safety. The first attempt at resolution in this case is to use as much as necessary of the range of an information reception location given in the tables, i.e. use the minimum distance for one feature and the maximum for the other. When reception locations are manipulated this way, the greater warning distances are, of course, used for the higher priority information. Flags and flashers also can be used as supplements to call attention to more important information.

- Where this does not result in an acceptable resolution, the site geometrics and the associated delineation should be considered to determine whether the necessary information can be conveyed via direct visual observation.

Step 11 - Resolve Conflicts Produced by Assignment of Reception Locations: Identify the conflicts and apply the general guidelines above to resolve them.

Figure 7 shows probable conflicts as follows: (a) Signs conveying the maneuver warning [4a] and feature warning [4b] for the curve to the alternate route may fall within the lane closure and/or crossover curve; (b) The sign conveying the maneuver warning about the crossover curve [3a] may fall within the shoulder closure; (c) The signs conveying the feature warnings about the crossover curve [3b] and shoulder closure [1a] may fall at the same place; (d) The sign conveying the feature warning about the lane closure [2b] falls in the two-lane, two-way section upstream of the work zone, where it has no relevance.

Figure 8 shows a means to resolve conflicts noted above. The crossover curve can be relocated approximately 100 feet upstream, and the minimum distances can be used for the feature warning and maneuver warning regarding the curve to the alternate route (4b and 4a). By doing so, signs conveying this information can be located in the tangent section following the crossover curve. The lane closure can be relocated far enough upstream to allow use of the minimum distances for reception of the feature warning and maneuver warning information about the crossover curve (3b and 3a). By doing so, signs conveying this information can be located in the



	FEATURES (L. to R.)	(GROUP)	WARNING RECEPTION LOCATIONS - CONFLICTS RESOLVED	
			MANEUVER WARNING	FEATURE WARNING
1	LANE DIVERSION	(I)	2a (1175 ft. max.)	2b (242 ft. max.)
2	SHOULDER CLOSURE	(II)		(need eliminated)
3	CURVE TO CROSSOVER SECTION	(I)	3a (675 ft. min)	3b (99 ft. min.)
4	CURVE TO ALTERNATE ROUTE (DETOUR)	(I)	4a (675 ft. min)	4b (99 ft. min.)

Figure 8. Procedural step 11.

tangent section following the taper. Relocating the lane closure also eliminates the need for the feature warning about the shoulder closure, as well as the conflict between this information and the feature warning about the crossover curve. This is because the shoulder closure is buffered by the single lane section after the lane closure. Because the beginning of the lane-closure is now only about 300 feet downstream from the start of the multi-lane roadway, traffic coming from the two-lane, two-way section is maintained in single file and diverted as shown. Thus the first feature the driver encounters now is a lane diversion. Finally, because the lane diversion is now the first feature encountered, 55 mph is used as the estimated approach speed in determining the reception locations of the maneuver warning and feature warning (2a and 2b) from the tables.

Upon completion of Step 11, the "best fit" layout for the deployment of signing information will have been identified.

Step 12 - Integrate Necessary Speed Limit, Speed Advisory, and Speed Change Warnings: The approach speed estimates from Step 5 identify the work zone features for which speed reductions may be advisable or necessary. Where advisory speeds are to be presented, the advisory plates are typically used in conjunction with the appropriate warning signs and therefore do not have to be individually integrated into the overall information system layout. However, if regulatory speed signs or separate construction (black on orange) speed signs are to be used, the speed limit and speed change warning signs must be individually located. Considering the reception locations of information from previous steps in the procedure and the 10 mph maximum decrease per sign recommended in the MUTCD, locate the speed information and speed change warnings in accordance with the guidelines in Section 2B-13 and 14 (page 2B-8) of the MUTCD and mark the locations on the site plan.

Step 13 - Assign Locations for the General Warnings about the Work Zone and for Information about Work Zone Termination: Using the guidelines in Part VI of the MUTCD, assign "locations" for the general construction approach warnings, e.g. ROAD CONSTRUCTION XXX FEET, and the construction termination information, e.g. END CONSTRUCTION. The general construction warnings always should appear upstream of more specific information such as feature warnings. The distance associated with the general warnings should be measured to the beginning of the first evidence of construction.

Step 14 - Integrate Prohibitory/Restrictive Warnings and Route Guidance: This step involves the integration of other signs into the

overall information system. The need for (1) prohibitory/ restrictive warning information elements, i.e. passing prohibitions, two-way traffic warnings; and (2) route guidance information elements, i.e. detour routing, is dependent upon specific characteristics of the work zone, prevailing traffic conditions, etc. For example, if a crossover section has opposing flows separated by a portable concrete barrier, a specific passing prohibition may be unnecessary. However, if the opposing flows are separated only by posts or cones, the passing prohibition and two-way traffic warnings are very important and the information should be presented as early as possible in the two-lane, two-way section. Also, a work zone that handles high volumes and where traffic flow is not continuous may require a restrictive warning to alert the driver to the possibility of stopped traffic. However, this same work zone configuration operating under lower volume conditions may not require such a restrictive warning. In summary, following final decisions as to the work zone layout and the higher priority information reception locations, an engineering review should be made to identify any additional information requirements. Where applicable, the guidelines and tables used in previous steps can be used for determining reception locations and distributing these additional information elements. However, they will in most cases have limited applicability in that there will be few defined reference points. Most likely, these prohibitory/restrictive warnings will be fit into the overall system in such a way that they will not interfere with other information elements. The guiding principle in deploying this information is that of spreading the information load for the driver as much as is practical. An even distribution of information over the site is less likely to produce driver response problems than is a distribution which presents varying high and low information loads.

Step 15 - Integrate Confirming Information: This step considers the need for repeat (confirming or redundant) information elements. The need for and presentation frequency of confirmation, i.e. maintenance of lane position information, maintenance of speed information, etc., depends upon the length of the path following or through the feature with which the confirmation is associated, and the importance of the information. If a crossover curve is followed by a long two-lane, two-way section with only channelizing devices separating opposing flows, it is desirable for drivers to be reminded of previous warnings concerning passing and two-way traffic. Whereas if visible separators are used throughout the crossover route, the confirmation is more or less supplementary and can be used less frequently. If portable concrete barriers are used, confirmation of a passing prohibition is generally unnecessary. Where it is desirable to have the confirming message constantly available to the driver, sign spacing should be based upon the legibility distance of the signs.

Step 16 - Identify Delineation Requirements: Once the reception locations of signing information have been specified, the pavement marking and delineation needs must be specified. The existing MUTCD standards and guidelines (or relevant State standards) with regard to channelizing devices, markings, and lighting devices should be followed. Once the needed markings, delineation, and lighting devices are identified and located, any information conflicts which could not be resolved in a satisfactory manner via previously suggested guidelines should be reviewed. In some cases, addition of lighting devices such as arrowboards or flashers can supplement warning signs such that conflicting sign locations are made less significant.

Step 17 - Assign Feature and Prohibitory/Restrictive Location Information: Review the delineation and warning information along with the sight distance characteristics of each feature to determine where supplementary information is required to clearly identify the beginning of, or location of, work zone features, prohibitions, or restrictions.

Step 18 - Identify & Locate Potential Hazards: In cases where the construction/maintenance will create potentially hazardous conditions such as bumps, dips, rough surface, etc. and the location of the condition is predictable, warning and location information regarding the conditions should be included in the overall signing plan. This also applies to potential hazards such as entrances and exits for construction vehicles and equipment. Conditions such as these which are judged to be of sufficient severity to justify warning and location information should be treated in the same fashion as work zone features.

Step 19 - Identify and Locate Appropriate Signs: The information content requirements and the recommended signs for each feature are provided to the extent possible in the following section. These should be reviewed for each feature comprising the site and the sign most appropriate to each content requirement should be selected. It will be recalled that most locations identified in previous steps are information "reception" locations and not sign locations. The actual sign locations will be downstream of the information reception locations noted on the site plan. The distance downstream is determined on the basis of the most recent guidelines regarding legibility distance.* Assuming that a 30-inch and 36-inch sign has a minimum letter size of 5 inches (Series D)and a 48-inch sign has a minimum letter size of 8 inches (Series D), the respective legibility distances would be 125 feet (38 m) and 200 feet (61 m). Also locate any advisory speed plates previously judged necessary (Step 5) to accompany warning signs about

*Task Force Report to Signs Subcommittee, National Advisory Committee on Uniform Traffic Control Devices "Advance Placement of Warning Signs" June 1, 1979.

features. If the advisory speeds represent reductions from an upstream speed limit, remember that they should reduce the upstream limit a maximum 10 mph per sign.

Step 20 - Review Existing Signs and Markings: Following the assignment of all work zone information, the signs and markings that pre-dated the work zone should be reviewed to be certain that irrelevant or contradictory information is scheduled for removal.

D. Sign Content Recommendations

The driver information requirements for each work zone feature can only be specified in a rather general form. Factors such as the length of the feature, the type of adjacent features, the original geometrics on which the work zone is superimposed, the geometrics of the work zone itself,and traffic volume, all have an influence upon driver information needs. The existing variety and combinations of situational factors render the development of complete information requirements to serve all situations highly impractical. Thus the requirements presented here should be viewed as a checklist or as guidelines which can be used in conjunction with the same degree of engineering judgment currently employed.

For example, it is suggested that the sign content for warnings include information regarding the actual distance to a work zone feature as opposed to the use of the more general term AHEAD. This suggestion resulted from several considerations. First, while traffic engineers may know the recommended distance between the warning sign and the condition to which it calls attention, drivers cannot be expected to know it. Secondly, work zone field evaluations showed that, in practice, there is a great deal of variation between warning sign locations and the work zone feature or condition to which signs call attention. Because of this the AHEAD designation provides little useful information for the driver as to where any sort of change in speed or path might be required. The use of a specific distance, on the other hand, provides the driver with some meaningful reference point. In human factors terminology, information such as this structures driver expectancies more adequately and therefore reduces the probability of error. However, it is obvious that there are many situations where drivers will have an unrestricted view of a given work zone feature or condition, and where the specific distance information may therefore be unnecessary.

Another example is the suggestions for the temporary detour and lane diversion. Here, curve/turn warning information is called for on the entrance to the detour or diversion and for the return to the original roadway. However, if the detour or diversion is very short, the second set of warnings are obviously not required; in fact a single symbolic sign showing the geometrics of the situation might be used to provide both entrance and return information. In reviewing the information requirements for any given feature, anyone familiar with actual work zone layouts will be able to cite other situations in which some of the requirements do not apply and situations where the requirements may be more extensive than those specified.

Table 11. Work zone features by controlling maneuvers.

WORK ZONE FEATURE AND GROUP		CONTROLLING MANEUVER			
		Stop	Lane Change	Curve/ Turn	No Maneuver
Group I	Lane closure (multi-lane)		X		
	Lane closure (2 lane - 2 way)	X			
	Turn or curve to alternate route (detour)			X	
	Curve to or from temporary detour			X	
	Curve to or from crossover			X	
	Curve to or from lane diversion			X	
Group II	Roadside				X
	Shoulder closure				X
	Reduced lane width				X

Table 12. Controlling maneuver by warning information reception value.

INFORMATION RECEPTION VALUE	CONTROLLING MANEUVER: Stop	Lane Change*	Curve/Turn	No Maneuver
Decision Sight Distance (Table 13)			X	
Stopping Sight Distance (Table 14)	X			
Premaneuver Distance plus Braking Distance (Table 15)	X			
Detection - Recognition Distance (Table 16)				X

*Since lane changes are associated with lane closure features on multi-lane roadways, the information location guidelines recommended in the MUTCD should be used for warning information. This allows adequate distance for a distribution of lane change maneuvers on the approach to the lane closure.

Table 13. Decision sight distance.

DECISION SIGHT DISTANCE*		
Estimated Speed mph[1]	RANGE[2] (rounded)	
	Min. (feet)	Max. (feet)
30	450	625
35	525	725
40	600	825
45	675	925
50	750	1025
55	900	1175
60	1000	1275
65	1025	1350
70	1100	1450

*Based on the decision sight distance column of Table 9, " Recommended Decision Sight Distance," page 39 of FHWA-RD-78-78 "Decision Sight Distance for Highway Design and Traffic Control Requirements," 1978.

[1] 1 mph equals 1.609 km/hr., American Society for Testing and Materials publication, "Standard for Metric Practice," ASTM E 380-80, p. 531.

[2] 1 foot (U.S. Survey) equals .3048 m, ibid., p.529.

Table 14. Stopping sight distance.

STOPPING SIGHT DISTANCE*			
Estimated Speed mph[1]		RANGE[2] (rounded)	
Min.	Des.	Min. (feet)	Max. (feet)
28	30	200	200
32	35	220	250
36	40	275	325
40	45	320	400
44	50	375	475
48	55	435	550
52	60	525	650
55	65	550	725
58	70	625	850

*Based on the stopping sight distance column of "Minimum and Desirable Stopping Sight Distance (Wet Pavements)," from AASHTO policy publication "A Policy on Design Standards for Stopping Sight Distance - 1971."

[1] 1 mph equals 1.609 km/hr., American Society for Testing and Materials publication, "Standard for Metric Practice," ASTM E 380-80, p. 531.

[2] 1 foot (U.S. Survey) equals .3048 m, ibid., p.529.

Table 15. Premaneuver plus braking distance.

PREMANEUVER DISTANCE PLUS BRAKING DISTANCE*		
Estimated Speed mph[1]	RANGE[2] (rounded)	
	Min. (feet)	Max. (feet)
30	330	510
35	400	610
40	470	730
45	550	845
50	640	980
55	810	1150
60	910	1300
65	990	1440
70	1100	1610

*Based on the braking distance column (level wet pavement) of Table 1, "Minimum and Desirable Stopping Sight Distances (Wet Pavements)," page 4, and the detection and recognition plus decision and response initiation columns of Table 9, "Recommended Decision Sight Distance," page 39, FHWA-RD-78-78 "Decision Sight Distance for Highway Design and Traffic Control Requirements," 1978.

[1] 1 mph equals 1.609 km/hr, American Society for Testing and Materials publication, "Standard for Metric Practice," ASTM E 380-80, p. 531.

[2] 1 foot (U.S. Survey) equals .3048 m, ibid., p. 529.

Table 16. Detection-recognition distance.

DETECTION-RECOGNITION DISTANCE*		
Estimated Speed mph[1]	RANGE[2]	
	Min.[3](feet)	Max. (feet)
30	66	132
35	77	154
40	88	176
45	99	198
50	110	220
55	161	242
60	176	264
65	191	286
70	205	308

*Based on the detection and recognition column of Table 9, "Recommended Decision Sight Distance," page 39 of FHWA-RD-78-78 "Decision Sight Distance for Highway Design and Traffic Control Requirements," 1978.

[1] 1 mph equals 1.609 km/hr, American Society for Testing and Materials publication, "Standard for Metric Practice," ASTM E 380-80, p. 531.

[2] 1 foot (U.S. Survey) equals .3048 m, ibid., p. 529.

[3] For the lower speeds, the use of the minimum Detection-Recognition Distance to locate a feature warning in a tangent section may cause the feature warning sign to screen the maneuver warning sign that follows. A review of site geometrics in the vicinity of the adjacent signs will reveal whether a greater Detection-Recognition Distance must be used in order to avoid this problem.

The information content recommendations listed for each feature reflect the following general guidelines regarding driver needs:

- The driver should be informed as specifically as possible as to the work zone feature, situation (or possible situation) which will be encountered. This information creates an appropriate driver expectancy structure and provides a rationale for subsequent maneuvers or for maneuver prohibitions and restrictions.

- The driver should be informed regarding where the feature or situation will be encountered via presentation of accurate distance information.

- The driver should be informed as to the physical location of the feature or situation.

- The driver should be informed as to what maneuver(s) will be required on the approach to or at the work zone feature, and where the maneuver should be initiated.

- The driver should be informed as to what maneuvers will be prohibited and where the prohibition(s) must begin.

ROADSIDE

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify activity or condition (specific if necessary) Specify distance to activity or condition	W21-3 W21-6 Supplemental plate	*1	
MANEUVER WARNING	None required			
FEATURE LOCATION	Indicate beginning of activity or condition Identify length of activity	W21-3 W21-6 W7-3a	*1 *2	

*1 These are the only MUTCD signs that may apply. Other specific legends would have to be devised, where necessary.
*2 While the sign legend is applicable, this sign is shown only in a non-construction (yellow) version.

SHOULDER CLOSURE AND REDUCED LANE WIDTH

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES[2]
FEATURE WARNING	Specify shoulder condition or activity (e.g. soft shoulder, dropoff, narrow lane, etc.)	W8-4 W8-9 W8-9a W21-5 W5-1		9 10 14 15
	Specify distance to closure or narrow bridge	Supplemental plate		
MANEUVER WARNING	none required			
FEATURE LOCATION	Indicate beginning of closure/ reduced lane width	W8-4 W8-9 W21-5		
	Identify length of feature	W7-3a	*1	

*1 While the sign legend is applicable, this sign is shown only in a non-construction (yellow) version.
*2 Numbers in this column refer to sign numbers in Appendix B.

LANE CLOSURE (MULTI-LANE)

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify lane(s) closed (left, right, center) Specify distance to closure	W20-5 and variation in Figure 6-10 MUTCD or W4-2 with supplemental plate		
MANEUVER WARNING	Specify lane change/merge maneuver Specify lane change/merge direction	W9-2		
FEATURE LOCATION	Identify beginning of taper	6E-7 section of MUTCD on arrow board or W1-6		6 7

LANE CLOSURE (2 LANE - 2 WAY)

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify lane/closure flagging operation	W20-7 W20-7a		
	Specify distance to flagger	Supplemental plate		
MANEUVER WARNING	Specify flagging operation	W20-7		
	Specify distance to flagger	Supplemental plate		
	Specify preparation to stop	Section 6B-33 MUTCD	*2	
FEATURE LOCATION	Provide high visibility for flagger	Figure 6-15 MUTCD		
PROHIBITORY/RESTRICTIVE WARNING	Specify passing prohibition Specify distance to no passing section	R4-1	*1	31
PROHIBITORY/RESTRICTIVE LOCATION	Identify beginning of no passing section	W14-3		

*1 No distance associated with this sign.
*2 BE PREPARED TO STOP not presented on flagman sign.

CURVE/TURN TO AND FROM CROSSOVER SECTION

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify temporary detour Specify distance to crossover curve* or turn	None	*1	
	Specify advisory speed*	W13-1		
MANEUVER WARNING	Identify general design of curve* (direction(s) and curvature)	W1-4 or W1-3		
	Specify distance to curve*	Supplemental plate		
	Specify advisory speed*	W13-1		
FEATURE LOCATION	Identify beginning of curve	6B-7 Section of MUTCD on arrow boards or W1-6		
	Identify road closure	R11-2 M4-10R		

-- continued --

CURVE/TURN TO AND FROM CROSSOVER SECTION (Continued)

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
PROHIBITORY/RESTRICTIVE WARNING	Specify passing prohibition Identify two-way traffic situation	R4-1 W6-3		
PROHIBITORY/RESTRICTIVE LOCATION	Identify beginning of no passing zone or two-way traffic situation			

* Where the design speed of the curve is equal to the design speed of the roadway on the approach to the curve, these information items become less critical, or perhaps unnecessary, and the specific items to be presented can be chosen on the basis of an engineering evaluation. The information items regarding curvature, speed, etc., that are judged to be necessary are to be provided at an appropriate location upstream of the curve from the crossover section as well as the entry curve.

*1 The only MUTCD sign is DETOUR XXX FT.

CURVE/TURN TO AND FROM TEMPORARY DETOUR OR LANE DIVERSION

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify temporary detour Specify distance to curve/turn*	None	*1	
	Specify advisory speed*	W13-1		
MANEUVER WARNING	Identify general design of curve* (direction(s) and curvature)	W1-4 or W1-3		1 2 3
	Specify distance to curve*	Supplemental plate		
	Specify advisory speed*	W13-1		
FEATURE LOCATION	Identify beginning of curve	6E-7 Section of MUTCD on arrow boards or W1-6		
	Identify road closure	R11-2 M4-10R	*2	

* Where the design speed of the curve is equal to the design speed of the roadway on the approach to the curve, these information items become less critical, or perhaps unnecessary, and the specific items to be presented can be chosen on the basis of an engineering evaluation. The information items regarding curvature, speed, etc., that are judged to be necessary are to be provided at an appropriate location upstream of the curve from the temporary detour or lane diversion as well as the entry curve.

*1 The only MUTCD sign is DETOUR XXX FT.

*2 Roadway closure for temporary detours only, not lane diversions.

CURVE/TURN TO ALTERNATE ROUTE (DETOUR)

INFORMATION TYPE	SUGGESTED INFORMATION CONTENT	APPLICABLE MUTCD DEVICE(S)	NOTES	OTHER DEVICES
FEATURE WARNING	Specify detour situation Specify distance to detour curve or turn	W20-2	*1	
	Specify advisory speed	W13-1		
MANEUVER WARNING	Identify general design of curve (direction(s) and curvature)	W1-1 W1-2 W1-3 W1-4		
	Specify distance to curve	Supplemental plate		
	Specify advisory speed	W13-1		
FEATURE LOCATION	Identify beginning of curve	6E-7 Section of MUTCD on arrow boards or W1-6		30
	Identify roadway closure	M11-8 M4-10R		
ROUTE GUIDANCE	Identify alternate route(s)	M4-8 M4-9R	*2 *3	

*1 DETOUR LEFT or RIGHT XXX FT would be better.
*2 To be used with route marker assembly; use only if alternate route rejoins original route.
*3 Stands alone without route marker assembly; use for short detours.

CHAPTER V. THE EVALUATION OF TRAFFIC CONTROL DEVICES FOR WORK ZONES

A. Introduction and Overview

While the work zone models do provide a method of identifying information requirements, they do not specify the optimal means of fulfilling these requirements. Certain driver needs are at least partially met by information that is provided by road geometry and other environmental cues. However, in most instances this type of information is inadequate in and of itself and must be supplemented by a system of traffic control devices. The development of a system of traffic control devices to meet an identified information need should be based on the extent to which the devices reduce driver uncertainty about: (a) what the driver must do, (b) where he must do it, and (c) why he must do it. For any device to be effective, the message, regardless of informational content, must be presented at a location which affords the driver ample time to receive and respond appropriately to the intended message. These considerations comprise the foundation for the criteria used to evaluate the traffic control devices currently employed in highway work zones. More specifically, the three informational criteria identified above were selectively applied to devices as appropriate, while a fourth criterion - required recognition distance - was applied to each of the devices evaluated.

The actual evaluation procedure was conducted independently by several individuals expert in both traffic engineering and human factors. The methodological approach to the evaluation process began with an extensive survey of the traffic control devices used in work zones. This data collection effort provided the input for a comprehensive catalog of existing devices used. The catalog included two sections: devices illustrated in the MUTCD and devices which had been developed by individual states or other local jurisdictions. The latter set of devices were restricted to those encountered in the field data collection. Since the data collection was conducted in eight states in the East, the sample evaluated is not representative of the signs used throughout the country. Each of the devices found in the MUTCD was evaluated in a two phase process. First, the MUTCD was consulted to identify current specifications regarding the intended application of the device. The MUTCD intended application was used as a guideline for determining which of the three informational criteria were relevant to the device being considered. The criteria judged applicable were then used as the standards against which each device was evaluated. That is, the standards were used to assess device effectiveness for each of the operational situations in which the device was potentially applicable. As a result of this process, not only were device disadvantages identified, but the disadvantages were also classified as relevant to all application situations or to only selected applications.

The second phase of the evaluation process involved a comparison of device design characteristics with recognition distance requirements to identify the conditions under which each device met the recognition performance standard. First of all, it was assumed that the message of a device could not be recognized until the legend was legible. Further, device legibility was assumed to be a function of legend size. Specifically, letter height was used to determine the maximum available legibility for a given device with specific dimensions. In calculating available legibility distance, the

standard rule of 50 ft of legibility distance for each inch of letter height was employed. While the newer legibility guidelines are recommended for application because of the increased margin of safety, it was felt that the older guidelines were more appropriate for this evaluation.

While available legibility distance reflects the maximum performance associated with a device, it does not indicate whether the maximum performance is adequate. For adequacy to be achieved, maximum performance must exceed required performance. Stated differently, the maximum legibility distance of a given device must be greater than the distance at which the message of the device must be detected and recognized. A Decision Sight Distance model was employed to determine the recognition distance requirement of specific devices. This model provides a means of establishing the minimum distance at which a given device should be detected and recognized for the driver to respond safely and comfortably. Finally, the recognition performance of each device was evaluated by comparing the maximum available legibility distance of each legend size with the recognition distance requirements of the device. This procedure provided a means of determining the conditions (i.e. approach speed and sign dimension combinations) under which each device fails to meet recognition performance standards.

The final step in the traffic control device evaluation process involved consideration of the devices developed by state or local agencies that were cataloged during the survey of actual work zones. The objective of this effort was to identify devices that were judged more effective than those illustrated in the MUTCD. This procedure provided a basis for recommended changes in existing traffic control devices and for suggestions for new devices to satisfy needs that are not adequately met by more commonly used devices.

B. Informational Criteria

Because of the central role of the three informational criteria in the evaluation process, a brief discussion of criteria characteristics is warranted. These three criteria were derived from an analytical assessment of work zone information requirements, from a human factors perspective. The criteria are "informational" in that they relate to the effectiveness of a given traffic control device in communicating information that is required by the driver.

1. The Driver Response Criterion

The first of these criteria concerns what the driver must do in order to maintain effective guidance and control of the vehicle. This criterion refers to the driver's probable response to the information presented by a traffic control device. In this context, the term "driver response" should be interpreted broadly to include any effect that a given device has on the motorist. Since any type of information stimulates some kind of driver response, although it may not be overtly observable, any device, regardless of informational content, can be evaluated against the driver response criterion. For this reason, the criterion is applicable to road condition information as well as maneuver requirement information. The specific response that a given device requires of drivers (i.e. "what the driver must do") can involve a vehicle maneuver, a driver reaction without a maneuver, a

driver decision, or simply a state of driver awareness. The most critical work zone devices are those that require a specific vehicle maneuver; that is, a change in vehicle speed and/or path of travel. An example of such a device is the STOP sign (R1-1)*. Another important class of work zone devices are those that require a designated driver reaction that does not involve a vehicle maneuver. An example of such a device is the TURN OFF 2-WAY RADIOS sign (W22-2). A third class of work zone devices require the driver to make a decision without any overt response. The STOP AHEAD sign (W3-1), for example, should alert the driver to watch for a STOP sign and be prepared to decelerate as soon as the sign is detected. A final class of work zone devices require the driver to become alerted to and maintain an awareness of a particular condition. The END CONSTRUCTION sign (G20-2) is an example of such a device.

When a device is evaluated against the driver response criterion, the primary question is: "Does the device clearly communicate exactly what the driver must do?" A second question is: "Can the device, by itself, communicate the required information or must it be supplemented by other traffic control devices?" A related issue is: "If a device is intended for use only in conjunction with other devices, what are the consequences if the supplementary information is not received by the driver?" A fourth question that is applicable when evaluating a device against this criterion is: "Is the information presented clearly and unambiguously?" In this regard, the information communicated should not lend itself to an interpretation other than that which is intended. In addition, the information must be presented in such a way that it can be comprehended by the majority of the driving public. Sign legends containing words that require a relatively high reading level are less acceptable on the basis of this requirement. Finally, the information that is presented by a device must preclude driver confusion and uncertainty. Specifically, legends that specify right/left direction without diagrammatic supplementation can be confusing for some drivers. Consequently, such devices are problematic on the basis of this requirement.

2. The Reference Location Criterion

The second informational criterion involves where the driver must respond to the information presented by a particular traffic control device. The driver may be required to complete a particular response prior to reaching the device; an example of this type of device is WRONG WAY sign (R5-9). Alternatively, the device may require the driver to respond immediately adjacent to the device. Many warning signs, such as the Large Arrow sign (W1-6), are intended to be applied in this way. Third, the device may not require the driver to respond until some point beyond the location of the device; advance warning signs, such as the Advance Detour sign (W20-2), are generally of this nature. In general, reference distance information is required only for the third class of devices. However, just as the reference location criterion applies to devices that direct driver responses, it is equally applicable to road condition information. That is, the criterion is also relevant to the specification of a reference distance to a particular road condition. The Advance ROAD CONSTRUCTION sign (W20-1) is an example of a

*Parenthetical codes refer to the traffic control device codes used in the MUTCD.

device that not only provides road condition information but is also amenable to evaluation against the reference location criterion.

When a device is evaluated on the basis of the reference location criterion, the most important question is: "Does the device clearly specify where the driver must respond?" or, alternatively: "Does the device clearly specify the location of the designated road condition?" There are three possible answers to this question, listed here in order of preference:

(1) specific reference distance information is provided, e.g. ONE LANE ROAD __ FT (W20-4);

(2) general reference distance information is provided, e.g. ROAD MACHINERY AHEAD (W21-3); and

(3) no reference distance information is provided, e.g. RIGHT LANE ENDS (W9-1).

A second question that is relevant to the reference location criterion is: "When specific reference distance is provided, is it presented in such a way that the driver can continuously monitor the distance to the response location or designated road condition?"

3. The Road Condition Criterion

The third informational criterion is relevant to those devices that provide information about why a particular driver response is, or may be, required. In general, devices that present messages about unexpected, atypical or hazardous road conditions functionally provide drivers with information about why a particular response is, or may be, required. Information about road conditions can be presented either upstream of the designated condition (e.g. ONE LANE ROAD 1 MILE (W20-4)) or immediately adjacent to the condition described (e.g. FRESH OIL (W21-2)). The road condition criterion is related to both of these device types.

Evaluating a device on the basis of the road condition criterion asks the question: "Does the device clearly describe the road conditions?" Another question that is relevant to this criterion is: "How specific is the information about road conditions?" On the basis of the assumption that specific road condition information engenders expectancies regarding the necessity for certain maneuvers, detailed road condition information is preferred over more general information about conditions. For example, ROAD CONSTRUCTION 1 MILE (W20-1) functions as a general warning of obstructions or restrictions. This device requires that the driver maintain a state of readiness for a broad range of potential responses. In contrast, the more specific SHOULDER WORK sign (W21-5) guides the driver's attention to a particular type of hazard and, consequently, reduces the range of expected responses.

C. Traffic Control Device Evaluation Results

1. Introduction

The results of the evaluation of traffic control devices currently employed in highway work zones is summarized in this section. This summary

is intended to reflect the assessment of MUTCD devices only. In addition, the evaluation results have been summarized according to the criteria used in the evaluation process. Appendix A contains the evaluation results for each individual device perceived to possess potential problems in terms of the aforementioned criteria. In that appendix, each of these devices has been assigned to one of the three categories on the basis of the type of information presented by the device. These three informational categories, along with three others included for the discussion below, and three more included for classifications in Appendix B, are listed in Table 17. Appendix A first lists the MUTCD devices considered to be problematic in terms of information presentation. It next identifies the relevant evaluation comments about the potential disadvantages associated with each device; and finally, recommends a series of alternative solutions for remedying each of the identified weaknesses.

Table 17. Listing of discrete information categories.

Informational Category	Category Name
1	Work Zone Feature/Maneuver Warning
2	Work Zone Feature/Maneuver Location
3	Road Condition Warning
4	Prohibitory or Restrictive Location
5	Speed Change Warning
6	Speed Limit
7	Road Condition Location
8	Performance Maintenance
9	Route Guidance

2. Informational Criteria

a. Driver Response

The results of the evaluation against the driver response criterion are summarized in Table 18. One of the requirements of the driver response criterion is that the information presented by a device clearly communicate exactly what the driver must do. In this regard, only two devices were judged to have potential weaknesses: both of these devices belong to the Feature Location Category. Both the Double Arrow sign (W12-1) and the Large Arrow sign (W1-7) direct the driver to select either of two alternate routes because continued travel straight ahead is not possible. The potential problem with this kind of message is that rather than guiding traffic to a particular path, the driver must decide which of two alternate routes to select. This comprises an additional decision component for the required maneuver, thereby increasing the amount of time necessary to complete the maneuver. For this reason, caution must be exercised when using either of these devices, particularly in those situations where there is already a significant demand on driver decision and information processing time. This problem can be remedied to some extent, however, by providing supplementary

Table 18. Driver response evaluation results.

EVALUATION COMMENTS	TRAFFIC CONTROL DEVICES
Forces driver to select one of two alternative routes	Double Arrow (W12-1) Large Arrow [bidirectional](W1-7)
Requires supplementary navigational information	Double Arrow (W12-1) Large Arrow [bidirectional](W1-7)
Requires supplementary speed reduction information	Advance Flagman (W20-7 & W20-7a) ROAD NARROWS (W5-1) ONE LANE BRIDGE (W5-3) Narrow Bridge Warning (W5-2a)
Potentially ambiguous message	SPEED ZONE AHEAD (R2-5c) KEEP RIGHT (R4-7a & R4-7b) ONE LANE ROAD ___ FT (W20-4)
Requires relatively high reading level	ROAD CONSTRUCTION NEXT ___ MILES (G20-1) ROAD CONSTRUCTION ___ FT (W20-1) ROAD MACHINERY AHEAD (W21-3) LANE ENDS MERGE LEFT (W9-2)
Susceptible to right/left confusion	RIGHT LANE CLOSED ___ MILE (W20-5) LANE ENDS MERGE LEFT (W9-2) RIGHT LANE ENDS (W9-1)

navigational information to aid the driver in the path selection process. Unfortunately, while some geometric situations (such as T-intersections) are amenable to this solution, other situations (such as a center lane closure on a multi-lane facility) are not, in that either path is equally acceptable.

A second issue related to the driver response criterion is whether the device alone is capable of providing all of the required information or whether supplemental information is necessary. In evaluating devices against this standard it was assumed that advance warning signs are deployed only in conjunction with follow-up devices adjacent to the maneuver location. Further, it was assumed that road condition information generally requires supplementation with maneuver-related information. For these reasons, it was deemed inappropriate to critique the individual devices that were typically deployed in conjunction with supplemental information.

Of the MUTCD devices evaluated, seven were identified as requiring supplemental information. Two of these, the Double Arrow sign (W12-1) and the Large Arrow sign (W1-7), which have already been discussed, benefit from supplementary navigational information. Each of the five other devices are likely to function more effectively when used in conjunction with speed reduction information. First of all, both the literal and symbolic versions of Advance Flagman sign (W20-7 and W20-7a) give warning of the presence of a flagger on the road ahead. The presence of a flagger implies that the driver should be prepared to stop. However, if a motorist fails to make the appropriate inference, the consequences could be critical. For this reason, supplementary information that reduces approach speed and/or warns motorists of the potential need to stop (e.g. BE PREPARED TO STOP) would seem to be indicated. Another device in need of speed reduction information is the ROAD NARROWS sign (W5-1). The MUTCD indicates that this device is warranted whenever there is a sufficient reduction in pavement width such that two cars cannot pass safely without reducing speed. As a result, application of this device without supplemental speed information alerts motorists to the presence of a hazardous condition without indicating that a speed reduction is necessary. This, of course, could result in the maintenance of speeds that are not safe for conditions. Likewise, the potential hazard presented by a one lane bridge may require the driver to reduce speed or even bring the vehicle to full stop just prior to the bridge. Yet, although the ONE LANE BRIDGE sign (W5-3) warns drivers of the condition hazard, it does not indicate the possible need for any maneuver. Because of this, supplementary information that reduces approach speed and/or warns motorists of the potential need to stop would seem to be beneficial. Similarly, the Narrow Bridge Warning sign (W5-2a) functions to warn drivers of a hazardous condition without indicating the need for any change in speed. For those situations in which maintenance of initial speed could be hazardous, this device ought to be accompanied by speed advisory information.

The final requirement of the driver response criterion is that the information presented by a given device be clear and unambiguous. One aspect of this requirement is that the information communicated should not lend itself to an interpretation other than that which is intended. Three MUTCD devices were identified as having potential problems on the basis of this criterion. First, the message of the SPEED ZONE AHEAD sign (R2-5c) may be ambiguous to some drivers. Since this phrase is not commonly encountered aside from its appearance on this device, it is likely that there are some motorists who do

not know what a "speed zone" is. In fact, it is conceivable that some motorists may mistakenly assume that a speed zone is a stretch of road where the speed limit is raised rather than lowered. If the message is not understood by the driver, then the device has failed to provide the intended advance warning of a reduced speed zone. If the message is misinterpreted, then drivers may actually increase rather than decrease vehicle speeds. The consequence of this driver response would be an increase in the difference between the speed limit and the actual speed of the vehicle; this, of course, could create a very hazardous situation. The other two devices identified as amenable to misinterpretation are problematic only when applied on multiple lane facilities. When the KEEP RIGHT sign (R4-7a and R4-7b) is employed on a road having more than one lane in each direction of travel, the message could be misinterpreted as a direction for motorists to restrict themselves to the right lane of travel. The effect of this driver response could be either driver uncertainty or unnecessary lane changes. For this reason, caution must be exercised when using this device on multiple lane facilities.

For a device to be unambiguous, the message must not only preclude mininterpretation but also be readable and comprehensible. That is, information must be presented in such a way that it can be understood in only one way by the vast majority of the driving public. In this regard, in the opinion of certified Reading Specialists, the following words are typically not presented or mastered in the public schools until the fifth grade: "construction," "machinery," and "merge." There are two concrete bases that support this judgement: first, none of these words appear on any of the basic word lists - such as the Dolch - of commonly occurring words; and, second, none of these words are presented prior to the fourth grade in any of the major Reading Series - such as Ginn, Lippincott, etc. Given that the criterion for functional literacy is generally assumed to be the ability to read on a fifth grade level, each of these three words is of questionable comprehensibility for those motorists that can be characterized as functionally illiterate. In addition, since the frequency of daily usage of the word "merge" is especially low, its comprehensibility is particularly suspect. Of the MUTCD devices that were evaluated, the following were identified as being potentially incomprehensible because of the use of one of the three words listed above: ROAD CONSTRUCTION NEXT ___ MILES (G20-1), ROAD CONSTRUCTION ___ FT (W20-1), ROAD MACHINERY AHEAD (W21-3), and LANE ENDS MERGE LEFT (W9-2). The effect of including a non-readable word that is not understood on a traffic control device is to negate the informational value of the device because the driver does not receive the intended message.

Just as the message of a device may be ambiguous because it is not understood by some motorists, it may also be ambiguous because of driver confusion about the referent of a particular word. Specifically, although most drivers may be able to read the words "right" and "left", some people have difficulty responding rapidly due to confusion about the actual direction. For this reason, driver uncertainty can occur whenever a literal device specifies right/left direction without being supplemented by diagrammatic information. Of the MUTCD devices evaluated, three were identified as being characterized by this disadvantage, and all three devices belong to the Maneuver Warning category. These devices are: RIGHT LANE CLOSED ___ MILE (W20-5), LANE ENDS MERGE LEFT (W9-2), and RIGHT LANE ENDS (W9-1). The use of any of these three signs without diagrammatic supplementation could result in confusion and uncertainty among some drivers. This kind of uncertainty could delay or

preclude execution of the required maneuver.

b. Reference Location

The results of the evaluation of devices against the reference location criterion are summarized in Table 19. The reference location criterion concerns where the driver must respond to the information presented by a particular traffic control device. When evaluating a device against this criterion, the critical issue is whether the device presents specific reference distance information when such information is required. On the basis of this criterion, three devices were judged to be in need of such information regardless of the application situation. Each of these three devices require the driver to alter vehicle travel path, but none of the devices provide any indication of how much time/distance is available to complete the maneuver. Both the RIGHT LANE ENDS sign (W9-1) and the related LANE ENDS MERGE LEFT sign (W9-2) are problematic in this respect. Each of these devices requires the driver to shift into the left lane without indicating the amount of time that is available to complete the lane change. As a result, some drivers may execute the maneuver in a hasty, erratic manner while others delay until the maneuver is forced upon them by the physical geometry of the lane closure. In either case, the degree of risk associated with the maneuver is higher than necessary. In addition, if some drivers change lanes too hastily while others delay too long, a consequence is an extended, continuous disruption in the flow of traffic beyond that which is necessary. Another device which was considered to benefit from reference distance information regardless of application is the PASS WITH CARE sign (R4-2). This device informs the driver that it is safe to pass, but it fails to communicate the amount of time/distance available to complete the passing maneuver. Consequently, some drivers may take unnecessary risks by trying to hurry the maneuver more than necessary. On the other hand, other drivers may overestimate the available time/distance. Such a driver may attempt to pass a queue of slow-moving vehicles, for example, only to discover that the passing zone ends before the entire line has been overtaken.

A variety of devices were judged to benefit from the addition of reference information. They are listed in Table 20. The thread of commonality which ties these devices together from the drivers' viewpoint is that they represent comparatively rarely experienced events. As such, drivers frequently do not have sufficient experience to "know" where the hazard is with respect to its warning sign. This is even more true in work zones where the particular hazard may be both spatially and temporally impermanent. Failure to specify distance information in this situation can negate the warning value of the sign. If, for example, the driver is warned of a bump, reduces speed in expectancy of it and then does not encounter the hazard, initial speed may be resumed before encountering the bump thereby negating the effect of the warning.

Evaluating traffic control devices against the reference location criterion also involved an examination of those devices that do provide distance information. For this analysis, it was assumed to be advantageous if the reference distance information presented were both specific and amenable to monitoring by drivers during the approach to the designated condition. On the basis of these considerations, the most preferred unit of measure for specifying location information is the "mile," since it enables the driver to

Table 19. Reference location evaluation results.

EVALUATION COMMENTS	TRAFFIC CONTROL DEVICES
Requires distance information - all applications	RIGHT LANE ENDS (W9-1) LANE ENDS MERGE LEFT (W9-2) PASS WITH CARE (R4-2)
Requires distance information - selected applications	BUMP (W8-1) DIP (W8-2) Pavement Ends (W8-3 & W8-3a) SOFT SHOULDER (W8-4) LOW SHOULDER (W8-9) Slippery When Wet (W8-15) Railroad Advance Warning (W10-1) Hill (W7-1) SHOULDER WORK (W21-5) Pavement Width Transition (W4-2) ROAD NARROWS (W5-1)
Provides distance information in miles	ROAD CONSTRUCTION NEXT ___ MILES (G20-1) ROAD WORK ___ MILE (W21-4) RIGHT LANE CLOSED ___ MILE (W20-5) ROAD CLOSED ___ MILES AHEAD - LOCAL TRAFFIC ONLY (R11-3a)
Allows choice of feet or miles to indicate distance	ROAD CONSTRUCTION ___ FT [MILE] (W20-1) STREET CLOSED ___ FT [MILE] (W20-3) DETOUR ___ FT [MILE] (W20-2) ONE LANE ROAD FT [MILE] (W20-4)
Allows choice of feet or miles to indicate distance	ROAD CONSTRUCTION ___ FT [MILE] (W20-1) STREET CLOSED ___ FT [MILE] (W20-3) DETOUR ___ FT [MILE] (W20-2) ONE LANE ROAD ___ FT [MILE] (W20-4)
Provides distance information in feet	BLASTING ZONE ___ FT (W22-1) Supplemental plate for Advance Flagman (W20-7a)
Specifies location via the word "ahead"	STOP AHEAD (W3-1) YIELD AHEAD (W3-2) ROAD MACHINERY AHEAD (W21-3)

use the vehicle odometer as a means of monitoring distance. This is an advantage in that it provides greater assurance of driver certainty regarding the location of the designated maneuver or road condition. In specifying distance in miles, the most useful fractional unit is in tenths of a mile, since vehicle odometers also change in tenths. One potential problem with using tenths, however, is that a driver may not see the decimal point and misread the distance information. For example, he may see 1.0 MILES and misread the message as 10 MILES. To prevent this problem, some convention that reduces the probability of misreading must be consistently followed. One alternative is to use a positive image (i.e. black on white) to specify whole miles and a negative image (i.e. white on black) to specify tenths of miles. The discrimination between whole units and tenths would be even more certain if tenths were consistently color coded in a third color. That is, for a black on white device whole miles could appear as black on white numerals while tenths could appear as white on red numerals. Finally, using tenths of a mile as a unit of measure loses its informational value at distances shorter than 528 feet. For this reason, if distance information is required and if the distance involved is less than 528 feet, then feet should be used as the unit of measure.

Table 20. Condition warning signs requiring distance.

MUTCD Device Code	Information Presented
W8-1	BUMP
W8-2	DIP
W8-3 & W8-3a	PAVEMENT ENDS (literal & symbolic versions)
W8-4	SOFT SHOULDER
W8-9	LOW SHOULDER
W8-15	Slippery When Wet
W10-1	Railroad Advance Warning
W7-1	Hill
W21-5	SHOULDER WORK
W4-2	Pavement Width Transition
W5-1	ROAD NARROWS

According to MUTCD specifications, four devices were identified as meeting the criterion: ROAD CONSTRUCTION NEXT ___ MILES (G20-1), ROAD WORK ___ MILE (W21-4), RIGHT LANE CLOSED ___ MILE (W20-5), and ROAD CLOSED ___ MILES AHEAD - LOCAL TRAFFIC ONLY (R11-3a). In addition, MUTCD guidelines allow the choice of using either feet or miles to indicate distance for the following five devices: ROAD CONSTRUCTION ___ FT [MILE] (W20-1), STREET CLOSED ___ FT [MILE] (W20-3), DETOUR ___ FT [MILE] (W20-2), FLAGMAN ___ FT [MILE] (W20-7), and ONE LANE ROAD ___ FT [MILE] (W20-4). Given the monitoring requirement, specification of distance in miles is preferred unless the distance involved is less than 528 feet or 0.1 mile. For the same reason, the distance information presented by the BLASTING ZONE ___ FT sign (W22-1) and the supplemental plate for the symbolic Advance Flagman sign (W20-7a) may be more effectively provided with miles as the unit of measure. Finally, the following devices were identified as using the word "ahead" as a general means of referring to the location of either a road condition or maneuver requirement: STOP AHEAD (W3-2), YIELD AHEAD (W3-2), and ROAD MACHINERY AHEAD (W21-3). The

use of the general word "ahead" does not indicate the exact location for the required maneuver or road condition. As a result, the driver may either overestimate or underestimate the point at which any required maneuver must be initiated. This could lead to unnecessary variance in speed among the vehicles approaching the maneuver location.

c. Road Condition

The results of the evaluation of devices against the road condition criterion are summarized in Table 21. The road condition criterion is applicable to those devices that provide information about unexpected, atypical or hazardous road conditions. This criterion requires such information to be as unambiguous and specific as possible so that drivers can formulate accurate expectancies about upcoming road conditions and the maneuvers that may be required. The value of specific versus general information, then, is to reduce the attentional and perceptual load on the driver by focusing on the unexpected parameters of a traffic situation. On the basis of this criterion, five devices were judged to be less specific than desirable. The following two devices from the Information Category entitled Speed Change Warning Information were considered to be ambiguous: REDUCED SPEED AHEAD (R2-5a) and SPEED ZONE AHEAD (R2-5c). Since neither of these devices indicates the new reduced speed, the driver is required to detect and recognize a subsequent speed limit sign (R-1) to obtain the required information. Three other devices, from the Condition Warning Category, were judged to be less specific than possible. These devices are: ROAD CONSTRUCTION NEXT ___ MILES (G20-1), ROAD CONSTRUCTION ___ FT (W20-1), and ROAD WORK ___ MILE (W21-4). Each of these devices requires that the driver maintain vigilance for a broad range of potential conditions and/or required responses. If more specific information about the type of work being done (e.g. line painting vs. shoulder work) were provided, then attention could be focused on specific hazards, thereby reducing demands on the driver. Of course, some construction operations may be extensive enough to warrant the more general information. Consequently, the appropriateness of general versus specific information is dependent upon the particular application situation being considered and the likely impact on the driver.

Table 21. Road condition evaluation results.

EVALUATION COMMENTS	TRAFFIC CONTROL DEVICES
Requires specification of new, reduced speed limit	REDUCED SPEED AHEAD (R2-5a) SPEED ZONE AHEAD (R2-5c)
Describes general versus specific condition	ROAD CONSTRUCTION NEXT ___ MILES (G20-1) ROAD CONSTRUCTION ___ FT (W20-1) ROAD WORK ___ MILE (W21-4)

3. Recognition Distance Criterion

The results of the evaluation of devices against the recognition distance criterion are summarized in Table 22. The recognition distance criterion requires that the maximum available legibility distance of a particular device be greater than the distance by which the device must be detected and its message recognized. Since the legibility distance of a device is dependent upon letter height, whether the device meets recognition distance requirements is dependent upon the dimensions of the device. As a result, it is possible that recognition distance requirements are exceeded by some sign dimensions but not by others. The devices that are most problematic are those that do not meet recognition distance requirements when standard device dimensions are employed. The available legibility distances of the following devices were judged to be insufficient for recognition even with standard device dimensions: RIGHT LANE ENDS (W9-1), STOP AHEAD (W3-1), and REDUCED SPEED AHEAD (R2-5a). In addition, certain bits of information presented by other devices were considered inadequate on the basis of the recognition distance criterion. In this regard, the word "yield" on the YIELD sign (R1-2) does not meet recognition distance requirements for higher speeds. This disadvantage is not particularly significant if it can be assumed that drivers receive the message to yield on the basis of the unique color-shape coding of the device. Likewise, the "lane ends" portion of the RIGHT LANE ENDS sign (W9-1), as prescribed by the MUTCD, is confirmatory information. As such, it may not necessarily be subject to the same rigid criterion that is applicable to the other information presented by the device. Similarly, for the REDUCED SPEED XX MPH sign (R2-5b), both "reduced speed" and "mph" are not sufficient for recogniton. The intended message of the device (i.e. specification of the speed limit) may be received in spite of this, though, by virtue of the more than adequate legibility of the numerals and the high familiarity with speed signs. The same reasoning is also applicable to the SPEED LIMIT sign (R2-1), for which the numerals are legible while "speed limit" is not. For any of these devices, the consequence of insufficient available legibility distance is that the message intended by the device either may not be received or may be comprehended too late for the driver to respond safely.

Evaluating devices against the recognition distance criterion also involved an assessment of the adequacy of device legibility for sign dimensions that are smaller then the recommended standard size. The results of this analysis identified the following devices as insufficient for recognition when minimum dimensions are employed: RIGHT LANE CLOSED __ MILE (W20-5), ONE LANE ROAD __ FT [MILE] (W20-4), FLAGMAN __ FT (W20-7), STREET CLOSED __ FT [MILE] (W20-3), DETOUR __ FT [MILE] (W20-2). For these devices, when minimum dimensions are used, the intended message may not be received within an adequate time frame thereby invalidating the informational value of the device.

4. Unresolved Information Needs

The results of the evaluation procedure indicate two classes of driver information needs that are not fulfilled by current MUTCD devices. The first class of needs are those that are inadequately met by the existing devices, and the second, and more important group, contains needs that are not met at all by the MUTCD devices. As indicated earlier in this chapter,

Appendix A summarizes the information requirements that remain unfulfilled for each of the MUTCD devices judged to be inadequate in some respect.

Table 22. Recognition distance evaluation results.

EVALUATION COMMENTS	TRAFFIC CONTROL DEVICES
Standard device dimensions do not meet recognition distance requirements	YIELD (R1-2) LANE ENDS MERGE LEFT (W9-2) RIGHT LANE ENDS (W9-1) STOP AHEAD (W3-1) REDUCED SPEED XX MPH (R2-5b) SPEED LIMIT (R2-1) REDUCED SPEED AHEAD (R2-5a)
Minimum device dimensions do not meet recognition distance requirements	RIGHT LANE CLOSED ___ MILE (W20-5) ONE LANE ROAD ___ FT [MILE](W20-4) FLAGMAN ___ FT (W20-7) STREET CLOSED ___ FT [MILE](W20-3) DETOUR ___ FT [MILE] (W20-2)

The second class of driver information needs not met are those that are not met at all by current MUTCD devices. These needs were inferred both from the analysis of information requirements dictated by the work zone models utilized in this project and from the actual use of devices designed by various states to provide drivers with needed information. The State and local agency devices that meet these unresolved information needs are presented in Appendix B. It is organized to provide either a description or an illustration of the information presented by each of the devices and describes the intended application for each device.

APPENDIX A

EVALUATION COMMENTS FOR MUTCD DEVICES

Extensive cataloging of work zones undertaken as part of the research effort indicated apparent problems in the selection and application of MUTCD devices in work zones. Consequently, a thorough examination was made of devices observed in use in the field to identify specific shortcomings. A natural outgrowth of problem identification is solution identification. This appendix presents the results of that analysis.

For each device, one or more evaluation comments are presented. For each critical comment, one or more alternative solutions are suggested. It should be noted that the "solutions" are intended to be functional or conceptual solutions not detailed, specific answers to the problems identified. The intent is to suggest a potential path that might be followed to eliminate a specific device problem, not the precise manner in which to achieve the solution.

Information Category: Feature and Maneuver Warning

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
YIELD AHEAD (W3-2)	Specifies location via the word "ahead"	Use miles or feet to indicate distance
Narrow Bridge Warning (W5-2 and W5-2a)	May require supplementary speed reduction information	Use an advisory speed plate placed beneath the sign Supplement with speed limit or a TCD, similar in content to R2-5b, providing speed reduction information Redesign device to include speed reduction information
ONE LANE BRIDGE (W5-3)	May require distance information if sight distance is limited	Use supplemental plate
	May require supplementary speed reduction information	Use an advisory speed plate placed beneath the sign Supplement with other TCDs providing speed reduction information and/or "Be Prepared to Stop" message Redesign device to include speed reduction information
ROAD NARROWS (W5-1)	Same as (W5-2)	Same as (W5-2)

Information Category: Feature and Maneuver Warning (continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
RIGHT LANE ENDS (W9-1)	Susceptible to right/left confusion	Supplement with device which presents "right lane ends" message diagrammatically
	Requires distance information - all applications	Supplement with other TCDs that provide distance information
		Use a supplemental plate placed beneath the sign
		Redesign device to include distance information; format similar to W20-5
	Standard device dimensions do not meet recognition distance requirements	Increase standard size of device
		Redesign device to increase relative size of legend

Information Category: Feature and Maneuver Warning (Continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
LANE ENDS MERGE LEFT (W9-2)	Requires relatively high reading level	Supplement with diagramatic (W4-2)
	Susceptible to right/left confusion	See above
	May require distance information	Use a supplemental plate placed beneath the sign
		Supplement with other TCDs that provide distance information
		Redesign device to include distance information
	Standard device dimensions do not meet recognition distance requirements	Increase standard size of the device
		Redesign device to increase size of "lane ends"

Information Category: Feature and Maneuver Warning (Continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
DETOUR ___ FT [MILE] (W20-2)	Minimum device dimensions do not meet recognition distance requirements	Do not use minimum device dimensions
STREET CLOSED ___ FT [MILE] (W20-3)	Minimum device dimensions do not meet recognition distance requirements	Do not use minimum device dimensions
ONE LANE ROAD ___ FT [MILE] (W20-4)	Potentially ambiguous message	Do not use on multiple lane facilities Redesign device so that "one lane road is represented diagramatically while "__ mile" remains literal
RIGHT LANE CLOSED ___ MILE (W20-5)	Susceptible to right/left confusion	Supplement with device which presents "right lane closed" message diagrammatically Redesign device so that "right lane closed" is represented diagramatically while " __ mile" remains literal
	Minimum device dimension do not meet recognition distance requirements	Do not use minimum device dimensions

Information Category: Feature and Maneuver Warning (Continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
FLAGMAN ___ FT (W20-7 and W20-7a)	Requires supplementary speed reduction information	Use an advisory speed plate placed beneath the sign Supplement with speed limit or other TCD with content similar to R2-5b providing speed reduction information and/or "Be Prepared to Stop" message Redesign device to include speed reduction information
	Minimum device dimensions do not meet recognition distance requirements	Do not use minimum device dimensions
	Standard device dimensions do not meet recognition distance requirements	Use symbolic device (W20-7a)
SOFT SHOULDER (W8-4)	Requires distance information	Use a supplemental distance plate
LOW SHOULDER (W8-15)	Requires distance information	Use a supplemental distance plate
SHOULDER WORK (W21-5)	Requires distance information selected applications	Use a supplemental distance plate

Information Category: Work Zone Feature Location

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
KEEP RIGHT (R4-7a & R4-7b)	Potentially ambiguous message	Redesign device R4-7b so that number of arrows equals number of lanes
		Do not use on multiple lane facilities
	Device not conspicuous enough to serve as work zone feature location information	Increase size above standard and make orange and black
Large Arrow [bidirectional] (W1-7)	Forces driver to select one of two alternative routes	Supplement with other TCDs providing navigational information
		Redesign device so that route markers can be placed beneath each arrow-head
Double Arrow (W12-1))	Forces driver to select one of two alternative routes	Supplement with other TCDs providing navigational information
		Redesign device so that route markers can be placed beneath each arrow-head.
	Device not conspicuous enough to serve as work zone feature location information	Increase size above standard

Information Category: Work Zone Feature Location (Continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
ROAD CONSTRUCTION NEXT __ MILES (G20-1)	Requires relatively high reading level	Redesign device so that "construction" is replaced by "work" Redesign device so that "road construction" is replaced by symbolic counterpart
	Describes general versus specific condition	Use only at first feature of work zone or first evidence (limit) of construction as specified in MUTCD Supplement with oversize, specific sign at beginning of each feature, such as LEFT LANE CLOSED, or LOW SHOULDER with plate W7-3a NEXT X MILES

Information Category: Road Condition Warning

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
Pavement Width Transition (W4-2)	Requires distance information	Use a supplemental plate
Hill (W7-1)	Requires distance information	Use a distance information plate
BUMP (W8-1)	Requires distance information	Use a distance information plate
DIP (W8-2)	Requires distance information	Use a distance information plate
Pavement Ends (W8-3 &W8-3a)	Requires distance information	Use a distance information plate
Slippery When Wet (W8-15)	Requires distance information	Use a supplemental plate
Railroad Advance Warning (W10-1)	Requires distance information	Use a supplemental plate

Information Category: Road Condition Warning (Continued)

TRAFFIC CONTROL DEVICES	EVALUATION COMMENTS	ALTERNATIVE SOLUTIONS
ROAD CONSTRUCTION ___ FT [MILE] (W20-1)	Requires relatively high reading level	Redesign device so that "construction" is replaced by "work" (e.g. see W21-4)
ROAD MACHINERY AHEAD (W21-3)	Requires relatively high reading level	Redesign device so that "machinery" is replaced by "equipment"
BLASTING ZONE ___ FT (W22-1)	Provides distance information in feet	Use miles to indicate distance

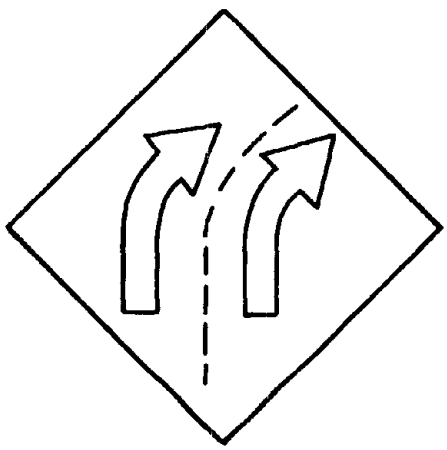
APPENDIX B

A SAMPLE OF STATE AND LOCAL AGENCY DEVICES

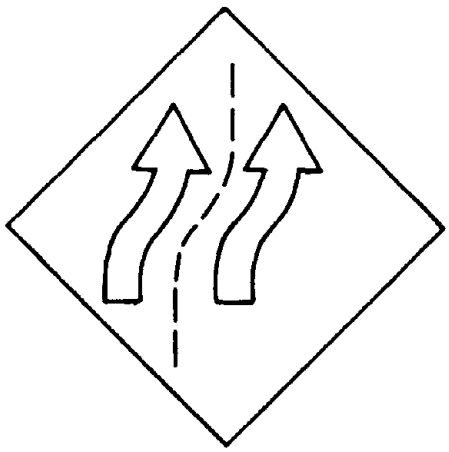
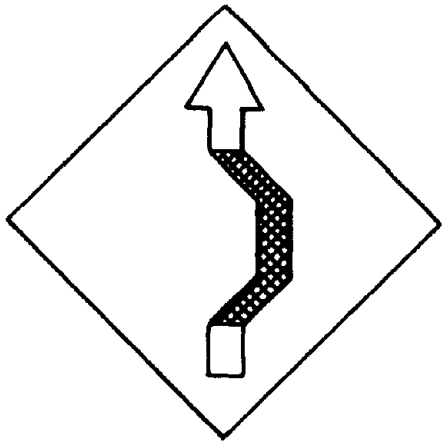
A comprehensive cataloging of traffic control devices was undertaken during the survey of work zones. A variety of warning and other types of signs have been designed and used by state and local agencies. Most of these designs follow the principles set forth in Sections 2C-41 and 6B-33 (Other Warning Signs) of the MUTCD and appear to fulfill or offer the potential of fulfilling some information needs more adequately than devices illustrated in the MUTCD

These devices are presented in this appendix with potential areas of application. These examples represent what is actually in use in one or more of the eight Eastern states in which work zones were cataloged. Although the specifics of the devices presented may require modification, the devices and the needs they fulfill warrant attention as potential additions to the set of MUTCD devices currently in use in work zones. It should be noted that the devices as shown in the appendix are not exact replicas of those cataloged. For purposes of illustrating the content, no attempt was made to duplicate the stroke width, letter height, etc.

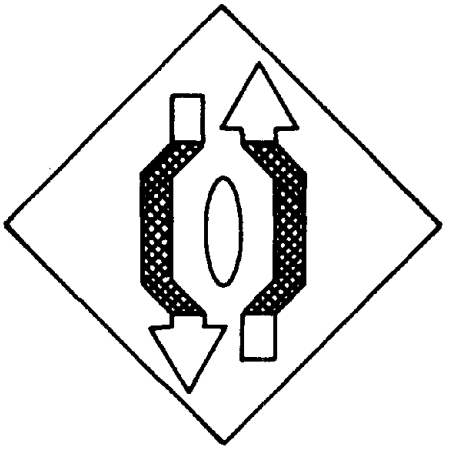
Information Category: Feature or Maneuver Warnings

	INFORMATION PRESENTED	INTENDED APPLICATION
1	 work zones: black on orange other: black on yellow	To prepare motorists to stop, after advance warning of hazard has been provided but before the actual location of the hazard has been reached [e.g. locate after ONE LANE ROAD ___ MILE (W20-4), ONE LANE BRIDGE (W5-3), and Advance Flagman sign (W20-7 & W20-7a)] See Section 6B-33 of the MUTCD.
2	 black on orange	To provide warning to drivers in work zones that the path of travel curves to the right and that two lanes of travel are maintained through the condition

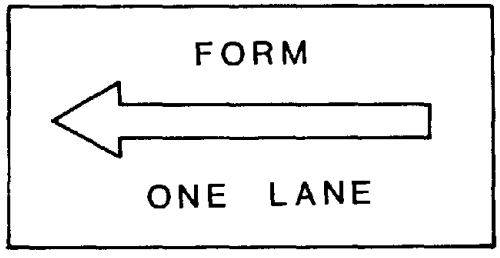
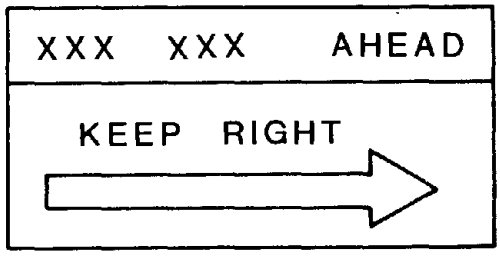
Information Category: Feature or Maneuver Warnings

INFORMATION PRESENTED	INTENDED APPLICATION
3  black on orange	To provide warning to drivers in work zones that the path of travel curves in opposite directions and that two lanes of travel are maintained through the condition
4  black on orange	To provide warning to drivers in work zones that the path of travel is briefly diverted toward the right onto a temporary roadway. This device could also be designed with two arrows to indicate that two lanes of travel are maintained through the condition.

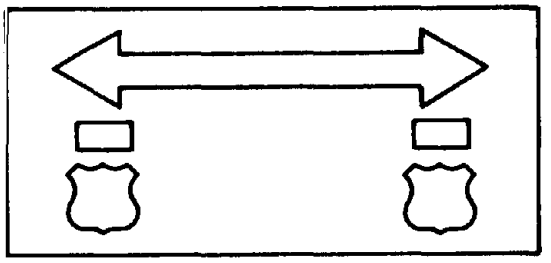
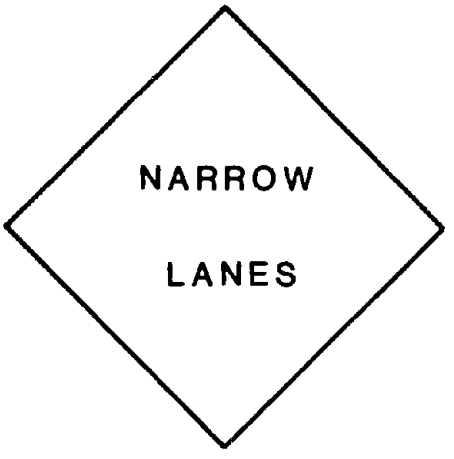
Information Category: Feature or Maneuver Warnings

INFORMATION PRESENTED	INTENDED APPLICATION
5  black on orange	To provide warning to drivers in work zones that an undivided road is briefly diverted over a temporary path in order to circumvent an obstruction

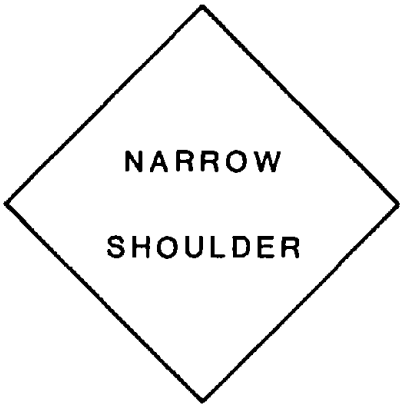
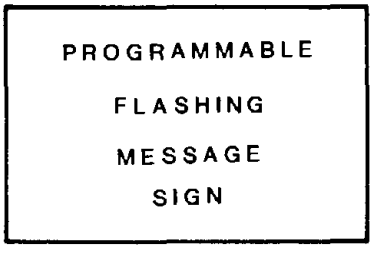
Information Category: Feature and Maneuver Location

INFORMATION PRESENTED	INTENDED APPLICATION
6  black on orange	At the beginning of a taper, to designate the location of the lane of travel and to confirm the requirement to form a single lane
7  black on orange	At the beginning of a taper, to designate the location of the lane of travel and to provide specific condition warning information, such as: PIPELINE WORK AHEAD, LINE PAINTING AHEAD, SHOULDER WORK AHEAD, etc.

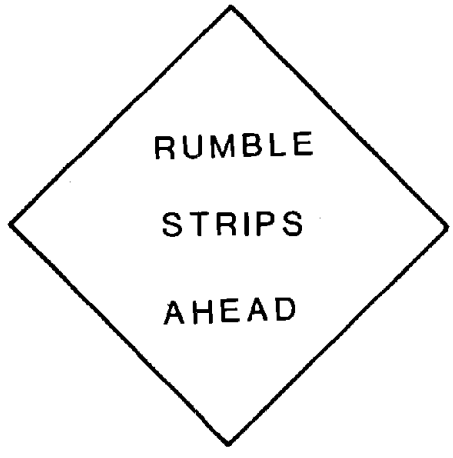
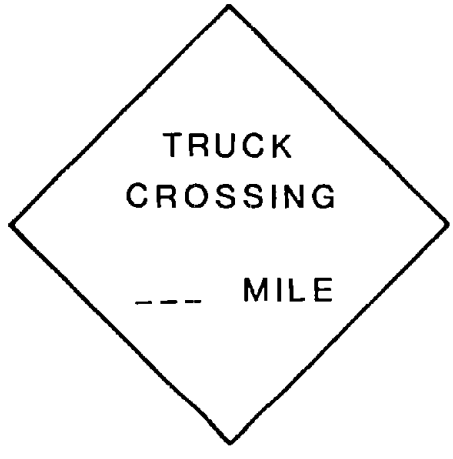
Information Category: Feature and Maneuver Location

INFORMATION PRESENTED	INTENDED APPLICATION
8  work zones: black on orange other: black on yellow	At locations where the road is closed to through traffic, to direct the driver to select one of two designated alternate routes [the Detour Marker M4-8 can be used on this device to identify one of these routes as a detour]
9  work zones: black on orange other: black on yellow	To inform drivers that the lanes of travel are significantly narrower than the previous width

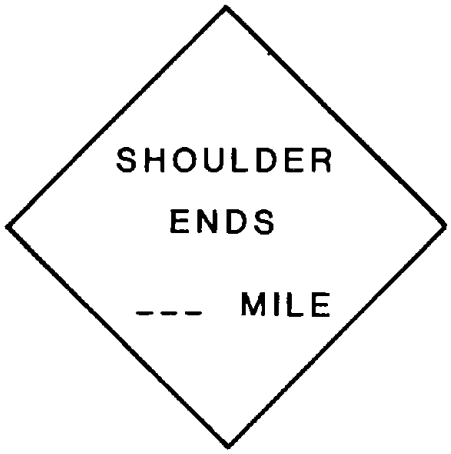
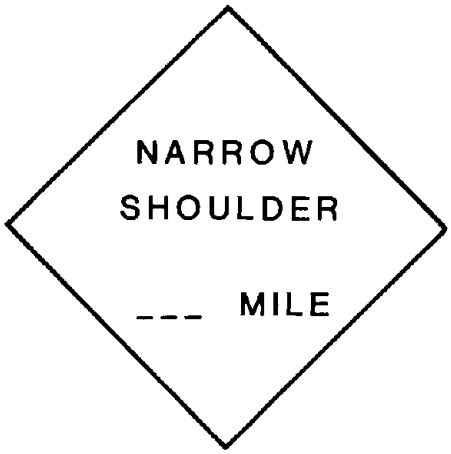
Information Category: Feature and Maneuver Location

INFORMATION PRESENTED	INTENDED APPLICATION
10  work zones: black on orange other: black on yellow	To inform drivers that the shoulder of the road is significantly narrower than the previous width
11  self illuminating	At the beginning of a work zone, to provide the driver with any message that warrants a high level of conspicuity (See Section 2A-5 of MUTCD)

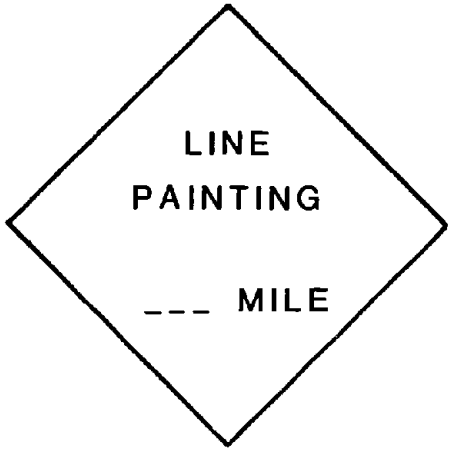
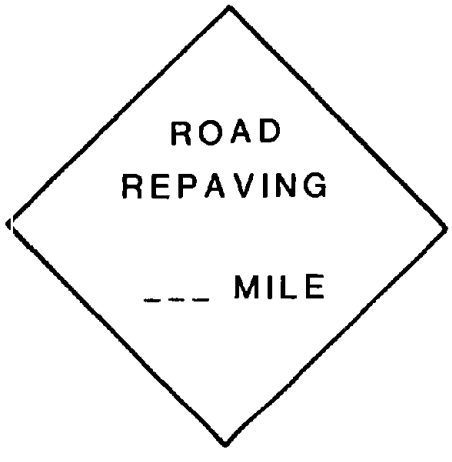
Information Category: Condition Warning

INFORMATION PRESENTED	INTENDED APPLICATION
12  black on orange	To provide warning to drivers in work zones of the presence of rumble strips on the surface of the road ahead
13  work zones: black on orange other: black on yellow	To give advance warning to drivers that heavy, slow trucks may be entering and/or leaving the roadway ahead

Information Category: Condition Warning

INFORMATION PRESENTED	INTENDED APPLICATION
14  work zones: black on orange other: black on yellow	To give advance warning that the shoulder of the road ahead ends
15  work zones: black on orange other: black on yellow	To give advance warning that the shoulder of the road ahead becomes significantly narrower than its present width

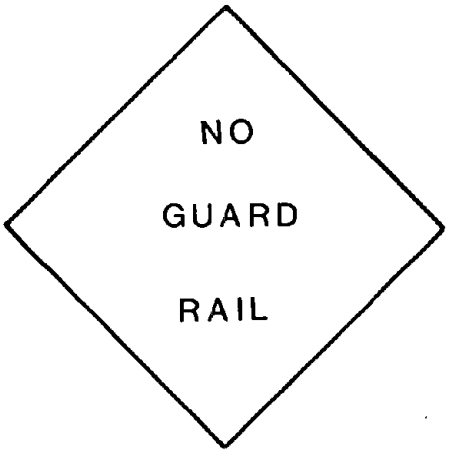
Information Category: Condition Warning

INFORMATION PRESENTED	INTENDED APPLICATION
16  black on orange	To give advance warning that road lines are being repainted on the road ahead
17  black on orange	To give advance warning that the road ahead is being repaved

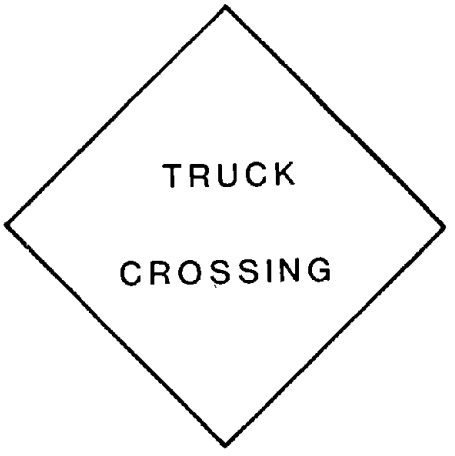
Information Category: Condition Warning

INFORMATION PRESENTED	INTENDED APPLICATION
18  work zones: black on orange other: black on yellow	To be placed beneath advance warning signs, when appropriate, to provide supplementary distance information about the designated hazard. Tenth mile information highlighted by use of reverse color, that is, orange on black.

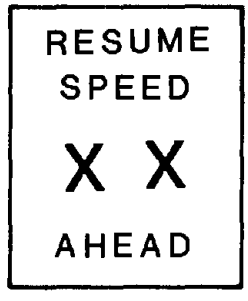
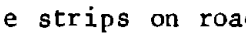
Information Category: Condition Location

INFORMATION PRESENTED	INTENDED APPLICATION
19  work zones: black on orange other: black on yellow	To alert drivers to the absence of a guard rail

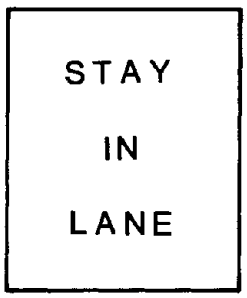
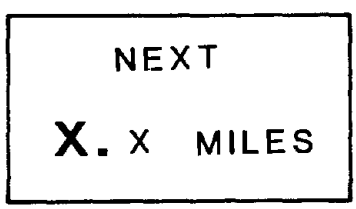
Information Category: Condition Location

INFORMATION PRESENTED	INTENDED APPLICATION
20  work zones: black on orange other: black on yellow	To alert the driver that heavy, slow trucks may be entering and/or leaving the roadway

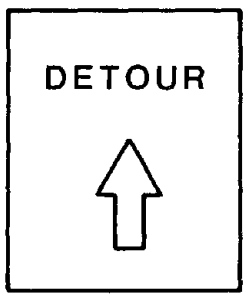
Information Category: Speed Change Warning

INFORMATION PRESENTED	INTENDED APPLICATION
21  red on white	To provide warning to drivers that the speed limit is changing to the designated maximum speed
22  rumble strips on roadway	To provide both tactile and auditory warning that vehicle speed must be reduced below the prior level

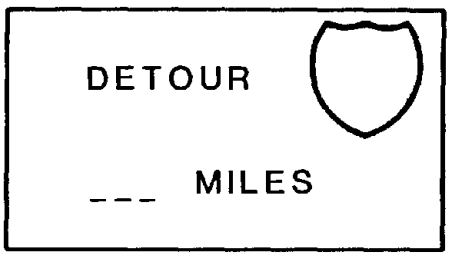
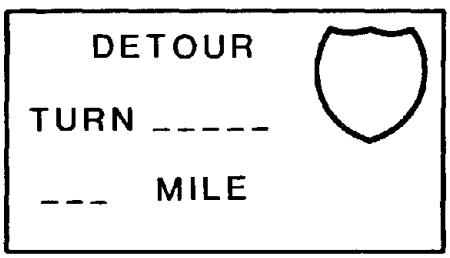
Information Category: Performance Maintenance

INFORMATION PRESENTED	INTENDED APPLICATION
23  black on white	To inform motorists that they must remain in their lane of travel until they are advised otherwise
24  black on orange	To be mounted beneath either the Detour Marker (M4-8) or the Detour sign (M4-9) as a means of providing information about the length of the detour. Can also be used for specifying length of a given condition or hazard

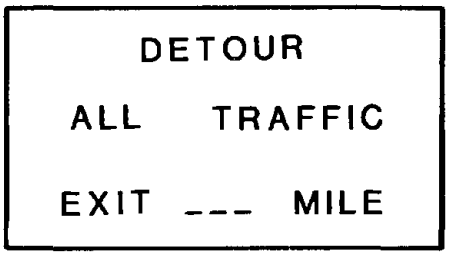
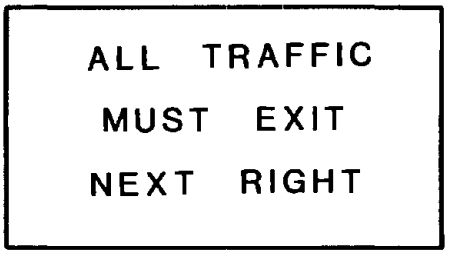
Information Category: Performance Maintenance

INFORMATION PRESENTED	INTENDED APPLICATION
25  black on orange	To be used as a method of marking detours for roads where a route number does not exist; this is a special version of M4-9

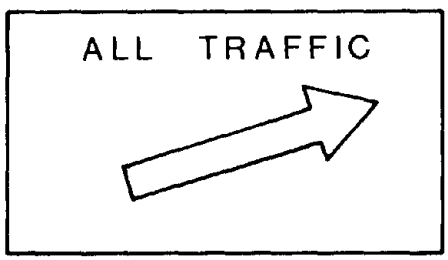
Information Category: Route Guidance

	INFORMATION PRESENTED	INTENDED APPLICATION
26	The following devices are designed to be used, as needed, to detour traffic from a high speed facility that is closed for construction.	
	 black on orange	To provide advance warning that all through traffic must detour to avoid the closing of the facility some distance beyond
27	 black on orange	To provide advance warning to motorist that a ___ turn is required at the designated distance to avoid the closing of the road and to follow the temporary detour route

Information Category: Route Guidance

INFORMATION PRESENTED	INTENDED APPLICATION
28  black on orange	To direct all traffic to exit at the specified location to avoid the closing of the road and to follow the temporary detour route
29  black on orange	To direct all traffic to exit at the next ramp

Information Category: Route Guidance

INFORMATION PRESENTED	INTENDED APPLICATION
30  black on orange	At the location of the exit ramp, to divert all traffic onto the ramp

* U. S. GOVERNMENT PRINTING OFFICE 1982 361-428/2284