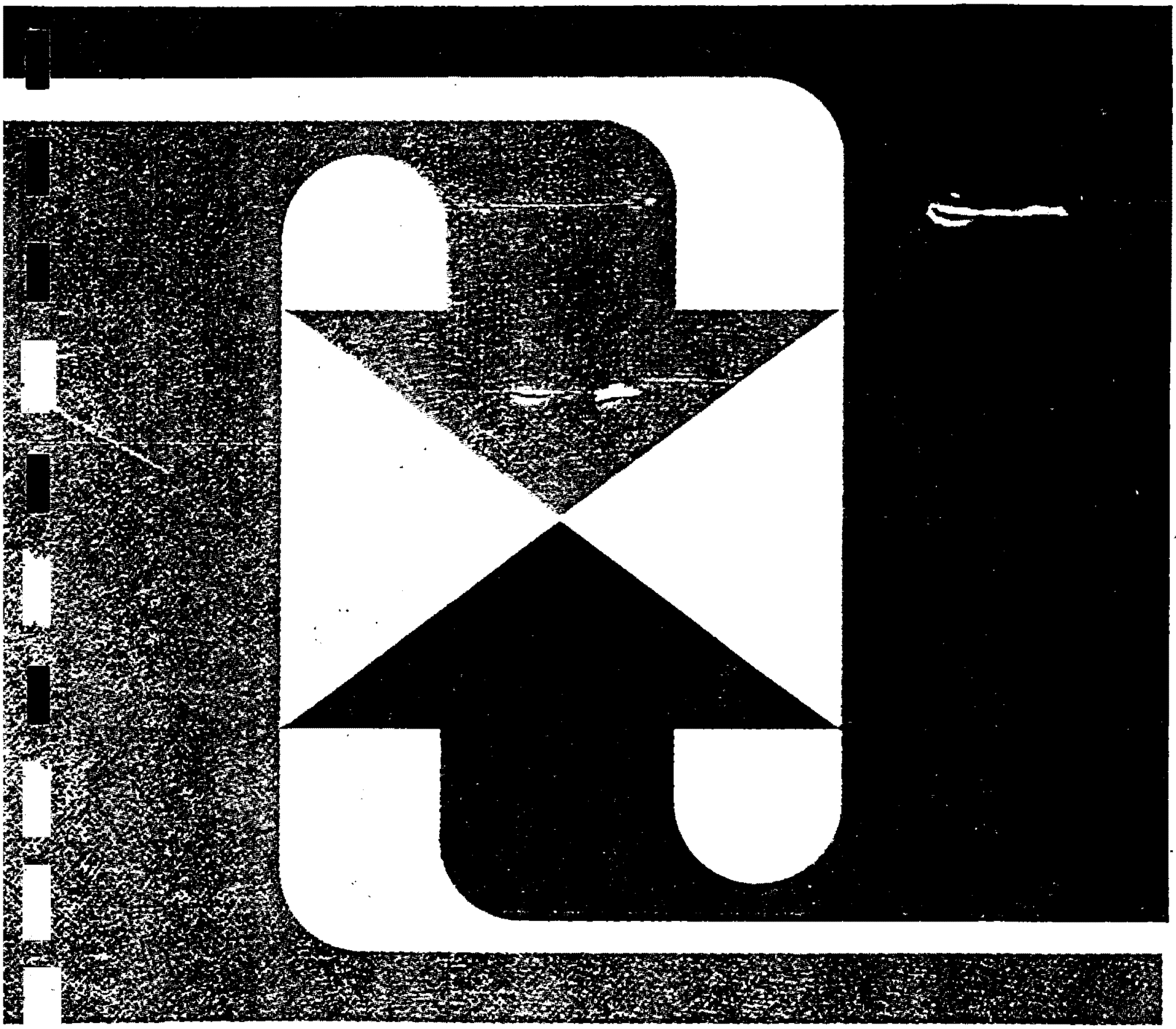
TRAFFIC CONTROL DEVICES HANDBOOK



U.S. Department of Transportation
Federal Highway Administration

TRAFFIC CONTROL DEVICES HANDBOOK

U.S. Department of Transportation
Federal Highway Administration
1983

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

26148

JUN 27 2000

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Part 1. GENERAL

Part I. GENERAL

1A. INTRODUCTION

This Traffic Control Devices Handbook is primarily intended to augment the Manual on Uniform Traffic Control Devices (MUTCD) by serving an interpretative function and by, linking the MUTCD standards and warrants with the activities related to complying with these national uniform standards. As such, the Handbook does not establish Federal Highway Administration (FHWA) policies or standards. Nor does it attempt to detail basic engineering and design techniques. For these, standard textbooks should be used. The Handbook offers guidelines for implementing the standards and applications contained in the Manual.

The Handbook provides information related to the fundamental concepts of traffic regulation and control, traffic control devices, current application practices, and promising traffic engineering techniques of the future. The materials used to develop this Handbook reflect the experience of State, county, and city agencies. The Handbook summarizes future directions and developments as reported in recent research and by industry's technical representatives. Although intended for use by various levels of design, traffic, and maintenance engineering personnel, the Handbook may also prove of value to consulting engineers, educators, students and others.

The initial part of the Handbook describes the organization and intended use of the Handbook. It also discusses items of general interest relevant to all subsequent parts. A brief overview of the fundamental principles of standards and warrants for traffic control devices is followed by a discussion of the legal responsibility involved in installing and properly maintaining traffic control devices. Finally, some of the opportunities available to agencies for obtaining assistance in traffic control are summarized.

1A-1 Evolution and Role of MUTCD

The design, installation, operation, and maintenance of traffic control devices are vital elements of a good traffic operations program. As traffic control devices are the primary, and often the only, means of communicating with the driving public, such devices must be used discriminately, uniformly, and effectively to assure correct driver interpretation and response. For consistent and safe operation the driver must receive appropriate regulatory, warning, and guidance information in a uniform manner as he maneuvers his vehicle over the roadway system in varying conditions of traffic, terrain, and weather.

The establishment of appropriate messages and uniformity of application is formalized in the MUTCD. The first edition of that document was published in 1935. Since that time, great strides have been taken towards uniformity. The coverage and sophistication of the Manual has steadily progressed as additional research and experience became available. More has been learned about driver reaction to roadway stimuli and the role that the roadway environment plays in traffic operations. Significant changes were made in subsequent editions of the MUTCD in 1948, 1961, and again in 1971. The latest edition of the MUTCD was published in 1978 and was distributed during 1979.

As evidenced by the history of the MUTCD, improvements are constantly being made in the design and application of control devices. There has been continual activity by the various forms of a National Committee on Uniform Traffic Control Devices in generating recommendations on requests for interpretations, changes, and experimentations. There have been over 40 experimental projects approved by the FHWA through the committee process. Innumerable independent research activities have been handled by various agencies. Over 350 requests for changes, interpretations and experimentation have been ruled on by the FHWA.

The MUTCD is the official standard for use on all streets and highways open to public travel. Many States and local jurisdictions have adopted, by appropriate legislative action, the MUTCD as their official standard. In some cases, certain specific designs, applications, or requirements of the Manual have been modified or eliminated by individual State legislative actions. Frequently, these modifications reflect more stringent requirements than the minimums expressed in the MUTCD.

The need for uniformity in application of control devices cannot be overstressed. From the legal liability standpoint, a major case can be made for applying at least the minimum standards as specified in the MUTCD. Litigation arising from inattention to basic guidelines for applications of traffic control devices may cost cities and counties inordinate sums of money. Conversely, the courts tend to look with favor on highway agencies who can show that "reasonable care" has been exercised in maintaining a safe driving environment. By following the guidelines in the MUTCD and by exercising sound engineering judgement, the potential for adverse judgments in litigation can be minimized. This is discussed more fully in Section D of this part.

Although the MUTCD is not a statute, it carries the power of a statute in defining national standards. Equivalent State and local Manuals which meet or exceed the MUTCD's minimum requirements also carry the power of a statute.

1A-2 Organization of Handbook

The Handbook has been structured to reflect the major "PART" headings of the MUTCD as follows.

PART I. General

PART II. Signs

PART III. Markings

PART IV. Signals

PART V. Islands

PART VI. Work Zone Traffic Control

PART VII. Traffic Control for School Areas

PART VIII. Traffic Control Systems for Railroad Highway Grade Crossings

PART IX. Traffic Control for Bicycle Facilities

Parts II through IV relate to specific control devices (i.e. Signs, Markings, Signals). The remaining Parts V through IX address traffic control devices for special situations or facilities. To the extent possible, the internal organization of each part is structured around the following basic format.

Each part begins with a *General* section which introduces the subject matter, defines the types and purposes of the devices, and identifies driver (or pedestrian) needs for appropriate response to the various control devices or techniques.

The second major heading, *Application*, covers those activities and supporting information related to preinstallation studies and decisions. Where appropriate, various planning considerations are included, such as: determining the most cost-effective techniques in complying with MUTCD requirements; evaluation of materials; procurement alternatives; etc.

The next major heading, *Installation*, was selected as an "umbrella" term to cover such concerns as geometric placement, visual needs, spacing, and position. It also includes installation or erection procedures, hardware, equipment, staffing, and crew safety. This heading is dropped in Parts VII, VIII, and IX since the necessary installation information is generally covered in the parts on Signs, Markings, and Signals.

Operations and Maintenance, are either combined or are two individual sections depending on the volume of information to be presented. The operational considerations may include a general definition of specific engineering studies required to determine the adequacy of existing traffic control devices or the need for additional or other forms of devices. Current practice in maintaining the in-place devices is covered under *Maintenance*. This heading is dropped in Parts VII, and IX as it does not appear necessary to repeat the maintenance practices contained in Signs, Markings, and Signals.

The final heading, *Other Considerations*, includes those subject areas that either fall outside of the general or typical applications discussed previously or require a special treatment. It may also provide a graphic layout of significant, but unique applications.

1A-3 User Orientation

Potential users of this Handbook include a wide range of disciplines such as traffic engineers, highway engineers, engineering technicians, maintenance foremen, etc. Users will have varying Levels of expertise and training within these disciplines. The Handbook presents the material in a form that should be easily understood by a Traffic Operations Engineering Technician, Level III.

This is not intended to imply that the Handbook is primarily for the use of Engineering Technicians. The objective is to provide sufficient background and explanation of concepts and fundamentals so that those using the Handbook can understand and apply the principles involved in the determination of need for, and installation of, traffic control devices.

The level of technical detail contained in the various parts of the Handbook reflects the characteristics of the various technologies involved. For example, the technical detail of signal timing in Part IV, SIGNALS, is much more complex than, say, the installation of painted markings in Part III.

1A-4 Relationship to the MUTCD

This Handbook is intended to be used "in conjunction with" not "in place of" the MUTCD. The requirements of the MUTCD (or equivalent State Manual), take precedence in all cases. It is not the intention to repeat or paraphrase the standards and guidelines presented in the MUTCD except where a short quotation is integral to a particular discussion. Consequently, it is assumed that users of this Handbook have a current copy of the MUTCD and are familiar with its purpose and content.

Section 1A-7 of the MUTCD provides a list of reference documents that are important to all traffic engineering agencies involved with traffic control devices. In addition, most State agencies frequently provide standard or model specifications, plans, and policy guidelines to local agencies upon request.

A reference list is provided at the end of each part of the Handbook to assist those requiring further or more detailed information than provided in the Handbook. Although the information contained herein was compiled from numerous documents, the documents referenced in the text were limited to readily available standard texts.

1B. INTRODUCTION TO TRAFFIC CONTROL DEVICES

As stated in the MUTCD, ". . . Traffic control devices are all signs, signals, markings, and devices placed on, over, or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate, warn or guide traffic." To be effective, a traffic control device should meet the following basic requirements:

- It should be capable of fulfilling an important need.
- It should command attention.
- It should convey a clear, simple meaning.
- It should command respect of road users.
- It should be located to give adequate time for response.
- It must be sanctioned by law if it controls or regulates traffic.

1B-1 General Purpose of Traffic Control Devices

The general purpose of traffic control devices is to provide visual information to the road user. Devices may be divided into groups depicting those that regulate, warn, or guide traffic.

Regulatory devices are used so that the motorist is:

- Informed of regulations that are in force—speed limits, parking restrictions, one-way operation, no passing zones, load limits, etc.
- Instructed to take some action—stop, yield, right turn, trucks use right lane, etc.
- Prohibited from making certain maneuvers—turn prohibitions, do not enter, do not pass, etc.
- Permitted to make certain maneuvers—right turn on red signal, U-turns, pass with care, etc.
- Assigned right-of-way—traffic signals, through street designation, channelization, etc.

As the name implies, warning devices warn the motorist of some condition he may not be expecting. Specifically, warning devices are used to:

- Indicate presence of geometric features with potential hazards—curves, intersections, grades, truck crossings, etc.
- Define major changes in roadway character—road narrows, one-lane bridge, divided highway ends, pavement ends, etc.
- Mark obstructions or other physical hazards in or near the roadway—bump, dip, fixed objects, low clearances, etc.
- Locate areas where hazards may exist under certain conditions—schools, rock slide areas, slippery when wet, railroad crossing, etc.

- Inform motorist of regulatory controls ahead—signal ahead, stop ahead, speed zone ahead, etc.
- Advise driver of appropriate action—advisory speed signs, traffic signal progressive speed sign, merging traffic, etc.

Guide devices typically provide the motorist with the following information:

- Route identification—highway route markers (Interstate, U.S., State, and local routes), city street name signs, truck routes, detours, etc.
- Directions to the traveler—destination and distance signs, junction signs, interchange signing, etc.
- Delineation of roadway—delineators, pavement markings, etc.
- Information—rest area, services signs, parking area sign, first-aid locations, city limits (and other political boundaries), mileposts, stream names, elevations, landmarks, scenic views, etc.

1B–2 Need for Uniformity of Devices

Uniformity in the use of traffic control devices is a nationwide objective and is becoming increasingly important with increasing traffic demand on existing roadways. Present-day driving conditions of high speeds, complex intersections and interchanges, increased volumes, roadside distractions, etc., require traffic control devices that a driver can see, recognize, and understand quickly. The driver must have time to make a decision and take appropriate action safely, thereby reducing the necessity for last-second, hazardous maneuvers. A significant portion of today's travel is the intercity and interstate trips. Uniform traffic control devices help reduce motorist confusion when driving in an unfamiliar area.

It is difficult to justify the use of nonstandard devices when such use is questioned in court. (See Section D, Legal Implications). Use of approved devices reduces the potential for adverse judgments in tort liability cases. Another economic benefit is that traffic operations are simplified through economy in manufacture, installation, maintenance, and administration of control devices.

Uniformity may be viewed from several perspectives, each of which has an associated benefit. Uniformity in *design* aids the motorist in instant recognition and comprehension. Control device design includes shape, color, size, symbol, wording, lettering, illumination, and reflectorization. Uniform design is gradually being achieved in the United States, although many exceptions can still be found, especially in smaller communities.

Uniformity in *meaning* aids the motorist in complying with the device. Most control devices have at least general uniformity of meaning. There are, however, some instances where uniformity of meaning has not been achieved nationally. Two notable examples are YIELD signs and red signal indications (i.e. permissible right turn on red).

Uniformity in *application* promotes driver observance and avoids excessive or unwarranted use of the control devices. Such uniformity would insure that similar conditions would be controlled by the same type of device. Unfortunately, many devices are installed under political or public pressure at locations where they are not warranted. These installations lead to driver apathy, disregard, and disrespect for such types of controls.

Uniformity in *location* reduces the possibility of the motorist not seeing a control device. Standard device location may assist the driver in determining where the directed action is to take place, e.g., position to stop at stop signs and signals, location of ramps with respect to freeway directional signing, etc. Uniform location cannot always be achieved in actual practice. In such instances, the general rule is to install the device as near the standard location as possible.

Various steps have been taken to promote uniformity on a nationwide basis. Various Federal Aid Highway Acts authorize the FHWA to require that all control devices used on highways receiving Federal-aid funds conform to standards set forth in the MUTCD. In addition to the MUTCD, the major contributions toward national uniformity includes two guides:

- The Uniform Vehicle Code (Ref. 1-1) is a specimen set of motor vehicle laws, designed and advanced as a comprehensive guide or standard for State motor vehicle or traffic laws. It contains provisions dealing with uniform control devices, including:
  - — A requirement that the State highway department adopt a State manual of uniform traffic control devices.
  - — Requirements for all jurisdictions within the State to conform to the standards set forth in this State manual.
  - — Prohibition of the sale of nonconforming traffic control devices.
  - — Authority to install traffic control devices on or adjacent to highways restricted to state and local highway agencies.
  - — Definition of meaning and obedience required for various control devices.

- The Model Traffic Ordinance (Ref. 1-2) is a specimen set of motor vehicle laws ordinances for a municipality. It discusses the powers and authority of municipalities and the need to conform to the State vehicle code and State uniform manual.

1B-3 Standards and Warrants for Traffic Control Devices

Each jurisdiction responsible for traffic control devices should be operating within uniform policies and standards as set forth in the MUTCD or the State equivalent. Policies are frequently established in the form of warrants or guidelines to assure motorist and pedestrian safety and convenience.

A "warrant" is a set of criteria which can be used to define the relative need for, and appropriateness of, a particular device (e.g. STOP or YIELD sign, traffic signal, etc.). Warrants are usually expressed in the form of numerical requirements such as the volume of vehicular or pedestrian traffic. A warrant normally carries with it a means of assigning priorities among several alternative choices. There are two fundamental concepts involved in this determination:

- The most effective traffic control device is that which is the least restrictive while still accomplishing the intended purpose.
- Driver response to the influences of a traffic control device has been previously identified by observation, field experience, and laboratory test under a variety of traffic and driver conditions.

Warrants should be viewed as guidelines, not as absolute values. Satisfaction of a warrant is not a guarantee that the device is needed. Conversely, the fact that a warrant is not fully satisfied does not constitute absolute assurance that the device could not serve a useful purpose. The application of warrants is effective only when combined with knowledgeable engineering judgment considering all pertinent facts.

The term "standards" in the context of this Handbook applies to the actual design, application, installation and maintenance of control devices; i.e. color, shape, size, location, etc.

Traffic technicians and other traffic professionals, have an obligation to the public to thoroughly understand the principles involved in the determination of need for, and installation of, traffic control devices. Application guidelines given in the MUTCD, are representative of typical situations only. Traffic personnel must be able to apply the warrants and standards to the prevailing field conditions to assure that the purpose and intent of the particular traffic control device is fully realized.

1C. ENGINEERING STUDIES AND RECORDKEEPING

There is little question that properly applied traffic control measures can improve traffic flow and safety. However, these measures can be effective only if they are used when their need is supported by engineering studies of accidents, traffic flow characteristics, and relevant physical conditions. It is therefore incumbent upon traffic engineering agencies to recognize the role these studies play and their significance.

1C-1 Background

Throughout the MUTCD and this Handbook, reference is frequently made to the need for engineering studies and engineering judgment in the proper application of traffic control measures and devices. In almost all cases, the most commonly required engineering studies depend upon information about local conditions. Data required for the various types of studies must be collected and compiled so that it can be easily analyzed and evaluated to determine the most appropriate action for a given situation.

In reality, many of the guidelines provided in the MUTCD and other recognized texts address typical situations (Ref. 1-3, 1-4). This assumes that "typical" situations actually exist. Actually, no two roadway environments are exactly alike. There are innumerable variables and few constants. Consequently, engineering studies and adequate recordkeeping are often the first steps necessary to effectively apply the fundamentals and concepts contained in the MUTCD.

As the use of traffic control devices has evolved and improved over the years, the quality and techniques related to engineering studies have also changed and improved. Most State agencies have developed their own procedures and guidelines for conducting engineering studies based on State policies. In addition, both Federal and State funding programs carefully define the type of project studies required to be eligible to receive financial assistance in implementing traffic control and safety improvements.

It is not within the purview of this Handbook to detail all types, forms, and procedures involved in engineering studies. These are well-documented both in standard traffic engineering texbooks and State procedural manuals. As these studies often require specialized knowledge and engineering determinations, small agencies that do not maintain a full staff of experienced engineers should seek assistance from their State highway agency, their county engineering or public works department, large neighboring cities, or a traffic engineering consultant.

The most commonly-used types of engineering studies and information requirements are summarized below.

1C-2 Accident Analysis

The reduction of vehicular and pedestrian accidents and the resulting decrease in the toll of fatalities, injuries, and economic loss is a primary goal of the entire traffic engineering community. The value of traffic accident information and analysis and the application of this information toward the correction of traffic safety problems cannot be overstressed. It serves as a primary indication of the overall operational characteristics of the road system and specific deficiencies, and the need for improved traffic control devices.

Basically, traffic accident information can be used to:

- Identify and analyze high accident locations,
- Conduct before and after studies,
- Evaluate requests for additional traffic control,
- Evaluate roadway features,
- Identify and rank improvement projects,
- Establish and maintain traffic regulatory devices, and
- Identify need for police surveillance and enforcement.

In most jurisdictions, the responsibility for a basic accident record system is assigned to the police department. It is therefore necessary to establish administrative procedures to assure that the traffic engineering staffs are provided with appropriate information on all reported accidents occurring within their jurisdiction. As a minimum, this information should be current and should include: time, date, location, severity (fatality, injury, property damage only), type of accident (pedestrian, fixed object, run off the road, etc.), and the file reference number on the police or driver accident report. The forms, formats, and data elements included vary from agency to agency. While most accident record systems are now computerized, some smaller agencies continue to compile and record these data manually.

Spot accident location maps are usually maintained on a current basis by local agencies as an aid in identifying high accident locations. A spot map furnishes a quick visual reference to concentrations and magnitudes of accidents which may warrant detailed analysis. Typically, each accident is located on a map. Pins of different colors, size, or markings are used to code the type, severity, or time of the accident. Other means of identification, such as colored pencil dots, colored stick-on dots, or other symbols may be used in combination with pins to represent other desired descriptive data.

Collision diagrams are another tool of value to accident analysis. These diagrams plot, by means of arrows and symbols, the paths of vehicles (or pedestrians) involved in all accidents at a particular location, usually an intersection. Symbols may be used to indicate different types of collisions, vehicle types, time periods, severity classifications, lighting conditions, etc. Letter designations can be used to define weather and pavement type and condition.

Collision diagrams are especially helpful in studying the patterns and frequency of various types of accidents. Such a study will generally reveal the specific traffic movements involved in most accidents. This type of information provides valuable clues as to what type of corrective measures may bring about a reduction in accidents. Collision diagrams are usually updated annually. (Key locations may require updating every 2 or 3 months.)

At the end of the year, it is standard practice in most agencies to compute accident rates for the purposes of evaluating the benefits of improvements or to determine whether a particular section of highway (usually less than a mile) or specific location is experiencing significantly higher accident rates than the local or State average. Accident rates may be expressed as:

- Accidents per million vehicle miles,
- Accidents per mile, and
- Accidents per million vehicles at an intersection or specific location.

On high volume roads, the rate in vehicle miles may tend to obscure a situation responsible for numerous accidents. Conversely, on low volume roads, vehicle miles may overemphasize the importance of a few accidents. Using a rate base of accidents per mile appears to normalize this problem. Collision diagrams should be developed for locations with significantly higher accident rates.

1C-3 Traffic Volume Studies

Traffic volume data is a fundamental requirement in almost all engineering studies. A volume study may be limited to peak hour, direction of travel, type of vehicle, or geographic location. Such studies provide essential information needed to identify locations where traffic control devices are needed (or not needed). Traffic counts also provide an important parameter when evaluating improvements and recommendations.

The type of data collected in a specific traffic volume study depends on what it is to be used for. Some of the various counts and their general purpose are outlined below:

- *Street counts* (total volume for both directions) are used in developing daily volumes, preparing traffic flow maps, determining trends, etc.
- *Directional Counts* are used for capacity analysis, determining signal timing, justifying traffic controls, planning improvements, obtaining accumulations of vehicles within a cordon, etc.
- *Turning Movement or Intersection Counts* are used in designing channelization, planning turn prohibitions, computing capacity, analyzing high accident intersections, evaluating congestion, etc.

- *Classification Counts* (which obtain volumes of the various types of classes of vehicles in the traffic stream) are used in establishing structural and geometric design criteria, computing expected highway user revenues, computing capacity (effect of commercial vehicles), determining correction factors for machine counts, etc.
- *Occupancy Counts* are made to determine the distribution of passengers per vehicle, accumulation of persons within an area, proportion of persons utilizing transit facilities, etc.
- *Pedestrian Counts* are used in evaluating sidewalks and crosswalk needs, justifying pedestrian signals, timing traffic signals, etc.
- *Cordon Counts* are made at the perimeter of an area (CBD, shopping center, industrial area, etc.). Vehicles and/or persons entering and leaving the area during a specified time period are counted. These data provide information relative to the accumulation of vehicles or persons within the area.
- *Screen Line Counts* are classified counts taken at all streets intersecting an imaginary line (screen line) bisecting an area. These counts are used to determine trends, expand Origin-Destination data, traffic assignment, etc.

Volume counts can be made mechanically or manually. The counting method used will depend in large measure on the type of volume count to be made. Permanent or portable machine counters are available. They can be used to obtain vehicle counts at midblock, directional volume, lane volume, or total volume. The various types of commonly-used machine counters include:

- *Permanent Counters* are installed to obtain counts on a continuing basis. Such counts are used to provide factors for adjusting short counts to ADT and for finding the 30th highest or other hour of the year.
- *Portable Counters* are used to obtain temporary or short-term counts. They consist of an electrically-operated counter usually actuated by air impulses from a pneumatic hose (road tube) stretched across a roadway.
- *Recording Counters* provide a permanent record of volumes either by printing totals on a paper tape, by drawing a trace on a graph, or by punching a paper tape which can be analyzed by a computer. These counters may be obtained with various recording intervals.
- *Nonrecording Counters* have a visible counter which must be read by an observer at desired time intervals.

Manual counts are required for certain studies where the necessary information cannot be recorded mechanically. For light volumes, tally marks on a form are adequate. Manually operated tally counters are available for heavier volumes. If needed, several of these counters can be joined together to form a counting board. The types of volume data that are usually counted manually include:

- Turning movement counts,
- Classification counts (types of vehicles),
- Occupancy counts (passengers per vehicle),
- Pedestrian counts, and
- Multilane freeway counts—lane counts.

Techniques involved in the selection of counting periods, the counting program development, and the reduction and presentation of data are documented in a number of standard references such as Ref. 1-3.

1C-4 Spot Speed Studies

A spot speed study is made by measuring the individual speeds of a sample of the vehicles passing a given point (spot) on a street or highway. These individual speeds are used to estimate the speed distribution of the entire traffic stream at the location under the conditions prevailing at the time of the study.

Many facets of traffic control planning require speed distribution information. All vehicles do not travel at the same speed at a location. The amount of dispersion or spread in these speeds affects traffic control requirements, capacity, and safety. If all vehicles traveled at the same speed, traffic volume flow would be at a maximum, and accidents caused by overtaking or passing and rear-end collisions would be eliminated. The distributions are used to:

- Establish maximum and minimum speed limits.
- Determine need for posting safe speeds at curves.
- Provide information relative to the proper location of regulatory, warning, and guide signs.
- Establish boundaries of no passing zones.
- Analyze special operational situations (e.g. work zones, school areas, etc).

The period during which speeds are measured depends on the purpose of the study. Usually off-peak average hours are used. It is important that trend studies and "before and after" studies be made during the same hours under comparable conditions. Adverse weather and unusual volume conditions should be avoided. Normally, the speeds of at least 50, preferably 100, vehicles should be measured in any one sample. The vehicles should be selected on a random basis from the traffic stream to avoid bias in the results.

The simplest and most common method of collecting speed data is to measure the time required for a vehicle to traverse a measured distance. This time may be measured manually or by electromechanical, electrical, or electronic means. When manual means (stopwatches) are used, the length of the measured distance is usually a multiple of 88 feet (depending upon average speed) for convenience in reducing the data.

Another common method is to measure the distance a vehicle will travel in a given time. This procedure is most commonly used in photographic studies where pictures of the traffic stream are taken at precise intervals. The distance a vehicle moves in successive pictures related to the time interval gives the speed.

As with volume studies, most agencies have established procedures for conducting speed studies and numerous textbooks detail the various forms, techniques, and analytical procedures related to spot speed studies and speed zoning.

1C-5 Traffic Control Devices Inventories

The FHWA's Highway Safety Program Standard 13 (Ref. 1-5) requires each State and its political subdivisions to have a traffic control devices program which includes:

- An inventory of all traffic control devices.
- Periodic review of existing traffic control devices including a systematic upgrading of substandard devices to conform to standards issued or endorsed by the Federal Highway Administrator.
- A maintenance schedule adequate to ensure proper operation and timely repair of control devices including daytime and nighttime inspections.

Numerous official and unofficial documents, reports, and studies indicate the requirement, the need for, and the benefits to be derived from a good traffic control devices inventory program. AASHTO's Highway Design and Operational Practices Related to Highway Safety (Ref. 1-6) emphasizes the need for a continuing traffic operational review to detect problems as they develop, and the need to maintain a high level of service on the highway facility. A Traffic Control Devices Inventory can be conducted manually using a trained individual or crew to inspect each device, and record the data on its condition, location, whether it is standard, and whether it serves its intended purpose. Although this is generally the best method for small jurisdictions, or to meet specific but limited requirements, this method is time consuming and expensive.

Larger jurisdictions are using photographic instrumentation in the form of photo-logging or video-logging to record data. These data can then be programmed into a computer for retrieval in various formats. This provides a record system which can be updated periodically as changes are made with work order reports being fed into the computer files.

A more definitive discussion of traffic control device inventories is presented in Section 2D-1.

1D. LEGAL IMPLICATIONS

Traffic and maintenance engineers are becoming increasingly involved in a field of litigation that was recently of concern only to attorneys. Today, it is incumbent that State highway department and local transportation agency staffs become aware and keep abreast of highway law in general and the legal elements of functional operational practices in particular. Accordingly, the fundamental legal implications of applying, installing, operating, and maintaining uniform traffic control devices have been included in this Handbook to provide a basic understanding of the purpose, intent and direction of current liability laws.

1D-1 Background

Until recently, government entities were generally immune from lawsuits on the theory of "sovereign immunity" derived from English common law. Under the sovereign immunity doctrine, a government entity can be sued only if it consents to the suit in advance. Over the past 25 years this situation has changed dramatically. Sovereign immunity has been eroded through the actions of courts and/or legislatures and now survives in less than a third of the States. Consequently, many State highway departments have become vulnerable to lawsuits for damages resulting from highway accidents.

This discussion of legal considerations in the administration and management of traffic control devices systems is a very basic discussion of a very complex subject. It is not meant to interpret the law or establish guidelines. It is intended only to alert transportation agencies of the need to recognize and respond to the possible consequences of failure to maintain and safeguard the highway system.

There are numerous reports and references prepared by legal staffs that can be consulted for more definitive information. Also the Institute of Transportation Engineers (ITE) has developed a one-day seminar as part of its Continuing Education Program entitled "Traffic Improvements—Legal Aspects and Liability" that is intended to upgrade and expand awareness among operating and maintenance personnel. In addition, the legal staffs of government agencies can often be called upon to interpret for their operating units the statutes applicable to their functions and to suggest ways to avoid tort litigation.

In any event, and by whatever methods or resources that are available, agency engineering and maintenance personnel have a strong "need to know" in the area of legal implications.

1D-2 Definition of Tort Liability

To understand the legal responsibilities of traffic agencies, it is necessary to understand the basic principles and terminology of tort law.

The definitions and principles fundamental to potential highway operating agency liability are briefly explained below.

A *tort* in legal terminology is a civil wrong other than breach of contract, for which a court of law will provide a remedy in the form of an action for money damages. Torts can be either intentional (e.g., assault and battery, false imprisonment, trespass, and theft) or unintentional (e.g., negligence). The primary concern to highway agencies are allegations of negligence.

Liability for a tort means the legal obligation to pay money damages to the person injured or damaged. More than one person or organization may be liable for damages arising out of the same incident. In the case of negligent conduct by an employee, both the employee and the employer may be liable. The same may be true with respect to a Government official, i.e., both the government agency and the staff employee may be liable.

Negligence can be defined as the failure to do something which a "reasonable person" would ordinarily do, or the doing of something which a reasonably prudent person would not do. Negligent conduct is that which creates an unreasonable risk for others to whom is owed a duty of exercising care.

The *reasonable person* (sometimes called the "reasonable man", the "ordinarily prudent person", the "ordinary man", and so on) is a criteria used to set the standard of care in judging conduct. In effect, this test of negligence represents the "failure to use ordinary care," and is most often used in determining liability. In the context of this Handbook, engineers may be found to be negligent if their conduct does not measure up to that of a hypothetical reasonable, prudent, and careful engineer under similar circumstances.

Contributory Negligence refers to conduct which falls below the standard of care a person (e.g. a driver) is legally required to exercise for his own safety and this failure is a contributing cause to the injury or damage he has suffered. Until recent years when the doctrine of "comparative negligence" was adopted, a finding of contributory negligence by the court would bar a plaintiff from recovering damages even if the defendent's negligence had been established.

Comparative Negligence is a rule of law adopted by most States whereby the negligence of both parties is compared, and recovery is permitted despite the contributory negligence of the plaintiff. However, plaintiff's damages are usually decreased proportionately to his own contributing negligence.

Duty in tort law is an obligation requiring persons to conform to a certain standard of conduct for the protection of others against unreasonable risks. Negligence is a breach of duty to exercise reasonable care owed to those persons to whom the duty applies. In this context, a highway department owes a duty to all travelers on the highway to avoid creating unreasonable risks for those travelers, and to meet the standard of care imposed upon that department.

The *Standard of Care* may be established by a multitude of factors. As a minimum, all persons are required to avoid the creation of unreasonable risks, where feasible. In addition, statutes and regulations governing conduct are also components of the standard of care by which conduct is judged. (For example, Rules of the Road for Operating Vehicles.)

Finally, and perhaps most importantly, the *accepted standards and practices* of a profession, trade, or industry define the standard of care by which conduct is judged. Included in the definition of "accepted standards and practices" is the MUTCD and other similar standards.

In general, "a violation of a uniform law or regulation may be evidence of negligence or may constitute negligence per se." The MUTCD was adopted as a national standard pursuant to the authority of Title 23 of the U.S. Code. As regulated, this requirement has the full force and effect of the law. All States should have incorporated into their own State laws the MUTCD standards which provides acceptance in the local jurisdiction. A failure by government personnel to conform with the requirements of the MUTCD, or its equivalent, may be sufficient to establish negligence (and therefore liability) should an accident result from failure to conform. On the other hand, as the MUTCD only sets forth minimum requirements, compliance may not in itself be sufficient to establish reasonable care. If more than a "minimum" is required by a specific situation, it should be done.

To place the above concepts in perspective, it is necessary to recognize the following characteristics of tort liability.

- Negligence is the failure to use reasonable care.
- Court decisions in tort claims are based on the concept of the existence of a "reasonable person" exercising "ordinary care."
- The three elements necessary in every tort claim are:
  - Existence of legal duty owed by the defendant to the plaintiff,
  - A breach of that duty, and
  - The occurrence of damage or injury which is the foreseeable result of that breach of duty.

In effect, this means that the plaintiff (the one bringing the suit), if he is to win a judgment in a basic negligence case, must prove:

- The defendant (agency) had a legal duty to use reasonable care towards the plaintiff (the injured party).
- The defendant breached that duty, (fell below the standard of care thus committing an act of negligence).

- The damages (injuries, property damage, pain and suffering, loss of income, etc.) suffered by the plaintiff were caused by the breach (defendant's negligence), and were the foreseeable result of that breach.
- Finally, to recover all of the damages suffered, the plaintiff must not have contributed to that negligence, or must have been less at fault than the agency.

1D-3 Legal Duty and Liability

Government officials concerned with highway construction, operations, and maintenance have definite obligations to the traveling public; that is, certain duties are specifically or generally imposed by law. There is a recognized duty to maintain the roadway in a reasonably safe condition. This involves inspection, anticipation of defects, and conformity with generally accepted standards and practices. Significantly, this requirement does not call for a perfect condition or for actions "beyond the limits of human ingenuity."

To understand the concepts of legal duty, it is necessary to recognize the distinctions between *discretionary* acts and *ministerial* (nondiscretionary) acts. Many States which no longer retain their sovereign immunity have enacted a Tort Claims Act. This Act prescribes the conditions under which the State, their agencies, and their employees may be held accountable. Most of these include a limited exemption from liability for negligence in the performance (or in the nonperformance) of so-called discretionary activities.

The term "discretionary" refers to the power and duty to make an informed choice among alternatives. It requires consideration of these alternatives and the exercise of independent and professional judgment in arriving at a decision or in choosing a course of action. On the other hand, ministerial duties involve clearly defined tasks performed with minimum leeway as to personal judgment and not requiring any evaluating or weighing of alternatives. Consequently, they are nondiscretionary.

In modern law, the distinctions between discretionary and ministerial functions are of great importance in judging tort claims against governmental entities. In general, a public organization or its employees are not liable for negligence in the performance of discretionary activities. However, the courts are constantly revising the law in these areas, and the classification of a particular governmental activity as either discretionary or ministerial is subject to shifting legal interpretations.

It should be recognized that the limited exemption from liability which has been afforded to discretionary activities in no way provides absolute protection from legal liability. If discretion is abused or exercised recklessly or unjustly, courts may move in and substitute their own discretion for that of the agency.

The courts are fairly uniform in holding that the design of highways is a discretionary function because it involves high-level planning activity and evaluation of policies, alternatives, and other factors. This is supported by court decisions which hold that design functions are quasi-legislative in character and must be protected from second-guessing by the courts who are inexpert at making such decisions. Design immunity statutes represent a further effort by legislatures to immunize governmental bodies and employees from liability arising out of negligence or errors in a plan or design duly approved under current standards of reasonable safety.

1D-4 Notice of Defect

An agency has a duty to correct a dangerous condition when that agency has actual or "constructive" notice of the hazard. Most courts hold that the State must have had notice of the defect or hazard for a sufficient or reasonable time "to afford them a reasonable opportunity to repair the condition or take precautions against the danger."

This notice requirement does not apply when the dangerous condition is the result of the State's own negligence. For example, it is not required for the State to have notice of faulty construction, maintenance, or repair of its highways, because the State is expected to know of its own actions. However, if the danger did not arise as a consequence of the active negligence (such as faulty construction), the agency has the duty to repair once it has actual or constructive notice of the defect.

Statutes may require that States have notice of the condition for a specified period of time. If, for example, the notice period is 5 days, and an accident was caused by a defect that originated early in the day of the accident, the statutory notice period would not be satisfied and the agency would not have had a reasonable opportunity to effect repairs.

On the other hand, the notice may be satisfied where the condition has existed for such a time and is of such a nature that the State should have discovered the condition by reasonable diligence, particularly where there is no statutory specified time. In this instance, the notice is said to be constructive, and the State's knowledge of the condition is said to be implied. In deciding whether the State had notice, the courts may consider whether the defect was latent and difficult to discover. That is, the court will consider the nature of the defect, its location and duration, the extent and use of the highway, and whether the defect could be readily and instantly perceived. Routine inspection and correction procedures are important in light of the trend by courts to permit less and less time before finding "constructive notice".

1D-5 Meaning for State/Local Agencies

The incident of civil litigation, primarily in the area of torts, has increased by many orders of magnitude in the last decade. This strong tendency toward legal action is closely followed by the trend towards large awards to litigants.

This fast growing trend toward litigation and large awards coupled with the erosion of sovereign immunity for governmental agencies poses a critical problem for highway departments. A 1980 AASHTO survey of all State highway agencies reported over 8,000 pending tort claims totaling over $3 billion.

These increasing claims and awards against highway agencies have also resulted in the increased cost of liability insurance, when it is not cancelled. Deductibles have been increased to multimillion dollar levels in some cases, forcing some States to self-insure.

It should be highly obvious that it is more logical to expend public funds in sound management practices and in the proper highway maintenance than in the settlement of claims or in payment of adverse judgments. Consequently, it would seem appropriate to review maintenance activities and reporting procedures to limit exposure to tort liability. It would also seem helpful to assure that all agency employees involved in such activities are well informed of the legal implications of their functions.

It has been suggested that agencies could significantly reduce tort liability suits involving traffic control devices by implementing four basic principles:

- Know the laws relating to traffic control devices,
- Conduct and maintain an inventory of devices,
- Replace devices at the end of their effective life, and
- Apply State traffic control device specifications and standards.

The major point to be recognized is that the MUTCD establishes only minimum requirements. Awareness of the MUTCD standards and complete knowledge of the highway network within a given jurisdiction can combine to develop a program of upgrading where warranted. If properly used and applied, the MUTCD can serve as the best defense against liability actions.

1E. ASSISTANCE PROGRAMS

There are few, if any, traffic agencies that are completely self-sufficient. Even the larger, completely staffed departments need funding assistance and occasional technical assistance or access to training programs to maintain or upgrade the skills of their staff.

This section summarizes some of the resources available to State, county, and local jurisdictions to assist in implementing and maintaining a safe and efficient driving environment.

1E-1 Funding Assistance

Both within and among the various levels of government involved with traffic control devices, the common thread is the need for financial assistance to comply with nationally-recognized standards and requirements. Basically, this is a shared responsibility among Federal, State, and local agencies. There are a number of Federal funding programs which may be available to support engineering and construction costs related to installation or upgrading of traffic control devices at the local level. All such Federal funding programs are administered through the State agency. The background and basic fundamentals of available funding assistance are summarized below.

Sources of Revenue

The major source of revenue for highway purposes is from "highway user taxes." These are the Federal, State, and local taxes which are levied on users of highway facilities, with those who make more use of the facilities paying the largest tax. Included are fuel taxes, driver license and automobile registration fees, and special taxes on heavy vehicles and vehicle parts and accessories.

Title 23 of the United States Code

The United States Code (U.S.C.) contains the Federal laws which have been codified, or arranged in a systematized manner. Title 23 of the Code is titled "Highways" and embodies most of the laws that govern the Federal highway program. As new acts are passed, sections of Title 23 are amended, repealed, or added. The Code thus contains only those provisions presently in effect.

The Code is divided into four chapters:

- Chapter 1. Federal-Aid Highways,
- Chapter 2. Other Highways,
- Chapter 3. General Provisions, and
- Chapter 4. Highway Safety.

Federal-Aid Highway Program

The term "Federal-Aid Highway Program" is an umbrella term referring to all activities funded through the Federal Government and administered by the individual State highway agency. The Federal Government, through the Department of Transportation's FHWA, provides guidance to the State highway agencies in developing their plans for highway facilities which are to be constructed or improved with Federal-aid funds. States or local units of government select the projects, but FHWA is responsible for review and approval at key stages when Federal-aid highway funds are to be used in financing a project.

Funding for Traffic Control Devices

It is beyond the scope of this Handbook to list all current program categories for which funding assistance may be available for eligible projects involving traffic control devices. However, one of the more common Federal-aid programs in which traffic control devices are frequently involved is the Urban System. In urban areas, the law requires designation of an urban system. It also requires that the governor designate a metropolitan planning organization (MPO) as the planning agency to develop a comprehensive transportation plan for the area and to identify an annual element of that plan which lists projects for early implementation. The annual element is submitted to the State highway agency.

The State highway agency, as recipient of most Federal-aid highway funds, submits an annual program of projects to the FHWA indicating intent to finance the projects with Federal-aid funds. The State selects projects from the annual element of the various MPO's for inclusion in the annual program. The FHWA has review and final approval authority for projects and the obligation of funds.

Highway Safety Funds authorized under Section 402 of Title 23, U.S. Code are frequently used for traffic control device programs off the Federal-aid system. These 402 funds are administered by the Governor's Highway Safety Representative in each State and are available on a 75-percent Federal and 25-percent local or State share. Providing "inkind" services for the local/State share is called a "softmatch', and can have the effect of making the project 100-percent Federal funded depending on the policies established in each State.

Since standardization of traffic control devices is a part of Highway Safety Standard 13, Traffic Engineering Services, each State's Annual Highway Safety Program should address this need (Ref. 1–5). To obtain 402 Funds, the Governor's Highway Safety Representative should be contacted for information on how to apply. Policies, priorities, and procedures vary from State to State.

Another source of funding is Highway Planning and Research (HP&R) funds which are administered by the State highway agency. The Federal-

Aid Highway Program Manual (Ref. 1-7) States: "These funds (HP&R) may be used in statewide or systemwide studies or inventories of needs for standard traffic control devices on or off the Federal-aid system, and for research costs and installation of devices or equipment connected with research studies of traffic control devices on or off the Federal-aid system."

To obtain further information on available funding resources and eligibility requirements, local agencies should contact the district or regional representative of the State highway or transportation department. Most States have guidelines to assist local agencies in preparing requests or application for funding assistance.

1E-2 Technical Assistance and Training

Technical assistance is available from a number of levels of government and from the private sector. The Department of Transportation has devoted major attention to technical assistance to States and through the States to cities. The Act of Congress which established the DOT directs the Secretary to ". . . promote and undertake development, collection, and dissemination of technological, statistical, economic and other information . . ."

Continuation and broadening of this type of endeavor by all Federal agencies was called for by the President in a message to Congress on Science and Technology, forwarded on March 16, 1972. DOT's response was to direct increased emphasis to technology sharing in carrying out its long-established technical assistance activities. The Department's expanded activities in technology sharing and its actions to bring about more effective interaction with State, county, and city governments has had a widespread beneficial effect.

One of the important elements in technical research sponsored by FHWA is "stimulation;" that is, to stimulate or motivate agencies to upgrade or improve traffic operations and safety. A significant part of the FHWA budget is devoted to this purpose. The Federal Railroad Administration (FRA) budget also has a large stimulation component. The ultimate user of much of its research results will be the railroad industry.

The DOT provides technical assistance to a variety of agencies at the State/Local level including: State departments of transportation, State highway departments, public service or utilities commissions, State multi-functional planning organizations, regional/local planning agencies dealing with transportation, transportation operators, the public service functions of universities, and many others.

By necessity, DOT has evolved into a heavily field-oriented agency. This organizational pattern enables the Department to cooperate effectively on-site with the States. The Department's field offices afford a broad base for direct communication with public officials. They also serve as a technical resource to be drawn upon by States and cities and as a liaison with the technical information banks maintained by the Department.

To assist all levels of government in upgrading technical staff skills, the National Highway Institute (NHI), was authorized by the Federal-Aid Highway Act of 1970. Its purpose is to develop and administer, in cooperation with State highway departments, training programs for FHWA and State and local highway agency personnel engaged in Federal-aid highway work.

The National Highway Institute, in cooperation with the Office of Highway Safety, administers a program for awarding fellowship grants to graduate level study in highway safety. The NHI also awards grants for undergraduate and graduate study in various highway transportation related disciplines. About 130 grants each year are awarded primarily to employees of State and local transportation agencies.

In addition to its educational grant programs, NHI conducts or arranges for presentation of courses which meet the greatest common highway training needs at Federal, State, and local levels. Areas covered range from program management courses to detailed technical subjects. Specific courses include such subjects as highway maintenance, traffic control through construction areas, automated traffic control systems, etc.

The courses developed by NHI are conducted in various locations around the country at no charge to the participant. (Travel expenses are the responsibility of the individual or agency). To encourage intergovernmental communication, Federal, State, and local personnel attend the same sessions of these courses.

The NHI also publishes a monthly bulletin entitled "Announcement of Training Opportunities and Training Aids." This publication focuses on short courses, correspondence courses, training packages, and publications related to transportation. Other special purpose bulletins are issued to describe relevant training programs and to list audiovisual materials available through the NHI lending library. Further information on available courses or obtaining current bulletins may be obtained from

National Highway Institute, HHI-1
Federal Highway Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

In addition to the training opportunities provided by NHI, many States have developed and conduct their own training programs for State and local personnel oriented to statewide problems. Announcement of State courses are normally sent to counties and municipalities within the State. State district offices should be contacted for further information.

The Institute of Transportation Engineers (ITE),professional societies, and universities periodically conduct special training courses, for a fee. In some cases, the training package can be purchased which includes: a student textbook, audiovisual materials, and tests. These training packages are particularly useful for self-study or for small groups within a local agency. Local chapters of the ITE or University Transportation Engineering Departments can provide further information on the cost and availability of such training courses.

REFERENCES

1-1 National Committee on Uniform Traffic Laws & Ordinances, *Uniform Vehicle Code*, Charlottesville, VA., Michie Co., 1968.

1-2 National Committee on Uniform Traffic Laws & Ordinances, *Model Traffic Ordinance*, Charlottesville, VA., Michie Co., 1968.

1-3 Box, P.C., & J.C. Oppenlander, *Manual on Traffic Engineering Studies* (4th. ed.); Arlington, VA., Institute of Transportation Engineers, 1976.

1-4 Baerwald, J.E., ed., et al., *Transportation and Traffic Engineering Handbook*, Englewood-Cliffs, N.J., Prentice-Hall, 1976.

1-5 U.S. Department of Transportation, *Highway Safety Program Standards*, Wash., D.C., 1974.

1-6 American Association of State Highway & Transportation Officials, *Highway Design and Operational Practices Related to Highway Safety*, Wash., D.C., 1974.

1-7 Federal Highway Administration, *Federal-Aid Highway Program Manual*, V 6-8-3-1, Wash., D.C., 1974.

Part II. SIGNS

Part II. SIGNS

2A. GENERAL

The majority of motorists will drive in an orderly and safe manner if they are provided with clear, reliable information and guidance. Disrespect and lack of obedience to traffic control devices may be due in part to the lack of attention given to their design, application, installation, and/or maintenance. Traffic signs are being constantly evaluated in terms of effectiveness. This has led to new techniques to improve communication with the motoring public (such as the increased use of symbol signs).

This Part of the Handbook discusses the current practices in the application, installation, operation, and maintenance of signs used on the Nation's street and highway system.

2A-1 Purpose and Type of Signs

The purpose of a sign is to convey a message to the driver that will result in the orderly and predictable movement of traffic. As signs become increasingly integrated into the street and highway system, the roadway becomes a safer facility for motorists, pedestrians, bicyclists, and others.

There are three basic types of signs: Regulatory, Warning, and Guide signs. Table 2-1 shows the intended use and lists some examples of each type. Figure 2-1 displays some of the most commonly used signs.

Uniformity is very important to the driver. Motorists have a right to expect that a given traffic control device will always have the same meaning and require the same driver action wherever it is encountered. Part II of the MUTCD defines the standard signs approved for use across the Nation. Besides wasting public funds, the misuse or excessive use of signs may cause delay, confusion, and disregard for other traffic control devices. Each year, lack of attention to the proper application of traffic control devices results in million of dollars in liability judgments against State and local jurisdictions. Accordingly, the application of sound principles in establishing standards and in the selection, installation, and operation of traffic control devices is a critical and cost-effective responsibility of the operating agency.

2A-2 Sign Design Elements

Signs are designed to draw attention to themselves through contrast, color, shape, composition, reflectorization, and illumination. Coupled with these features a simple message will provide a clear and understandable instruction to the driver. Sign size and placement should

Sign Type	Intended Use	Typical Uses
Regulatory	To inform users of traffic laws and regulations which apply at definite locations and at specific times	• Intersection control • Definition of right-of-way • Speed limits • Turning movement control • Pedestrian control • Exclusions and prohibitions • Parking control and limits • Regulations for maintenance and construction
Warning	To warn traffic of unusual or potentially hazardous condition(s) on or adjacent to a street or highway	• Horizontal and vertical alignment • School areas • Crossings and entrances to streets, highways, and freeways • Intersection areas • Road construction and maintenance
Guide	To provide simple and specific information to aid motorist in reaching their destination	• Route markings • Destination signing • Information signing • General services • Parks and recreational signing.

Table 2-1. SIGN TYPES

be such to allow adequate time for proper response. Uniform and reasonable instructions to the motorist will instill respect and instinctive willing compliance with the sign message.

Many design elements work together to communicate the sign's meaning to drivers. These elements are color, shape, legend or symbols, lettering, sign size, reflectorization, and illumination. The role each element plays in the design process is discussed in the following sections.

Color

The standard colors used for traffic signs are listed below. As with all design elements, it is important that all agencies use the same colors for the same purpose.

- Red indicates stop or a prohibition. Examples include WRONG WAY, DO NOT ENTER, and NO PARKING.
- Green shows movement permitted or gives directional guidance. Examples include: directional signs or permissive parking regulations.

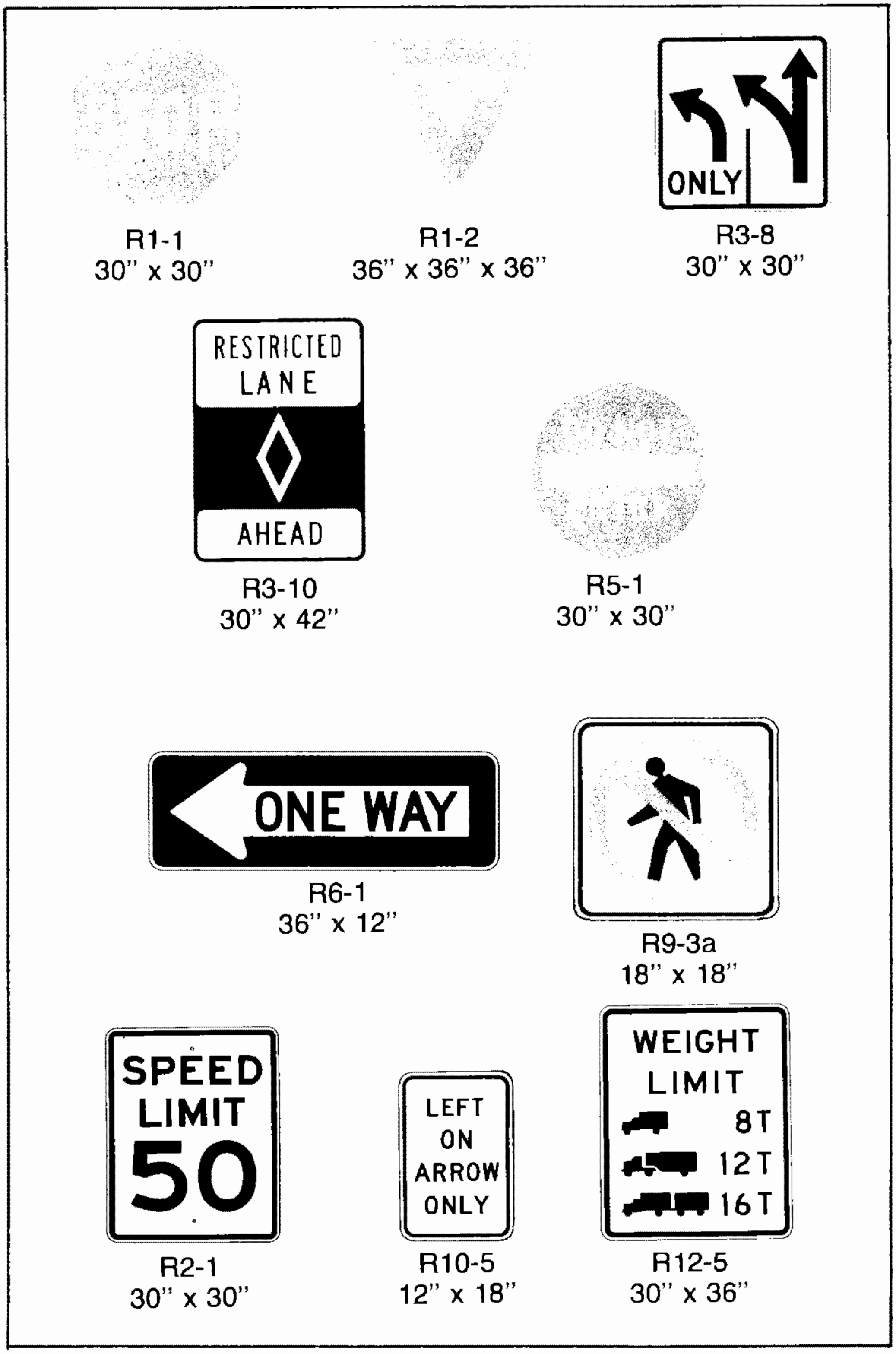


Figure 2-1-a Commonly Used Regulatory Signs

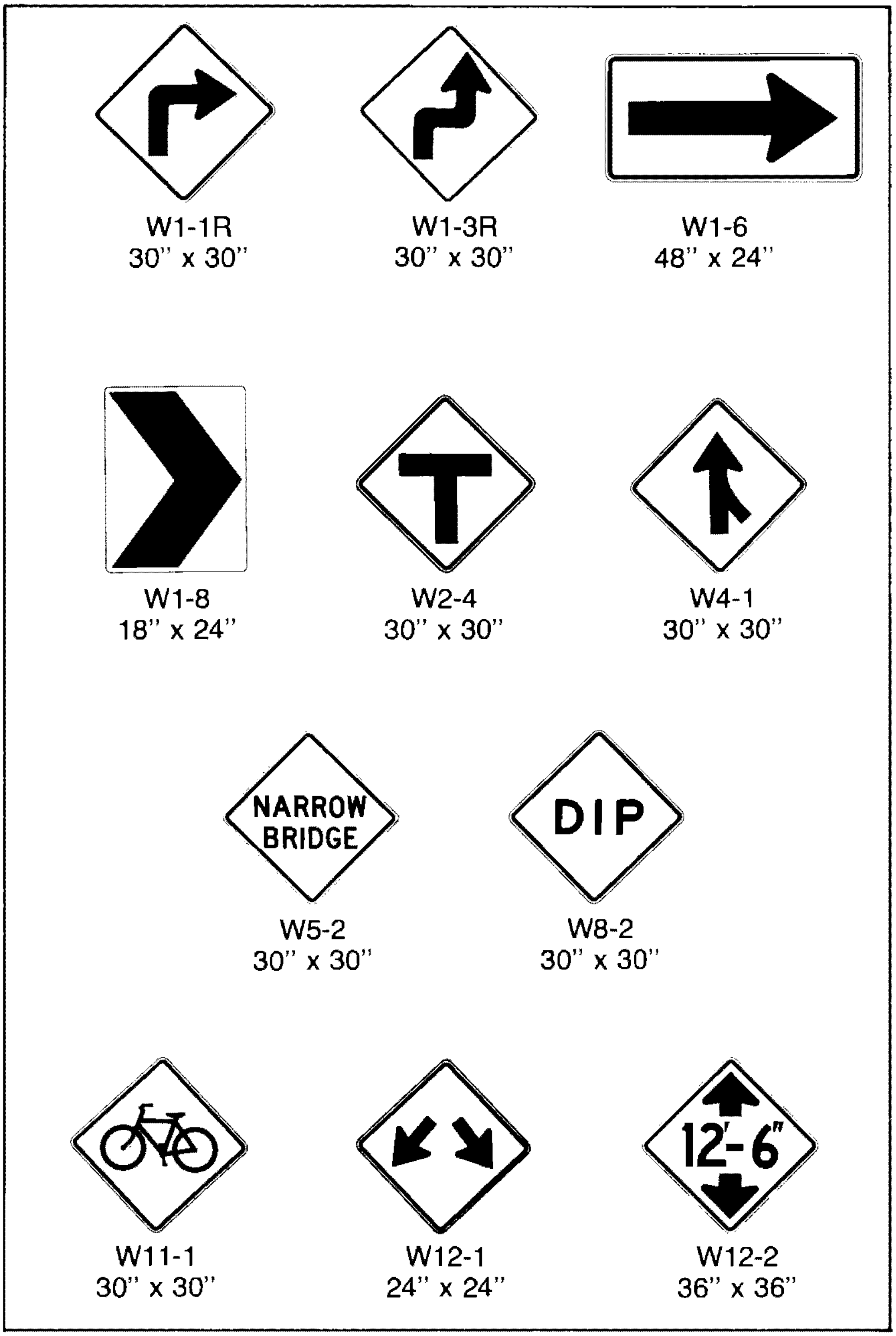
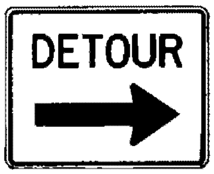


Figure 2-1-b Commonly Used Warning Signs

Motorist services signs.

U.S.
Route Marker
M1-4
24" x 24" (2 digit)
30" x 24" (3 digit)

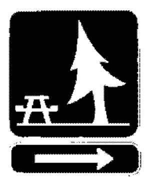


M4-9R
30" x 24"

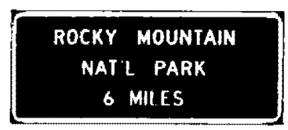
D1-3
Variable Size

D3
Variable Size

D4
30" x 24"



D5-5a
24" x 24"
24" x 6"



D7-1
Variable Size

D9-2
24" x 24"

I-5
24" x 24"

Figure 2-1-c Commonly Used Guide Signs

- Yellow indicates a general warning such as MERGE, SCHOOL CROSSING, or LANE ENDS.
- Blue is for signs leading to motorist services such as lodging, food, and gas.
- Black on white is for regulatory signs. Examples include ONE WAY, KEEP RIGHT, and SPEED LIMIT.
- Orange is used in construction and maintenance work zones. It warns the drivers of unusual conditions and of men and machines working on or near the roadway.
- Brown is used as a background color for recreational and cultural facility signs.

The three types of signs (Regulatory, Warning, Guide) have specific color combinations associated with them as shown in Table 2-2.

Shape

As with color, standard shapes have been designated for various categories of signs so drivers can more easily recognize and understand the message. For example, a diamond-shaped sign should be recognized immediately as a warning sign even before a driver is close enough to read the message. The basic shapes are defined in Figure 2-2. Table 2-2 summarizes the combinations of shapes and colors that are most commonly linked with the three basic types of signs.

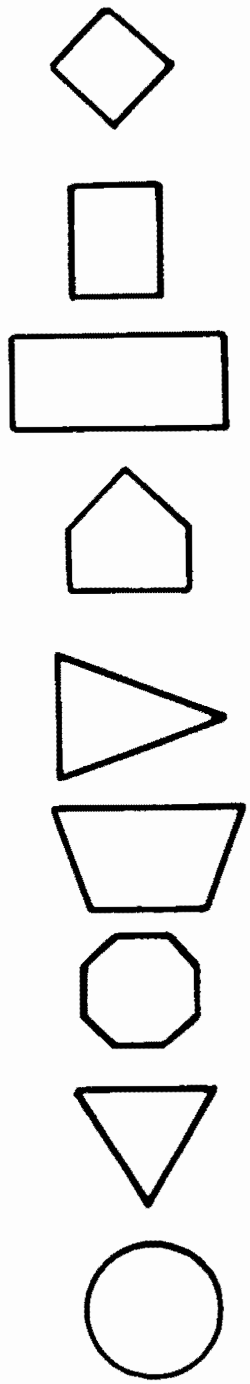
Symbols, Legends, and Lettering

The message that a sign or marking conveys to a driver is also a function of its legend and/or symbol. The legend (or word message) on a sign is intended to convey the specific information needed by the driver. To allow the driver time to understand and respond, the message must be simple and clear.

The size of letters and symbols is critical to sign legibility. Standard sign letters are prescribed in the "Standard Alphabets for Highway Signs" published by the Federal Highway Administration (Ref. 2-1). This document provides letter and numeral width and spacing for six standard capital letter alphabets, Series B through F. Each letter (or numeral) is shown on a grid so that it can be enlarged proportionally to fit the desired sign dimensions. The letter width varies from the slender Series B through the thicker (bolder) letters provided in Series F. In addition, a lower case alphabet is provided for use with Series E (modified). Series D or Series C are the most commonly used for sign messages.

The use of symbols for signs has become a major element in driver communications. Symbol signs can be interpreted at a glance without the need to read a word message.

STANDARD SHAPES



The **diamond** shape is used for the majority of warning signs.

The **rectangle,** with the longer dimension vertical, is used for the majority of the regulatory signs and some warning signs.

The **rectangle,** with longer dimension horizontal, is used for the majority of guide signs and some warning signs.

The **pentagon** with point up is used only for the School and School Crossing signs.

The **pennant** shape, with the longer dimension horizontal, is used only for the No-Passing Zone warning sign.

The **trapezoidal** shape is used for recreational guide signs only.

The **octagon** is used only for the STOP sign.

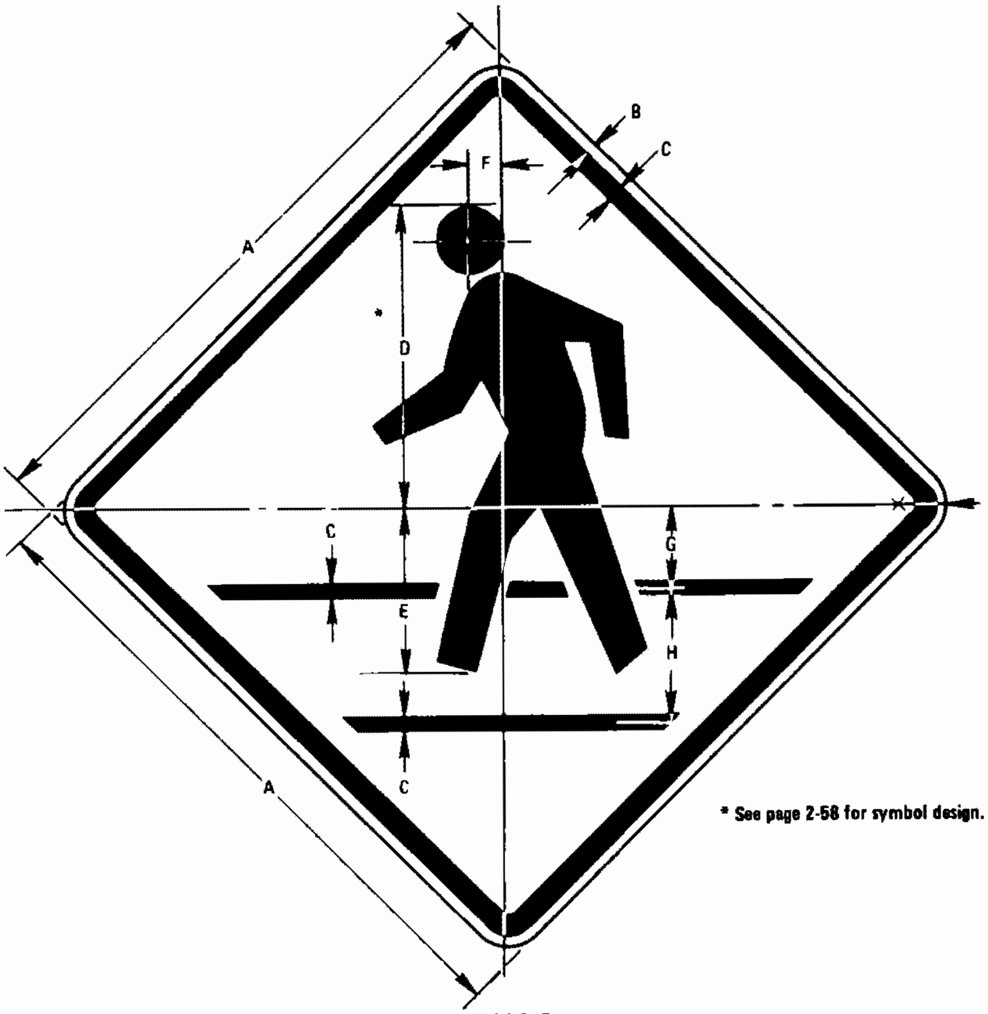
The **equilateral** triangle with one point down is used only for the YIELD sign.

The **round** shape is used for the Railroad Advance warning sign and for Civil Defense Evacuation route signing.

Figure 2-2 Standard Shapes

Type	*Shape*	*Color*
Regulatory	Usually rectangular with long side vertically aligned	• Black letters on white background
	"STOP" Sign is octagonal	• Stop and wrong way signs, white letters on red background
	"YIELD" Sign is triangular	• Yield sign has red letters on a white background with a red border • Green letters on white background for parking time limit zones • Red letters on white background for parking prohibitions
Warning	Usually diamond shaped with some specific exceptions. The exceptions are rectangular shapes for chevron sign, arrow sign, and advisory speed plates. Other exceptions include the triangular pennant shaped "NO PASSING ZONE" Sign, the Pentagon sign used for School and School Crossing, and the Circular sign used for railroad crossings.	• Always black letters or symbols on a yellow background
Guide	Usually rectangular with the longer side horizontal	• Majority of cases has white letters or symbols on green background.
	Recreational and Cultural interest signs can be trapezoidal in shape.	• White letters and/or symbols on brown background used for parks and recreational signing.
	Interstate and US Route marker shields have distinctive shapes as shown in the MUTCD.	• White letters and/or symbols on blue background used for general service signing.
	State route marker shields may have distinctive shapes.	• Black arrows and/or numbers on white background for route marker signing.

Table 2-2. SIGN DESIGN ELEMENTS



W11A-2

SIGN	DIMENSIONS (INCHES)								
	A	B	C	D	E	F	G	H	J
BIKE	18	3/8	5/8	8-3/8	4-3/4	3/4	2-3/8	3-5/8	1-1/2
MIN.	24	3/8	5/8	11	6-3/8	1-3/16	3-1/8	4-3/4	1-1/2
STD.	30	1/2	3/4	14	8	1-1/2	4	6	1-7/8
EXPWY.	36	5/8	7/8	16-3/4	9-5/8	1-13/16	4-3/4	7-1/4	2-1/4
SPECIAL	48	3/4	1-1/4	22	12-3/4	2-3/8	6-1/4	9-1/2	3

COLORS
LEGEND – BLACK (NON-REFL)
BACKGROUND – YELLOW (REFL)
2-73

Figure 2-3 Sample Drawing from Standard Highway Signs Book

There is some evidence to suggest that some of the less known symbols are not universally understood by the motoring public. These should have an accompanying word plate ("educational plaque") which is to remain in place for at least 3 years. In some cases, it may be desirable to consider a permanent installation of the educational plaque with the symbol sign.

Size

The MUTCD specifies the minimum size for a number of standard highway signs. Where increased legibility or emphasis is needed, larger sizes are desirable and permissible. Generally, the larger size signs are needed for high speed facilities, while the smaller signs may be adequate for low speed urban areas. The size of commonly used groups of signs include:

- Parking Signs: 12 × 18 inches
- "STOP" Signs: 30 × 30 inches or larger on high volume, high speed roads (24 × 24 inches on low speed secondary roads or low volume streets.)
- Speed Series Signs (regulatory speed limits): 24 × 30 inches
- Diamond-Shaped Warning Signs: 30 × 30 inches or 36 × 36 inches

Detailed drawings have been prepared for Standard Highway Signs for use by agencies involved in fabrication, installation, and maintenance of signs on streets and highways (Ref. 2-2). The Standard Highway Signs Book provides specific information on the appropriate sizes of each sign prescribed in the MUTCD. Examples are given in Figure 2-3.

Reflectorization

Reflectorization is the most frequently used means of making signs visible to the driver at night. Most agencies reflectorize all regulatory and warning signs as standard practice. In fact, sign manufacturers fabricate reflectorized signs almost exclusively. A request for a nonreflectorized sign is treated as a special order and is normally more expensive.

Illumination

Lighting may be used as an alternative technique to provide night visibility of signs. Signs can be externally illuminated by high intensity discharge or florescent lighting sources. These lights are independently mounted so that the light is directed onto the face of the sign. Internally-illuminated signs utilize flourescent tubes, neon bulbs, or other sources mounted within the sign.

2A-3 Driver's Needs

To guide and operate a vehicle smoothly and safely, the driver must perceive the appropriate travel path while guiding and controlling his vehicle over the roadway. The driver must be able to see the sign, read the message, and understand its meaning before he can guide his vehicle along the proper path.

There are a number of factors that can interfere with or distract the driver from this seeing, reading, and understanding cycle. To begin with, all signs should be located where the driver will be able to see them while guiding and operating a vehicle. After the driver is aware of the sign's location, the driver must next be able to read the legend (letters, numbers, symbols, etc.) on the sign. Thus, the longitudinal and lateral position of the sign, and the legend style and size are critical.

To see the sign during periods of darkness, contrast is necessary. Contrast is a product of the brightness of the message on the sign panel in relation to the brightness of the background of the sign panel. This brightness is produced by the illumination from the vehicle's headlights or other illumination. For example, for a guide sign, the green sign background contrasts well with the light colored reflectorized letters or symbols.

The environment in which the sign is installed also affects the contrast. For example, in rural areas at night during clear weather, a standard reflectorized sign is highly visible since there is no environmental "clutter" to distract from the contrast of the sign. Conversely, in highly developed urban situations, illuminated commerical signs and city street lighting can "wash out" sign contrast.

During daylight hours., the surrounding background is visible and competes with signs for driver attention. Consequently, the size, shape, and color of the sign are factors that contribute to the driver's ability to see the sign. Contrast during daytime is also important. The most common environmental backgrounds for a sign are the green of vegetation and the blue of the sky. For this reason, a border is placed around signs. With a border, signs show up as a geometrical shape, one that does not occur naturally. The geometrical shape provides the contrast between the sign and its environmental background.

When the eye is in a fixed position it is acutely sensitive within a 5 or 6 degree cone, but is satisfactorily sensitive up to a maximum cone of 20 degrees. It is generally accepted that all of the letters, words, and symbols on a sign should fall within a visual cone of 10 degrees for proper viewing and comprehension. This is roughly equivalent to the width of the hand (4 inches) held at arms length in line with the center of the road (Ref. 2-3).

After the driver sees the sign, he must understand its message and determine what action should be taken. To assist the driver in this task, the following factors should be considered:

- Comprehension—The message should be logical, thus minimizing misinterpretation and ambiguity.
- Emphasis—The more important information should be emphasized by size, location, or letter type.

Speed Study

MPH		MPH		MPH	
16		36	(36 x 6 = 216)	56	
17		37	(37 x 7 = 259)	57	
18		38	(38 x 5 = 190)	58	
19		39	(39 x 4 = 156)	59	
20		40	(40 x 4 = 160)	60	
21		41	(41 x 3 = 123)	61	
22		42		62	
23		43		63	
24		44		64	
25		45		65	
26		46		66	
27		47		67	
28		48		68	
29		49		69	
30	(30 x 7 = 210)	50		70	
31	(31 x 8 = 248)	51		71	
32	(32 x 20 = 640)	52		72	
33	(33 x 22 = 726)	53		73	
34	(34 x 17 = 578)	54		74	
35	(35 x 12 = 420)	55			

MUNICIPALITY CITY OF ANYTOWN

DATE 8-8-80 TIME 10:30 AM - 11:45 AM

LOCATION "A" STREET BETWEEN 10TH & 11TH STREETS

DIRECTION OF CLOCKED VEHICLE NORTHBOUND

WEATHER CLEAR ROAD CONDITION DRY

RECORDER JOE DOE 85 PERCENTILE 37 M.P.H.

Total Vehicles = 115
85% Tol. Veh. = 97.75 say 98
85% Speed = 37 mph

Total Vehicle M.P.H. = 3926
3926 ÷ 115 = Avg. Spd. 34 m.p.h.

Procedures

1. Add up the number of vehicles for each individual speed and place it at the extreme right end of the line for that particular speed.
2. Add up the total number of vehicles for all speeds.
3. Multiply the total number by 0.85.
4. The total determined in # 3 is the number of vehicles traveling at the 85 percentile speed or less.
5. Beginning at the lowest recorded speed, begin adding up the individual number of vehicles until the total in # 4 is reached. The speed to the left of this number is the speed at which 85 percent of the total number of vehicles are traveling at or less.

Figure 2-4 Sample Speed Study

- Expectancy—The legend and its location must conform to the driver's expectation.
- Uniformity—Similar types of information must be presented in a similar manner for similar decision situations.
- Sign Consistency—Similar types of information should be kept in the same general location on sign panels.

In the context of sign application, the "85th percentile speed" is the critical factor. This speed factor is defined as "that speed below which 85 percent of all vehicles travel and above which 15 percent travel." The 85th percentile speed is nationally recognized and accepted as the basis of posting speed limits unless there is a combination of unusual geometrics, high accident conditions, limited sight distance, or other extenuating circumstances.

The procedure for determining the 85th percentile speed is given in many engineering texts (for example, Ref. 2-4 and 2-5). Some of the key aspects involved in this procedure include:

- Methods for measuring speeds are varied and have inherent advantages and disadvantages. Commonly used methods include the radar meter, 20-pen graphic recorder, and enoscope (Ref. 2-6).
- The speed sample should be taken in good weather during off-peak hours to measure relatively free moving vehicles.
- The desired sample size is at least 100 vehicles. In rural areas and low volume roadways this may be difficult to achieve in a reasonable time period. The sample size may be lowered accordingly in these cases. Should this present a problem, the prevailing traffic speeds can be estimated by driving the route.

  A sample study procedure to calculate the 85th percentile and average speeds is illustrated in Figure 2-4.

2B. APPLICATION

Uniformity of application means treating similar situations in a like manner. It is a vital consideration in sign design, selection, and placement. Although the MUTCD sets forth criteria for applying signs under specific conditions, engineering judgment is essential to the proper use of signs. The traffic engineering studies and techniques used to determine the need for applying specific types of signs are discussed in this section. Materials and procurement issues are also discussed.

2B-1 Planning

Proper sign application is primarily based on the vehicle speed, driver perception and reaction requirements, and the location of the sign. Although the MUTCD frequently mentions the need to conduct traffic engineering studies, it does not discuss them. Some of the more common types of engineering studies used to determine the proper application of signs include:

- Spot speed studies,
- Stop and yield sign controls,
- Determining advance posting requirements for warning signs, and
- Identifying signing needs related to road geometrics (signing curves).

Spot Speed Studies

The determination of when, how, and where to use traffic control devices is frequently based on knowing prevailing speeds. Speed is one of the basic measures of traffic performance.

STOP and YIELD Sign Controls

STOP Signs

STOP signs are one of the oldest methods of controlling traffic at intersections where the application of the normal right-of-way rule is unduly hazardous. Even though it is generally recognized that STOP signs are the most restrictive type of signing, there has been a steady growth in the proliferation of unwarranted STOP sign installations. Many of these installations have resulted from requests by local residents to control vehicle speeds in neighborhoods or for pedestrian safety. Unwarranted installations of STOP signs cause unnecessary stops, excess fuel consumption, and breed disrespect for all STOP signs.

The warrants for STOP signs contained in the 1978 MUTCD (Section 2B-5) are basically unchanged from the original 1927 MUTCD although there are approximately six times as many motor vehicles. The warrants are preceded by the statement that: Because the STOP sign causes a substantial inconvenience to motorists, it should be used only where warranted."

The MUTCD presents four conditions where STOP signs may be warranted:

1. At the intersection of a less important road with a main road where application of the normal right-of-way rule is unduly hazardous.
2. On a street entering a through highway or street.
3. At an unsignalized intersection in a signalized area.
4. At other intersections where a combination of high speed, restricted view, and serious accident record indicates a need for control by the STOP sign.

Despite these warrants, many unwarranted STOP signs have been installed around the country. While many people believe that STOP signs are the most effective way of controlling speed and improving safety on residential streets, traffic and safety engineers disagree. They say that many of the STOP signs installed by town councils to placate neighborhood groups work to the disadvantage of the public. Traffic experts agree that unnecessary STOP signs:

- Cause accidents they are designed to prevent.
- Breed contempt for other necessary STOP signs.
- Waste millions of gallons of gasoline annually.
- Create added noise and air pollution.
- Increase, rather than decrease, speeds between intersections.

The MUTCD lists the following conditions where STOP signs should not be installed; on through roadways or expressways, on the major street where two main highways intersect (unless a traffic engineering study justifies this installation), indiscriminately at all unprotected railroad crossings, and for the sole purpose of speed control.

Much research has been conducted to try to establish more specific warrants for the installation of STOP signs. Although various criteria have been suggested, none have been incorporated into the MUTCD. The Federal Highway Administration, in an effort to minimize the use of inefficient STOP signs, is reviewing the existing warrants in the 1978 MUTCD.

Multiway STOP Controls

The use of the "multiway-Stop" or the "all-way" stop sign installation is discouraged. Although a multiway-stop installation may be warranted under any of the conditions given in Section 2B-6 of the MUTCD, they should not be used unless the volumes of traffic per approach leg on intersecting highways are approximately equal. A traffic control signal is often a more satisfactory control for an intersection experiencing heavy volumes of traffic.

Multiway stop controls are frequently used in residential areas. The guidelines that are evolving for the installation of multiway stop controls in residential areas are:

- At the intersection of two collector streets that are primary to the area.
- Where there is a 60–40 percent volume split for a four-way intersection.
- Where there is a 75–25 percent volume split for a three-way intersection.
- Where there are three or more correctable accidents in 1 year.

Engineering judgment should be carefully exercised in applying these guidelines to avoid the excessive use of this highly restrictive control. In addition, all existing multiway stop controlled intersections should be periodically reviewed to determine if another type of control would be more appropriate.

YIELD Signs and STOP Signs

The YIELD sign is intended to assign the right-of-way at intersections where it is not usually necessary to stop before proceeding into the intersection. Conversely, the STOP sign is intended for use where it is usually necessary to stop before proceeding into the intersection. The following conditions should be fully evaluated to determine how the right-of-way should be assigned:

- *Traffic volumes:* Normally, the heavier volume of traffic should be given the right-of-way.
- *Approach speeds:* The higher speed traffic should normally be given the right-of-way.
- *Types of highways:* When a minor highway intersects a major highway, it is usually desirable to control the minor highway.
- *Sight distance:* Sight distance across the corners of the intersection is the most important factor and is critical in determining safe approach speeds.

The decision as to whether to use a STOP or a YIELD sign is primarily based upon sight distance at the intersection. Sight distance determines the Critical Approach Speed. The critical approach speed is the threshold speed above which a vehicle approaching an intersection would not be able to react to a vehicle on another approach in time to avoid a possible accident. It is not the 85th percentile speed. Many of the existing intersections having STOP signs could be converted to the less restrictive YIELD sign without sacrificing safety.

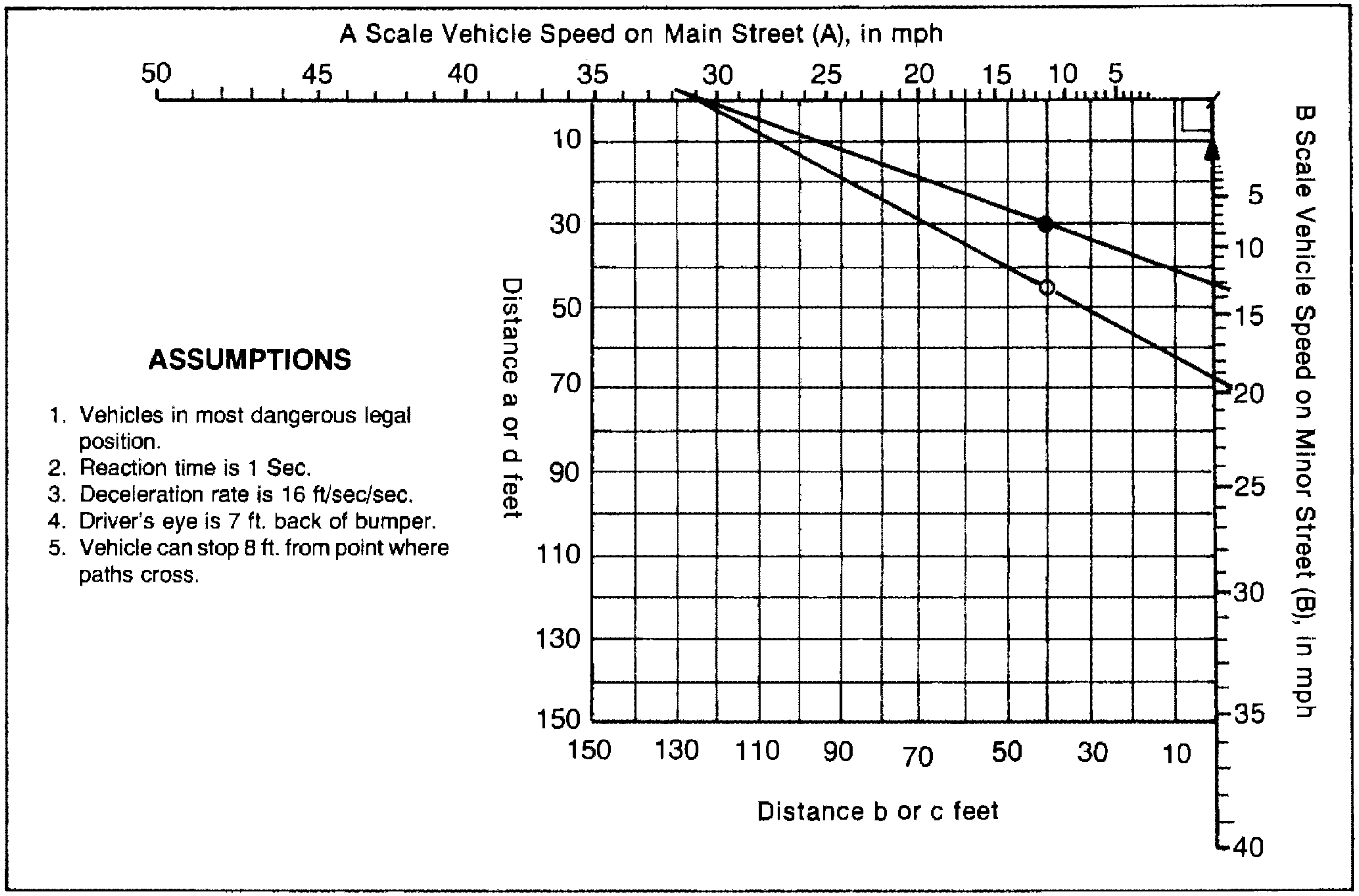


Figure 2-5a Critical Approach Speed Chart

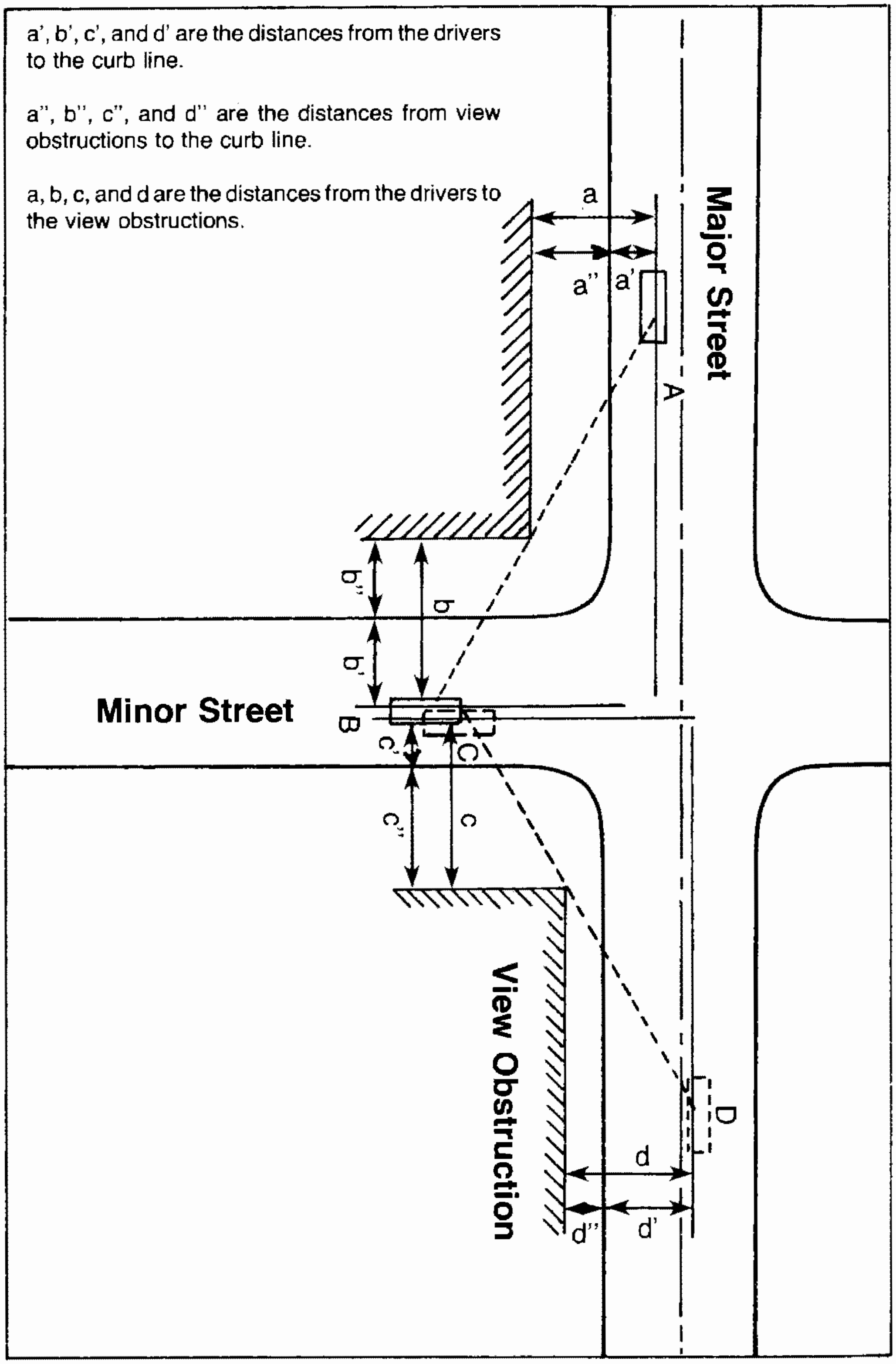


Figure 2-5b Typical Critical Approach Speed Problem

Figure 2-5a and 2-5b illustrates a graphic procedure which can be used to calculate the critical approach speed. This may be used to determine whether a STOP or whether a YIELD sign is appropriate for the minor street approach. A roadway with a critical approach speed between 10 and 15 mph would normally be controlled with a YIELD sign; a roadway with a critical approach speed of 10 mph or less would normally be controlled with a STOP sign. If the obstruction is reduced, removed, or relocated, the additional sight distance may be improved so that a YIELD sign may be used. This procedure can also be used to determine if existing stop conditions could be changed to a yield condition.

For a more thorough discussion of this technique see Appendix B of "Stop, Yield, and No Control at Intersections," FHWA/RD-81/084, June 81 or the "Traffic Engineering Handbook," Institute of Traffic Engineers, 1965.

Example:

Assume the following situation:

- Major street posted speed limit 30 mph.
- Parking prohibited on major street.
- Parking allowed on minor street.
- Measured distances to view obstructions:
  a″ = 24 feet
  b″ = 19 feet
  c″ = 28 feet
  d″ = 12 feet
- Major street width 60 feet
- Minor street width 36 feet

Solution:

1. Determine the speed value for the major street by measuring the approach speeds and determining the 85th percentile value or by using the value of the speed limit. For this example:
   Use 31 mph = 85th percentile speed
2. Determine the values of a′, b′, c′, and d′ for the most dangerous legal position, (i.e., position where sight distance is minimum yet car is within appropriate lane). The values for a′ and c′ are either 12 feet (with parking) or 6 feet (without parking); values for b′ and d′either one-half the street width plus 3 feet, or the street width minus 12 feet, whichever is smaller. For the example:
   a′ = 6 feet
   b′ = 21 feet (½ × 36′ + 3′ = 21′ or 36′ − 12′ = 24′; use 21′)
   c′ = 12 feet
   d′ = 33 feet (½ × 60′ + 3′ = 33′ or 60′ − 12′ = 34′; use 33′)

3. Determine critical distances a, b, c, and d. For the example:

   $a = a' + a'' = 6 + 24 = 30$ feet

   $b = b' + b'' = 21 + 19 = 40$ feet

   $c = c' + c'' = 12 + 28 = 40$ feet

   $d = d' + d'' = 33 + 12 = 45$ feet

4. Locate two points on the chart representing the view obstructions by using the values of (a and b) and (c and d) obtained above.
5. Draw straight lines through the speed value in mph (31) for the major street (on the "A" scale) and the points of the view obstructions as located in item 4 above.
6. The intersections of these lines with the "B" scale are the safe approach speeds on the minor street relative to the two view obstructions (13 mph for the conflict from the left and 19 mph for the conflict from the right).
7. The slower of these two approach speeds (13 mph) is the critical speed and is the maximum safe approach speed of a vehicle entering the intersection from the minor street.
8. Duplicate the procedure for the opposite approach of the minor street if applicable.
9. For this example, the minor street approach would be controlled with a YIELD sign.

Advanced Posting Distances for Warning Signs

Warning signs are primarily intended to provide timely and critical information to drivers unfamiliar with the facility. Consequently, warning signs must be located in advance of the condition to which they apply. Basically, the advance posting distance is currently determined by two factors:

- The 85th percentile speed or posted speed limit, whichever is higher.
- The action required by the condition to be encountered.

These two factors govern the time available for the driver to see, comprehend, and react to the message by performing any necessary manuever or action. Time factors in response to a typical traffic control device traditionally include Perception, Intellection, Emotion, and Volition, or "PIEV" (Ref. 2-3). The basic problem is then, given the vehicle speed and the reaction time of the typical driver, what is the appropriate advance posting distance? A recent revision to the MUTCD provides suggested minimum advance posting distances. The distances range from 100 feet to 775 feet.

Table 2-3 (which is shown as Table II-1 in the MUTCD) lists the minimum sign placement distances for the following three conditions:

- Condition A—High Driver Judgment. This involves complex driving situations where the driver needs extra time to make and execute a decision (e.g., a lane change or merge on a high volume/high speed roadway.)
- Condition B—Stop Condition. This covers situations in which the driver may be required to come to a complete stop (e.g.,signalized or STOP sign intersection, pedestrian crossing, crossroad, etc.)
- Condition C—Deceleration Condition. In this case the driver will likely be required to decrease speed in order to take the proper action or maneuver (e.g., to slow for a turn, curve, dip, etc.)

Under Condition A (High Judgment Needed), a supplementary legend specifying distance to the condition should be used in urban areas if there is an intersection between the advance warning sign and the condition. Otherwise, the driver might become confused and interpret the sign to mean that the condition is at the intervening crossroad. For conditions B and C, the distances are based on a sign legibility distance of 125 feet which would be provided by 30 and 36-inch signs. If 48-inch signs are used, the legibility distance may be increased to 200 feet which would allow a reduction of 75 feet in the placement distances given in Table 2-3.

Height and lateral placement of warning signs should conform to the general specifications for the placement of signs, as prescribed in Section 2C-3 of the MUTCD. Signs warning of conditions which are temporary or intermittent in occurrence (e.g., road repairs) are normally mounted on portable supports. Care should be taken to insure that these signs are clearly visible to approaching traffic.

Signing Curves

The warning signs such as the turn sign, curve sign, reverse curve sign, etc., are part of what is known as the alignment series. Shaped arrows are used to indicate the roadway alignment to be expected. Table 2-3 can be used to determine the advance posting distance for alignment warning signs. The point of reference used is the point at which the curve begins. Except where two successive curves qualify as combination curves, advance posting of one curve is never ahead of the previous curve.

Whether or not a particular curve needs to be signed is based on the recommended speed at which the curve may be traversed. This speed may be determined by the use of the curves in Figure 2-6, by the use of a ball-bank indicator (Figure 2-7), or by mathematical computation.

The curves given in Figure 2-6 are used when the radius, R, and super-elevation, e, of the curve are known. The radius and super-elevation of the curve may be obtained from actual measurement or from construction plans of the roadway. The combination of radius and super-elevation giving the lowest speed for the curve should be used.

The ball-bank indicator is a curved level which is used to determine the safe speed around a curve as indicated by trial speed runs. The trial speed runs involve the use of the vehicle and ball-bank indicator to show the combined effect of the body roll angle, the centrifugal force, and the superelevation angle.

The device is mounted in the car and checked to assure that the ball within the level is on zero when the car is on a level surface and loaded as it

Suggested Minimum Warning Sign Placement Distance—Feet [1]

Posted or 85 percentile speed mph (use higher speed)	Condition A high judgement needed [2] (10 Secs PIEV)	GENERAL WARNIG SIGNS [3]					
		Condition B STOP condition	Condition C Deceleartion conditions to listed advisory speed—MPH (or desired speed at condition)				
		0	10	20	30	40	50
20	175	([4])	([4])				
25	250	([4])	100				
30	325	100	150	100			
35	400	150	200	175			
40	475	225	275	250	175		
45	550	300	350	325	250		
50	625	375	425	400	325	225	
55	700	450	500	475	400	300	
60	775	550	575	550	500	400	300

[1] Distances shown are for level roadways. Corrections should be made for grades. Distances based in 36-inch signs. If 48-inch Signs are used, the legibility distance may be increased to 200 feet. This would allow reducing the distance by 75 feet.

[2] In urban areas, a supplementary plate underneath the warning sign should be used specifying the distance to the condition if there is an in-between intersection which might confuse the motorist.

[3] Distance provides for 3-second PIEV, 125 feet Sign Legibility Distance, Braking Distance for Condition B and Comfortable Breaking Distance for Condition C as indicated in A *Policy on Geometric Design of Rural Highways,* 1965, AASHTO, Figure VIII-15B.

[4] No suggested minimum distance provided. At these speeds, sign location depends on physical conditions at site.

Typical signs for the Listed Conditions in Table II-1: Condition A—Merge, Right Lane Ends, etc.;Condition B—Cross Road, Stop Ahead, Signal Ahead, Ped-Xing, etc.; Condition C—Turn, Curve, Divided Road, Hill, Dip, etc.

Table 2-3. ADVANCE WARNING SIGN PLACEMENT

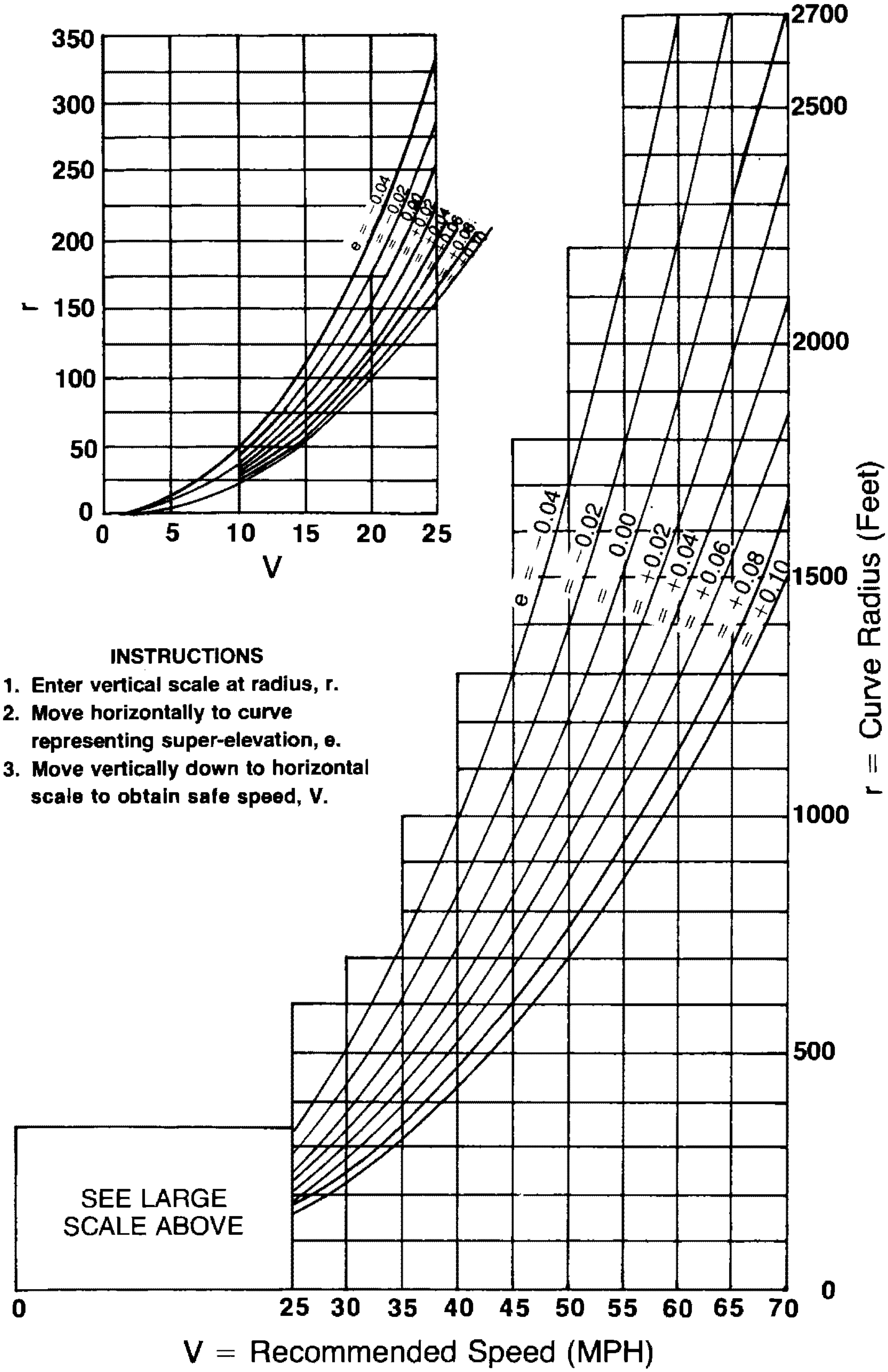


Figure 2-6 Recommended Safe Speed

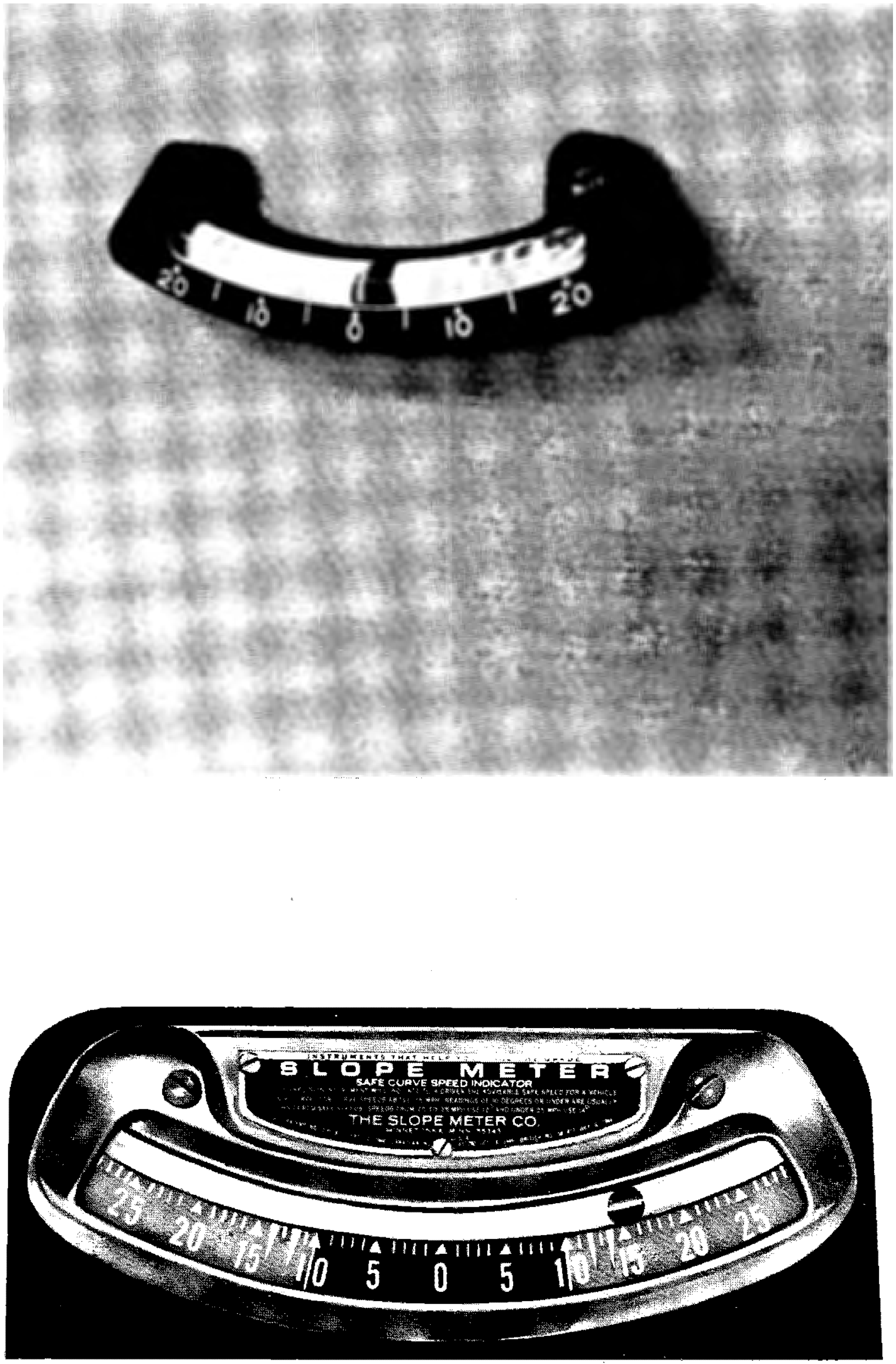


Figure 2-7 Ball-bank Indicator

will be during the run. It is desirable to use two people during the run so that the traffic, the speedometer, and the ball-bank indicator can be monitored throughout the trial speed runs. To obtain a true reading on the ball-bank indicator, the car must be driven parallel with the center line of the curve. The common practice of flattening out a curve by driving on the inside of the curve at the center should be avoided.

The first trial run is made at a speed somewhat below the anticipated maximum safe speed. Subsequent trial runs are conducted with 5 mph speed increments. If a reading of 14° or greater occurs at 20 mph or less than the safe speed is below 20 mph. The curve should be signed for that speed, i.e., 10 or 15 mph, at which a 14° reading occurs. A reading of 12° at a trial speed of 20, 25, and 30 mph indicates that the trial speed, i.e., 20, 25, or 30 mph is the safe speed. A reading of 10° at speeds of 35 mph or greater indicates a safe speed of 35 mph or greater.

Curves should be evaluated in both directions when using this method. Many times it is preferred to use the lower speed condition for signing both approaches.

While many agencies use the 14°, 12°, 10° criterion for signing curves other agencies use more conservative criteria. For example, a 10° reading at any speed would indicate the maximum safe speed in some States. Prior to applying this procedure a check should be made to insure what the accepted criteria are for the area in question.

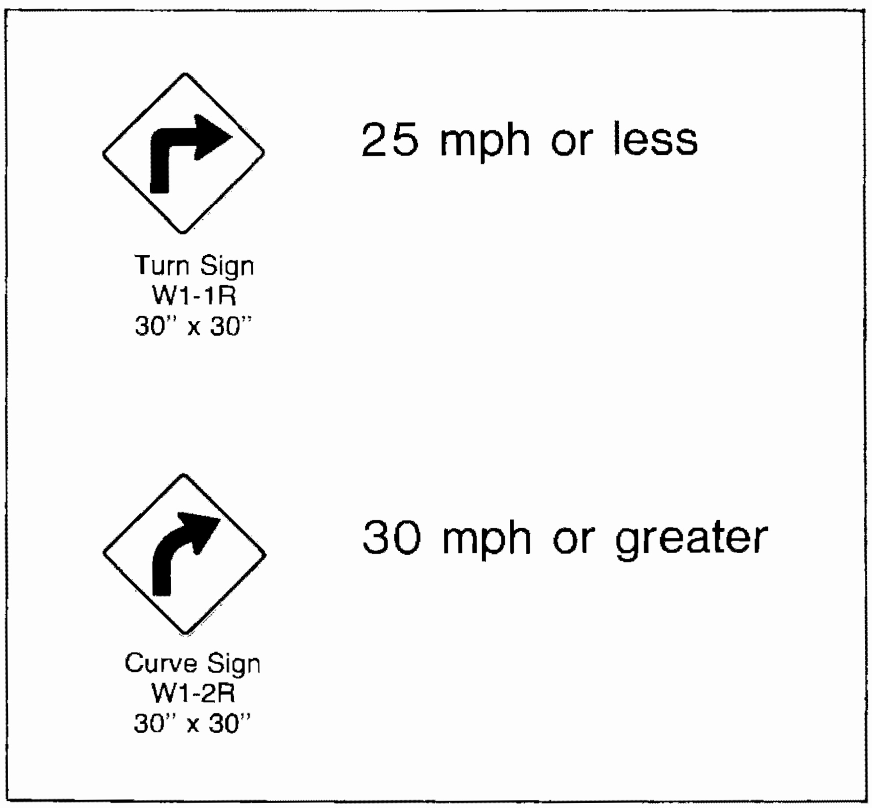


Figure 2-8 Appropriate Use of Turn Sign and Curve Sign

A third method for determining the safe speed of a curve is to apply the following formula:

$$V^2 = 15\,R\,(e + f)$$

where:

V = Speed in miles per hour
R = Radius of curve in feet
e = Rate of super-elevation in feet per foot
f = Safe coefficient of side friction

The speed determined by any one of the above methods is the basis for arriving at the recommended speed for the curve which, in turn, determines whether a turn or curve sign should be used. Figure 2-8 shows the appropriate sign to be used as indicated by the speed graph, the ball-bank indicator, or by mathematical techniques.

Advisory Speed Plate

The supplemental advisory speed plate may be used when the recommended speed is equal to, or less than, the legal speed limit. No advisory speed plate is used when the safe curve speed is greater than the legal speed limit.

Combination Curves

A combination curve consists of two successive curves. They may be connected with or without a short tangent section, and they may be in the same or in opposite directions. The recommended speed for the combination will be the lower recommended speed of the two curves. If either of the curves requires a turn sign, such a sign would be used for the combination curve.

A reverse curve is a type of combination consisting of two curves in opposite directions separated by a tangent of less than 600 feet. The Reverse Curve (W1-4) and Reverse Turn (W1-3) signs are intended for use under these conditions. The lower of the recommended speeds for the two curves will prevail. A combination curve with curves in opposite directions separated by more than 600 feet of tangent should be signed as separate curves.

The Reverse Turn sign is intended for use if either or both of the curves require a turn sign. It is often advantageous to supplement the Reverse Turn sign (W1-3) with a Turn sign (W1-1) and appropriate speed plate in advance of the second curve.

Another type of combination curve sign, the Winding Road sign (W1-5) may be used where there is a succession of three or more curves. Where there are fewer than three curves in succession, one or two Turn, Curve, Reverse Turn, or Reverse Curve signs should be considered.

The Reverse Turn, Reverse Curve, and Winding Road signs are provided in left and right designs. If the first curve is to the left, a "left" sign is used and if the first curve is to the right, a "right" sign is used.

2B-2 Materials

A typical sign installation is made up of the following elements:

- Sign blank,
- Sign face,
- Sign posts, and
- Sign foundation.

The MUTCD recognizes that a wide variety of materials are available that can be used effectively for highway sign installations. More significantly, it recognizes that technological progress may develop materials superior to those currently used. Consequently, any new material that can perform the necessary functions of a sign assembly should be considered for use.

This section covers the various types of materials, their physical properties, effectiveness, and use.

Sign Blanks

The most widely used sign blank materials are aluminum, wood (usually plywood), or steel (either galvanized or non-galvanized).

When deciding which type of sign blank material to use, both the advantages and disadvantages of each type should be considered. For example, aluminum is light weight and will not rust but is initially more expensive than steel or plywood. It also requires cross bracing for the larger sized signs. Galvanized steel is heavier and is usually more rigid. It will not rust if the zinc coating is not damaged and is more economical than aluminum. Steel is heavier than aluminum. Plywood is of medium strength, does not require cross bracing and is the least expensive of the materials. It is very porous and susceptible to weathering and cracking if not overlaid with a thin layer of plastic.

Sign Reflectorization

Signs are either reflectorized or illuminated so as to be visible at night. Retroreflective materials are used extensively for traffic signing because of their ability to reflect back to the driver a large portion of light from vehicle headlights. An adequate level of retroreflectorization can be obtained in a number of ways. Retroreflective sheeting is the most commonly used material. This sheeting gets its retroreflective characteristic from minute glass beads embedded in a flexible plastic sheeting or from minute corner cubes molded in the surface of a plastic sheeting. To reflect colored light, pigment or dye is incorporated in the reflective coating material.

Retroreflective materials are considered effective when they reflect a large proportion of light directly back toward the light source (headlights). The performance of retroreflecting materials depends on their optical characteristics, their ability to perform during inclement weather, and on their resistance to weathering. There are several grades of reflective sheeting specified in Ref. 2-17, page 271. Type II and III are the grades that are commonly used for signs. Care should be taken to insure that the right sign material is used for the conditions that the sign will be required to meet.

The Type II sheeting provides a durable, flexible, retroreflective sheeting designed for the production of multicolored signs, emblems, etc., which are intended to have a similar appearance in daytime and at night. The sheeting can be applied with a heat-activated, pressure sensitive adhesive. It is comprised of exposed glass beads imbedded in a plastic resin and protected by a highly durable transparent film. This type sheeting can be expected to provide satisfactory performance under normal use for a period of 5 to 7 years.

Type III sheeting has approximately three times the reflective brilliance of Type II, and is reported to have an effective performance life of up to 10 years under most conditions. It is also three times as expensive as Type II. Type III sheeting is a highly reflective, durable material. It may be economically justified where brighter signs are needed to provide added advance warning or where higher reflective brilliance is needed to compete with light from advertising signs, street lighting, etc. Ground mounted expressway signs that are installed far from the edge of the roadway may warrant the use of Type III sheeting.

Under certain circumstances, overhead signs using Type III sheeting may not require external illumination. In fact, some agencies have disconnected the light source of overhead signs after the signs were refurbished with Type III sheeting. However, each such candidate sign should receive a nighttime evaluation, with and without the lights, and under adverse weather conditions, to make sure that motorists will be able to see the sign.

Reflector buttons have also been used effectively for forming sign legends and borders. These consist of acrylic plastic reflectors or small individual reflecting units of glass that can be arranged in rows or patterns to form letters, symbols, or borders. In suitable sizes and spacings, they give the visual effect of continuous lines. When properly installed, they are reported to perform satisfactorily for 15 to 20 years.

Illumination

To achieve night visibility under certain conditions, it is sometimes necessary to use external or internal illumination rather than retroreflectorization. In general, illumination is provided by high intensity discharge or florescent light sources. Overhead signs often require illumination since they are located above the area normally illuminated by vehicular headlights. However, as noted above, some agencies have found that overhead signs constructed with Type III sheeting do not always require illumination.

A few internally illuminated signs are in use in the United States. Internal illumination is normally provided by placing the sign message on a translucent sign face. Florescent light provides an even distribution of light from behind the translucent face. As a general rule, only small signs, in urban areas, are internally lighted.

Both the high intensity discharge and the florescent lighting sources are installed in front of and slightly below the sign. Such a system permits a relatively even distribution of light across the sign face. Neon may be used, but its high intensity can result in an undesirable glare reflectance from the sign. High intensity discharge lighting units are a reliable and effective sign lighting source.

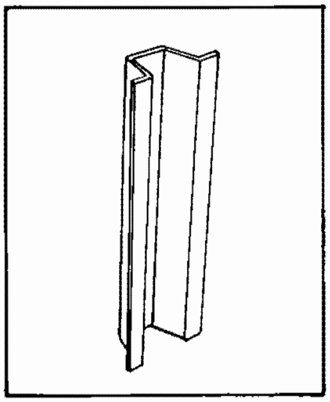
As noted above, the increased capability of modern retroreflective sign sheeting has curtailed the need for providing a fixed lighting source with the sign. The decision as to the type of illumination (if any) and type of reflective sheeting to be used for an installation should take into account the cost of energy associated with each lighting system considered.

Sign Posts

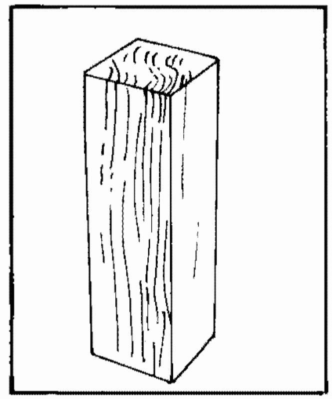
The steel U-post (also known as flanged channel post) is the most widely used sign support in the United States (Ref. 2–8). Other commonly used types are the wood post, the steel pipe, and the steel tube. These four types comprise more than 95 percent of all systems used. An extruded aluminum Type X post is also being used to a limited degree. Cross-sectional views of these five types are shown in Figure 2–9. In addition, rolled-steel shapes with breakaway bases are used extensively for larger signs along expressways and freeways.

A recent state-of-the-practice survey of the use of small highway signs (Ref. 2–8) revealed that there was no significant difference in the total installation cost (including materials and labor) for the four most widely used support posts. Wood posts were found to have the smallest unit material cost, followed by the steel U-posts, steel pipe, and the square steel tubing. The extruded aluminum Type X post with a breakaway base costs considerably more than the four listed above.

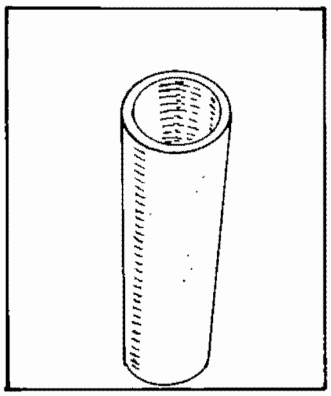
Supports for large overhead signs are usually steel or aluminum. The sign itself is usually mounted on an aluminum or steel mast arm, sign bridge, or cantilevered frame. Often it is possible to place large overhead signs on other structures crossing the roadway such as pedestrian bridges or highway or railroad grade separation structures. This not only saves the cost of the sign support structure but also eliminates a potential roadside hazard.



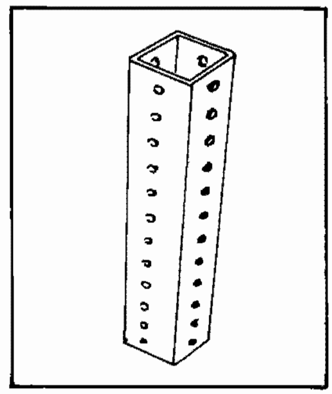
a. Steel U-Post



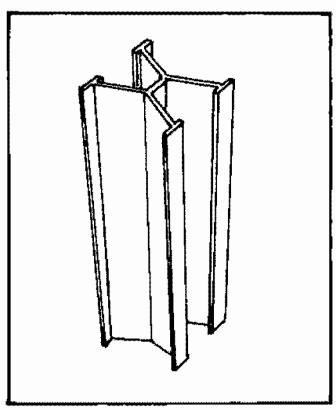
b. Wood Post



c. Steel Pipe Post



d. Square Steel Tube



e. Aluminum Type X Post

Figure 2-9 Typical Sign Posts

Sign Foundations

Foundation materials for signs vary from reinforced concrete (large signs and overhead sign bridges) to none (simply implanting the post into the ground). A detailed discussion of sign foundations is included in the Installation Section (Sec. 2C-2).

2B-3 Procurement

There are several options available in procuring signs. Signs can be purchased from outside sources or the agency can choose to fabricate their own signs. Many agencies choose to set up a sign shop to fabricate smaller, frequently-used regulatory, warning, and guide signs and to purchase the remainder of their sign needs.

This section describes the purchasing options available to an agency and the methods of warehousing and stockpiling the material after fabrication or purchase.

Sign Shop Operations

The size and scope of sign shop operations is dependent primarily on the economic justification for local sign fabrication versus purchasing prefabricated signs. Factors to be considered in this decision are:

- Cost of labor,
- Number of signs to be used (usually on a yearly basis),
- Cost of prefabricated signs,
- Time factor allowable for fabricating signs, and
- Space requirements (sign shop and stockpile area).

For smaller sign shop operations it is usually cost-effective to purchase the sign blanks from manufacturers rather than to purchase and cut larger sheet metal or wood. This eliminates the need for large sheet storage areas and metal cutting equipment.

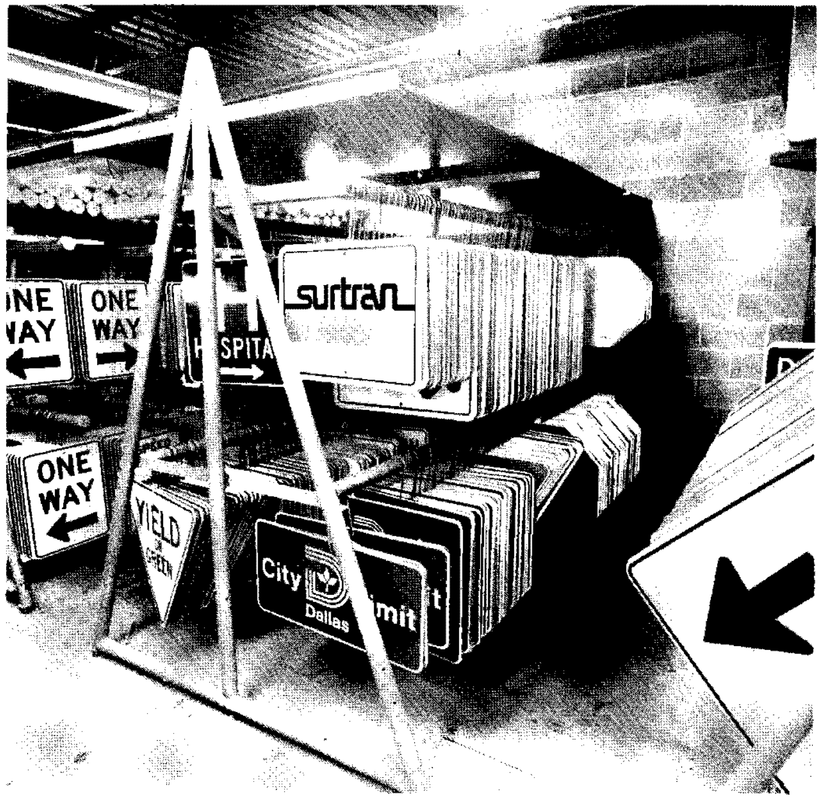
The process for small operations can be further simplified by using either wood or metal in fabrication rather than both. This eliminates the need for two different storage areas and two types of cutting equipment. Small local agencies usually follow their State's policy in the use of either wood or metal blanks.

When State highway agencies are equipped to fabricate signs, it is usually cost-effective for small local agencies to purchase their signs from the State. It also may be cost-effective for the State to centralize its sign fabrication at one operational site. More detailed information on sign shop practices is provided in publications prepared by suppliers of material and equipment. For example, Ref. 2-9, provides a discussion of practices and lists of available equipment and material suppliers.

Warehousing and Stockpiling

Where possible, signs are usually stacked in racks. Care must be used when handling the panels to avoid damaging the face of the sign. Figure 2-10 shows typical storing arrangements.

When stored, signs should not be placed where other material may accidently come in contact with the sign face. If signs or sign blanks are packaged or stored without spacing between them and they become wet,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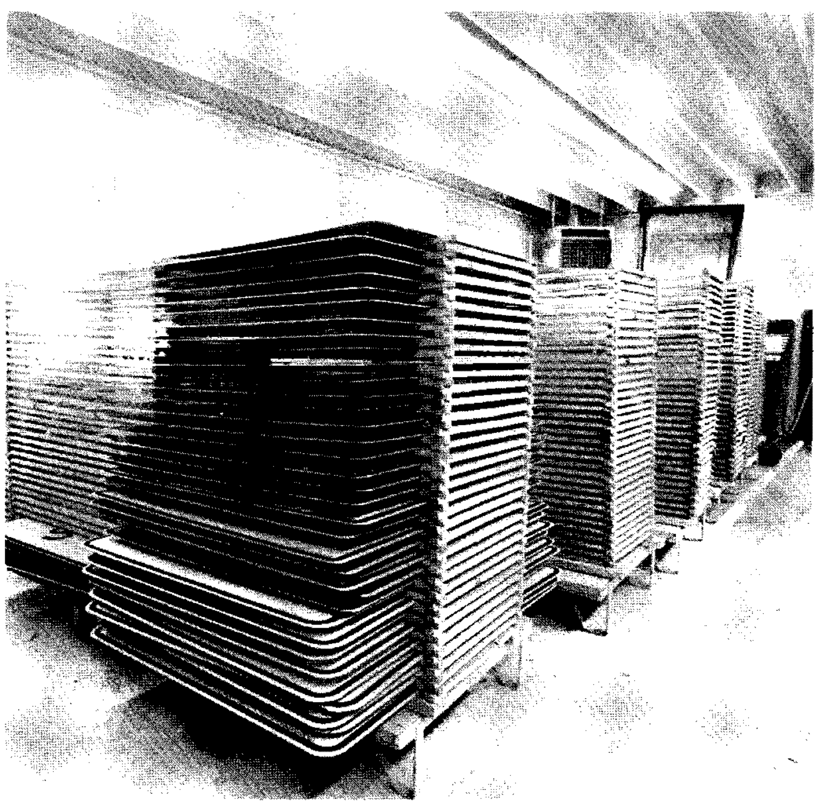


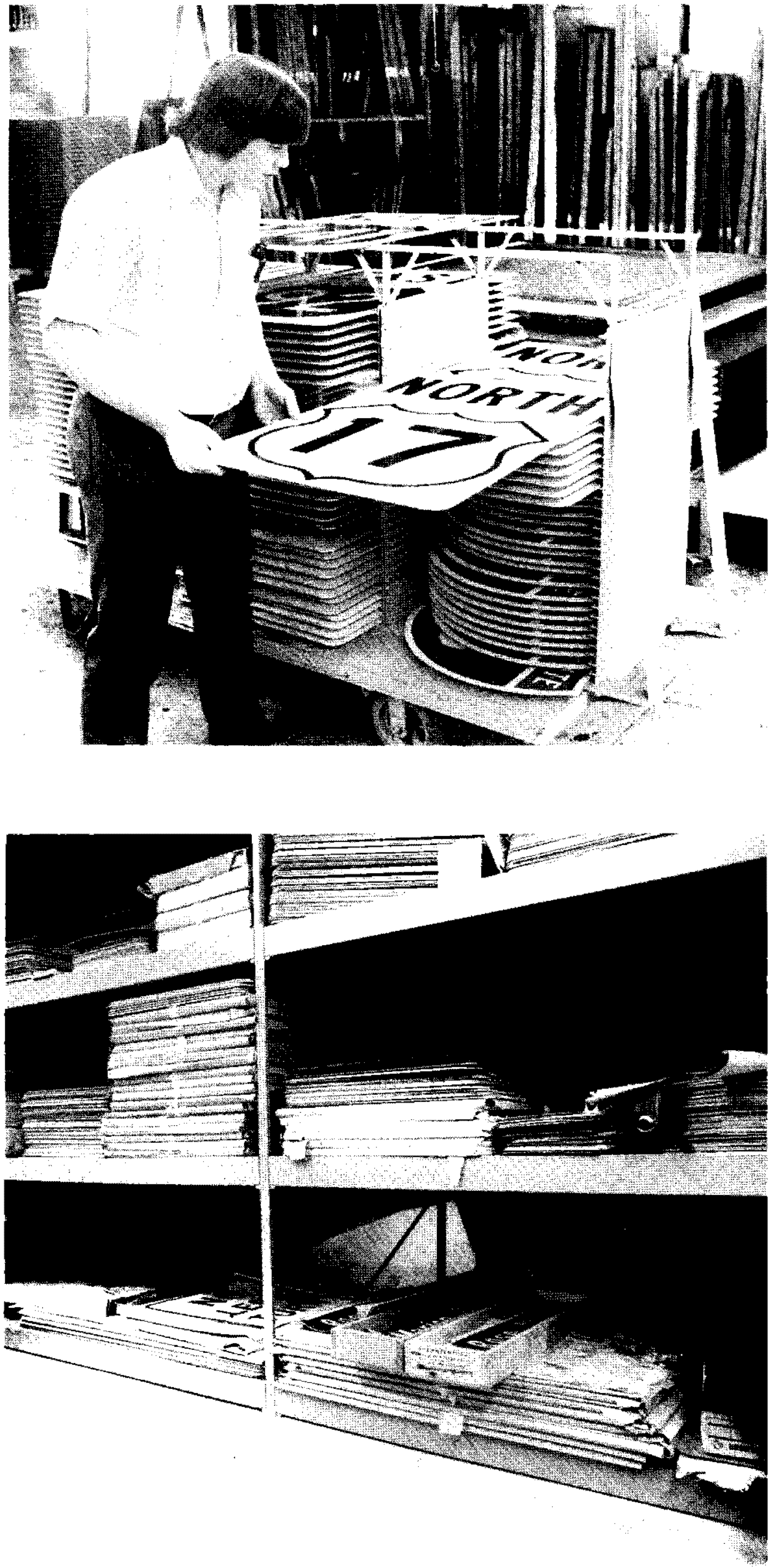


Figure 2-10 Typical Sign Storing Arrangements

they must be immediately unpackaged and dried to prevent permanent damage. Sheeting manufacturers usually provide recommendations for shipping and storage.

When loading signs on vehicles, they should be secured in racks in a vertical position to prevent rubbing against each other. Movers' blankets are convenient for protecting sign faces, if racks are not used. Packaged signs and those which have protective wrappings or slipsheets on the face must be kept dry. Signs without protective wrappings that are spaced apart do not usually have to be kept dry.

Sign Recycling

Reclaiming aluminum traffic sign materials can cut replacement cost significantly. One state reported an estimated yearly average of 15,000 signs saved with the recycling process (Ref. 2-10).

Some agencies use chemicals in an "acid bath" to strip away the sign surface. However, recent mechanical equipment developments consisting of a levelling device and a scarifying device have made it more feasible to recycle aluminum signs. The process is summarized below:

- A bent sign or one with bullet holes is placed in a levelling machine with 17 large rollers that exert pressure on the metal to force it flat without harming the surface. If a sign is badly bent, warped, or severely scratched, the sign may not level properly and must be rejected from the process. Such signs can be sold to scrap metal centers.
- The flattened sign is then placed in a scarifier or sander where it passes under a rotating sanding belt. The total cost of sanding belts averages 4 cents to 8 cents per square foot of sign material sanded.
- After sanding, the sign blank is treated with a light, tightly adherent chromate coating. This coating prevents corrosion and is essential for bond with adhesive backed products or enamels.
- The recycled sign is then treated just like a "new" sign blank.

Purchasing

Agencies that do not choose to fabricate their own signs, purchase them commercially or from other agencies. Even when State highway departments have a complete sign shop, they sometimes ask for bids for large-scale signing projects rather than fabricate them in-house. Some of the purchasing options available to an agency include:

- Commercial suppliers,
- Penal institutions that fabricate signs,
- Other agency sign shop operators, and
- States who have contracted with outside sources on large contracts.

Signs purchased from a penal system can usually be provided at a substantially lower price than those purchased from a commercial supplier. (The penal institutions may be limited by law as to the number of signs they can manufacture per year to protect the commercial suppliers from undue competition due to the lower pricing.) Purchasing from a State prison system also provides revenue to help defray the cost of operating these institutions. On the other hand, experience has shown that the competitive drive to produce quality products, on time, is often lacking and can create problems with delivery deadlines.

In some areas, local agencies have the opportunity to enter into cooperative purchase agreements with the State. In this manner, the agencies' smaller order can be lumped with the larger purchasing power of the State contract to receive a lower price for signs and/or materials. Some States order more than what they need so that they are in a position to sell signs to the local agencies at cost or even less so as to induce greater conformance with the MUTCD.

Material Specifications

Specifications for the following sign materials are usually available from State or large local agencies:

- Sign blanks,
- Retroreflective sheeting,
- Cut out letter sheeting,
- Posts, and
- Foundations.

2C. INSTALLATION

Of equal importance to the proper selection and application of signs, is the proper location, position, and erection of signs. A sign that is confusing or one that cannot be seen by the driver in time to respond is useless. This section discusses the factors involved in properly locating signs and also discusses effective installation practices in terms of techniques, materials, and equipment.

2C-1 Location and Position of Signs

Sign positioning as defined in the MUTCD is associated with an assumed set of conditions portraying a typical situation. Since no two roadways are exactly alike, it follows that these basic standards are intended as a guide. Uniform positioning of signs, while desirable, is not always easy to achieve as the alignment and design of the road often dictates the most advantageous position for the sign. Accordingly, the guidelines provided in the MUTCD should be tempered by the existing conditions to assure that the sign will be seen by the drivers and that the drivers will have adequate response time.

To the extent possible, it is a good idea to coordinate geometric design and signing design early in the planning and design stages of all new and reconstructed roadways. If a roadway design does not permit adequate placement of the required signs, then it may be worthwhile to consider a revision in the geometric design of the roadway. A bad geometric design cannot be corrected by signing.

On two-way roadways, signs are normally located on the right side facing approaching traffic. Under certain circumstances signs may be placed: on channelizing islands; overhead; or when short sharp curves to the right exist, signs may be placed on the left shoulder of the road directly in front of approaching vehicles.

On divided highways and one-way roads, supplemental regulatory, warning, and guide signs are often essential for motorists traveling in the left lanes of the roadway. Such signs may be placed in the median to the left of traffic and on the left side of one-way roadways.

All locations for signs should be carefully checked before installing the sign to assure that there is no sight obstruction between the sign location and its intended point of observation by the motorist. Some of the common problem placements to be avoided are:

- Dips in the roadway,
- Beyond the crest of a hill,
- Where a sign could be obscured by parked cars,
- Where a sign would create an obstruction for pedestrians, joggers, or bicyclists,
- Where a sign would interfere with the driver's visibility of hazardous locations or objects,

- Where sign visibility would be impaired due to existing overhead illumination,
- Where signs are vulnerable to roadside splatter or to being covered with snow by plowing operations, and,
- Too close to trees or other foliage that could cover the sign face or could grow and cover the sign face.

Longitudinal Placement

The longitudinal location of signs along the highway depends on the type of sign used, the nature of the message, and the desired motorist response. Latitude as to the final longitudinal location of signs varies from zero in the case of a speed limit sign, that is placed at the point where the speed limit begins, to 1 mile or more in the case of an advance exit sign. In most cases, signs can be shifted longitudinally without compromising their intended purpose. Signs should be shifted longitudinally to improve their visibility, to avoid blocking other signs, to enhance safety (by placing the sign behind otherwise needed roadside barriers), or to enhance operations (by providing more distance between signs in a series).

As a general rule of thumb, warning signs are normally placed in advance of the condition to which they call attention. Regulatory signs are placed where their mandate or prohibition applies or begins. Guide signs are placed at varying locations to inform drivers as to their route of travel, destinations, and points of interest.

While it is preferable to erect signs individually (except where one sign supplements another or where guide signs must be grouped), it is sometimes advantageous to group signs to eliminate extra posts. This is particularly true in urban areas where the number of signs to be installed is greater than the space available. Although different purpose signs should not be located closer together than 200 feet if it can be avoided, signs at intersections and in urban areas cannot always meet these requirements.

In situations where two or more signs are needed at approximately the same location, it is necessary to establish a priority to determine the order of placement. Regulatory signs take precedence over Warning and Guide signs. Guide signs are usually the least critical because there is more flexibility in their placement than the first two sign categories. Within the Regulatory sign group, the sign bearing the most important regulation supercedes the others.

An accepted order of priority for sign types is as follows:

- *Regulatory Signs*—speed limit, stop signs, turn prohibitions
- *Warning Signs*—curve sign, cross road sign, narrow bridge sign
- *Guide Signs*—trailblazers, destination signs
- *Emergency Service Signs*—hospital, telephone
- *Motorist Service Signs*—fuel, food, camping, information

- *Public Transportation Signs*—park and ride, bus stops
- *Traffic Generators Signs*—museums, ball parks, historic buildings
- General Information Signs—time zone, county line, city limits.

Signs should be placed so as to be compatible with other signs in the area and with other roadway features in the area. For example, speed limit signs should not be placed just before an intersection, school zone, or problem curve which is posted with a lower speed. The final decision for placement of signs must be based on the prevailing local traffic, roadway, and other conditions which require engineering judgment.

Lateral Clearance

Lateral clearance for roadside signs is the distance from the edge of the roadway (edge of pavement) to the nearest edge of the sign. All signs, regardless of size, constitute a potential hazard for the motorist. Therefore, signs are normally located as far from the roadway as practical. The following should be considered when determining the lateral clearance of signs:

- When possible, the larger signs should be located behind existing, otherwise required, roadside barriers. Care should be taken to insure that the sign support is outside the anticipated maximum deflection of the barrier. This will help insure that the barrier functions properly if it is hit and will also avoid damage to the sign and sign support system if the barrier is hit. Typical anticipated deflections are:

Concrete Safety Shape	Minimal deflection
W-Beam Strong Post	3 feet
W-Beam Weak Post	6-7 feet
Box Beam	5-6 feet
Cable Guardrail	11 feet

- All signs should be at least 2 feet outside the shoulder. Otherwise, trucks or other large vehicles using the shoulder may hit the sign.
- All signs should be 12 feet from the edge of pavement. Otherwise, any vehicle pulling off the road, due to mechanical problems, etc., is liable to hit the sign.
- Signs should be located at least 2 feet behind curb when curb sections are used. This will help insure that trucks and other large vehicles pulling up next to the curb will not hit the sign.
- For high speed facilities large ground mounted signs can be located quite far (50 feet or more) from the edge of pavement. This is done to provide a clear roadside recovery zone as discussed in Part III of the Guide for Selecting, Locating, and Designing Traffic Barriers (Ref. 2–22). Even with these substantial lateral clearances, the signs perform very well in meeting motorist viewing needs.

- Lateral clearance for overhead and contilevered sign support systems must also be considered. Some agencies have found that it is less expensive to span the entire clear roadside recovery zone than it would be to provide a shorter span and then install and maintain roadside barriers, end treatments, etc.

Overhead Signs

Signs placed directly over the travel lanes to which they apply can be of great assistance in increasing communications with the driver. Their principal applications are on multilane heavily traveled highways. Overhead signs are generally used:

- Where the message is applicable to a particular lane(s) over which the sign is placed and where lane use can be made significantly more effective;
- Where traffic or roadway conditions are such that an overhead mounting is necessary for adequate visibility (e.g., vertical or horizontal curvatures, closely spaced interchanges, three or more through lanes in one direction, etc.);
- At, or just in advance of, a divergence from a heavily traveled roadway (e.g., at a ramp exit where the roadway becomes wider, and a sign on the right side is usually not in the line of sight for the driver);
- Where there is no space for signs at the side of the roadway (e.g., where narrow right-of-way does not provide adequate width for a sign installation);
- Where ground-mounted placement would create an undue roadside hazard;
- Where, because of hazardous conditions, particularly effective guidance is needed for the unfamiliar driver;
- Where roadside development seriously detracts from the effectiveness of roadside signs (e.g., a brightly lighted area);
- For consistency, where other signs on a given section of highway are overhead; and
- Where MUTCD standards mandate overhead installation.

All overhead signs require a vertical clearance, to the roadway and shoulders, of 17 feet. Overhead signs are frequently placed on overcrossing structures. This reduces the hazard of sign supports as well as reducing the cost of the installation. When the sign is mounted on an overcrossing structure, the vertical clearance to the sign need not exceed the vertical clearance of the structure. If the structure is less than 17 feet, a low clearance sign (W12–2) should be used.

Height of Post-Mounted Signs

When determining the height of post-mounted signs two checks should be made. The first check deals with the visibility of the sign. To insure good visibility the vertical clearance from the bottom of the sign to the surface of the roadway should be as specified in Sec. 2A-23 of the MUTCD and as shown in Figure 2-1 of the MUTCD.

The second check has to do with the breakaway support system for the sign. Sign panels should be at least 7 feet above the terrain below the sign to insure that the safety mechanism (i.e., breakaway, slip base, load concentrating coupling, yielding, etc.) of the support system will function properly.

Both of these requirements are minimum clearance requirements. The final height of all post-mounted signs must meet or exceed both of these requirements. See Figure 2-11.

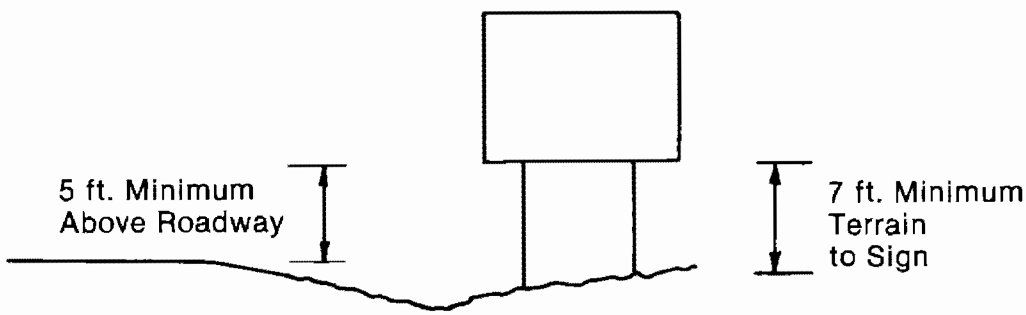


Figure 2-11 Height of Post-Mounted Signs

Orientation Angle

Signs are normally mounted at approximately right angles to the direction of, and facing the traffic that they are intended to serve. Parking signs are excepted from this rule. Some parking signs may be erected at an angle of between 30 to 45 degrees to the direction of traffic. Except for parking signs, post-mounted signs located close to the traveled way should be turned slightly away from the roadway to avoid glare reflection of headlights off the sign face directly back into the driver's eyes. An angle of about 93° to the line of approaching traffic has been found satisfactory for sign locations from 12 to 14 feet from the pavement edge. For signs 30 feet from the pavement edge, 87° has proved satisfactory. For each additional 10 feet of sign offset from the pavement edge, the sign is angled at one less degree. On curved alignments, the angle should be determined by the course of approach traffic, rather than by the roadway edge at the point where the sign is located. On grades it may be desirable to tilt a sign forward or back from the vertical to improve the viewing angle.

The face of all overhead signs should be tilted at least 3° towards traffic. This will help insure that dirt, dust, snow, and bird droppings will not drop onto the sign face. Orientation angles are shown in Figure 2-12.

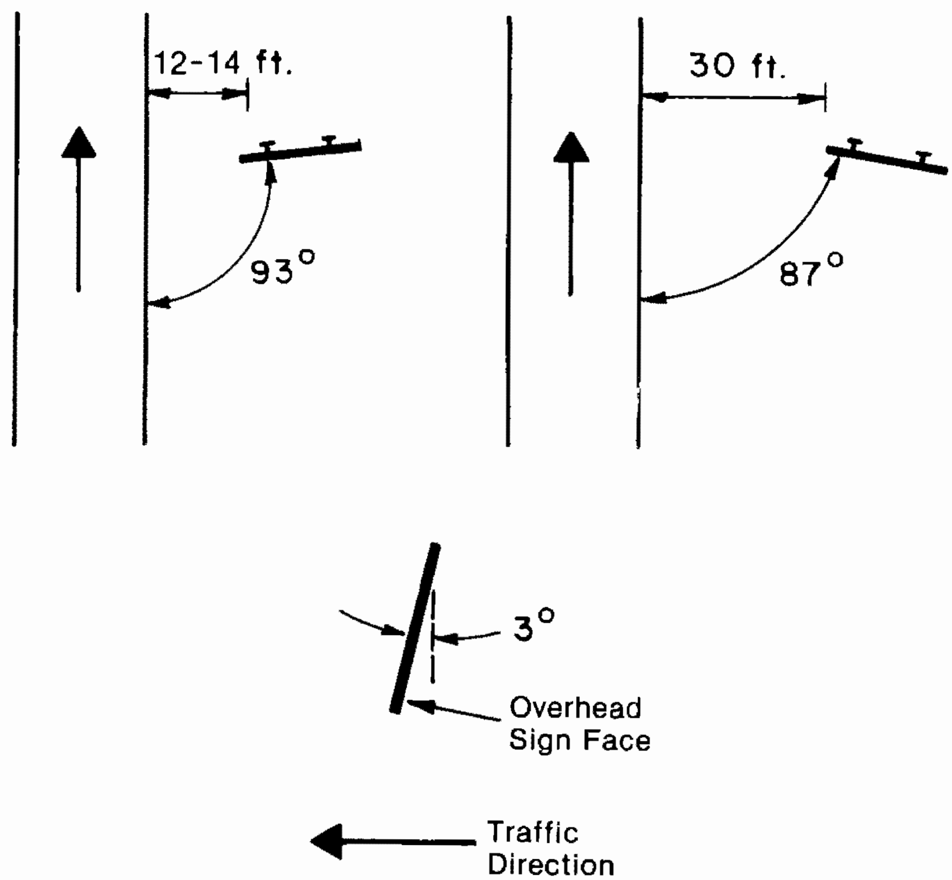


Figure 2-12 Orientation of Signs

2C-2 Sign Supports

The critical issue in selecting and installing ground-mounted signs is the type of support used. Ground-mounted highway signs are supported in a number of ways and by a variety of materials as discussed earlier under "2B-2 Materials". Rolled steel and aluminum shapes, wood posts, and steel and aluminum pipes are often used to support signs. In some cases, a trussed design is employed.

Installation of the support is accomplished by either driving the post into the soil, drilling and backfilling after placement of the post, or by placing the post in a concrete footing. Upon impact by an errant vehicle, the base of the support may be designed to break away, yield and bend over, fracture, or to be "rigid". The "rigid" design is acceptable only if placed behind a protective traffic barrier or if the probability of impact by errant vehicles is extremely low. Various support systems are shown in Figures 2-13 through 2-17.

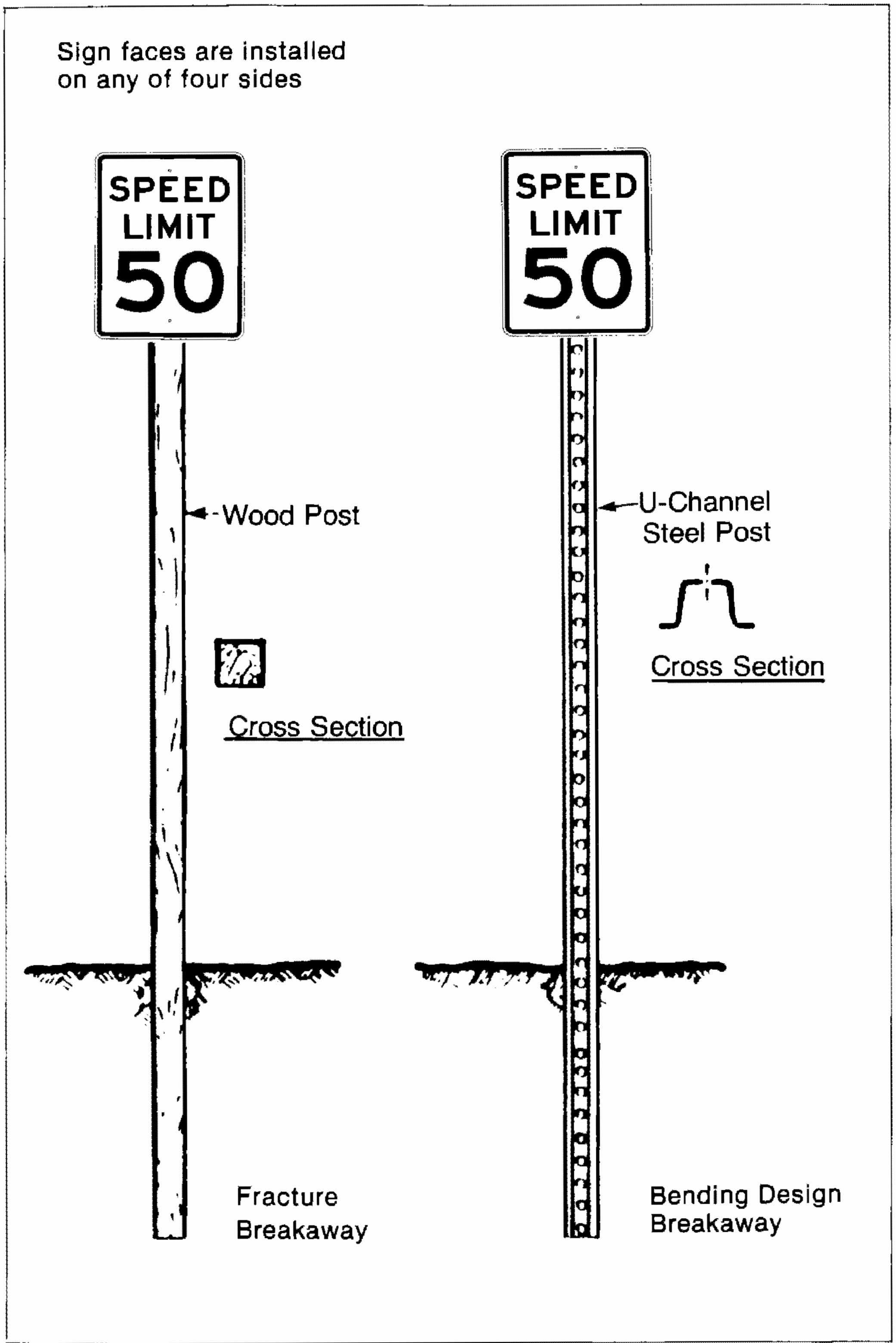


Figure 2-13 Sign Support Systems

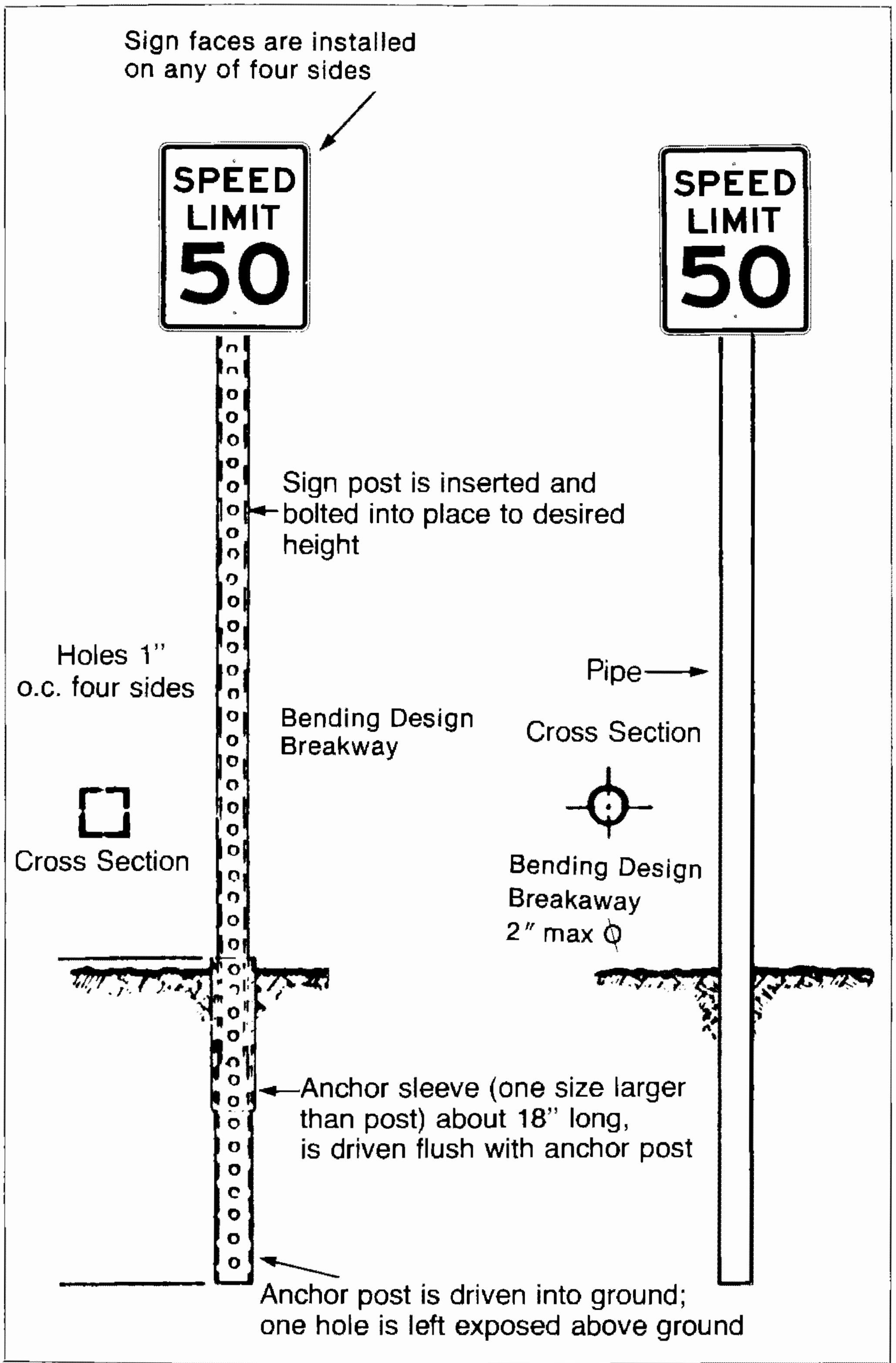


Figure 2-14 Sign Support Systems

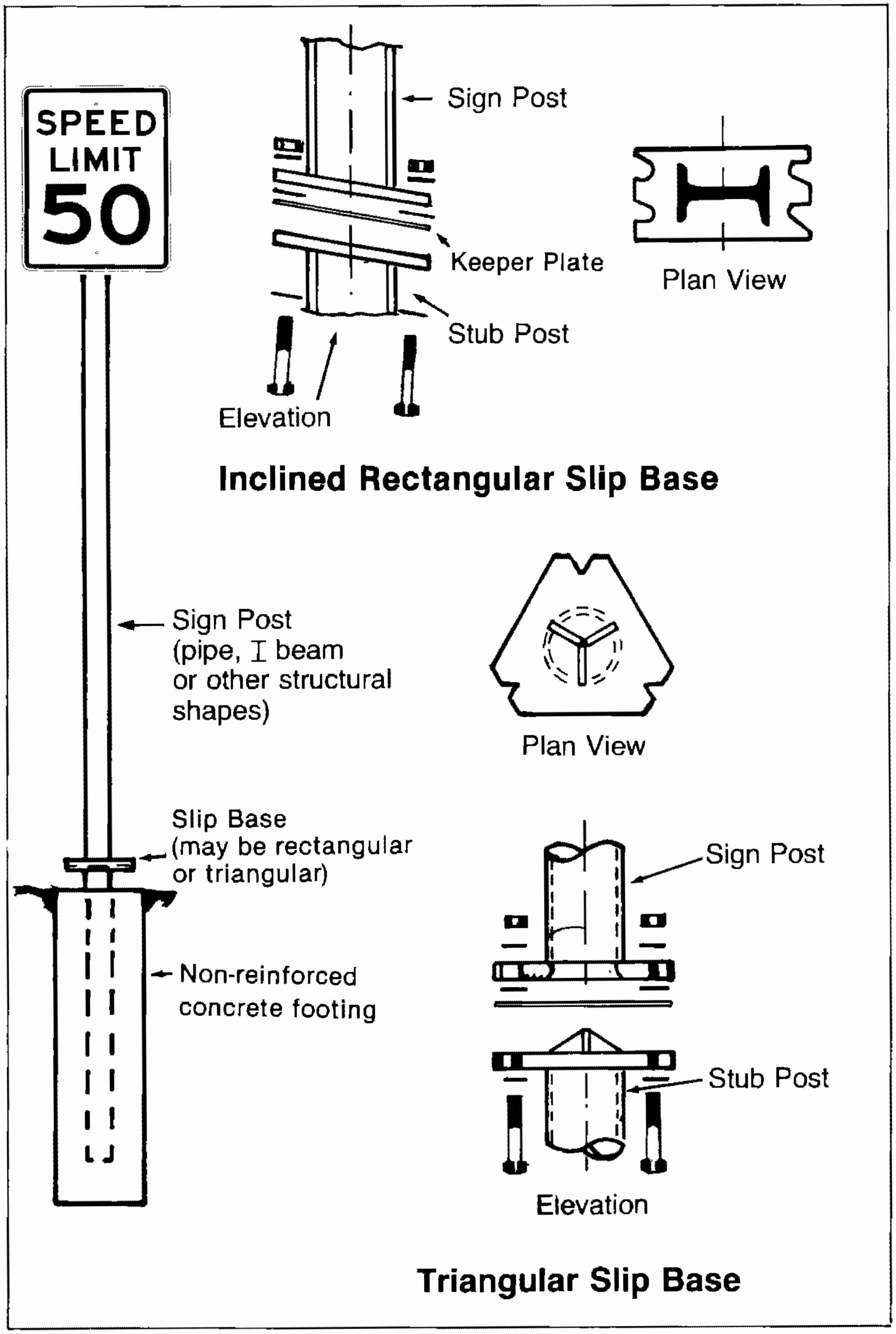


Figure 2-15 Sign Support Systems

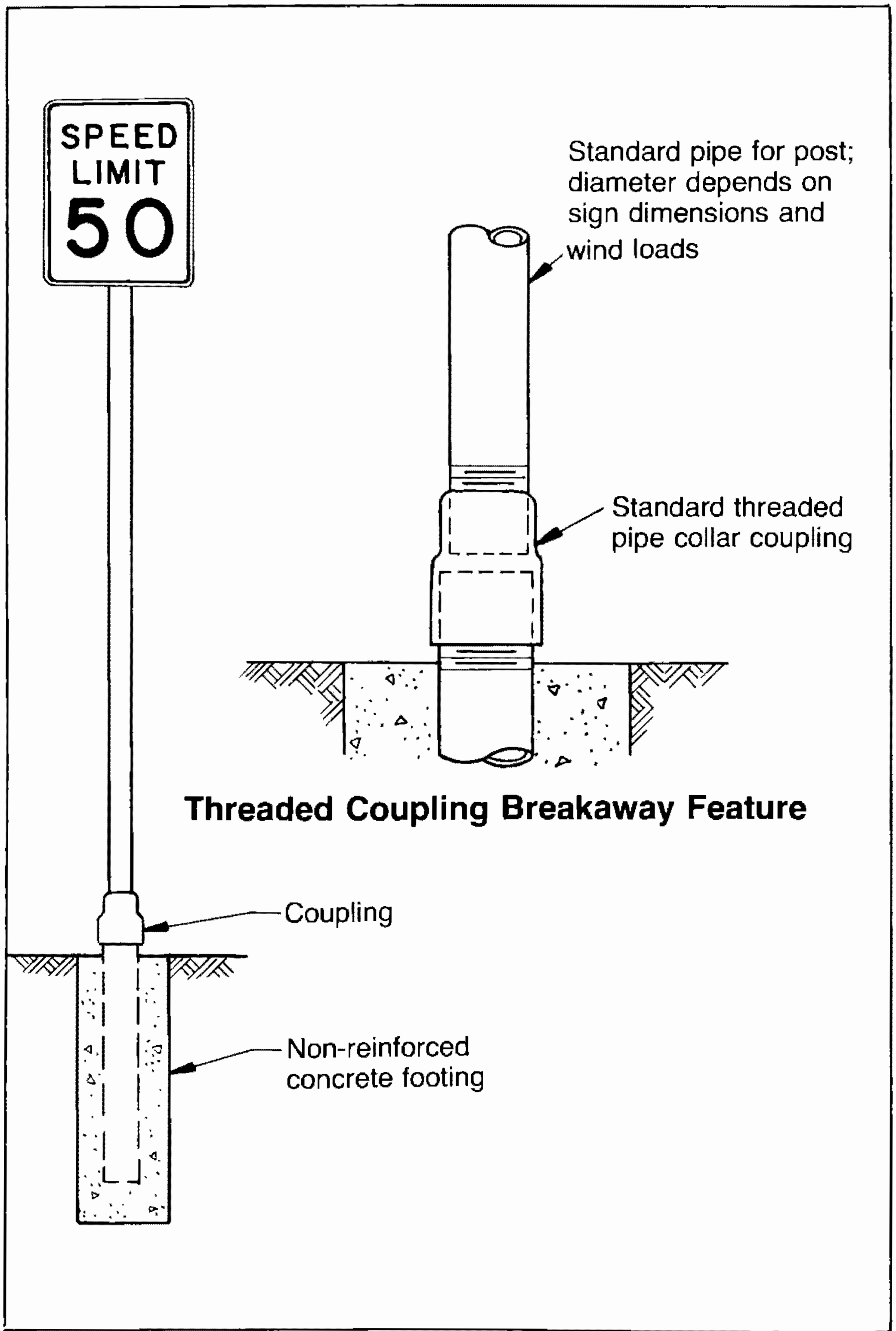


Figure 2-16 Sign Support Systems

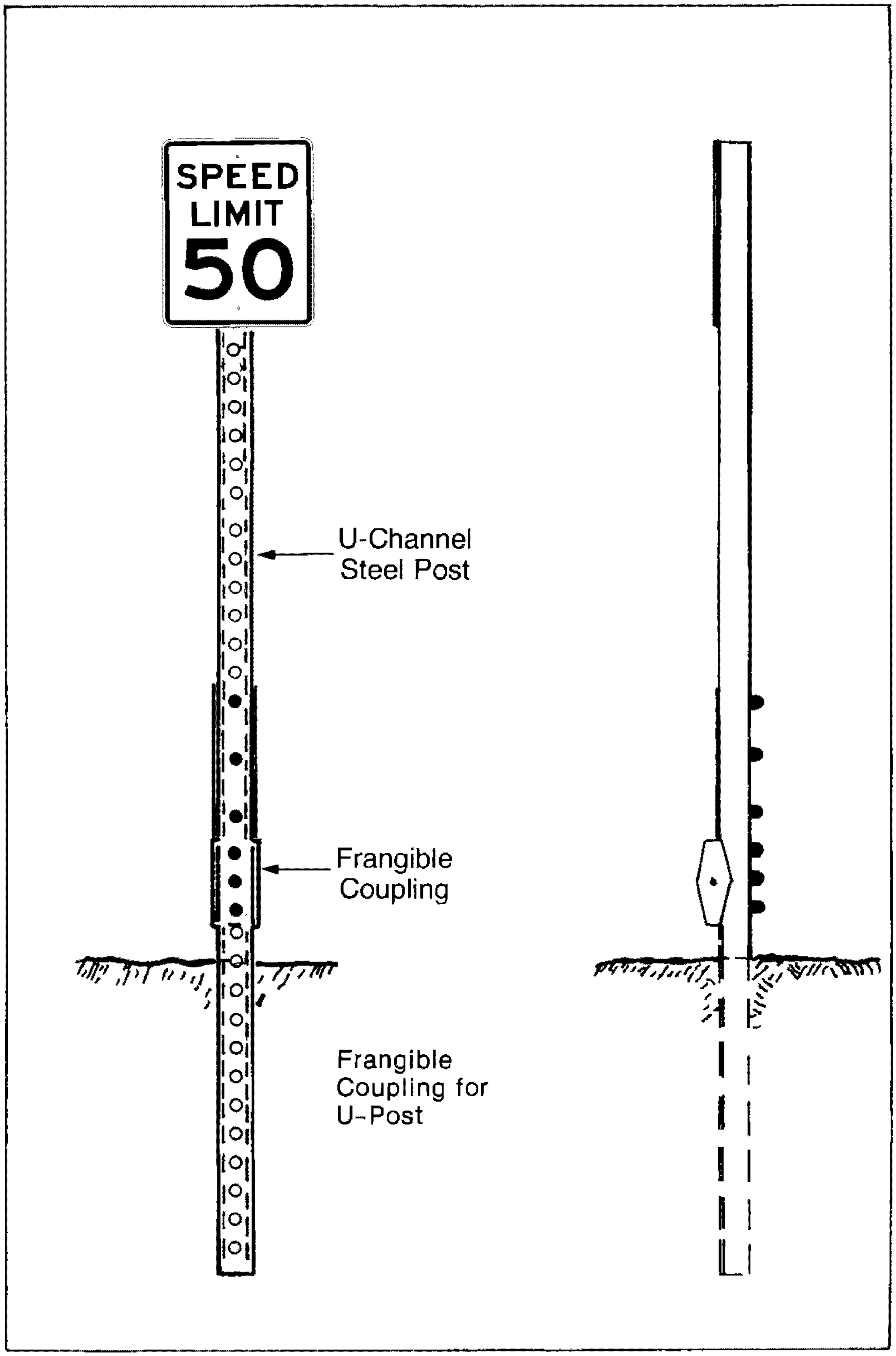


Figure 2-17 Sign Support Systems

A sign support system must be durable and structurally adequate for given wind and ice loads. Desirable characteristics of a sign support system include relatively low material, installation, and maintenance costs; easy to install; and readily available materials. Moreover, it should not present a hazard to the motorist.

An objective evaluation of specific sign support systems requires a thorough knowledge of the characteristics of the system. These characteristics include factors such as initial cost, maintenance cost, crash-worthiness, and manpower and equipment needed to install and maintain the system.

Experience compiled from a number of agencies indicates that the following factors should be considered in selecting the most appropriate sign support system:

- Treated wood posts may have a shorter life than steel or aluminum posts. Untreated wood post installations tend to rot at the base.
- Metal U-post and square tubes have precut holes that allow easy bolting of the sign face and/or sign brackets. Wood posts usually have to be field drilled.
- The square tube post has four flat sides. Signs can be bolted to all four sides whereas the U-post has only two sides to which signs can be bolted. Rectangular or square timber posts share this advantage.
- Many of the treated (galvanized, plastic coated, etc.) metal posts do not require painting. Treated timber posts are not normally painted.
- The lighter weight U-posts can be bent over by vandals.
- In general, the U-posts are less expensive than the other metal post sections.
- Larger ground mounted signs often require heavier rolled (I beam, wide flange beam, etc.) sections. These sections should only be used with a breakaway mechanism when they may be hit by an errant vehicle.
- Multiple supports should be used where design wind loads indicate that a single support would be inadequate.

To save installation costs and minimize sidewalk obstructions, signs should be placed on supports existing for other purposes, such as traffic signal, street light, and utility poles when permitted. Many utility companies service their facilities from equipment such as "cherry pickers." Thus, signs attached to wooden utility poles may not present a hazard to utility crews.

Sometimes small signs must be mounted overhead using a span wire as the support system. Span wire sign installations must be anchored at both the top and the bottom to avoid excessive swinging in the wind.

The trend toward subcompact and mini-sized vehicles continues in the United States. Sign support criteria and design are currently being re-evaluated. Before beginning any conversion project or new construction, agencies should check to determine the latest criteria and acceptable design. For a comprehensive methodology for selecting a cost-effective small-highway sign support system, refer to Ref 2-20.

A large number of small sign support systems have been installed without appropriate breakaway mechanisms. Many of the systems that used to be considered adequate will not meet current criteria. New installations should meet current AASHTO criteria (Ref. 2-21). Where possible, existing installations should be upgraded to current criteria. A discussion of some of the more commonly used small sign support systems follows.

Base Bending Metal Posts

Base bending metal sign posts have been used for many years to provide effective, economical supports for roadside signs. Their continued use is anticipated. However, analysis of tests clearly shows that more attention must now be given to the properties of these posts and to limiting the sizes which should be permitted.

A base bending metal post has no built-in breakaway or weakened design. Systems in this category include full length steel U-posts, aluminum X-posts, and standard steel and aluminum pipe posts. For successful impact performance the post must bend and lay down, and/or fracture, and/or pull out of the ground without causing an excessive change in vehicle velocity. However, tests have shown that posts that fracture offer much less impact resistance than posts of equal size that bend and lay down or that pull out of the ground, especially for high speed impacts.

Base bending posts that satisfy AASHTO performance specifications (Ref. 2-21) will perform satisfactorily when embedded in most roadside soils. Impact resistance of these posts decreases with decreasing soil strength since the posts are more likely to be pulled out of the soil. A base bending post should be embedded no deeper than neceasary for environmental loads, and no deeper than 3 ½ feet without providing concrete foundation collars, soil bearing plates, or anchors.

Base bending posts are multidirectional. That is, they will perform satisfactorily regardless of the direction from which they are impacted.

Breakaway Sign Supports

The basic concept of the breakaway sign support is to provide a structure that will resist wind loads yet fail at a particular point when struck by a vehicle. The breakaway action is accomplished by separation of the support from the base rather than by fracturing or tearing through the support itself.

Breakaway supports are further classified on their ability to properly separate from the base under impact from only one direction or from any direction. Mechanisms that are designed to release satisfactorily under impact from only one direction are called *unidirectional* breakaway supports. Those that are designed to release satisfactorily under impact from any direction are called *multi-directional* breakaway supports.

Unidirectional breakaway supports are subdivided into horizontal slip base designs and inclined slip base designs. When the expected impact comes from only one direction, an inclined slip base should be used. When the sign can be struck from opposite directions, a horizontal slip base design should be used.

For signs with two or more posts separated by 8 feet or more, a hinged breakaway mechanism is used. A horizontal slip base is used in conjunction with a hinge plate located just below the sign panel. On impact, the slip base is activated causing a rotation of the post about a hinge plate on the back of the post. This action is illustrated in Figure 2-18.

By using a slotted friction plate on both sides of the beam, this action can be started by an impact from either the front or the back.

Note: This device is used for signs with two or more posts.

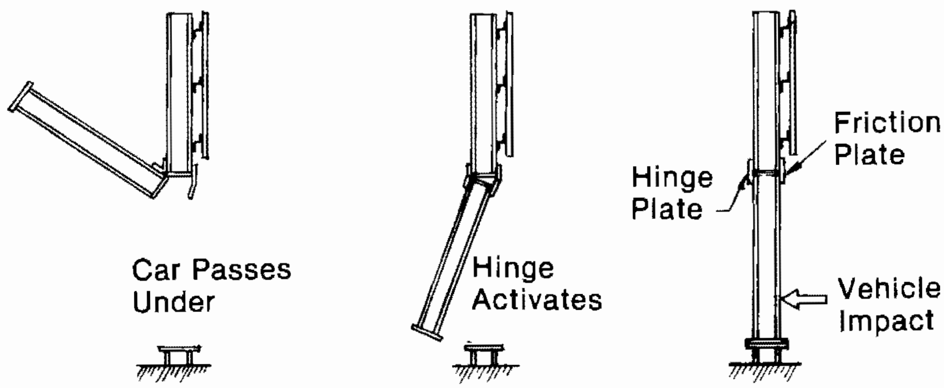


Figure 2-18 Breakaway Action—Horizontal Slip Base

Inclined slip bases are designed so that the two parallel metal slip plates are inclined about 10 degrees upwards from the horizontal in the direction which the impacting vehicle is traveling. See Figure 2-15. The sign panel and support are given an upward thrust and rotational action as the vehicle breaks away the mechanism. The sign panel and support stay together as a unit and the vehicle passes under the assembly as it rotates up and over the vehicle, landing behind the vehicle. This action is illustrated in Figure 2-19.

Two mechanisms are used primarily to provide multidirectional breakaway systems—the triangular slip base, and the load concentration coupler.

Note: For use with Single Post Sign Systems

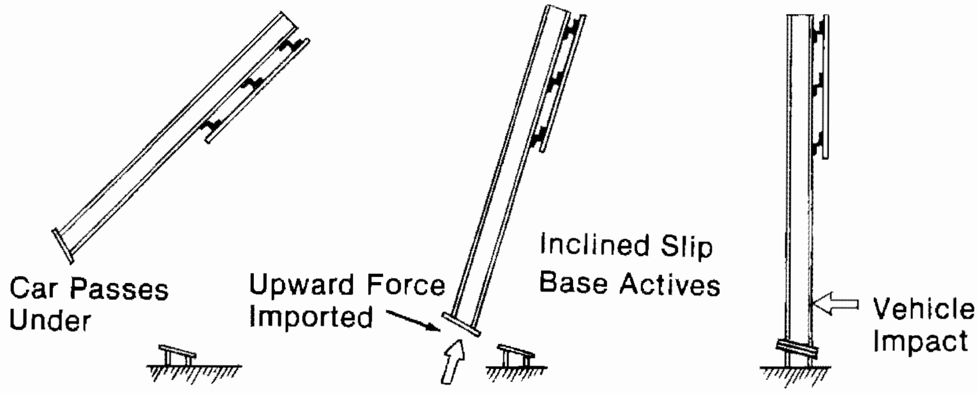


Figure 2-19 Breakaway Action—Inclined Slip Base

The *triangular slip base* is designed to separate on the same principle as the unidirectional slip base—two parallel plates slide apart when the bolts are pushed out sideways under impact. The system employs only three slotted bolt holes (rather than four as on the unidirectional slip base). They are positioned at the flattened corners of the triangular plate. A side force from any direction slides the top plate across the lower stub plate by pushing the bolts out of the slots. The desired lifting action (to provide clearance under the rotating sign and support) is achieved by three triangular plates welded to the stub post. The sign support post rides up this "cone" as it slides sideways; thus, it is pushed upwards as it rotates away ahead of the vehicle. The device is illustrated in Figure 2-15.

To perform properly, the bolts in the three slip base mechanisms must be installed and maintained at the appropriate torque. If too much torque is applied to the bolts then, the system will not breakaway if impacted. If too little torque is applied, the mechanism will vibrate loose and the sign and post will "walk off" the foundation.

Load-concentration couplers are metal riser inserts that bolt the support post plate to the stub post plate. The inserts are fabricated in a shape containing built in stress-risers that cause the device to fracture at a particular point. The concentration coupler is illustrated in Figure 2-20. A major advantage of the load-concentration coupler over the other slip base designs is that they do not have to be retorqued.

A less elaborate multidirectional breakaway base operating on the load-concentration coupling principle consists of joining the support to the stub pipe with a threaded pipe coupling. The pipe threads provide a weakened area on which failure occurs on impact. The sign post pulls out of the coupling and either passes over the vehicle or is hooked on the front of the vehicle depending on the impact speed. Such a device is shown in Figure 2-16.

Designed Fracture Posts

Timber sign supports can be used successfully as breakaway supports. Previous practice allowed larger timber sections to be "weakened" by cutting notches and/or drilling holes in the timber sections. While such

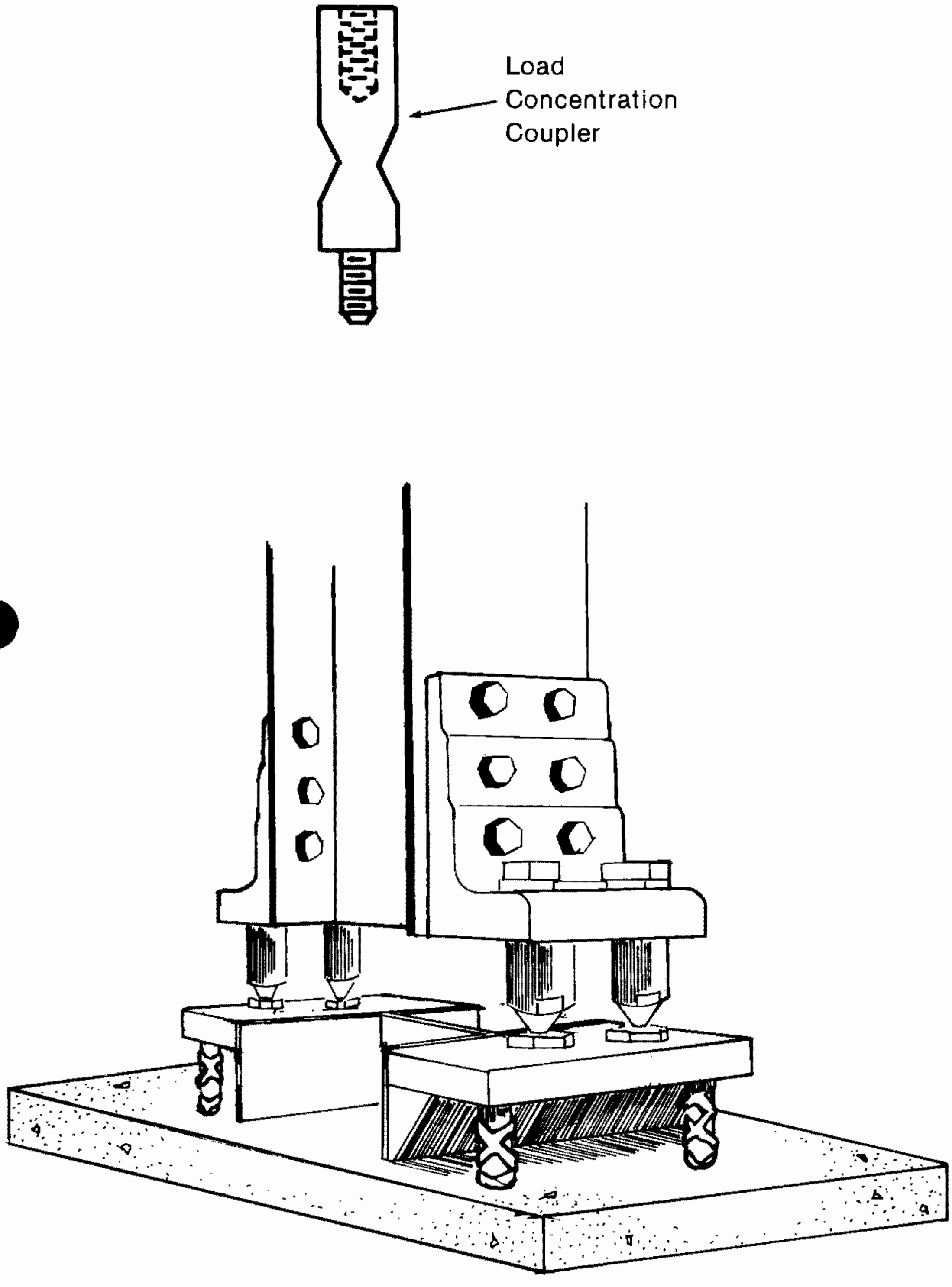


Figure 2-20 Load Concentration Coupler

weakening of the supports may be desirable, the validity of designing a sign support system based on the weakened section should be demonstrated through dynamic testing before such designs are utilized.

Available information suggests that soil mounted timber design (without concrete foundation collars or soil bearing plates) would be acceptable if the posts had uniform cross sections and if, in an 8-foot path, there was or were:

- A single post with an elastic section modulus no greater than 24 in^3 (full dimension 4″ × 6″ posts),
- Two posts, each with an elastic modulus no greater than 18 in^3 (full dimension 3″ × 6″ or 4″ × 5″ *posts), and*
- Three posts, each with an elastic section modulus no greater than 14 in^3 (full dimension 3″ × 5″ or 4″ × 4″ posts).

The height of the sign panel above the ground line is critical for timber supports. Based on dynamic tests of wood post signs, it is suggested that the minimum clearance to the bottom of the sign be 6 feet with a more desirable value of 7 feet.

2C-3 Erection of Signs

The different types of materials and sign supports used require different erection techniques. A summary of current practices is discussed and illustrated below.

The basic hardward used to erect signs consists of bolts, washers, clamps, fittings, and brackets. These fasten the sign to the post and solidify the connection so that wind, vandals, or the impact by outside forces do not destroy or degrade the intended use of the sign. These fasteners are usually made of steel or aluminum, plated or galvanized for protection from the elements. Braces of aluminum or steel are used when multiple sign installations, large signs, or wind conditions necessitate stronger attachment to the post than a single or double bolt. For circular aluminum or steel post or pipe, the sign may be clamped or banded. Fasteners and braces should be designed to insure that signs will remain attached to the post throughout the impact sequence should they be impacted by an errant vehicle. A typical application is shown in Figure 2-21.

To erect large guide signs and freeways signs, heavy equipment such as cranes must be used. Multiple post installation for roadside freeway or expressway guide signs must be sunk well into the ground. For large freeway guide signs reinforced concrete footings are commonly used.

The smaller type sign posts are usually driven into the ground with a hammer or a pneumatic hammer. If a rectangular sleeve or anchor post is placed in the ground or sidewalk, then the sign post can simply be slipped into the sleeve and bolted down.

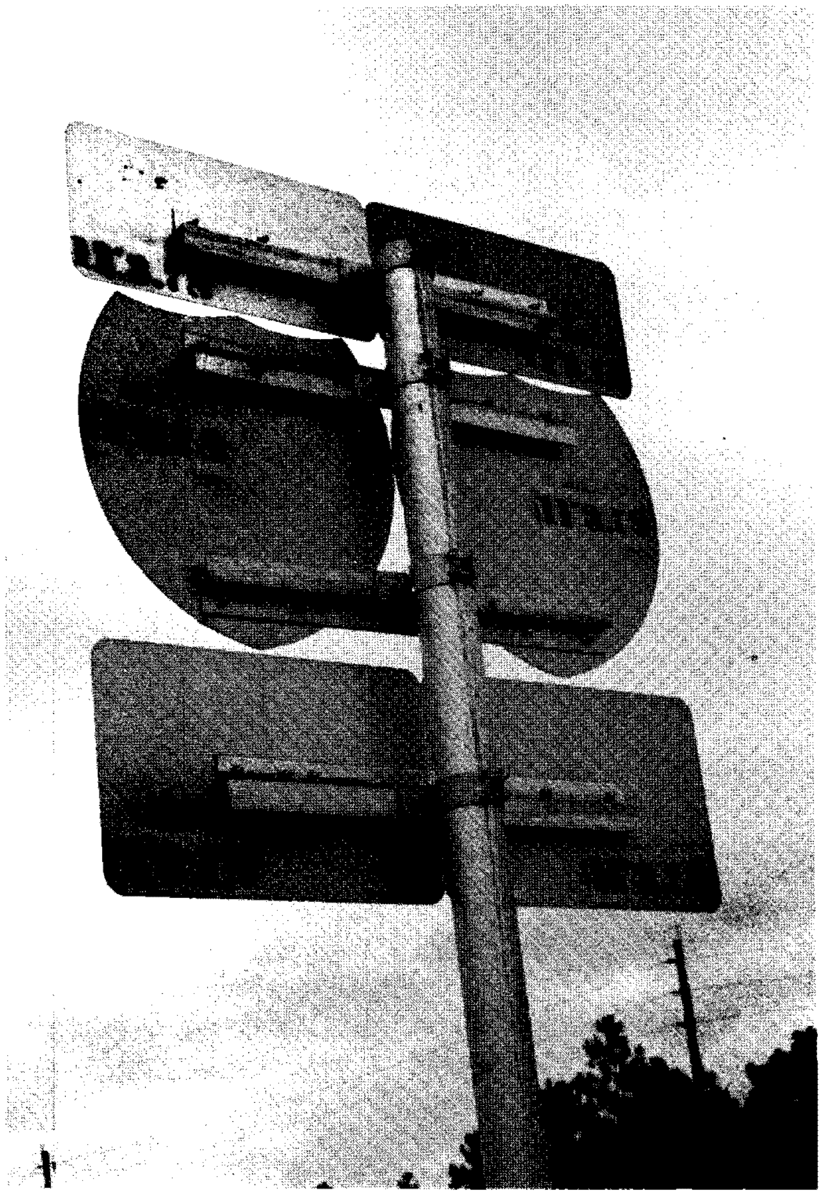


Figure 2-21 Typical Sign Hardware

2D. OPERATIONS AND MAINTENANCE

Day-by-day traffic operations involve an awareness of the effectiveness of the traffic control devices placed in the field. Studies must be performed and inventories maintained to determine (1) where the devices are and their condition, (2) how effectively the devices are performing, and (3) the maintenance needs of the devices.

2D-1 Traffic Control Device Inventories

Adequate recordkeeping is a necessity for sign operation and maintenance just as it is for other traffic engineering functions. Many agencies lack up-to-date sign and marking inventories. The National Highway Safety Act of 1966 established a standard for engineers to develop such inventories. This section summarizes the general procedure for conducting proper sign inventories.

Prior to actually entering the field to collect data, an agency must determine what is to be collected, how it will be collected, and what output reports and data will be needed. The development of forms to collect the data is a function of whether the output will be in a manual or computerized format.

Manual inventories may be compiled in several ways; directly on a map, onto a standard form, or in a card format. Essentially, the manual operation consists of placing the sign location and sign codes for each sign installation on a control base map. The map generally consists of an aerial photo base map usually at a scale of 1 inch = 40 feet, 50 feet, or 100 feet. Engineering plans, section maps, and roadway plans are sometimes used to depict sign locations and characteristics.

Blue prints of the aerial photographs or engineering plans are taken into the field and sign data are simply recorded on these work sheets while driving the designated routes. After data collection the sign location and the sign type and code may also be placed on the maps in the office. Additional data collected are sometimes placed in a card file. The file would contain one card per sign, with the following information:

- Location, street, and distance from cross street, sign facing (direction)
- Sign type, MUTCD or State sign code, condition, message,
- Sign size
- Post type, condition, whether painted or not

The back of the card can be used for subsequent installation or replacement data as well. A typical file card and aerial photo base map is shown in Figures 2-22 and 2-23, respectively.

Output records can be maintained manually by tabulating signs and posts in terms of type, size, material, and deficiency (if any).

DATE	INITIALS	WORK PERFORMED	W.O. #	REMARKS
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		
		☐ Sign/Replace ☐ Post/Replace ☐ Post/Straighten		

COMMENTS ____________

____

____

____

____

Installation __________ Date / / Good Fair Replace Clean

Field Survey __________ Date / / Good Fair Replace Clean

LOCATION

On the __________ side of ____________________, ______ feet __________ of the intersection of ____________________ and ____________________ facing ____________________

SUPPLEMENTARY LOCATION

__________ feet __________ of the intersection of __________ and ____________________

STREET	TYPE SIGN	SIGN CODE	SIGN SIZE	TYPE POST	POST COND.	POST PAINTED

Figure 2-22 Sign File Card

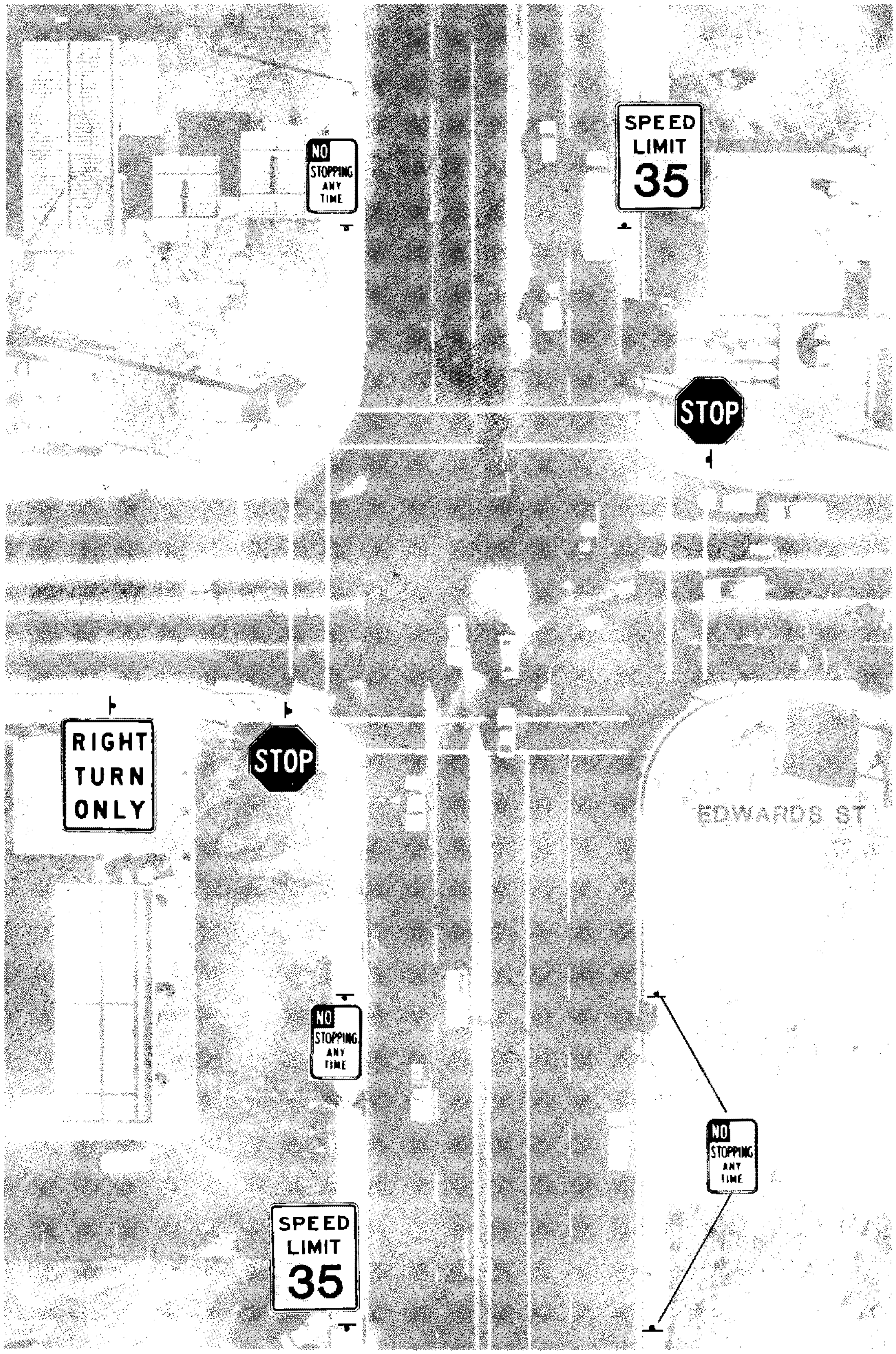
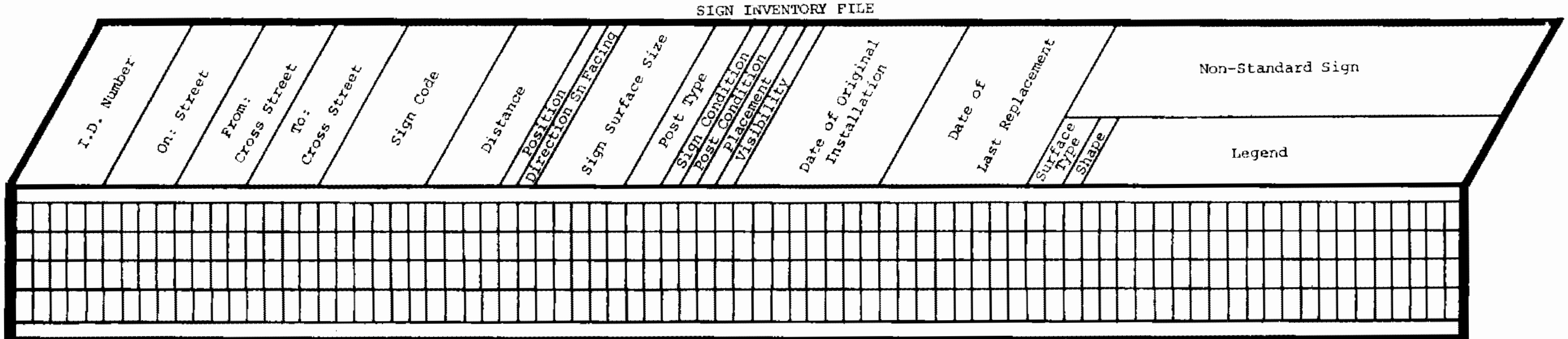


Figure 2-23 Sign Photo Base Map

SIGN INVENTORY FILE



28. Position

N: North Side Curb
S: South Side Curb
E: East Side Curb
W: West Side Curb
M: Median
O: Overhead

29. Direction Sign Facing

N. S. E. or W.
B. Both

30-34. Surface Size

Width x Height

18-23. Sign Code

Use Standard Codes or
N: Non-Standard Sign

35-36. Post Type

WD: Wood
MR: Round Metal (pipe)
MU: Metal U Channel
SS: Signal Standard Steel
SM: Signal Standard Marbelite
MA: Mast Arm
ST: Structure
SL: Street Light
OO: Others

37. Sign Condition

E: Excellent
G: Good
D: Damaged
I: Illegible
F: Faded

38. Post Condition

E: Excellent
G: Good
R: Rusty
D: Damaged

39. Placement

G: Good
P: Poor
I: Inappropriate Location
N: Non-Standard Application
U: Unnecessary

40. Visibility

E: Excellent
G: Good
O: Obscured
P: Poor

57-58 Surface Type

RS: Reflective Plastic Sheeting
RB: Reflective Buttons
RT: Reflective Edge Tape or Symbol Applique
NR: Non-Reflective
IL: Illuminated

59 Shape

R: Rectangular/Square
D: Diamond
C: Circular
T: Triangle (point up)
Y: Triangle (point down)
A: Arrow
S: Shield
X: Cross
O: Others

Figure 2-24 Sample Sign Inventory File

In this manner, summary tables and files together with a visual portrayal of sign location on a map provide a concise manual inventory. For a medium size city or county, one person on a full-time basis can handle the collection of data, summarization, and output summaries after the initial inventory is conducted.

A computerized inventory requires the establishment of a field form that is computer-compatible. Usually 80 columns are available. Each column provides coded information that allows documentation of much of the same data that is included in the manual inventory. Output tabulations can be manipulated faster, but the data must be initially programmed into the computer.

A sample form that shows sign information and codes for each data element is presented in Figure 2-24. There is no limit to the number of codes that can be provided under each category. It is limited only by the practicality of data collection in the field. Generally, the form shown in Figure 2–24 is taken into the field to record the data. Upon collection, the data are ready to be keypunched or input into the computer directly. The software to output the data elements has been developed by many State and city agencies and can be modified by a competent programmer. Printouts of computerized inventories can list the location, type of sign, and numerous other characteristics, as desired.

A complete inventory should be conducted every 5 years (average life of a typical sign). Supervisory personnel should conduct periodic inspections (both day and night), to identify any sign deficiencies. In addition, employees of the highway department, traffic, police, and other governmental workers whose duties require that they travel on streets and highways should be encouraged to report any damaged or obscured sign which they observe.

Signs can be identified by placing a small tag, decal, or printed stencil on the back of the sign. Then the roadway the sign is on, the date the sign was erected, agency logo, and post mile or distance reference can be entered on the tag, decal, or stencil.

2D–2 Determining Sign Effectiveness

Among the methods that can be used to determine the effectiveness of traffic control devices include:

- Before and after studies,
- Analysis of accident records and enforcement records,
- Measurements of the device's performance based on its condition,
- Analysis of complaints or comments from citizens.

Before-and-After Studies

Before-and-after analyses are designed to evaluate the effectiveness of highway or traffic improvements in accordance with selected criteria. The criteria for evaluation are generally cost-effectiveness, efficiency, and safety of the traffic flow through the improved roadway section or intersection. Economic assessments are often expressed as the dollar value of the benefits to the road users, the adjacent property owners, and the general public as well as the actual costs for making and operating the necessary improvements. These economic evaluations are generally computed on an annual basis.

Measures of efficiency are usually described by changes in type, frequency, and duration of traffic delays, and increased compliance of drivers or pedestrians to traffic regulations and control devices. Safety evaluations are provided by changes in type and frequency of traffic accidents or conflicts. However, other measures of traffic flow and/or safety conditions can be selected as decisionmaking variables in a before-and-after study.

A before-and-after study should be planned as an integral part of the evaluation process for any significant traffic improvement. Common sources of mistakes made in comparing before-and-after data are:

- Poor choice of time periods for before-and-after data,
- Inadequate or noncomparable data,
- Failure to allow for a stabilizing period for the public to adjust to the change,
- Failure to take into account other changes that may affect the situation,
- Lack of control data to account for traffic trends,
- Failure to rate according to exposure,
- Evaluating a change as significant when in reality the change is within the realm of chance variation.

Analysis of Accident Records

The analysis of accident records and good reporting of collisions are a prime requirement in determining operational effectiveness. Unless the collisions are reported and documented, the engineer simply does not have an adequate data base.

Establishing a high accident location list and developing collision diagrams or strip maps of collisions are all part of a comprehensive accident identification and surveillance program. This program should be established to define where problems are occurring and if the present devices are doing their job. Ref. 2-11, 2-12, and 2-13 provide guidelines directed to developing and optimizing present accident record systems.

In analyzing accident records for two comparable periods of accident data, it is best to take a full year before and after the improvement to avoid any differences that might exist because of seasonal fluctuations in traffic patterns. For instance, if a 6-month period is compared immediately preceding and following an improvement that was made in March, the before situation reflects conditions of winter, and the after period reflects summer and autumn traffic conditions. If winter accidents were naturally more frequent than summer accidents in the locality concerned, then the "after" phase may include a reduction in accidents not necessarily attributable to the traffic engineering change.

If accident statistics were available for only 6 to 8 months prior to the change, then it would be better to select an after period for the same months in the following year. Comparing periods of several years before and after is generally acceptable. However, if a longer time period is used, it is especially important to take into account changing conditions (e.g. trend to smaller cars, 55 mph speed limit, etc.)

In comparing traffic movement characteristics, such as speed, volume, and delay, the selection of time periods should be such that they do not influence the results. For example, if before the installation of a speed zone, a speed study was made in the early afternoons of several weekdays, then the after study should be made during similar weekday afternoons.

Observations should be spread over a period of days wherever possible. There is less chance of selecting an abnormal period of time if the data for several days are averaged. These should be before and after the improvement is installed.

Tabular comparisons of numbers of accidents should be supplemented by collision diagrams to emphasize the relative frequencies of different types of accidents before and after a specific sign installation. For instance, after the installation of Multiway Stop Signs, collision diagrams might reveal a decrease in right-angle collisions, but an increase in rear-end collisions. Accidents can be separated by a severity classification in making comparisons. Reporting of property damage-only (PDO) accidents is often erratic and not as regular as the reporting of injury and fatal accidents. Misleading results may be obtained if totals of all types of accidents are compared regardless of severity, particularly where accident frequency is low.

Performance Measurements

It is desirable to periodically measure the reflectivity of signs. If the reflective properties of a sign when it was new are known, this can be compared with the reflectivity at later times. Reflective properties can be measured by a reflectometer, or by the subjective judgment exercised during night inspections.

The reflectometer is a sensitive hand-held "light meter" that emits a beam of light to the sign surface that is reflected back to a sensor unit. The reading is an indication of the existing reflective properties of the sign face. Reflectometers are available, but they are relatively expensive. Research has been underway for some time to develop an inexpensive, simple device that can be used in daylight to measure the reflectivity of a sign at night.

One way to evaluate sign effectiveness (reflectivity), is to observe the signs at night, under both bright and dim headlight illumination. At best, this is an inexact technique since it is dependent upon the eyesight of the viewer, the distance and angle from the sign, the judgment of the viewer as to what level of reflectivity is acceptable, and the condition of the headlights of the test vehicle.

A more practical technique would be for a two-person crew (driver-observer and recorder) to drive the roads at the posted speed and to evaluate individual signs based on the amount of time that they were visible (legible) to the driver. Signs that are visible for two seconds, or less, should be replaced as soon as possible. Signs that are visible for three seconds are considered borderline and should be scheduled for replacement. Signs that are visible for four or more seconds are usually considered acceptable.

Analysis of Complaints or Comments

Highway users will often inform highway agency personnel that certain traffic control devices are either damaged, out of order, knocked down, or that they are needed. While some comments from the public are very negative and charged with emotion and others are very calm statements of fact, they are all a valuable source of information as to how the "system" is operating.

Many agencies have found that a system for receiving, recording, and responding to complaints, is highly desirable. Such a system helps insure that prompt corrective action is taken when needed (e.g., a stop sign is knocked down) and allows for prioritizing other activities.

Also, by recording complaints, a permanent record is established, one that can be reviewed from time to time. These records might form a basis for changing work emphasis areas, reallocating resources, or might even indicate a need for training. A typical complaint form is shown in Figure 2-25.

2D-3 Maintenance Procedures

The physical appearance of highway signs (good or bad) is apparent to all highway users and undoubtedly serves to credit or discredit the department or agency responsible for the signing. Signs that are poorly

COMPLAINT FORM

Work Order

Complaint : Date ______________________ Time __________

Complainant: ______________________________

Address: ______________________________

Telephone: ______________________________

Location: ______________________________

____

Description: ______________________________

____

____

Call Taken by: ______________________________

Corrective Action: Priority:

Assigned to ______________________________

Date ______________________ Time __________

Action Taken ______________________________

____

____

____

Completion Date ______________________ Time __________

Complainant Contacted: ◯ Yes

◯ Requested not to be contacted

Figure 2-25 Complaint Form

maintained lose their credibility as official traffic control devices. Messages must be clearly discernible to warn, regulate, and guide motorists. To assure adequate maintenance, a suitable schedule for inspection, cleaning, refurbishing, and replacement of signs should be established.

Periodic daytime and nighttime inspections should be conducted by supervisory personnel to detect sign deficiencies and to insure proper sign maintenance. Inspection procedures normally focus on the condition of the sign face. However, it is also necessary to assess sign placement, whether the sign is standard, and if the sign is truly needed. Other major inspection items are the condition of the sign supports (including slip base torque), sign location, legibility, and general condition. In addition to this routine inspection, employees of the agency, police, and other governmental workers whose duties require travel on streets and highways should be encouraged to report any damaged or obscured signs.

Signs should also be cleaned at periodic intervals to assure adequate day and night visibility. Signs in construction areas may require cleaning more frequently due to blowing dust and dirt caused by construction activities.

Sign washing usually requires a truck with a pump, water and detergent tanks, brushes, and a two-person crew. Automatic cab-operated controls have been developed to wash small signs and delineators. The automatic equipment can wash small signs at a rate of 400 to 450 signs per day and can be operated by one man.

In some cases, signs can be refurbished or rejuvenated in the field to prolong their useful life. New sign panels can be applied in the field. During this refurbishing work, any defects such as faulty hardware, loose or tilted sign supports, or unstable posts should be corrected. If the sign cannot be refurbished in the field, it should be replaced. The old sign can then be taken to the shop for refurbishing, reclamation, or scrapping. Signs that are no longer serviceable or repairable should be replaced without delay. When signs that are no longer necessary are removed, the posts and foundation (if any) should also be removed. Post holes should be backfilled.

Vandalism, in some areas, creates a significant problem. Willfull defacement and destruction of road signs include graffiti, gun blasts, splashes or sprays of paint, and outright theft. Some forms of vandalism can have serious consequences. For example, the alteration of a speed limit sign or the theft of a stop sign. Another serious problem is reorienting directional arrows to point along a hazardous path. All such malicious mischief should be corrected as soon as it is discovered. All public employees should be encouraged to report occurrences of this nature.

To combat acts of vandalism and to minimize their effects, the following measures are frequently effective.

- Use of sign material that will continue to perform even though marred.
- Use of temporary materials or easily replaceable sign facings.
- Use of commercially available vandal-resistant hardware.
- Use of anchor rods or cleats at the bottom of the signpost to prevent its rotation or removal.
- Installing signs high enough to be out of "reach."
- Placement of signs away from the edge of the pavement using the maximum lateral offset where possible.

- Use of the road authority's insignia on the back of the sign to identify it as an official device or use of small plaques on the sign post below the sign to make known the penalty imposed by law for acts of vandalism.
- Use of special cleaning materials for the removal of paint and stickers from the sign faces.
- Studies have shown that vandalized signs that remain in place tend to lead to more vandalism. Thus the prompt restoration or replacement of vandalized signs will help curtail further vandalism.

A handbook to help agencies implement an antivandalism program is being prepared and should be distributed in the near future. Information as to the status of this program can be obtained from the Federal Highway Administration, Office of Traffic Operations, Washington, D.C. 20590.

2D-4 Removal of Unnecessary Signs

Although the MUTCD is generally clear on the warrants to install various signs, particularly multiway STOP signs, local citizen or political pressure frequently results in the placement of unnecessary signs. There is a tendency for drivers to ignore unnecessary STOP signs and simply "roll" their vehicle through the intersection. Driver inconvenience, delay, and waste of fuel are sufficient reasons to avoid excessive signing.

Obsolete or inappropriate signs such as the nonstandard DANGEROUS INTERSECTION or CAUTION-CHILDREN AT PLAY should be removed and proper signing installed as required for the specific condition. If a problem is evidenced by studies of accident patterns or speeds, other mitigation measures may be developed to eliminate or to alleviate the problem. Nonstandard or unwarranted signs are never the appropriate solution.

Removal of some signs (STOP, YIELD) may require legal action at the agency level. Other signs such as parking and regulatory signs may also require legal approval prior to change or removal. Each agency should check to determine how much latitude their code allows with regard to the removal of signs.

Current practice indicates that sign removals are infrequent unless a MUTCD standard has changed and there is a need to conform to new uniform standards. Even in these cases, conformance through removal is a slow process.

In the majority of instances, removals are undertaken after a traffic control device inventory of the agency's entire road system. Recommendations for removal (and installation) are usually clearly documented in this process so that removals can be justified and implemented on a priority basis.

2E. OTHER CONSIDERATIONS

This section discusses special use signs, specifically changeable message signs and Civil Defense signs. The emphasis here is placed on supplementing the MUTCD requirements where they are less than definitive.

2E-1 Changeable Message Signs

The standards for changeable message signs (CMS) sometimes referred to as variable message signs (VMS) have not as yet been established. There are only minimal guides in the MUTCD.

Changeable message signs are playing an increasingly important role in highway safety, operations, and the improved use of existing facilities. As the application of CMS's expands in both urban and rural areas, all agencies need a working knowledge of the features, uses, and effectiveness of CMS systems.

CMS systems can perform a critical role on high-speed highways by furnishing drivers with realtime information on a current condition. To be effective, the CMS system must provide timely, accurate, and reliable information.

Changeable message signs are applicable to the following four categories of operational problems:

- *Recurring problems.* Mainly peak-period traffic congestion where demand exceeds capacity for relatively short time periods. Problems associated with special events (e.g., ball games, parades, etc.) also fall into this category.
- *Nonrecurring Problems.* Freeway incident management caused by random, unpredictable, but frequent incidents such as traffic accidents, temporary freeway blockage, chemical spillage, maintenance operations.
- *Environmental Problems.* Such as rain, ice, snow, fog, etc.
- *Special Operational Conditions.* Operational features such as reversible, exclusive, or contraflow lanes and certain design features such as drawbridges, tunnels, toll booths, and weigh stations are included in this category.

Table 2–4 summarizes the techniques and possible traffic operations applications for CMS's. For the most part, the use of these devices are dictated by the cost and personnel considerations of each agency.

A wide variety of CMS's are available to the highway agency. Each type has its own unique characteristics. CMS systems may range from fixed-time on-site control to remote automatic control. Many freeway traffic advisory and incident management CMS systems are computer-based. Some agencies are now considering the feasibility of having more "intelligence" in the field via microcomputers installed at each sign site.

CMS Sign Installation	Type of CMS Operation	Description	Possible Applications
	Remote Automatic Control	Sign messages are displayed and changed automatically by a remote control system when varying adverse environmental roadway or traffic conditions are sensed be detectors. Manual override capability is normally provided.	(A)
	On-site Automatic Control	Sign messages are displayed and changed automatically by an on-site control system when varying adverse environmental roadway or traffic conditions are sensed by detectors.	(B)
	Remote Manual Control	Sign messages, based on varying environmental roadway or traffic conditions, are displayed and changed by sign operators from remote central office location.	(C)
Permanent	On-site Manual Control	Sign messages, based on varying environmental roadway or traffic conditions, are displayed and changed by and operator using a control panel located at the sign site. In the case of a manually operated fold-out sign, the sign is opened to display a message. In both cases, personnel must travel to the sign site after the need for a message has been determined.	(D)
	Fixed-time Automatic Control	Sign messages are displayed and changed automatically at preselected times of the day.	(E)
	Fixed-time Remote Manual Control	Sign messages are displayed and changed at preselected time by operators from a remote location.	(F)
	Fixed-time On-site Manual Control	Sign messages are desplayed and changed at preselected time by operators at the sign site.	(F)
	Variable Message On-site Control for Unpredictable Event	Sign is moved into place when an unpredictable event occurs (e.g., major accident). Sign messages are displayed and changed on-site, based on varying traffic conditions.	(G)
Transportable	Variable Message On-site Control for Predictable Event	Sign is moved into place for a predictable event (e.g., special event, parade, holiday traffic congestion at a tunnel, bridge, etc.). Sign messages are displayed and changed on-site based on varying traffic conditions.	(H)

(A) Traffic management and diversion, (traffic advisory and incident management, freeway to freeway diversion special events, adverse road and weather conditions, speed control); warning of adverse conditions (weather, environmental, road); control at crossings (bridge, tunnel, mountain pass); special roadway control (restricted roadways).

(B) Traffic advisory (warning of slow traffic, speed control); warning of adverse conditions (weather, environmental, road, high truck loads); control at crossings (bridge tunnel mountain pass); control during construction and maintenance; special roadway control (restricted roadways).

(C) Same as for *Remote Automatic Control.* Also, control at weigh stations and toll stations; control during construction and maintenance.

(D) Same as for *Remote Manual Control. Note:* Due to the delays in traveling to the CMS site(s), messages generally are not as timely in comparison with remote control operation.

(E) Special-use lane and roadway control (reversible, exclusive, and contraflow lanes and restricted roadways).

(F) Same as for *Fixed-time Automatic Control.*

(G) Traffic management and diversion (traffic advisory and incident management, freeway-to-freeway diversion, adverse road or weather conditions).

(H) Traffic management and diversion (special events); control at crossings (bridge, tunnel, mountain pass); control during construction and maintenance.

Table 2-4. SIGN CONTROL AND OPERATION TECHNIQUES

Surveillance is an essential part of CMS systems. In the case of traffic advisory and incident management, electronic surveillance is normally supplemented with information received from secondary sources such as police patrols, highway agency vehicles, and helicopter units. Some highway agencies use closed circuit television (CCTV) to rapidly detect, validate incidents and determine the nature and scope of the problem.

To date, the application of CMS's for freeway-to-freeway diversion has been limited, but is currently receiving increased attention. CMS's are frequently used to manage traffic during special events and through construction and maintenance work zones. These are applications where CMS's, either permanently installed or transportable, can yield considerable savings in user costs and can be implemented easily by a highway agency. In addition, favorable results are reported with application of CMS's for managing traffic during adverse road and weather conditions.

Changeable signs used for speed control have yielded inconclusive results. However, changeable message regulatory speed signs used in conjunction with changeable message advisory signs resulted in a reduction in accident and fatality rates. In addition, the flashing beacon and changeable message speed sign used in school areas has resulted in reduced speeds through the control areas. Experience does indicate, however, that drivers are unwilling to reduce their speeds in compliance with the posted speeds unless there is an apparent reason to do so.

Much of the available information on current uses of CMS systems is discussed in Ref. 2–14. This report contains state-of-the-art summaries of the CMS types and characteristics, control systems, surveillance and interconnect techniques. The report focuses on current practices dealing with the use of CMS's for traffic management and diversion. The concepts discussed should be valuable in assessing the requirements for other applications, namely, warning of adverse conditions, control at crossings, control during construction and maintenance, and special-use lane and roadway control. Various applications of previous and current operational systems and planned systems are summarized in Ref. 2–14.

2E–2 Civil Defense Signs

In the event there is a need for emergency highway traffic regulations, such as during a natural disaster or enemy attack, the signs needed to provide guidance must conform with those existing signs and special civil defense signing shown in the MUTCD. The Federal Highway Administration has entered into an agreement with all states, the District of Columbia and Puerto Rico to prepare an emergency highway traffic regulating plan and to have it updated annually. Procedures to prepare these guides are given in "A Guide for Highway Traffic Regulation in An Emergency," (Ref. 2–15).

An adequate traffic operations plan requires a comprehensive effort that includes the following stages:

- Evaluate the existing traffic system in terms of the demand imposed by the movement plan.
- Define general operational needs.
- Analyze major operational problem locations.
- Develop a basic operational plan, including:
  - Traffic guidance procedures
  - Traffic regulation procedures
  - Terminal operations
  - Route operations
- Prepare implementation programs, indicating operational requirements by time period.
- Develop a maintenance and testing program to ensure the effectiveness of devices used in the plan.
- Establish review and updating procedures to keep the operational plan current.

The Civil Defense guide, "Traffic Operations for Movement to Shelter," provides more details pertaining to the establishment of the plan (Ref. 2-16).

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Part III. MARKINGS

Part III. MARKINGS

3A. GENERAL

Today, roadway markings are a common and expected component of the highway system. The question is no longer whether markings are effective but rather when and how to provide the best system of roadway delineation for the least cost.

The primary purpose of a roadway delineation system is to provide the visual information needed by the driver to steer a vehicle safely in a variety of situations. The delineation technique used must define the path of safe travel and must be visible in daylight and darkness and in periods of adverse weather such as rain and fog.

Markings have definite functions in a traffic control system. As defined in the MUTCD, they are applied for the purpose of regulating and guiding the movement of traffic, and promoting safety on the highway. In some cases, they are used to supplement the regulations or warnings of other traffic control devices. In other cases, they are the sole means of effectively conveying certain regulations, warnings, and information in clearly understandable terms, without diverting the driver's attention from the roadway. In addition, the capacity of a highway is often increased by the orderly and proper regulation of traffic flow which results from correct application of pavement markings.

The application of markings is more than a matter of placing lines on the roadway. It is, in effect, the installation of a traffic-regulating system on a highway. As with all other traffic control devices, markings must be readily recognized and understood. Motorists should be confronted with the same type of markings wherever they travel, and these markings should convey exactly the same meaning wherever they are encountered.

3A-1 Purpose and Types of Markings

Basically, roadway markings can be classified as either longitudinal lines or transverse markings. These markings serve to provide "positive" guidance by defining the limits of a driver's field of safe travel (such as lane lines, center lines, edge lines or crosswalks, stop bars, etc.) They are also used for "negative" guidance; that is, for informing the driver where it is not safe or permitted to travel (e.g. no-passing zones, gore areas, islands, painted medians, etc.) Markings, in the form of words and symbols, are also used to communicate information such as directional arrows, speed limitations, approach warnings (STOP AHEAD, PED XING, SIGNAL AHEAD, etc.)

On-the-roadway markings are also used to define parking spaces or stalls by means of lines or "T's" and "L's." Local agencies may also use painted curbs to supplement parking signs and define restricted areas.

In addition to those markings applied to the surface of the roadway, the MUTCD also includes post-mounted delineators and object markers as part of the "Markings" system. Post-mounted delineators are used to outline the edge of the roadway and to guide motorists through critical locations such as curves and turns. These reflective devices should be visible under normal night conditions from a distance of 1,000 feet. These devices not only provide "far" delineation of roadway alignment, but may provide the only form of delineation visible when rain or snow obscure pavement markings.

Object markers consist of various types of arrangements of reflectorized material placed on or next to obstructions within or near the roadway to alert and/or warn drivers that such obstructions exist. Such obstructions include the approach end of islands or medians, bridge piers and abutments, underpass piers, handrails, guardrails, culvert walls, etc.

3A-2 Driver's Needs

The ideal form of roadway markings and the best materials to be used would be those which provide the most guidance and warning to the driver. The ability of drivers to safely and accurately operate their vehicles is based on their perception of the roadway situation, their level of alertness, the information available, and their ability to comprehend and act on the available information.

During clear daylight hours, visibility usually presents little problem. Visual information is indirectly available from features of the roadway and surrounding terrain; hence, markings and delineation devices are less important to the driving task. At night, these indirect indications of alignment become ineffective and motorists must rely on reflectorized roadway markings to define the safe route of travel. Rain and other adverse weather conditions degrade roadway marking visibility.

The effects of limited visibility on driver performance as summarized below have been defined as a result of simulation experiments and field tests (Ref. 3-1).

- As visibility range is reduced, delineation configuration or pattern becomes increasingly important. Solid edge lines, longer dashes, and shorter pattern length tend to counteract some of the effect of reduced visibility.
- The car hood restricts minimum forward view to approximately 20 feet ahead of the driver's position; when one dash disappears below the hoodline before a succeeding dash is visible, steering performance becomes very erratic. Thus, delineation gap length is a key variable.

- Longer dashes can give some indication of road curvature even though only one dash is visible. Retroreflective raised pavement markers (RPM) are limited in providing curvature information unless more than one marker is visible. Thus, RPM's should be spaced more closely on curving sections.
- Preferred speed decreases with reduced visibility, or at constant speed, steering performance degrades.

Field test data also indicate that the visibility of markings have a profound effect on vehicular control. When markings are degraded (by reduced contrast or by a covering of water) drivers typically shift their vehicle's mean lateral lane position away from the line on their left to approximately the center of their traffic lane. Mean speed is not appreciably affected except under rainy conditions. Even under the worst visibility condition, the average speed reduction is only on the order of 2 mph.

Field tests under rainy conditions have shown the superior effectiveness of retroreflective raised pavement markers. With only painted striping for guidance, wet weather drivers tend to drive erratically within their lane (lateral variability). At the same time, they show signs of heightened agitation, indicating a greater effort is being exerted. In roadway sections where RPM's supplement painted markings, driver performance improves and driver's agitation lessens. Even in dry weather, the drivers control their vehicle with less lateral position variability when raised markers are used along with striping. It should not be concluded that the addition of RPM's improves driver performance under all circumstances, although it appears likely.

3A-3 Reflectivity for Night Visibility

According to the MUTCD: "markings which must be visible at night shall be reflectorized unless ambient illumination assures adequate visibility." There are so few roadways within a typical agency's jurisdiction that are well illuminated that the trend among State and local agencies is to reflectorize all roadway markings. Exceptions are painted curbs and parking lines.

The scientific principle involved in reflectorizing pavement markings is based on retroreflection. That is, the light is reflected back to the light source. Under most circumstances, the major source of light available during night driving is provided by vehicle headlights. As shown in Figure 3-1, the light rays from headlight beams shining on a nonreflectorized marking are reflected in all directions; thus, only a very small portion of the light is reflected directly back to the light source (driver's vehicle). With retroreflection, much more light is returned directly to the vehicle light source and is therefore more visible to the driver.

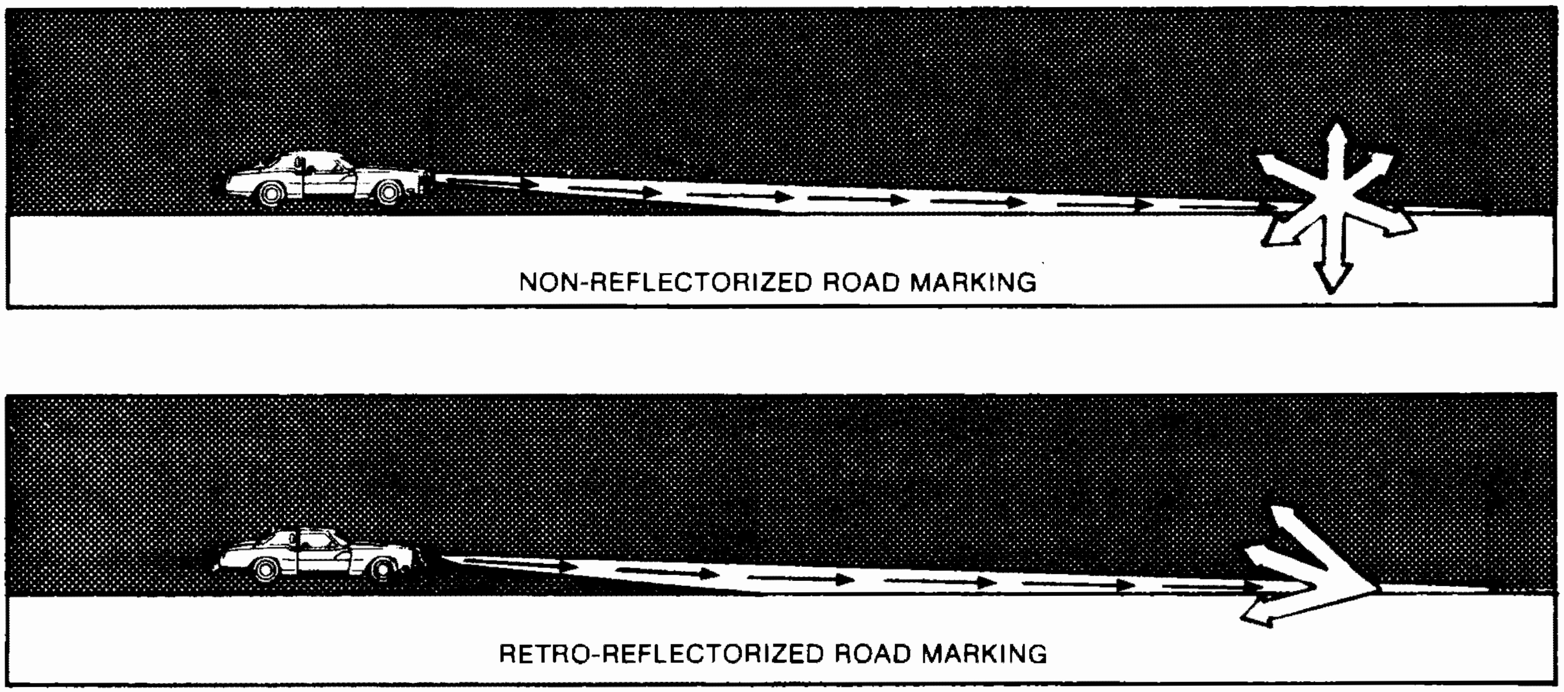


Figure 3-1 Light Reflection Characteristics

There are two common retroreflective techniques used for markings and delineators: spherical (glass beads) and corner cube.

Glass beads were the earliest form of retroreflectors used for night visibility. They can be dropped in wet paint or thermoplastic, premixed, or both. They may also be embedded in plastic sheeting or tapes.

For glass beads to refract and redirect light, two properties are necessary: transparency and roundness. First, the glass bead must be transparent so that light can pass into the sphere. The light beam, as it enters the bead, is bent (refracted) downward by the refractive index of the glass to a point below where the bead is imbedded in the paint. Light striking the back of the paint-coated bead surface is refracted back toward the path of entry much like a lens (Figure 3-2). If the paint were not present, the light would continue through the bead and would be lost.

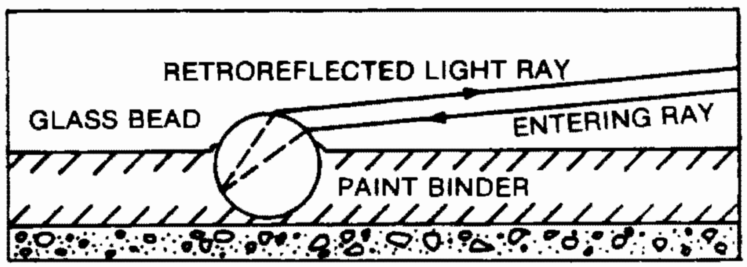


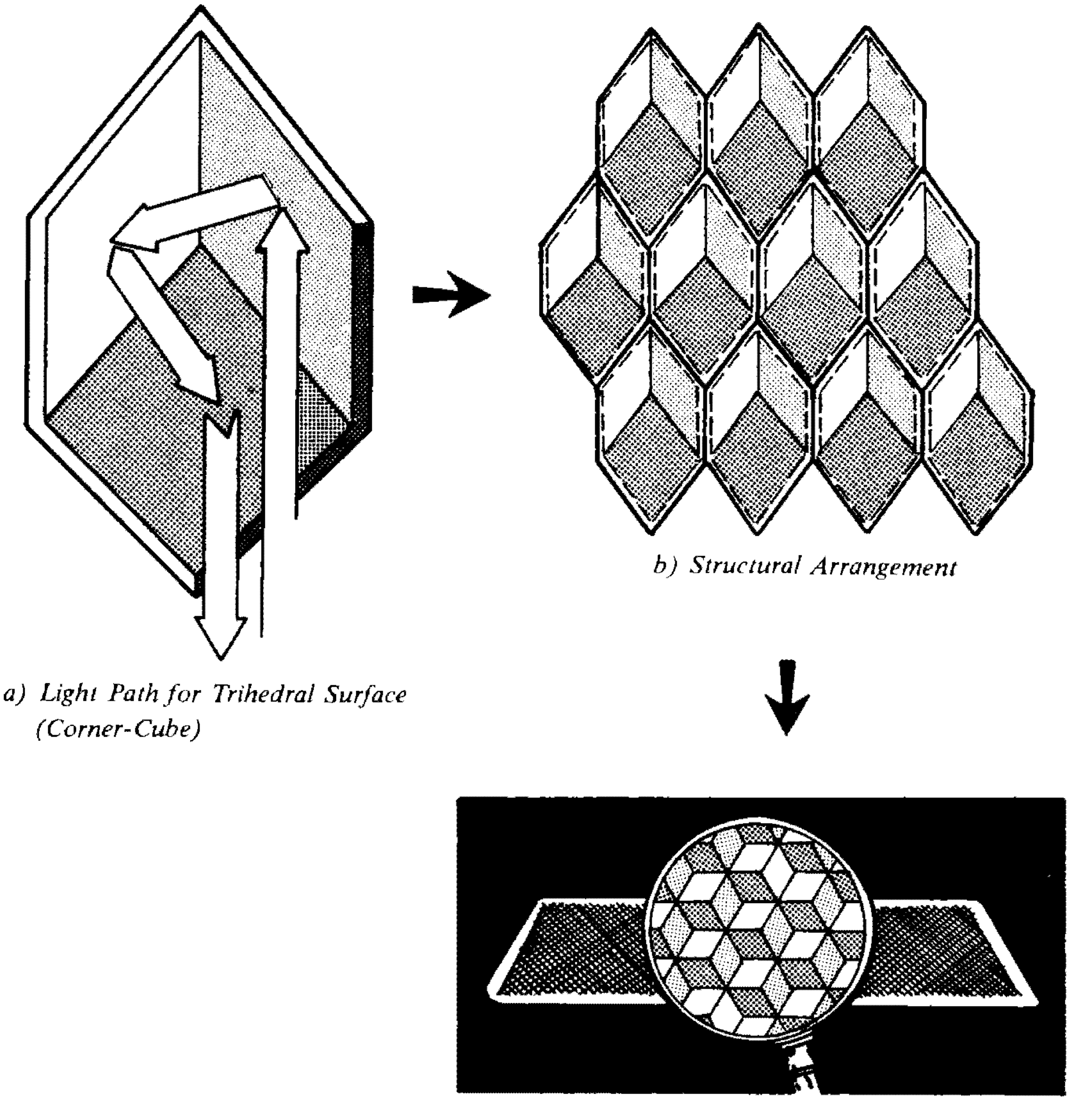
Figure 3-2 Glass Bead Reflection

The amount of light reflected by glass beads is a function of several factors: index of refraction; bead shape, size, and surface characteristics; and the number of beads present and exposed to light rays.

When a headlight beam strikes thousands of these small spherical beads, the visibility of the line is greatly enhanced in terms of brightness. The degree of brightness depends on the Refractive Index (RI). Commonly, beads used in traffic paint have a RI of 1.50. There are some 1.65 RI beads used with thermoplastic and 1.90 beads are used for airport markings.

Despite the increased brightness gained with the higher refractive index, most State and local highway agencies consider 1.50 RI beads the most cost effective. Because such beads are made from cullet, a recycled product, they are less expensive than the higher RI beads manufactured from basic raw materials. They also exhibit more chemical stability and require fewer pounds per gallon as they are less dense. Some agencies use a mixture of 1.50 and 1.65 beads on highways, and a few supplement the 1.50 beads with 1.90.

Corner cube retroreflectors utilize a trihedralangled mirror reflection. In this system, three mirrored surfaces are arranged at a proper angle to receive the rays of headlights on one of the three mirrors. From there the



a) Light Path for Trihedral Surface (Corner-Cube)

b) Structural Arrangement

c) Magnified View of Precision Molded Corner-Cube Reflex Elements

Figure 3-3 Principle and Structure of Corner-Cube Reflectors

ray is reflected to a second mirrored surface, then to the third, and finally outward on a line parallel to the entering direction. These tiny tri-mirrored surfaces are arranged as shown in Figure 3-3 to provide the reflective unit for raised pavement markers, post delineators, and object markers. Approximately 360 reflective corner cubes are contained in the face of a marker measuring 3 5/8 x 1 inch.

The corner-cube delineators are many times brighter than those made from reflective sheeting (glass beads) and white reflectors of either type are brighter than yellow. Various configurations of the optical elements are used by the different manufacturers to obtain wide angle reflection.

3A-4 General Design Requirements

In addition to the requirement that traffic devices be visible at night, the MUTCD defines general uses and applications of markings in terms of standard colors, widths, patterns, shapes, and placement. For example, longitudinal lines must conform to standard highway colors. Standard highway colors include yellow, white, and red. The use of black paint is allowed in combination with the three standard colors where the pavement itself is too light-colored to provide sufficient contrast. The fundamentals of use and of color and patterns for longitudinal lines given below are summarized from the MUTCD:

- Yellow lines delineate the separation of traffic flows in opposing directions or mark the left edge of the pavement of divided highways and one-way roads and ramps.
- White lines delineate the separation of traffic flows in the same direction or mark the right edge of the pavement.
- Red markings delineate roadways that shall not be entered or used by the viewer of those markings.
- Broken lines are permissive in character.
- Solid lines are restrictive in character.
- Width of lines indicates the degree of emphasis.
- Double lines indicate maximum restrictions or prohibitions.

The basic application configuration of pavement stripes are given in the MUTCD (Figures 3-2 through 3-7) and should be consulted for specific application information. Fundamental usage is summarized in Table 3-1.

DESCRIPTION	COLOR	WIDTH	APPLICATION
Single Broken	White	4″	Separation of lanes on which travel is in the same direction, with crossing from one to the other permitted; i.e., lane lines on multilane roadways.
	Yellow	4″	Separation of lanes on which travel is in opposite directions, and where overtaking with care is permitted; i.e., centerline on 2-lane, 2-way roadways.
Single Solid	White	4″	Separation of lanes, or of a lane and shoulder, where lane changing is discouraged; i.e., lane lines at intersection approaches, right edge stripes.
		6″	Lane lines separating a motor vehicle lane from a bike lane.
		8″	Delineation of locations where crossing is strongly discouraged; i.e., separation of special turn lanes from through lanes, gore areas at ramp terminals, paved turnouts.
	Yellow	4″	Delineation of left edge lines on divided highways, one-way roads, and ramps.
Double Yellow	White	4-3-4″*	Separation of lanes on which travel is in the same direction, with crossing from one side to the other prohibited; e.g., channelization in advance of obstructions which may be passed on either side.
	Yellow	4-3-4″*	Separation of lanes on which travel is in opposite directions, where overtaking is prohibited in both directions. Left turn maneuvers across this marking are permitted. Also used in advance of obstructions which may be passed only on the right side.
Solid plus Broken	Yellow	4-3-4″*	Separation of lanes on which travel is in opposite directions, where overtaking is permitted with care for traffic adjacent to the broken line, but prohibited for traffic adjacent to solid line. Used on 2-way roadways with 2 or 3 lanes. Also used to delineate edges of a two-way left turn lane—solid lines on the outside, broken lines on the inside.
Double Broken	Yellow	4-3-4″*	Delineates the edges of reversible lanes.
Single Dotted	Either	4″	Extension of lane lines through intersections. Color same as that of line being extended. Also used to extend right edge line of freeway shoulder lanes through off-ramp diverging areas in problem locations.
	White	8″	Separation of through lane and auxiliary lane or dropped lane.
Transverse	White	12″	Limit lines or STOP bars; also crosswalk edge lines (minimum 6 ft apart) when not in the vicinity of school grounds.
Diagonal	White	12″	Crosshatch markings, placed at an angle of 45°, at varying distances apart, on shoulders or channelization islands to add emphasis to these roadway features.

* 4-3-4″ indicates typical width of stripes and gap between them. This spacing may vary among states.

Table 3-1. Types of Pavement Stripes

3B. APPLICATION

There are a number of factors that should be considered in selecting the most practical and effective delineation treatment, technique, or configuration. This is relatively straightforward for new facilities. Older facilities which require upgrading or maintenance present somewhat different problems.

This section summarizes the implication of various site-specific characteristics and discusses the advantages and disadvantages of the forms of markings used in typical installations. This section closes with a discussion of effective procurement practices.

3B-1 General Planning

After it has been determined that a certain system of pavement markings is required at a particular site, the unique characteristics of the site will have an impact on the type of material or device selected for application. The climate, pavement type and condition, traffic characteristics, and roadway geometry all exert an influence in selecting the most appropriate and cost-effective treatment. Significant factors such as initial cost, service life, required installation equipment, maintenance requirements, etc., are discussed later in relation to specific types of marking techniques.

Effects of Climatic Conditions

The prevailing climate and weather conditions greatly influence the effectiveness of markings and other delineation techniques from the standpoint of visibility and durability. Installation activities are also influenced by weather.

Rain, at any time, reduces the ability of the driver to visualize his surroundings. At night, glare from the headlights from oncoming vehicles, windshield wiper action, and the slippery pavement surface coupled with degraded reflectivity of painted markings make the driving task on rainy nights particularly hazardous and difficult. Reflectorized raised pavement markers and post delineators are much more effective than painted markings under these conditions. During daytime rainy periods, the raised markers do little to improve visibility, but the audible effect of passing over the markers serves to alert the driver of his encroachment into an adjacent lane.

Rain does not adversely effect the durability of pavement markings. Conversely, it has been reported that the tire action on wet markings serves to clean the markings of old tire tracks. Maintenance personnel cite numerous incidents of improved daytime visibility (i.e., contrast), particularly of thermoplastic lane lines after several hours of rain. Post delineators, however, are subject to splashing from wet highways which degrades their reflectivity.

Snow, even more than rain, affects the drivers' visibility since even moderate snowfall will obliterate most all pavement markings. The problem of delineation in high snowfall areas is compounded by potential damage to pavement markings from snowplow activity, studded tires, and the use of chemicals and de-icing salts. Post delineators (with extension posts where drifts are abnormally high) will provide effective edge line and road alignment delineation but are vulnerable to knockdowns by the snowplows.

Fog creates an extremely hazardous situation by seriously reducing driver visibility. There are no really cost-effective marking techniques that will provide adequate roadway delineation in fog. However, experiments with various forms of surface highway lighting have been undertaken. "Near" delineation of the roadway has been improved somewhat by closer spacing of high intensity reflective raised markers combined with nonreflective RPM's to create a rumble effect when passing over the line. Similarly, the gap between stripes has been shortened in problem locations.

Blowing sand, like fog, can seriously reduce visibility. It can also collect on the roadway and obscure pavement markings. It may damage paint, thermoplastic, and RPM's through the abrasive sandpaper effect of tire action on the marking. Because of the hazards inherent in blind driving through fog or blowing sands, some agencies close the highway or provide platoon escorts through the affected areas.

In addition to the degradation of driver visibility caused by the physical presence of rain, snow, fog or blowing sands, weather in terms of extremely hot or cold climates can influence application and installation of pavement markings. For example, some materials such as thermoplastics or paint are specially formulated to withstand extreme temperatures. That is, a thermoplastic product formulated for the Northeast would not necessarily be applicable to the Southwest. The effects of the freeze-thaw cycle on the pavement surfaces and on the marking materials can induce early failure by weakening the bond with the pavement surface.

Summer heat can also be deleterious to pavement markings. In areas where surface temperatures frequently exceed 120°F, thermoplastic on asphalt pavement tends to "crawl" and distort. It will also become badly marked with tire tracks thus reducing daytime visibility (i.e., contrast). However, this will not significantly affect nighttime reflectivity. In addition, the ultraviolet rays of strong sunlight can affect the color and life of several forms of marking materials.

In summary, the climate and weather conditions must be considered to determine not only the most appropriate delineation treatment (spacing, etc.) but to assure that the delineation techniques and materials are compatible to the site specific conditions. The reduced visibility associated with the effects of weather such as rain, snow, fog, etc. can be significant.

The inability of a driver to see what is ahead makes driving extremely hazardous and accounts for a high percentage of accidents. Consequently, the safety aspects of providing the best possible guidance to the driver in such situations transcends the traditional cost-effectiveness concerns.

Effects of Pavement Surface

Variations in type and condition of the pavement surface determines, to a large extent, the durability and visibility of the materials used in pavement markings. It is therefore appropriate to review the basic characteristics of the two most widely used pavement surfaces, asphaltic concrete (AC) and portland cement concrete (PCC).

The term "asphaltic concrete" denotes a dense-graded road surface made of hot mineral aggregates plant-mixed with hot asphalt. Bituminous asphalt is a common form of AC pavement surfaces.

Another form of asphaltic concrete is referred to as "open-graded." In this form, only a coarse aggregate is used. When applied as a surface course, it has a high porosity and permeability as well as a rough surface texture. The porous characteristic allows numerous escape channels for water beneath a moving tire thus minimizing the potential for hydroplanning. The rough surface texture provides greater friction between the surface and the tires. In addition, an open graded surface may reduce the splash and spray effects.

Because of its porous nature, greater quantities of paint or hot-applied thermoplastic materials are required with the open-graded pavement surface. This is most evident during the initial stripe application. One other problem that occurs is that initial markings on an open-graded surface tend to loose their visibility in a short period of time. Subsequent applications are usually longer lasting. With raised markers, there may be a problem in obtaining a secure bond with the rough surface. This can result in a higher percentage of dislodged markers.

Portland cement concrete consists of a relatively rich mixture of Portland cement, sand, coarse aggregate, and water laid as a single course. Approximately 5 to 7 days curing time is required before the pavement surface is ready for use. PCC surfaces may be textured or grooved. Grooves can be installed during construction by tining or they can be sawed in existing PCC surfaces.

This texturing or grooving reduces the potential for hydroplanning and increases the potential friction between the tire and surface. However, greater quantities of paint or hot-applied thermoplastic materials are required. This drawback is not as pronounced as with the open-graded AC surfaces.

Frequently, PCC surfaces are a very light color. At times even AC surfaces can "bleach out" to a very light shade of gray. Black stripes are sometimes used with other pavement markings to increase contrast. As such, black is not a standard pavement marking color but is to be used only as a means of achieving contrast on light colored pavements.

The life of the surface treatment is significant in determining the appropriate delineation medium. For example, highly durable markings such as thermoplastics, epoxy, or raised markers could outlive an aging asphalt surface. Imminent resurfacing or reconditioning of AC surfaces would cancel out the major advantage of these long-term delineation materials. Accordingly, conventional paint should be considered for use under these conditions.

Effects of Traffic Characteristics

Traffic conditions can affect the choice of delineation treatments and techniques from two standpoints: traffic volumes and traffic composition. Traffic volumes are important in that average annual daily traffic (AADT) is often the major criterion used to select specific types of delineation techniques. For example, roadways with high volumes of traffic may be better served by the installation of highly durable devices (such as raised markers, hot laid thermoplastic, or epoxy) by eliminating the need for frequent restriping. The exposure of maintenance crews and the disruption to traffic can thus be significantly reduced. Higher initial cost should be balanced against the safety and long-term economic benefits of the more durable techniques.

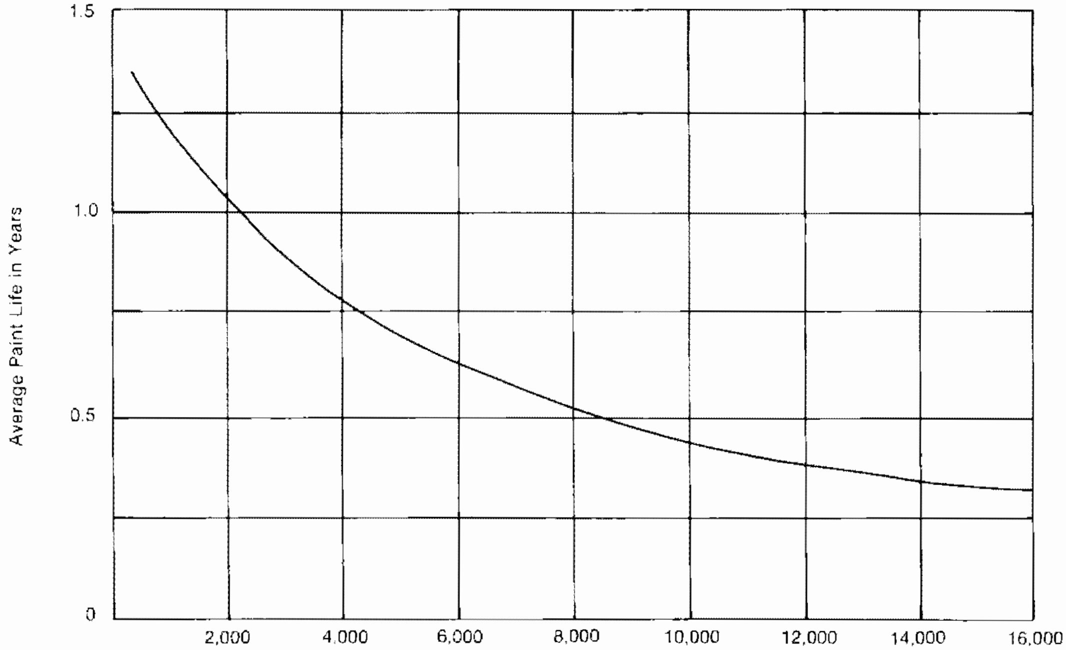
Low AADT may indicate that painted markings alone or in combination with RPM's or post-mounted delineators would provide adequate delineation and may last one or more years without restriping.

Traffic composition can affect the effective life of various delineation materials. Trucks, buses, and other heavy equipment constituting a large portion of traffic can damage or wear out roadway markings much faster than traffic composed primarily of passenger vehicles. Rural farm-to-market, low density roads or industrial access roadways, for example, may therefore require heavier or more durable applications than would be indicated strictly on the basis of AADT. As a general rule, however, AADT is most often correlated with service life as shown in Figure 3-4.

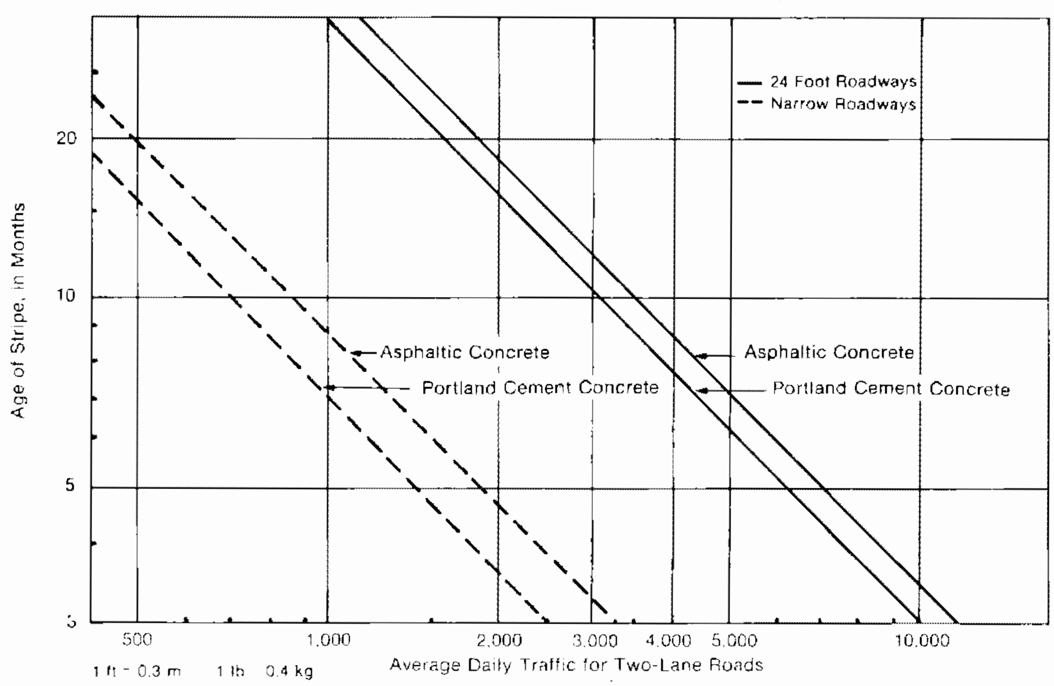
3B-2 Materials

The use of painted stripes on the roadway surface to divide the traffic stream and to provide guidance to the driver has existed since the dirt roadway gave way to paved surfaces. Today, painted markings used alone or in combination with other devices comprise the most commonly used delineation technique.

Paint, however, has a relatively short service life, particularly on freeways or other heavily traveled roadways. Thermoplastics, epoxies, polyesters, and other highly durable materials are replacing conventional paint on those facilities where the higher initial cost can be justified in terms of long range economy and safety.



a) Paint Striping as Affected by Traffic Density for Both Bituminous and Concrete Pavement (Ref. 5)



b) Conditions for Noticeable Traffic Stripe Wear (White Traffic Paint Placed at 15 mils. Wet with 6 lb. of beads/gal) (Ref. 5)

Figure 3-4 Representative Plots of Service Life vs. AADT

As a very thin layer of water can obscure their reflective properties, neither paint nor the durable plastic pavement markings are effective at night during rainy periods. Reflective raised pavement markers provide the best wet-night visibility. Their daytime vsibility is poor and must therefore be combined with nonreflectorized RPM's or painted markings. They are also usually vulnerable to snowplow activity. Snowplowable markers are available but are more expensive than conventional RPM's.

Painted Marking Materials

There are several ways of classifying paint. The first basic description involves the reflectance; that is, whether or not glass beads have been added for night visibility. "Reflectorized paint" contains glass beads of specified size and volume either premixed, dropped on, or in combination. Nonreflectorized paint is seldom used except for markings not requiring night visibility such as parking spaces, curbs, etc.

Paint can also be classified by whether it is cold-applied or hot-applied. The temperature at which paint is applied has a direct relationship to the third area of classification, drying time. Drying time is influenced by the chemical composition, the temperature of the paint and pavement during application, wind velocity, and paint thickness. The categories of paint based on drying time are generally defined as follows (Ref. 3-4):

- *Conventional:* Cold applied paint of normal viscosity requiring over 7 minutes to dry, can require several hours depending on thickness of coat, atmosphere and road condition.
- *Fast Dry:* Hot applied paint which will dry to no-track condition within 2 to 7 minutes.
- *Quick Dry:* Hot applied paint drying to no-track condition within 30 to 120 seconds.
- *Instant Dry:* Hot applied, heavily bodied paints which dry within 30 seconds.

Finally, paint can be classified according to the type or family of base material used in paint composition. Some of the commonly used bases include:

- Oil base (alkyd resin)
- Rubber base (chlorinated rubber)
- Oleoresinous (drying oil (dispersion) varnish, modified alkyd)
- Water base

In general, there are two basic criteria by which paint performance is judged: durability and visibility. Durability involves service life of the painted stripe as a function of the material remaining on the pavement surface over time. Visibility concerns the brightness of the material particularly at night. These properties are described by ASTM-D-7B-66T.

Drying time is also a major performance consideration since the faster drying paints 1) do not require coning of the area for an extended drying period, 2) decrease the exposure of the paint crew to traffic, and 3) lessen the disruption to traffic.

The service life of paint depends primarily on:

- Traffic density and type,
- Position of marking (center line, edge line, lane lines, transverse markings),
- Composition of material and substrate,
- Thickness of paint film, and
- Season of year paint is applied.

The position of the marking will determine the amount of traffic that actually passes over the marking. For example, longitudinal lines generally have a longer life than transverse markings and edge lines last longer than lane lines.

Thicker paint films on stable pavement surfaces will usually provide increased durability. This is not, however, a linear relationship. The additional life of a stripe thicker than 15 mils is not in direct proportion to the additional thickness used.

Although the estimated life of painted markings is a function of numerous site-specific variables, AADT is the most commonly used variable in defining service life. Most agencies consider a reasonable target to be 6 to 12 months under "normal" conditions. Three months service may be acceptable for roadways with very high traffic density, while some paints may last well over a year on roads with low AADT's. It should also be noted that paint wear is especially high in cold weather; therefore, painted markings applied in the fall will have a shorter life expectancy than those applied in the spring.

Thermoplastics and Other Durable Materials

The use of thermoplastic and other highly durable marking materials as an alternative to conventional traffic paint has been under study for over 15 years. The growing popularity of thermoplastic, epoxy, or polyester installation has been attributed to readiness for immediate use, superior durability, and the potential for long-term economy and traffic safety. While the initial cost of these highly durable markings can range as high as 5 to 15 times the cost of conventional painted markings, their long service life and improved visibility makes an attractive alternative in many situations.

The types of materials included in this category of markings are:

- Hot-Applied Thermoplastic (Extruded or Hot-Spray),
- Cold-Applied Preformed Plastics (Permanent or Removable),
- Epoxy Thermoplastic,
- Two-part Epoxy, and
- Polyester Striping Material.

Hot-Applied Thermoplastics are generally defined as synthetic resins which soften when heated and harden when cooled without changing the inherent properties of the material. The material includes three basic components: plastic and plasticizers (binder); pigment and fillers; and glass spheres. The exact chemical composition varies considerably. Formulas of commercially available materials are proprietary and continually change as the price of chemical components fluctuate.

For this reason, composition is usually specified in terms of minimum percent weight of each basic component. A typical range may be as follows:

Binder	15 to 35%
Glass Beads	14 to 33%
Titanium Dioxide (TiO^2)	8 to 12%
Calcium Carbonate or other inert filler	48 to 50%

Formulations differ for materials to be applied by the extrusion or hot spray process. They also differ for use in hot or cold climates.

There are two basic forms of cold-applied plastic materials. The first type is an extruded cold-flow plastic tape with imbedded glass beads, with or without a top surface dressing of beads. It is generally used in thicknesses of 90 mils or 60 mils. The second type include preformed plastics that are somewhat more pliant than the cold extruded type. Standard thickness of these films are 30 mils and 60 mils.

A special type of the preformed plastics has been recently introduced for use as temporary markings in construction work zones. The major advantage of this material is its ease of removal. It can be removed intact (or in large pieces) from either asphalt or PCC pavement surfaces manually or with a roll-up device without the use of heat, solvents, grinding, or sandblasting.

Epoxy Thermoplastics (EPOFLEX) is an instant setting material that has been extensively field tested and appears to perform well under severe winter conditions. This formulation differs from most epoxies in that no hardeners are used.

EPOFLEX is applied by a hot-spray process with a top dressing of beads dropped on almost simultaneously with spray gun operation. No-track hardening times of 5 seconds have been measured in the field under certain conditions. Application thicknesses ranging from 15 to 25 mils have provided adequate durability on both asphalt and portland cement concrete pavement. Primer is not required for this application.

In addition to its extremely short no-track time and its excellent performance on all pavement types, EPOFLEX has several other distinct advantages. It is a 100 percent solids formulation and is virtually smokeless at application temperatures. Both of these properties are sound environmental advantages.

The development phase of this material formulation has been completed. With the continuing successful performance of the field test installations, additional efforts are underway to implement the large scale use of EPOFLEX by States and other agencies. These efforts include the development of a model composition specification and retrofit designs for existing striping equipment.

The cost of approximately $10.00 per gallon for this new material is a current estimate. Retrofitting paint stripers for use with this material would involve a capital investment which would have to be amortized over the life of the stripe. However, current evaluation projects indicate that the materials costs are so low considering the durability of the material that a favorable cost ratio with conventional traffic paints can be attained (Ref. 3-5).

A sprayable Two-Part Epoxy resin compound has been under development by the Minnesota Department of Transportation, in conjunction with the H.B. Fuller Company, since 1970. The compound is intended to adhere to both bituminous asphalt and PCC, have superior abrasion resistance, and long term durability.

Two formulations resulted from this development effort. These compounds have undergone extensive testing since 1975 under the FHWA Demonstration Program and have generally performed successfully. The major difference in these two formulations is in the drying time. The faster cure time material is intended for application as center line striping since it generally can be installed without coning depending on the amount of glass beads used. (That is, the larger the volume of beads used, the shorter the drying time.)

The slower curing, less expensive formula is intended for edge line marking. The actual curing time of either product varies according to the temperature of the road surface. The higher the temperature, the faster the curing. It can, however, be applied at temperatures as low as 35 °F. Most significantly, it can be applied on wet surfaces and in the rain.

Several States have indicated that the two-part epoxy remains serviceable for up to 2 years on high volume roads which, in some cases, have required repainting every 3 months. The epoxy is more durable because it forms a chemical bond which makes it resistant to wear from sand, salt, snowplows, and traffic.

To date, these materials have been installed in 16 States on various types of roadways. The average service life that emerges from the experience in these installations should more clearly define the durability parameters.

Polyester pavement marking materials have been evaluated in terms of color, durability, and reflectivity performance for a 3-year period by the Ohio Department of Transportation in cooperation with FHWA. The indicated usage of this product is for asphaltic pavements only as it does not adequately bond to PCC. It can, however, be applied over existing markings on AC pavements.

This polyester material is applied at a thickness of 15 mils with a bead application rate (drop on) of 20 pounds per gallon. The two-component polyester system (resin/catalyst) will dry to a no-track condition in less than 30 minutes provided the pavement is dry and the surface temperature is at least 60 °F. Faster drying times are achieved at higher temperatures. Typical drying times are on the order of 8 to 12 minutes at 75 °F. Because the film-forming mechanism is not an evaporation process, it can be applied at temperatures down to 0 °F with proportionately longer drying times (Ref. 3-6).

Six 1978 resurfacing projects have tested the use of 7.5 mils thickness. The polyester markings are performing satisfactorily, but long term performance has not as yet been established.

When polyester markings are applied to a new asphalt surface, the polyester flakes off surface aggregate because of the free oils present, thus creating a line which appears full of holes when viewed closely. This "swiss cheese" effect, usually occurs within 2 months of application, but does not affect visibility from a typical viewing distance. After this initial loss, only "normal" deterioration occurs.

In general, polyester markings are more opaque than paint applied under similar conditions and present a better looking daytime line than two coats of paint. Night visibility of polyester is also superior to paint due to the increased number of beads used. It appears to perform better on asphalt pavements than conventional or fast-dry paints and some plastic materials. Although the per gallon cost is higher than paint, and lower than two-part epoxy, cost comparisons are not appropriate until the specific relationship between traffic factors and material performance is more clearly established.

Raised Pavement Markers

Reflectorized paint, thermoplastics, and other striping materials provide excellent day and clear-night visibility. Unfortunately, these reflectorized stripes often disappear when the roadway becomes wet. This loss of visibility occurs when it is most needed—during adverse weather conditions, particularly rainy or foggy nights.

Raised pavement markers (RPM), reflectorized and nonreflectorized, have emerged as highly durable marking devices which will provide both day and night visibility under adverse weather conditions. The superior night visibility can be seen in Figure 3-5.

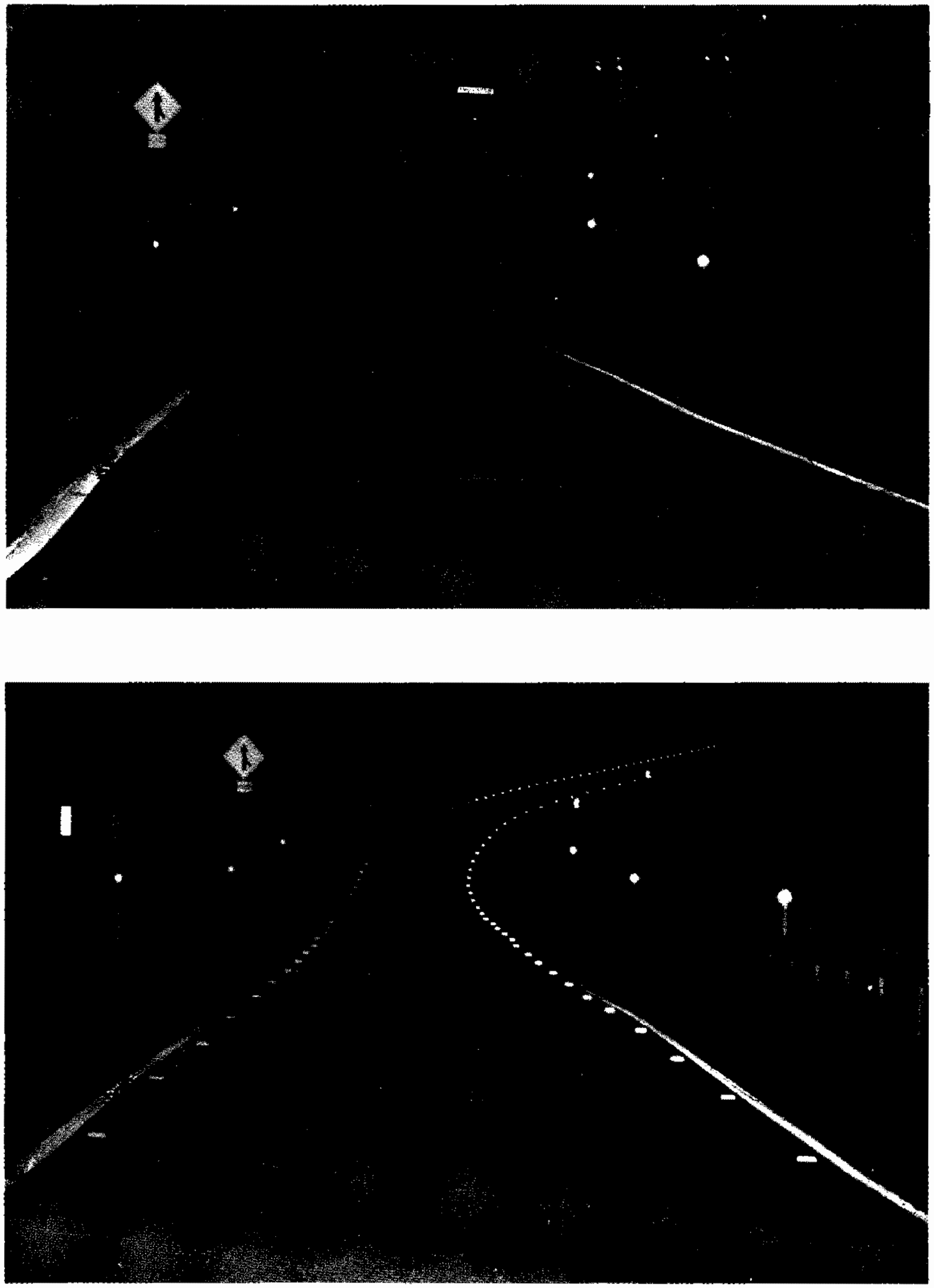
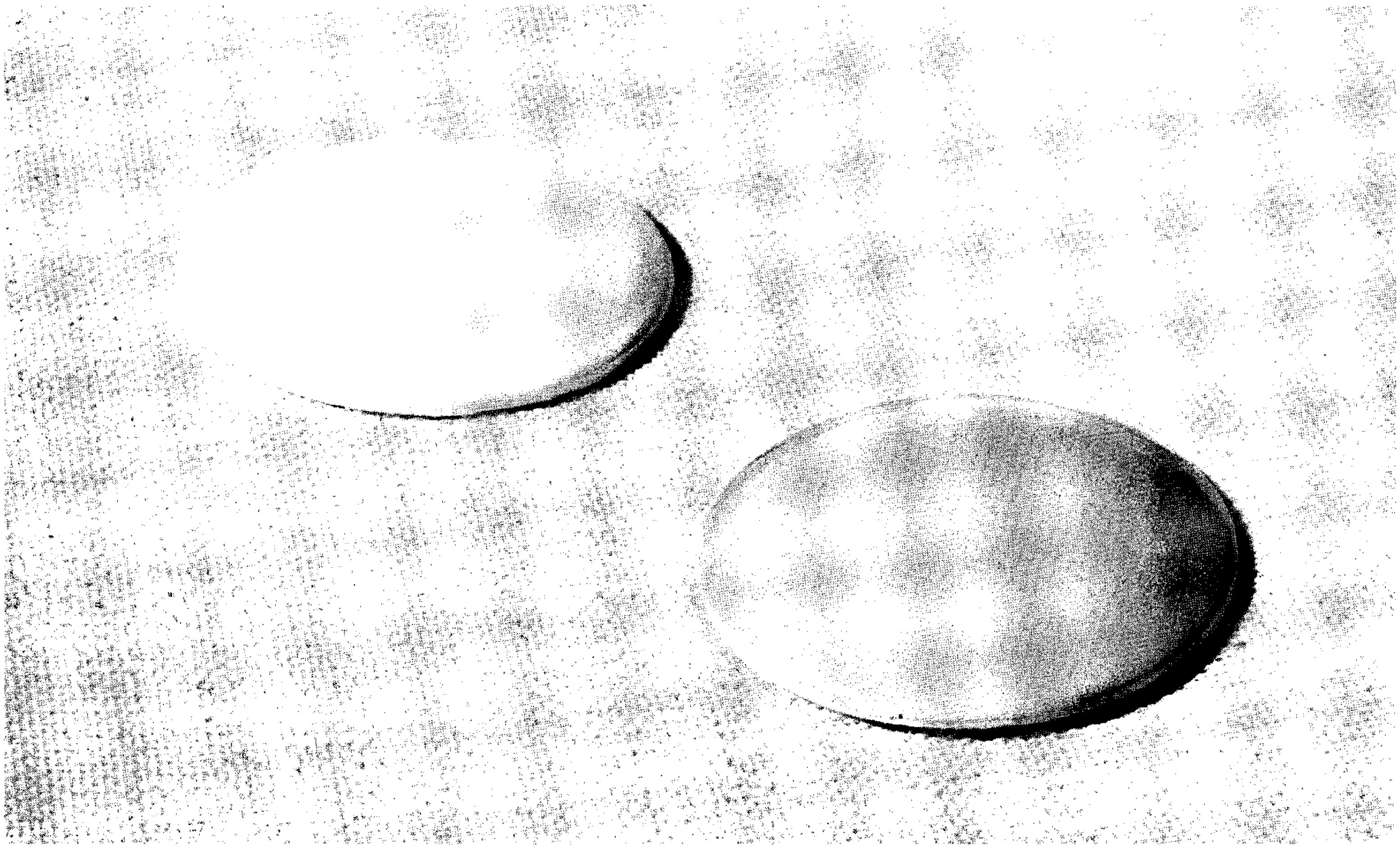
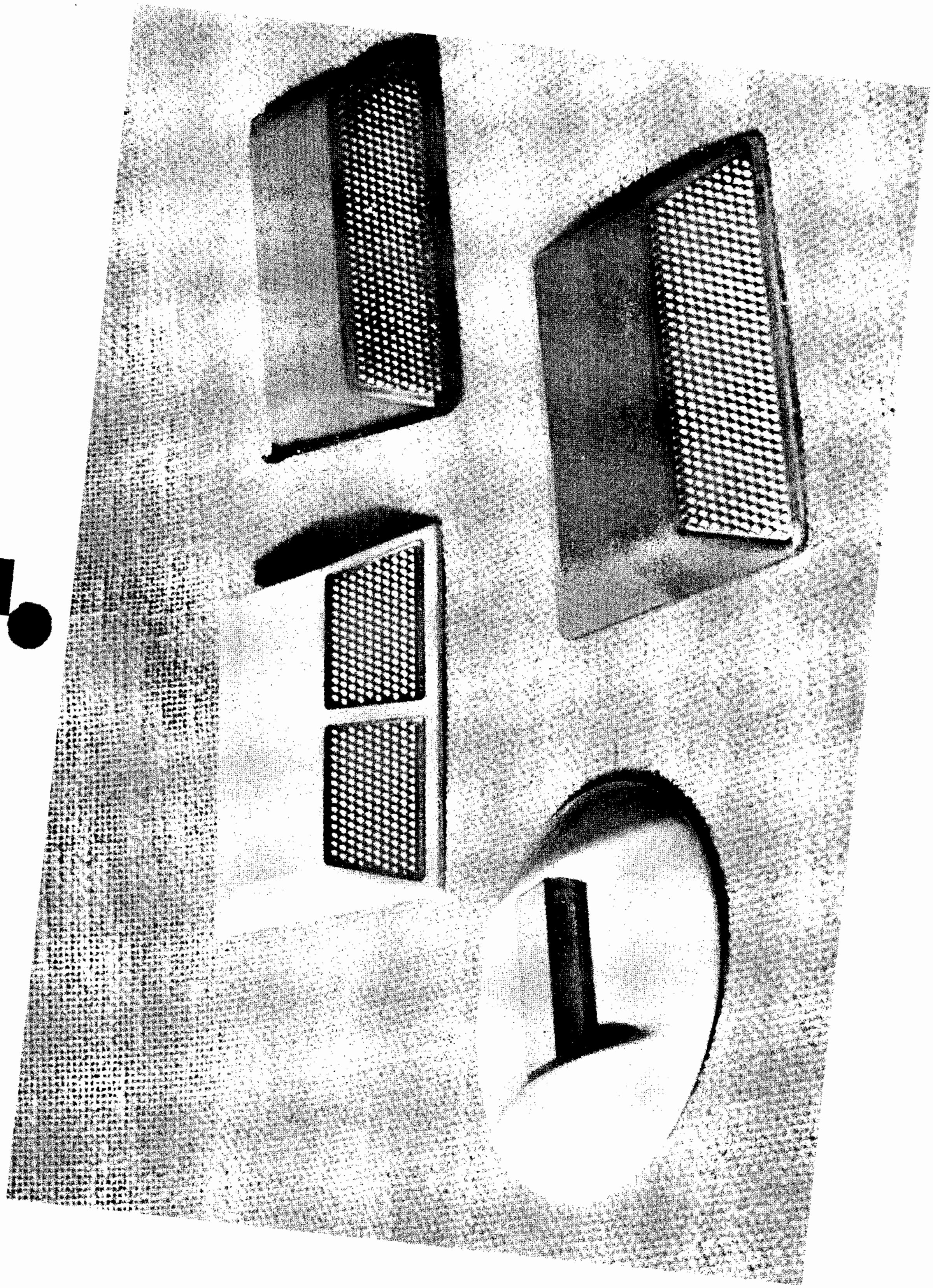


Figure 3-5 Night View of Roadway Without (Above) and with Reflectorized RPM's (Below)

Figure 3-6 Non-Reflective Ceramic and Reflective Raised Pavement Markers





There are a number of different types of RPM's currently manufactured. Examples of typical forms are shown in Figure 3-6. The characteristics of the particular categories of RPM's are directly related to their functional applications.

Nonreflectorized markers may be used in place of painted or thermoplastic longitudinal markings (center lines, lane lines). Reflectorized markers are interspersed to provide night visibility where there is no overhead lighting. More frequently, however, agencies tend to intersperse reflectorized raised markers with painted stripes for longitudinal markings. Reflectorized RPM's are particularly desirable at high hazard locations such as exit ramps, bridge approaches, lane transitions, horizontal curves, and construction zones because they provide better nighttime delineation.

There are three basic colors of markers in use: white, yellow, and red. The white and yellow markers are used alone or in combination with painted lines to convey the same meanings as the lines. Red reflective markers have been used to convey the message "WRONG WAY". Blue markers are now being used by Fire Departments in some areas to denote the location of nearby fire hydrants.

Raised pavement markers have certain advantages over the painted markings:

- Reflectorized RPM's provide increased reflectivity under wet-weather conditions.
- Both reflectorized and nonreflectorized RPM's have greater durability and life than painted lines; therefore, replacement is much less frequent and hazardous repainting operations under heavy traffic conditions can be avoided.
- The vehicle vibration and sound produced by vehicles crossing the markers creates a tactile and auditory warning as well as visual.
- By providing directional control of reflected color, RPM's can be used to convey a "WRONG-WAY" message.
- Nonreflectorized RPM's can be used as transverse "rumble strips."

A principal disadvantage is the high initial cost. To recover the initial investment and realize the full benefit of these durable long-life materials, their application tends to be limited to important roadways, hazardous locations, and roadways having a surface that will not soon be subject to major repair, replacement, or excavation activity.

Another area of primary concern is the susceptibility of conventional RPM's to snowplow activity. All pavement markings will be obliterated by heavy snowfall. The raised marker has the added disadvantage of being damaged or removed by the snow plow blade. A "snowplowable" marker is available that has demonstrated relative effectiveness in resisting snowplow damage (Figure 3-7).

Figure 3-7 Snowplowable Reflective Marker

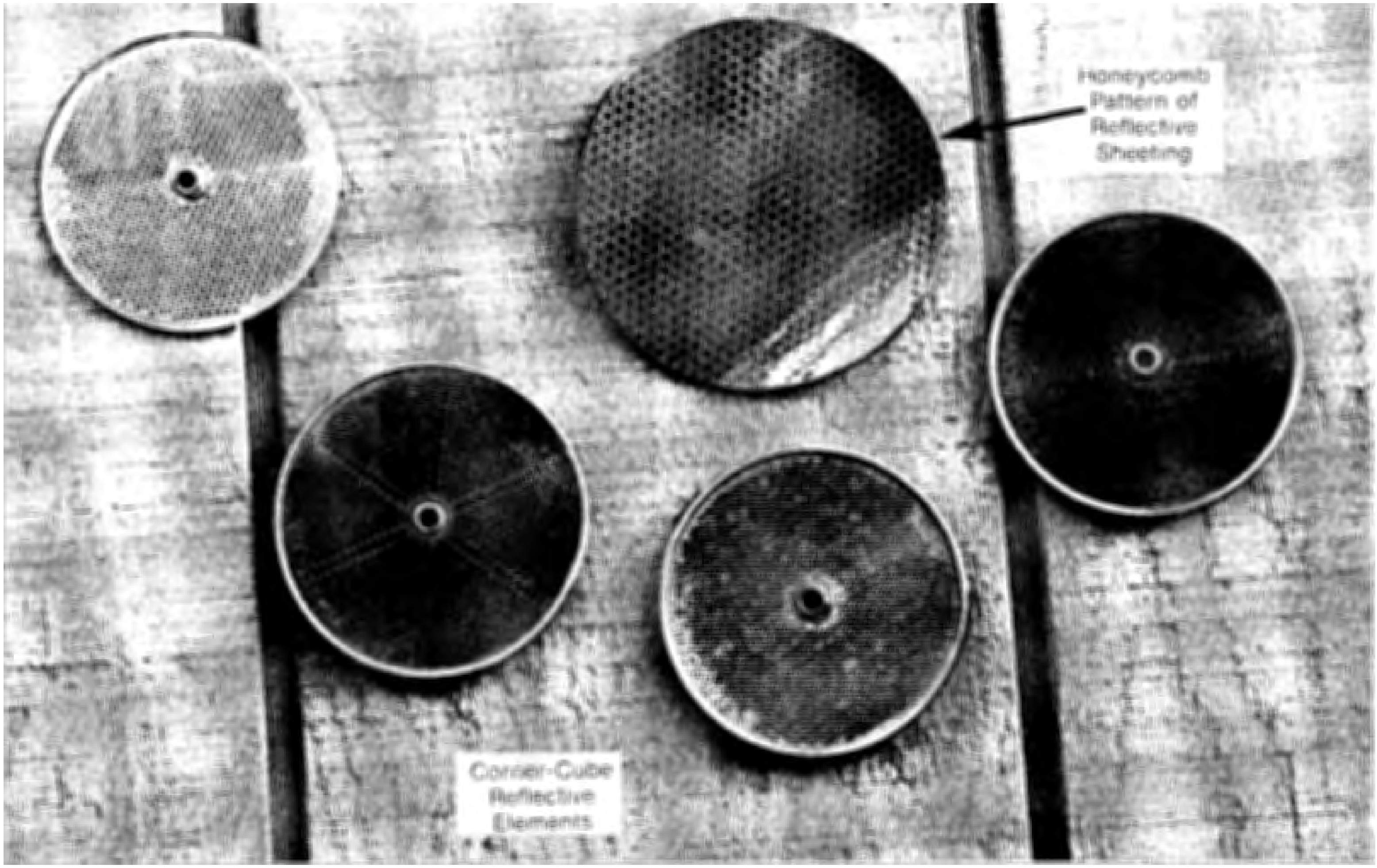


Figure 3-8 Typical Retroreflective Elements

The use of a RPM system to provide positive day and night guidance through construction zones is receiving increased attention. They are easy to install and remove and, after removal, do not leave a misleading indication to confuse drivers. Despite the safety benefits, the apparent high cost of these devices has retarded their use for construction zones. However, a nine-State study conducted by FHWA indicated that the cost of a marker and paint system compared favorably to the cost of paint striping and removal (Ref. 3-7). Most significantly, the study found that the use of reflective raised pavement markers on construction detours tends to reduce the number of accidents. The study suggested that the additional safety, improved operations, and unanimous favor of the public, government and construction personnel may well justify their expanded use.

Post-Mounted Delineators

Post-mounted delineators are defined in the MUTCD as "light-retroreflective devices mounted at the side of the roadway, in series, to indicate the roadway alignment." They are primarily guidance devices providing night visibility of the roadway alignment and are particularly useful during rain or snow conditions.

A roadside delineator unit consists of a reflective element as shown in Figure 3-8, the support or mounting post, and possibly a backplate. A white-faced target backplate (or "paddle") may be used where daylight route guidance is desirable, such as at curves on fill sections, intersections, or ramps hidden by vertical curves. There is a variety of materials available for each of these components.

Object Markers

The MUTCD defines three types of object marker configurations. Type 1 utilizes 9 reflective elements mounted on a diamond-shaped backplate. As an alternate device, a yellow reflective panel of equal size may be used. Type 2 is comprised of 3 reflective units on a rectangular backplate which can be installed either horizontally or vertically. A yellow refective panel of equal size can also be used as an alternate for this device. Type 3 is made up of reflectorized diagonal stripes as shown in Figure 3-9.

Basically, Types 1 and 3 are used to mark objects in the roadway, while Types 2 and 3 are used for objects adjacent to the roadway. Other materials such as reflective paint and reflective sheeting are used to define objects or obstructions near the road such as trees, sign supports, etc. Merely whitewashing the base of a tree with nonreflectorized paint does not provide the night visibility needed. This practice was prevelant 20 years ago, but has almost disappeared with the development of relatively inexpensive reflective materials.

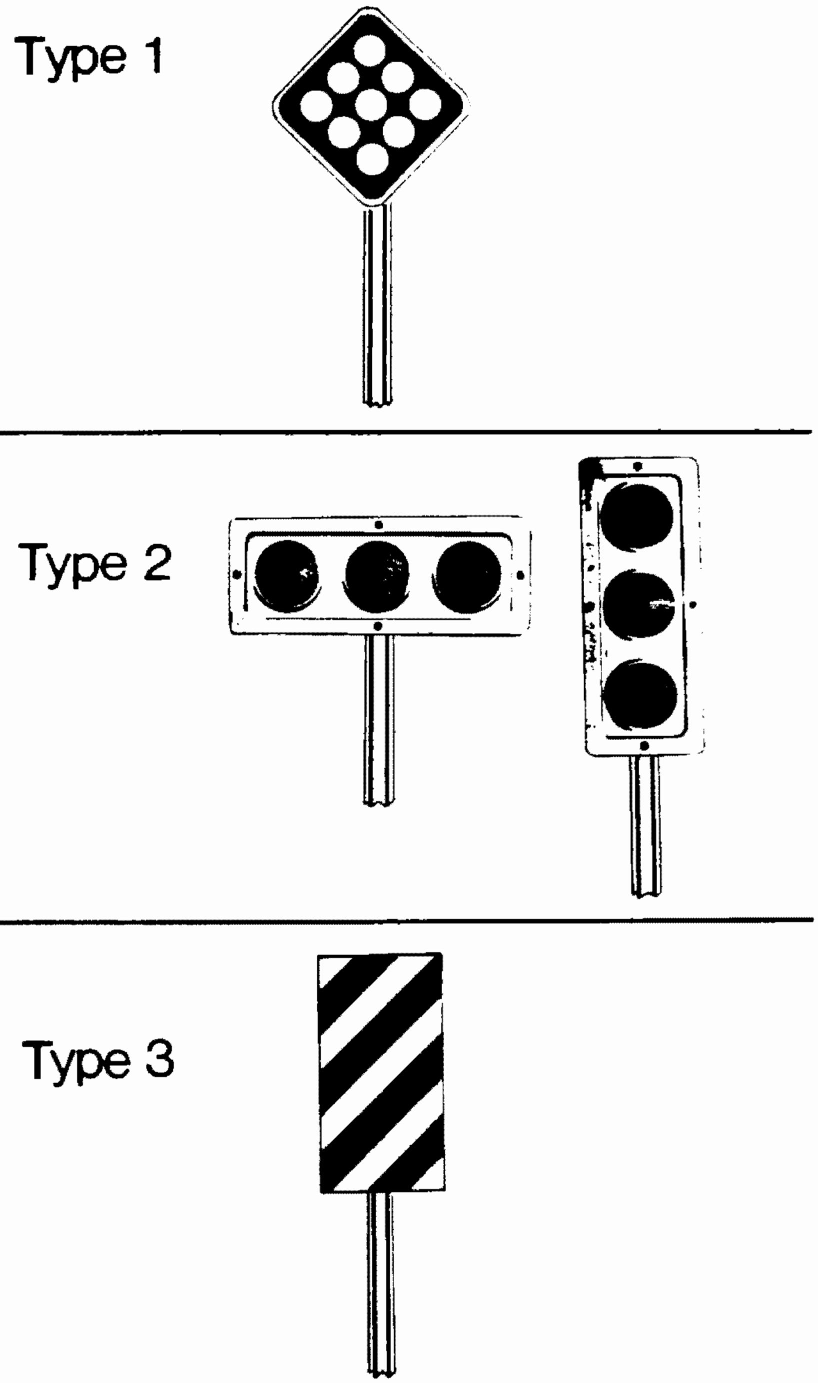


Figure 3-9 Types of Object Markers

3B-3 Procurement Practices

Another pre-installation activity which should be considered in selecting the most cost-effective application involves procurement alternatives. Typically, individual agencies have evolved their purchasing procedures over the years—often without periodic review to ascertain whether all possible economies have been realized. This section discusses some of the considerations and tradeoffs involved in the purchase of materials and equipment and the best use of contractor forces.

Quantity Purchase of Materials

In purchasing materials such as paint, thermoplastics, markers, or delineators, quantity discounts are generally available from suppliers. For example, a one-way reflective raised marker may cost $1.75 each when purchased in quantities of 1 to 99. When purchasing lots of 5,000 markers, the unit price is reduced to about $1.25. This would result in a savings of $2,500 when purchased in lots of 5,000. Extremely large scale purchases would reduce the unit cost even more.

Many States establish an arrangement with the supplier whereby local agencies will be supplied at the quantity prices quoted the State. This "buying off the State contract" requires an estimate of the quantity that may be needed and acceptance of the materials as specified by the State.

Interagency purchases is another method used by State and local agencies to obtain lower unit prices. In this case, the State prepares the specification, tests the materials, and selects the contractor. Local agencies are then allowed to buy material directly from the State. There is frequently a small surcharge to cover the State's administrative expenses in handling the paperwork. For instance, one State allows city and county units to purchase materials which are distributed from State warehouses for State cost plus a 5% surcharge. On the other hand, another State allows local agencies to order from the State, without surcharge.

Where the State makes no provision for bulk purchasing to accommodate local agencies, nearby agencies can band together in a cooperative purchase effort. Even if agencies are purchasing direct from the supplier, it is generally cost effective to purchase those materials with a long shelf life in sufficient quantity to obtain the unit discount. However, this may mean space problems in storing. In the case of paint, small agencies can purchase one or more years supply of paint (depending on shelf life) to be delivered at specified times throughout the period. Because material may be damaged or may deteriorate in storage, the savings in unit cost must be balanced against the potential waste.

Packaging and Storing

Another consideration that will effect the cost of materials is the size and type of packaging. Small sacks, pails, or cartons may prove easier to handle and store, but their higher cost compared to larger containers may not justify their use. This is primarily of concern with bulk type material (e.g., paint, thermoplastic, etc.).

Paint storage is usually a function of its packaging. It is tested at the factory, placed in sealed containers and shipped ready to use. The size of containers specified by the agency may vary from 5 gallon cans to the larger 30 gallon or 55 gallon drums.

Traffic paint that will remain in storage for some time and particularly throughout the winter months, should be stored upside down so that any deposit or settling will occur on the lid of the container. When the container is opened, the settled pigment may be easily scraped off the cover and incorporated with the balance of the mix.

A 1979 study of the cost effectiveness of various storage and warehousing practices (Ref. 3-8) specifically addressed the economic feasibility of:

- Recycling drums for shipment and storage of paint,
- The use of 55 gallon drums versus 30 gallon drums, and
- Bulk paint storage versus drum storage.

Several States tried using recycled drums, but experienced a significant leakage problem since the lids did not fit properly. Considering the loss of paint through leakage and the relatively small savings realized by using recycled drums, it was concluded that this did not represent an economically feasible alternate.

The study showed that the use of 55 gallon drums in lieu of 30 gallon drums resulted in a 40 percent reduction in the number of drums. Based on a comparison of drum costs and their resale values for both sizes, it was determined that considerable savings in purchasing costs alone could be realized from the use of 55 gallon drums. Some agencies order these barrels painted so that they may be subsequently used as channelizing devices.

The problem in converting to the larger drums lies in handling the heavier loaded drums at the various storage areas. The full 30 gallon drums can be loaded by hand. The much heavier 55 gallon drums require forklifts or other loading equipment. Therefore, the labor cost of loading may offset some of the initial savings. However, an additional savings would accrue since the amount of waste (paint remaining in drums) would be reduced because fewer drums would be utilized.

A real potential for savings appears to exist in the bulk paint storage concept. Possible cost savings, plus the ability to store large quantities of paint in a small area, make the bulk storage method an attractive alternative.

In addition to a \$0.35 per gallon saving by eliminating the cost of the drums, it has been estimated that about 3 gallons of paint remain in each emptied barrel. Thus, an additional savings would accrue from reduction in waste. Conversely, the installation of storage facilities, maintenance, and energy costs will offset some of these potential savings.

The State of Illinois recently installed bulk storage facilities in two of its nine highway districts. Evaluation of these installations is presently underway to determine its real cost effectiveness.

Thermoplastic storage depends on the form of materials used. Hot melt thermoplastic materials are available in block or granular form and are packaged in cardboard containers or heavy duty bags in weights of 20 to 50 pounds. The containers (or bags) should be stacked flat and stored on pallets in a dry place. Water or dampness will not harm the materials, but may weaken or otherwise damage the cardboard containers. The manufacturers suggest that cardboard containers should be stacked no more than 13 cartons high. In periods of extremely hot weather, it is suggested that stacks be limited to 10 cartons.

The cold-applied preformed thermoplastic tape for striping is packaged in cartons designed for easy application. It is also available in standard words and symbols and in sheets for customizing special requirements. Handling and shelf life under normal circumstances do not ordinarily present a problem. However, some agencies have complained that some precut words and symbols are supplied in such a complex pattern that they are difficult to piece together on the street.

Raised markers, post-mounted delineators, and object markers are relatively small and have a stable shelf life. Accordingly, these devices present few storage or handling problems.

Inventory and Recordkeeping

Good business practice dictates an adequate and well-documented inventory of supplies and materials. This, of course, requires planning and scheduling. Shortages can foul up scheduled maintenance activities and/or require emergency purchases at inflated prices.

In general practice, the anticipated volume of materials is established during budget prepartion activities. Frequently, however, the budgeted item is based on some traditional "rule of thumb" such as last year's usage plus a percent increase. Where good historical records are available as a basis, this practice may suffice.

It is more likely that the budget cuts being experienced in today's environment are such that project and activity priorities become more important. In addition, it is becoming increasingly difficult to estimate with reasonable accuracy future cost on the basis of last year's costs. The economic advantages that can be realized by careful planning, scheduling, and balancing the inventory of needed materials will normally offset the effort involved.

Use of Model Specification

A great deal of time and effort has been expended by ITE, ASTM, and individual agencies in developing specifications for the purchase of various categories of materials and equipment. Model specifications are available for most commonly used delineation devices or components. These documents reflect extensive research and field experience and can be easily adapted for local use.

State transportation departments are generally cooperative in furnishing copies of their standard specifications to local agencies. This will save time and most probably will produce a comprehensive and complete specification in accordance with standard practice and regional characteristics. The most critical issue in the preparation of a specification is the choice between issuing a composition (formulation) specification or a functional (performance) specification.

For example, paint specifications have traditionally appeared as a chemical composition specification. Inasmuch as the cost and availability of some of the chemical components used in the manufacture of paint may vary radically from week to week, detailed composition specifications favored by many agencies in the past are being replaced by performance specifications. In some cases, a combination performance-composition specification is used which indicates the percent by weight of the desired ingredients by generic classification without specifying a brand name or chemical formula.

Each form of specification has its own unique advantages and disadvantages. One recent study surveyed 24 states and 15 national paint manufacturers. While the majority of the states surveyed continued to use composition specifications, the manufacturers appeared to favor the performance specification (Ref. 3-8).

The performance specification enables a user to realize the full advantage of current paint manufacturing technology. The state-of-the-art in paint manufacturing has moved ahead so rapidly that it is extremely difficult for the engineer to understand this advanced technology and keep pace with the paint chemist. Furthermore, the manufacturers indicated that the most effective way to lower the cost is through their own research and development technology. For example, during this 1978-79 study, the average bid price for the chemical composition specification was $3.60 per gal. for yellow and $3.36 per gal. for white paint. With the performance specification the average bid price was $3.15 per gal. for yellow and $2.95 per gal. for white.

The major disadvantage in using the performance specification is the difficulty in judging performance. Most States use a point system for evaluating the paint. This assessment is highly subjective and depends on the view of the individual members of the evaluation team. Values assigned to color, durability, contrast, appearance, etc. varied in many States depending on the priorities of the specific agency.

Another disadvantage is the potential difficulty in getting suppliers to replace paint that does not meet the performance specification. This can be a time-consuming process and may necessitate legal action.

The advantage of a composition specification is the assurance that the purchaser is getting a paint of a desired formulation. The development of a composition specification is normally the function of the Materials department of the using agency. In this process, several types of paint with varying formulations are applied on asphalt and concrete road surfaces for evaluation. Based on the results obtained, a composition specification is then written to assure that the user obtains that product giving maximum service life. Quality control testing in the laboratory is included in the specification to assure that the product furnished is within the standards required for successful application and performance.

After carefully weighing the advantages and disadvantages associated with paint specifications, the study concluded that ". . . Paint purchased using performance specifications appears to result in a lower average price than paint using chemical component specifications " (Ref. 3-8).

It also concluded that when policy directs that the composition specification be used, the chemical components should be reviewed annually to determine the most cost-effective composition. It is frequently possible to substitute one chemical compound for another or reduce the quantity of a high price component without sacrificing performance or color.

3C. INSTALLATION

The equipment, procedures, and policies involved in the installation of various pavement markings and delineation devices have a profound influence on the ultimate performance. Among the major concerns is compatibility of materials and equipment, size and capabilities of crew, protection of crew, and traffic control during the installation process.

While it might be assumed that the preferred material will dictate the type of equipment, in actual practice the opposite is usually true. That is, the material used is frequently based on the capabilities of available equipment. For example, it may be determined from lab and field tests and from economic analyses that a rapid-dry hot-laid paint will provide the necessary durability and is economic from the standpoint of crew safety and traffic disruption. If the agency equipment is compatible only with cold-laid paint, most agencies will opt to use the cold-laid materials. Capital expenditures for new equipment or the use of a contractor are often beyond the available budget.

This serves to illustrate the point that tradeoffs and compromises involving engineering judgment must be made among all the elements involved in the selection of the most appropriate delineation treatment. There are few straightforward decisions that can be made independently.

Such factors as application thickness, volume of beads, surface and ambient temperature requirements, application speed, drying time, etc. may be based on agency policy, the condition and type of pavement, the type of markings applied, and a number of other variables. Consequently, the installation factors for each generic group of materials should be examined individually.

3C-1 Painted Markings

A number of national research studies and local demonstration projects have been undertaken to provide guidelines and recommendations for the installation of painted markings. As paint has been used for striping purposes since paved roadways came into use, there is a great deal of available information. Experienced State and local crews also contribute to the body of knowledge. In addition, manufacturer/suppliers continue to improve the effectiveness of their products to remain competitive with other delineation materials.

Nonetheless, installation practices and procedures differ considerably to accommodate the individual site and traffic characteristics. The following discussion focuses on some of the major issues involved in the installation process.

Thickness of Paint Film

In general practice, the application thickness for painted stripes is about 15 mils (wet) and contains about 4 to 6 lbs. of beads per gallon of paint. At least, this is the established policy for numerous agencies. However, during on-the-street installation, it is extremely difficult to lay paint this precisely.

Although striping equipment can be set to deliver the paint and beads at a predetermined rate that should approximate a 15-mil thick line, the porousness of the surface, the ambient temperature, and the amount of spray distortion from winds, etc. tend to vary film thickness. An experienced striping crew can usually come close to controlling the flow visually so that the resulting stripe is most effective. In some cases, for example, a particular section of the stripe may exceed 20 mils if, in the judgment of the operator, that area receives excess wear. Other sections may measure less than 15 mils if the markings receive little wear. The point to be made here is that experience with available equipment and local knowledge of the roadway environment frequently produces better results than general guidelines based on "average" or "typical" conditions.

Pretreatment of Pavement

Earlier experience with traffic paints suggested that better adhesion with the pavement might be achieved by some form of pretreatment. It was fairly well documented that repainted stripes performed better than the initial application on bare pavement. It was therefore hypothesized that pretreatment, particularly on PCC, would lengthen the life of paint.

Several forms of pretreatments have been used without significantly increasing durability. Some States, however, have followed the practice of applying a light coating of paint without beads as a sealer on new pavement surfaces. The first or primer coating laid at 4 to 5 gallons per mile dries rapidly and seals the pavement. This eliminates the discoloration which sometimes occurs from the solvent action of the traffic paint on asphalt pavements, and provides better adhesion on PCC (Ref. 3-9).

One of the major concerns has been that paint is most frequently applied to dirty pavement surfaces. Laboratory tests have indicated that cleaning the surface prior to application substantially improves adhesion. Field studies have evaluated such surface preparation techniques as airblasting, sandblasting, grinding, burning, washing (hydroblasting), acid etching, and wire brushing. Of these methods, wire brushing appeared best suited for cleaning the surface. It was easy to use, worked well over irregular surfaces, did not damage the surface, and removed road film.

Actually, under the conditions of the field tests (hot, dry weather, relatively clean roads) the service life of paint was not noticeably improved. It may still be a useful tool for other road conditions and may be more important in the application of spray or extruded thermoplastic markings which do not have the wetting capabilities of solvent-based paint (Ref. 3-10).

Installation Equipment

Painted markings can be applied with a variety of equipment. Selection of the proper equipment will depend on the size of community, miles of roadway, geographic characteristics, pavement surfaces, and the types of markings.

Equipment basically falls within two broad categories. The first is the small, self-propelled, manually controlled, low-capacity paint striper and the other is the heavy duty, multilane, truck-mounted unit. The smaller applicator is generally used for striping crosswalks and other transverse lines and legends. Typical small paint units are illustrated in Figure 3-10.

The larger truck-mounted unit is almost always used for longitudinal striping. These units are available commercially or can be customized based on agency specifications. While the specifics may differ, the heavy-duty units shown in Figure 3-11 are typical examples of large scale stripers. A representative layout is shown in Figure 3-12.

The striper truck should be equipped with an accurately calibrated speedometer so that the truck speed is known. A volume meter for each paint supply is a valuable addition to monitor the quantity of paint applied.

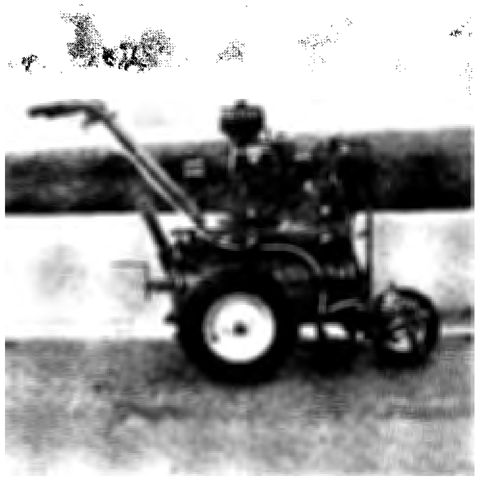
An air pressure system transports the paint to the spray guns at a pressure determined by the quantity of paint to be delivered. It also supplies air at a lower pressure to an air jet at the paint nozzle to atomize the paint. Air also moves the glass beads from the bead tank to the gravity-type bead dispensers. (When hot paint is used, the glass beads are pneumatically applied.) Air is also used in control valves for the paint guns, etc. Some agencies use a forward air blast to remove chips and other debris from the area being sprayed.

The air pressure is also connected to the cleaning system, which consists of a tank of paint solvent that can be connected to the paint lines and nozzles by suitable valves. The lines, nozzles, and screens must be cleaned daily after use.

The paint spray guns and bead dispensers are mounted on carriages underneath the truck bed just behind the rear axle. The carriages can be moved laterally by the spray gun operator. If edge lining is done at the same time as center lining, two carriages are needed.

The paint spray guns and bead applicators are synchronized so that the bead applicator starts at the appropriate time after the paint spray gun starts. All spray guns and bead applicators are controlled by an intermittent timer containing a timing mechanism driven by a ground contact wheel.

Heating the paint prior to application has proved effective in terms of achieving more uniform consistency under changing temperature conditions and in reducing drying time. Low heat (up to about 120°F) can be obtained by using a heat exchanger in the paint supply tank. This uses hot



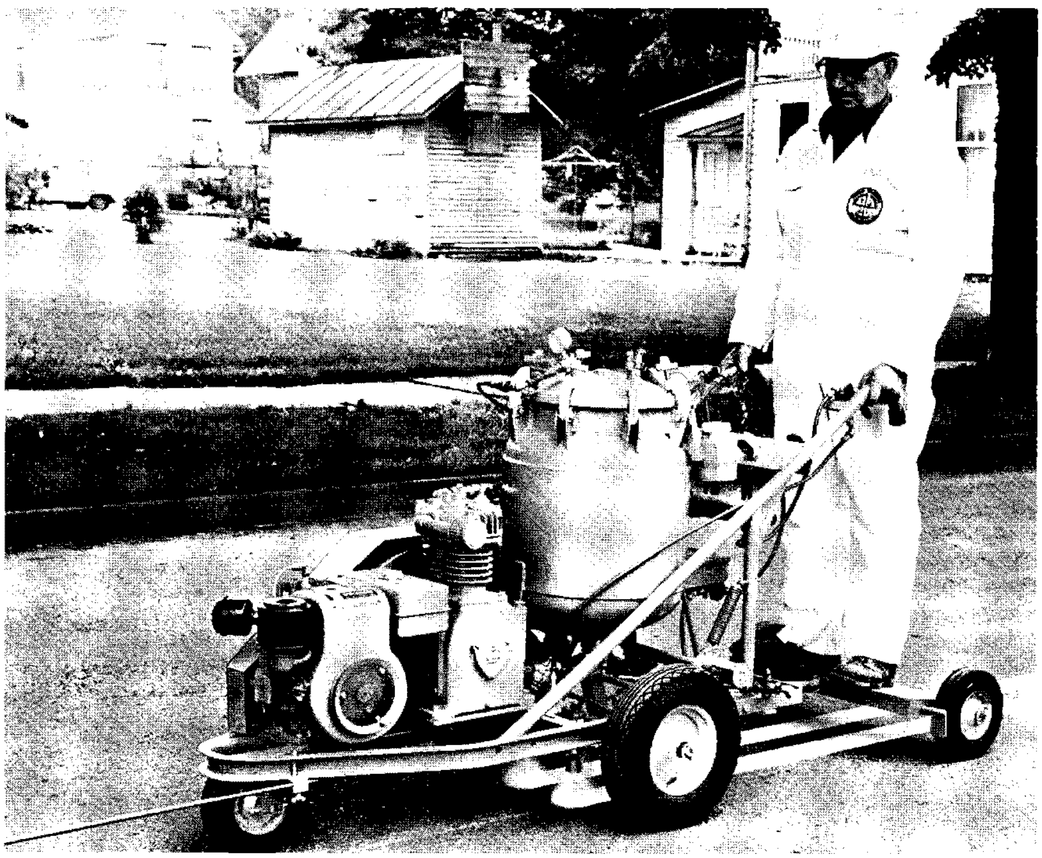


Figure 3-10 Small Paint Application Units

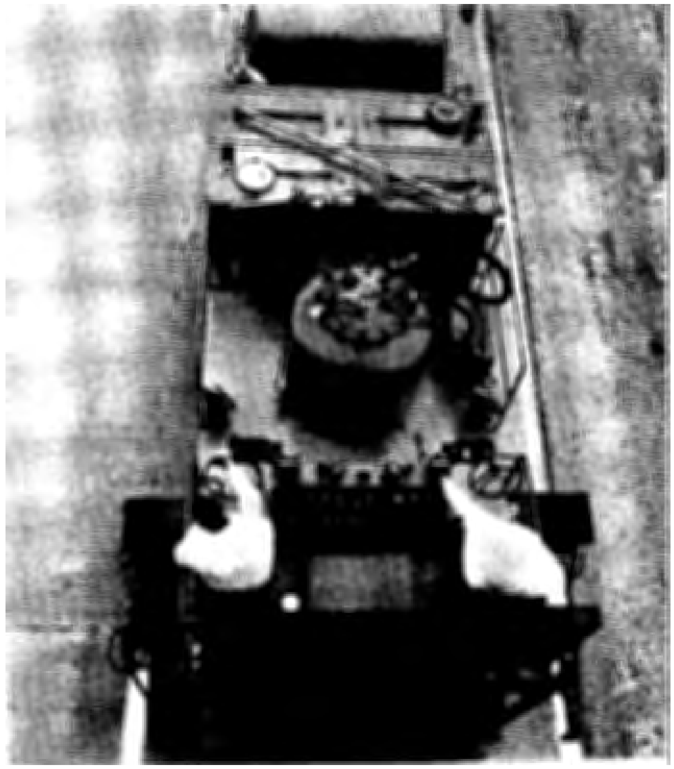


Figure 3-11 Truck-Mounted Paint Application Units

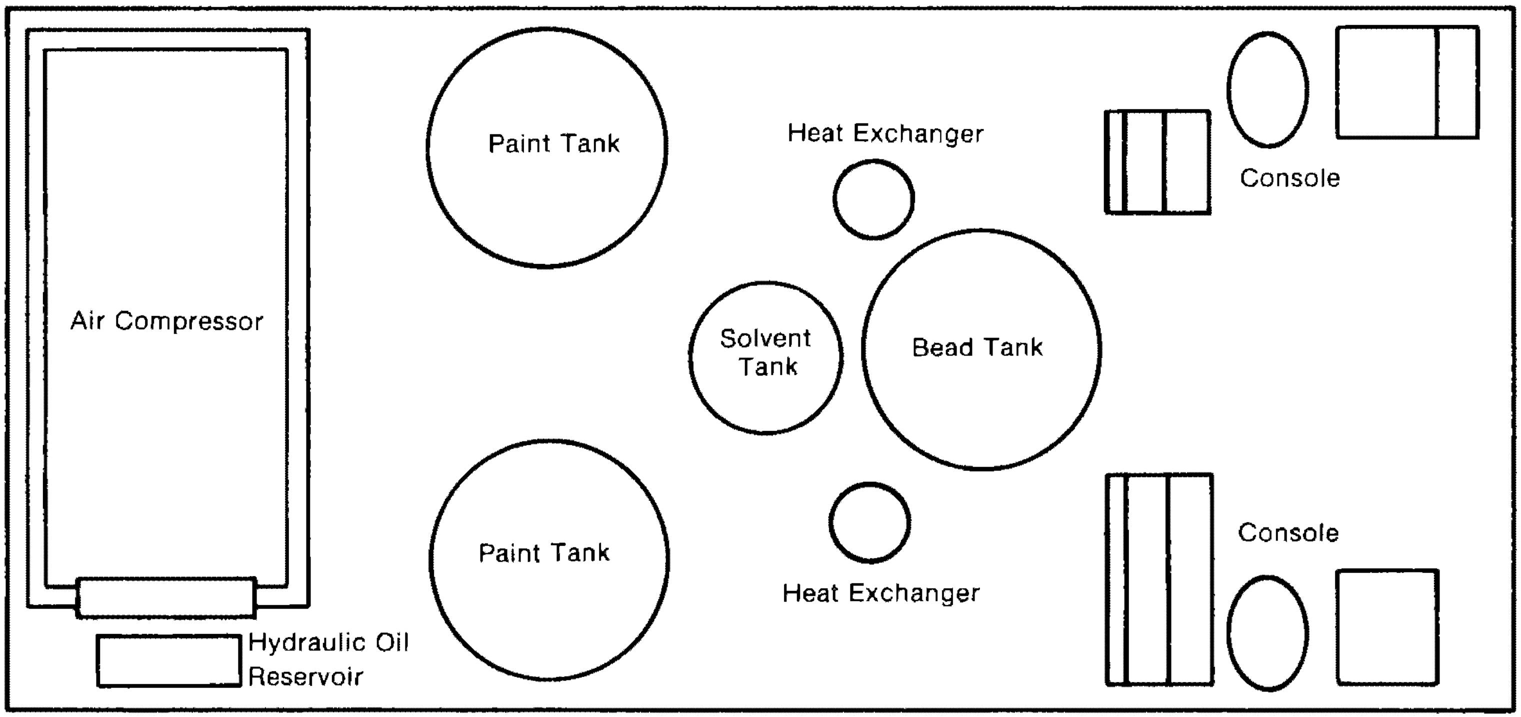


Figure 3-12 Layout of Large Scale Paint Striper

water from the truck radiator or from the compressor radiator. If higher temperatures are required, it is necessary to jacket the paint supply lines and to supply hot water to the jackets.

Temperatures above 180 °F generally require an external heating system to supply heated liquid (a coolant or special fluid) to the heat exchanger and to heat the paint lines. Some pavement stripers for quick dry-heated paint have a compressor located behind the driver and a heat exchanger mounted on the truck bed.

One type of striper is capable of applying material under varying pressures up to 2,000 psi and temperatures up to 350 °F. Another form of striper used by Florida has a million-BTU (293-kW) heater, a 250-cfm compressor, dual steering, and a paint temperature capability of up to 225 °F while painting three lines.

A new California striper generates heat in a patented device that uses rotational, mechanical energy to heat paint directly without the need for a heat exchanger. Temperature can be controlled to within 1 °F over a range from ambient to 400 °F. The prototype has been tested with various materials and at speeds up to 20 mph. Paint drying time, depending on material, ranges from 6 to 90 sec.

Another feature of this striper is a multiple nozzle airless spray gun capable of layer operation; e.g., two thin layers of paint, followed by beads, then another layer of paint and a top course of beads. Because it is not necessary to clear the paint lines and spray guns at the end of a day's work, a full day of striping is possible. This new striper is reported to reduce bead use by 15 percent and paint by 10 percent (Ref. 3–11).

Line Protection and Safety

Although heated paints and a few quick drying cold applied paints do not require protection of the freshly painted line from traffic, there are still a number of slower drying paint materials that require some form of protection. The type of protection required dictates the size of the installation crew.

The most common form of protection is traffic cones. The striper itself may be equipped with an apparatus that sets the cones or with a platform at the rear or side of the striper to accommodate a crew member who sets the cones manually. In other operations, the cones are placed from a following truck equipped with a flashing arrow board. For small spot maintenance jobs or in placing crosswalk markings, cones can be placed manually.

For the most part, the cones are placed in the skip portion of a broken line, or are offset on the side or alternate side of solid lines. Machines for picking up cones have been developed by some States. Other agencies pick up cones manually.

On high volume roadways, some agencies use one or more following trucks equipped with arrow boards for directing traffic away from the equipment and crew and to protect the line from traffic. Extreme care and caution in these situations are required to protect the working crew and to minimize the hazard to the motorist. Sometimes it may be advisable to equip the trailing follow up truck with a portable truck-mounted crash cushion.

Crew Size

The size of the crew depends on the nature of the operation and on agency policy. For relatively large scale operations, if edge lines are applied at the same time as center lines and no passing lines, two spray gun operators are needed. Thus, considering that the striper truck has a driver and assistant, a minimum crew of four is required. A supply truck and operator is generally required for most operations. If cones are needed, another person is required. The crew foreman coordinates the operation and generally follows the striper. The cones must be retrieved by another truck with two or three workers. The trucks supplying the paint striper are also used for protection of the line if cones are not needed and generally follow at about 500 foot intervals.

The simplest mechanical paint striping operation requires a crew of, five a supply truck, a shadow vehicle with arrow board and the striper truck. For small scale manual operations, crew size can number as few as 3 to 4 workers.

Considerable planning and coordination is needed to attain an efficient low-cost operation. Because the striping operation is seasonal in many States, it is necessary that the crew should begin placing markings as early in the morning as possible, but not before conditions are suitable. Because of rigid work hours, striping is too often started in the morning before the pavement surface has dried.

Good workmanship is often sacrificed because of the constant push for increased production. Shortcuts in application are seldom cost effective. Materials can be wasted, machinery clogged, and the quality of the stripe jeopardized if proper attention to detail is abandoned in favor of a few additional miles of striping.

3C-2 Thermoplastic Markings

The various categories of thermoplastic markings require very different installation techniques. In selecting the most appropriate thermoplastic materials, the application procedure for each category should be carefully considered from the standpoint of the physical requirements to achieve a proper bond, as well as the equipment and manpower requirements.

The type of application (transverse or longitudinal markings), type of facility (urban/rural etc.), type of pavement, magnitude of the installation, and other project characteristics will influence the method of application. For example, a small intersection project to install crosswalks or stop bars will differ from a major improvement project in which markings are a line item in the construction contract.

In almost all cases, thermoplastics, hot or cold laid can be applied with small, manually-operated equipment or can be applied mechanically with large, fully automated equipment. The exception is applying cold preformed tapes, legends, or symbols. These must be applied by hand, but it is a relatively simple operation. The major characteristics of the basic installation procedures are reviewed below.

Application Thickness

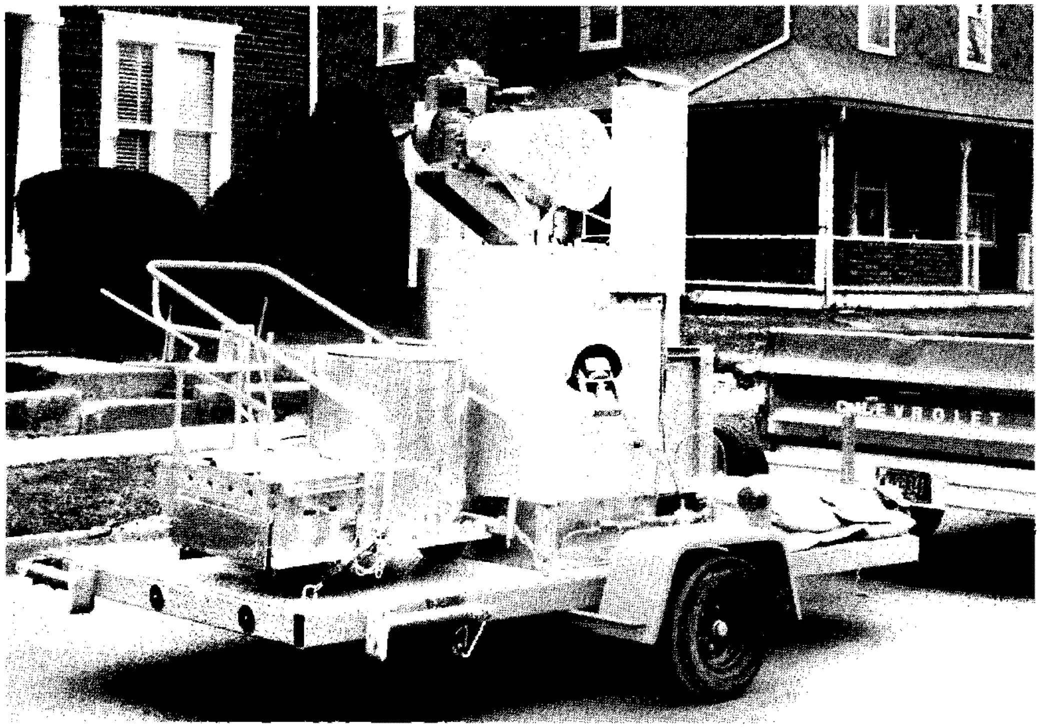
The matter of application thickness for hot laid material is the subject of some controversy. If durability is a function of thickness, the thicker markings would naturally have a longer life but would require more material and would thus cost more. It can be argued that this extended life may outlast the reflective properties, and, in some cases, the roadway surface itself. Therefore, the value of an expected life of 6 to 10 years could be meaningless if the pavement is subject to resurfacing or if the bead loss (reflectivity) renders the stripe ineffective at night.

The thicker markings in the range of 90 to 120 mils provide slightly better wet night visibility when the beads are still in place, but are more vulnerable to snowplow activity. In practice, the thicker application continues to be specified so that either the extrusion or spray process can be used. The extrusion process is more compatible to thick applications, especially if 120 mils is desired. The spray process is best suited to application of 90 mils or less. These lighter coatings have generally performed well and are more cost effective.

Proponents of the thinner applications (40 to 60 mils) report acceptable durability and reflectivity over a 3 to 4 year life span, lower material costs, faster application, and less damage by snowplow activity. The average wear of thermoplastic material (including studded tire wear, traffic abrasion, and snowplow shaving) has been estimated at 10 mils loss per year. Thus, a stripe of 40 mils could be expected to survive 3 to 4 years (Ref. 3–12). Even these thinner applications provide limited wet night visibility since moderate surface water film does not cover the marking and, therefore, does not completely inhibit reflectivity.

Equipment for Hot Applied Thermoplastic Installation

Molten thermoplastic can be extruded or sprayed on to the pavement surface by means of a manually-operated device for small runs (Figure 3–13) or by large automated equipment for major construction projects (Figure 3–14). Typically, 2,000 pounds of thermoplastic materials supplied in granular or block form will yield approximately 6,600 feet of 4-inch striping with a 90-mil thickness.



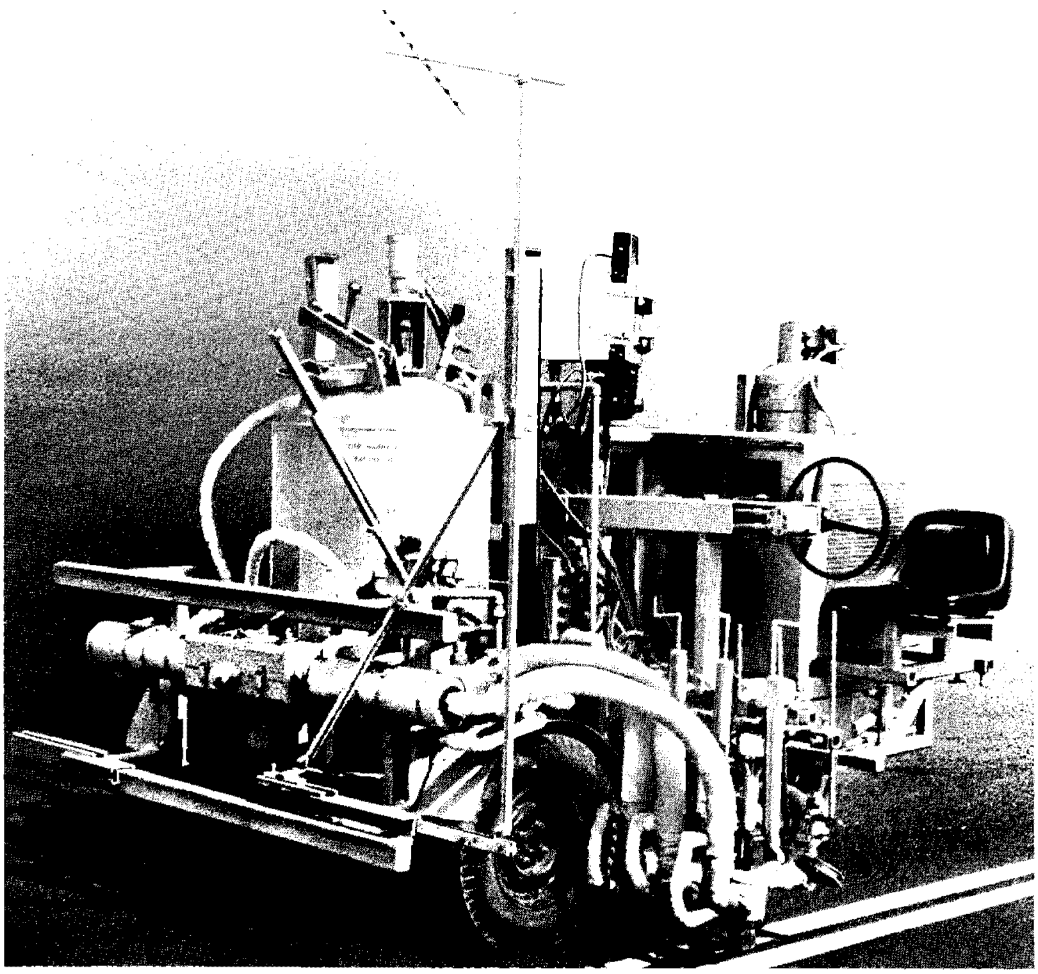


Figure 3-13 Small Thermoplastic Application Equipment

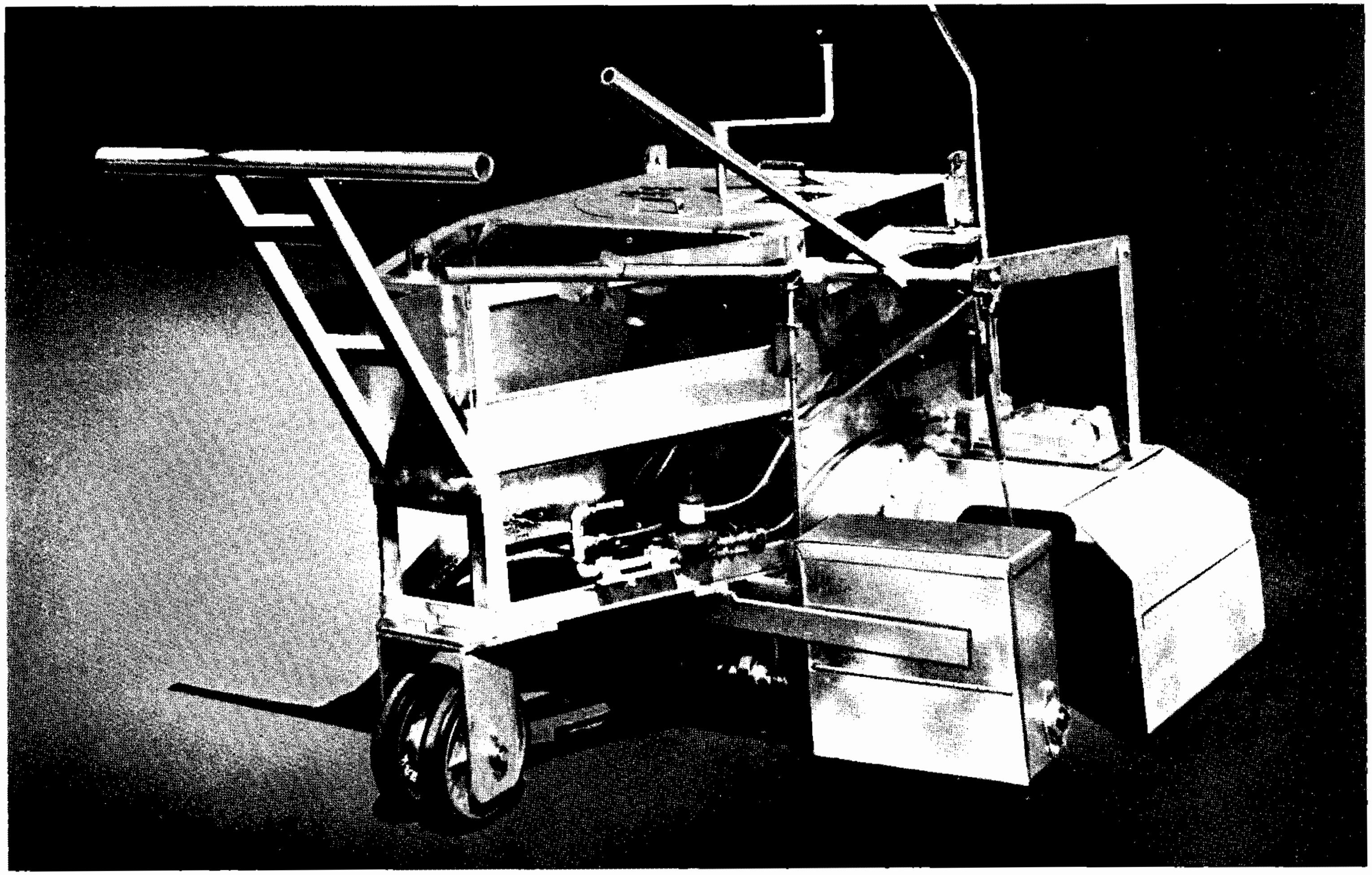
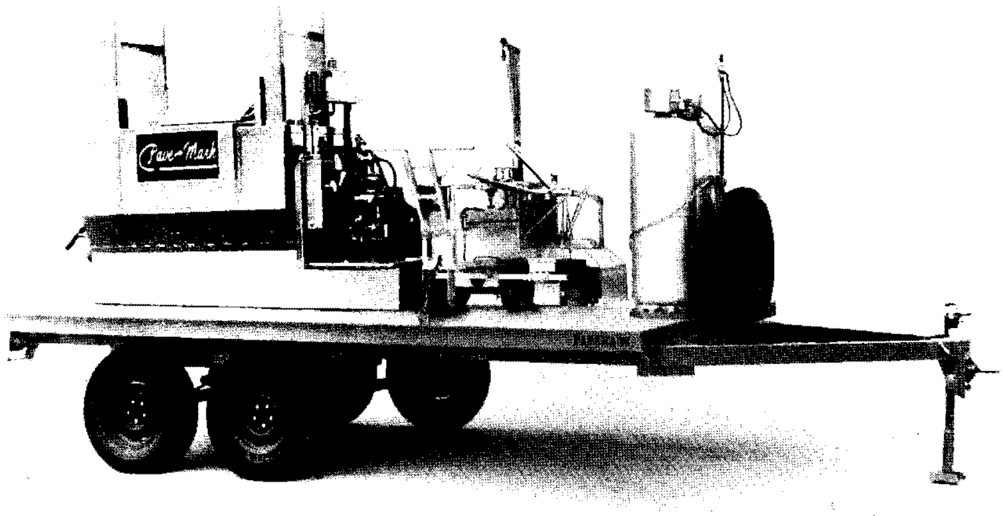


Figure 3-13 Small Thermoplastic Application Equipment (Con't)



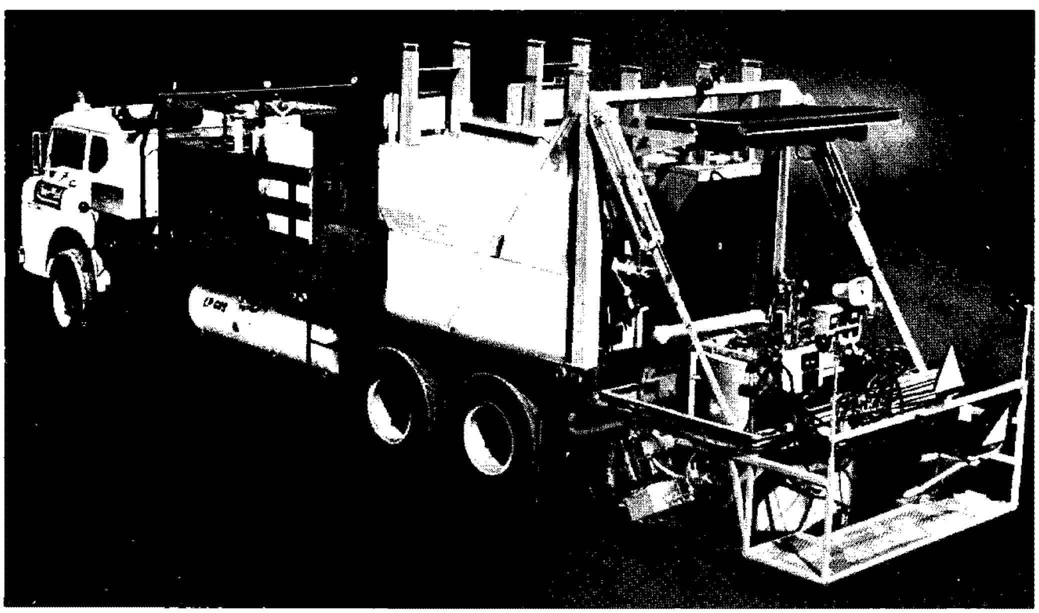


Figure 3-14 Large Scale Thermoplastic Application Equipment

The manual applicator usually consists of a melting pot holding a manual mixing paddle to keep the plastics from segregating or scorching, the extrusion spigot and die, and a bead hopper and dispenser. In one design, the machine is equipped with a propane tank and regulator to fuel the burner under the melting pot. Another type of equipment utilizes an auxiliary unit for heating the materials which are then transferred to the dispensing unit. An infrared burner over the extrusion die can be used to maintain the temperature during application.

For hot-spray manual application, the striper unit draws its compressed air supply through a long hose from a small truck-mounted machine. These small units have an average capacity of about 12 gallons of molten thermoplastic, equaling about 100 pounds.

Truck or skid-mounted thermoplastic stripers are self-contained units consisting of large melters with automatic agitators, heaters, electronic controls, intermittent interconnected timers to control the flow or spray to form solid or broken lines, material dispensing unit (extrusion die or spray nozzle), and bead hoppers and bead dispensers. The larger mobile units (Figure 3-14) range in size from a 1,000 pound to a 3,000 pound capacity melting pot.

Installation Crews

Applications utilizing these large machines are frequently contracted to specialty firms. The equipment costs can exceed $150,000 and local staffs are seldom experienced in operating such complex machinery. Some agencies maintain a small mobile unit for maintenance jobs or small installations such as new crosswalks or stop bars. Large installations are either bid separately (for existing pavements) or are included as part of a new construction or resurfacing contract. There are, however, a number of agencies who prefer to purchase medium size equipment and conduct their own striping activities often with assistance from the materials supplier. Crew sizes range from two workers for manual application to up to five for the largest equipment. (Not including following vehicles or other protection and traffic control personnel.)

Conditioning the Pavement Surface

The operational procedures for the application of hot applied thermoplastic markings is quite similar to the application of paint. Where no previous markings exist, the roadway must be marked with guidelines (cat tracks). The roadway should be dry with no surface dampness, dew, or subsurface wetness. The ambient temperature should be above 50 °F or the temperature recommended by the manufacturer.

The type and condition of the pavement surface during installation is a critical factor in assuring the best possible bond between the thermoplastic film and the roadway. The experience to date shows that better adhesion is generally achieved on bituminous pavement (AC) than on PCC. (It has been suggested that the improved bond results from the bituminous surface softening by the heat emitted from the striping equipment and molten material, thus fusing more completely with the film. A second possibility is that as a result of the difference in thermal coefficient of expansion of the PCC pavement and the thermoplastic film, that the thermoplastic will not adhere to the PCC pavement). Preparation of the surface may involve cleaning and/or the application of a primer-sealer to promote adhesion.

Although practices among highway departments differ, most specifications call for application on dry and clean pavement. The appropriate degree of dryness is usually a subjective judgment of the engineer in charge. Early morning dampness is suspected of causing some early failures.

The techniques for removing loose dirt, old paint, oils, etc. to provide the required clean surface include sandblasting, airblasting, hydroblasting, brooming, acid etching or grinding. (Some agencies report no precleaning requirements for bituminous pavements.) The most appropriate technique depends on the condition of the surface and whether any residual paint must be removed. Sandblasting and acid etching are usually restricted to PCC. Better adhesion on PCC is obtained when the surface is subjected to light grinding before application.

Depending on type of pavement surface and the recommendation of the supplier, primer may be required prior to application. The New York State Department of Transportation and a number of other agencies reported no difference in performance with or without primers when applied to bituminous pavements (Ref. 3-13). However, the use of a primer-sealer on PCC surfaces and old bituminous pavements is recommended by most material suppliers.

After conducting an extensive test of hot extruded thermoplastic installations, the State of New York has specified the use of epoxy primer on PCC. The large automated hot spray equipment used in California is equipped to lay a two-component epoxy directly ahead of the spray thermoplastic (Ref. 3-12). The most commonly used primer in recent years has been an epoxy resin. Synthetic rubber-based primers have not proved as effective.

There appears to be no clearcut consensus on the pretreatment—by primer or by cleaning—of the pavement surface prior to application. There is also little agreement on the optimum application rate of primer. Basically, it depends on age, porosity, and texture of the pavement as well as on the active solid contents of the epoxy solution used. The wet film thickness of primers range from 2 to 5 mils and is normally based on manufacturer's recommendation. Recent studies, however, indicate that 2 mils is adequate.

The proper handling and application of rapid-dry epoxy primer coatings is necessary for good bonding. For example, evidence suggests that the thermoplastic materials should be applied when the primer is still tacky (Ref. 3–5). Failures have been reported when the primer was either too dry or too wet. One specification (Ref. 3–12) requires that the spray-applied primer should be of a type that remains tacky for at least 10 minutes at 73 °F.

Installation of Cold-Laid Plastics

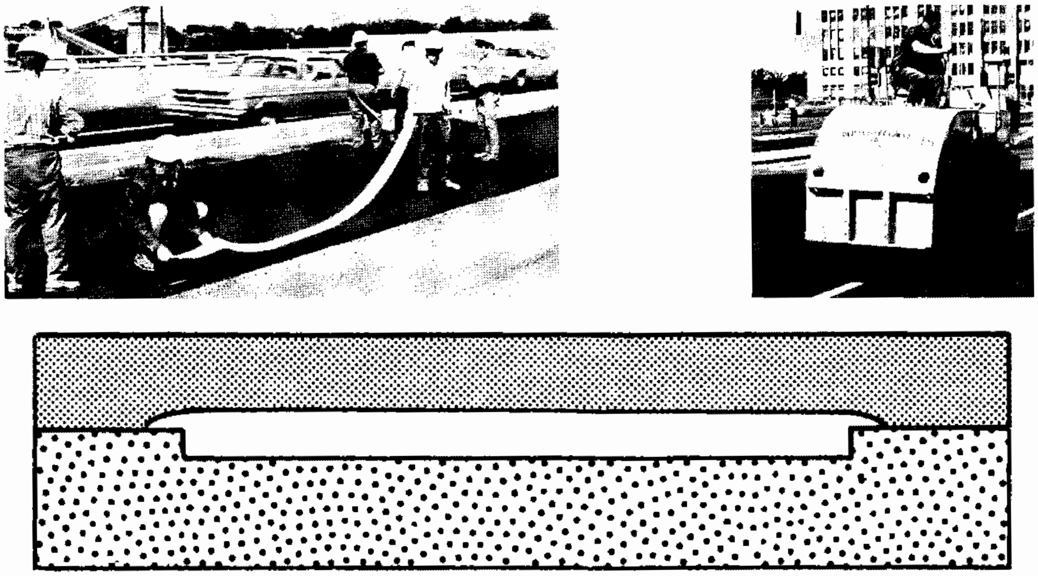
The cold-laid plastic pavement markings are supplied in continuous rolls of various lengths and widths, for yellow or white line markings, and in precut shapes to form standard letters and symbols. It is also provided in sheets from which special shapes, forms, or letters can be customized.

The line markings can be installed by the inlay method or the overlay method (Figure 3–15) depending on the specific application. With either of these methods, the markings are ready to receive traffic immediately after installation.

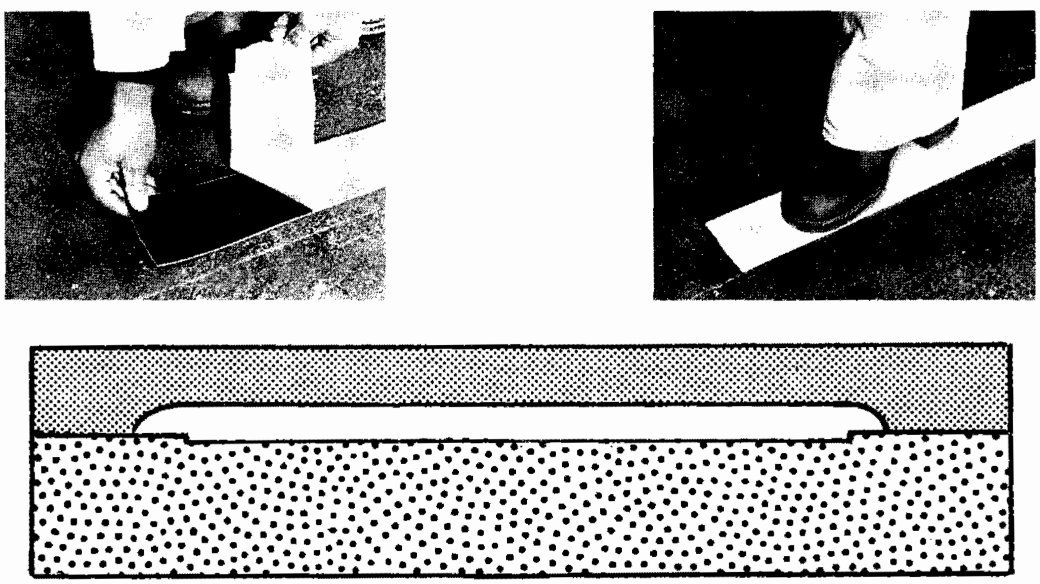
The inlay method is used with new construction or resurfacing of asphalt concrete surfaces. While the asphalt is still warm (at least 130 °F) the pressure sensitive, selfbonding tape is positioned in place and is tamped firmly into the asphalt during the final compaction. For longitudinal markings, a tape applicator device is available which follows the breakdown rollers and lays skip lines, double yellow lines, and solid white edge lines automatically (Figure 3–16). The tape as positioned is securely bonded to the pavement by the finish roller following behind. Precut shapes and letters must be positioned manually before compaction. The rolling tends to bevel the plastic strip into the pavement thus enhancing the bond and sealing out moisture.

The overlay method is employed on existing pavements. Pressure-sensitive film works well on good AC surfaces. On PCC pavement or old AC better bonding is achieved when contact cement is applied previous to installation. In this case, manufacturers may recommend two coats on the pavement and one on the film, particularly for intersection markings with heavy turning movements. The markings can be tamped by simply stepping on them, but most agencies prefer to use a light hand roller (tamper) to insure good initial adhesion until the tire pressure of traffic can securely bond the film to the pavement.

For construction or maintenance jobs which require the temporary delineation of new or altered travel lanes through the work zone, a thinner, self-adhesive tape can be applied directly on the pavement. Two forms of temporary marking tape are available. One form is intended for use in those types of construction projects where the removal of markings will not be required. The other form is designed for easy removability. Major advantages of the latter material are that it is highly reflective, is



a) Inlay Method (For New Asphalt Surfaces)



b) Overlay Method (For Existing Asphalt and PCC Surfaces)

Figure 3-15 Basic Methods of Installing Cold-Laid Plastic

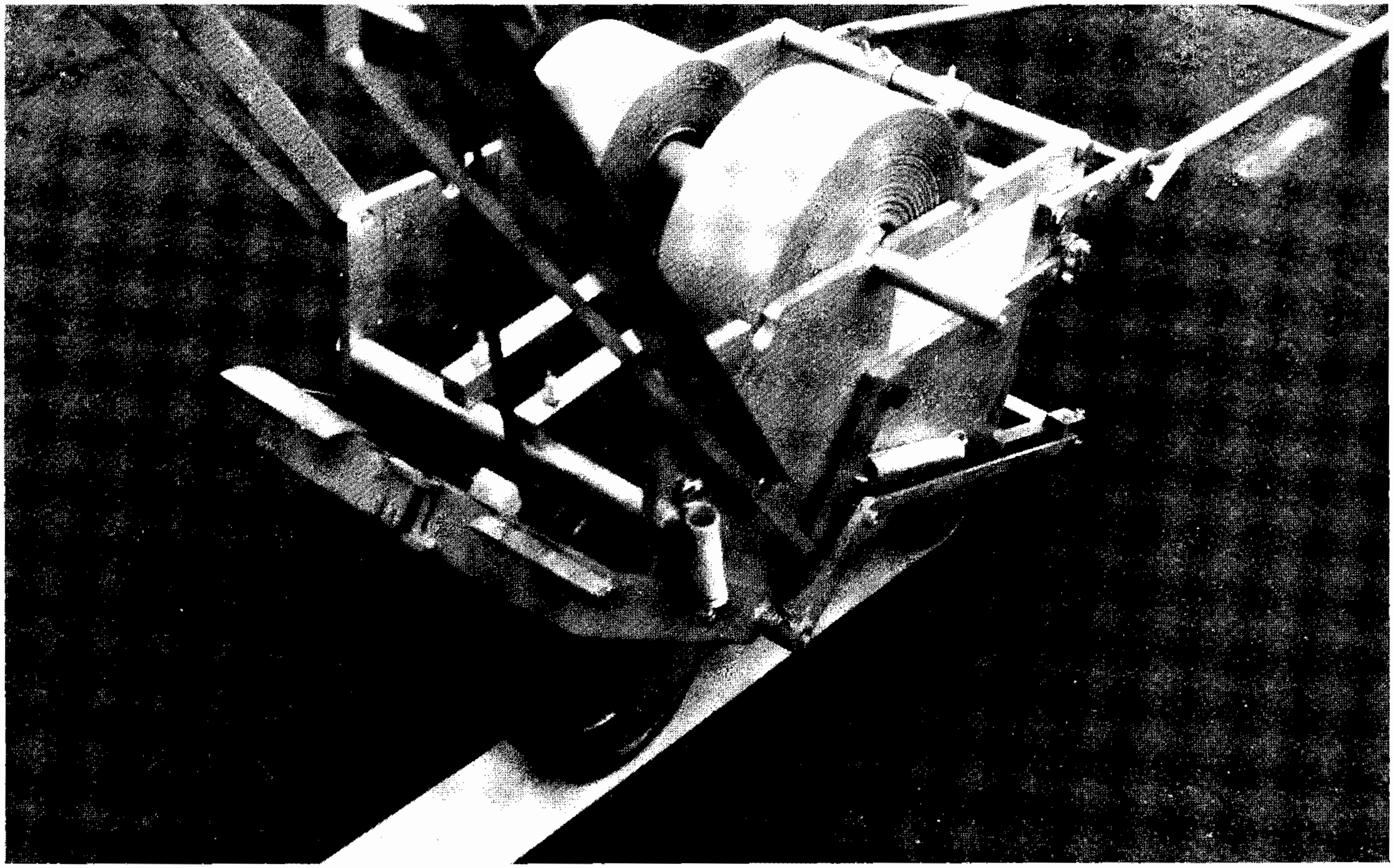


Figure 3-16 Pavement Marking Tape Applicator

quickly installed by a two-person crew, and can be removed easily when traffic flow changes are made.

3C-3 Raised Pavement Markers

The installation of RPM's is a simple operation. It requires neither special complex equipment nor specialized staff capability. New installations are commonly part of a construction or improvement contract. Maintenance (replacement), on the other hand, is usually performed by State or local forces.

General practice and individual procedures related to the various types of markers are discussed below.

General Practice

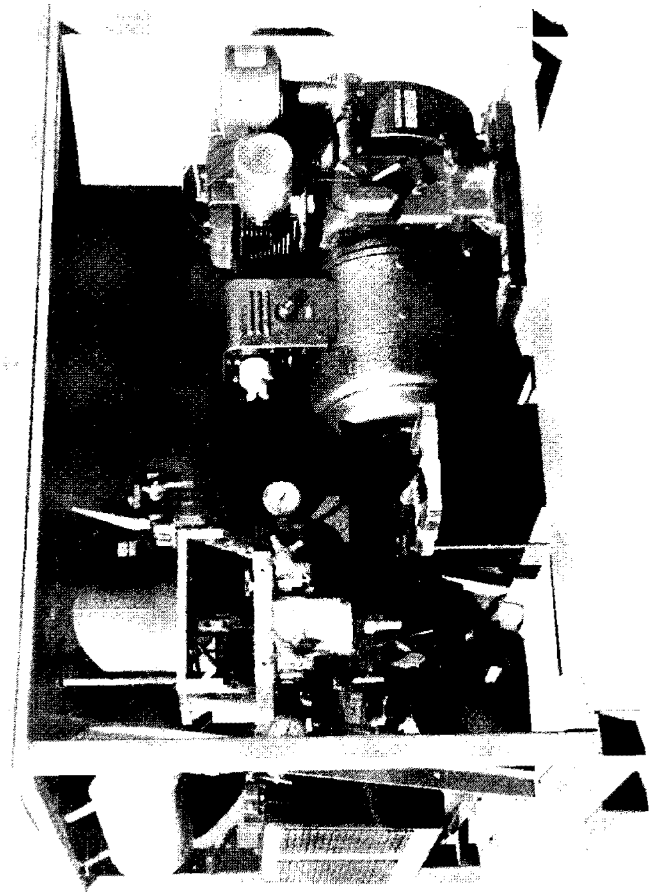
Most agencies indicate that the portion of the highway surface to which the marker is to be bonded by adhesive should be free of dirt, curing compound, grease, oil, moisture, loose or unsound layers, paint and any other material which would adversely affect the bond of the adhesive. Cleaning the surface of PCC and old asphalt concrete pavement should be undertaken prior to application of the device. Clean, newly placed asphalt concrete need not be blast-cleaned unless the surface contains an abnormal amount of asphalt or unless the surface is contaminated with dirt, grease, paint, oil, etc. However, new AC pavement should be allowed to cure 60 days, if possible, before installing RPM's.

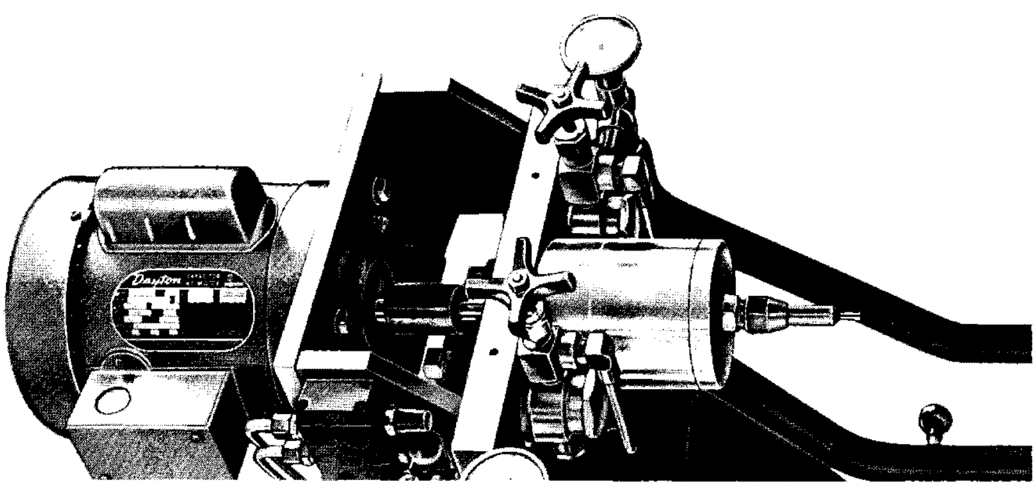
The adhesive should be placed uniformly on the cleaned pavement surface or on the bottom of the marker. There should be a quantity sufficient to result in complete coverage of the contact area with no voids present and with a slight excess after the marker has been pressed in place. The marker should be placed in position and pressure applied until firm contact is made with the pavement.

Excess adhesive around the edge of the marker, on the pavement, or on the reflective surfaces of the markers should be removed. A soft rag moistened with mineral spirits conforming to Federal Specifications TT-T-291 or Kerosene can be used to remove any excess adhesive. The marker must be protected against traffic impact until the adhesive has hardened. Traffic control and protection of the markers are similar to that required for striping operations.

Reflective markers should be placed so that the reflective face of the marker is perpendicular to a line parallel to the roadway center line. No pavement markers should be placed over longitudinal or transverse joints of the pavement surface.

When the raised markers are used to supplement a solid painted or thermoplastic pavement stripe, they are generally offset 2 inches from the edge of the stripe. This permits repainting the stripe without degrading the reflective properties of the markers.




Dayton

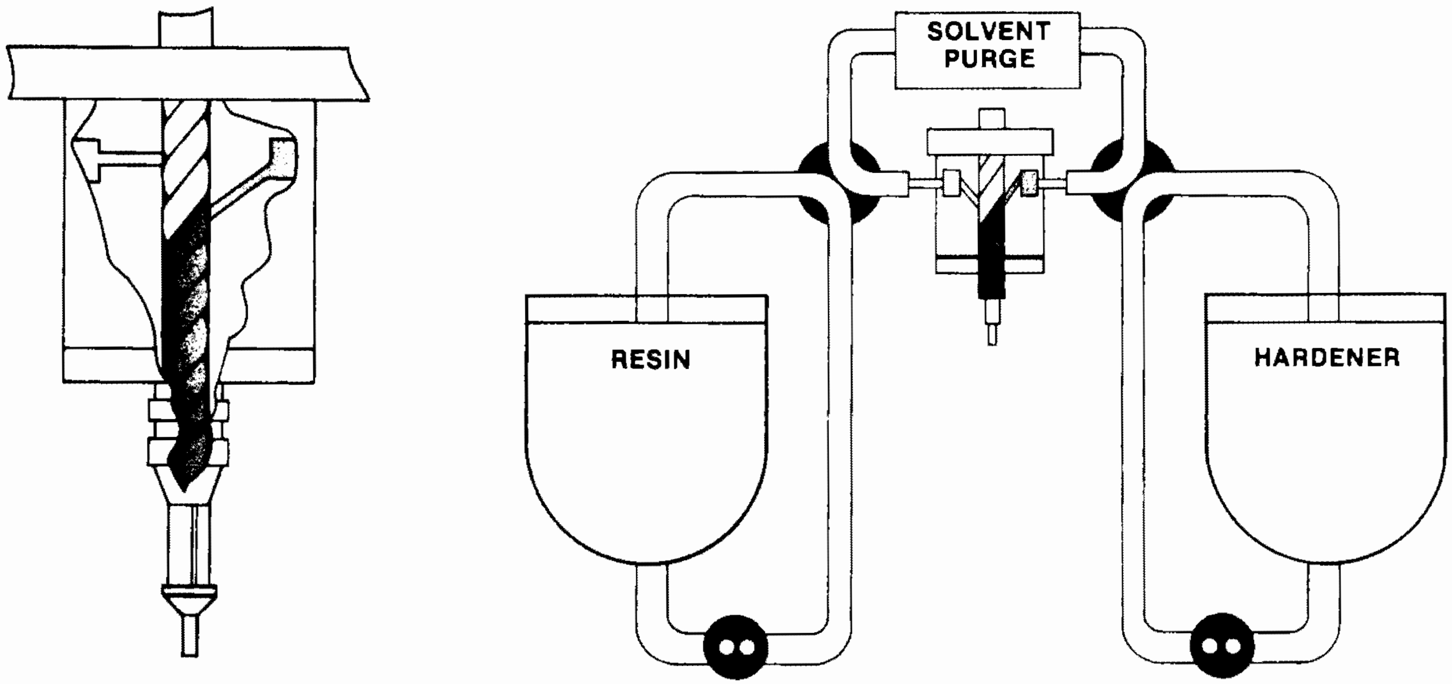


Figure 3-17 Typical Epoxy Mixing and Dispensing Equipment

Using Epoxy Adhesives

There are numerous formulations of epoxy bonding agents. The proper proportioning, mixing, extruding, and handling in general are critical to the application procedure.

Essentially, all two-part epoxies require that the mixing operation and the placement of the marker on the pavement be done quickly. Whether hand mixed or machine mixed, most standard types of epoxy require that the marker be coated, aligned, and pressed into place within minutes after mixing is started. Consequently, no more than a quart of adhesive should be hand mixed at one time.

Rapid-set adhesive is usually mixed by a two-component automatic mixing and extrusion apparatus such as that shown in Figure 3–17. For a typical large scale installation, a crew member is positioned on a platform located low on the side of the truck between the two axles. The mixing and extruding apparatus is located nearby. A predetermined amount of the mixed epoxy is expelled onto the bottom surface of the marker which the operator then positions on the pavement within the 40 to 60 seconds allowed.

To achieve a proper bond, care should be exercised to assure that the adhesive is used in accordance with manufacturer's instructions. For example, some standard set type adhesives require that the pavement and air temperature be above 50° F. Rapid set can usually be applied at temperatures as low as 30° F. Normally, no marker should be set if the relative humidity is over 80% or if the pavement is not surface dry.

One final note: epoxy adhesives can cause severe skin irritation if proper precautions are not followed. Crews should use gloves and protective cream to prevent contact with the adhesive. If contact with the skin occurs, the area of contact should be washed thoroughly with soap and water as soon as possible. Solvents should not be used to remove adhesive from skin. (Toluene or equivalent may be used to clean tools and equipment.)

Snowplowable Markers

The use of conventional RPM's has increased dramatically in areas experiencing minimal snowfall. Damage from snowplow blades has been the major deterrent to their installation in snow areas. The loss and damage factor associated with snowplow activity is prohibitive and has led to the development of a "snowplowable" marker. This marker consists of a two-way replaceable reflector assembly protected by a specially hardened metal casting (See Figure 3–7). The casting is firmly anchored by an epoxy adhesive into double grooves cut vertically in the pavement by radial saw blades. Installation details and specifications are given in Figure 3–18.

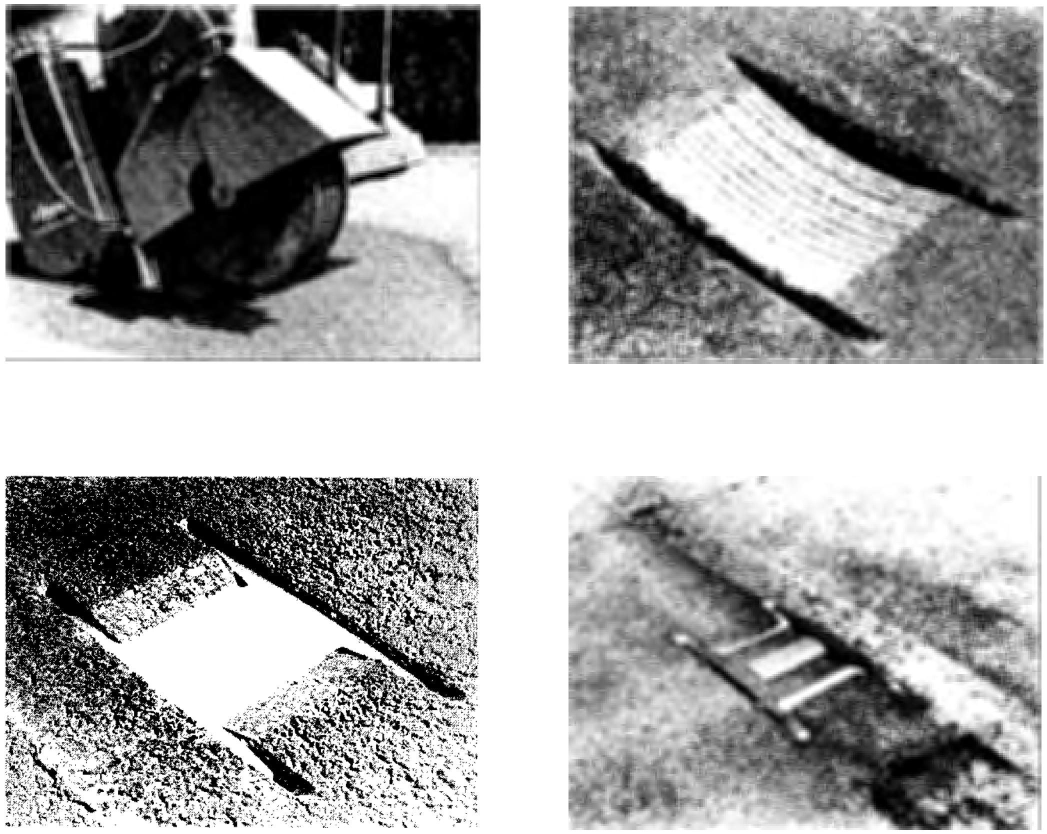


Figure 3-18 Application Detail of Snowplowable Reflectorized Marker

The snowplow blade rides up and over the shallow tapered planes usually without damage to the reflector unit, casing, or snowplow blade. Because of the low profile of the casting (6° slope with 7/16 inch maximum height) the rise and fall of plow blade is hardly discernible to the plow operator when the plow is moving slowly.

3D. OPERATIONS AND MAINTENANCE

The operations and maintenance of roadway marking systems are usually a function of local or State forces. Observations of maintenance activities and discussions with maintenance crews suggest that procedures have evolved over time that are both efficient and effective for the needs of the agency or individual crew. In view of the benefits that accrue from crew experiences and familiarity with equipment and local conditions, most maintenance manuals are relatively general, leaving the step-by-step procedures to the responsible agency within the limitations of established policy and standards.

The following observations address those maintenance practices and developments that have proved effective or show promise for future use.

3D-1 Maintenance Levels

As in all maintenance functions, there are two basic categories of maintenance: periodic or preventative maintenance (routine), and immediate or emergency repairs (as needed). In the context of delineation, the former is performed to maintain the system at a safe operational level commensurate with established policy or standards. The latter functions usually involve returning a suddenly hazardous situation to a safe condition shortly after it occurs and is identified.

The approach to routine maintenance varies among agencies. If expected service life is adopted as the primary determinate for routinely scheduling the replacement of markings, the performance history, and the traffic characteristics of individual roadway sections must be known. For example, if experience or field tests have indicated that a particular type of lane-line marking can be expected to remain effective for 2 years on long sections of high-speed multilane freeways and 1 year in areas of heavy turning movements such as near ramps and merge and diverge areas, then replacement can be scheduled accordingly. Such routine replacement is not always a cost-effective procedure even though this practice does not require night inspection. The condition of the marking to be replaced may not warrant the effort, or the marking system may have deteriorated beyond safe levels.

A more desirable criteria for replacement is based on a predetermined level of wear that can be tolerated without seriously degrading drivers' visibility, particularly under adverse weather conditions. Once the level is specified, inspections are conducted, usually at night, to identify areas which fall below the acceptable level. Such night inspections are usually scheduled near the end of the expected service life. In some cases, spot checks are conducted annually prior to the onset of adverse weather cycles. Inspection of roadway markings may also be included as part of regularly scheduled traffic control device inventories. Inventories, however, are seldom conducted as frequently as needed to assure that the markings are still effective.

"As needed" maintenance is important from the standpoint of legal responsibility as discussed in Part I under "Legal Implications". Care must be exercised to assure that appropriate delineation is not interrupted by major accidents or natural disasters which may have damaged or removed raised markers or post-mounted delineators to the point of critically degrading the intent of the marking system.

This type of maintenance is also commonly associated with construction work zones and unexpected snow or ice storms. In areas accustomed to seasonal snowfall, inspection and maintenance after the snowfall season is usually considered routine maintenance.

3D-2 Maintenance of Painted Markings

In the case of painted markings, maintenance involves repainting when the striping loses its contrast, base film, and reflectivity. The decision to repaint and scheduling the activity is usually based on established policy and is a function of the agency maintenance chief. The availability of materials, equipment, and crews are also important considerations from a maintenance standpoint. Materials must be selected, purchased, and stored. Equipment must be serviced and maintained to assure proper operation and prevent on-the-road breakdowns. Trained crews must be available and appropriately scheduled.

Scheduling Restriping Activities

Some agencies have predetermined schedules which identify sections of roadway to be periodically restriped. Restriping programs involving a large volume of streets and highways can be computerized to assure a cost-effective allocation of equipment, crew, and materials. When a smaller mileage is involved, a manual scheduling process is commonly used. In either case, past experience and agency policy define which roadways must be restriped once, twice, or three or more times a year.

Other agencies may prefer to schedule restriping based on night inspection of the various facilities. In some instances, residential streets and other low ADT roadways are scheduled on a periodic basis and the busier high ADT facilities are scheduled on an "as needed" basis indicated by night inspection.

Determining when to replace painted markings is, as best, an inexact science vulnerable to subjective judgment and budgetary expedience. Several agencies have reported that overtime costs for night inspection cannot be justified, especially since the resulting evaluation is based on an individual's opinion without a precise scientific technique. Local knowledge of traffic and climatic conditions coupled with experience with the various delineation materials is considered an equally effective technique for scheduling these activities.

The weather patterns of the area determines, to a large extent, the time period available for maintenance. In high snowfall areas, for example, painting is usually limited to the late spring, summer, and early fall months. The materials selected and application techniques employed normally reflect the relatively short life expectancy of painted markings under heavy winter conditions.

Another factor that should be considered in scheduling repainting activities is coordination with major improvement programs and with other maintenance activities. Resurfacing, realignment, or changes in traffic patterns which would require new or repainted markings may render previously scheduled restriping unnecessary. If these activities are not adequately coordinated, significant expense of removing a newly restriped line could be incurred. While agencies hesitate to report such lapses, it is a relatively common occurrence.

This is not to suggest that restriping should be indefinitely postponed because of planned changes or improvements, particularly if the markings are significantly degraded in a hazardous location. The type of paint, the thickness laid, or the use of temporary markings should be carefully considered when changes are anticipated. The option to postpone restriping must be balanced against the possible cost of removal and the potential safety and legal ramifications should the lack of adequate delineation create an unsafe condition.

Removal of Painted Markings

Every highway maintenance facility needs to provide a capability for removing existing markings that no longer define the safe path of travel. The difficulties involved in the removal of markings have been compounded by the increasingly successful effort to improve paint durability and adhesion.

Traditionally, methods of removal include grinding, burning, chemical treatment, sandblasting, hydroblasting, and high pressure water jetting (Ref 3-16). Over-painting no longer appropriate markings with black paint and bituminous solutions is specifically disallowed by the MUTCD. This treatment has proved unsatisfactory as the original lines eventually reappear as the overlying material wears away under traffic. In addition, lines which are covered in this way are still visible under certain conditions (low angles of illumination).

A prime requisite in determining the best method for stripe removal is that the treatment should have a minimum effect on the roadway surface; that is, it will not materially damage the pavement surface or texture. Chemical treatment may cause damage to the pavement surface, drainage channels or pipes, and consequently is seldom considered satisfactory.

Removal of markings by grinding is not considered totally successful as some remnants of the marking usually remain. Generally, sandblasting has been the preferred method of treatment.

Sandblasting is particularly effective when the surface is rough and porous. This technique will do little damage to asphalt and the resulting scar will be barely noticeable. Sand deposited on the pavement should be removed as the work progresses to prevent accumulations which might interfere with drainage or constitute a traffic hazard. High pressure water or hydroblasting has also been used successfully under some conditions.

The problem of removing traffic markings without damaging the pavement or leaving discernible traces of the marking has received considerable attention during the last several years. The most promising system so far involves burning off the material. This technique, called the Excess Oxygen System, consists of two wide, flat burner heads mounted in tandem on a simple hand-propelled cart (Figure 3–19). The front nozzle (fuel head) burns propane and oxygen while the second nozzle directs pure oxygen at the burning surface. This combination produces an extremely hot flame (5,000 °F) which rapidly combusts the paint stripe. This rapid flash burning allows fast lineal travel down the roadway.

The rapid progression down the roadway permits less heat to be transferred to the pavement. Consequently, the possibility of pavement surface damage is substantially reduced. After the passage of the burner, the residual ash on the pavement surface consists largely of combusted glass beads, pigments, extenders, and fillers, indicating that burning has been completed. The resinous binder material will have been burned away. The ash should appear uniformly across the marking area to indicate sufficient burning.

The rate of removal varies with the thickness of the marking. Up to 20 mils of a typical alkyd-chlorinated rubber paint marking can be removed per pass at a rate of 7 to 15 feet per minute. For heavier build-up of paint, more than one pass may be necessary because of the ashing residue. That is, as the ash residue accumulates, it provides a shielding that prohibits further penetration of the flame into the marking.

The equipment and its operation is simple and inexpensive. Much of the required equipment already exists in most highway division maintenance facilities. The only equipment unique to this method is the fuel and excess oxygen heads which are commercially available as an off-the-shelf item. Plans, specifications, and operations manuals are available from FHWA (Ref. 3–14 and 3–15). A number of States are building their own version of this unit at a cost ranging from $200 to $400. The operating cost including fuel, labor, and vehicle costs is reported to range from $0.05 to $0.10 per linear foot of 4-inch marking removed.

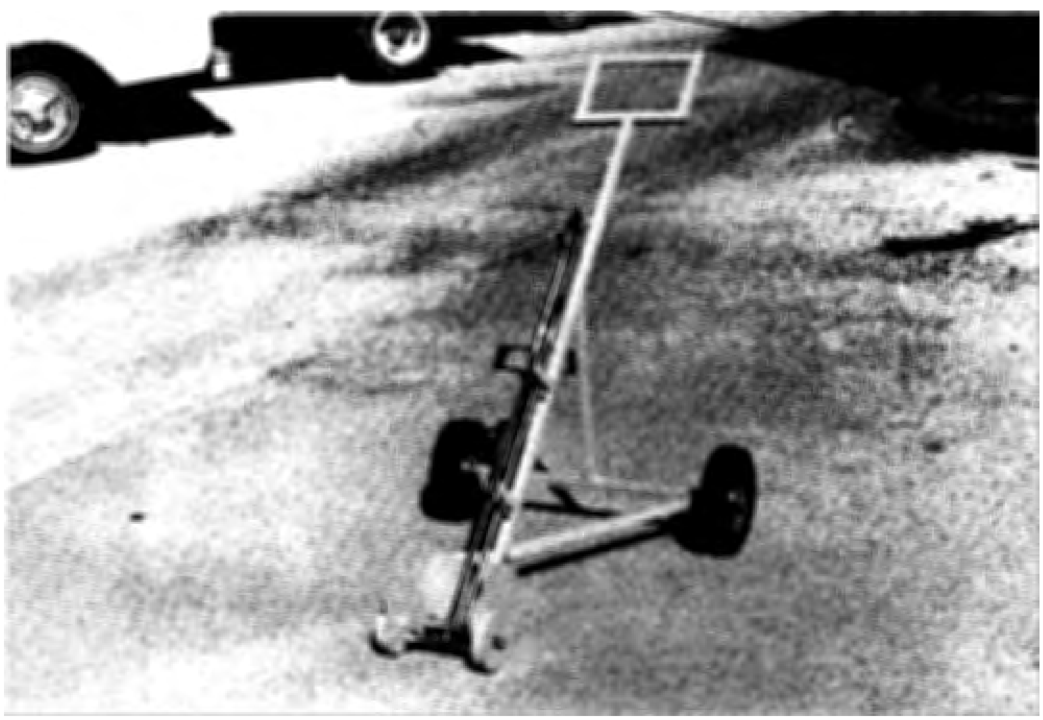


Figure 3-19 Excess Oxygen Paint Removal Unit

3D-3 Maintenance of Thermoplastics

One of the advantages of a thermoplastic marking is its durability. Depending on the material used and the roadway characteristics, thermoplastics can provide virtually maintenance-free delineation for a number of years. Some of the maintenance concerns related to thermoplastics are discussed below.

Staining

In very hot climate, thermoplastic markings can become discolored or badly stained by tire tracks particularly on bituminous pavements (AC). This degrades the daytime contrast and visibility, but seldom effect night reflectivity. Thermoplastics are, however, somewhat self-cleaning during rainy weather. That is, the tire action on wet markings will remove most of the stains. In hot, dry areas, it may be desirable to consider cleaning the markings by washing with a mild detergent.

Patching

The nature of thermoplastic, especially the thicker extruded installations, is such that pieces of the markings will chip away if the bond to the pavement is faulty or if the internal cohesion of the pavement itself is unstable. Almost all of the thermoplastic materials, hot and cold applied, can be patched by placing a thin overlay of compatible material over that portion of the old line. This is usually accomplished with a manual applicator.

Replacement

When the thermoplastic markings are no longer effective and must be replaced for safe operations, it is common practice to renew the lines with an overlay of compatible material. This can be treated as a scheduled maintenance activity, a separate project, or as part of a larger improvement program. Depending on the size of the installation and agency policy, the work may be performed by agency forces or contracted.

In some cases, thermoplastic markings outlive their reflective properties. One agency experimented with using paint and reflective beads overlaying the old thermoplastic to obtain night visibility. The paint was used as a binder to retain the beads since much of the thermoplastic line was still in place. If the paint adheres to the thermoplastic and if the thermoplastic base is securely bonded to the pavement, this could represent an inexpensive method of upgrading markings with inadequate reflectivity. However, there is no available information on the performance of this combination.

Removal

Thermoplastic markings are intended for longlife installations. As such, they are relatively difficult to remove. Those properties that enhance durability (thickness, integral bond with pavement) serve as deterrents to easy removal.

On either bituminous asphalt or PCC, the removal of a thermoplastic marking will leave some degree of scarring on the pavement surface. The extent of the scar will depend on the method of removal employed. Sandblasting is frequently used for large scale removal jobs. One operation features a high-pressure water jet used in conjunction with sandblasting. This minimizes the residual sand left on the pavement and enhances the effects of the sandblasting.

The excessive oxygen paint removal equipment described above has also been used to remove hot-spray applied thermoplastic. In this case, the hot flame melts the plastic which is then removed with a straight hoe. Subsequently, the residual marking is reburned and the burned residue is brushed away leaving only a slight indication of where the line had been. This will disappear with traffic wear.

For smaller jobs, an air hammer and chipping blade may be used, although on asphalt surfaces this requires extreme care to prevent inordinate damage to the pavement. To remove an occasional arrow or legend, a hand hammer and a chisel can do a satisfactory job.

Permanent installations will, of course, be completely covered during any type of roadway resurfacing or rehabilitation project. No vestige of the marking will remain.

The self-adhesive cold-laid tape specified for short-term temporary markings in construction zones can be removed with relative ease. The material can simply be dislodged and removed by hand or rolled up on the applicator as shown in Figure 3-20. This type of operation will leave no lasting scar. A dim indication of where the material was formerly installed may remain, but this will be eradicated by traffic film in a short time.

The aluminum-based tape material is more difficult to remove if primer was used and/or if the marking has been in place for a long period. In these cases, the aluminum base can be heated to break the adhesive bond. The markings must then be scraped from the roadway surface.

Because of the long life and inherent difficulties in removing permanent thermoplastic markings, application of this material should be carefully considered to insure that changes in marking patterns are not imminent. Road maintenance programs, future permit work and utility repair programs should also be considered to avoid installing thermoplastics on a roadway that will be resurfaced during the early life of these markings.

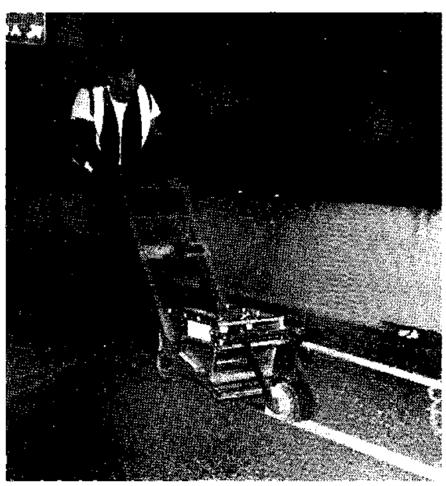


Figure 3-20 Removal of Cold-Applied Markings

3D-4 Maintenance of Raised Pavement Markers

California is probably the largest user of RPM's in the United States. The State has adopted a policy of using raised markers on all freeways and a majority of primary roads where snow is not a problem. California now has in excess of 30 million markers in place and replaces approximately 380,000 a year.

While not applicable to all situations, various California districts have developed several interesting shortcuts in marker replacement. For example, on some freeways where two successive reflective markers are badly damaged another reflective RPM will be placed immediately in front of the defective marker. This can be accomplished very quickly since time is not expended in removing the original marker. It is not unusual to find random groups of two and three damaged reflective markers lined up in place near a new marker.

Replacement on long sections of several freeway miles is often scheduled for early Saturday or Sunday morning when coning will not be too disruptive to traffic. Whenever possible, other site maintenance is scheduled for the same period to take advantage of lane closure and other protective activities.

The simplest form of operation consists of a crew member walking alongside the epoxy-dispensing truck and indicating what markers are to be replaced. The crew member acting as the "applicator" is located in the well of the truck. He activates the epoxy dispenser which extrudes a measured quantity of the mixed epoxy onto the bottom side of the marker which is then placed next to the damaged marker or near the location of a missing marker. A following crew member removes the old marker by hammer and chisel with one or two taps and disposes of it in a hopper in the back of the truck. Cones and following vehicles are used as needed to protect the crew and the markers from traffic. This operation can move at 1 to 3 miles per hour depending on the number of markers to be removed and replaced.

Semi-annual nighttime inspections are conducted on roadway sections containing markers nearing the end of their expected service life by the maintenance engineer and his staff to determine the scheduling priority. Generally, this type of replacement operation is scheduled when 50 percent or more of the markers are defective or missing. It is also general practice to routinely replace any damaged or missing markers during other maintenance operations that require coning and/or lane closure.

When self-adhesive markers are used for temporary delineation on roadways through, or adjacent to, construction work zones, inspection and maintenance are critical safety considerations. In particular, areas of heavy truck or construction equipment traffic should be carefully monitored and missing markers replaced to assure that the temporary traveled way is clearly defined. This is often either a responsibility shared with the contractor or the sole responsibility of the contractor. The courts, however, have proved somewhat capricious in the adjudication of agency responsibility in accident litigation. Even when the responsibility rests solely with the contractor, the cost expended by the State in monitoring these hazardous locations is very small relative to accident judgments.

It has been noted that during hot dry periods, road film, oil, grease, and other street debris will seriously degrade the reflectance properties of reflective markers. It is also noted that tire marks can stain nonreflectorized ceramic markers to the point that they are no longer visible, day or night. Most of the commonly used markers are self-cleaning to some extent when wet. Loss of delineation from staining is, therefore, not a critical problem in geographic areas that normally experience summer rains. It can become significant in hot dry areas of the west and southwest.

Because of the long, hot, dry summers experienced in parts of California, the feasibility of cleaning markers was investigated. It was found that film on markers was not easily soluble in any of the common organic solvents, but was easily removed with a cleanser containing a fine abrasive. To accomplish this, a unit was mounted on the side of a 2-ton truck. A detergent water solution from the truck was supplied to the brush during the cleaning operation. The device folded into three sections for easy transport. This unit was used successfully in five California districts and similar equipment could be useful to other agencies experiencing this type of problem.

3D–5 Maintenance of Post-Mounted Delineators and Object Markers

Post-mounted delineators and some forms of object markers are highly susceptible to knockdowns, vandalism, and theft. Bent or missing delineators obviously needing attention should be repaired promptly in order to serve their intended purpose. This is particularly urgent where the bent or knocked-down post protrudes in or near the travelled way.

As indicated earlier, "road splash" and dirt can degrade the visibility of the reflective units to an unacceptable level although the reflective properties are still intact when clean. Some agencies have developed methods for washing these reflectors during dry periods. These techniques range from simple watering under pressure to a revolving brush device.

Post-mounted delineators and object markers are also vulnerable to damage from heavy snowdrifts, snowplows, and other roadside maintenance vehicles. Maintenance crews should be instructed to return to plumb position posts that have been inadvertently hit by equipment during other maintenance activities.

In high snowfall areas, the condition of post-mounted delineators should be routinely observed at the end of the snow season. Replacement and maintenance should be scheduled for those severely damaged by snowplow equipment or bent askew from the weight of the snow pushed onto the shoulder by the plows.

Prior to the beginning of the snowfall season, many agencies install snow poles to extend the delineator above the height of the expected snow drift. It is a relatively simple procedure to attach the snow pole by means of two brackets and associated bolts and washers which fit existing holes. The removal of extended snow poles in the spring can be combined with cleaning, replacement or other delineator-oriented maintenance.

Maintenance for these delineators does not ordinarily require a large crew or complex equipment. Because the posts are located slightly off the shoulder (or object marker panel within an island), there may be a tendency to forego proper safety precautions while conducting the work. While lane closure or coning may not be required in all cases, protection of the workers by signing or by a strategically placed service vehicle is strongly recommended. Vehicle encroachment onto the shoulder or island is too common to be ignored.

Lastly, the long life of post-mounted delineators and object markers may result in a low priority of maintenance for these devices. Lack of prompt attention to the replacement of missing delineators or damaged posts may ultimately prove costly. In extreme weather, post delineators are often the only means of guidance available to the driver. The same priority assigned to the installation of this form of delineation is equally applicable to an effective level of maintenance.

3E. SPECIAL CONSIDERATIONS

The MUTCD is quite clear in prescribing and illustrating guidelines for the application of conventional markings, pavement word messages and symbols, curb markings, etc. There are two topics of concern to marking systems that have not been precisely defined in the MUTCD: application patterns of raised markers and new techniques for establishing no passing zones. Primarily, these items have been the subject of investigation and evaluation for incorporation into the MUTCD as a rule change or request for interpretation.

The following section presents a general summary discussion of the suggested guidelines currently under development. Because these guidelines have not as yet been formally adopted, the up-to-date status and specific applications should be confirmed by the using agency.

3E-1 Configurations for Raised Markers Usage

The MUTCD presently provides illustrations and application guidelines for the configuration of marking systems using paint, thermoplastic, and other durable markings. While it states that "...Individual unit markers, generally less than 1 inch in height, may be used for pavement marking purposes" it does not show possible configurations or patterns for the use of these devices.

An effort is underway to develop national standards for the placement of pavement markers when they are used alone or in combination with other on-the-road striping. Figures 3-21 through 3-30 are intended as general guidelines only and are subject to change when efforts have been completed to adopt national standards. Figures 3-21, 3-22, and 3-23 present the basic patterns and spacing for centerlines, lane lines and other solid lines currently in general use.

Figures 3-24 through 3-30 are based on a report prepared by the Amerace Corporation and modified by the FHWA. Since policy among agencies may differ, the patterns shown are generally dimensionless. In these figures, "Normal Spacing, N" represents the combined length of the stripe and gap. Drawing dimensions can be adjusted to meet individual agency requirements.

The marker pattern for construction zones that appears to provide the driver with the best visual perception on tangent sections when markers are used to supplement painted lines consists of a spacing of 40-foot. That is, a reflective RPM is placed midway between each 10-foot paint stripe as shown in Figure 3-30, a and b.

A spacing of 20 feet is recommended for curves since it provides the driver with twice the number of markers as shown in Figure 3-30, d and e. It also recognizes the premise that the loss rate on curves will be higher, leaving voids in the pattern.

SYMBOLS

Yellow Stripe

White Stripe

Two-Way Yellow RPM

Two-Way White RPM

One-Way Yellow RPM

One-Way White RPM

Non-Refl. Yellow RPM

Non-Refl. White RPM

White/Red RPM

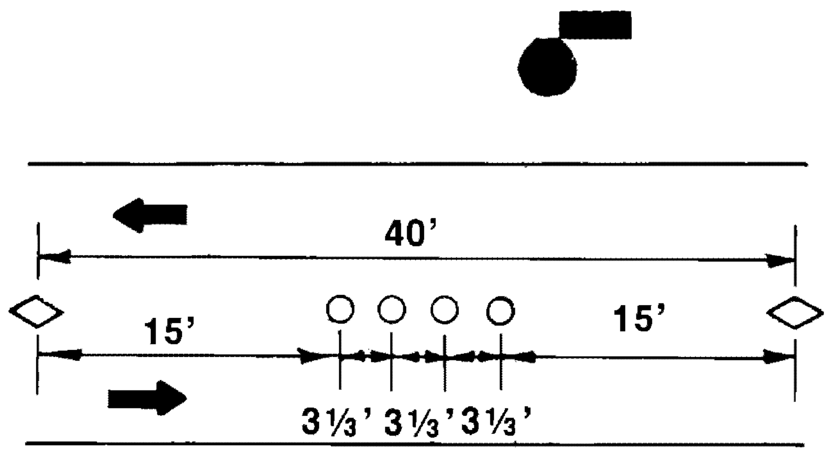
Yellow/Red RPM

N Normal Spacing

Directional Arrow

Pavement Arrow

Symbols to be Used with Figures 3-21 through 3-30



a. RPM System (2-lane, 2-way)

b. Combination RPM/Stripe

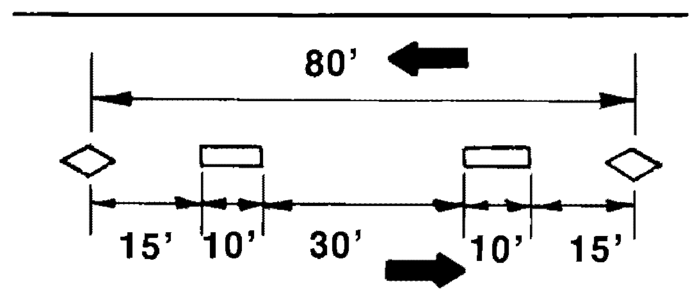
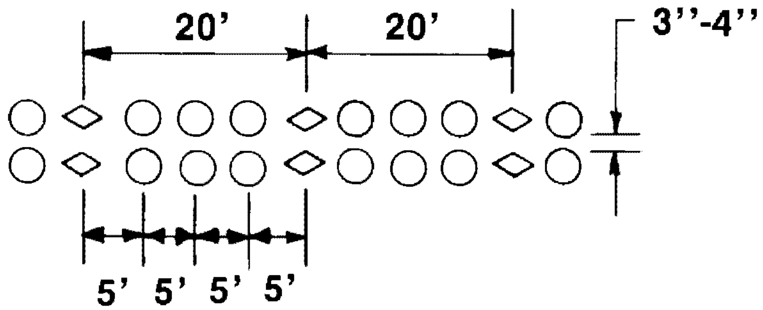


Figure 3-21 Centerline Patterns

c. RPM System (multilane, 2-way)



d. Combination RPM/Stripe System (multilane, 2-way)

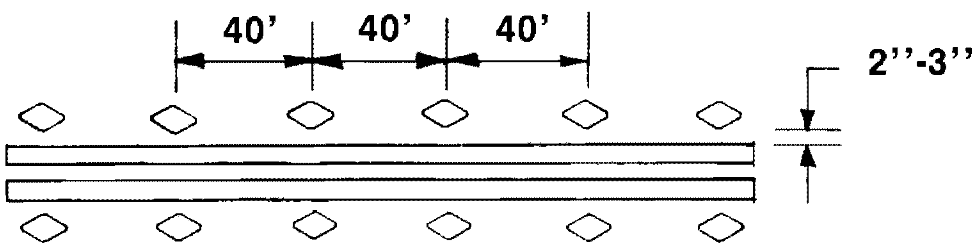
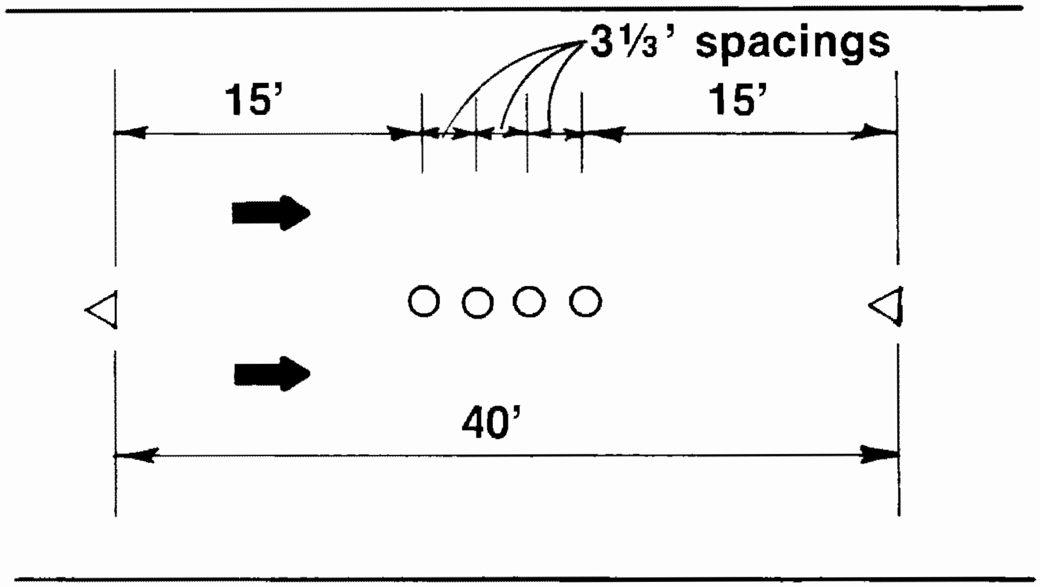


Figure 3-21 Centerline Patterns (Con't)



a. RPM System

b. Combination RPM/Stripe System

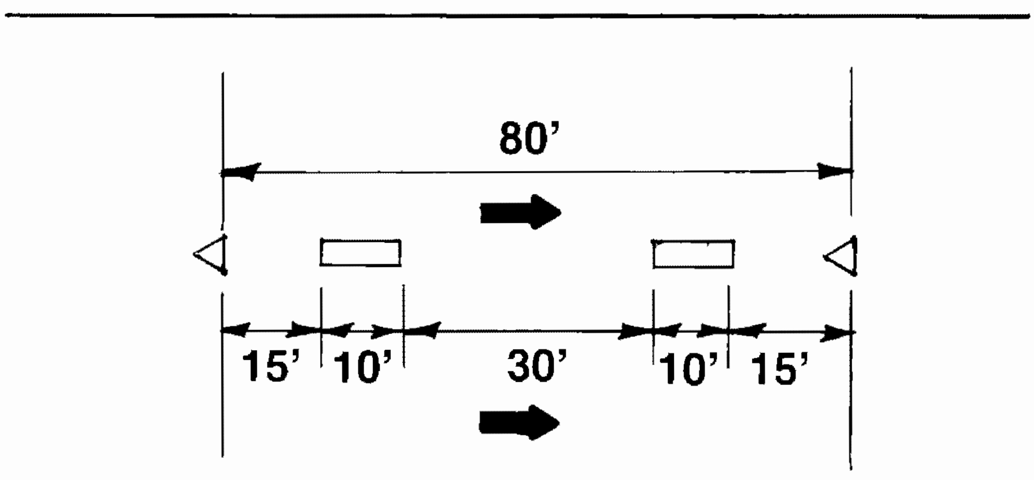
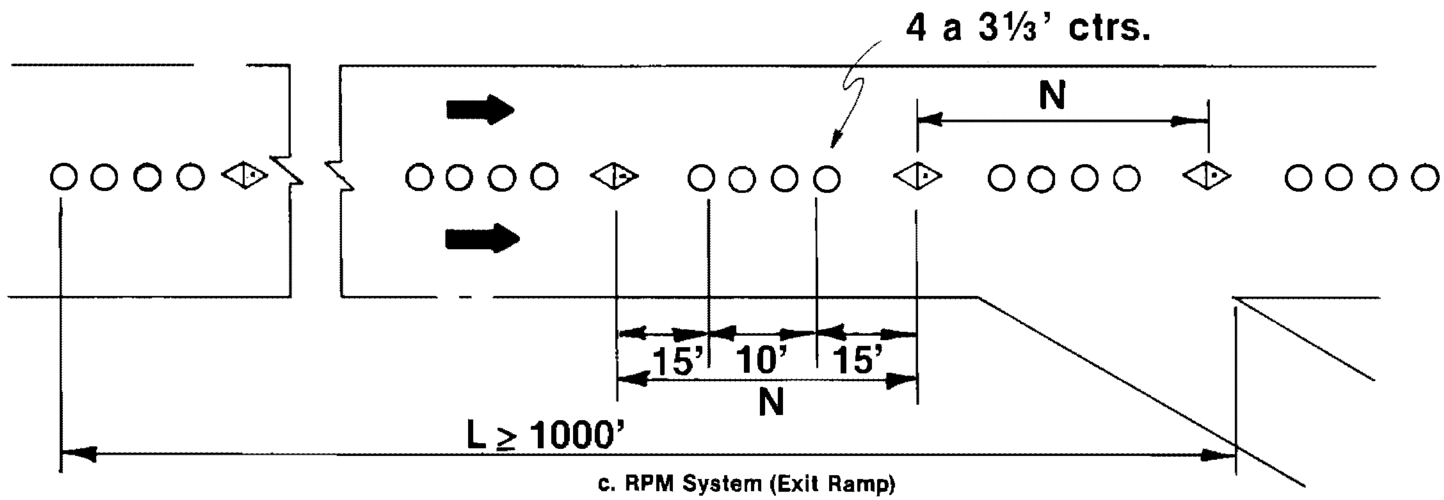


Figure 3-22 Lane Line Patterns



c. RPM System (Exit Ramp)

d. Combination RPM/Stripe System (Exit Ramp)

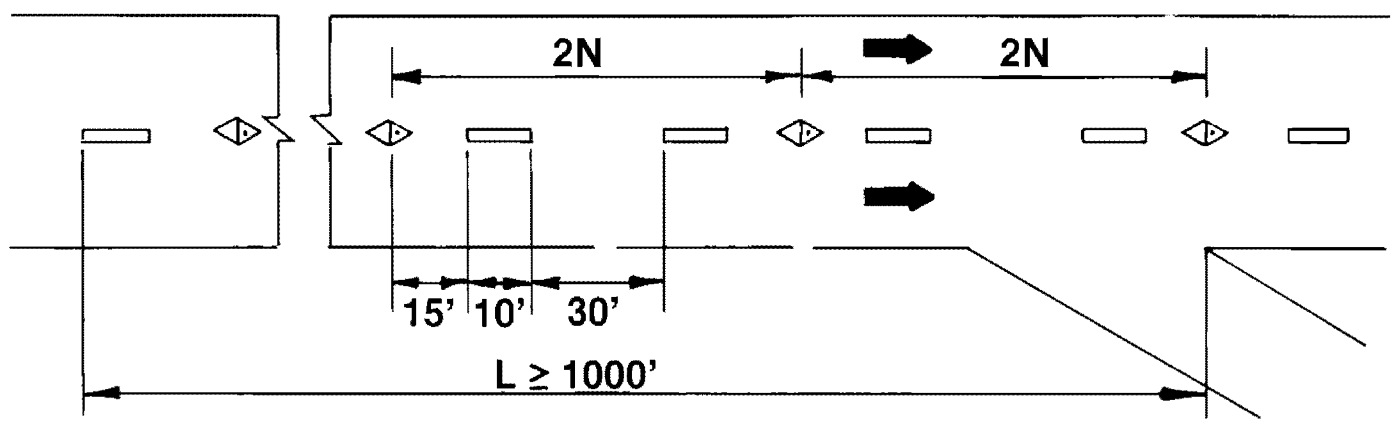
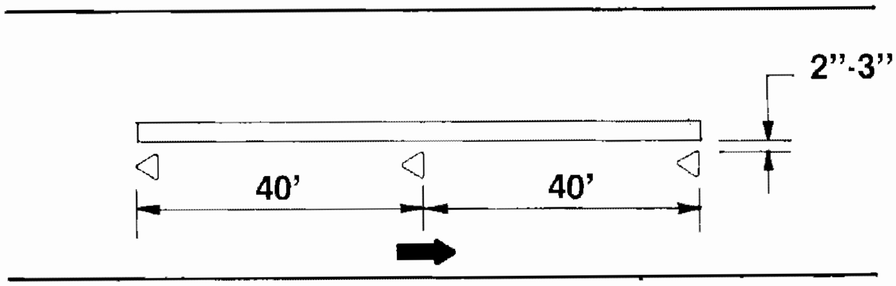
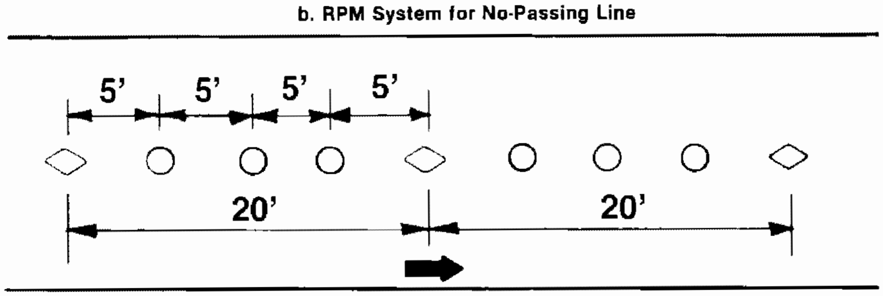


Figure 3-22 Lane Line Patterns (Con't)



a. Combination RPM/Stripe System for Left Edgeline (RPM's are not recommended for Right Edgelines)

b. RPM System for No-Passing Line



c. Combination RPM/Stripe System for No-Passing Line

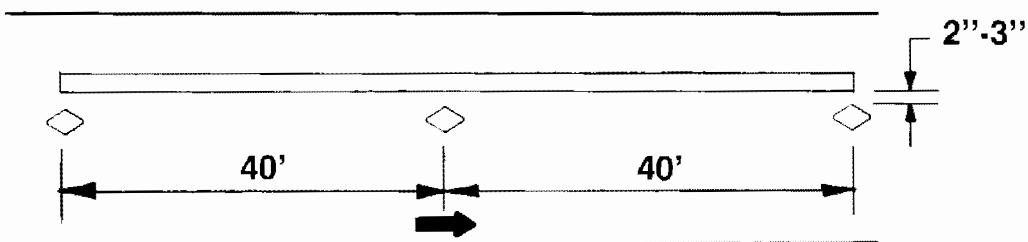
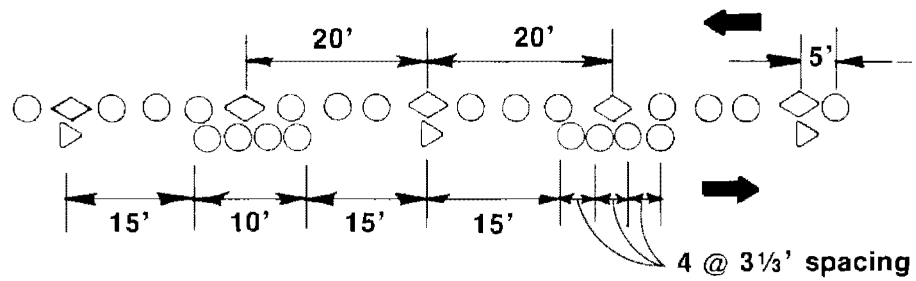


Figure 3-23 Marking Patterns for Solid Lines



d. RPM for No-Passing/Passing Zones

e. Combination RPM/Stripe System for No-Passing/Passing Zones

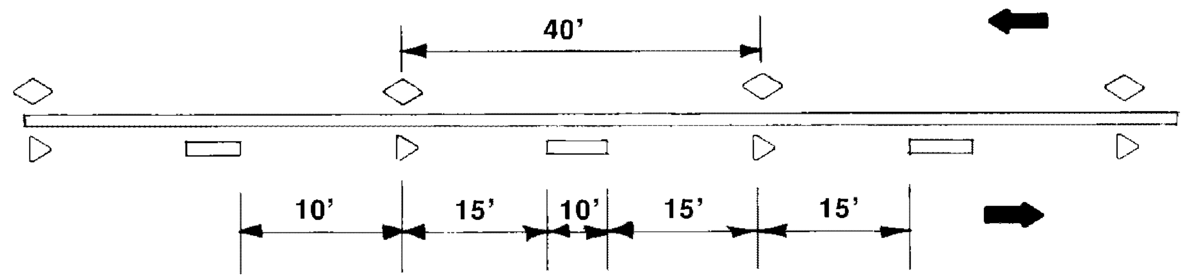
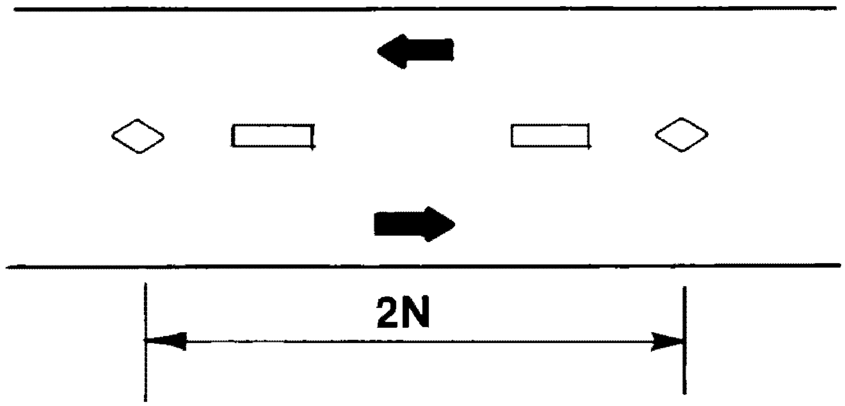
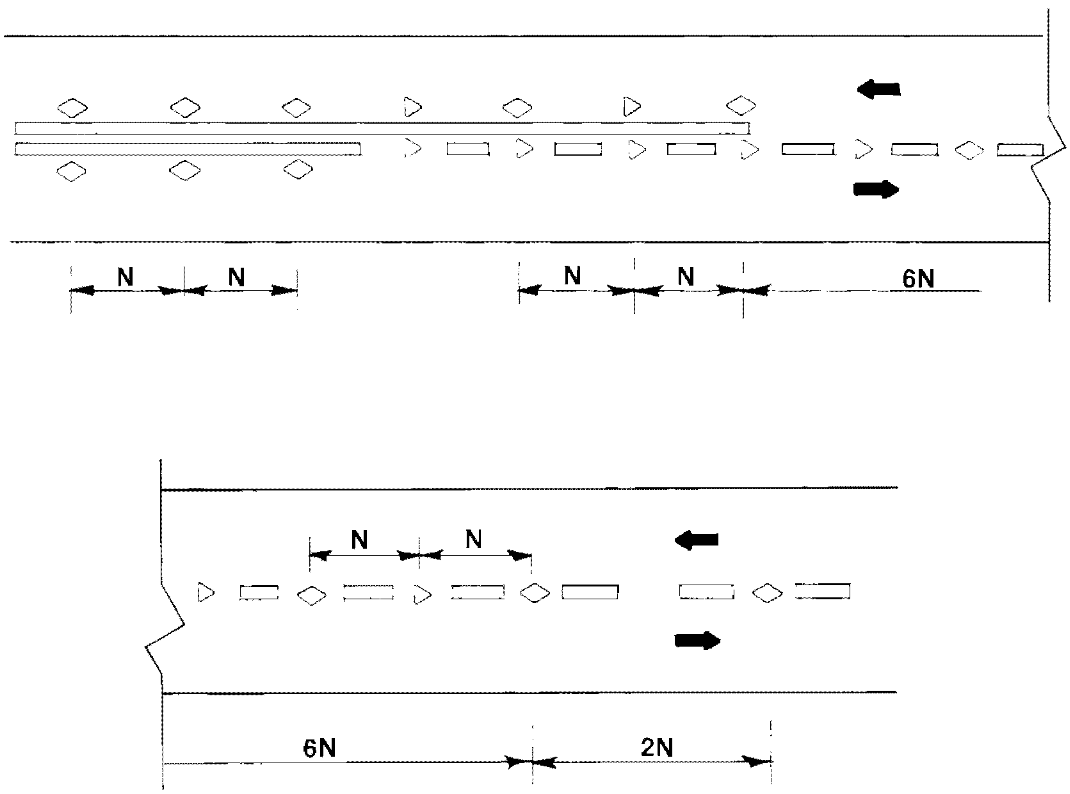


Figure 3-23 Marking Patterns for Solid Lines (Con't)

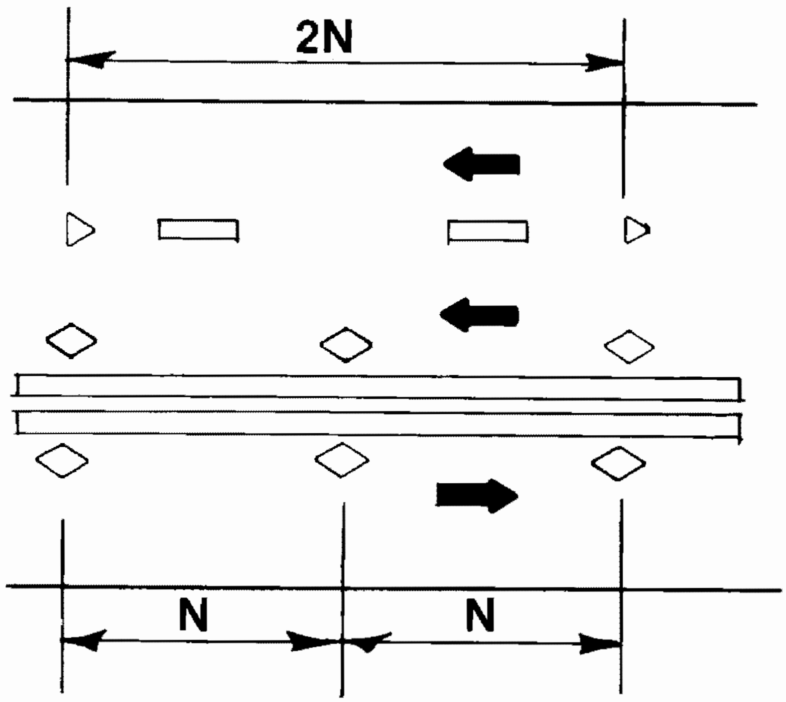


a. Two Lanes



b. No-Passing Zones (Two Lanes)

Figure 3-24 Marking Patterns for Two-Way Roads



c. Three Lanes

d. Four Lanes

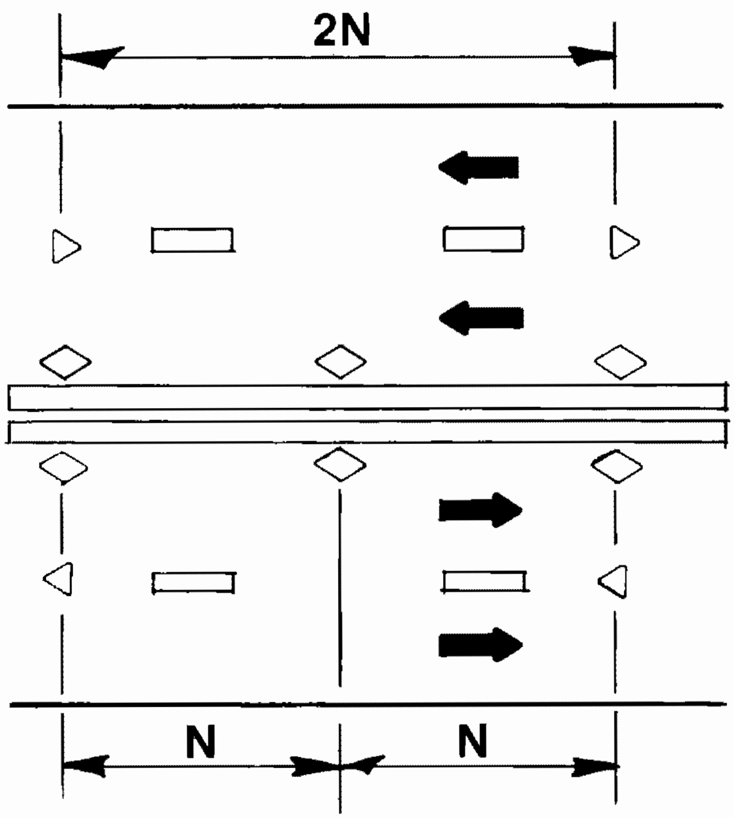


Figure 3-24 Marking Patterns for Two-Way Roads (Con't)

a. Two-lanes to 1-lane on 3-lane Road

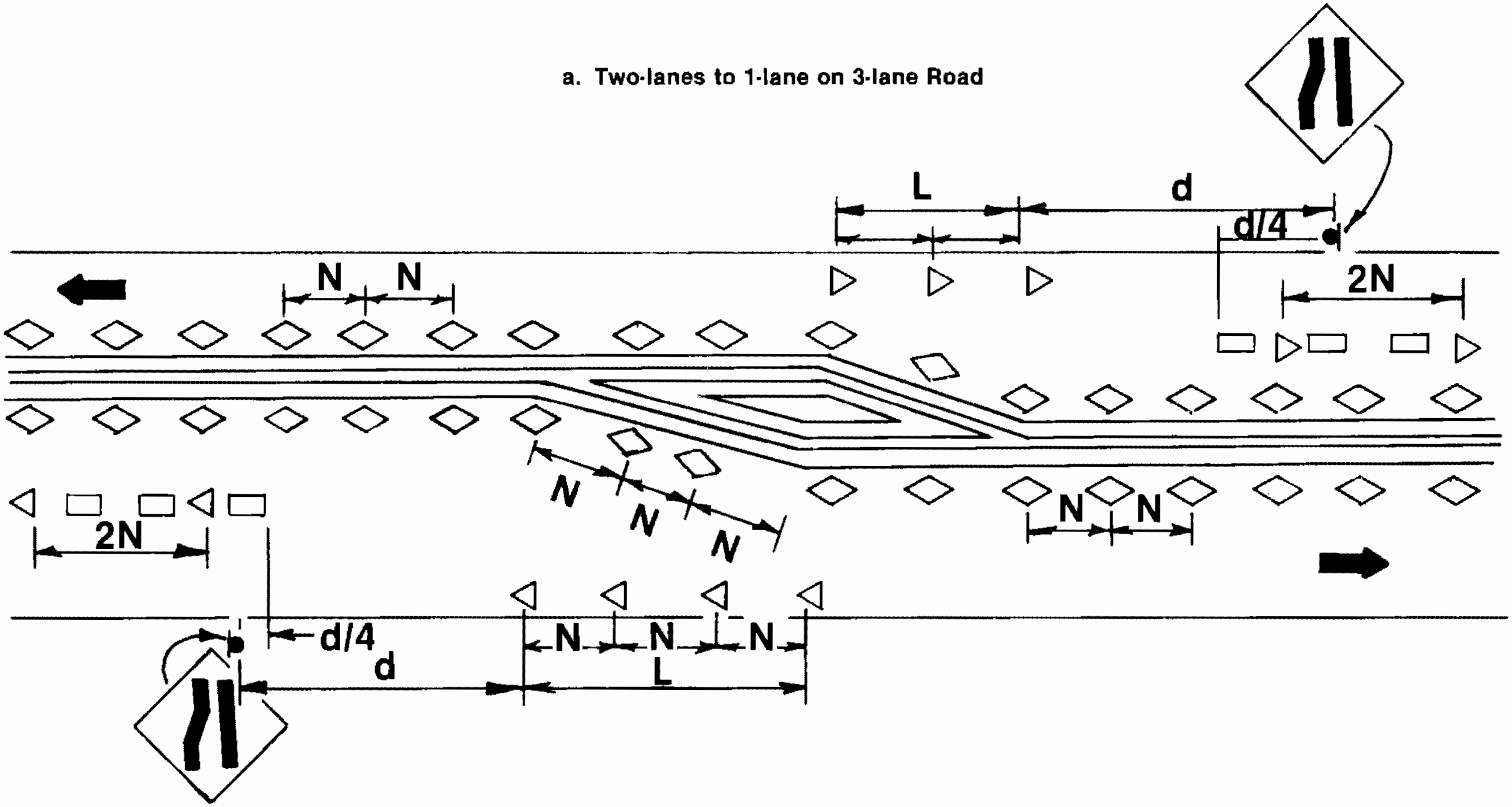


Figure 3-25 Marking Patterns for Transition Sections

b. Four-lanes to 2-lanes (Left)

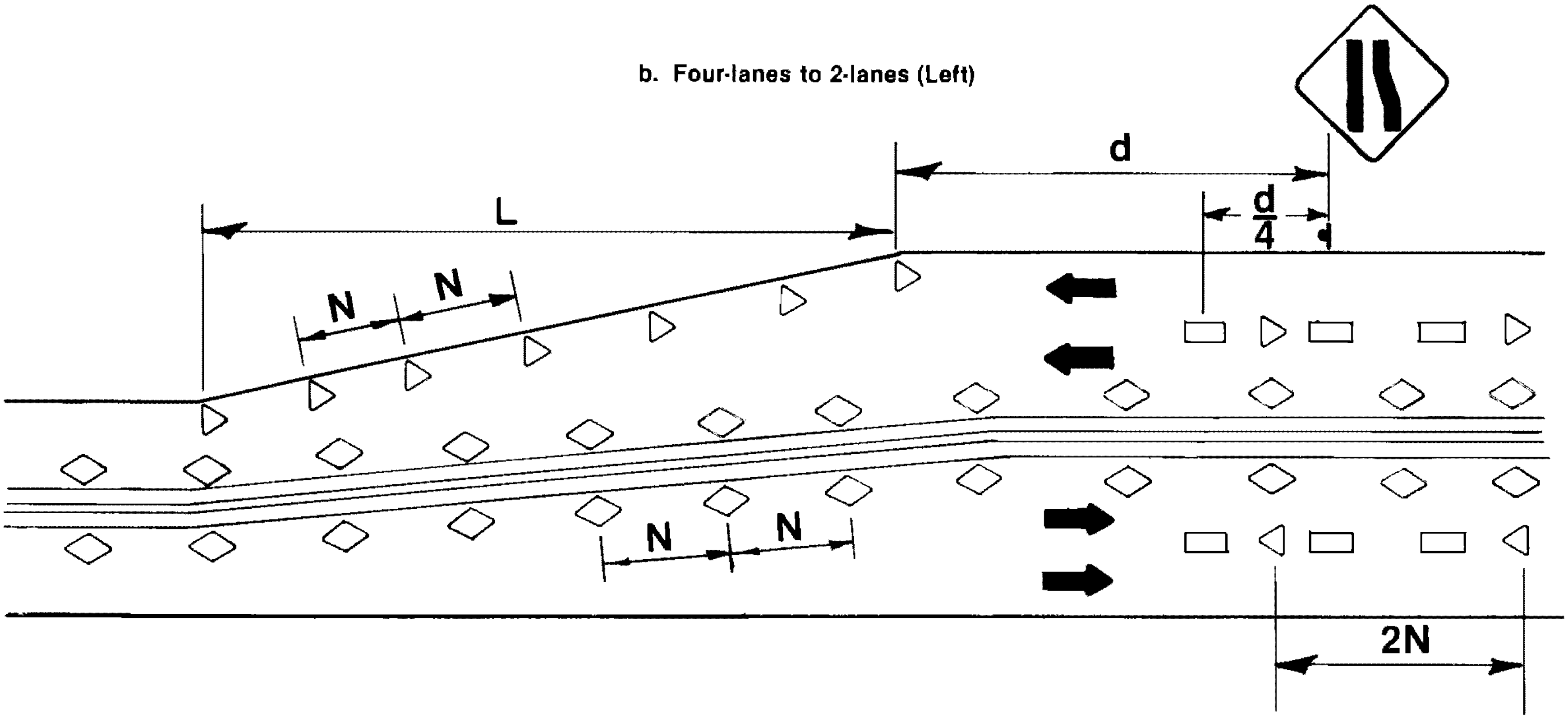


Figure 3-25 Marking Patterns for Transition Section (Con't)

c. Four-lanes to 2-lanes (Right)

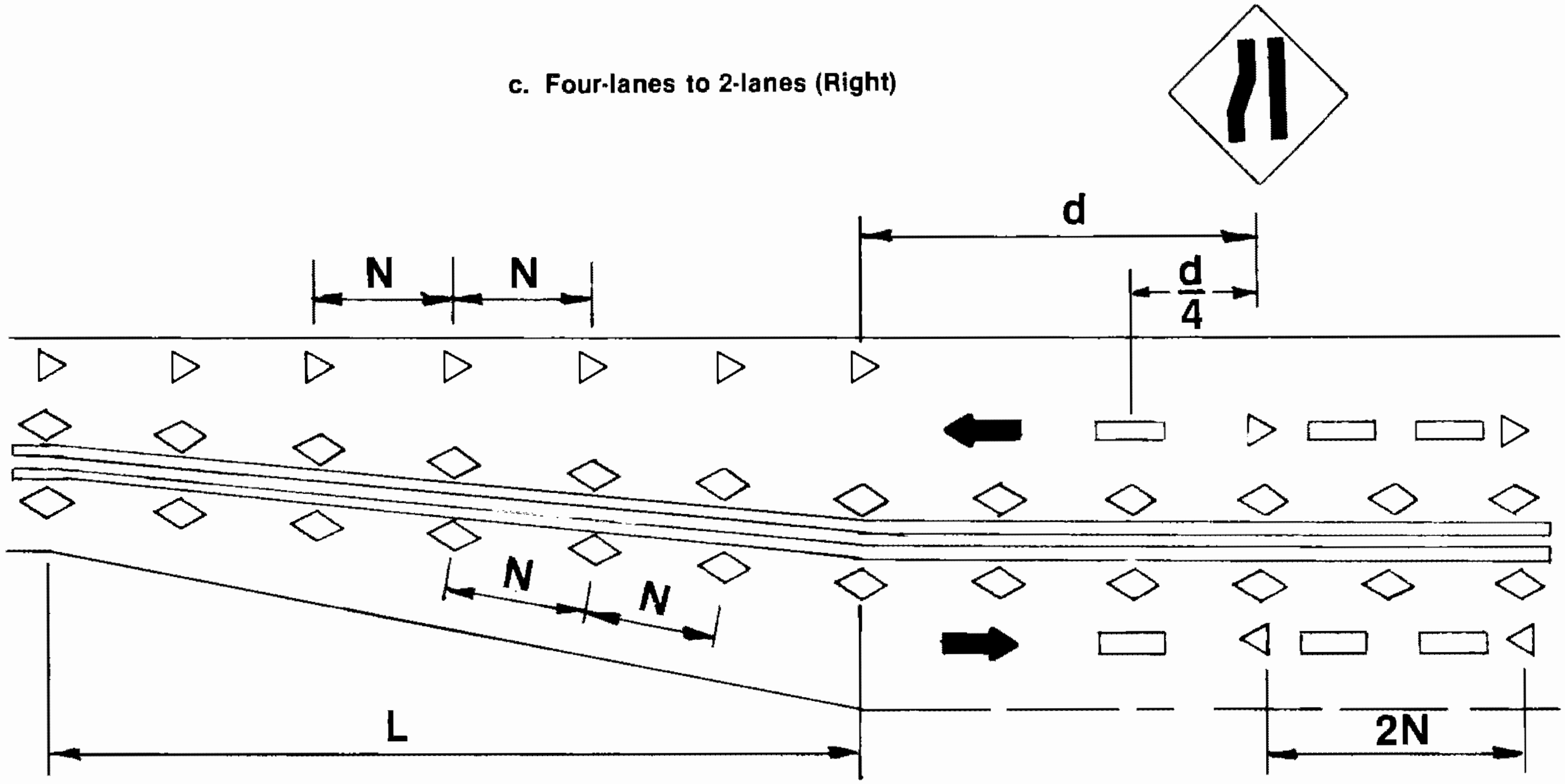


Figure 3-25 Marking Patterns for Transition Section (Con't)

a. Four lanes, 2-way Road

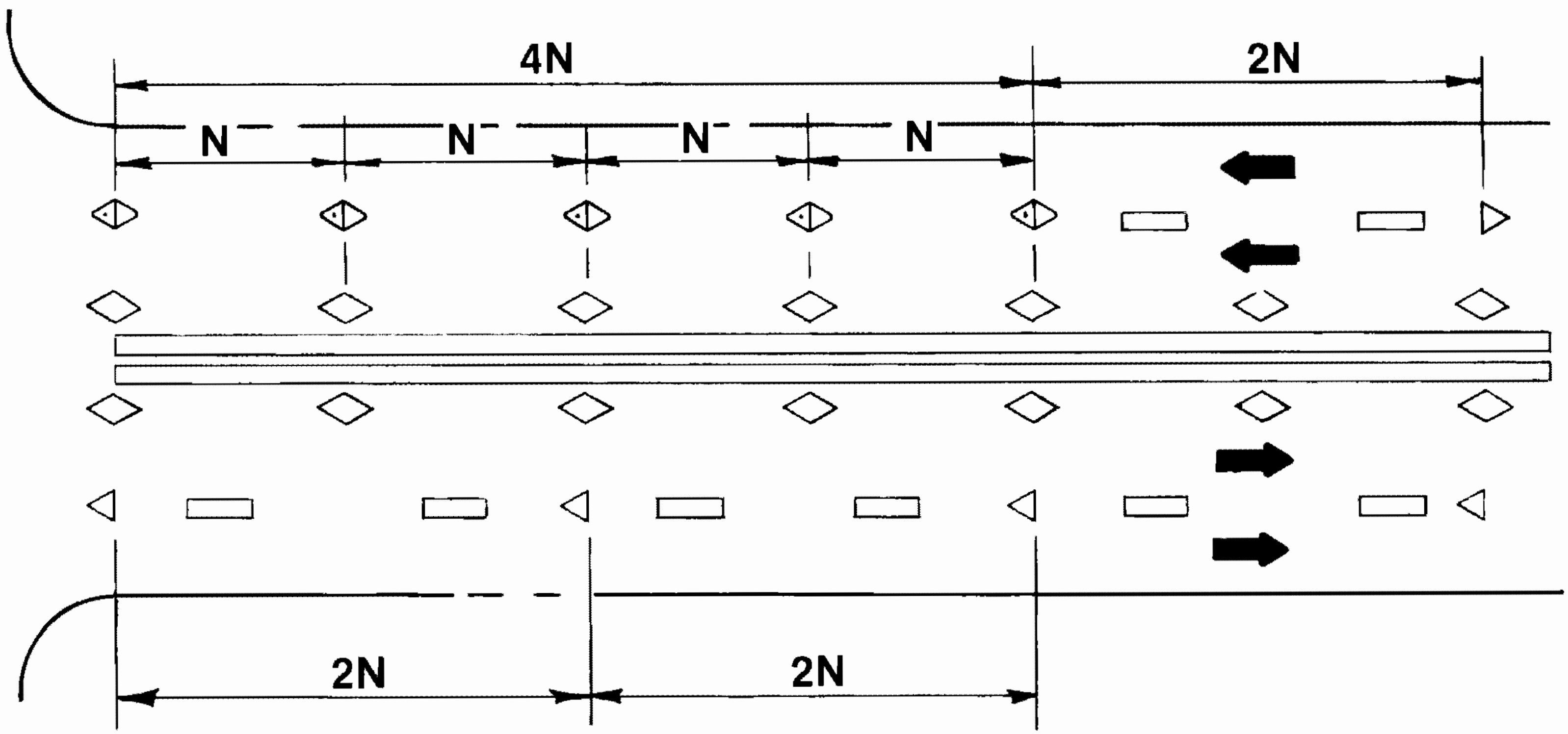


Figure 3-26 Marking Patterns for Intersection Approaches

b. Two-lane, 2-Way Road

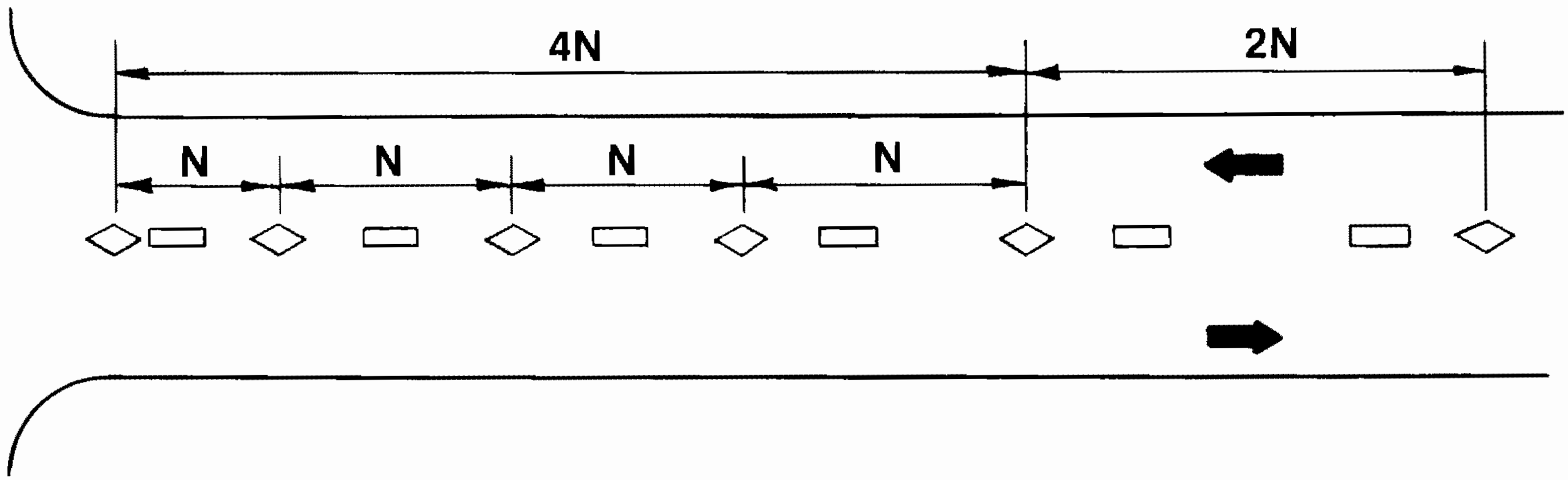


Figure 3-26 Marking Patterns for Intersection Approaches (Con't)

c. Two-lane, 1-Way Road

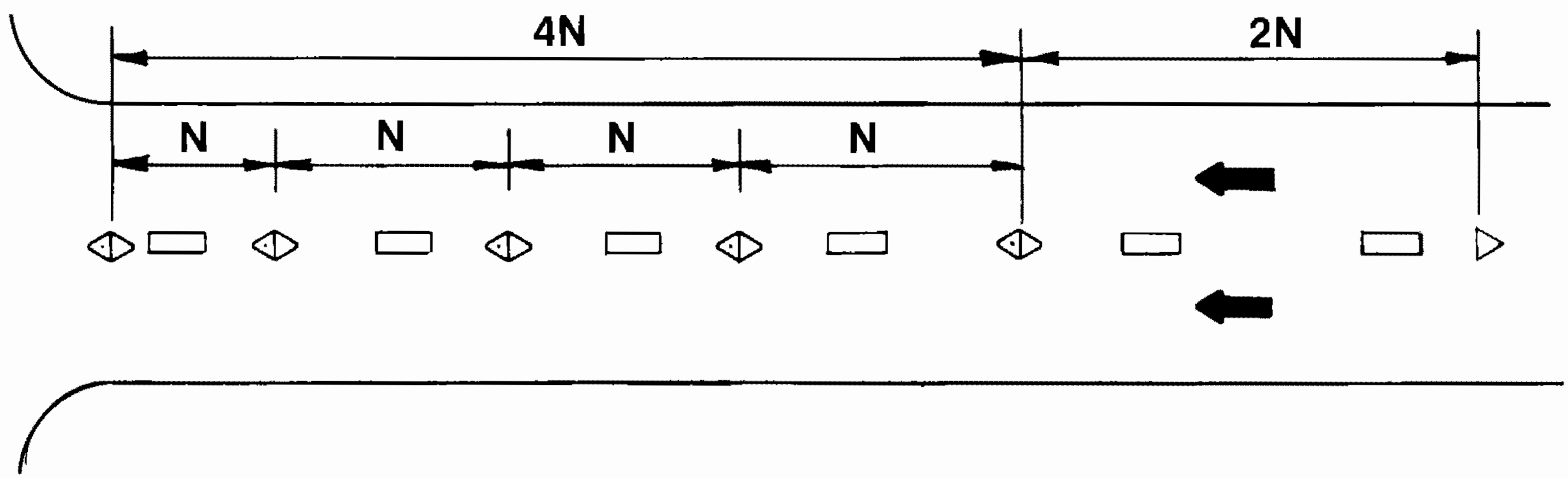


Figure 3-26 Marking Patterns for Intersection Approaches (Con't)

a. Two lanes, 2-Way Road

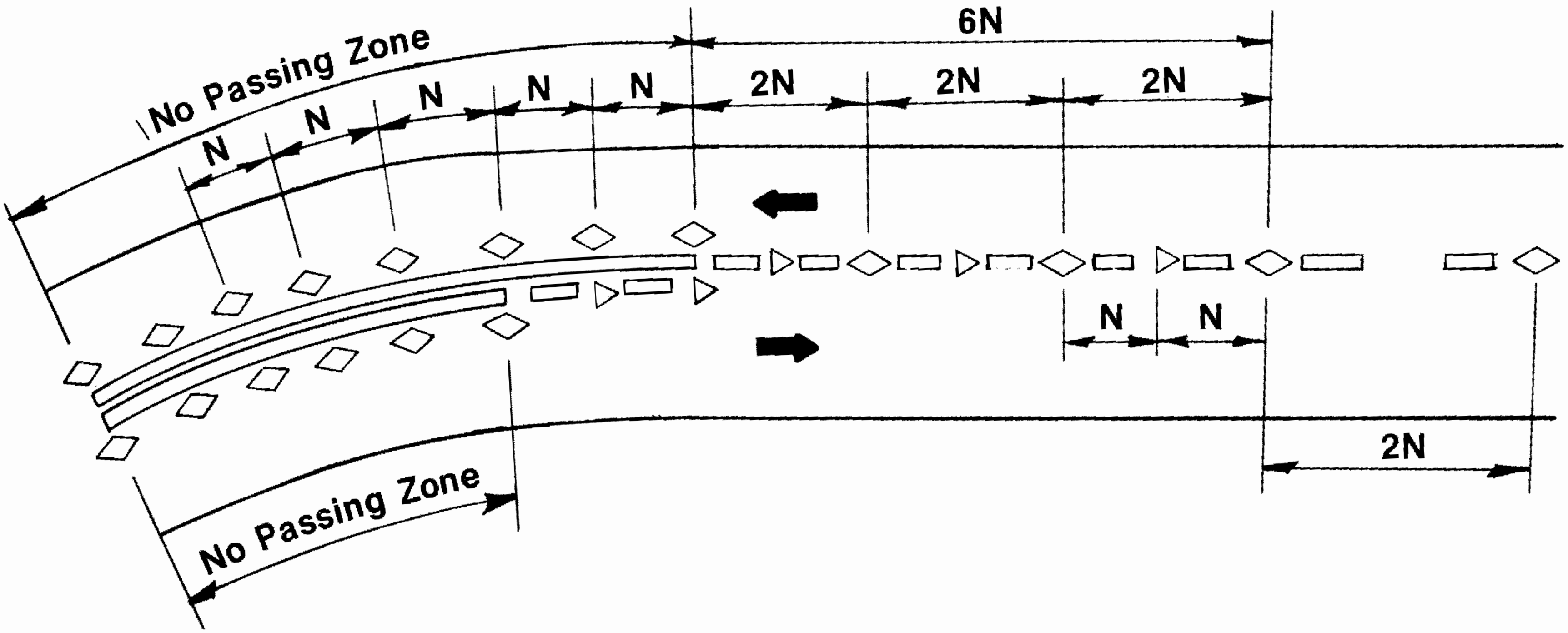


Figure 3-27 Marking Patterns for Horizontal Curves Having 6 degrees or Greater Curvature

b. Three lanes, 2-Way Road

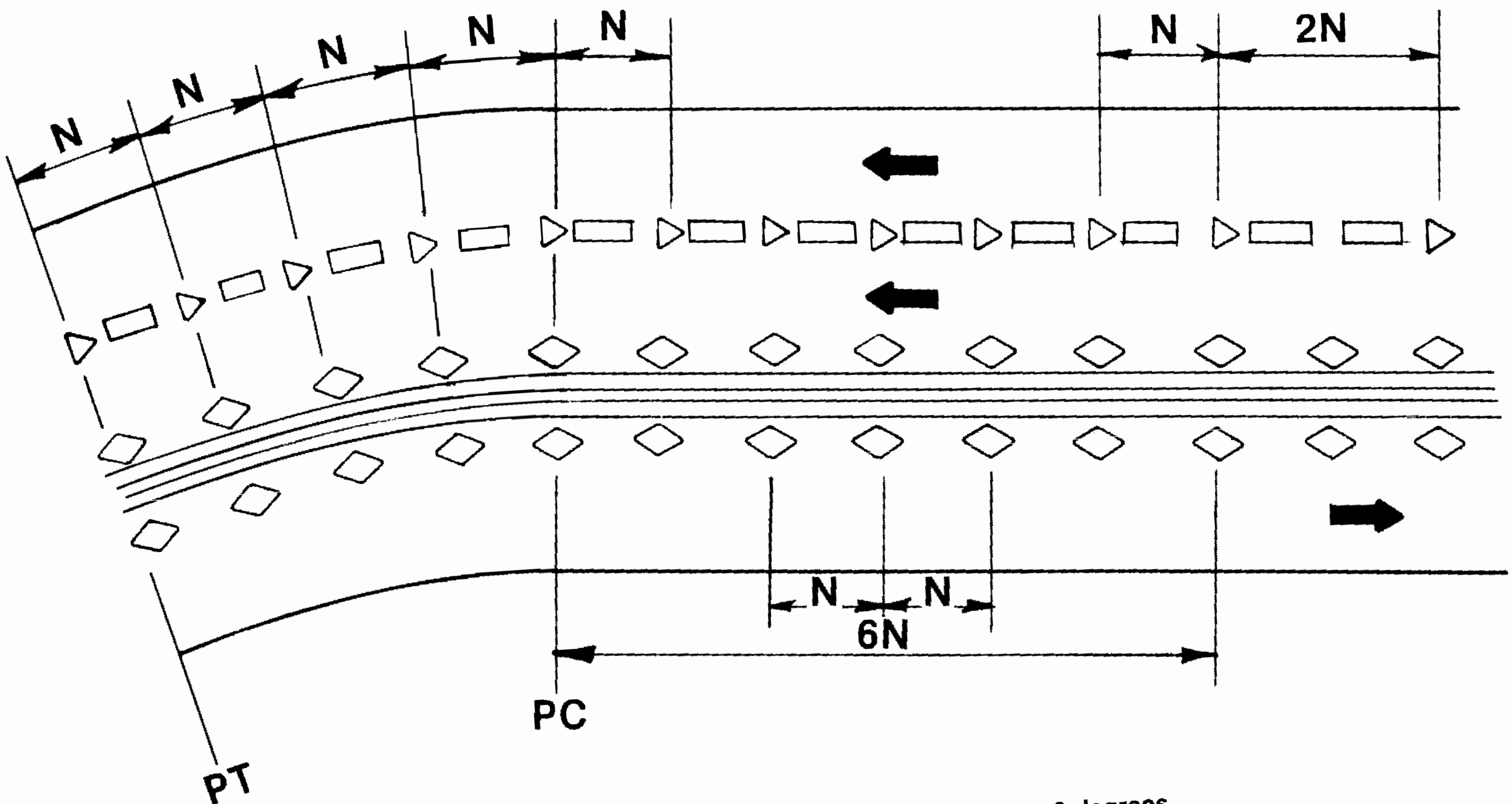


Figure 3-27 Marking Patterns for Horizontal Curves Having 6 degrees or Greater Curveature (Con't)

c. Four lanes, 2-Way Road

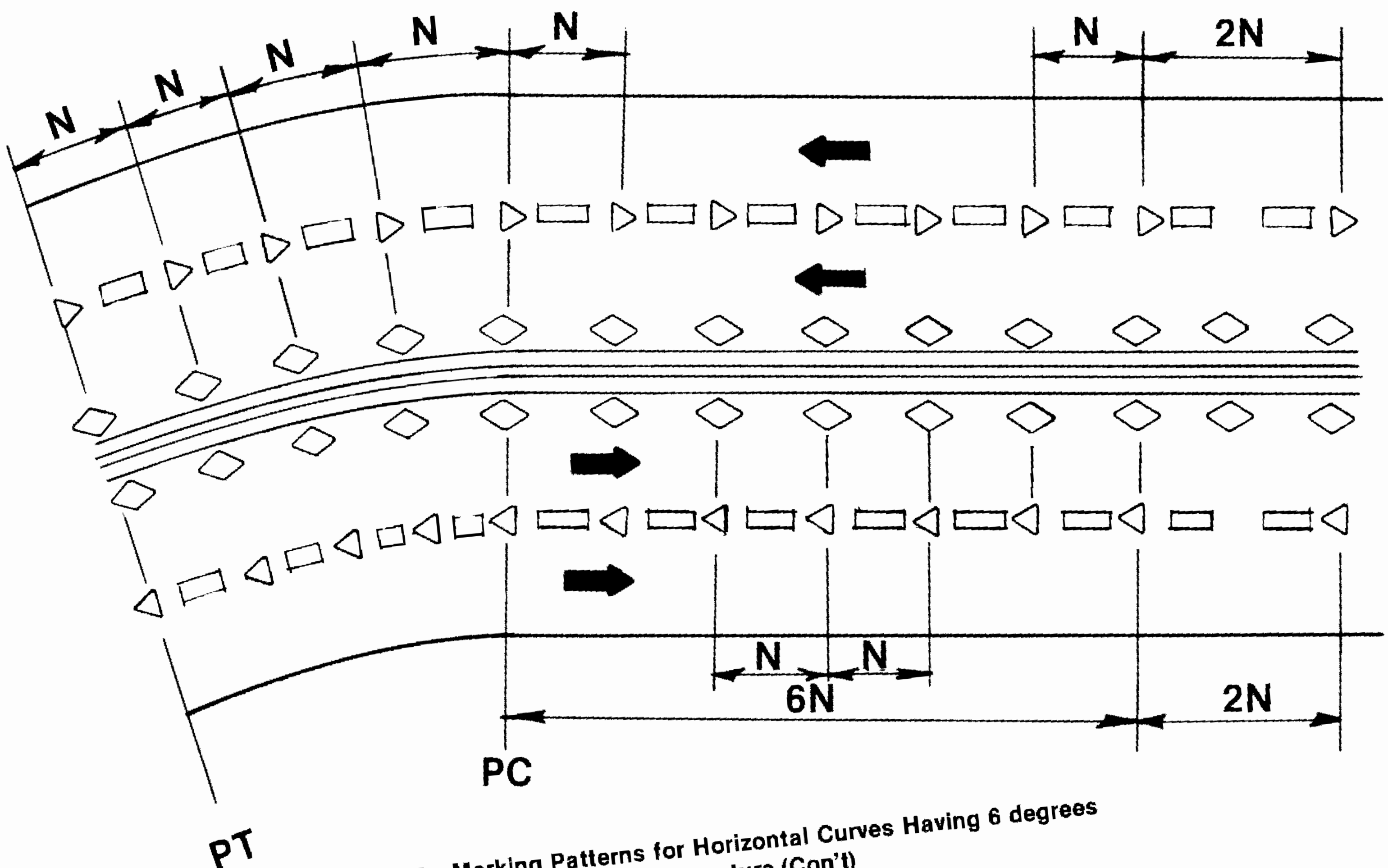
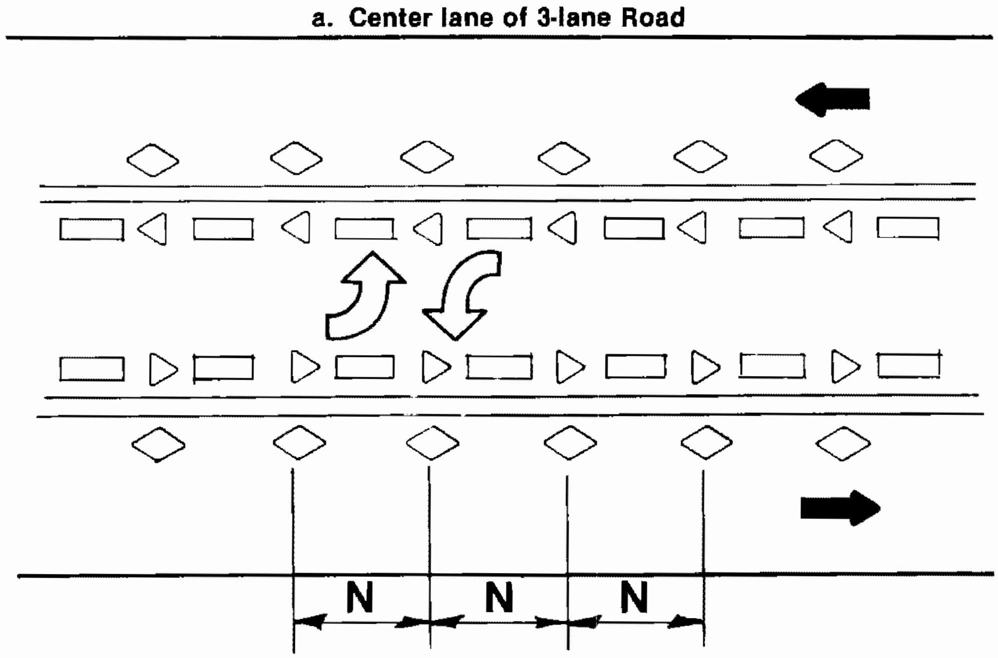


Figure 3-27 Marking Patterns for Horizontal Curves Having 6 degrees or Greater Curvature (Con't)



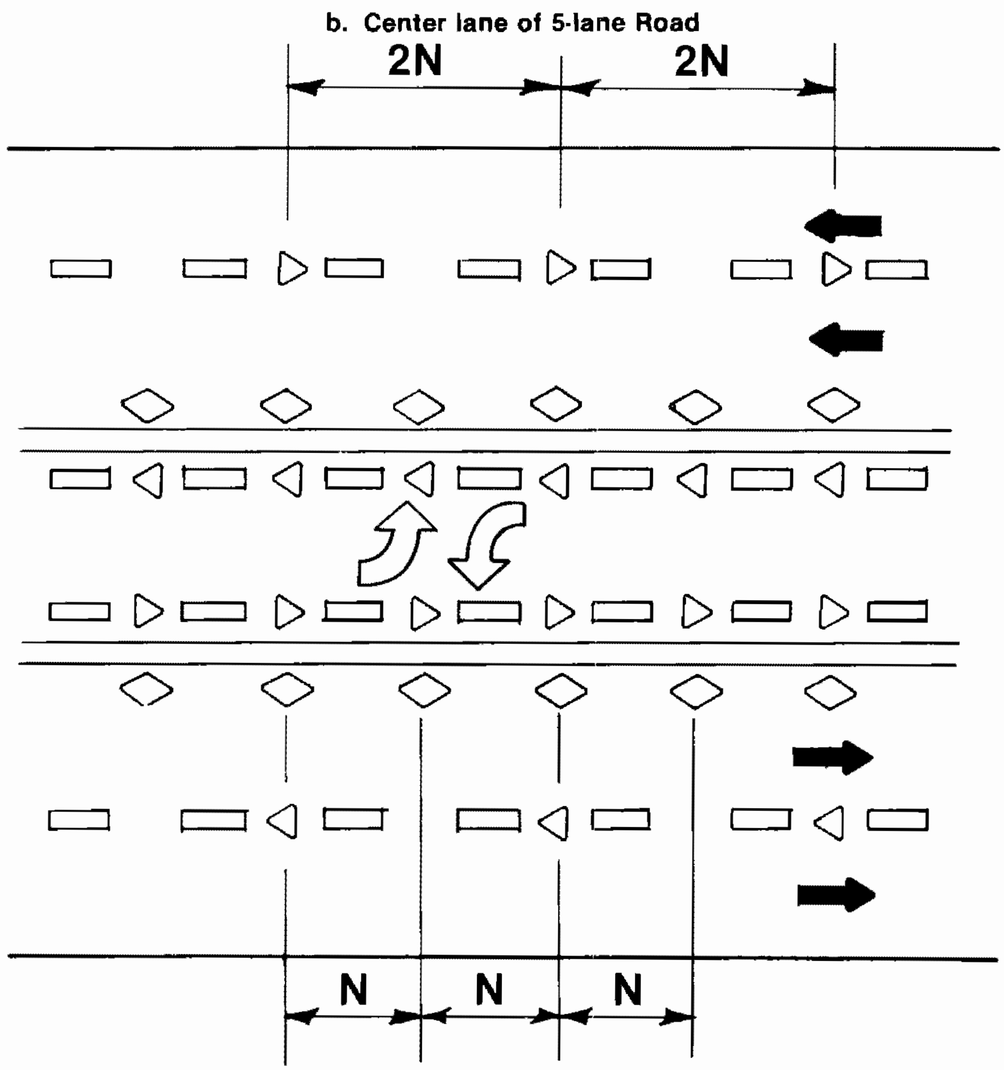


Figure 3-28 Marking Patterns for Left-Turn Lanes

c. Left-Turn Bay

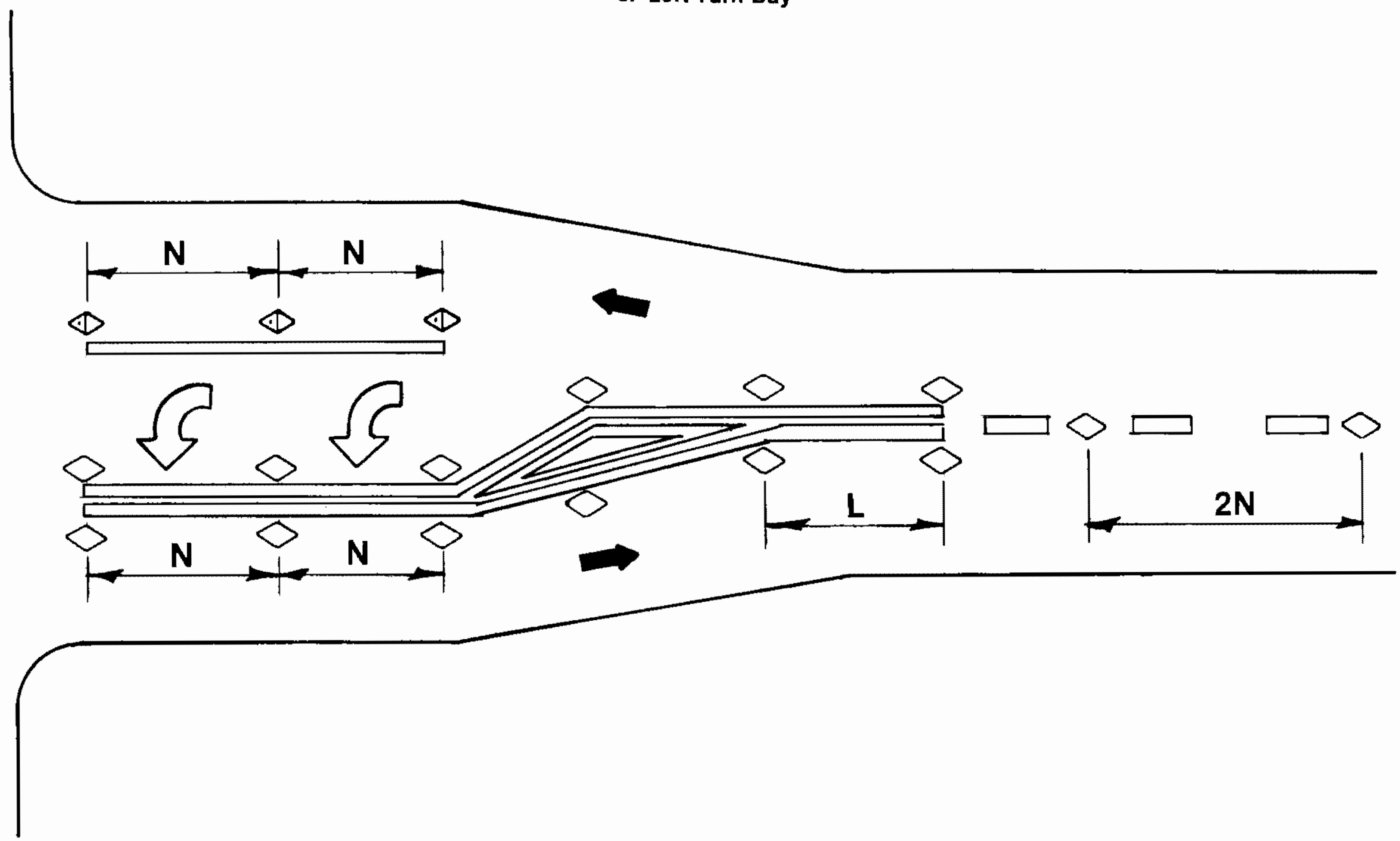


Figure 3-28 Marking Patterns for Left-Turn Lanes (Con't)

a. Combination RPM/Stripe System (Exit Ramp)

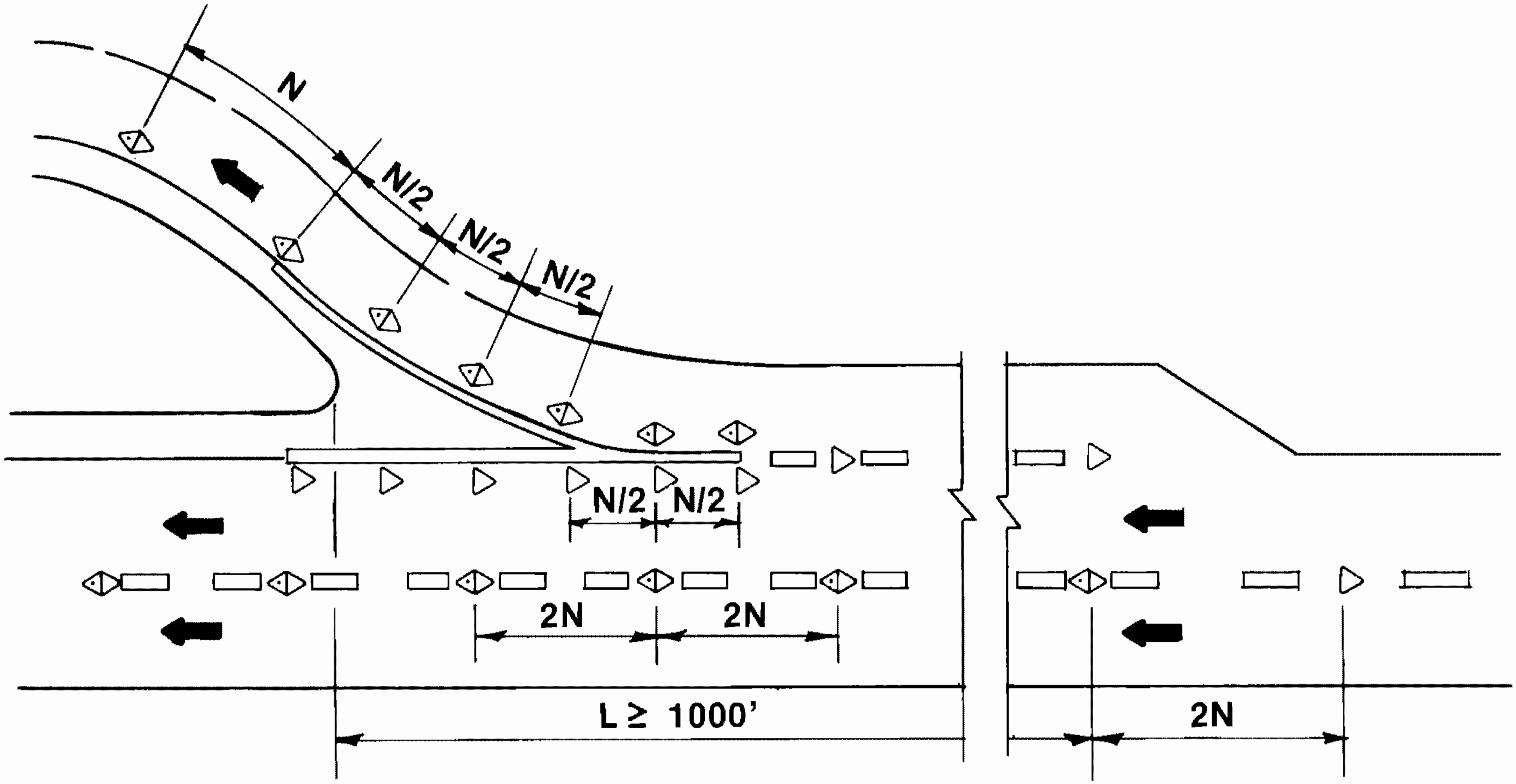


Figure 3-29 Marking Patterns for Freeway Ramps

b. Combination RPM/Strip System (Entrance Ramp)

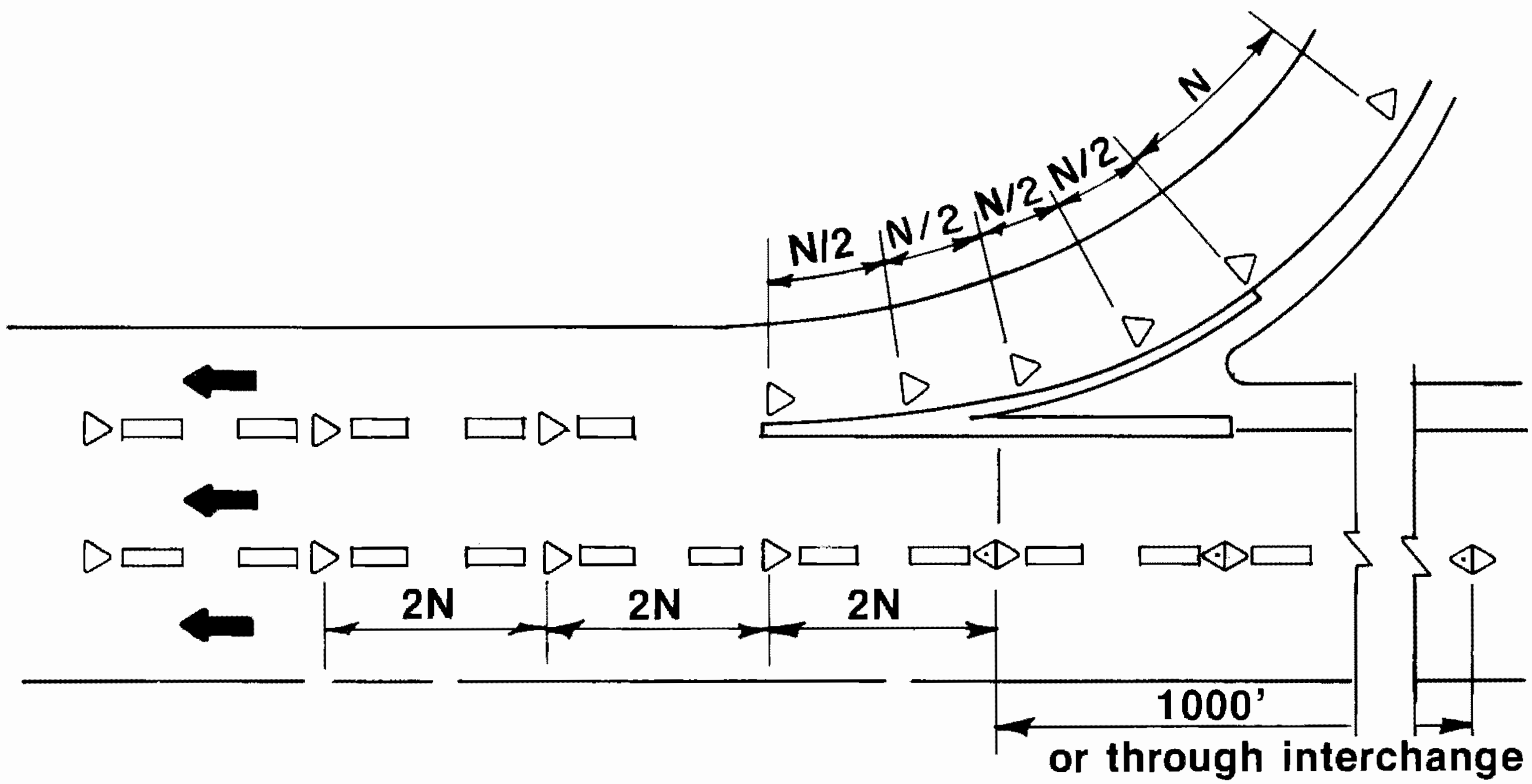


Figure 3-29 Marking Patterns for Freeway Ramps (Con't)

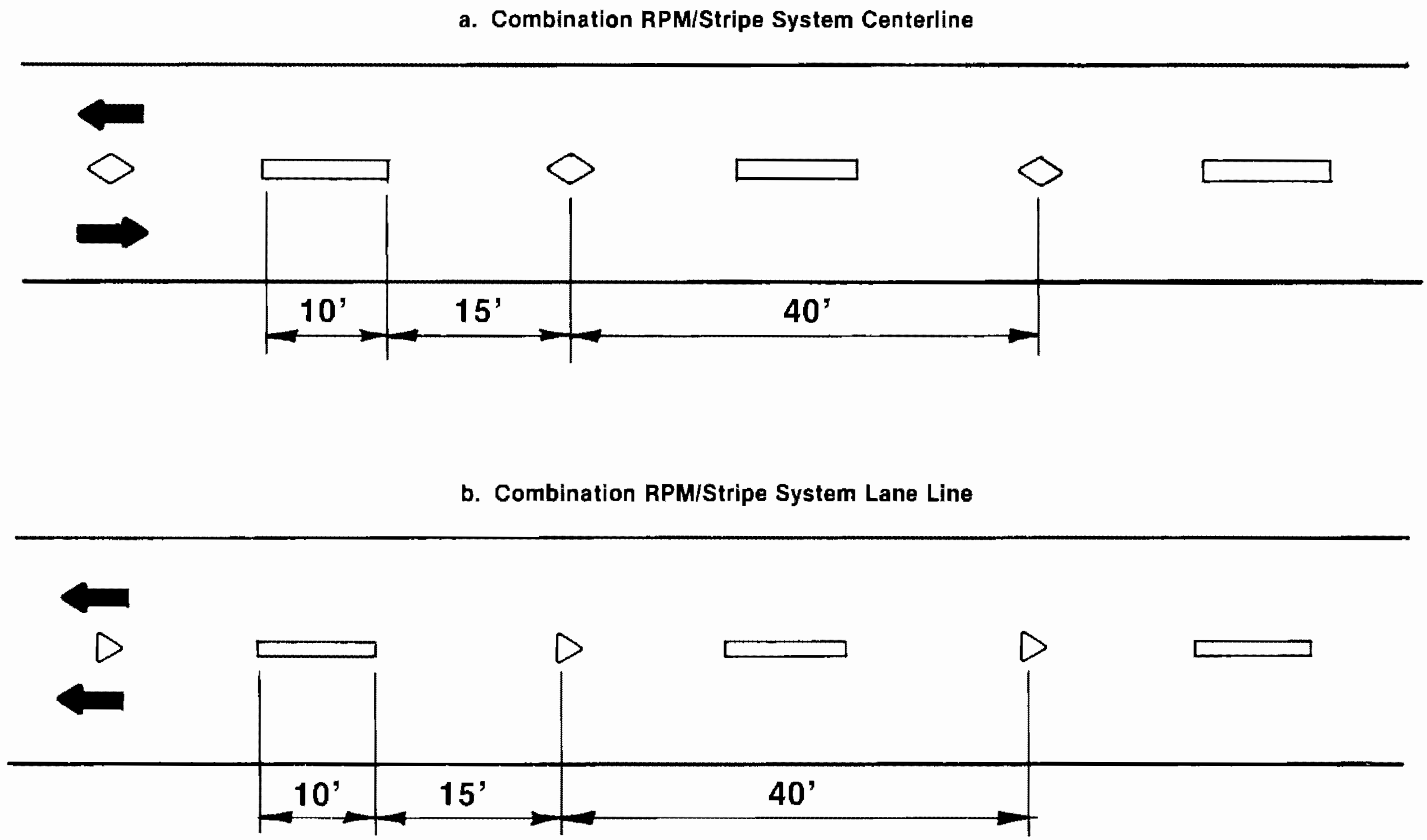
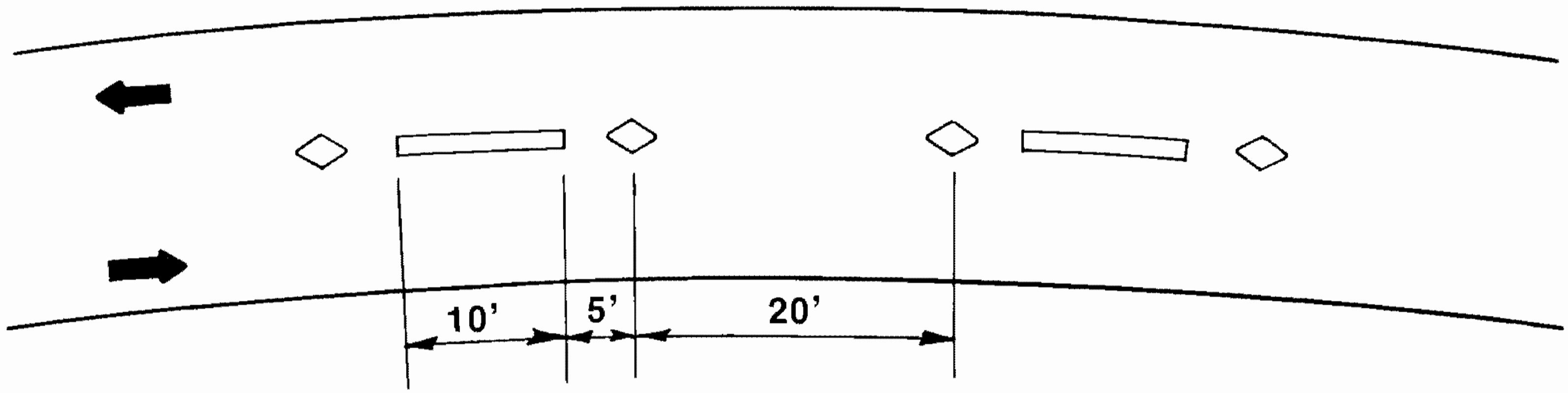
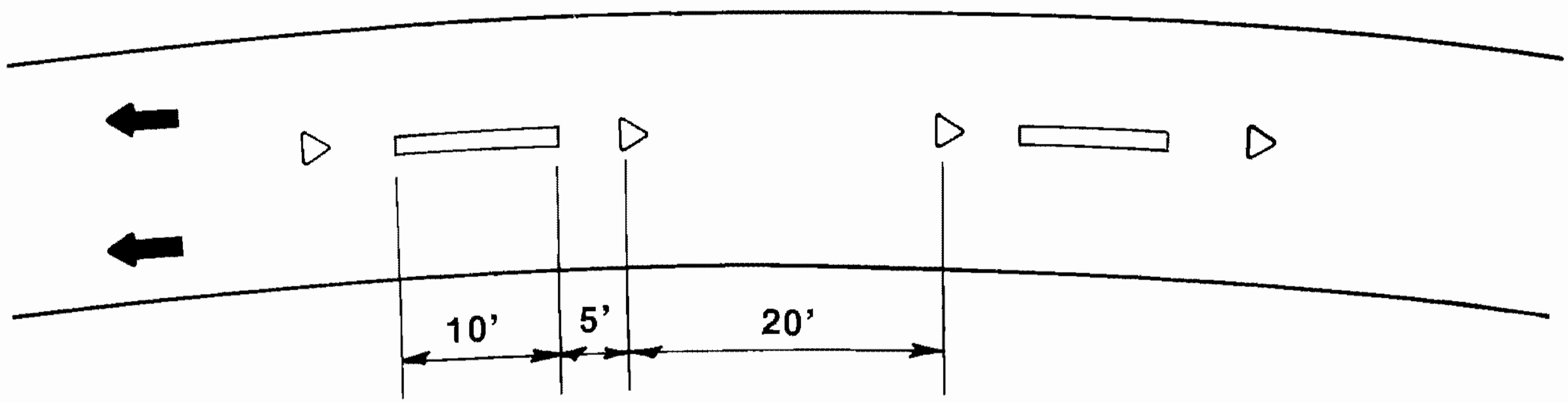


Figure 3-30 Marking Patterns for Construction Zones

c. RPM Lane Line with Stripe Edgelines





d. Combination RPM/Stripe Centerline System (Curve Section). Note: No-Passing Zones Markings are not Shown)

e. Combination RPM/Stripe Lane Line (Curve Section)

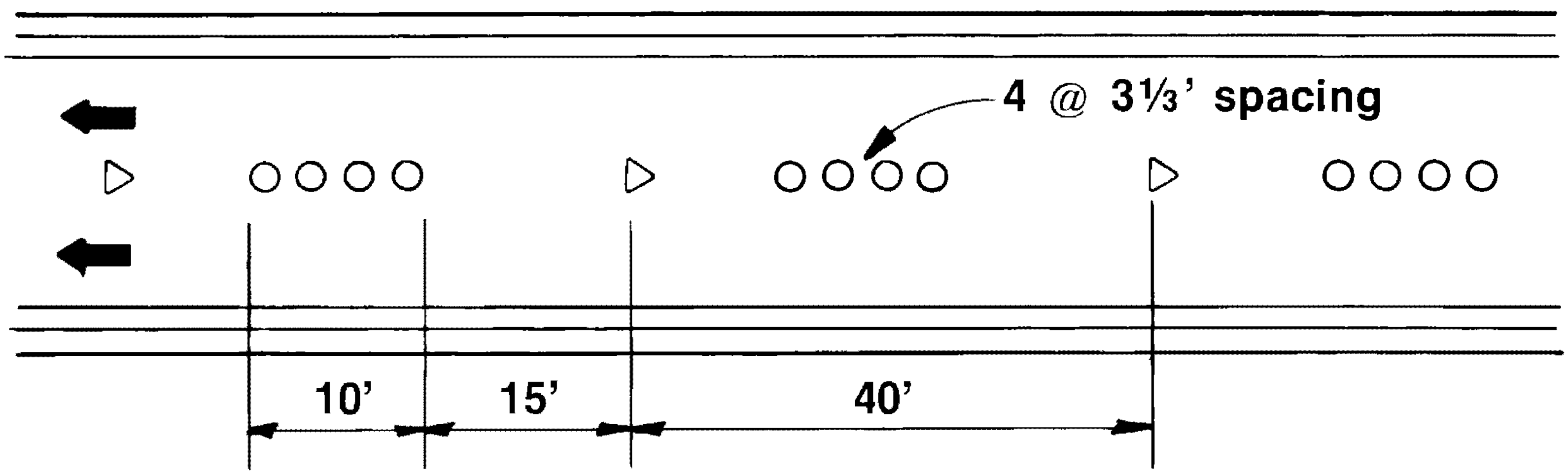


Figure 3-30 Marking Patterns for Construction Zones (Con't)

The color of the markers used (white or yellow) should be the same as that required for painted pavement stripes the markers represent.

3E–2 Passing and No-Passing Zones

With the possible exception of merging at a freeway entrance ramp, performing a passing maneuver on a two-lane rural highway is one of the most difficult and potentially hazardous tasks a driver undertakes. The successful execution of a passing maneuver depends on a complex interrelationship among the three basic elements of the dynamic system involved: the driver, the vehicle, and the environment in which the passing maneuver occurs.

Current criteria and guidelines for establishing passing and no-passing zones vary substantially from State to State. A recent report prepared for the Federal Highway Administration by the Texas Transportation Institute entitled "Passing and No-Passing Zones: Signs, Markings, and Warrants" (Ref. 3-17) discusses proposed criteria and guidelines for establishing passing and no-passing zones. This report includes a thorough discussion of current criteria and techniques for establishing passing and no-passing zones.

Various methods have been used to establish no-passing zones. These methods include:

- The "eye-ball" method.
- The walking method.
- The towed-target method.
- The two-vehicle method.
- The distance measuring equipment method.

Eye-Ball Method

The eye-ball method is seldom used but is cheaper and faster than other methods because only one vehicle and two persons are generally employed. After some exposure to this method, the driver and observer gain enough experience to estimate within 50 to 100 feet where the no-passing zone should begin due to an approaching horizontal sight distance restriction. This estimate is then verified by reading an odometer at this point and then traveling to the point where the approaching vehicle would have appeared. Vertical curves present a problem due to the difficulty in determining the precise point of visual restriction. For sharp crest curves, the procedure follows that previously described for horizontal curves. For long vertical curves, where it is virtually impossible to determine how far over the crest an approaching vehicle might be seen, the crew must stop their vehicle at the required passing distance from the crest and observe the point where approaching vehicles come into view.

Walking Method

The walking method is a more accurate method. However, it is time consuming. Two persons using a predetermined length of rope, chain, or wire, walk along the centerline of the roadway with the line kept taut. The distance between the two men is equal to the minimum passing sight distance being used. The "height of eye" is established by means of a target carried by each man. An advantage of this technique is that no-passing zones may be determined for both lanes of traffic when both men have targets.

Towed-Target Method

The towed target method employs a vehicle towing a target on the end of a cable. The length of the cable is equal to the minimum passing sight distance. The vehicle is driven over the road, when the target "disappears," the vehicle is stopped and the road is marked to indicate the beginning of a no-passing zone. The vehicle then resumes driving the road and when the target reappears the vehicle is again stopped and the roadway is marked to indicate the end of the zone.

A variation of this method is to use two vehicles connected by a cable of length equal to the minimum passing sight distance.

Two-Vehicle Method

For this method, two vehicles equipped with two-way radios and calibrated odometers are used. They are deployed with the appropriate minimum sight distance between them. The procedure is discussed in the following paragraphs.

To set the minimum sight distances interval, both cars should park abreast on the roadway and the odometers set at 0.00 miles. The lead vehicle will then move forward the minimum passing sight distance for the speed indicated. When the lead vehicle has gone the required distance, it should stop and the odometer should be reset to 0.00 miles. From then on, radio contact should be maintained between the vehicles to coordinate their movement. Upon a signal from the trailing vehicle, both vehicles can move forward. The vehicles are to be kept at the correct distance and speed by the lead vehicle observer calling off mileages often enough to keep identical readings on the odometers of the two vehicles. To practice this procedure, readings should be called off every tenth of a mile with the vehicles traveling approximately 3 to 5 miles per hour. Later with added experience, this speed may be increased to 15 to 20 mph. If identical readings cannot be maintained, the trailing vehicle should have a lower reading. This will result in the vehicles being farther apart than required. One note of caution, the vehicles should not be backed up to adjust the spacing as the odometers will not operate backwards.

While making measurements, the driver of the trailing vehicle should stop both vehicles just before the lead vehicle goes out of sight. At this time, the trailings vehicle can move up to obtain identical odometer readings. From this point each car will move forward 0.01 miles and stop, and then move another 0.01 mile, until the target on the lead vehicle goes out of sight over the crest of a hill or is obscured by "obstructions" along the roadside on horizontal curves. With practice, a team may be able to move continuously and stop only when the lead vehicle goes out of sight. When the lead vehicle's target disappears, the pavement should be marked with spray paint or by some other method.

The trailing vehicle operator should mark to the right of the centerline; the leading vehicle operator to the left. The trailing vehicle marks will represent the beginning and end of the no-passing zone for vehicles traveling in the direction of the survey; the lead vehicle marks will represent the no-passing zone for the opposite direction of travel. At the first stop, the lead driver should make an upside-down "T" on the left of the centerline or left shoulder, and the trailing driver an upside-down "T" on the right of the centerline or right shoulder.

The two vehicles should then proceed forward with identical odometer readings until the driver of the trailing vehicle sees the top of the lead vehicle. Both vehicles are stopped and the trailing vehicle is moved forward to obtain identical odometer readings. Then both vehicles should move forward .01 mile and stop to determine if the target has reappeared. This "stepping" is repeated until the target reappears. Both drivers should then stop and mark two more "T's" on the road as shown in Figure 3-31. The lead driver marks a right-side-up "T" on the left of the centerline or left shoulder and the trailing driver marks a right-side-up "T" on the right of the centerline or right shoulder.

It is possible for vehicles positioned in-between the survey vehicles to become "lost" in depressions although the vehicles are spaced the minimum sight distance apart and the drivers may see each other (Figure 3-32). Reverse horizontal curves can create similar situations.

The following procedure is suggested for handling these "lost vehicle" situations. The driver of the lead vehicle decides where he believes the low point of a depression is and stops there, after notifying the trailing vehicle of what he is doing. The trailing vehicle then moves forward until he sees the target on the lead vehicle. If it is noted by the trailing driver that other oncoming vehicles continue to become "lost," the trailing vehicle must move forward to a point where the driver does not "lose" an oncoming car in the depressions. At this point an upright "T" is marked to the right of the centerline or right shoulder by the trailing vehicle's driver. With the trailing vehicle stopped, the lead vehicle then moves forward so it has an odometer reading identical to the trailing vehicle and marks an upright "T" to the left of the centerline or left shoulder at this point. The two vehicles are now together and may proceed with the survey.

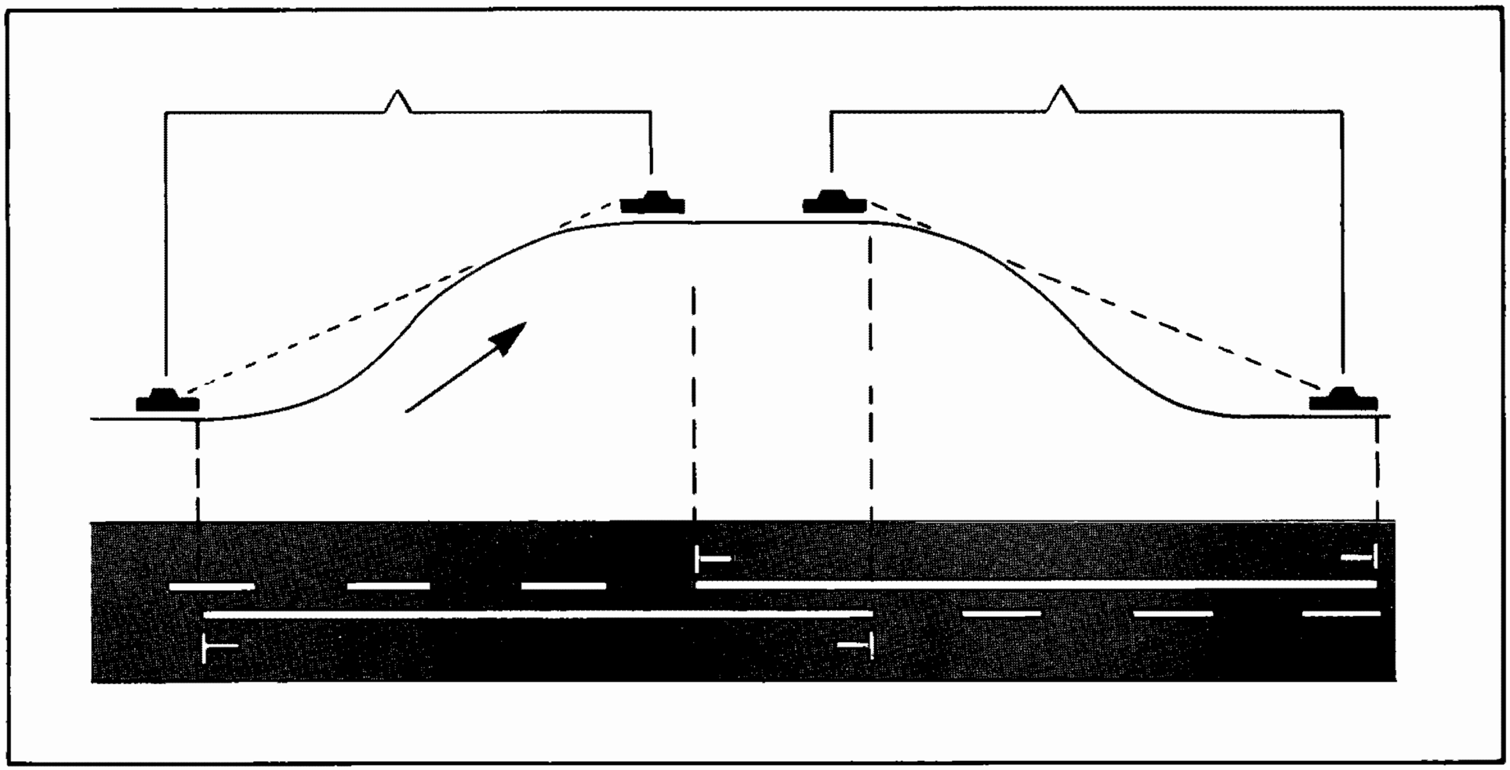


Figure 3-31 Establishing "T" Marks for Identifying No-Passing Zone Locations

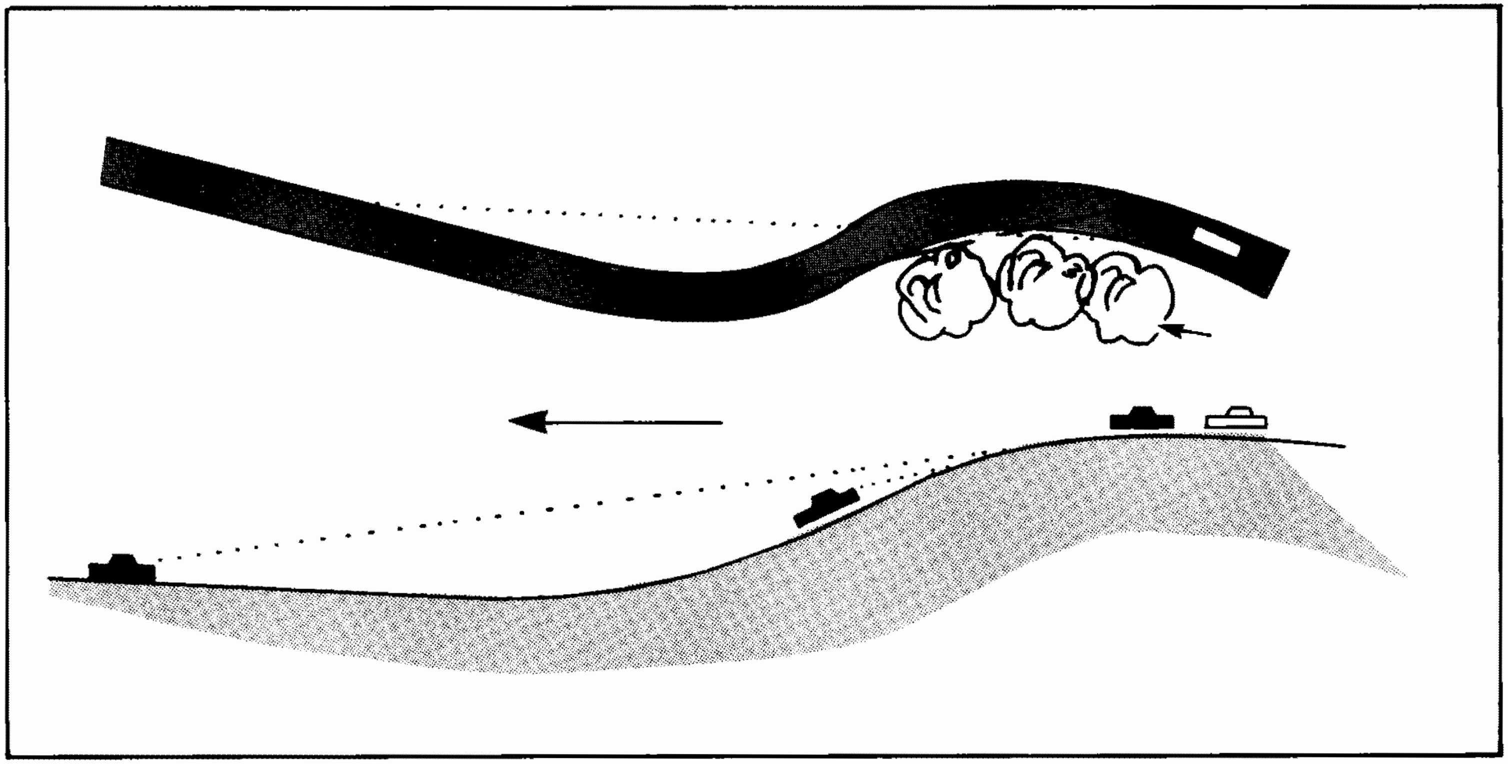


Figure 3-32 How Obstructions and Depressions Cause Vehicles to Become "Lost"

The lead vehicle should stop at major intersections and radio the trailing driver that he is at an intersection. The recorder in the trailing vehicle should add the minimum passing sight distance to his odometer reading and record the correct log mile of the intersection.

The minimum passing sight distance used during a survey run may be changed to accommodate a change of speed zone without going through the starting procedure. If the distance is to be increased, the odometer of the leading vehicle is turned back the difference in distance and then driven ahead until the odometer again reads the mileage when originally stopped. To decrease the distance, the odometer of the leading vehicle is turned ahead the difference in distance and then the trailing vehicle is driven forward to the new reading.

At the slow vehicle pace necessary to conduct this survey, care must be taken when locating no-passing zones to see that traffic does not become confused or congested. Both vehicles should pull over on the shoulder when the rear driver notices several cars being held back.

Distance Measuring Equipment Method

Recent developments in computer technology and distance measuring devices have led to a system that measures, records, and marks passing and no-passing zones in both directions with a single pass of the equipment. The system is rather expensive and some States have hired contractors that have such equipment to measure, mark, and record the passing/no-passing zones. Other States have either assembled their equipment or have purchased such equipment.

There units are accurate and reliable. They provide a printout of the passing and no-passing zones, and they automatically mark the roads in such a way that the pavement striper operator can place the appropriate centerline pavement markings.

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Part IV. SIGNALS

Part 4 SIGNALS—con't

Part IV. SIGNALS

4A. GENERAL

Traffic control signals are defined as "power-operated traffic devices which alternately direct traffic to stop and to proceed." More specifically, traffic signals are used to control the assignment of right-of-way at locations where conflicts exist or where passive devices, such as signs and markings, do not provide the necessary flexibility of control to properly move traffic in a safe and efficient manner.

This Part of the Handbook describes the characteristics and the operation of traffic signals and is intended to serve as a guide in selecting, installing, and operating traffic signals. Although design considerations may be mentioned, the Handbook is not intended to constitute a design guide.

4A-1 Overview of Contents

The technology associated with traffic signal operations is much more dynamic than that involved in most other forms of traffic control devices. The state-of-the-art continues to advance as new hardware and control techniques are developed. While the new technology has resulted in improved tools for traffic control signal operations, these tools must be properly designed, installed, operated, and maintained if their full potential is to be realized.

Accordingly, this Part of the Handbook contains more technical content than previous Parts. In addition, the organization of the material differs somewhat from the general Handbook format. To accommodate the progression of the decisions, activities, and functions related to highway traffic signal devices, this Part is structured to parallel the process sequence. That is, investigating the need for a traffic signal, determining the operational requirements, translating these requirements into traffic control equipment requirements, preparing for equipment procurement and installation, determining optimum operation of the traffic signal, and operating and maintaining the traffic control signal over its expected life.

Much of the information presented in this Part reflects the composite experience and current practices of numerous agencies across the country. It also builds on procedures documented in the "Transportation and Traffic Engineering Handbook" (Ref. 4-1) as well as the standards and warrants provided in the MUTCD. In some instances, portions of these two companion documents are quoted or summarized for convenience and continuity. In other cases, the applicable reference is provided. Both documents should be readily available and should be used in conjunction with this Part. Other basic references of significance are the "Official Traffic Signal Manual of the International Municipal Signal Association" (Ref. 4–2), and the "Institute of Transportation Engineers' Manual on Traffic Signal Design" (Ref. 4–3).

The balance of this initial section introduces the concepts and functions underlying traffic signal control devices.

4A–2 Types of Highway Traffic Signals

The MUTCD describes a *highway traffic signal* as any power-operated traffic control device, other than a barricade warning light or steady burning electric lamp, by which traffic is warned or directed to take some specific action. A large percentage of highway traffic signals are *traffic control signals* which are defined as a type of highway traffic signal by which traffic is alternately directed to stop and then permitted to proceed. Traffic control signals assign the right-of-way to conflicting movements at intersections and mid-block crossings. Accordingly, the emphasis in this Part is on signal control at intersections. Other signal applications may be categorized as follows:

- *Hazard Identification Beacons* warn motorists of unexpected conditions in or immediately adjacent to the roadway (such as a bridge pier in the center of the road), or which supplement passive control devices (such as flashing beacons at stop sign controlled intersections).
- *Lane-use Control Signals* are used to indicate and control the direction of travel on reversible lanes or adjacent lanes; for example, one or more lanes where traffic can proceed in one direction during a certain time of day and in the reverse direction during another.
- *Freeway Ramp Control Signals* are a special application of traffic control signals installed on freeway entrance ramps to limit, or "meter," the amount of traffic entering the freeway.
- *Movable Bridge Signals* are used to stop traffic on approaches to drawbridge sections when the bridge is not available for use by highway traffic.
- *Railroad Crossing Signals* are used to warn traffic of an approaching train at railroad grade crossings.

These signal categories are discussed in Section I of this Part.

4A–3 Purpose of Traffic Control Signals

The primary function of traffic control signals is to assign the right-of-way at intersecting streets or highways where, without such control, a continual flow of vehicles on one roadway would cause excessive delay to vehicles and/or pedestrians waiting on the other roadway.

A properly designed, operated, and maintained traffic control signal can be a very valuable device for the control of vehicle and pedestrian traffic. Because it assigns right-of-way to various traffic movements, the traffic control signal exerts a significant influence on traffic flow and will have a significant impact on the vehicles and pedestrians which it controls. Consequently, it is important that the selection and use of such an important traffic control device be preceded by a thorough engineering study of both roadway and traffic conditions. In addition, existing traffic control signals should be reviewed on a regular basis. Timing plans and traffic data should be updated as needed.

Since the advent of the motor vehicle, many traffic control signals have been installed throughout the world. This vast experience with the operation and effectiveness of traffic control signals has enabled those close to the traffic situation to analyze the ramifications of traffic signal control. The establishment of "traffic signal warrants" for signalized control is one of the results of this experience. However, many traffic control signal installations, even though warranted by traffic and roadway conditions, have been poorly designed, ineffectively placed, improperly operated, or poorly maintained. The typical consequences of these conditions are excessive delay, wasted fuel, disobedience to traffic signal indications, the use of less adequate alternate routes to avoid signals, and often, increased accident frequency. Similar difficulties are found when traffic signals are installed under conditions that do not satisfy the minimum warrants.

It is unfortunate that traffic control signals have become regarded by the public as a panacea or "cure-all" or safety solution for any and all traffic problems at intersections. In other words, traffic control signals are considered by many as primarily a "safety" device. Actually, safety which admittedly is an important factor, is not the primary purpose for signalization.

In reality, if the signal is warranted and is properly designed and operated, improved safety may result, but this is only a "by-product" of the main purpose for traffic signal control which is the "orderly movement" of traffic.

If traffic signal control is being considered solely as a safety measure, a careful study should be made to determine whether the signal will indeed solve the type of accident problem being experienced. Accident experience frequently increases at unwarranted signals or at locations where installation was not based on sound engineering analysis. Accidents related to signal control usually develop during periods of comparatively low volume and result from rear-end collisions, blind spots in drivers' field of vision, and drivers either willfully or unintentionally running a red light. In many cases, the most spectacular and damaging accidents occur at signalized intersections.

Another unsatisfactory feature of unnecessary traffic signals is the needless delay forced upon drivers. Even the best designed and operated signals usually increase delay when compared to unsignalized intersections. However, *unnecessary delay* is defined as the time drivers are forced to wait at a red signal when there is no traffic using the green indication on the cross street. Unnecessary delay is a common feature of an improperly designed or an inefficiently operated traffic control signal. This unnecessary delay results in significant energy waste and higher motorist costs, not to mention the increased transportation costs included in the price of consumer goods. Moreover, delay at unwarranted or poorly designed traffic control signals can breed gross disrespect toward signals as well as other traffic control devices.

4A-4 Basic Types of Control

Traffic control signals are usually described as either pretimed or traffic actuated. Each type may be used in either an independent (isolated) or interconnected (system) application.

Pretimed control uses either electromechanical or electronic timing circuits to provide a repetitive cycle and split (cycle division among the conflicting movements) timing. The timing is repeated over and over regardless of the presence or absence of traffic demand. When operating as part of a system, adjacent intersections operate on the same cycle length and have fixed offsets (relationship of beginning of main street green displays). There may be more than one pattern of cycle lengths, offsets, and splits.

Actuated control can also use electromechanical or electronic timing circuits to provide the signal timing. However, the timing is varied for some or all controlled conflicting movements dependent upon vehicular and/or pedestrian demand. Demand is determined from detectors placed in or near the roadway or pedestrian crossing. When all controlled conflicting movements are timed relative to demand, the control is termed "full-actuated." When only secondary movements vary with demand, the control is termed "semi-actuated."

Full-actuated control is generally used for an isolated application. An isolated application is one where the traffic control signal operates independent of any other traffic control signal. Conversely, a system or interconnected application means that a given traffic control signal's operation is related to (coordinated with) one or more other traffic control signal locations. In system applications, a fully actuated controller must operate as a semi-actuated controller because it must operate on the same cycle length as all the other controllers that are interconnected with it. In systems, pretimed and actuated control may be mixed.

These control concepts and their applications are described in more detail in the following sections.

4B. DETERMINING NEED FOR TRAFFIC SIGNAL CONTROL

The first and basic question that must be addressed is whether or not traffic signalization is needed. Since traffic signals are considered the most restrictive of the traditional traffic control devices, they should be used only where the less restrictive signs or markings do not provide the necessary level of control.

Requests for the installation of traffic signals originate from numerous sources including:

- General Public (individual citizens, citizen groups),
- Government officials,
- Industrial and commercial developers and operators,
- Media,
- Engineering staff of the responsbile agency, and
- Other agencies.

However, it is the responsibility of the traffic engineering agency to make a decision whether such requests are justified. The decision should be based on a comprehensive investigation of traffic conditions and location characteristics. The comprehensive investigation will provide the data necessary for the design and operation of a traffic control signal that is found to be justified.

It is not unusual to find that there are a number of locations where the minimum warrants are satisfied, but there are not adequate resources (budget, manpower) to affect immediate installation. Data obtained from comprehensive field investigations can be used to establish priorities as to which traffic control signals should be installed first.

The next three sections discuss the studies required to determine the need for a traffic control signal, the warrants for a traffic control signal, and procedures for prioritizing the installation of warranted traffic control signals.

4B-1 Required Studies

Section 4C-1 of the MUTCD lists the data that should be obtained to determine the need for a traffic control signal installation. Once obtained, the data can be used in the design and operation of warranted traffic control signals. Studies that provide such data include:

- Traffic volumes (vehicular and pedestrian),
- Approach travel speeds,
- Physical condition diagrams,
- Accident history and collision diagrams,
- Gap studies, and
- Delay studies.

Traffic Volumes

For a discussion on traffic volume studies refer to Section 1C-3 of this Handbook.

Approach Travel Speeds

For a discussion of approach travel speeds refer to Sections 1C-4 and 2B-1 of this Handbook.

Physical Condition Diagrams

The physical condition diagram should show the items listed under the paragraph numbered 5 on page 4C-1 of the MUTCD. The diagram should normally be drawn to scale. Depending on the size of the study and the amount of detail to be shown a scale of 1 inch = 20, 40, or 50 feet may be used. Many consider the 1 inch = 20 feet to be a convenient scale to show signal installation details (i.e., poles, signal heads, conduit, controller location, etc.).

Accident History and Collision Diagrams

For a discussion on accident history and collision diagrams refer to Section 1C-2 of this Handbook.

Gap Studies

A method is being developed through a federally-funded research project to determine the need for a traffic signal by using site specific information on gaps in the major road traffic. The traffic volume to gap ratio has been shown to be an accurate predictor of side street delay, which in turn is a more accurate indication of signal need than engineering judgment.

The method consists of determining the number and size of gaps (during a 4-hour period) using a modified volume counter or commercially available gap counter. The gap data is converted to an equivalent number of adequate gaps (known as the gap availability parameter). The side street volume and gap availability parameter are plotted on an analysis diagram which shows the average side street delay. If the average side street delay exceeds the threshold value of tolerable delay for the community in question (i.e., 25 seconds per vehicle) then a signal may be warranted. For information as to the current status of this research project contact the Office of Traffic Operations, FHWA.

Delay Studies

Two methods are used to measure the amount of intersection delay in the field. They are the Stopped Time Delay Method and the Travel Time Method.

Stopped Time Delay Method

This method consists of determining the amount of time that vehicles are actually stopped at the intersection. The amount of stopped time can be determined by a visual observation, the manual use of delay meters, or from a timed series of photographs taken from a suitable vantage point.

Travel Time Method

Various methods are used to determine the travel time from a point in "front" of the intersection to one "behind" the intersection. This can be accomplished by observation and stopwatch timing, by using a test vehicle through the area, by using a 20 pen recorder with road tubes at critical points, and by a timed series of photographs taken from a suitable vantage point.

These procedures are more thoroughly discussed and referenced in "Traffic Engineering Theory and Practice" (Ref. 4-25) and in the "Manual of Traffic Engineering Studies" (Ref. 4-4).

4B–2 Signal Warrants

The data obtained through the procedures discussed in Section 4B–1 are compared with the minimum MUTCD warrants to determine whether the installation of a traffic control signal is justified or *warranted.* The MUTCD lists the following eight warrants:

- Warrant 1—Minimum vehicular volume
- Warrant 2—Interruption of continuous traffic
- Warrant 3—Minimum pedestrian volume
- Warrant 4—School crossings
- Warrant 5—Progressive movement
- Warrant 6—Accident experience
- Warrant 7—Systems
- Warrant 8—Combination of warrants

Traffic control signals should not be installed unless one or more of the warrants are met. It should be recognized that the satisfaction of a warrant does not necessarily completely justify a signal installation. There may be cases where, even though a warrant is satisfied, the signal would increase the hazard or delay. In such cases, engineering judgment must be exercised to determine the best course of action. In other cases, sufficient funding may not be available for the installation and maintenance of all of the warranted signals.

Several of the volume warrants are based in part on the number of approach lanes to the intersection. Providing additional approach lanes through parking removal or by widening the roadway may be a practical alternative to a signal installation. In any event, the warrant evaluation should consider any proposed additional approach lanes.

The warrants related to traffic volume consider the traffic for the eight highest volume hours of the day. At some high generator locations, there are sharp peak hour volumes that cause congestion and conflict while low volume levels exist for the balance of the day. Several peak hour warrants have been developed and used in the States of Texas, Pennsylvania, Missouri, and Illinois. A major research effort is now being conducted by the National Cooperative Highway Research Program (NCHRP 3-20A) to develop and recommend a peak hour warrant. The current status of this research effort may be obtained by contacting the Office of Traffic Operations, Federal Highway Administration.

4B-3 Prioritizing Warranted Signals

The decision as to which warranted signal location is to be installed first should be based on a priority ranking list. The priority ranking systems used in current practice vary considerably, particularly in the assignment

Satisfaction of Volume Warrants	Additional points for the number of hours a warrant is met.
Satisfaction of Warrants	Additional points for the number of warrants met.
Accidents	Additional points for correctable accidents over the warrant number.
Coordination	Additional points if signal fits into an arterial progression of grid system. Reduction in points if signal does not lend itself to coordination.
School Crossing Proximity	Additional points if intersection is a school crossing, or is proximate to school crossing.
Pedestrian Volume	Additional points if signal location has moderate to high pedestrian activity associated with it.
Intersection Geometrics	Reduction in points for "T" intersections. Additional points for higher speed locations, sight distance restrictions, vertical or horizontal curvature conditions.
Area Considerations	Points added or subtracted for CBD, urban, or rural locations.

Table 4-1 Elements for Consideration in Signal Priority Ranking Systems

of weighted values to the various ranking elements. Since it is not possible to establish a prioritized rating system applicable to all agencies, each agency utilizing such techniques should design their own priority ranking system. Some commonly used priority considerations are listed in Table 4-1.

Techniques are coming into use that simulate traffic flow. These include the simulation part of the TRANSYT program (macroscopic model) and the NETSIM or SOAP Programs (microscopic models). An agency proficient in the use of such models can use them to analyze the impact of candidate signals on such measures of effectiveness as delay, stops, fuel consumption, and person delay (reflecting bus and other high occupancy vehicles). Thus, it is becoming practical to reflect these measures of effectiveness in the priority ranking of candidate signal installations. The priority rating system used by individual agencies should be structured so that the elements critical to the agency's jurisdictional needs are weighted accordingly.

4B-4 Use of Flashing Operations

There are a number of situations when a traffic signal may be needed during a particular time of day but is not needed during others. Both pretimed and actuated signals can often be operated in the flashing mode when not needed to control traffic.

Traditionally, many jurisdictions use flashing operations for the following situations:

- At night and during periods of light traffic,
- When a signal malfunctions,
- As an interim measure prior to full removal of an unwarranted signal,
- At new installations prior to full signal turn on.

Operating a traffic control signal in the flashing mode offers a number of potential benefits to the agency and to the motorist. Among them are:

- Reduce stops and needless delay to arterial traffic,
- Reduce delay to side street traffic,
- Less stops and delays will result in a reduction in fuel consumption, and
- Electrical consumption by the traffic control signal can be reduced by 50 to 65 percent.

Each intersection that is being considered for operation in the flashing mode should be carefully analyzed as recent research indicates that accident rates may increase, especially at night.

The following considerations should be taken into account when making a decision to use the flashing mode at a signalized intersection:

- Flashing yellow/red operation may be appropriate at simple, four-legged or three-legged, intersections where the minor street drivers have an unrestricted view of approaching main street traffic, and the traffic volumes are low.
- At locations that flash yellow/red, the accident pattern should be monitored. Signal operation should be changed to regular operation if the accident pattern and/or severity increases or if an increase in conflicts is perceived. Indications that a potential problem exists may include:
  - A short-term rate of 3 right-angle accidents in 1 year.
  - A long-term rate of 2.0 right-angle accidents per million vehicles entering during the flashing operation if the rate is based on 3 to 5 observed right-angle accidents.
  - A long-term rate of 1.6 right-angle accidents per million vehicles entering during the flashing operation if the rate is based on 6 or more observed right-angle accidents.
- A "speedway" effect can be avoided and uniform speeds can be achieved by maintaining enough operating signals at an appropriate spacing to provide signal progression at the desired speed.

When a traffic control signal is put on flashing operation a yellow indication is normally used for the major street and red indications are used for all other approaches. The MUTCD stipulates that yellow indications shall not be used for all approaches. Sections 4B-6, 4B-7, and 4B-18 of the MUTCD list other requirements for flashing operations.

4B-5 Signal Removal

As discussed in the introduction to this Part, traffic signals are not a "cure-all" for all traffic problems. Installation of nonwarranted signals can result in unnecessary delay and an increase in certain types of accidents. In addition, even when installed under warranted conditions, changing traffic patterns may render an existing signal no longer necessary. It is, therefore, incumbent upon the responsible agency to periodically evaluate the effectiveness and necessity for particular signals and to remove those that are no longer warranted.

A recent study (Ref. 4-6) established criteria for removal of signals that are not needed. Basically, these criteria include:

- Traffic performance,
- Safety (accidents),
- Fuel consumption, and
- Pollution reduction.

The two basic stages emphasized in this study involve:

- Preliminary screening—A set of criteria each involving a yes/no decision (Fig. 4-1).
- Detailed Analysis—A process for estimating the major technical and social impacts of removing a signal including accidents, fuel consumption, related costs, and public opposition (Fig. 4-2).

After it has been determined that the signal is no longer necessary, the removal procedures should address the following objectives:

- Make motorists aware of the change in intersection control during the initial transition period.
- Convey to the public (including potential opponents) that the signal removal decision was carefully assessed and is likely to result in safety, energy conservation, and traffic operations benefits.

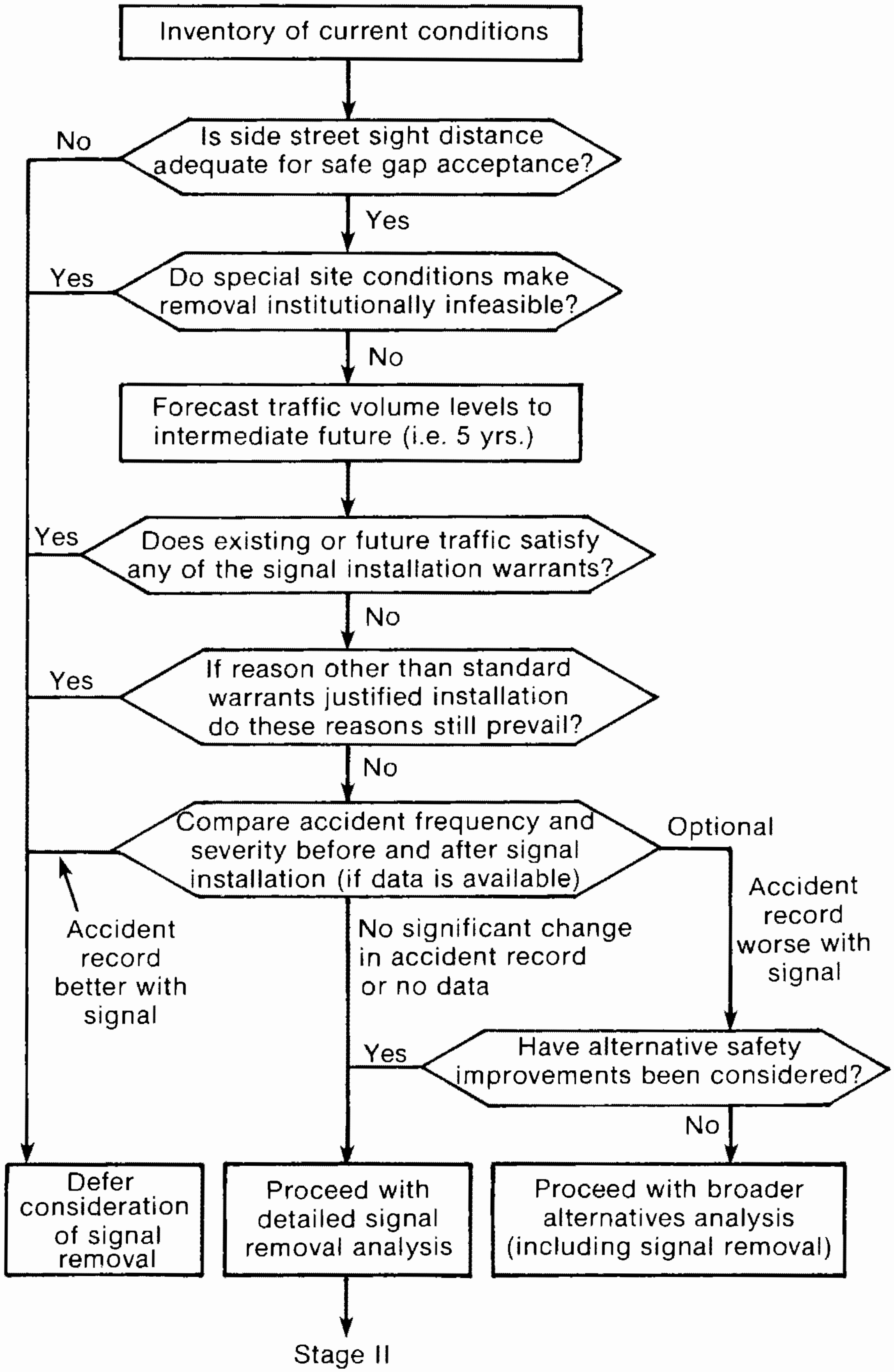


Figure 4-1 Signal Removal—Preliminary Screening

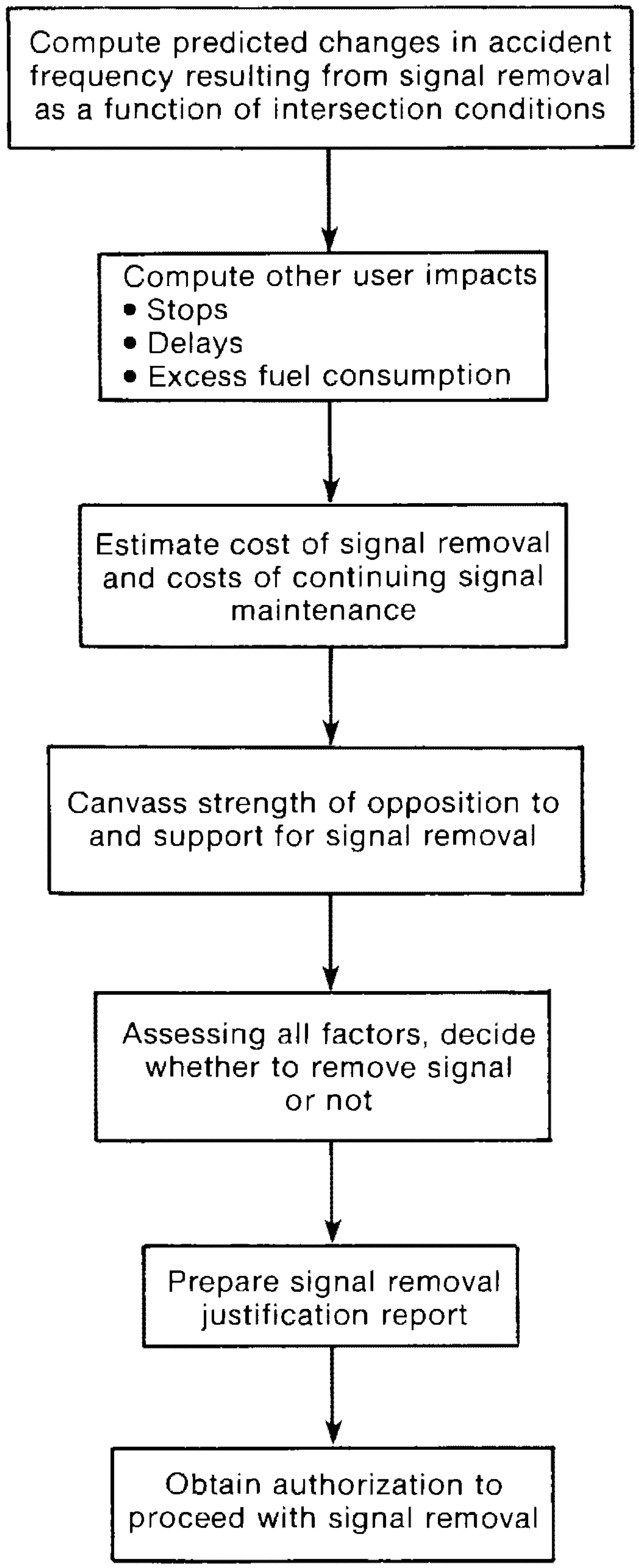


Figure 4–2 Signal Removal—Detailed Analysis

4C. OPERATIONAL REQUIREMENTS

This section describes a rational approach to determining the operational requirements of a signalized intersection. At this point in the process, it is presumed that a signal has been shown to be warranted and it must now be decided what type of equipment should be installed. Specifically, the need at this point is to determine:

- Controller phasing,
- Pretimed or actuated operation,
- Local detection alternatives, and
- Isolated versus system operation.

4C-1 Controller Phasing

In the context of traffic control signals, a phase is defined as that part of the time cycle allocated to a traffic movement receiving the right-of-way, or to any combination of traffic movements receiving the right-of-way simultaneously. A traffic movement may be a vehicular movement alone, a pedestrian movement alone, or a combination of vehicular and pedestrian movements. The sum of all traffic phases is equal to the time cycle.

A two-phase operation is most often used. In a two-phase operation, at a typical four-legged intersection, one phase accommodates the traffic on one street and the second phase accommodates traffic on the other street. Additional phases will often be necessary if additional legs (from a third street or major driveway) come into the intersection. Also, additional phases may be used to provide protected left turn intervals (left turn arrows).

Left-turn phases facilitate left turning traffic. However, this is done at the expense of the amount of green time available for through traffic.

Left-turn phasing at signals in a coordinated system will frequently necessitate longer cycle lengths. These longer cycle lengths usually make it difficult to provide a good signal progression through the coordinated systems. Thus, while left-turn phasing and multiphased operation have advantages in some situations, they also have some drawbacks. Sound engineering judgment needs to be applied in considering their use.

Different left-turn operations are used at different locations. In some instances, left turns can be made only on the green arrow (protected). At other locations, left turns can be made on both the green arrow (protected) and circular green (permitted). This is commonly referred to as protected/permitted or P/P phasing. Where green arrows are not used, left turns are made on circular green through appropriate gaps in the opposing traffic (permitted only). The type of operation used affects the various phasing schemes. Left-turn treatments are discussed in more detail below and in considerable detail in Ref. 4-5.

Pedestrian movements may also be incorporated into the various phasing schemes. Depending on the magnitude of these movements they may influence the selection of a particular phase. For example, on wide streets with heavy pedestrian movements, a lead-lag left-turn phase scheme may provide more time for pedestrains to cross at the intersection. At intersections with heavy pedestrian traffic and heavy turning movements, the use of an exclusive phase for pedestrians may be appropriate. However, such phasing will invariably have a detrimental effect on traffic flow. The following items should be carefully considered when designing exclusive pedestrian phases:

- They will usually reduce the capacity of the intersection,
- They will usually result in longer cycle lengths which in turn will have a detrimental effect (increased stops and delays) throughout the signal system network,
- Pedestrian delay may be increased, and
- Due to the increased delay, pedestrians may elect to ignore the—DONT WALK signal unless police enforcement is conspicuous.

General Phasing Guidelines

As a general rule, the number of phases should be held to a minimum. Additional phases reduce the green time available for other phases. They may decrease intersection efficiency because of additional starting delays, additional change (yellow) intervals, longer cycles, and adverse impact on optimal progression.

In determining the number of phases required at an intersection, the goals of safety and capacity may conflict. For example, in many situations protected left turn phases are safer than permitted left turns. However, the added phases may result in longer cycle lengths, reduced progression in the systems, and increased delay and percent of vehicles stopping.

The number of phases chosen is primarily a left-turn issue. In general, as left-turning volumes and opposing through traffic volumes increase, a point is reached where it is difficult for left-turning traffic to find adequate gaps. The provision of a separate left-turn lane will alleviate the problem somewhat by providing storage space in which turning vehicles can wait for an acceptable gap in opposing traffic. If the problem persists, the decision to provide separate left-turn phasing should be carefully weighed. (See Section 4–F for discussion of phase interval timing and cycle length calculations.)

While phases for protecting left-turning vehicles are the most popular and most often added phases, these separate phases reduce the available green time. As a result, other methods of handling left-turn conflicts should be considered first. Potential solutions include prohibiting left turns and geometric improvements.

Prohibiting Left Turns.

Left turns can be prohibited where suitable alternative routes are available. This is particularly effective on major arterials with evenly spaced intersections. Alternate pairs of intersections are signalized. Left turns are prohibited at signalized intersections and permitted at unsignalized intersections where left turn bays have been constructed. Left turns are made at these unsignalized intersections through gaps in opposing platoons.

Left turns can be prohibited on a full or part-time basis. The following should be taken into account when considering a left-turn prohibition:

- Volume and classification (type) of vehicles diverted,
- Adequacy of marked or likely to be utilized routes, (environmental considerations, pavement and bridge or culvert structural capacity, safety features, adjacent land use, etc.)
- Transit routes,
- Additional traveltime and distance,
- Enforcement needs, (particularly during initial week or two of change), and
- Will the prohibition solve the problem or will it simply move the problem somewhere else.

Geometric Improvements

Another obvious, but generally cost-prohibitive solution, is to reconstruct the intersections. Either an interchange or a "New Jersey Jug Handle" can eliminate the need of a multiphase controller operation.

Lead-Left/Lag-Left Turn Phasing

In a cycle, there are two alternatives available for left turn phasing. When the protected left turn precedes the accompanying through movement, it is called a "lead-left." When the left turn phasing follows the through movement, it is called a "lag-left." In general, signals operate with opposing left turns operating at the same time. In actuated equipment, it is frequently desirable to split the left-turn phase so that when demand on one left-turn phase ceases, the opposing through movement is released. This works only with dual lead-left operations. In dual lag-left, they must operate simultaneously. Both sequences have advantages and disadvantages. They are summarized below.

Lead-Left Turn Phase

The following advantages are generally attributed to leading left-turn phases:

- Increases intersection capacity on one or two lane approaches without left-turn lanes compared with two-phase traffic signal operation.

- Minimizes conflicts between left turn and opposing straight through vehicles by clearing the left turn vehicles through the intersection first.
- Motorists tend to react quicker than with lag-left operations.
- Preferable where left-turn lanes do not exist and where there is a significant left-turn demand.
- Can be used to provide coordinated progressive traffic movement in an interconnected signal system with unequal spacings.

The disadvantages which may accrue as a result of lead-left turn phasing includes:

- Left-turning vehicles may continue to turn when the green is exhibited to the opposing through movement.
- Through movement vehicles may make a false start in an attempt to move with the leading turning vehicle movement.

Lag-Left Turn Phases

Discretion should be used with lag-left turn phasing as they may introduce operational problems which should be recognized and avoided during the design and implementation process. By far the most critical of these problems is where one approach's right-of-way is terminated while the opposing approach continues with a green arrow and an adjacent through movement. This may result in a "trap" for left-turning drivers facing a yellow indication. Ordinarily, the left-turning driver facing a yellow display will expect the opposing through traffic to also have a yellow signal and since the through traffic will be stopping, he believes that he can complete the turn on the yellow indication or immediately after. Since through traffic is not stopping, a potentially hazardous condition exists.

In spite of the "trap" problem, there are some advantages associated with lag-left phasing:

- Both directions of straight through traffic start at the same time.
- Approximates the normal driving behavior of vehicle operators.
- Provides for vehicle/pedestrian separation as pedestrians normally cross at the beginning of the straight through green interval. Where pedestrian signals are used, pedestrian clearance has been completed at the beginning of the lagging-green interval.
- Left turns do not preempt the right-of-way from the opposing straight through traffic movement.
- Cuts off only the platoon stragglers from adjacent signalized interconnected intersections.

In addition to the entrapment problem there are two other significant disadvantages to the use of a lag-left turn phase. They tend to restrict the use of a lagging left turn phasing to pretime operation or to a few specific situations in actuated control such as "T" intersections. These disadvantages are:

- Creates conflicts for the opposing left turns at the beginning of the lag interval since the opposing left-turn drivers expect both movements to stop at the same time. (Many traffic engineers feel that the left turn from the approach opposite the lag needs to be prohibited to remove the accident potential).
- Where a left-turn lane does not exist, left-turn traffic must stop and wait for a gap in the lag left-turn phase. This creates an obstruction to through movement during the initial green interval.

Left-Turn Phase Criteria

The left-turn phase criteria suggested below are a combination of left-turn phasing warrants used in several States, and the results of a research study entitled, "Warrants for Left-Turn Signal Phasing" (Ref. 4–7). In this study, 45 States responded to a survey requesting left-turn warrant information. Six States cited numerical warrants, while several States had more than one warrant. These warrants are not mandated by the MUTCD and are provided here for information purposes only. These warrants are grouped by type:

Volume

- The product of left turning vehicles and conflicting through vehicles during the peak hour is greater than 100,000.
- As above, with the product greater than 50,000.
- Left turn volume greater than 100 (or 90) vehicles during the peak hour.
- Left turn peak period volumes greater than two vehicles per cycle per approach still waiting at the end of green (for pretimed signals).
- Left turn volumes greater than 50 vehicles per peak hour when through traffic speed exceeds 45 mph.

Delay

- Delay to left turn vehicles greater than two cycles.
- One left-turning vehicle delayed one cycle or more during one hour.

Accidents

- Five or more left-turn accidents within a 12-month period.

The significant common point in many of these warrants is the peak period emphasis. That is, most of the warrants are satisfied if the criteria are met for a peak hour.

Suggested Guidelines

The following guidelines may be used when considering the addition of separate left-turn phasing. These guidelines apply to intersection approaches having a separate left-turn lane.

Volumes—Consider left-turn phasing when the product of left-turning and opposing volumes during peak hours exceeds 100,000 on a four-lane street or 50,000 on a two-lane street. Also, the left-turn volume must be greater than two vehicles per cycle during the peak-hour period. Volumes meeting these levels indicate that further study of the intersection is required.

Delay—Install left-turn phasing if a left-turn delay of 2.0 vehicle-hours or more occurs in a peak hour on a critical approach. Also, there must be a minimum left-turn volume of greater than two per cycle during the peak hour, and the average delay per left-turning vehicle must be at least 35 seconds.

Accident Experience—Install left-turn phasing if the critical number of left-turn accidents has occurred. For one approach the critical number is four left-turn accidents in 1 year or six in 2 years. For both approaches, the critical number is six left-turn accidents in 1 year or ten in 2 years.

For approaches without left-turn lanes, the initial solution to be considered is to create a left-turn lane. On two-lane approaches this may be possible if the through and right-turn movements can be accommodated in one lane. Then, the left lane is converted to a left-turn lane by the use of appropriate pavement markings and signs. Where two lanes are needed for the through and right-turn movements, a left-turn lane can sometimes be created by a combination of widening, shifting lanes, narrowing lanes, and the use of appropriate signs and markings.

A lead-left for the heaviest movement or directional separation may be used when: 1) the through and right-turn traffic demand cannot be accommodated in one lane, or there is only one lane on the approach; and 2) a left-turn problem has been identified using the suggested warrant guidelines above. This movement normally is not detectorized and simply displays the left-turn arrow(s) immediately prior to the through phase. It is recommended that a five-section signal display be used and that a yellow arrow lens be used to clear this movement. The duration of this phase can be determined on the basis of traffic demand, but it is normally short and generally does not exceed 6 to 12 seconds.

Protected/Permitted Left-Turn Phasing

Protected/permitted left-turn phasing is a left-turning movement of traffic at a signalized intersection having a separate left-turn lane and phase in the signal cycle to provide a protected (green arrow) interval as well as a nonprotected (circular green) interval.

Implicit in discussions concerning the utilization of the protected/permitted left-turn phasing technique is the assumption that the need for a protected left-turn interval has been established. One of the basic precepts of the protected/permitted left-turn phasing technique for actuated installations is that the protected green arrow is displayed only when needed in a traffic demand condition. It is therefore emphasized that the protected/permitted left-turn phasing technique is an efficiency concept as opposed to an accident reduction concept (although it will probably offer safer operation than strictly permissive operation).

The following suggestions for the use of protected/permitted left-turn phasing is based on research study results (Ref. 4–8) and the conventional uses in general practice:

- Where left-turn phasing has been determined to be warranted on a volume basis, consider the use of protected/permitted left-turn phasing before protected only left-turn phasing is implemented.
- When using leading protected/permitted phasing, consider the use of the left-turn queue detection to improve overall intersection operating efficiency.

In general, for intersections with traffic volumes indicating a need for a separate left-turn phase, protected/permitted left-turn phasing will provide safer left-turn operations than strictly permitted left turns, but will not provide the degree of safety of a full-time protected left-turn phase.

Phase Selection Technique

Several analytical techniques are available to determine the optimum phasing for a given set of geometric and traffic conditions. First, a phasing is assumed, then the level of service (degree of saturation) is calculated, and finally the unprotected left turn movements are checked. The techniques are all related to the Critical Movement Analysis (CMA) as described in TRB Circular 212 and recommended by the Highway Capacity Committee of TRB for testing the calculations for level of service for signalized intersections (Ref. 4–9).

A computer program entitled Signal Operations Analysis Package (SOAP) has been developed by Ken Courage, University of Florida Transportation Research Center, for the Federal Highway Administration. This program provides a computerized method of developing signal control plans for isolated intersections. A wide range of control alternatives can be evaluated including pretimed or actuated multiphase control. The typical physical condition analyzed by SOAP is a four-legged intersection with left turns, through traffic, and right turns.

SOAP determines the optimal signal timing and phasing, and produces several measures of effectiveness, including delay, stops, fuel consumption, volume-to-capacity ratio, and left-turn conflicts. Phasing diagrams may also be produced (Ref. 4-10). A sample SOAP output is shown in Figure 4-3. The program is also being developed for use on microcomputers. Current information on the Signal Operations Analysis Package can be obtained from the Office of Traffic Operations, Federal Highway Administration.

```
     SOAP/M SIGNAL TIMING DESIGN

              GATOR & ORANGE



   -----
   !INPUT!                                (NB)         (SB)         (EB)         (WB)
   -----                               THRU LEFT    THRU LEFT    THRU LEFT    THRU LEFT

     VOLUMES        (VPH)              1520  175     930   90     500   50     600   40
     SAT FLOW   (VPHG OR #LANES)          2    1       2    1       1    1       1    1
     HEADWAY        (SEC)               2.2  2.5     2.2  2.5     2.2  2.5     2.2  2.5
     PCF       (#-RED/TOTAL)              0    0       0    0       0    0       0    0
     GREEN/MOV      (SEC)                15   10      15    0      15    0      15    0
     TRUCKS         (%)                   5    5       5    5       5    5       5    5
     LEFT TURNS  (LEFT/CYCLE)             0    0       0    0       0    0       0    0


                              PHF:    1.1
                  CONTROLLER TYPE:          PRETIMED
                     CYCLE LENGTH:     90   SECONDS
                        LOST TIME:    3.5   SEC/PHASE CHANGE

    --------------------------
   !SIGNAL TIMING CALCULATIONS!
    --------------------------           (NB)         (SB)         (EB)         (WB)
                                      THRU LEFT    THRU LEFT    THRU LEFT    THRU LEFT

        VOLUME/CAPACITY                 .53  .14     .32  .07     .35  .04     .41  .03
               VOLUME:     (VPH)       1565  180     957   92     515   51     618   41
             SAT FLOW:     (VPHG)      3273 1440    3273 1440    1636 1440    1636 1440
  LEFT TURN SATURATION:    (VPHG)            350          100          475          750


     GREEN TIME/MOVEMENT
             AVAILABLE:    (SEC)       51.4 15.1    36.3    0    38.5    0    38.5    0
     SPECIFIED MINIMUM:    (SEC)         15   10      15    0      15    0      15    0
              REQUIRED:    (SEC)       50.9 15.9    32.5  9.8    34.6    7    40.8  6.3

      3 PHASE OPERATION    (SEC)  (%)              DEGREE OF SATURATION
         NB THRU&LEFT:     36.3  40.4                     NORTH/SOUTH:     53 %
         NB&SB THRU  :     15.1  16.8                       EAST/WEST:     41 %
         EB&WB GREEN :     38.6  42.8                           TOTAL:     94 %
                     :
                     :                             TOTAL LOST TIME:     10 (SEC)
                     :                                CYCLE LENGTH:     90 (SEC)
```

Figure 4-3 Sample SOAP Output

```
     SOAP/M   SIGNAL TIMING EVALUATION

              GATOR & ORANGE



    ---------------
   !LEFT TURN CHECK!
    ---------------
                                  (NB)         (SB)         (EB)         (WB)
                                  LEFT         LEFT         LEFT         LEFT

                VOLUME:           180           92           51           41
  CAPACITY    (PROTECTED):        185            0            0            0
  CAPACITY  (UNPROTECTED):         46           26           48          107
  CAPACITY  (CLEARANCE):          0            80           80           80
                 TOTAL:           232          106          128          187
          UNSAFE LT'S:              0            0            0            0

    -------------------------     (NB)         (SB)         (EB)         (WB)
   !MEASURES OF EFFECTIVENESS!  THRU LEFT    THRU LEFT    THRU LEFT    THRU LEFT
    -------------------------

    DEGREE OF SATURATION:  (%)    90    78     80    87     81    40     97    22
           OVERSATURATED?         NO    NO     NO    NO     NO    NO     NO    NO


      AVERAGE DELAY: (SEC/VEH)    14 35.5    20.4 51.5    20.8 41.8    21.8 35.7
        TOTAL DELAY:    (HOURS)  6.1   1.8    5.4   1.3    3.0   0.6    3.7   0.4
        GRAND TOTAL: (VEH-HRS/HR)  << 22 >>

    STOPS PER MOVEMENT:  (%)      90    96     90   100     89    97     98    93

      FUEL CONSUMPTION: (GAL/HR) 17.7   2.8   11.9   1.7    6.4   0.8    8.3   0.6
           GRAND TOTAL: (GAL/HR)  << 50 >>

   LEFT TURN CONFLICTS: (/HR)           0            0            0            0


    -------------------
   !ANNUAL COST SUMMARY!
    -------------------
                                       (BASED ON 4 HRS PER DAY)

                                AMOUNT      UNIT VALUE       COST($)

           DELAY:   (VEH-HRS)    26,400       $ 3.00          79,200
           STOPS:             4,416,330       $ 0.014         61,828
            FUEL:   (GALLONS)    60,221       $ 1.30          78,287

                                                TOTAL:       219,315
```

Figure 4-3 Sample SOAP Output (Con't)

4C-2 Pretimed Versus Actuated Control

There is no direct method of determining whether a local intersection should be pretimed, semi-actuated, or full-actuated. This is not a trivial issue. There have been numerous attempts to resolve this dilemma.

Recently, this issue was addressed in a research project conducted under the National Cooperative Highway Research Program Project 3-27. The objective of this project was to develop guidelines for selecting the most appropriate type of traffic signal control for an individual intersection in

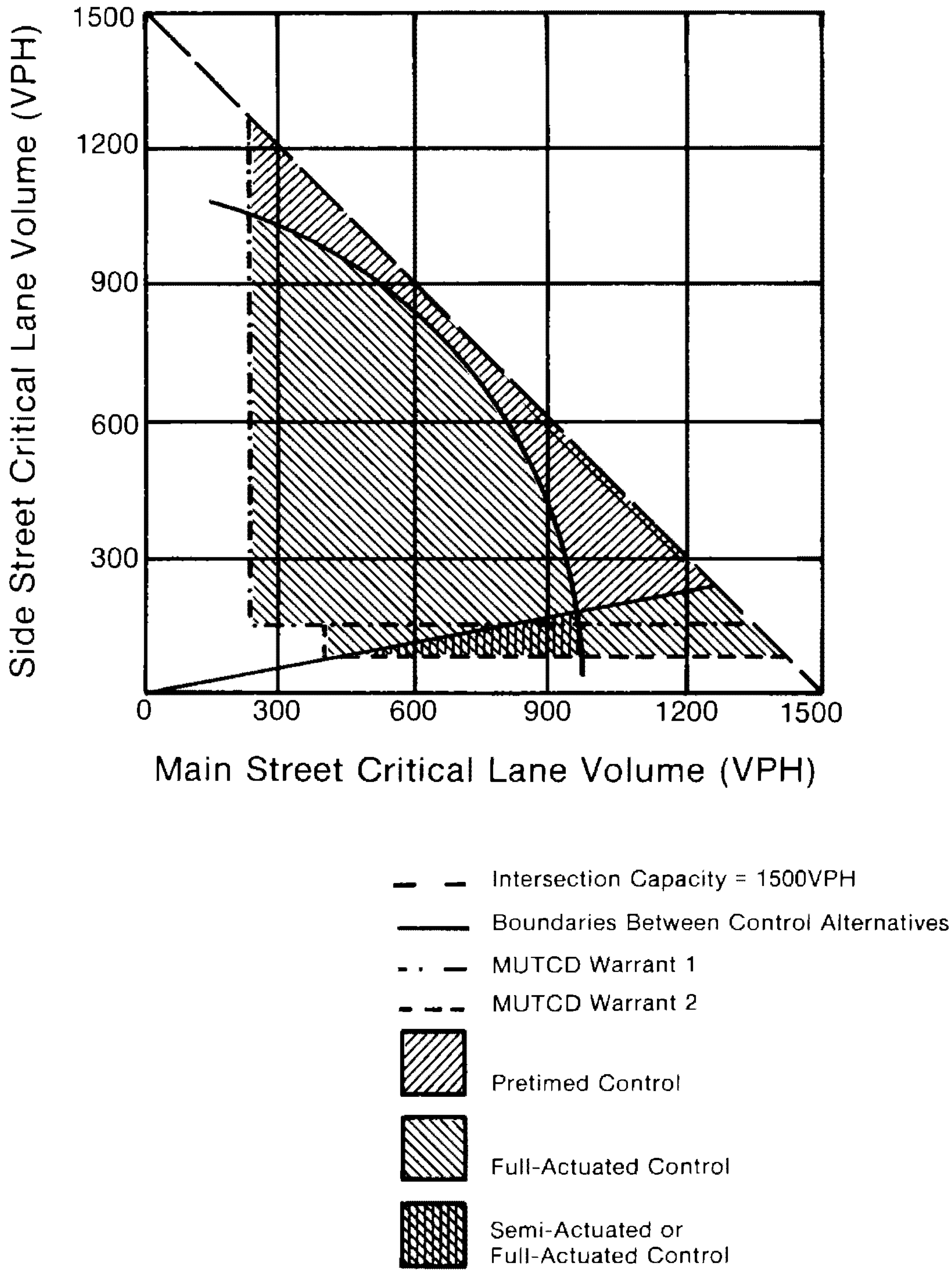


Figure 4-4 Pretimed Vs Actuated Control Determination Graph

both rural and urban areas. Although the emphasis was on the selection of a particular form of signal control, supplemental information was provided on equipment costs and detector location.

The research results demonstrated that the form of control that minimizes vehicle stops and delays at an intersection also minimizes fuel consumption and emissions. Furthermore, it was found that the difference in the annual costs for equipment acquisition, installation, operation, and maintenance between the control alternatives were significantly less than the differences between the benefits. For this reason, the control alternative that minimized stops and delays also proved to be the most cost-effective.

Data collection and analysis consists of listing existing roadway and traffic conditions and computing critical signal timing parameters. The comparison of alternatives is based on the graphically displayed definition of regions for which each form of control is most effective. The axis of the graph are main street critical lane volume and side street critical lane volume. A typical graph is shown in Figure 4–4. The regions defined are for pretimed, semi-actuated, and full-actuated control.

As can be seen on the figure, there is no unique region where semi-actuated control is optimum. The largest region is best served by full-actuated controllers. Pretimed control is optimum only in the regions approaching the capacity of the intersection. A similar graph must be developed for each intersection scenario.

The above discussion and graphic example are based on a rural, isolated situation and may not be applicable to a typical urban installation. The following guidelines may be of value for urban situations.

In general, each of the principal types of traffic signal control, pretimed and traffic-actuated, possess certain advantages not afforded by the other. The choice of equipment should be made only after a review of the relative merits and adaptability to the particular requirements of the location proposed for signalization. The following discussion is intended to bring out basic differences in the different types of control, insofar as their operating characteristics and suitability for various traffic requirements are concerned. It should be remembered that each type of control is capable of being modified in various ways for improved efficiency and flexibility.

Pretimed Control

With basic pretimed control, a consistent and regularly repeated sequence of signal indications are given to traffic. Pretimed control is best suited to intersections where traffic patterns are relatively stable or where the variations in traffic that do occur can be accommodated by a pretimed schedule without causing unreasonable delays or congestion. Pretimed control is particularly adaptable to intersections where it is desired to coordinate signal operation with existing or planned signal installations at nearby intersections. Semi-actuated controllers can be coordinated from a master controller or synchronizer.

Traffic-Actuated Control

The traffic-actuated controller differs basically from the pretimed controller in that signal indications are not of fixed length, but are determined by and conformed within certain limits to the changing traffic flow or to the background cycle from the master controller. The length of cycle and the sequence of intervals may or may not remain the same from cycle to cycle, depending on the type of controller and auxiliary equipment being utilized. In some cases, certain intervals may be omitted when there is no actuation or demand from waiting vehicles or pedestrians.

Advantages of Pretimed Control

Among the advantages of pretimed control are the following:

- The consistent starting time and interval duration of pretimed control facilitates coordination with adjacent traffic signals. It also provides more precise coordination than does traffic-actuated control, especially when coordination is needed with adjacent traffic signals on two or more intersecting streets, or in a grid system. This capability can permit progressive movement and a degree of speed control through a system of several well-spaced traffic signals. A precise timing relationship permits the operation of two or more very closely spaced intersections at maximum efficiency.
- Pretimed controllers are not dependent for proper operation on the movement of approaching vehicles past detectors. Thus the operation of the controller is not adversely affected by such conditions as a stopped vehicle or construction work within the area.
- Pretimed control may be more acceptable than traffic-actuated control in areas where large and fairly consistent pedestrian volumes are present, and where confusion may occur with the operation of pedestrian push buttons.
- Generally, pretimed equipment costs less to purchase and install, and it is simpler and more easily maintained than traffic-actuated equipment.

A degree of simple coordination of pretimed and semi-actuated controllers can be attained by the use of controllers equipped with synchronous timing motors without wire interconnection or remote supervision. However, because of interruptions or irregularities of electric service, frequent checking and adjustment of signals is required to assure reliable coordination in systems without supervisory circuits. Wire interconnected systems are, therefore, preferable to those without wire interconnection.

Advantages of Traffic-Actuated Control

At intersections where traffic volumes fluctuate widely and irregularly, where traffic loads shift frequently, or where interruptions to main-street flow must be minimized, maximum efficiency in signal operation may be attained by the use of traffic-actuated control.

Among the special advantages of traffic-actuated control are the following:

- Traffic-actuated control may provide maximum efficiency at intersections where fluctuations in traffic cannot be anticipated and programmed for with pretimed control.
- Traffic-actuated control may provide maximum efficiency at complex intersections where one or more movements are sporadic or subject to variation in volume.
- Semi-traffic-actuated control will usually provide maximum efficiency at intersections of a major street and a minor street by interrupting the major-street flow only when required for minor-street vehicular or pedestrain traffic. Such interruptions will be restricted to the minimum time required.
- Traffic-actuated control may provide maximum efficiency at intersections unfavorably located within progressive pretimed systems, where interruptions of major street traffic are undesirable and must be held to a minimum in frequency and duration. A background time cycle may be superimposed upon the operation to effect coordination with nearby signals.
- Traffic-actuated control may provide the advantages of continuous stop-and-go operation even in periods of light traffic without causing unnecessary delay to traffic on the major street.
- Traffic-actuated control is particularly applicable at locations where traffic signal control is warranted for only brief periods during the day.
- Traffic-actuated control tends to reduce problems associated with the arbitrary stopping of vehicles.

Other Factors Governing Selection of Type of Control

In addition to the warrants for pretimed signals as a basis for selecting the appropriate type of traffic control, initial equipment cost, installation cost, and anticipated operating expenses need to be considered. Pretimed control is generally less expensive to install and maintain than other types of control. Attention should also be given to economic benefits or losses which may be incurred by motorists and pedestrians. Unnecessary stoppage and delays to traffic movement result in economic losses, and can accumulate to a significant total during the life of the traffic control equipment. In many cases the reduction in motor-vehicle operating costs will justify installation of signal control equipment which has a higher initial cost but greater efficiency in handling traffic.

Accident hazards are another consideration. While signals are most effective in reducing right-angle collisions, they tend to increase the frequency of rear-end collisions. The possible reduction in the number of accidents through efficient operation of traffic signals frequently will offset added signal installation and maintenance costs.

Extreme care should be used in selecting traffic control equipment so that proper features for present and future operation will be obtained when controllers are purchased or can be added at a later date without excessive cost.

4C-3 Local Detection Alternatives

There is a vital relationship between phasing, type of controller, and the detection techniques employed. The highlights of this relationship are presented below including detector techniques for low speed and high speed approaches.

Low Speed Approaches

Approaches experiencing speeds less than 35 mph are considered low-speed approaches. The design of the detection system depends on whether the controller phase for that approach has been set by the traffic engineer to "locking" or "non-locking" detection memory (sometimes termed "memory ON" or "memory OFF," respectively).

Controllers with Locking Detection Memory

The locking feature means that a vehicle call for the green is remembered or held by the controller (even after the calling vehicle leaves the detection area) until the call has been satisfied by the display of the appropriate green indication. Locking detection memory is associated with the use of small-area detection ("point" detection) such as a 6 x 6 foot loop or magnetometer. The advantage of this scheme, often termed "conventional control," is that detection cost is minimized. However, this type of control is incapable of screening out false calls for the green (such as occur with "right turn on red").

Actuated controllers have a single timing adjustment (for each phase) labeled "Unit Extension" (or Passage Time or Vehicle Interval). This unit extension fixes both the allowable gap (to hold the green) and passage time (from detection to stop line) at one common value. Inasmuch as the practical allowable gap is usually 3 or 4 seconds, it follows that the detector might ideally be located 3 or 4 seconds of travel time back from the intersection. This would be the most efficient detector position for accurately timing the end of green after passage of the last vehicle of a queue or platoon.

However, the inability of the controller to count waiting cars creates a long minimum assured green if the "3 or 4 second" principle is applied at approaches with speeds higher than 25 to 30 mph. Therefore, the principle is amended to locate detectors 3 to 4 seconds of travel time, but not more than 120 feet from the stop line. This amended principle is summarized in Table 4-2.

Controllers with Non-Locking Detection Memory

A controller phase may be switch-set to a detection memory circuit that is "non-locking" rather than "locking". In the non-locking mode, a waiting call is dropped or forgotten by that controller phase as soon as the vehicle leaves the detection area. Non-locking detection memory is associated with the use of large area detection at the stop line, such as 6 x 50 foot loop or multiple magnetometer detectors. This scheme is often called "loop-occupancy control."

One advantage of this mode is that it avoids the problem associated with the conventional control of not providing information on traffic between the detector and the stop line. It can, therefore, reduce delay by screening out many of the false calls for the green. It reduces the frequency of an unnecessary green display to an approach that has no vehicles waiting. One disadvantage is the higher cost of installing the large-area detection. In addition, long loops can be more of a maintenance problem, particularly in localities where the pavement condition is poor, and ice and snow are major factors.

Application to Left-Turn Lanes

Left-turn lanes with separate signal control prompted the use of non-locking detection memory. In this application, a call placed during the yellow interval cannot bring the green back to an empty approach. Another potential advantage exists if the left-turn is permitted, that is, the left-turn is permitted to "filter" across oncoming traffic on the circular green shown to the through movement.

Approach Speed, mph	*Detector Set-Back, feet*	*Initial Interval, seconds*		*Unit Extension, seconds*		*Minimum Assured Green, seconds*
15	77	8.5	+	3.5	=	12
20	103	10.5	+	3.5	=	14
25	120	10.5	+	3.5	=	14
30	120	10.5	+	3.5	=	14
35 or more	Basic actuated controller not appropriate. Variable initial interval required.					

Table 4-2 Detection Locations and Related Timing for Actuated Controllers (Locking Detection Memory)

To do this, the left-turn bay uses a delayed-call detector, which is designed to output to the controller only if a vehicle is continuously detected beyond a preset time period (such as 5 seconds). The use of a delayed-call detector in a left-turn bay allows the detector (and controller) to ignore vehicles that are in transit over the loop. They would be in transit if oncoming through traffic is light enough to permit them to turn left without the need for a protected left-turn arrow. If, on the other hand, oncoming through traffic is so heavy that left-turning vehicles queue up over the loop, then the green arrow would be called.

High Speed Approaches

Approaches experiencing speeds of 35 mph or higher are considered high speed approaches. If the yellow interval commences while the vehicle is in a "dilemma zone" (zone of indecision), it may be difficult for the driver to decide whether to stop or proceed across the intersection. An abrupt stop may produce a rear-end collision. The decision to go through on the red, may produce a right-angle accident. Table 4-3 shows the boundaries of the dilemma zone. To minimize the untimely display of yellow, a vehicle-actuated signal controller and appropriate detection can be installed. Many schemes have been devised for controllers with locking and non-locking detection memory, with basic and volume-density controller circuitry, and with various types of detection.

Approach Speed,	*Distance from Intersection (feet) for Probabilities of Stopping*	
mph	*10%*	*90%*
35	102	254
40	122	284
45	152	327
50	172	353
55	234	386

Table 4-3 Dilemma Zone Boundaries

Density Controller

The most straightforward, conventional design for a high speed approach uses a density controller with a single small-area detector at the upstream boundary of the dilemma zone. This scheme is often used as the baseline design for comparison with new detector configurations.

A density controller is an advanced actuated model that can count waiting vehicles beyond the first vehicle because it has a feature known as "variable initial interval." It also has timing adjustments for the selection of allowable gap independent of passage time. For many years it was common to use "volume-density" controllers which, in their two-phase models, had three gap-reduction factors. The NEMA functional standards for volume-density controllers, adopted in 1976, specify that the allowable gap will be reduced only on the basis of "time waiting" on the red. (See Section 4D-1). Such a machine is often termed a "modified density" or simply a "density" controller.

A more efficient operation can be achieved for the intersection than is possible with full-actuated control because detection is farther back on an approach, 400 feet is typical. This approach detection is supplemented by a calling detector which operates only when that phase is red (or yellow). It is disabled when the signal turns green so that it cannot extend the green.

Other Controllers

High-speed designs using non-locking detection memory always include a long loop at the stop line (as well as one or more small ones upstream). The long loop improves the controller's knowledge of traffic at the stop line but tends to increase the allowable gap. Designs for both basic full-actuated and density controllers have been devised. Basic full-actuated, non-locking controllers have been used for a number of years with an extended-call detector just upstream of the dilemma zone.

Extended-Call Design

The State of California uses a 70-foot loop at the stop line supplemented by a single 6 x 6 foot extended-call detector 250 to 350 feet from the stop line, depending on the approach speed. The controller's Unit Extension is set at zero or ½ second. The setting of the "stretch" time on the extended-call detector should carry the vehicle approaching on the green through its dilemma zone.

Just as with the Minimum Gap setting on the density controller, the stretch setting requires a compromise. If only 2.5 seconds is used, the result is an efficient operation but provides poor protection for the slower vehicles in the stream. If slower vehicles are to be protected by increasing the stretch, then the green may be extended to the Maximum Interval. The difficulty with allowable gap is increased significantly by vehicles creating extensions of the green not only when they cross the stretch detector, but also when they pass over the long loop at the stop line. This type of control appears to be limited to routes carrying no more than 8,000 to 10,000 ADT.

4C-4 Isolated Versus System Operation

The potential benefits to be derived from the coordinated operation of two signalized intersections are directly related to the platoon characteristics of vehicle arrivals at that intersection. If a well-defined compact platoon of vehicles exists, coordinated operation can provide a significant reduction in stops and delays.

Section 4B-17 of the MUTCD states that, "Traffic control signals within ½ mile of one another along a major route or in a network of interconnecting major routes should be operated in coordination, preferably with interconnected controllers. However, coordination need not be maintained across boundaries between signal systems which operate on different time cycles. Coordinated operation normally should include both pretimed signals and traffic-actuated signals within the appropriate distances."

The effectiveness of coordinated control depends on whether traffic will maintain itself in platoons. The ability to maintain platoons is contingent on traffic characteristics, topography, condition of the roadway, and roadside friction. While no specific rules with regard to distance between signals can be given, there are many examples of effective coordination where signals are spaced 1 mile apart. Such coordination is especially effective where roadside frictions are minimal, speeds are fairly high, and the traffic control signals are visible for some distance in advance of the intersection.

In most cases, traffic flowing on a well-designed facility, without driveways, with opportunities for passing, and with provisions for left turns can maintain a cohesive platoon structure for distances in excess of ½ mile. Conversely, if the design of a facility is such that traffic cannot flow in an unimpeded manner, it may not be possible to identify a platoon at the downstream intersection and coordination may not be effective. Nonetheless, it is probably better to attempt to coordinate signalized intersections if at all possible.

The question of how to group intersections into an interconnected system is a complex item. The objective is to assemble those intersections requiring similar timing strategies in terms of cycle lengths and offset coordination into groups of reasonable size. A number of factors need to be considered, including:

- Geographic relationships—Distance between intersections; natural and artificial boundaries, such as rivers and controlled-access facilities.
- Volume levels—The larger the volume the greater the need for coordination between signals.
- Traffic flow characteristics—If traffic arrivals are uniform throughout the cycle, the red portion of the cycle would produce the same stops and delays regardless of its position within the cycle. On the other hand, pulse flow, in platoons, enhances the benefits of coordination.

4D. TRAFFIC CONTROL SIGNAL EQUIPMENT

This section describes the various types of hardware used for traffic control signals. Emphasis is placed on currently used traffic and pedestrian control equipment. Whenever practical, the control concepts and elements of the equipment are discussed rather than the electronic or mechanical characteristics. This discussion of equipment does not constitute a standard detail nor a specification. Rather, it provides the information needed to apply the equipment.

4D-1 Traffic Signal Controllers

Historically, there were three types of traffic signal controllers: pretimed, semi-actuated, and full-actuated. Currently, this has been reduced to two types: pretimed and actuated. Either the semi-actuated or full-actuated mode can be provided within the basic actuated controller.

Also, historically, there were numerous variations of controller type within each basic category. Various intervals were defined and timed in different manners. The controllers also differed in the way they interfaced with the signal circuits that control the lamps in the signal displays. Each manufacturer, often by specific design, featured slight differences which made his equipment incompatible with other manufacturers' equipment.

In recent years, most controller manufacturers in the United States have voluntarily agreed to conform to standards developed through the National Electrical Manufacturer's Association (NEMA). These standards are intended to cover actuated controllers, detectors, conflict monitors, load switches, flashers, and general cabinet requirements. As of 1982, there was no comparable standard for pretimed controllers.

Although the "NEMA standards" for controllers are the basis for most actuated control equipment, an additional form of controller which does not conform to NEMA standards is being used by some agencies. This controller is called a "Type 170" after the nomenclature established by the States of California and New York. It uses a general purpose microprocessor and a variety of software for different applications including both pretimed and actuated operation.

NEMA controllers have standard functions and input-output format, but several electronic techniques (including microprocessing) are used by manufacturers to provide the functions. The Type 170 controller uses fixed hardware and varies functions by altering the software.

Functional Characteristics of Controllers

A pretimed controller is one which operates within a fixed cycle length using preset phase interval durations. This type of control equipment is best suited where traffic patterns and volumes are predictable and do not vary significantly. The equipment can be either electromechanical or electronic and usually can accommodate several cycle lengths, splits and offsets.

An actuated controller operates with variable vehicular and pedestrian timing and phasing intervals. These intervals depend on traffic volumes or the presence of pedestrians. The flows are determined by vehicular detectors placed in the roadway or by pedestrian pushbuttons. The basic applications of actuated control include semi-actuated, full-actuated, and volume density.

In a semi-actuated control application, one phase (usually the major street) operates in the non-actuated mode. It is best suited where the volume of the cross street traffic is not predictable and the volumes fluctuate. A semi-actuated operation is often used where the actuated controller is incorporated into a system. The non-actuated phase is the phase which is coordinated with adjacent intersections and the actuated phases are allowed to respond to detected demand. The sum of the phase times must equal the system cycle length.

In a full-actuated application, the controller operates on a continuously variable cycle length. All phase green times are determined by the number and spacing of vehicles being detected on the various controlled approaches. Full actuated operation is generally used where the intersection operates independently and where demands on all approaches vary throughout the day.

In a volume density application, the controllers provide a more complex set of criteria for allocating green time than a standard full-actuated controller. These criteria include "Added Initial" and "Time Waiting—Gap Reduction." Volume density control requires specially placed detectors on all high speed approaches and operates on a continuously variable cycle length. It is best suited for independent operation where traffic demand is heavy on all approaches (such as at the intersection of two major streets) and where speeds are high, say in excess of 35 to 40 miles per hour.

Controller Timing Characteristics

A *pretimed* controller provides a fixed amount of time for each phase interval. As stated earlier, this type of control is used in coordinated systems, particularly as part of a "grid" system or where traffic patterns and volumes are predictable.

Each phase of movement can be divided into a number of discretely timed intervals such as phase green, WALK, flashing DON'T WALK, yellow, or all red clearance. The pretimed controller provides the same timing for these intervals for each cycle regardless of demand.

Changes in timing are accomplished by selecting another timing dial which can provide a different cycle length, interval timing, and/or offset. Thus, pretimed controllers have a degree of flexibility in varying timing. Timing plans are usually selected on a time-of-day/day-of-week basis using a master controller or a time clock. Timing plans can also be selected in response to traffic patterns identified from detector data which is sent to a master controller. The master controller identifies a given traffic pattern and selects the appropriate timing plan and then implements it.

An *actuated* controller, when operated in an isolated mode, provides continuously variable cycle lengths in accordance with pedestrian and/or vehicle demand, restrained by certain phase maximums. The various intervals are described later.

Controllers operating in the *semi-actuated* mode receive a guaranteed minimum green time on the non-actuated phase. Right-of-way is relinquished only when a call is received on the actuated phase(s). After timing the appropriate clearance interval(s), a green is displayed on the actuated phase for the initial period. The travel approach being serviced will retain the right-of-way as long as vehicles are detected and the vehicle extension interval is reset. The green will terminate when either the vehicle extension interval is allowed to time out, or when a preset maximum green time has been reached. In either case, clearance intervals are timed and right-of-way is returned to the non-actuated phase. If the actuated phase was terminated by the preset maximum setting, a vehicle call is placed on the phase when the clearance interval is entered. This ensures that the controller returns to the actuated phase on the next cycle in case a vehicle was "trapped" between the detector and the stop bar. In general, short vehicle extension intervals will provide a more efficient operation.

Full-actuated operation requires detectors on all approaches. The major difference between full and semi-actuated operation is that right-of-way is not returned automatically to a designated phase under the full-actuated mode unless it is recalled by a special switch on the controller. Also, main street green varies with demand rather than being a preset minimum. The controller will remain in the green interval of the phase last serviced until a conflicting call is registered.

NEMA specifies that the maximum green time should not begin timing until there is a conflicting call. Therefore, under full-actuation, a phase may remain green for some time until a conflicting call is registered without having started timing maximum green time. Depending on the detector activity for the phase with the right-of-way, the controller may or may not service the opposing phase immediately upon receipt of a demand.

Volume density operation includes an additional set of criteria for terminating a phase when there is conflicting demand. Normally, right-of-way is relinquished when either the time between actuations exceeds the passage or extension time, or when the maximum green time has been reached. Volume density operation reduces the allowed gap on the street with the right-of-way (time between actuations) to a preset minimum value. This is done over a specified time period. Specifically, on a NEMA controller, the additional settings required are seconds per actuation, time before reduction, time to reduce, and minimum gap.

Title	*Range*	*Function Performed*
WALK	0 to 99 secs 1 sec increments	Establishes length of WALK interval. Timed only when there is demand for pedestrian service on phase. Vehicle minimum green will be: sum of WALK and PED CLEARANCE, MINIMUM GREEN, ADDED INITIAL, whichever is longer.
PED CLR	0 to 99 secs 1 sec increments	Establishes length of PEDESTRIAN CLEARANCE interval. Timed only when there is demand for pedestrian service on phase. Vehicle minimum green will be; sum of WALK and PED CLEARANCE, MINIMUM GREEN, or ADDED INITIAL, whichever is longer.
MIN GRN	0 to 99 secs 1 sec increments	Establishes length of INITIAL state of green interval. Sets minimum right-of-way time to start standing traffic in green interval. Vehicle minimum green will be MINIMUM GREEN, ADDED INITIAL, or sum of WALK and PED CLEARANCE, whichever is longer.
SEC PER ACT X 0.1	0 to 9.9 secs 0.1 sec increments	Establishes number of seconds by which each vehicle (actuation) builds ADDED INITIAL during nongreen time on phase. Maximum ADDED INITIAL is 30 seconds. Vehicle minimum green will be ADDED INITIAL, sum of WALK and PED CLEARANCE, or MINIMUM GREEN, whichever is longer.
PASS TIME X 0.1	0 to 9.9 secs 0.1 sec increments	Establishes increment of right-of-way time extension for each vehicle actuation during the green interval. This is time allotted for an average speed vehicle to move from the detector to and through the intersection. Passage time is extendible by continuous vehicle actuation to the limit established by the setting of the MAX I or MAX II control for the phase. With demand for service on a conflicting phase, right-of-way is transferred immediately if PASSAGE TIME times out without being reset. In absence of a serviceable conflicting call, Controller Unit advances to GREEN REST state if PASSAGE TIME times out without being reset and GREEN REST option is chosen.

Table 4-4 Description of Phase Module Timing Control Switches

Title	Range	Function Performed
PASS TIME CONT.		In modules with gap reduction capability serviceable conflicting call causes allowed gap between actuations on phase with right-of-way to be reduced in proportion to time vehicle has waited against red on conflicting phase, after expiration of TIME BEFORE REDUCTION period. If PASSAGE TIME has not expired but right-of-way is terminated on reduced gap less than the PASSAGE TIME, a memory call is placed on the phase and right-of-way is returned to the phase at the earliest opportunity without need for additional demand for service. If the Last Vehicle Passage (LVP) option is exercised and the allowed gap is exceeded, the remaining portion of the passage time in effect will time out before termination of the green. If allowed gap is not exceeded, and PASSAGE TIME is continuously reset, the limit to which the phase may remain in the green interval is established by the setting of the MAX I or MAX II timing control for the phase. If the phase terminates at the maximum, memory call is also placed on the phase.
TIME BEFORE RDCN	0 to 99 secs 1 sec increments	Establishes a preset time before allowed gap begins to reduce. TIME BEFORE REDUCTION begins with first demand for service on a conflicting phase.
TIME TO REDUCE	0 to 99 secs 1 sec increments	Establishes time in which allowed gap is reduced from PASSAGE TIME value to MINIMUM GAP—after TIME BEFORE REDUCTION has expired. Allowed gap is reduced from PASSAGE TIME value, once per second, by the reduction rate value until it is equal to the MINIMUM GAP. $\text{Reduction Rate} = \dfrac{\text{Passage Time Minimum Gap}}{\text{Time to Reduce}}$
MIN GAP X 0.1	0 to 9.9 secs 0.1 sec increments	Establishes minimum value to which allowed gap between actuations on phase with green can be reduced upon expiration of TIME TO REDUCE.

Table 4-4 (Continued)

Title	*Range*	*Function Performed*
MAX I	0 to 99 secs 1 sec increments	Establishes one of two maximum limits to which green interval can be extended on a phase in the presence of serviceable demand on a conflicting phase. If the green interval terminates at the Maximum, a memory call is placed on the phase and right-of-way is returned to the phase at the earliest opportunity without need for additional demand for service. Timing of the maximum begins at the start of the green interval when there is serviceable vehicle demand on a conflicting phase, thereby providing a TRUE MAXIMUM GREEN. MAXIMUM GREEN I is automatically in effect if MAX II selection input is not asserted.
MAX II	0 to 99 secs 1 sec increments	Same as MAX I when MAX II selection input is asserted and MAXIMUM GREEN II is in effect.
YEL CHG X 0.1	0 to 9.9 secs 0.1 sec increments	Establishes length of YELLOW CHANGE interval following the green interval or green rest state, when there is serviceable demand on a conflicting phase.
RED CLR X 0.1	0 to 9.9 secs 0.1 sec increments	Establishes length of RED CLEARANCE interval following the YELLOW CHANGE interval. Interval is omitted when timing control switch is turned to "00" or if external OMIT RED CLEAR input is asserted.

Table 4-4 (Continued)

The seconds per actuation setting establishes the number of seconds by which each vehicle actuation increases the initial period. This is computed only during a phase's nongreen time. If a large number of vehicles cross the detector during the phase red period, the initial interval will be replaced by the longer added initial value.

Gap reduction begins with a conflicting call. It reduces the allowed gap or spacing between successive vehicles to a preset minimum value. This makes the controller increasingly sensitive to gaps in traffic and will terminate the phase when it detects a gap larger than the allowed gap or upon reaching the maximum green time limit. Table 4-4 summarizes the typical characteristics of phase module timing control switches.

Controller Hardware Characteristics

Pretimed. There are two types of pretimed controller hardware: electromechanical and electronic. The electromechanical design has been used for many years and has proved to be highly reliable and easy to maintain. It is comprised of one or more timing dials driven by synchronous motors and a camshaft. The dials use different gears to determine the cycle length. Keys fit into the dial and at a preset point, cause a set of contacts to close and activate the camshaft motor to advance the camshaft. The camshaft is made up of separate cams for each aspect (green, WALK, yellow, red, etc.). These cams are configured to allow the signal contacts to open and close, that is, to turn on and off the lamps of the signal displays in the proper sequence.

A special interlock cam and interlock dial key are used to ensure that the dial and camshaft stay in step. If the two are out of step, the dial will advance the camshaft into the main phase green where the camshaft rests until the dial rotates to the interlock key. At this point, the dial and cam are back in step and normal operation resumes. A typical dial unit and camshaft unit for pretimed controllers are shown in Figure 4-5.

Recently, with the introduction of microprocessors and the rising cost of parts for the electromechanical controllers, electronic pretimed controllers have been developed. These units usually employ microprocessor technology and operate as an electromechanical pretimed controller. That is, they have the functional equivalent of dials, keys and camshafts. These electronic units are usually programmed via a keyboard, and the timings are stored in Random Access Memory (RAM). Other program data and the program which operate the controller itself are usually stored in Programmable Read Only Memory (PROM).

Because the units are microprocessor based, several manufacturers have included additional features not ordinarily found in an electromechanical pretimed controller. Some of these features are a built-in preemption sequence; a capability to program an output circuit to be either on, off, or flashing during each interval; an actuation input; and selection of offset-seeking techniques (short-way or dwell). Since the unit is electronic, additional auxiliary equipment is required such as conflict monitors and load switches.

Actuated. Today, all new controllers are of digital design. There has been much discussion about the NEMA standards and the 170 type controllers in recent years. The NEMA standard for traffic controllers defines a set of requirements covering the following areas: functional, environmental, interface levels, and physical characteristics. The objective of the NEMA standard is to attain compatability and interchangeability of equipment manufactured in conformance with these standards while providing for the safe installation, operation, and performance of the equipment.

The objectives behind the development of the Type 170 controller were interchangeability and simplified maintenance by building all units to the same hardware specification. The controllers were developed primarily by the States of California and New York. There are a number of manufacturers who can meet the Type 170 hardware specifications.

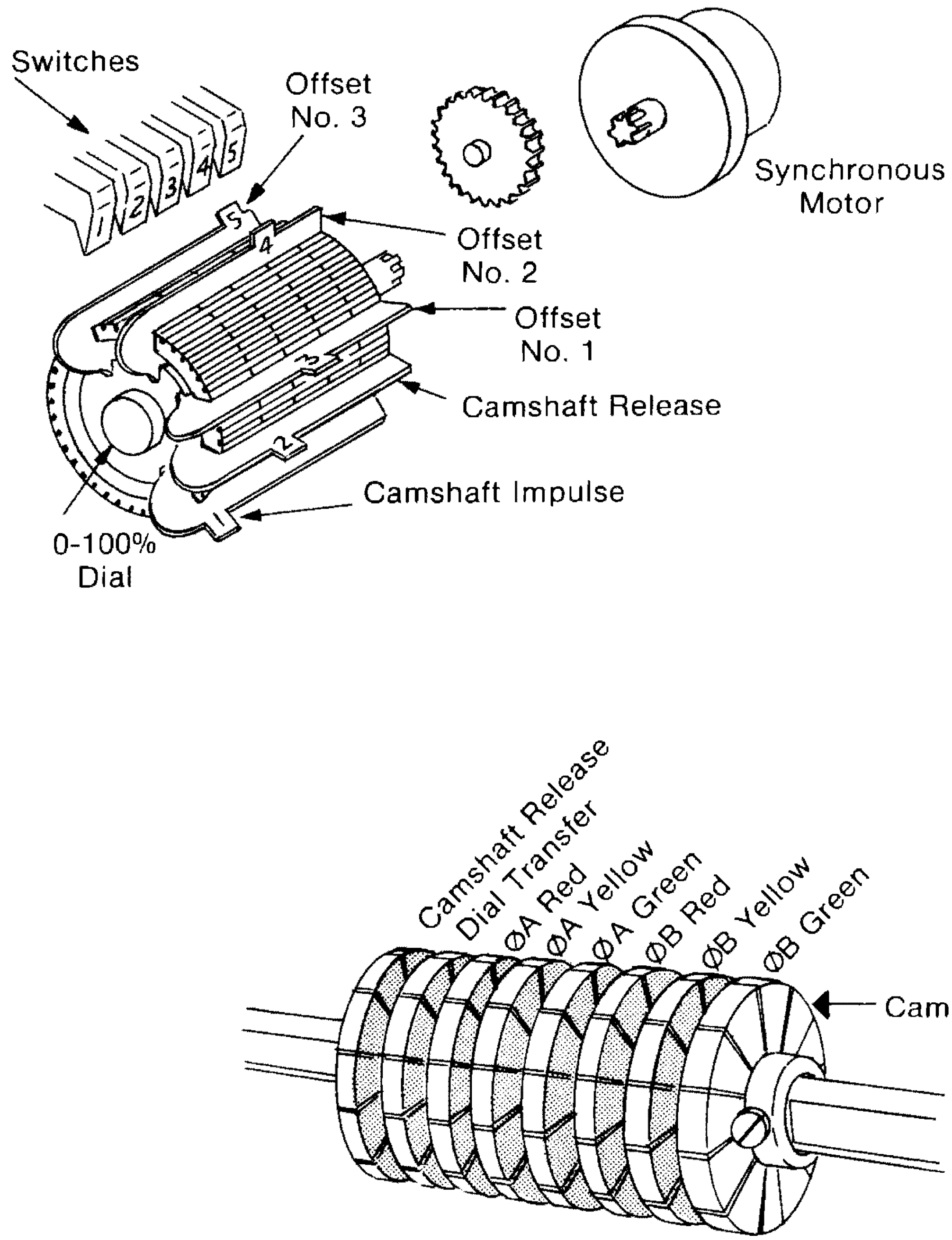


Figure 4-5 Pretimed Controller—Dial Unit and Camshaft Unit

Since NEMA primarily standardized the functional operation and the interface levels of the machine and not the specific hardware, NEMA controllers can be purchased with information input by keyboard entry, thumbwheel switches, program pins, or DIP switches. Figure 4-6 illustrates three data entry types. Each type of man-machine interface performs the same function, namely entering timings into the controller. If the machine is microprocessor based, each manufacturer has developed a software package which is furnished as an integral part of the controller.

Keyboard entry provides one of the most cost-effective approaches to inputting information. Since the process is handled as a software routine (a one-time development cost), hardware costs are minimized. Maintenance personnel must be trained in the use of keyboard entry techniques. Often special codes and/or the hexadecimal numbering system have to be learned.

Thumbwheel switches provide a means of directly entering and reading interval timings. No special training or number conversion is required. However, the cost of thumbwheel switches is relatively high in addition to the cost of the required decode circuitry.

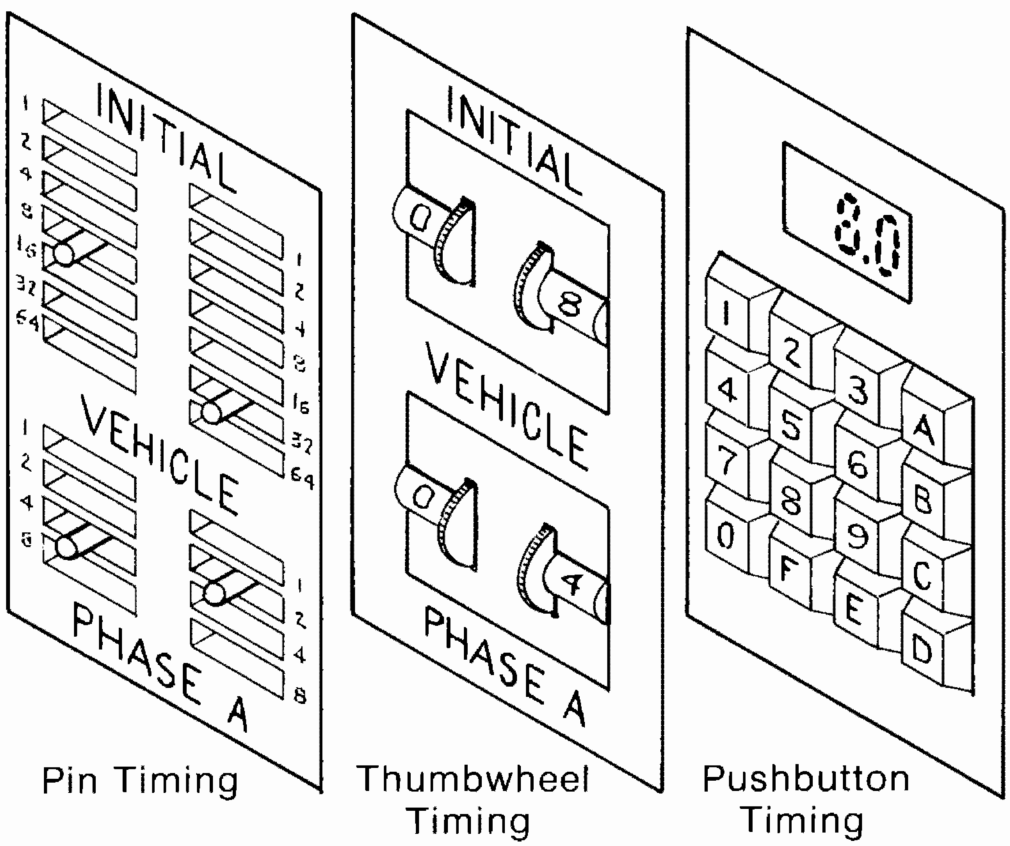


Figure 4-6 Data Entry Apparatus

How Provided	Function	Operation
1. PER PHASE	Phase Omit	When asserted will cause selected phase to be omitted with no loss of memory of demand for service.
	Pedestrian Omit	When asserted will prevent selection of a phase based only on pedestrian demand. When phase is selected and serviced on vehicle demand, subordinate pedestrian service is inhibited.
	Hold	When asserted combines hold and yield functions for coordination purposes. Retains existing right-of-way but causes controller unit response to be dependent on pedestrian requirements and vehicle actuation or non-actuation.
2. PER RING	Force-Off	When asserted, causes termination of green interval after initial state has timed subject to conflicting call. Memory call (vehicle demand) is left on phase for subsequent service.
	Red Rest	When asserted causes all phases in ring to enter red rest state upon termination of green interval. Normal clearance timing is provided.
	Inhibit Max. Termination	When asserted prevents green interval termination upon expiration of maximum timing. Gap time-out and Force-off continue to terminate green interval.
	Omit Red Clearance	When asserted causes red clearance intervals to be omitted on all phases of the ring.
	Pedestrain Recycle	When asserted, controls recycling of subordinate pedestrian movement depending on whether phase is operating in actuated or non-actuated mode.
	Stop Timing	When asserted, prevents but does not reset timing in the ring. When removed, timing resumes from point of interruption. Advancement from one interval to another is restricted to assertion of the INTERVAL ADVANCE control point.
	MAX II	When asserted, causes all phases in ring to time maximum set on MAX II rather than MAX I timing controls.

Table 4-5 NEMA Standard External Control Functions

How Provided	*Function*	*Operation*
3. PER UNIT	External Minimum Recall	When asserted, causes vehicle demand for service to be placed on all phases.
	Indicator Lamps Disable	When asserted, turns off all status display indicators.
	Walk Rest Modifier	When asserted, phases selected for non-actuated operation will remain in timed-out pedestrian walk interval, in absence of conflicting phase demand for service.
	External Start	When asserted, causes all phases to revert to start-on condition, then time normally upon removal of input.
	Call for Actuated (2 per unit)	When asserted, selected phases will operate in the non-actuated mode (only applicable to phases with a subordinate pedestrian phase).
	Manual Control Enable	When asserted, automatically places vehicle and pedestrian demand for service on all phases and stops controller unit timing in all intervals except vehicle clearances. Also prevents INTERVAL ADVANCE operation during vehicle clearances.
	Interval Advance	When asserted, terminates interval which is timing. In conjunction with MANUAL CONTROL ENABLE will allow manual operation of the controller unit with timed yellow change and red clearance intervals.

Table 4-5 (Continued)

Position	Function Performed
	RECALL OFF—LOCKING DETECTOR
L	Phase operates in full-actuated mode and rests on phase last served in absence of serviceable demand on conflicting phase and with red rest not asserted. Memory of vehicle actuation is locked into controller unit until phase is serviced.
	RECALL OFF—NON-LOCKING DETECTOR
NL	Phase operates in full-actuated mode and rests on phase last served in absence of serviceable demand on conflicting phase and with red rest not asserted. Memory of vehicle actuation is retained in controller unit only while vehicle is present in detector's zone of influence (presence detection). Controller unit recognizes vehicle presence only, but does not remember vehicle demand.
	MINIMUM VEHICLE RECALL
VC	Vehicle recall operating mode in which the controller automatically returns to and provides vehicle right-of-way on the selected phase once each traffic signal cycle—without the need for vehicle demand for service. Subordinate walk and ped clearance intervals are omitted unless called for by pedestrian demand for service.
	PEDESTRIAN RECALL
PC	Pedestrian recall operating mode in which the controller unit automatically returns to and provides vehicle right-of-way, as well as subordinate walk and ped clearance intervals on the selected phase once each traffic signal cycle without the need for vehicle and/or pedestrian demand for service.
	NON-ACTUATED
NA	Non-actuated operating mode in which the controller unit returns to the non-actuated phase once each traffic signal cycle and times the WALK interval in accordance with the setting of the WALK timing control. When WALK timing expires, response of the controller unit will depend upon presence of a serviceable conflicting call and assertion or non-assertion of hold, force-Off, and walk rest modifier external inputs. If the Hold input is not asserted, controller unit will advance into and time the Ped Clearance interval—then to the green rest state—when WALK timing expires.
	VEHICLE RECALL TO MAX
VM	Vehicle recall operating mode in which the selected phase times to maximum as though there were an omnipresent serviceable conflicting call. Termination of the green Interval will not occur when max timing expires unless there is serviceable demand on a conflicting phase.

Table 4-6 Description of Phase Control Function (Mode) Switches

Indicator Title	Phase Timing Module	Fuction Performed
PHASE INDICATORS		Illuminated to signify that phase controlled by this phase module is active—in green, yellow change, red clearance, walk or ped clearance interval. Illuminated to signifiy that phase controlled by this phase module is commited to be next in sequence.
CALL INDICATORS		Illuminated to signify presence of vehicle demand on phase controlled by this phase module. Flashes with each vehicle actuation during green interval. Remains illuminated by memory call received during yellow change or red clearance intervals. Illuminated to signify presence of pedestrian demand on phase controlled by this phase module except during WALK interval.

Table 4-7 Function of Phase Module Indicators

Indicator Title	Function Performed
MAX II SELECTED	Illuminated to signify that MAXIMUM GREEN has been selected for that ring by assertion of MAX II selection input and that maximum timing is under control of MAX II timing control. If MAX II is not seclected, MAX I is automatically in effect.
PASSAGE GAP-FL	Illuminated at end of green interval and during yellow change Interval to signify termination of PASSAGE TIME. Flashes once per second at end of green interval to signify reduced gap termination.
MAXIMUM FORCE OFF-FL	Illuminated at end of green interval and during yellow change Interval to signify MAXIMUM termination, or flashes once per second if termination of green interval is a consequence of assertion of the FORCE-OFF input.
WALK PED CLR-FL	Illuminated steadily to signify that the WALK interval of a subordinate pedestrian phase is in effect and being timed. Flashes once per second to signify that the PED CLEARANCE interval of a subordinate pedestrian phase is in effect and being timed. Flashes once per second to signify that the PED CLEARANCE interval of a subordinate pedestrian phase is in effect and being timed.
NON-ACT	Illuminated steadily when the phase being served has been selected for non-actuated operation by assertion of the CALL to NON-ACT input-or from the phase control function switch on a phase module panel.
INT	A 7-segment light emitting diode (LED) readout which displays a numeric status code to signify the interval, intervals, or portions thereof which are timing. Status code interpretation is based on a printed legend on the panel of the I/0 5-M (Ring 2) module-or blank panel in the absence of a ring 2 I/0 Module. The status code is as follows:

INT INDICATOR STATUS CODE

CODE	ACTUATED MODE	NON-ACTUATED MODE
0	Minimum	Walk
1	Extension	Walk-Hold
2	Maximum	Pedestrian Clearance
3	Green Rest	Green Rest
4	Yellow Change	Yellow Change
5	Red Clearance	Red Clearance
6	Red Rest	Red Rest

Table 4-8 Description of Input/Output (I/O) Module Switches and Indicators

Programming pins are less expensive than thumbwheel switches, but maintenance personnel must become familiar with the binary coded decimal numbering (BCD) system. Settings may be harder to read and errors may be made when adding up the timings associated with each pin. Pins can also be easily dropped or lost while changing timing settings at the intersection.

DIP (Dual In-line Package) switches function identically to the program pins. Since they cannot be removed there is no problem with misplacing or losing pins while changing timing at the intersection.

The following tables briefly summarize the NEMA concepts and design standards. Note the one major difference is in the variation and allowable limits of the size of the controller units. Tables 4-5 through 4-8 define the NEMA external control functions and indicator and switch functions.

4D-2 Traffic Detectors

Traffic detectors are used to sense pedestrian or vehicular demand. The demand information is then provided to the actuated controller and an appropriate action taken. The functional characteristics of the most commonly used detectors are described in this section. Other types of detectors which may still be in place in the roadway or which may be used for special applications are briefly mentioned. (Detectors used to sense bicycle traffic are discussed in Part IX, Sec. 9B-3). Finally, the need for good installation techniques and the need for proper maintenance of the detection system are discussed.

The majority of the information was extracted from the Traffic Control Systems Handbook, U.S. Department of Transportation, Federal Highway Administration. (Ref. 4-13)

Pushbutton Detectors

Pushbutton detectors are the only commonly used form of pedestrian demand detectors. The detector consists of a button which when pushed by the pedestrian causes a contact closure. The contact closure allows low voltage current to flow to the controller to register a "demand" for serving the pedestrian phase of an actuated controller. At the first appropriate opportunity, the WALK indication is shown for the "demanded" phase followed by a flashing DON'T WALK clearance display.

The pushbutton is housed in an environmental enclosure to protect it from damage from weather or vandalism. The device is mechanically simple and generally reliable. All response and pedestrian timing data are contained in the intersection controller.

Loop Detectors

The loop detector is the most widely used means of vehicle detection. It has two components, the amplifier and the in-pavement loop (sensor). The detector oscillator (amplifier) transmits its own energy (electrical field) and operates on the principle that a vehicle resting in, or passing over, the loop will unbalance a tuned circuit and send an impulse to the amplifier. Because of the flexibility of its design, the loop detector provides for the broadest range of vehicle detection. For example, loops can be designed to sense vehicle presence and to detect the passage of a vehicle. Lane occupancy, speed, and volume can also be determined from loop detector output signals.

Loops are constructed with electrical characteristics that match an oscillator/amplifier (more accurately called an oscillator). The oscillator serves as a source of energy for the loop. When a vehicle passes over the loop or is stopped within the loop area, it absorbs a certain amount of this energy creating an imbalance between the loop and the oscillator. This imbalance activates a relay which sends an electrical output to the controller signifying that it has detected the presence of a vehicle.

The loop itself is constructed by cutting slots in the pavement with a saw and placing one to three turns of wire in the slots. The wire is then covered with a sealant. An alternate, more durable construction is to place the turns of wire in a plastic conduit within or just below the pavement surface, or within a plastic sleeve laid in a saw-cut slot in the pavement. The most common loop size for actuated control is a 6 x 6-foot square. A wide variety of loop sizes may be used to meet specific needs.

The loop-detector amplifier is normally installed in the controller cabinet. Amplifiers are provided in individual units to accommodate one to four detectors. The amplifier units are small and the housing is a metallic or plastic. Amplifiers are connected to the loops using twisted pair or shielded cable and to the controller using standard connectors and cables.

Magnetic Detectors

There are three basic types of magnetic detectors; the standard magnetic detector, a directional magnetic detector, and magnetometers. All three types consist of two components, an in-road detector and an amplifier unit generally mounted in the controller cabinet.

Magnetic detectors operate on the basis of a change in the lines of flux from the earth's magnetic field. A coil of wire with a highly permeable core is placed below the surface of the roadway. When a metallic object such as a vehicle comes near or passes over the coil, the constant lines of flux passing through the coil are deflected by the vehicle, thus causing a voltage to be developed in the coil. A high-gain amplifier causes this voltage to operate a relay and send a message to the controller that a vehicle has been detected.

For the standard magnetic detectors to sense a change in the magnetic field, the vehicle must be in motion. Generally, vehicles traveling less than 5 mph are not detected. This means that the magnetic detector can provide the equivalent of count data but not occupancy or presence.

Magnetometer detectors are a special type of magnetic detector designed to sense the presence of a vehicle. This is accomplished by measuring the focusing effect of the earth's magnetic field which results when ferrous metal is in the vicinity of the detector.

The in-road unit is placed in a vertical position by drilling a hole down through the pavement surface. The lead-in is placed in a saw cut leading to the curb or cabinet area. The in-road sensor is the size and shape of a small can. The cabinet-mounted amplifier is similar in size to a loop-detector amplifier.

Other Types of Detectors

In addition to the more commonly used detectors described above, other types of detectors include pressure, radar, and sonic detectors. Until the development of the loop and magnetometer detectors, these were the common detectors. These other general detectors are described below.

Pressure Detectors. Vehicle-pressure detectors are activated by the weight of a vehicle. The weight causes closure of contact plates sealed in a rubber pressure plate which sends a signal to the controller. The contact plates normally close at 100 pounds pressure or less, so that the pressure detector will operate satisfactorily for virtually all types of vehicles. A metal frame installed in the pavement provides support for the pressure plate and holds it in place.

This detector was widely used for many years. Currently, it is virtually never used in normal applications. The pressure detector provided only count data, was expensive to install, required a lane closure for extended periods during installation, and resulted in a "dip" when the roadway was resurfaced.

Radar Detectors. Radar detection operates on the Doppler effect in that microwaves are beamed toward the roadway by the detector unit. The passage of a vehicle through these beams causes them to be reflected at a different frequency back to the sensing unit (antenna). The detector senses the change in frequency which denotes the passage of a vehicle.

Basically, two types of radar units are used for vehicle detection. In one type, the sensor and detection electronics are constructed as one unit which is located over the roadway or in a "side-fire" position. In the other type, the sensor and detection electronics are separate. The detection electronics are pole-mounted at a height where the device can be easily maintained from the ground.

Radar detectors are available with two types of sensing units (antennas). The most common type of antenna is adjustable for the coverage of one to three lanes. An optional antenna with a narrow band of detection can be used to detect traffic in a single lane.

The use of radar detectors requires a Federal Communications Commission (FCC) radio station license, which can be obtained by a State or municipality free of charge, renewable every 5 years. A single FCC license will cover all the radar detectors in a city or State.

Although still manufactured and used, the detectors are becoming less common because they detect motion only, are relatively complex to maintain, and the units are vulnerable to vandalism.

Sonic Detectors. Sonic and radar detectors operate on the same principle; that is, they both transmit a beam of energy into an area and receive a reflected beam from a vehicle. The sonic detector transmits pulses of ultrasonic energy through a transducer towards the roadway. The presence of a vehicle causes these beams to be reflected back to the transducer, at a different frequency. The transducer senses the change and converts it to electrical energy and relays this energy to a transceiver. The transceiver then sends an impulse to the controller to denote the presence or passage of a vehicle.

Transducers are mounted over the roadway, while transceivers are mounted in a separate cabinet or in the controller cabinet. Unlike the radar detector which can only detect motion, sonic detectors can also be used as vehicle-presence detectors. Sonic detectors are also still available, however, their use is much less common than a few years ago.

High Intensity Light Detector. This type of detection system makes use of a high-intensity light emitter mounted on the vehicle and a detector mounted on, or near, the traffic control signal. It is one type of system used for priority control for emergency and transit vehicles. Once an emergency or priority vehicle is detected, the detector relays a signal to a phase selector which is connected to the signal controller. This phase selector then checks the status of the controller. The selector either extends the green interval for the emergency vehicle or terminates the green on the street or streets opposing the emergency or priority vehicle causing a transfer of green to the direction of travel of the priority vehicle.

Comparison of Detectors

Table 4-9 presents a summary of the functional capabilities of general detectors and light-emission special purpose detectors. In most traffic signal applications, loops or magnetometers are used because of their flexibility and because they sense vehicle presence rather than motion. Magnetic detectors or loops in conduit may be useful where pavement conditions are extremely poor.

	Measuring Capability						
Detector	*Count*	*Presence*	*Motion*	*Occu-pancy*	*Method of operation*	*Advantages*	*Disadvantages*
Loop	Yes*	Yes	No	Yes	Vehicle passage cuts magnetic lines of flux that are generated around the loop thereby increasing or decreasing the inductance so that a change is detected and transmitted to an amplifying circuit.	1. Size and shape of detection zone can be easily set by size of loop. 2. Excellent presence detector. 3. Capable of measuring all traffic parameters. 4. Relatively easy to install. 5. Relatively inexpensive to abandon loop and reuse amplifier at new location. 6. Capable of detecting small vehicles. 7. Under roadway location and not subject to damage except in poor pavement.	1. Cost of installation may be excessive. 2. Requires closing of traffic lane or lanes for short period of time. 3. Sometimes difficult to tune to detect small and large vehicles under variety conditions. 4. Affected significantly by lack of maintenance and roadway failure.
Magne-tometer	Yes	Yes	No	Yes	Similar method of operation as nondirectional and directional magnetic detectors. Makes use of small cylindrical sensing head that is placed below pavement surface.	1. Relatively easy to install. 2. Capable of measuring count or presence. 3. Reliable. 4. Not affected by the lines in vicinity. 5. Under roadway location and not subject to damage. 6. Relative ease of relocation.	1. Requires closing of traffic lane for installation. 2. May double count some vehicles due to magnetic material distribution. 3. Poorly defined detection zone.
Magnetic Non-directional	Yes	No	No	No	Vehicle passage over coil of wire embedded in roadway disturbs earth's lines of flux that are passing through coil and induces a voltage in the coil. Voltage is amplified by high-gain amplifier to operate detector relay.	1. Under roadway location and not subject to damage. 2. Relatively easy to install. 3. Do not necessitate closing of traffic lanes. 4. Relative ease of relocation. 5. Low maintenance.	1. Nondirectional. 2. Difficult to set detection zone. 3. Subject to false calls where located near large d.c. lines. 4. Cannot detect presence.

Table 4-9 Summary of Functional Capabilities of Detectors

	Measuring Capability						
Detector	*Count*	*Presence*	*Motion*	*Occu-pancy*	*Method of operation*	*Advantages*	*Disadvantages*
Pressure	Yes	No	No	No	Weight of vehicles causes closure of metallic contacts to complete a circuit.	1. Well-defined detection zone. 2. Rugged construction. 3. Reliable. 4. Capable of detecting all moving vehicles, regardless of speed. 5. Low maintenance and easy to repair.	1. Counts axles which yields poor count accuracy. 2. Does not measure presence. 3. Installation may disrupt traffic for excessive period of time. 4. Major resurfacing will render it inoperative. 5. Cannot be easily relocated.
Radar	Yes	No	Yes	No	Passage of vehicle reflects radar microwaves (Doppler principle) back to antenna to operate detector relay.	1. Immune to electromagnetic interference. 2. Does not necessitate closing of traffic lanes to install.	1. Relatively expensive to purchase and install, particularly if existing poles not available for use. 2. Requires FCC license to operate. 3. Requires experienced personnel for installation and maintenance. 4. Does not measure presence.
Emergency Vehicle Detector	No	No	No	No	High-intensity light emitted from a device mounted on a vehicle is received by a light-sensitive detector indicating the presence of a priority vehicle.	1. Provides a mean to recognize selected vehicles.	1. Expensive. 2. Required equipment on vehicles.
Magnetic Directional (two-coil version)	Yes	No	No	No	Same method of operation as non-directional magnetic detector.	1. Directional. 2. Not affected by d.c. lines in vicinity. 3. Well-defined detection zone. 4. Low maintenance. 5. Under roadway location and not subject to damage.	1. Required closing of traffic lane for installation. 2. More expensive than nondirectional magnetic detector. 3. Cannot detect presence. 4. Cannot be easily relocated.

* Short loops (e.g., 6 feet) may be used to count. Long loops (e.g., 60 feet) do not count accurately because of multiple occupancy on the loop.

Table 4-9 Summary of Functional Capabilities of Detectors—Continued

Installation and Maintenance Practice

Any type of traffic detection system must operate with a high degree of reliability. In signal installations utilizing detectors, the overall effectiveness of the traffic signal operation is directly related to the efficiency and reliability of the detectors, which, in turn, are dependent on the care exercised in installing and maintaining the detectors.

Specific installation instructions are available from the manufacturer of each type of detector. These instructions should be rigidly adhered to during the installation process. In addition, the physical condition at the intersection, the detector placement, the distance from the stop line, the relation to adjacent driveways, and the number of lanes to be detected should be considered prior to installation. A poorly placed detector, a loop of the wrong width or length, or an improperly installed detector can seriously affect the efficient operation of a controller. In the worst instance, such a condition could make the controller completely inoperative. Conversely, when care and effort are expended to develop and employ a proper detector installation procedure, then extremely low failure rates can be expected.

In addition to the manufacturer's instructions (which are usually included with every detector shipment), the Traffic Signal Manual published by the International Municipal Signal Association (Ref. 4–2) provides further details on installation practices and maintenance procedures. Another valuable reference source is ''Inductive Loop Detectors—Theory and Practice'' (Ref. 4–14), which is available from the Federal Highway Administration.

4D–3 Intersection Hardware

Traffic signal hardware located at the intersection is discussed in this section. Installation procedures are also noted. Mounting details affecting clarity of the signal and its conspicuity are discussed under Implementation Considerations, Section 4E.

Poles and Guys

The four types of poles used in traffic signal installations include steel, aluminum, concrete, and wood. Currently, wood poles are seldom used for new installations but are frequently used for temporary signals.

Steel or Aluminum Poles. There are two types of steel poles. One has an embedded base that is an integral part of the pole. The base is set in a concrete foundation. The second type has a shoe or transformer base which is mounted on a concrete foundation with anchor bolts. The bolts are embedded in the concrete foundation.

Galvanized or ungalvanized steel poles are available in tubular (one piece) configurations. Galvanized steel poles are also available in sections that have the advantage of being easy and quick to assemble and can be installed in the field by two men with a minimum of equipment. If struck by a vehicle, some of the sections may be salvaged while others may need to be replaced. Both sectional and tubular steel poles can be used for span wire or mast arm installations. Standard mast arm designs of up to 45 feet are common and longer arms are available on special order.

Aluminum poles are available with either a shoe base or a transformer base. Some manufacturers offer a transformer slip base which allows the pole to be rotated at the time of installation. Aluminum poles are rarely used for span wire installations since such an application requires the use of back guys.

The selection of the proper base depends largely upon the application. The shoe base provides less space for cable splicing and, therefore, a covered hand hold located near the bottom of the pole is sometimes specified. It is, however, more acceptable in some locations where sidewalk area is at a premium. On the other hand if space is not at a premium, the transformer base provides a large above ground splicing access point.

Manufacturers of aluminum and steel poles usually provide general information on pole height and strength in their specifications and installation instructions. Essentially, pole height depends on:

- The type of installation (span wire or mast arm),
- The distance to be spanned or length and size of the mast arm, and
- The signal configuration.

After all signals and cable have been installed, final adjustments are made to plumb the poles. For shoe base mounted poles this is accomplished through the use of adjusting nuts placed on the anchor bolts under the pole base prior to setting the pole. Shims may also be used. Transformer base mounted poles are plumbed with shims. After the pole is plumbed, the exposed area at the base of the pole is grouted and trowel finished.

Embedded and wood poles are raked during installation so that when the hardware is added to the pole, the pole is brought to a vertical position.

Concrete poles. Concrete poles are primarily used in urban areas. Transportation costs and their inability to support long and heavy mast arms are major factors limiting wider usage.

Prestressed concrete poles can be used for spans over 200 feet without back guys. They are available in several lengths and diameters depending on the requirements of the intersection. The manufacturer should be given all installation details including length of span, number and weight of signals, and any special characteristics of the intersection such as an unusually high crown or lateral slope of the roadway.

Installation of concrete poles generally follows the procedures for setting embedded-type poles. More detailed information is available from the manufacturers.

Wood Poles. Wood poles for traffic signal installations range in length from 30 to 45 feet. The depth of the hole required to set the pole will vary with the desired final height of the pole and with the type of soil. As a general rule, 1 foot in depth is required for each 5 feet above ground with 1 foot added for loosely compacted earth. Proper backfilling and tamping is imperative. As one worker backfills, a second should be continuously tamping the backfill into the excavation while both rotate around the pole. If a pole is properly backfilled and compacted, all of the soil excavated to set the pole should be used in the process.

When wood poles are used to support mast arm or span-wire suspended signals, guy wires are usually required. Wood poles are generally raked 6 to 8 inches away from the direction of strain when they are set. Final adjustments are made by taking up or slacking off on back guys after all signals and cable are in place.

Sidewalk arm guys must be employed when the guy crosses over a sidewalk area. The sidewalk arm consists of a piece of 2-inch pipe and appropriate hardware. The length of the pipe is dependent on the distance between pole and anchor when the anchor is set a safe distance back from the sidewalk line. Anchor guy guards (generally white plastic sleeves) should be used where pedestrians might walk into the guy wire.

Mast Arms

Varying design styles and lengths of mast arms are available in galvanized or ungalvanized steel or in aluminum. The choice will depend on the arm length required for satisfactory signal placement and on the number, location, and configuration of signal heads to be installed. The major characteristics of the common design styles are described below.

Tubular Arms consist of a single steel or aluminum arm (either one piece or sectional) rigidly attached to the support pole. The characteristics of the arm (diameter, shape, and cross section) vary with the manufacturer and the length of the arm. This design requires no bracing or guys, but may require vibration damping techniques.

Signals may be suspended either vertically or horizontally from the end or at any point along the arm by use of appropriate mounting hardware. Cable from the controller to the various signal locations is run inside the pole and arm. A modification of this type is the rigid single member truss which spans the entire roadway and is supported at each end.

Truss-Type Mast Arms are made up of two longitudinal members with vertical braces or stringers of varying lengths between them. Wiring to the signals is usually carried through the top longitudinal member with the signals mounted vertically. Individual design configuration vary with the manufacturers.

Trombone-Type Arms are similar to the truss type except that the two longitudinal members are parallel throughout their length. Signals are mounted horizontally usually between the members. Mast arm attachment varies widely with some mast arms bolted to a fixed plate on the pole, clamped to the pole, or slip-fitted over the top of the pole.

Breakaway and Location Considerations

In areas where speeds exceed 35 mph breakaway design should be considered for all poles and posts near the roadway, except in cases where the potential hazard of a fallen traffic signal, cable, or mast arm may be as serious a safety problem as a nonyielding roadside obstruction. Overhead signal supports, base-mounted controller cabinets, and other rigidly supported appurtenances should be located as far as practical from the roadway. In many cases, existing roadside barriers can be used to shield motorists from nonyielding poles, posts, etc. Sometimes, existing roadside barriers can be extended to accomplish the same result. Signal poles and posts should never be located in front of a barrier unless they are yielding and an engineering analysis indicates that both the yielding pole or post and the roadside barrier will function as designed.

Finally, when poles and posts are located behind a roadside barrier, sufficient deflection distance must be provided. Deflection distances are discussed in Section 2C-1 of this Handbook.

Controller Cabinet

Essentially, there are three categories of controller cabinets: pedestal-mounted, pole-mounted, and base-mounted as shown on Figure 4-7. Depending on size, these cabinets are available in several kinds of assemblies. Accessory cabinets, used for housing detector amplifiers or similar related equipment, are primarily cast aluminum or sheet steel with cast top and bottom construction and are generally pole-mounted. The base-mounted meter cabinet is an exception.

Controller cabinet style and size will depend primarily on the type and size of control equipment to be used. In some instances, a compromise must be made where sidewalk space is at a premium. In this case, an extra or separate pedestal-mounted type controller cabinet can then serve as a splice cabinet and housing for accessory items.

In selecting a location for the controller cabinet, the following should be considered:

- For safety reasons it should be located as far from the roadway as practical. It may be possible to locate it behind otherwise needed roadside barriers.
- It should be positioned so that a person working on the cabinet contained devices will have a clear view of all intersection approaches.

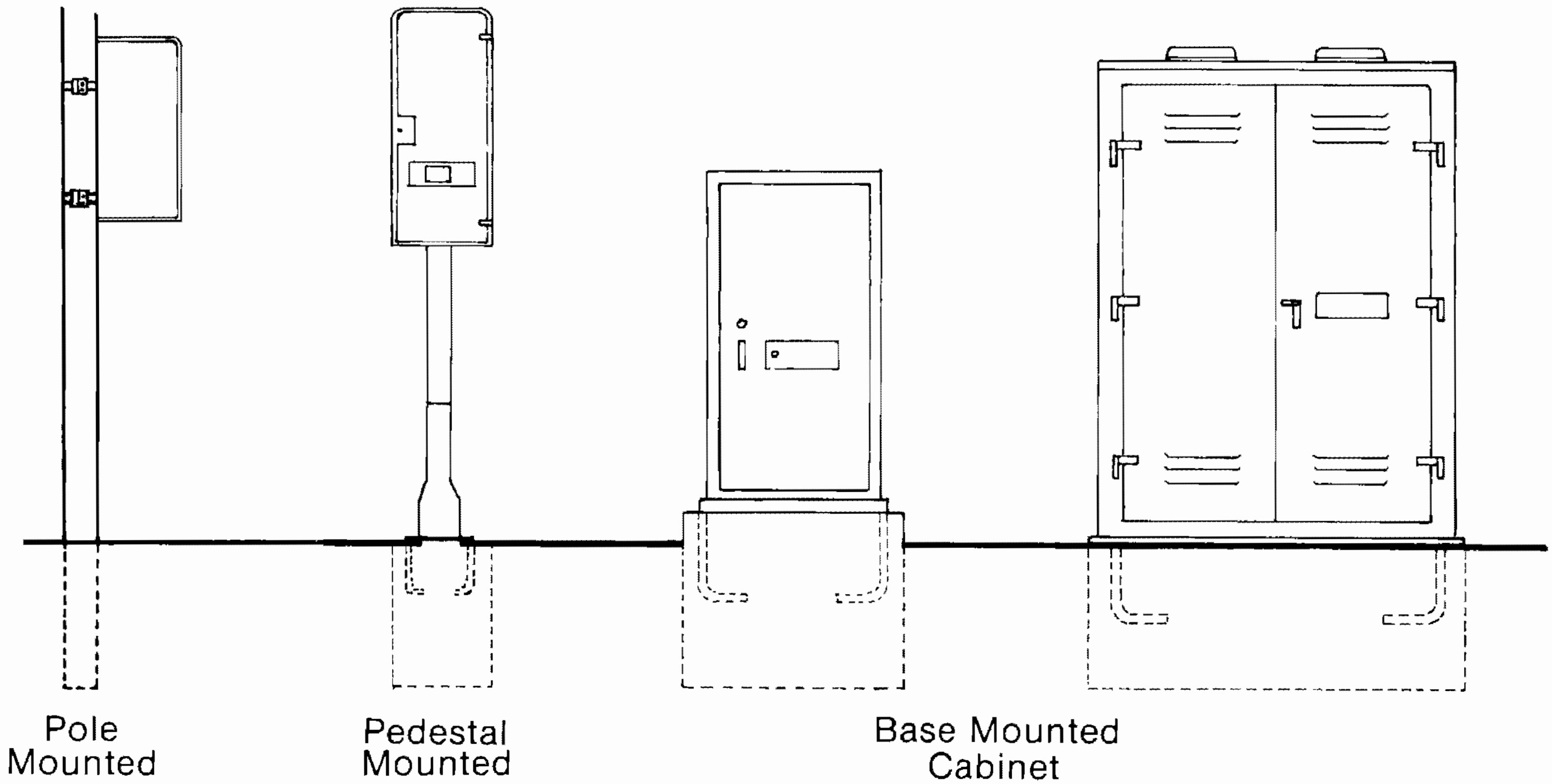


Figure 4-7 Controller Cabinet Mountings

- The cabinet door should face away from the intersection so as to provide a better view of the intersection to technicians working within the cabinet.
- It should be easily accessible and, if possible, should be near an area for parking repair vehicles.
- The area should be well drained. In rural areas it may be desirable to provide a paved pad on which to stand while working on devices within the cabinet.
- The cabinet should not be placed where it would be hazardous to pedestrians, joggers, or bicyclists.
- The placement of cabinets within a channelizing island is discouraged. Such placement makes the cabinets vulnerable to accidents and also exposes workers to an unnecessary risk.

Wiring

Wiring between the controller cabinet and the individual signal heads may be carried underground or overhead. In overhead installations, the cables are wrapped to the span wire, lashed to the span wire, or placed in support rings on the span wire. Underground installations use cables or individual conductors pulled through conduit.

Each of the individual conductors must be clearly distinguishable to facilitate initial installation and any future alterations or maintenance. The color coding used to distinguish the conductors should be as bright and distinct as possible and should not be subject to fading or deterioration when exposed to moisture, dirt, solvents, etc. Coding normally consists of a base color on a base color with either a longitudinal stripe or a spiral stripe that completely encircles the conductor. The color arrangements are usually provided in the standard specifications associated with almost all State standards. Spare wires should be provided throughout the installation to provide for future flexibility and for replacement of damaged conductors.

For overhead wiring installations, weatherproof junction boxes attached to each pole and containing terminal blocks may be considered. From these boxes, the necessary lengths of cable are brought down the pole to the pole plate entrance hole and through the arm into the signal. They are terminated on a terminal strip in the signal head.

If practical, the junction box on the controller pole should be taken as the central point of the main cable run. This should be laid out to form an almost complete circle around the intersection, with each conductor being connected to the same terminal in each box. With this type of arrangement, all conductors will be available at each junction box. Any signal may be connected to the required cable thus providing almost complete flexibility in regard to the initial installation and any future changes.

Underground wiring installations are more costly than overhead installations. However, it is much more permanent and is not unsightly as is overhead wiring. It should be considered whenever engineering judgment indicates it may be feasible from an installation and maintenance standpoint.

When roads are being constructed or widened, or where intersections are being improved, conduit should be installed at any location where future signals may be required. This conduit should be laid under all traveled portions of the roadway completely encircling the intersection with access to all median or channelizing islands. The exact location of the conduit and its ends should be marked on the ground and carefully recorded on the "as-built" plans so that the conduit may be located without difficulty when signal installation commences.

Conduits should either be sealed or junction boxes (or "pull boxes") should be placed and set at the ends of the conduit. The location of pull boxes will be dictated by changes in conduit direction, access to adjacent signal poles, and by intermediate points on long straight runs. Whenever possible, pull boxes should be located close to the controller cabinet, pole, or other object to which connection may be required. Where hollow poles are employed, short lengths of conduit should be installed from the nearest pull box directly into the poles so that all wiring can be concealed. For solid poles or for a pole-mounted controller cabinet, metal conduit should be used to connect to the bottom of the cabinet or to carry the wire up the pole to a height of at least 10 feet. Local electrical code requirements should always be met.

4E. IMPLEMENTATION CONSIDERATIONS

The proper implementation of a traffic control signal is critical if it is to serve its purpose in directing and regulating traffic. An improperly installed signal may create more problems than it solves.

This section covers those factors that should be considered during the design and implementation of a traffic control signal. Although not intended as a design manual, it should be of value to the designer by pointing out areas of concern and various methods for minimizing problems for the motorist, the pedestrian, and the highway agency.

There are two underlying principles that must be carefully considered throughout the design and implementation process. These are conspicuity and clarity. Simply stated, the signal must be seen in order for the driver to react, and the required action to be taken must be obvious. Conspicuity means that the signal must not only be visible, but must be obvious to the eye and must attract attention. The effectiveness of a traffic control signal installation is highly dependent on its attention getting capability. This ability to get attention is much more than simply being visible. Rather, the traffic control signal must have a probability of detection approaching 100 percent. Failure of even a small percentage of motorists to perceive an indication in a timely fashion will have a significant adverse effect on the safety of an intersection. The attention getting capability is a function of the distance over which the signal is visible, the size of the lenses, the brightness of the display, the number of signal phases, the level of background light, and competing visual objects in the foreground and background, or visual noise.

Clarity means that the message or instructions given must be easily understood. Once the traffic signal is perceived by the motorist, it's message must be understood almost instantaneously. Even momentary confusion or misunderstanding by a limited percentage of motorists will have significant adverse effects. Clarity is a function of uniformity of signal display and operation.

The MUTCD, in Sections 4B-5 through 4B-14, sets forth the meanings and minimum standards for traffic control signal displays. This section of the Handbook discusses those requirements in terms of the considerations necessary to properly install traffic control signals in the field.

4E-1 Signal Face Display

The primary purpose of a traffic control signal is to transmit information to the driver. This information or message is portrayed by selective illumination of one or more signal indications. The meaning of each indication is designated by the color of the indication, its position in the array, and in the cases of arrows, by the physical orientation of the arrow. Basically, the message indicates whether, at a particular instant, a specific traffic movement is permitted or prohibited.

The speed and accuracy of driver (or pedestrian) response to any light signal is a function of:

- The amount of light reaching the observer's eye,
- The position of the signal in the observer's field of view,
- The signal-to-background contrast ratio,
- The amount of competing information sources (visual clutter or "noise"),
- The degree to which the occurrence of a signal was expected,
- The degree to which the precise location of the signal was known,
- The degree to which the message conformed to the observer's knowledge, and
- The degree to which the message corresponded to the observer's expectancies.

The various elements of a signal face display which have a pronounced effect on the driver's ability to detect, identify, interpret, and respond to the message are discussed below and are detailed in Ref. 4–15.

Size

Two sizes of signal lenses are specified as standard in the MUTCD. They have nominal diameters of 8 or 12 inches. The 12-inch lens yields a maximum center luminance two or more times higher than the maximum center luminance of an 8-inch lens. The larger size should be used when an increased light output is required to achieve conspicuity. Specific cases for which the larger sizes are either required or recommended include:

- All arrow indications,
- All approaches for which the minimum visibility distance requirements of Section 4B–12(1) of the MUTCD cannot be met,
- All signal indications located beyond 120 feet from the stop bar,
- All intersections with 85 percentile approach speeds exceeding 40 mph,
- All intersection approaches where drivers may view both traffic control and lane-direction-control signs simultaneously,
- All locations where signalization might be unexpected,
- All special problem locations, such as those with conflicting or competing background lighting (unless backplates are used),
- All locations with rural cross-sections where only post-mounted signals are used, and
- All locations where an engineering study indicates that extra visibility and target value are required.

Some authorities argue that at many installations, a 12-inch red indication can be effectively combined with an 8-inch yellow and an 8-inch green indication. (However, an 8-inch red indication should not be combined with a 12-inch yellow or green.) However, other authorities argue that if a 12-inch red lens is required for conspicuity of the traffic control signal, then the 12-inch yellow and green lenses should also be required as any one of the three may be being displayed when the motorist has his first opportunity to detect the presence of the traffic control signal. Locations where a 12-inch red with 8-inch yellow and green configuration may be beneficial include:

- Intersections installed under the accident warrant,
- Intersections installed under the pedestrian warrant with approach speeds in excess of 30 mph,
- Drawbridge signals,
- Emergency signals,
- Over-the-road signals at signalized mid-block locations,
- Approaches for which the minimum visibility distance requirements cannot be met, and
- All portable signals.

Arrangement

The arrangement of lenses in the signal face are clearly specified in Section 4B-9 of the MUTCD. Typical arrangements are shown in Figure 4B-9 of the MUTCD.

Illumination

The basic illumination requirements given in Section 4B-10 of the MUTCD specify that each signal lens shall be illuminated independently and shall be clearly visible to the traffic it controls for at least ¼ mile under normal atmospheric conditions. The requirements for color, brightness, and intensity variations for signal heads and pedestrian signals are prescribed in two publications prepared by the Institute of Transportation Engineers: "Standards for Adjustable Face Vehicle Traffic Control Signal Heads" (Ref. 4-16) and "Adjustable Face Pedestrian Signal Head Standard" (Ref. 4-17).

These standards cover lamp wattage, candle power distribution, tests and inspection of lenses, and photometric and colorimetric testing characteristics for signal heads. For pedestrian signals, however, there are no specific standards for lamp wattage and candle power distribution . . . only that "The lighted pedestrian signal shall be uniformly illuminated over the entire message surface without shadows when viewed from usual angles encountered in service. The pedestrian indications should attract the attention of, and be readable to, the pedestrian (both day and night) at all distances from 10 feet to the full width of the area to be crossed." (Ref. 4-17)

Visibility and Shielding

To be effective, a signal must be clearly visible and conspicuous to the driver it is intended to control. There are several problem areas that can affect and/or degrade the visibility of signal indications.

First, during periods of direct sunlight, the driver may have difficulties in determining which signal indication is actually illuminated as they all appear to have the same intensity. This is termed the "sun phantom" effect. Next, signal indications may lose their contrast value and conspicuity when viewed against a bright sky or other background lighting such as intensive advertising displays. The signal indication becomes lost in the midst of such visual clutter.

Another critical problem involves the overlap of conflicting signal indications; that is, the motorist may become confused if confronted with a clear view of the indication intended to control a different movement in an adjacent lane as well as the indication controlling the lane he is in.

Finally, in some cases, signal indications that perform effectively during daylight hours are too intense at night, creating undesirable glare.

These problems can usually be resolved or alleviated by the selective use of visors, shields, louvers, or backplates. The use of these various devices are discussed below.

Visors

To reduce the sun phantom effect, visors are attached to the front of the signal face to shade it from direct sunlight and to provide additional contrast between the lens and the signal head. Visors are generally used under normal circumstances at all locations. Typical visors are shown on Figure 4–8.

Visors may be full circle or cut-away. A tunnel visor is a full circle visor with a cutout section at the bottom. Visors with the cutout section are generally preferred as snow or water cannot accumulate and they reduce the problem of birds nesting in the visor. When full circle visors are used, wire mesh can be placed over the front of the visor to prevent nesting.

Angle visors are merely cut away visors turned on their side. Angle visors may also be used to reduce the visibility of a signal face from the side at angle approaches. These visors extend further on one side to shield the face from the side streets without reducing the conspicuity of the signal to approaching traffic. Figure 4–9 shows a typical application of angle visors.

Louvers are metal or plastic vanes that can be placed inside a tunnel visor to reduce signal visibility from the side. As with angle visors, they are used where an approach to the intersection is such that signals meant for another approach could otherwise be seen. The problem with louvered indications is that they reduce the amount of light emitted from the signal face for the primary approach as well as the secondary approach. Higher

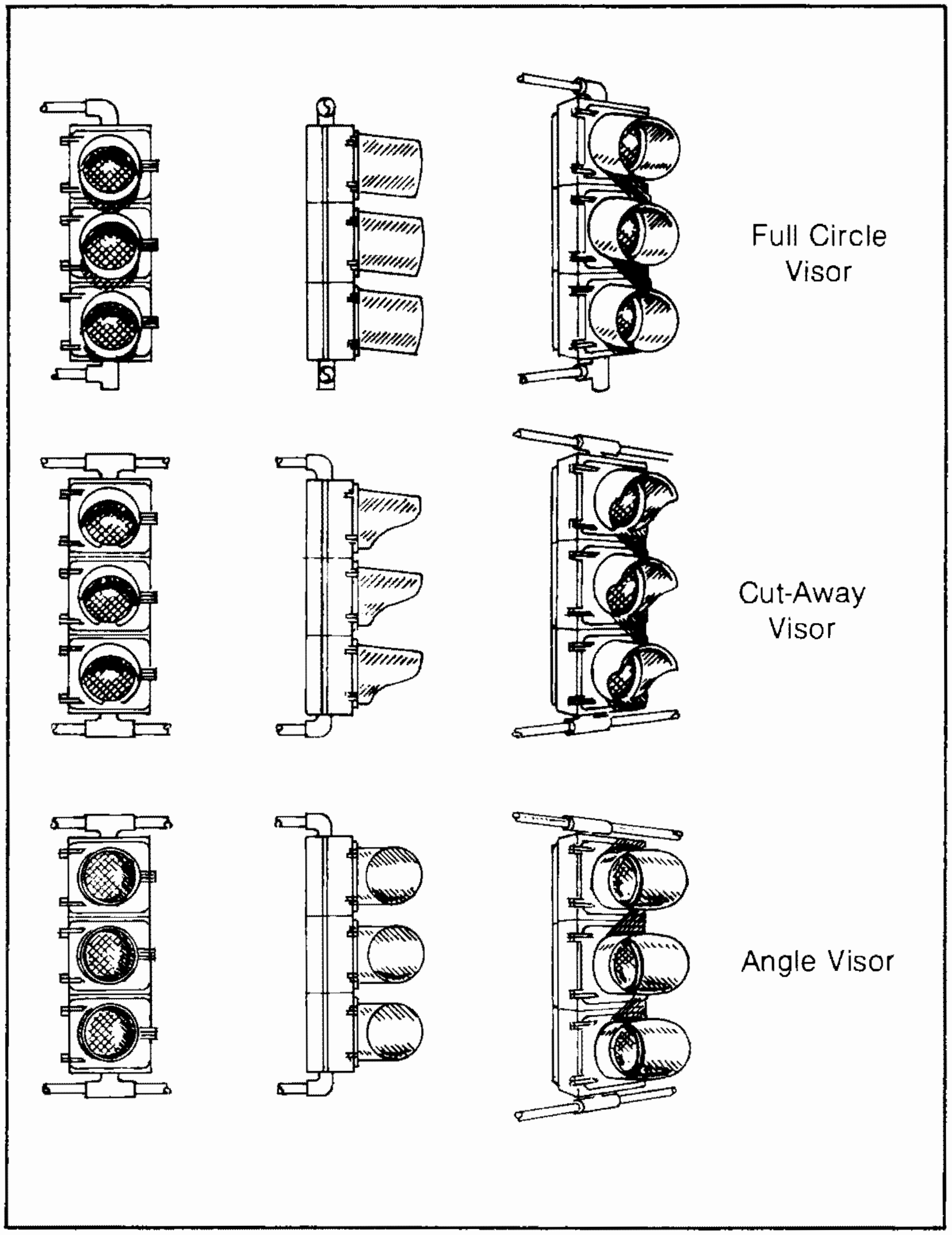


Figure 4-8 Typical Visors

luminance would be required to obtain the same visibility as unlouvered indications.

Backplates

Backplates are metal or plastic frames placed around a signal head. They extend approximately 5 to 8 inches beyond all sides of the head and are generally black or some other dark color. Typical backplates are shown in Figure 4-10.

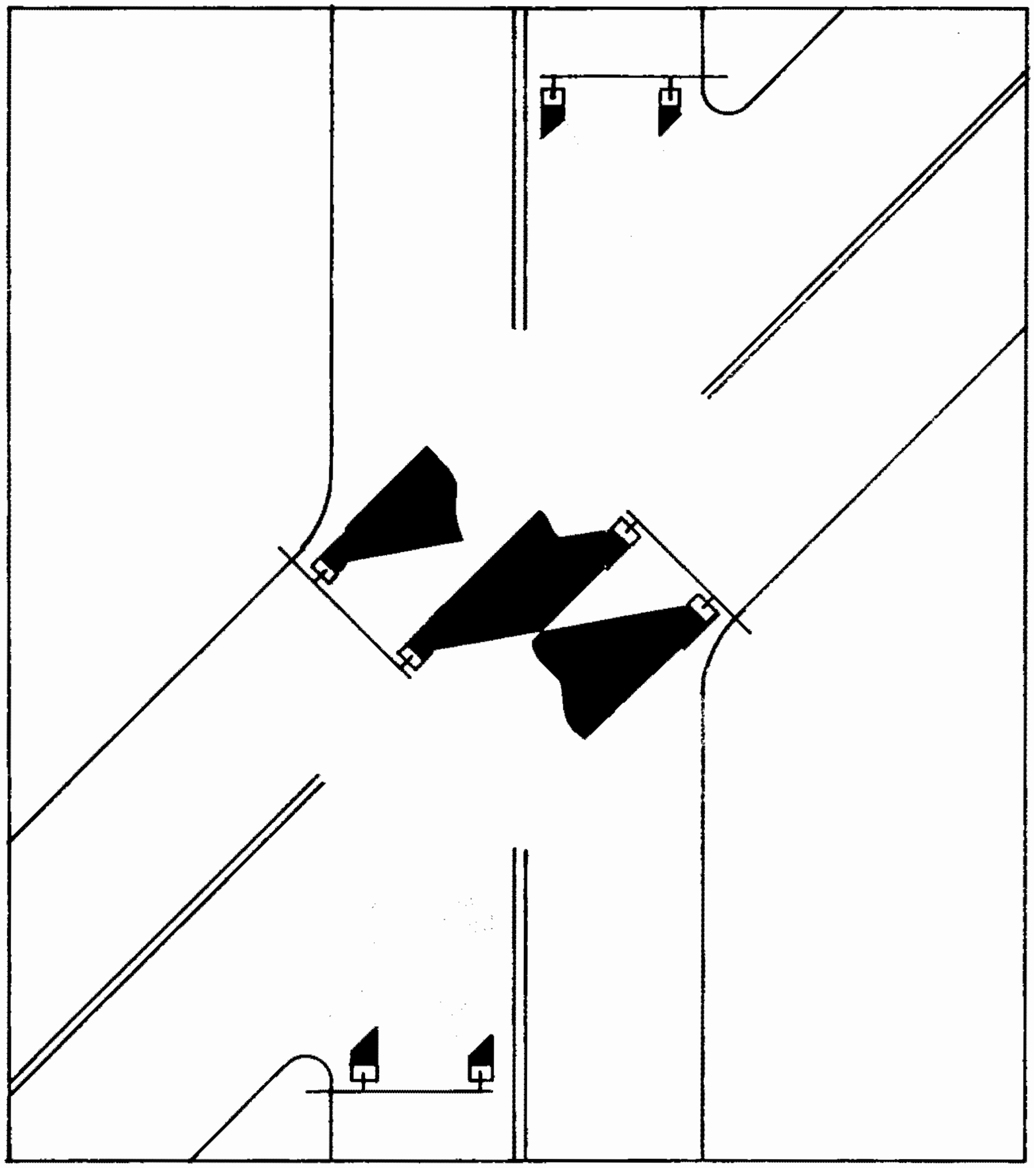


Figure 4-9 Angle Visors

Backplates increase signal conspicuity by providing contrast against the surrounding background. Optical and human factor considerations supported by research indicate their desirability for all installations where the signals may be viewed against the sky or other bright backgrounds (Ref. 4-15). Backplates may also be considered where background lighting or advertisements reduce signal conspicuity.

The use of backplates presents two potential problems. Namely, the added weight and the increased area that is subject to wind load. Slots in the backplate can be used to partially alleviate the wind loading problems (Figure 4-11). However, it is important to design new installations so that the supporting poles, mast-arms, or cables are sufficiently strong to carry the increased weight and wind loads when backplates are used.

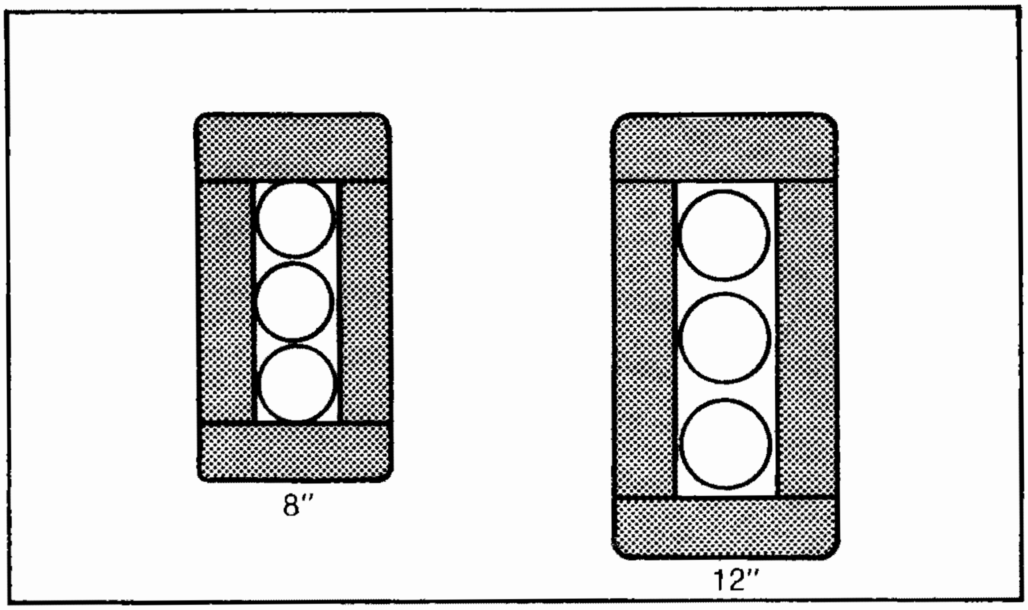


Figure 4-10 Backplates

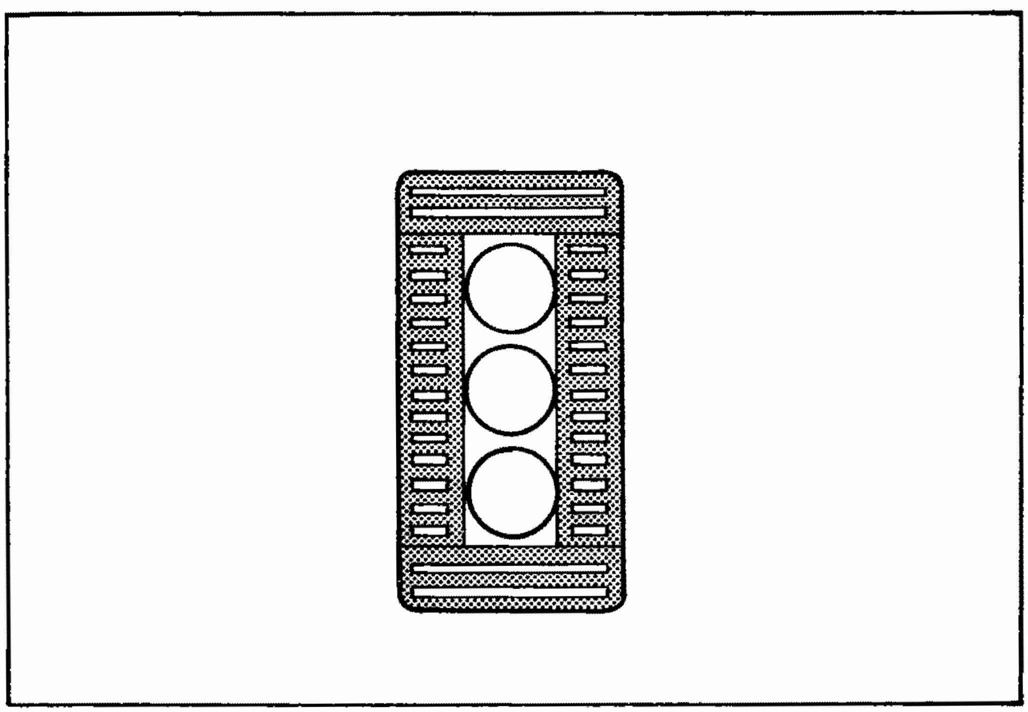


Figure 4-11 Slotted Backplates

Visibility Limiting Signals

As the name implies, visibility limiting signals are those that restrict signal visibility to the traffic in the specific lane(s) to which they apply. Unlike louvered visors, visibility limiting signals do not reduce the light intensity of the display as optical techniques are used instead of restricting hardware. This technique uses optically directed lenses to provide a sharp optical cut-off of the indication, both vertically and horizontally as needed, to prescribed limits, and with an accuracy not possible with louvered visors.

The satisfactory operation of the optically directed signals depends on correct alignment. Consequently, the signal face must usually be installed on a rigid mounting rather than being suspended from overhead span wires. For some applications of optically directed signals, it may be possible to suspend the signal from an overhead span wire if a "tether" wire is attached to the bottom of the signal in such a way as to limit the movement of the device. The brightness of this type of signal indication is beneficial during daylight hours, but may create a problem at night. A dimming device may be used during periods of darkness to reduce the visible glow seen by drivers approaching in adjacent lanes.

Applications of visibility limiting control may be classified into lateral separation (such as for a lane or approach), and longitudinal or distance separation. Table 4–10 presents typical examples of both types of applications. The cost of these optically directed signals is two to three times that of the standard signal head. This tends to limit their use to locations where they are necessary.

Type	*Applications*
Lateral	• Separate left or right turn lanes
	• Adjacent parallel roadways (frontage roads)
	• Acute-angled intersections
	• Multilegged intersections
Longitudinal	• Closely spaced intersections
	• Offset
	• Diamond intersections at freeway interchanges
	• Wide intersections
	• Railroad grade crossings with preemption

Table 4-10 Lateral and Longitudinal Application for Visibility Limiting Signals

Number and Location of Signal Faces

The placement of the primary signal faces (as specified in Section 4B-12 of the MUTCD) is based on visibility requirements. The locational considerations include lateral and vertical angles of sight toward a signal face as determined by:

- Typical driver eye position,
- Vehicle design, and
- Vertical, longitudinal, and lateral position of the signal face.

The first two elements are beyond the control of the traffic engineer and his staff. The third element is a function of the intersection geometry and may vary widely. Consequently, the geometry of each intersection to be signalized should be studied individually to determine the optimum physical layout of the traffic signal indications and to assure that the signal indication lies within the motorist's vertical and horizontal cone of vision.

Cone of Vision

A driver's vertical vision is restricted by the top of the vehicle's windshield. This requires that overhead signals be far enough beyond the stop bar to be viewed by a stopped vehicle (see discussion in 4E-2 Signal Mounting Considerations).

The lateral location of the face is determined by the driver's cone of vision and the width of the intersecting cross streets. The MUTCD requires that at least one (and preferably, two) signal faces be located within a cone 20° to the left or 20° to the right of the "center of the approach lanes extended." It should be recognized that this is the maximum acceptable cone.

In the context of this requirement, the cone of vision originates at a point which represents the center of the approach lanes at the stop bar. There is some controversy as to what lanes should be included. For example, should the center line bisect the entire approach width including the parking lane and the left-turn lane? Parking lanes should be excluded if they will not be used as a traffic lane during the service life of the signal installation. Separate turn lanes should be included unless they are controlled by separate signal displays.

Figure 4-12 illustrates the maximum cone of vision superimposed on a two-lane approach with a parking lane and with various width cross-streets. The figure also defines the critical distances from the stop bar. This cone would remain the same if a separately-controlled left-turn lane were added. The cone would shift left 6 feet if a 12-foot wide left-turn lane, not separately controlled, were added.

Supplemental Signal Indications

The MUTCD requires a minimum of two signal faces for each approach located on the far side of the intersection. A single indication can be used for a single, exclusive turn lane, unless the movement accommodated in that lane represents the major movement from the approach.

Supplementary signal indications should be used if they will significantly improve the visibility or the conspicuity of the signal indications. Examples of conditions where additional signal indications may be desirable include:

- Approach widths in excess of three full lanes,
- Intersecting street widths in excess of 80 feet,
- Driver uncertainty concerning the proper location at which to stop,
- High percentages of large trucks in the traffic stream that tend to block the view of signal indications in their normal location, and
- Approach alignment that makes continuous visibility of normally-positioned signals impossible.

Additional signal heads installed to enhance signal visibility should be located as close as practical to the projection of the driver's line of sight.

Minimum Visibility Requirements

The MUTCD cites the minimum distance from the stop bar at which a signal should be continuously visible for various approach speeds. These distances were primarily based on the required stopping distance. Actually, the minimum visibility distances cited by the MUTCD are very close to the Desirable Stopping Sight Distance specified by AASHTO. However, analytical considerations of the human factors involved in the driving tasks indicate that the point of first visibility should be greater than the distance simply required for safe stopping.

Accordingly, a proposed change to the MUTCD is currently being recommended which will increase some of the minimum distances. Table 4-11 presents the minimum visibility distances currently specified by the MUTCD, the proposed minimum visibility distances, and "desired" visibility distances.

These distances do not consider the impact of roadway grade. In situations where it is desirable to adjust the minimum visibility distances to reflect an upgrade or downgrade approach, the adjustment values given in Table 4-12 may serve as a guideline.

In cases where the visibility requirements discussed above cannot be accommodated, an advance warning sign should be installed to alert approaching drivers. Should the driver not have a continuous view of at least one signal indication for the minimum visibility distance, the sign may be supplemented by a Hazard Identification Beacon as recommended in the MUTCD.

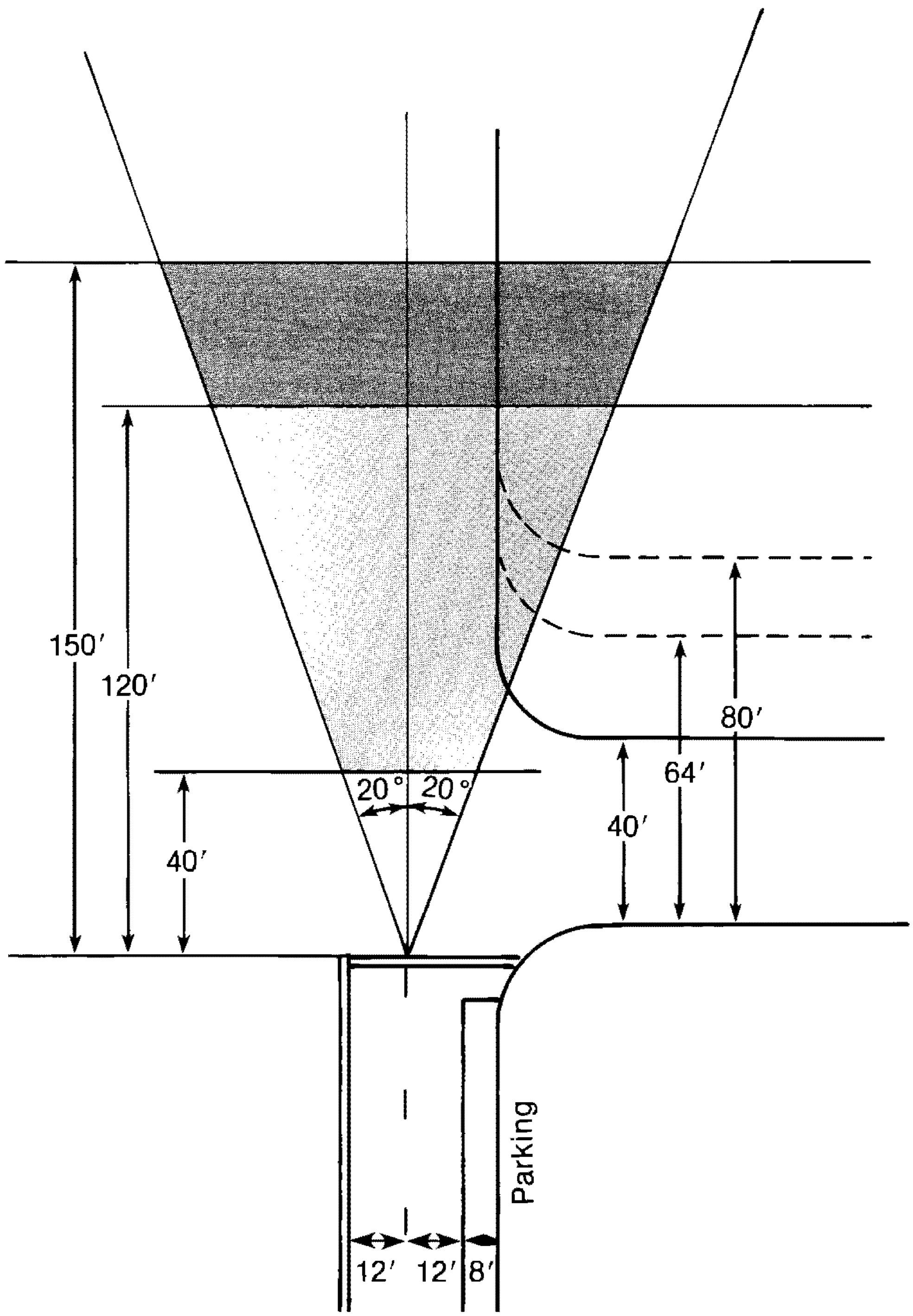


Figure 4-12 Typical Cone of Vision

85 Percentile Speed (mph)	Minimum Visibility Distance (ft.) Current	Minimum Visibility Distance (ft.) Proposed	Desirable Distance (ft.)
20	100	175	265
25	175	215	325
30	250	270	405
35	325	325	480
40	400	390	570
45	475	460	660
50	550	540	760
55	625	625	870
60	700	715	980

Table 4-11 Minimum Visibility Distances

85 Percentile Speed	Add for Downgrade 5%	Add for Downgrade 10%	Subtract for Upgrade 5%	Subtract for Upgrade 10%
MPH	FT.	FT.	FT.	FT.
20	5	15	5	10
25	10	20	10	15
30	15	30	10	20
35	20	45	15	25
40	30	65	20	35
45	40	90	30	50
50	50	120	35	65
55	60	150	45	80
60	70	190	55	95

Table 4-12 Adjustments for Grade Guidelines

Other Requirements

Other MUTCD requirements (Section 4B-12) that affect the location of signal displays are summarized below:

- Where a signal face is meant to control a specific lane or lanes of approach, its position should be unmistakably in line with the path of that movement;
- Near-side signals should be located as near as possible to the stop line;
- Required signal faces for any one approach must be mounted no less than 8 feet apart, measured horizontally and perpendicular to the line of approaching traffic;

- Where possible, at least one, and preferably both signal displays which control through traffic must be located a minimum of 40 feet and a maximum of 120 feet beyond the stop line; and
- Where the nearest signal face is more than 120 feet and less than 150 feet beyond the stop line, either 12-inch signal indications or a supplemental near-side signal indication is required. Where, because of roadway geometry, the nearest signal face is 150 feet or more beyond the stop line, a supplemental near-side signal face must be used.

Should the indications of a separate signal face(s), serving a separately-controlled turn lane, be visible to other traffic, a LEFT (or RIGHT) TURN SIGNAL sign is required to be located adjacent to the signal face. If the signal face consists solely of arrow indications, such a sign is not required.

Signal Displays for Left-Turn Movements

There are three modes of left-turn signal control: permitted left-turn, protected/prohibited left-turn, and protected/permitted left-turn. The various display configurations for each mode of control are discussed below.

In the *permitted* form of left-turn operation, the left-turning traffic moves on a circular green indication along with the parallel through movement. This is the simplest mode. The driver is permitted to turn left whenever there is an adequate gap in opposing traffic. In this case, there may or may not be a separate left-turn lane. The signal display for left turning traffic is the same as for through traffic (i.e., circular indications only, no arrows are used.) No type of regulatory LEFT TURN sign is required, but an informational-type sign (e.g., LEFT TURN YIELD) may be used.

Although a bit more complex, the *protected/prohibited* mode is relatively straight forward in that left-turning traffic moves on a left green arrow and only on a left green arrow display. A separate signal face should be used to control the left-turn. In most cases, an exclusive left-turn lane is utilized.

A separate left-turn face must be used where the sequence does not provide for the simultaneous movement of through traffic. The clearance interval display may consist of either a yellow left arrow or a circular yellow. The red interval may utilize a red arrow only if a yellow arrow indication is used. Otherwise, a circular red is used.

If a separate signal face is used, it should be positioned in line with the path of the turn movement approach. A LEFT TURN SIGNAL sign (R10–10) is required unless the signal face consists of arrows only, or unless it is properly hooded, shielded, or louvered to assure that conflicting circular yellow or red indications are not visible to motorists in the through lanes.

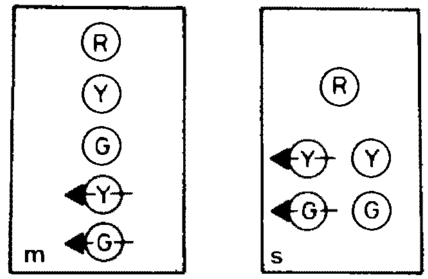


Figure 4-13 Five Section Head Displays

The third mode of control—*protected/permitted*—is much more complicated in that it combines both of the previous modes. In addition, there are four distinct sequencing schemes that are commonly employed:

- Lead-left turn with parallel through,
- Simultaneous lead-left turns with parallel through traffic stopped,
- Lag-left turn with parallel through, and
- Simultaneous lag-left turns with parallel through traffic stopped.

At least five section heads are needed for these displays. They may be arranged as shown in Figure 4-13.

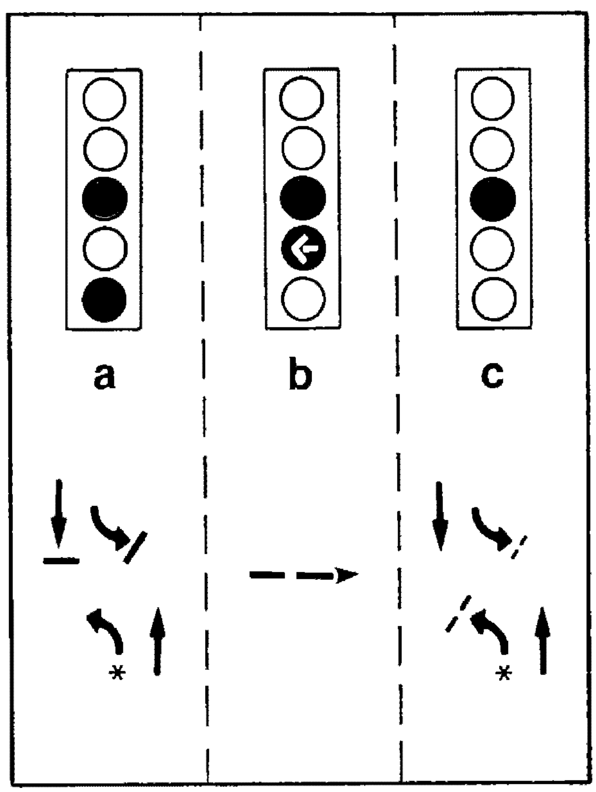


Figure 4-14 Lead-Left Turn with Parallel Through Movement

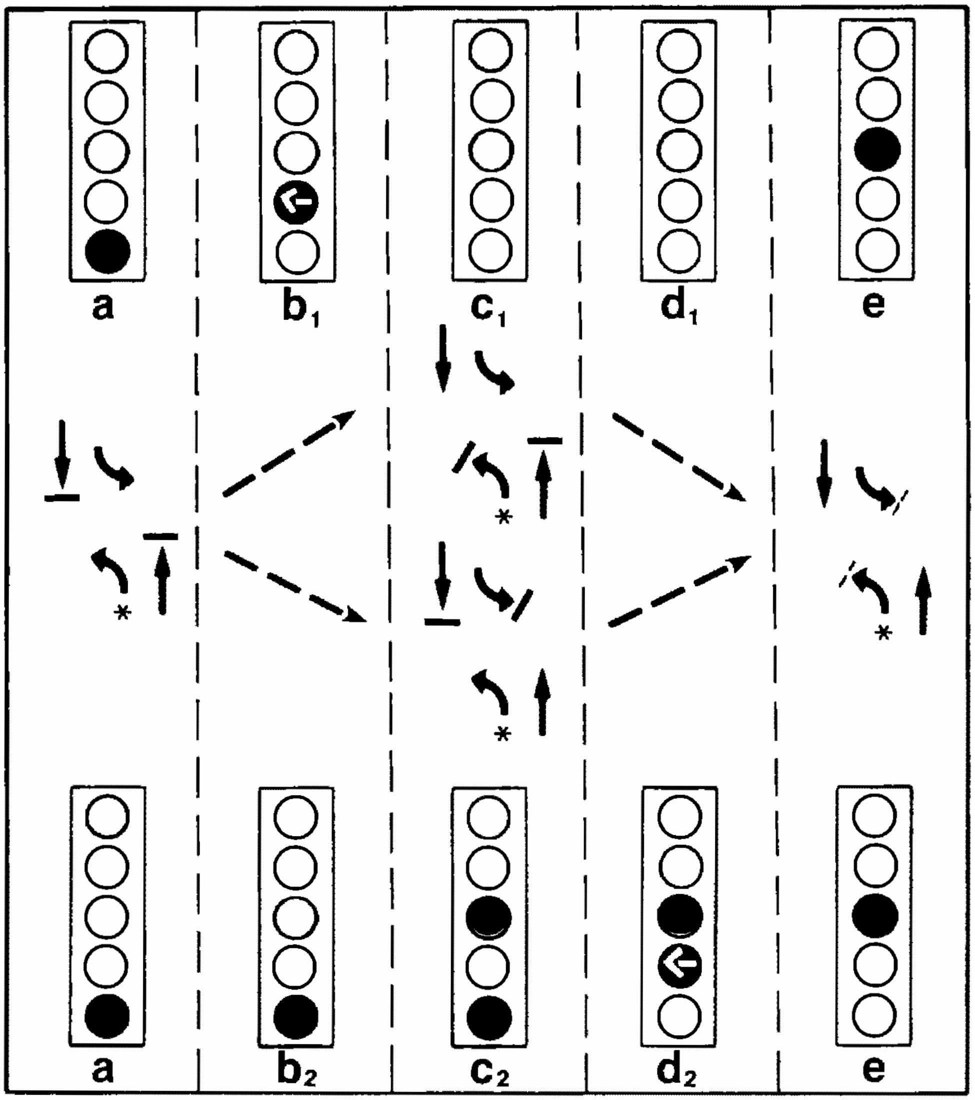


Figure 4-15 Simultaneous Lead-Left Turns

Although not conclusive, there is some evidence that the use of a separate signal face in the left-turn lane tends to confuse a small percentage of drivers. When a green circular indication is given they mistakenly assume that this is an indication that they have the right-of-way over oncoming traffic. These motorists may proceed to make their turn without yielding to the oncoming traffic. One alternative to remedy this situation is to use a five lens signal placed in line with, or to the right of, the lane line common between the left-turn lane and the left-most through lane. This alternative is recommended by the Federal Highway Administration. When this alternative is used, the second signal face would be a typical thru-lens face.

The different displays for these modes of control are discussed below and are illustrated in Figures 4–14 through 4–17. Each of these illustrations contain a stick diagram of the various movements. A heavy bar across the movement arrow indicates the movement is stopped by a red indication. A dotted bar across a left-turn arrow indicates that the left-turn is permitted, but no longer protected. The signal displays shown above the movement diagram are those visible to the starred(*) left-turn movement. The heavy dashed arrow represents the change to the next display. Where different sequences can occur, they are shown and labeled as b_1, b_2, c_1, c_2, etc.

The sequence and associated displays for lead-left-turn with parallel through movements are illustrated in Figure 4–14. As shown in this illustration (Sequence "a"), the left-turning traffic moves on a green arrow and the parallel through traffic moves on a circular green displayed simultaneously. The opposing left-turn (if present) and through traffic are stopped. A yellow left-turn arrow may be used for the left-turn change interval. Although a change interval is required, a separate display is not. Sequence "b" illustrates the yellow left-turn arrow displayed in conjunction with the circular green for through traffic. At the end of the change interval, both opposing through traffic streams move on the circular green (sequence "c"). During this remaining circular green time for through traffic, left turns are still permitted if there is an adequate gap in opposing traffic.

The more common case (5-or 8-phase operation) has the leading left turns occurring simultaneously. When demand on one left-turn approach is satisfied, that left-turn is terminated and the opposing through movement released. The sequence and display for this operation are shown in Figure 4–15.

In this illustration, sequence "a" shows both left turns proceeding on green arrows with both opposing through traffic stopped by circular red indications. If the starred (*) demand is satisfied, the sequence for the signal for that approach will follow the upper path of the illustration and the yellow arrow will be displayed as shown in "b_1." Interval c_1 and d_1 will display only a circular red since neither movement can proceed. During interval "e_1," the circular green is displayed, through traffic can proceed, and left turns are permitted through adequate gaps.

The sequence shown on the lower path of Figure 4–15 occurs when the opposing left-turn demand is satisfied first. In this case, the opposing left turn has a change interval while the starred (*) movement retains a green arrow/sequence "b_2". The circular green joins the green arrow in interval "c_2" permitting the parallel through movement to proceed. When the protected left-turn is to be terminated, the yellow arrow is displayed (sequence "d_2"). After the change interval, only a circular green remains (sequence "e") permitting left-turn through adequate gaps.

In the following lag-left schemes, the protected left-turn interval follows the circular green through traffic interval during which left turns were

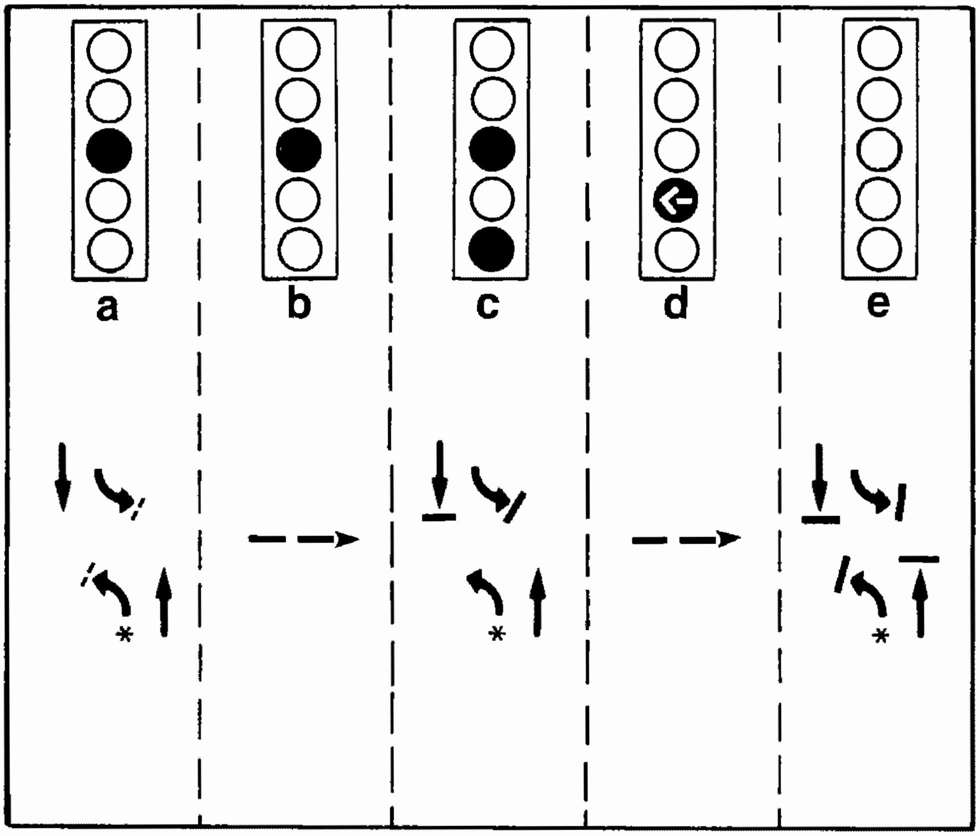


Figure 4-16 Protected Lag-Left Turns

permitted during adequate gaps in through traffic. Figure 4-16 shows the lag-left turn where the opposing left-turn is stopped, prohibited, or impractical. Sequence "a" illustrates the through movement interval where left turns are permitted. Sequence "b" shows the change interval when the right-of-way for the opposing through traffic is being terminated. During the protected interval (sequence "c"), the green arrow advises the left-turning driver of the protected status. Sequence "d" is the change interval when the left-turn movement and the parallel through movement are terminated at the same time. If these two movements are always terminated at the same time, the yellow arrow is unnecessary and a four-section head can be used. On the other hand, if the through movement can terminate separately from the left-turn movement, the yellow arrow is required and a five-section head is necessary.

The last scheme has both lagging left-turn moves simultaneously as shown in Figure 4–17. The normal through traffic interval (sequence "a") includes the permitted left-turn opportunity. The circular green is followed by a circular yellow change interval ("b"). Sequence "c" displays a circular red to through traffic and a green arrow for the

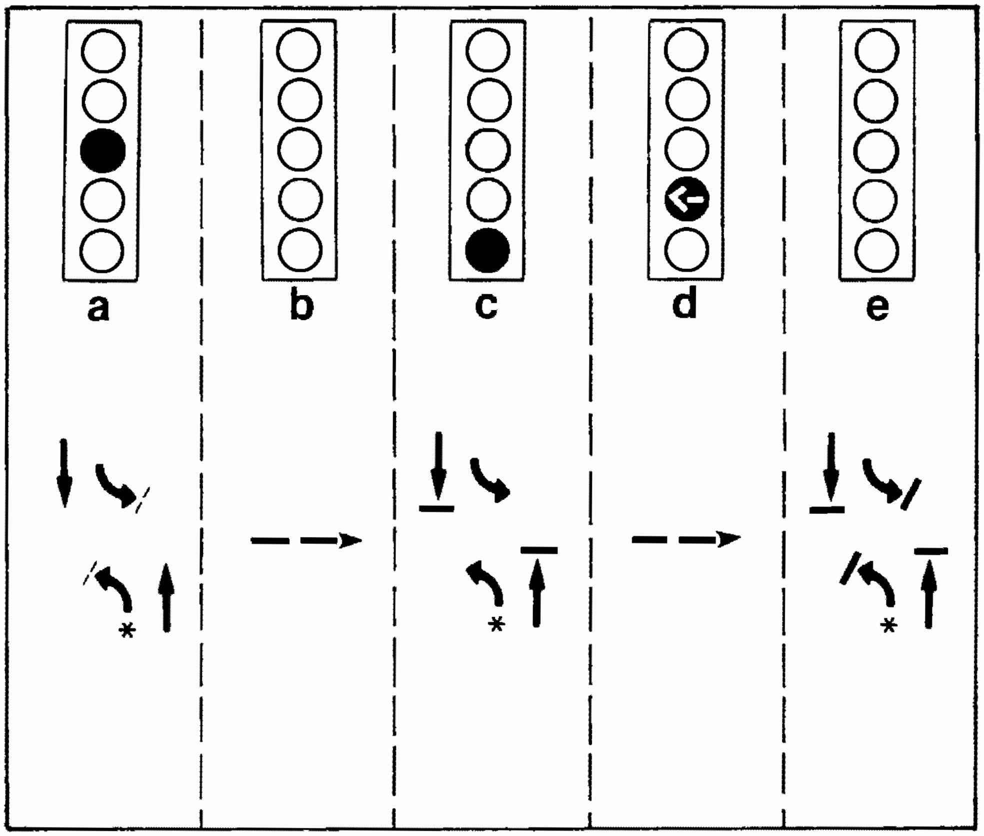


Figure 4-17 Simultaneous Lag-Left Turns

protected left-turn. This protected movement is ended by a yellow arrow change interval (''d'') leading to the singular display of a circular red while the right-of-way is transferred to the cross street.

To supplement the protected/permitted types of operations depicted in Figures 4-15 through 4-17, an informational type of sign (e.g., LEFT TURN PROTECTED ON GREEN ARROW ONLY) may be used, but is not required. The regulatory left-turn signal signs (e.g., LEFT ON ARROW ONLY) may not be used.

Signal Displays for Curve Approaches

Two special implementation considerations involve horizontal or vertical curve approaches to a traffic signal. The first issue relates to minimum sight distance as required by the MUTCD and the second involves driver expectancy as to the lateral placement of signals.

There are several techniques that can be used to resolve the minimum sight distance issue. Signal faces may be raised to maximum limits on vertical curve approaches. They can be supplemented by near-side signals, either overhead or postmounted. The near-side signals can be mounted on a separate post, on the back of a left-side mast arm, or overhead on the

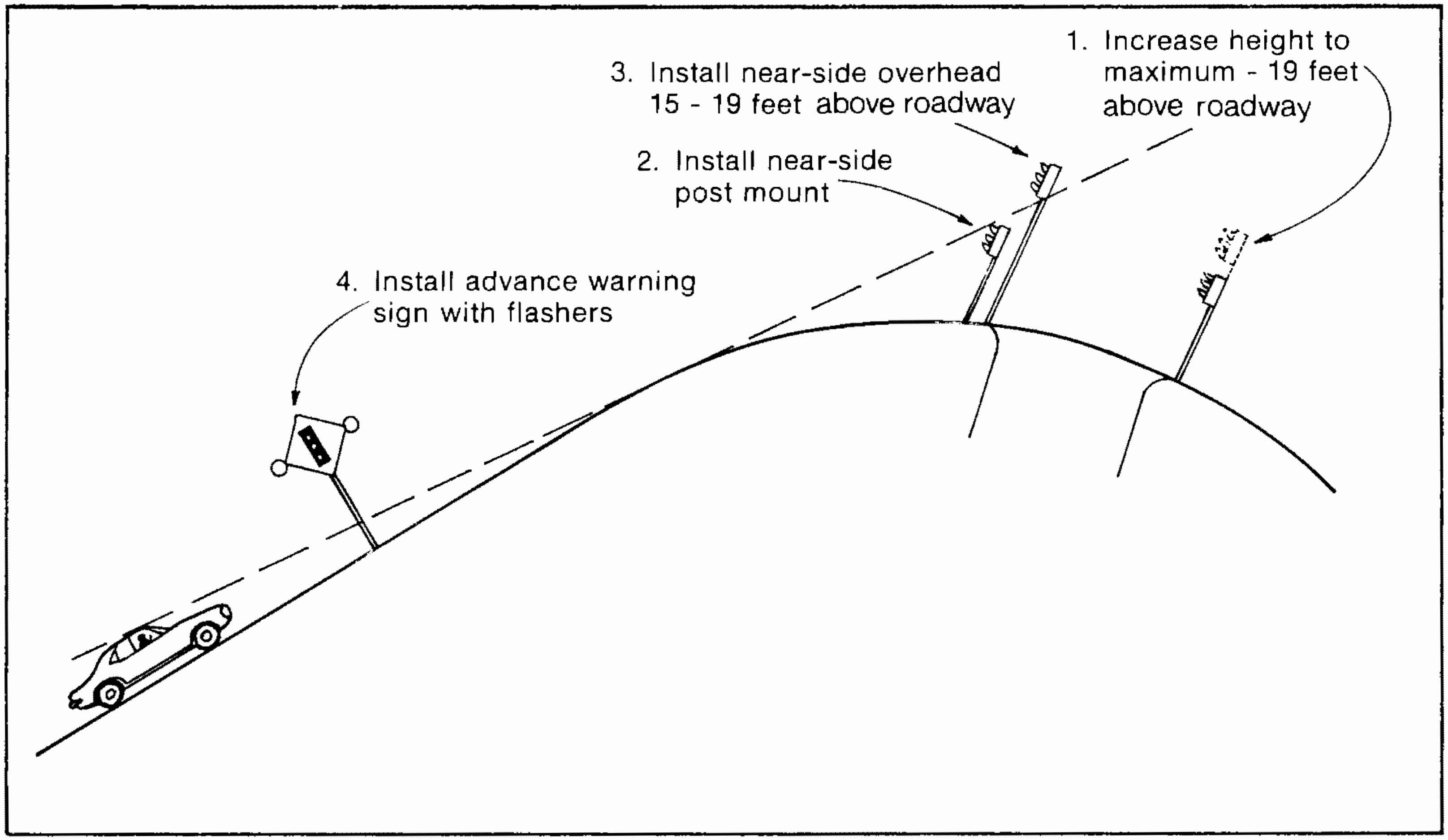


Figure 4-18 Signal Display for Vertical Curve Approach

span wire. Where necessary, an advance warning sign with flashers may be installed. On very high speed approaches, advance warning signs may be installed overhead and changeable message signals may also be used to alleviate the sight distance problem. The use of advance warning signs with flashers is generally limited because of the need to provide power to a location several hundred feet from the intersection. These techniques are illustrated in Figure 4–18. For vertical curve approaches, the designer should plot approach profiles and position the appropriate devices as necessary to meet minimum requirements.

Similar opportunities exist for horizontal curve approaches. Supplementary near-side signals may be installed on the left (for a right-hand curve) or right (for a left-hand curve) depending on sight restrictions. The supplemental signals may be installed on posts or overhead as needed to provide adequate sight distance. Where adequate sight distance requirements cannot be met using supplemental signals, advance warning devices similar to those for a vertical curve may be required.

Horizontal curves present a second problem; that is, the driver's perception of his travel path and its relationship to the intersection. To the extent practical, the signal locations should reinforce proper path choice. This is especially critical at unlighted locations, at night, where the motorist may not have the surrounding visual clues necessary to safely define the intersection approach. It may be necessary to shift a primary signal face or install supplemental signal faces to lead the motorist into the proper path through the intersection.

Although there are no established guidelines concerning this problem, several steps can be considered. First, the approaches can be driven several times, especially at night, to identify points where confusion might exist. Second, the intersection can then be plotted in a plan view and lines of sight drawn in relation to alternative head placement.

There are two concurrent problems that need to be resolved. The signals must be conspicuous for a sufficient distance in advance of the intersection and the message of the signals must be clear in the critical zone near the intersection. Probable driver actions can then be considered. Based on the awareness of the problem developed during these steps, the designer can then prepare a layout and review it in the field.

Figure 4–19 illustrates a layout with three potential supplemental head positions (a, b, c) shown. Position "a" is a low mount near-left, position; "b" is a mast arm mount near-left on the back of a primary mast arm; and position "c" is a post-mounted near right signal. Although positions "a" and "b" are the most conspicuous, they might tend to draw the motorist toward the left of the curve as he is conditioned to see the first signal (primary signal) on the right. Position "c" might be preferable in that it would draw the motorist around the curve.

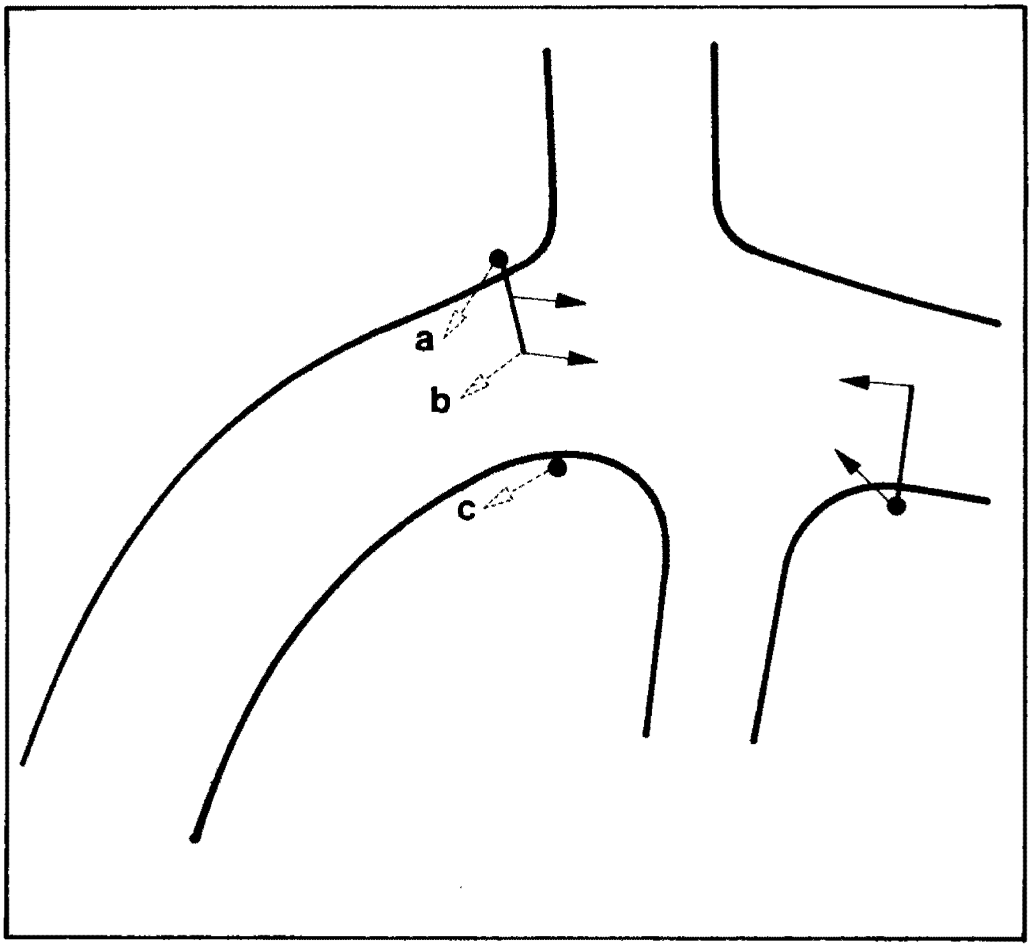


Figure 4-19 Signal Display for Horizontal Curve Approach

Mounting Height of Signal Faces

The minimum and maximum vertical clearances to the bottom of signal housing are measured from the level of the center of the roadway or sidewalk and are given in Table 4-13 for typical locations.

In selecting mounting height, potential interference with overhead utility lines and potential blockage of the line of sight by vegetation or other obstructions should be considered. Normally, maximum possible mounting height of over-the-roadway signals will minimize blockage of the signal indication by trucks. At least one low-mounted signal at the minimum mounting height should be provided to ensure that stopped or approaching drivers can see the signal from the stop line without interference from the top of their windshields or sun visors.

Location	*Minimum Mounting Height, feet*	*Maximum Mounting Height, feet*
Over the Roadway	15	19
Shoulder or Sidewalk	8	15
Median	4.5	15

Table 4-13 Signal Mounting Heights

4E-2 Signal Mounting Considerations

The type of signal mounting (post, mast, or span wire) used by a given jurisdiction depends somewhat on local practice and aesthetic appearance. The material used for the poles (wood, steel, aluminum, or reinforced concrete) may depend on local availability, maintenance procedures, costs, and aesthetic preference. The specific characteristics of each type of mounting should be considered during the design and implementation process.

Post Mounting

Signal faces may be mounted on posts placed outside the roadway. Generally, metal posts 8 to 12 feet high are placed at the intersection corners, and signal faces are mounted on the top or the side of the posts—maintaining a minimum 8-feet clearance above the ground or sidewalk.

Post-mounted median displays are by nature in a vulnerable position. They are hazardous to the motorist and are frequently a high maintenance item. Nonetheless they may be necessary in order to insure clarity of meaning for left turn signals or at channelized intersections. In these cases their use may be less hazardous than if some other form of signal display were used.

When a post-mounted median display is needed, the support should be of an acceptable breakaway design. The height and mass of the signal face should be designed so as to reduce the likelihood of the signal face penetrating the windshield if a vehicle should collide with the post mounted median display.

There are two ways to position post-mounted signals. In the simplest form, a single pole is installed in the center of the curb return and two signal assemblies are mounted on each pole as shown in Figure 4-20. This typical intersection layout requires four poles and eight signal faces. As required by the MUTCD, the faces are placed on the far right and far left corners of an approach. If the intersecting streets are not too wide (say, not over 90–100 feet) nor too narrow (say, less than 30 feet), it is usually possible to place at least one face between the required 40 feet and 120 feet from the stop line if there is a crosswalk and the post is mounted near the center of the curb return. It may also be possible to place at least one curb return. It may also be possible to place at least one face within the 20° cone of vision. However, none of the faces are close to the center of the approach. Moreover, the horizontal placement is directly affected by the radius of the curb return. When using this method, care should be taken to insure that pedestrian traffic (if present) will not be significantly obstructed.

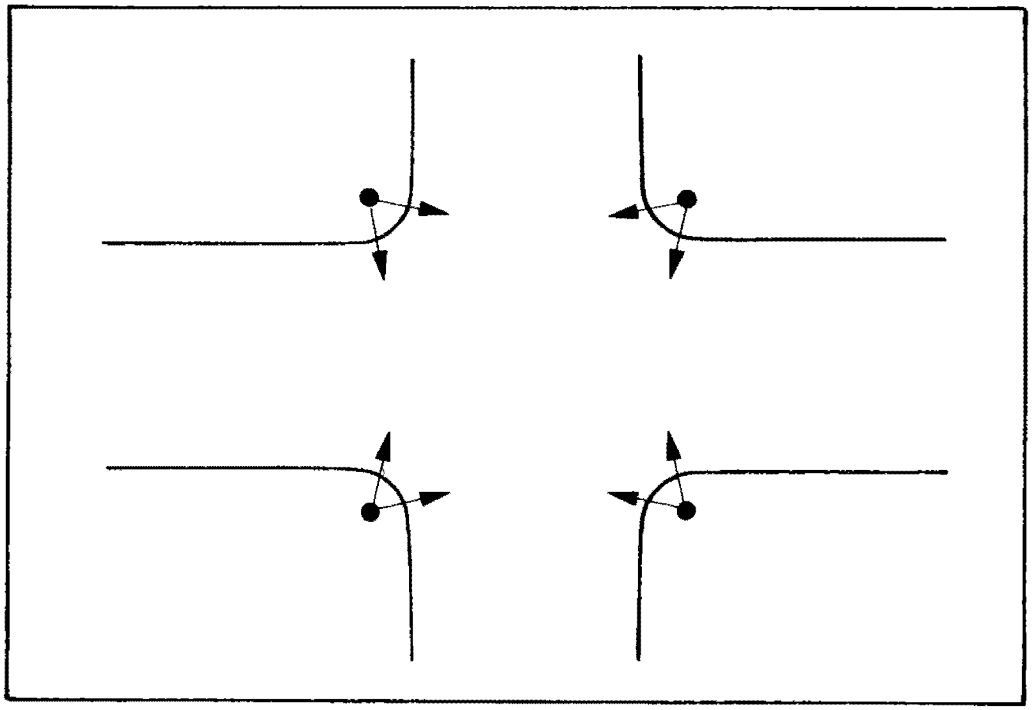


Figure 4-20 Post-Mounted Signals

The second method of positioning post-mounted signals is to use two posts at each corner of the intersection. By splitting the poles as shown in Figure 4–21, the negative effect of the radius of the curb return is neutralized. For example, it can be seen in figure 4–21 that the use of the single post-mounted display (position "a") moves the face 8 feet further from the center line of the approach. This can be alleviated somewhat by providing two posts, one for each direction, as shown at positions "b". This reduces the distance away from the center line of the approach by 6 feet, leaving only a 2 foot offset to provide minimum clearance from the curb.

It can be seen that the signal at position "a" violates both the 20° cone of vision and the 40-foot minimum distance from the stop bar. The signal at position "b" satisfies the minimum distance from the stop bar, but does not fall within the 20° cone of vision. Signal placement can be further enhanced by adding a crosswalk, or, if a crosswalk is not justified, by moving the stop bar back.

In figure 4–22, a 10-foot wide crosswalk has been added. Now the signal at location "b" satisfies both the minimum distance and the cone of vision requirements.

The following points should be recognized when considering the use of post-mounted signals.

- Under normal conditions, especially where four lane streets intersect narrow streets, it is difficult to meet minimum distance requirements of the MUTCD.

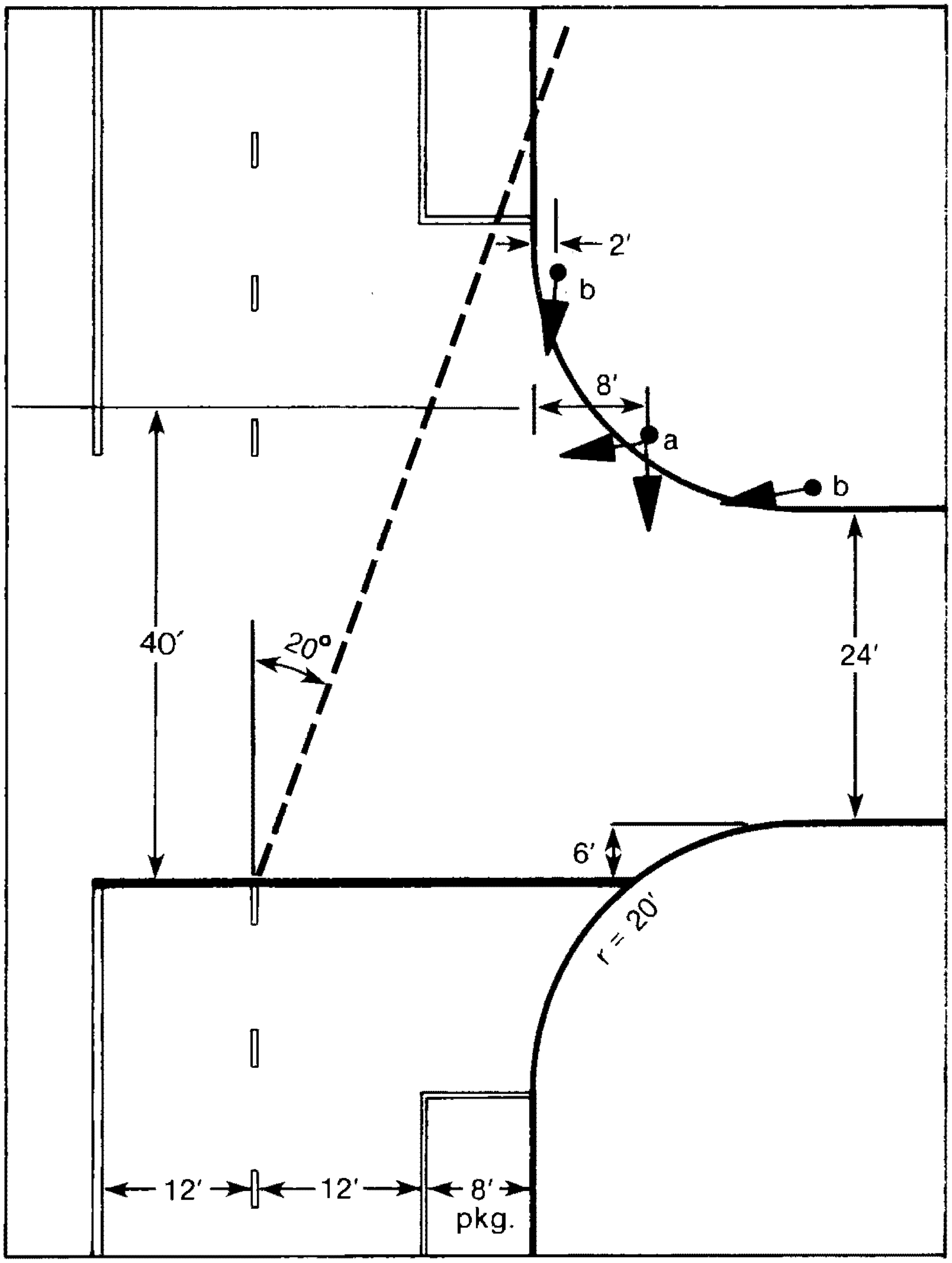


Figure 4-21 "Split" Post-Mounted Signals

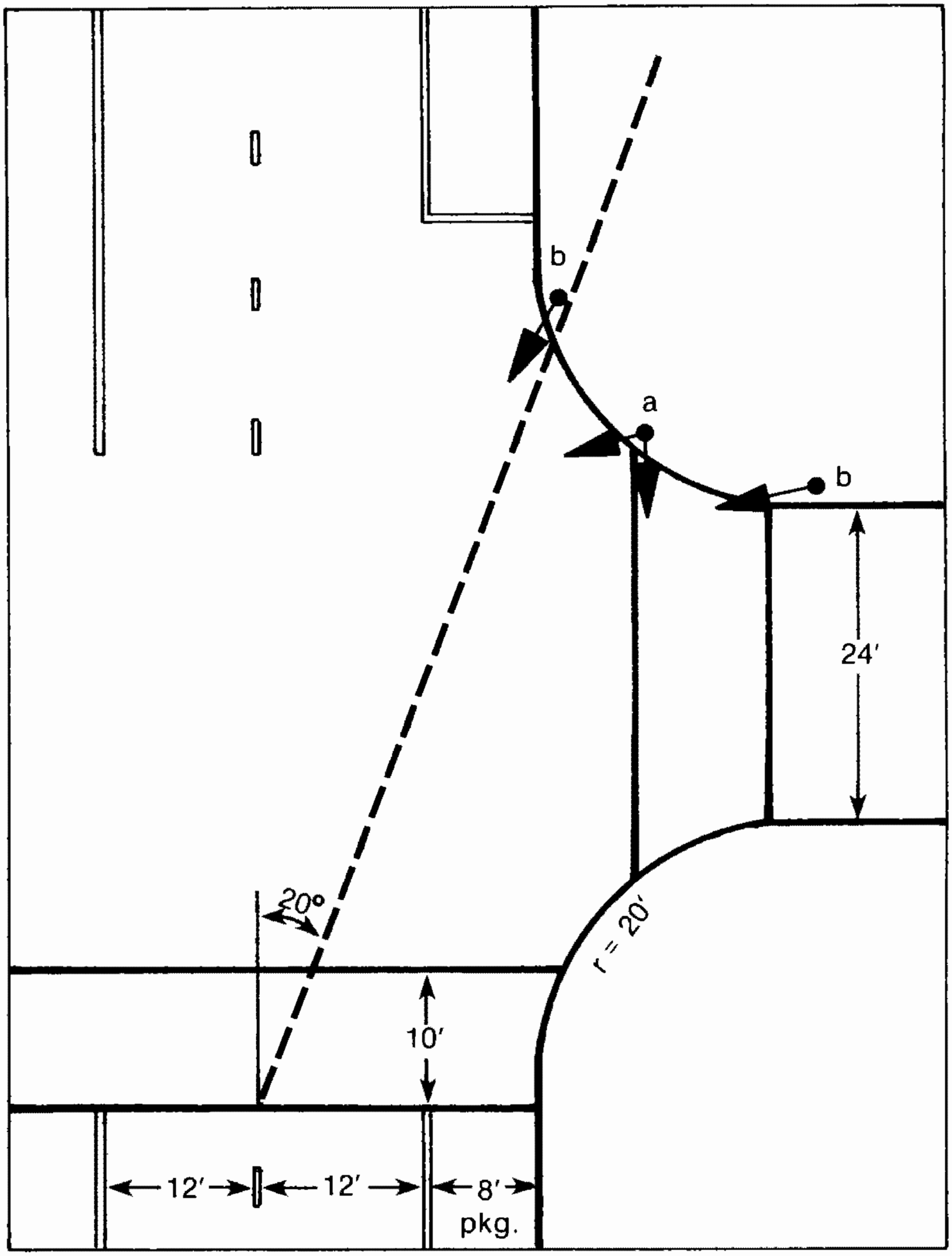


Figure 4-22 "Split" Post-Mounted Signals With Crosswalk Added

- Even where minimum distance requirements can be met, the faces are consistently near the outside limits of the desirable cone of vision. The faces are, therefore, in positions which are less conspicuous than if they were closer to the center of the cone.
- Where a curb return has a radius of over 10 feet, consideration should be given to splitting the faces. This will reduce the distance of the face from the center of the approach and increase its distance from the stop bar.
- Because of the potential conspicuity problem of post-mounted signals as primary indications, each location should be plotted and the cone of vision and minimum distances overlayed on the sketch to insure that minimum distance requirements can be met.
- Moving the stop bar further back from the approach or adding a crosswalk may make the signal fall within the cone of vision and may satisfy minimum distance requirements.
- In view of the potential conspicuity problem, post-mounted signals as primary indications appear applicable, primarily on narrower approaches with relatively low speeds.

Even when post-mounted signals meet the minimum MUTCD requirements for conspicuity, there are other considerations that should be reviewed. For example, in commercial areas, buildings often extend to the property line. This is generally 10 to 20 feet from the curb line, but may be less. The storefronts may contain lighted displays and the buildings are frequently used for mounting multicolor lighted advertising signs. Thus, the signal display may be competing with large advertising signs for the motorists' attention. This may be critical at night. Although the signal may be visible, it may not be sufficiently conspicuous to capture the driver's eye, particularly if it is located at the edge of his cone of vision. Moreover, awnings or building overhangs may encroach into the public right-of-way and may conflict with posts.

Other considerations include:

- In some areas, handicap ramps are installed near the middle of the curb return and special consideration must be given to locating posts.
- The use of 12-inch lenses to increase signal visibility is less applicable to post mounting, especially at lower mounting heights. Glare may become a problem when an 8-foot height is used.
- When multiphase control is needed, it is impractical to locate displays near the lanes being controlled unless medians are available. This generally means that, under like conditions, the post-mounted signal display will be less clear than other types of display.

- Given that 2 feet of clearance should be maintained on each side of a signal, posts should generally not be installed in medians less than 5-feet wide. All posts mounted in the median should have a breakway feature.
- Signals for a protected left-turn phase are mounted on posts in the median or the far left corner. Left-turn signals should not be installed on posts on the far right, or in the median if the left turn is not protected.
- Post-mounted signals located beyond vertical curves may not be high enough to be seen over the crest of the hill. Special consideration must be given to visibility under these circumstances.

Table 4–14 summarizes the major advantages and disadvantages of the post-mounted signals.

Advantages
• Low installation costs
• Easy maintenance, no roadway interference
• Generally considered most aesthetically acceptable
• Generally good locations for pedestrian signals and push buttons
• Provides good visibility where wide medians with left-turn lanes and phasing exist
• Unlimited vertical clearance of roadway
Disadvantages
• Requires underground wiring which may off-set initial cost advantages
• May not provide locations which meet minimum conspicuity
• Generally does not provide good conspicuity
• May not provide mounting locations such that a display with clear meaning is provided
• Height limitations may provide problems where approach is on a vertical curve
• Are subject to vehicular impact if installed close to the roadway, particularly in medians

Table 4-14 Post-mount Signal Summary

Span-Wire Mounting

Span-wire mounting provides a means for installing some or all of the traffic signal faces overhead. In this application, poles are installed at two or more locations at the intersection, a messenger (or support) cable is strung between the poles, and signal heads are installed as required along the messenger. Additional heads, such as pedestrian signal displays may be installed on the poles and pedestrian pushbuttons may also be mounted on the poles. Wiring is run overhead along the messenger cable to the signal heads.

There are a variety of ways to install the poles and messenger cables. The most common are the two-pole simple span, the box span, and the "Z" span.

Two-pole Simple Span: In the two-pole simple span, poles should be installed on the far right corners of the major street approaches as shown on Figure 4–23. Installing the poles on the far right of the major or wider approaches affords the best opportunity for meeting the minimum distance from stop bar requirement.

As with post-mounted signals, it is difficult to meet the minimum distance from stop bar requirements at intersections with narrow streets. However, overall conspicuity is markedly improved since faces may be installed directly in line with the motorists' approach to the intersection. Also, the signals are removed from the influence of conflicting lighted displays or advertising signs.

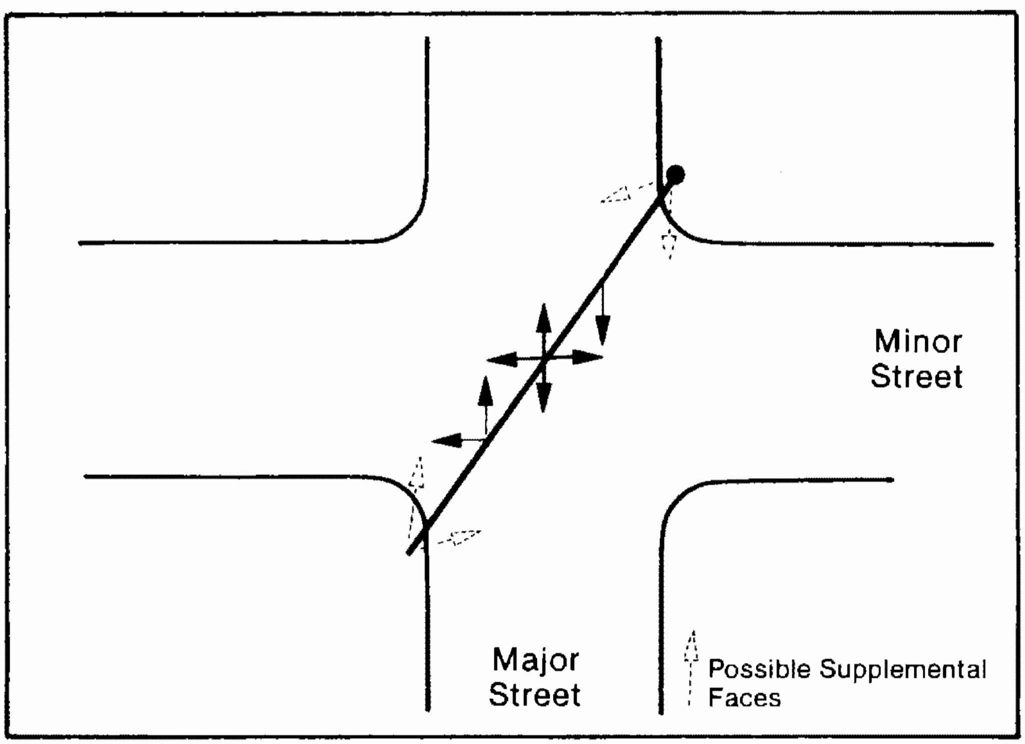


Figure 4-23 Span-Wire Mounting—Two-Pole Simple Span

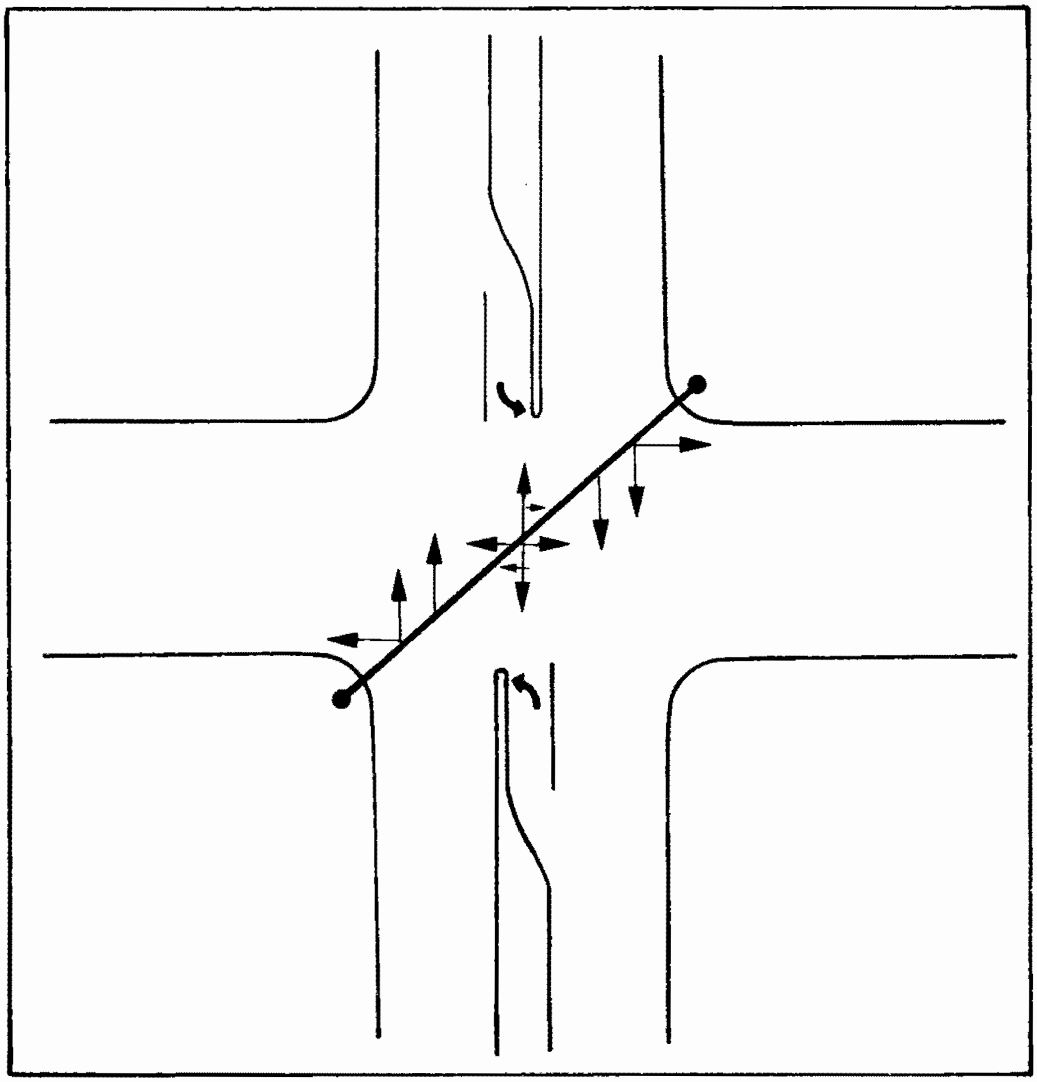


Figure 4-24 Two-Pole Simple Span with Left-Turn Indications

Because it may be difficult to locate faces over 40 feet from a stop bar and since the faces are 15 to 19 feet above the pavement, stopped motorists sitting in their cars may not be able to see the display. In these cases, supplemental heads may be placed on the poles as shown in Figure 4–23. Posts may also be shifted further away from the major street approach to increase the distances as shown.

In some situations, pedestrians may not be able to see all displays from all corners of the intersection. This may be alleviated by placing supplemental heads on the poles. Where pedestrian actuation is needed, supplemental posts to mount the pedestrian pushbutton will be required on the two corners which do not have span-wire poles.

Where multiple phases are needed, span-wire mounting allows the signal faces to be installed in the path of the lane being controlled. Figure 4–24 shows typical placement where a left-turn lane and left-turn phase are provided.

Although centered in the appropriate lane the left-turn display often can be significantly less than 40 feet from the stop bar and is, therefore, very difficult for the motorist to see when in a normal stop position.

Finally, since the span crosses the longest axis on the intersection and carries a minimum of eight heads, pole and cable loading must be carefully considered.

Table 4–15 summarizes the advantages and disadvantages of the simple span. In general, the simple span is the least desirable of span-wire mounting alternatives because of stop bar and pedestrian visibility problems.

Box Span

The box span uses four poles located at the intersection corners with messenger cable stretched between the posts to "box-in" the intersection. Figure 4–25 shows a typical box span layout. Signal faces are placed over the roadway on the far side of each approach.

Advantages
• Low installation costs • Minimum number of poles to clutter sidewalk area • Easy to install, little or no underground work required • May be combined with utility poles • Allows good lateral placement of signals for maximum conspicuity
Disadvantages
• Poorest face locations with respect to stop bar for small intersections • May result in very long spans • All heads are located on one span maximizing loading on cable and posts • Often considered aesthetically objectionable because of head "clutter" • Poor pedestrian visibility of indications • No provision for serving all corners with pedestrian push buttons

Table 4-15 Simple Span Summary

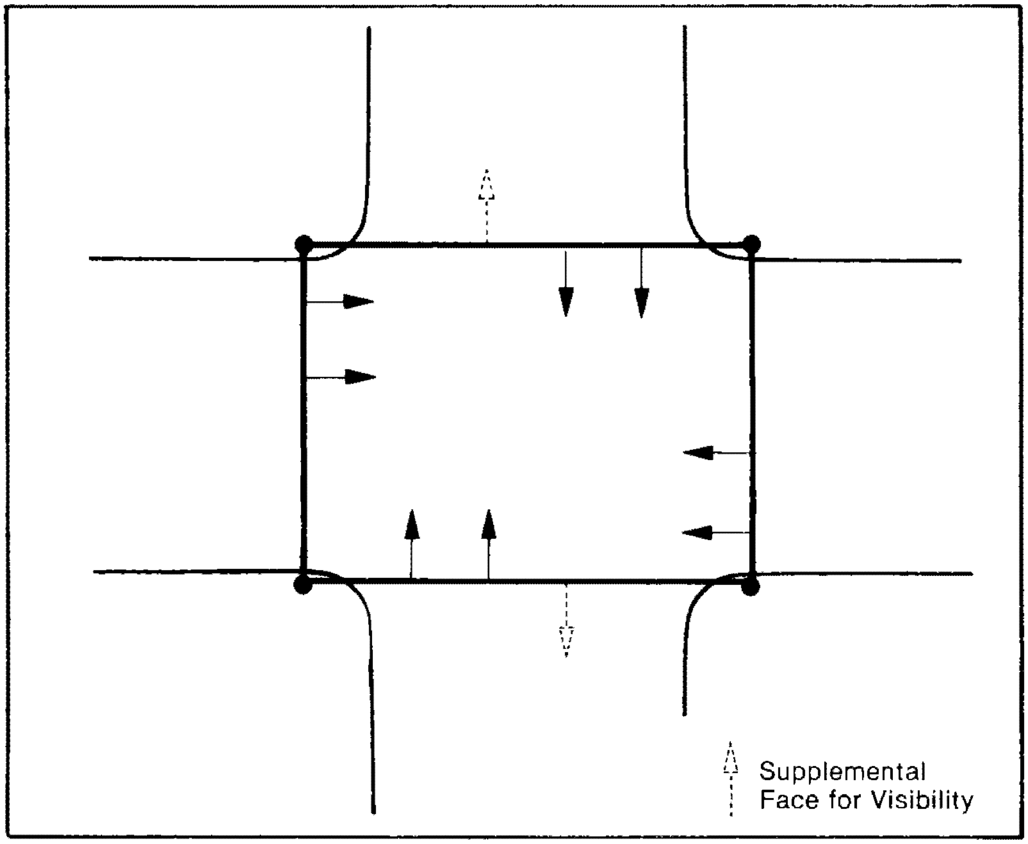


Figure 4-25 Span-Wire Mounting—Box Span

The box span permits the same flexibility in locating the signal heads with respect to approach lanes as does the simple span while overcoming the problems of minimum distance from stop bar requirements. At narrow street locations, posts may be moved away from the major street approach as shown in Figure 4-25.

Because signals are all located on the far side of the intersection, pedestrians can usually see an indication clearly. However, at especially wide intersections this could be a potential problem. In such cases, pedestrian or supplemental signal heads may be required.

At vertical or horizontal curve locations, approach visibility may be a problem. Near side signal faces may be required. Typical locations are shown in Figure 4-25.

A variety of phasing and pedestrian requirements can be accommodated using the box span concept. Figure 4-26 shows a location with left-turn phasing and pedestrian signals.

The box span may have problems when applied to offset intersections or extremely wide intersections. It may be necessary to locate poles such that a variety of angles exist or such that signals are over 120 feet from the stop

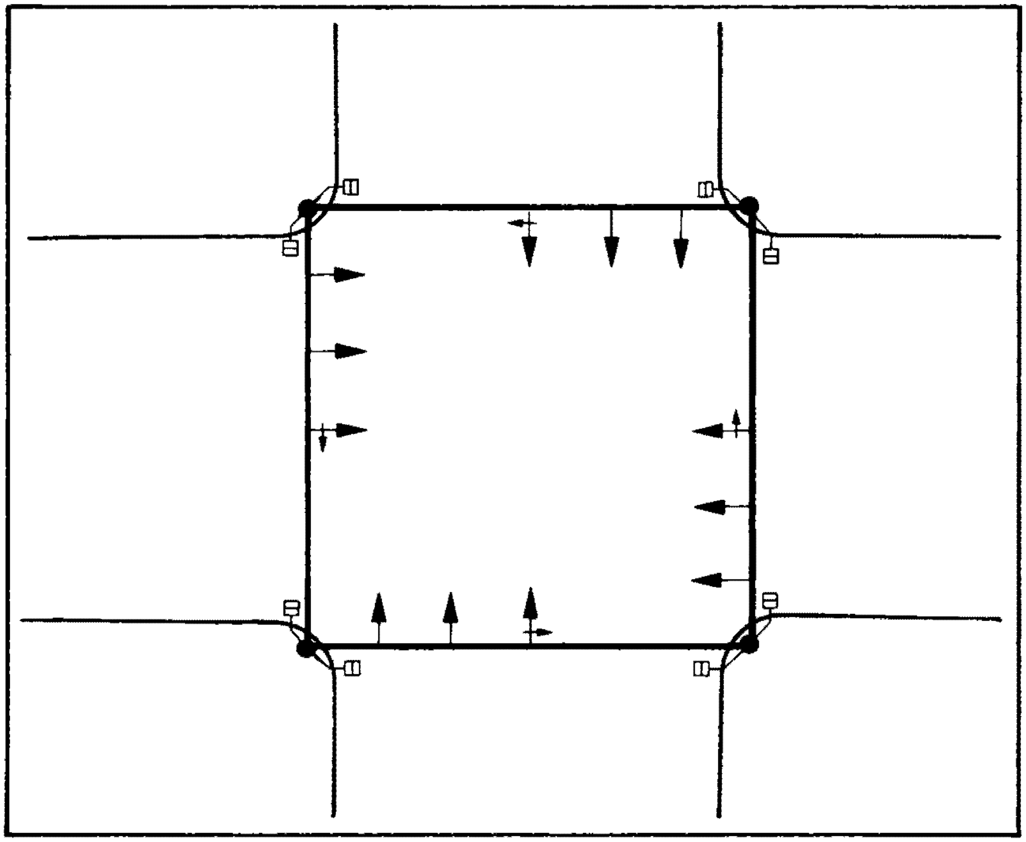


Figure 4-26 Box Span with Left-Turn Indications and Pedestrian Signals

bar. Where these conditions exist, consideration should be given to suspending a messenger cable "box" using connector cables to the posts. This balances post loadings and permits signal faces to be moved toward the approaches. Figure 4-27 shows a typical application of this modified box span concept.

It is generally accepted that the box span is the best approach to signal mounting using span-wire. Typical advantages and disadvantages of the box-span signal mounting technique are summarized in Table 4-16.

"Z" Span

A "Z" span is a special application of a four pole span-wire mounting system. It can be applied at locations with very wide medians and wide approaches where the signals for the minor street would be too far from the stop bar. It is also applicable where the length of span across the major roadway becomes excessive or at certain offset intersections. Except for special applications, the "Z" span is generally considered less desirable than the box-span because of the need for large poles installed in the median and the pedestrian visibility problems.

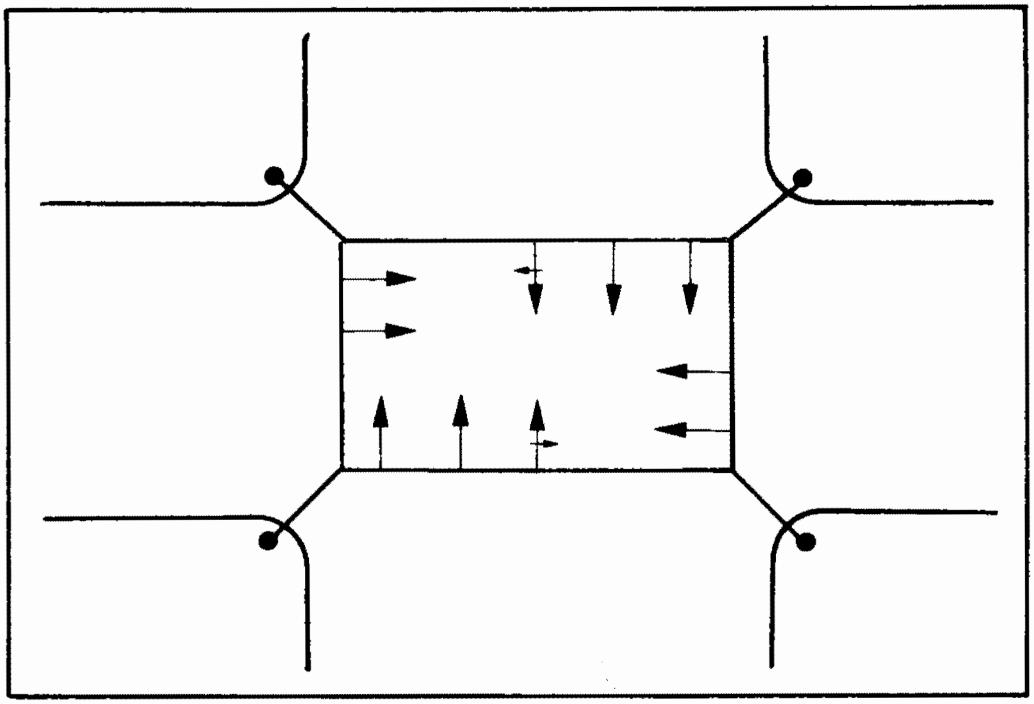


Figure 4-27 Span-Wire Mounting—Cable Box

Mast-Arm Mounting

Mast-arm mounting provides a means of installing some or all of the signal faces, overhead, without messenger cables, and without overhead signal wiring. Mast-arm mounting can also be easily used with post-mounted signals to meet all general visibility and clarity requirements.

There are two distinct types of simple mast-arm installations. They are shown on Figures 4–28 and 4–29. In the first, the primary face is placed overhead and can be located to provide maximum conspicuity. The second head is mounted at a lower height on the pole itself and is easily seen from a stop bar position. The other type places both faces overhead in a primary sight line. Either type meets the MUTCD requirements.

The basic visual characteristics of mast-arm mountings are similar to those of a box span. Under most circumstances, equivalent visual displays can be achieved. The signal displays are generally visible to pedestrians, as with the box span, and poles are available on all corners if needed for pedestrian or supplemental signal heads.

As intersection approach widths increase, and as mast arms are lengthened to reach the desired point in the approach, costs increase quite dramatically. A mast arm is a simple cantilever structure and loadings or the mast arm (both static and dynamic) substantially increase structural requirements. Although mast arm lengths of 30 to 45 feet are not uncommon, designers must seriously consider cost implications at these lengths. In addition, mast-arm mounting, as with post-mounting, assumes underground wiring.

Advantages

- Easy to install, little or no underground work required
- Allows excellent lateral placement of signal faces for maximum conspicuity
- Allows good signal placement with respect to stop bar
- Span length and loadings substantially from simple two post span
- Provides convenient post locations for supplemental signal faces and pedestrian faces and pushbuttons
- Permits "internal boxes" to reduce distances from stop bar at extremely wide intersections
- Generally perceived as more aesthetically pleasing than simple plan

Disadvantages

- Requires four posts and is more expensive than simple span
- Adds to intersection clutter by adding the two posts
- As with all span-wire mountings, seen by some users as unpleasing aesthetically

Table 4-16 Box span Summary

Efforts to reduce mast arm lengths by installing poles in medians have the same concerns as with the use of the "Z span". That is, major structures are placed in areas where they offer a potential hazard to vehicular traffic.

The primary mast-arm display should be oriented toward the far-right signal location. This may require the signal pole to be moved near the far end of the curb return. This location may be too far from the minor street crosswalk to be usable for pedestrian signals or pushbuttons. The pole may also be well outside the cone of vision for a supplemental far left indication. Therefore, post-mounted signals are often used to complement the mast-arm signals.

It is common for mast-arm signals to be rigidly mounted. Overall wind loading on the pole will be greater than with free swinging signals.

In general, the mast-arm mounted signals can be used to provide as high a level of clarity and conspicuity as any other form of display. Table 4-17 lists typical advantages and disadvantages of mast-arm mounted signals.

Advantages

- Allows excellent lateral placement and placement relative to stop bar for maximum conspicuity
- May provide post locations for supplementary signals or pedestrian faces and pushbuttons
- Generally accepted as the most aesthetically pleasing method for installing overhead signals, particularly in developed areas
- Rigid mountings provide the most positive control of signal movement in wind

Disadvantages

- Costs are generally the highest
- On very wide approaches it may be difficult to properly place signal faces

Table 4-17 Mast-Arm Summary

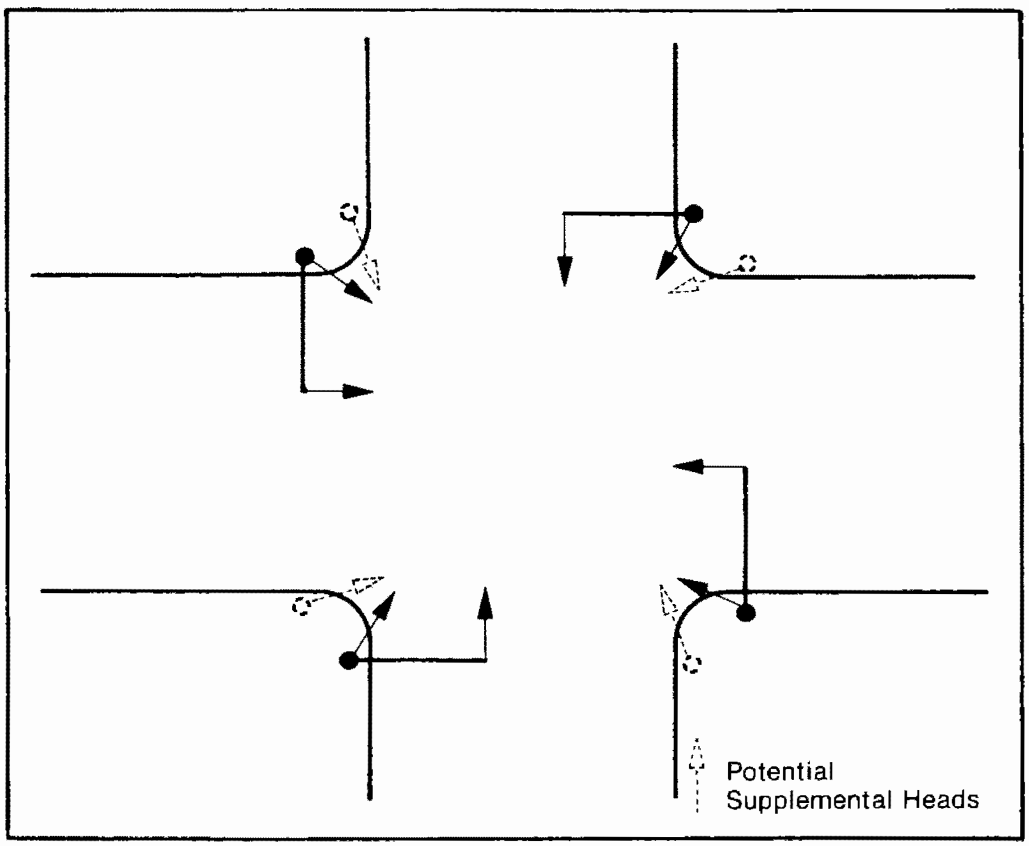


Figure 4-28 Mast-Arm Mounting

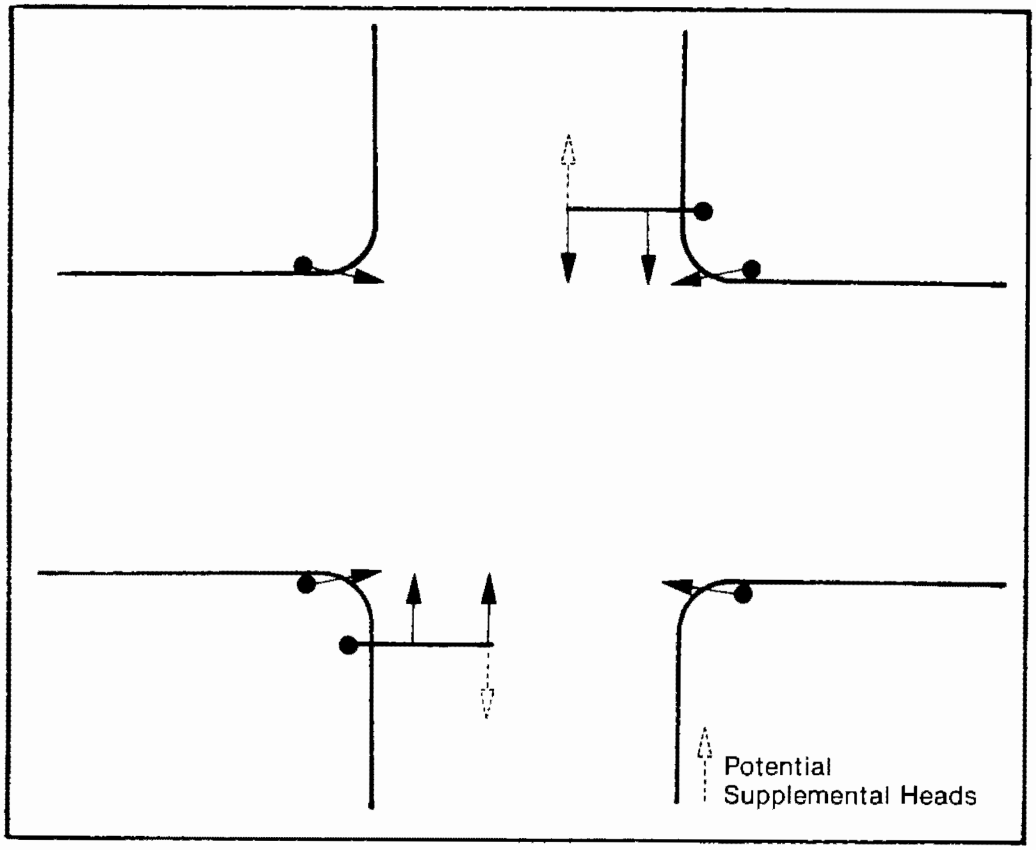


Figure 4-29 Mast-Arm Mounting

4E-3 Additional Implementation Considerations

There are a number of design-related issues which must be considered in addition to the general arrangement and mounting elements. Some of these additional implementation considerations are briefly reviewed in this section.

Rigid Mounting versus Free Swinging

The two common methods for mounting signal faces on span wires and mast arms are rigid and free swinging. In a rigid mounting, the head is held in a fixed position throughout Its length. In a free swinging mounting, the head is attached at the top and allowed to swing freely when buffeted by the wind. Sideways and twisting movements associated with the free swing head can be minimized by using special mounting hardware.

Free-swinging installations are usually associated with span wire mountings and rigid mounting with mast arms. However, both mounting techniques can be used with span wire or mast arms (with the exception of trombone arms where rigid mounting is the norm).

It is generally agreed that a signal face in a fixed position is best for providing clear signal indications. A fixed position is essential with visibility-limited signal heads. The major advantage of the free-swinging heads is to reduce the wind loading on the support poles, arms, or messenger cables, particularly in areas where extremely high velocity winds may be expected. Free-swinging heads are also an advantage at simple span locations; because of the long spans and large number of faces supported by two posts and a single cable.

As design practices move away from simple spans, and with the availability of adequate support poles, mast arms, and cables, the use of rigid mounting has become more practical and is preferred by some traffic engineers. On mast arms, rigid mountings can be provided by standard hardware which clamps the signal directly to the mast arm. For span-wire mounting, a second cable called a tether cable, is required. This may be installed below the signal face as shown on Figure 4–30. It may also be installed above the signal head and connected to pipe extenders to keep the signal faces level regardless of sag as shown on Figure 4–31.

Roadside Safety Considerations

To this point, implementation considerations have concentrated on conspicuity and clarity. It is also important to consider roadside safety. The main element of concern is pole placement. The natural desire to minimize span-wire or mast-arm length and to place poles as close to the roadway as practical is often at odds with important safety considerations.

Poles should be located as far away from the roadway as possible, especially in areas with high speed traffic, no space for parking lanes, or on the outside line of a curve or with heavy turning movements. This may provide an additional 10 feet or so of clear area. The pole may also be shifted toward, or away from, the cross street (within the minimum-maximum distance to stop bar constraints). Often a shift of 20 to 40 feet may greatly reduce the probability of the pole being hit. The pole could also be shifted around the curb return toward the minor street. That is especially applicable where span-wire mountings are used.

As noted in Section 4D–3, poles can often be placed behind existing traffic barriers. This will shield motorists from nonyielding poles, posts, etc. Sometimes existing roadside barriers can be extended to accomplish the same result. Signal poles and posts should never be located in front of a barrier unless they are yielding and an engineering analysis indicates that both the yielding pole or post and the roadside barrier will function as designed.

Pole placement should also consider bus stop locations, especially at near side stops where the door openings are near the stop bar and possible pole locations. A pole 2.5 feet away from the curb and opposite a point where a bus door might be opened is extremely hazardous. Passengers

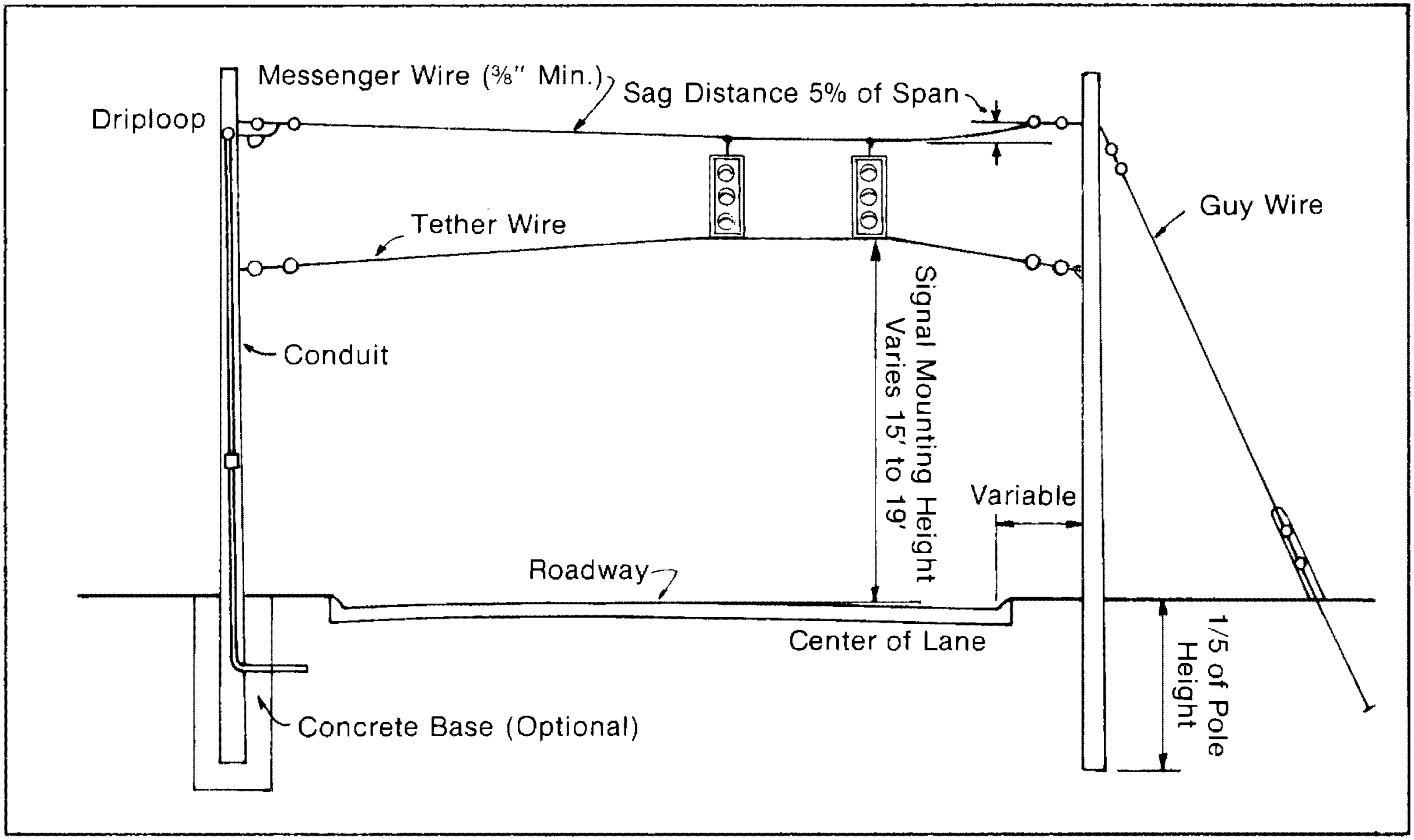


Figure 4-30 Tether Wire Below Signal Face

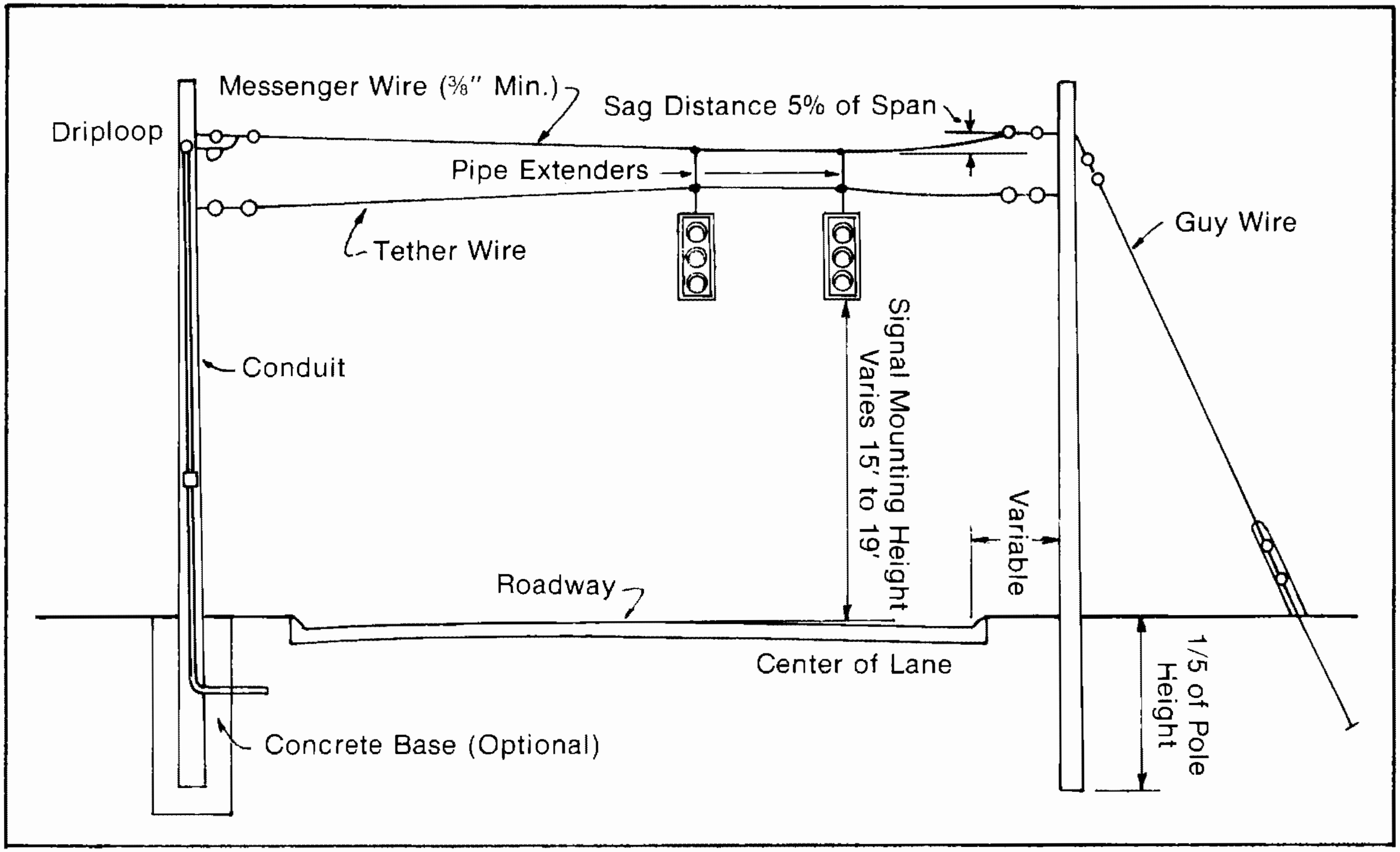


Figure 4-31 Tether Wire Above Signal Face

stepping off the bus do not expect an immediate obstacle and could walk head-on into the pole.

Above and below ground utilities must also be specifically considered in pole placement. Proximity to power lines, gas lines, etc., will require special implementation and maintenance considerations.

Pole supports for overhead signal installations should not be placed in the medians unless the median is very wide. Median pedestal supports should be breakaway. The height of the signal head should be such that it will not hit the windshield of a vehicle impacting the pedestal.

Controller cabinets should also be placed such that they are not a hazard or likely to be damaged. On curves, this would indicate a location on the inside portion of the curve. Where there are heavy turning movements, cabinets should be located on an opposite side of the "inside" corner of the heavy turning movement. Cabinets should also be placed such that parking of repair trucks is facilitated. This would normally indicate a location toward the minor street.

4F. TRAFFIC SIGNAL TIMING

This section describes various techniques and procedures that may be used to establish signal timing settings that will produce efficient traffic flow through signalized intersections. There are two basic forms of signal timing: pretimed control and traffic-actuated control.

With *pretimed control*, a consistent and regularly repeated sequence of signal indications is given to traffic. The duration of each interval of the sequence is also consistent. Pretimed control is best suited to intersections where traffic patterns are relatively stable or where the traffic variations that do occur are predictable and can be accommodated by a preestablished schedule. Pretimed control is especially adaptable to coordination with nearby signals.

Traffic-actuated control differs in that signal indications are not of fixed length and the length of cycle and sequence of intervals may or may not remain the same from cycle to cycle, depending on the particular type of controller equipment. In some cases, certain intervals may be omitted when there is no demand for those intervals.

Actuated control is especially efficient at isolated locations where nearby signalized intersections are not a consideration. Actuated control can also be used within a signal system at intersections characterized by wide and irregular fluctuation of traffic volumes.

The hardware and functional characteristics of pretimed and actuated controllers are described in Section 4D-1. A discussion of the operational aspects of pretimed versus actuated control is given in Section 4C-2. The following sections focus on the fundamental timing parameters related to pretimed and actuated control for coordinated and isolated intersections.

The techniques to develop signal timing described in this section emphasize the practical experiences of practicing traffic engineers. Some analytical techniques are included and reasonable ranges for various parameters are suggested. Signal timing fundamentals for pretimed controllers are presented followed by a discussion of how these fundamentals are applied in an isolated intersection environment. Timing for actuated controllers is then addressed. The following section (4G) describes how individual intersections may be combined into systems. It also includes timing of such systems.

4F-1 Timing Pretimed Controllers

There are several fundamental principles related to timing pretimed traffic signal controllers. Essentially, the fundamental principles include:

- Number of plans required,
- Phase change intervals,
- Pedestrian timing requirements,
- Cycle length calculations, and
- Split calculations.

Number of Plans Required

A signal timing plan consists of a unique combination of cycle length, split, and (for system operation) offset. For pretimed control equipment, the cycle length is the amount of time required to service each interval, in sequence, one time. Typical values of cycle length range from 40 seconds to 120 seconds.

Conventional three-dial, pretimed controllers are generally used to provide up to three timing plans, one with each dial. Microprocessor-based, pretimed control hardware is capable of at least four cycles and three splits.

The number of timing plans required for efficient intersection operation is primarily a function of traffic patterns and signal spacing characteristics. To a degree, it is also a function of the type of control equipment. By way of example, consider a two-phase intersection that is heavily loaded on the A-phase during the morning peak, heavily loaded on B-phase during the evening peak, and lightly loaded on both phases during the remainder of the day. In this case, there is a clear need for three distinct timing plans.

Although it is unwise to generalize about virtually any aspect of signalized traffic control, there are some attributes of traffic flow patterns that may be considered typical of many locations. Frequently observed patterns include:

- AM peak period demand,
- Average daily demand,
- PM peak period demand,
- Nighttime (low flow) demand,
- Weekend demand, and
- Special function demand.

One suggested technique used to determine the need for timing plans is based on directional traffic demand fluctuations throughout a typical day. Two indices of traffic pattern changes may be employed: total intersection demand (TD); and cross demand (CD). The data required to compute these indices include approach geometrics and volume counts. The approach geometrics are simply the number of approach lanes (exclusive of turning lanes) in the immediate vicinity of the intersection. The volume counts may be 15-minute counts, hourly counts, or a count spanning any convenient time measure. The directional lane demand is the approach count divided by the number of lanes on that approach.

This technique is admittedly coarse and is not intended for use in developing signal timing parameters, but rather it may be used simply to identify the need for individual signal timing plans.

Once the directional demand (normalized to lane-demand) is known, the indices can be computed as follows:

Equation 4-1 $$TD = (N, S)_{max} + (E, W)_{max}$$

where:

TD = Total intersection demand

$(N, S)_{max}$ = maximum of either northbound or southbound demand

$(E, W)_{max}$ = Maximum of either eastbound or westbound demand

Equation 4-2 $$CD = (N, S)_{max}/TD$$

where:

CD = Cross directional demand

$(N, S)_{max}$ = Maximum of either northbound or southbound demand, and

TD = Total intersection demand.

$$CD = \frac{(N,S)\ max}{TD}$$

The total intersection demand (TD) provides an indication of the intersection loading. In general, lightly loaded intersections can function with shorter cycle lengths than heavily loaded intersections. Thus, the TD provides an indication of the need for different cycle lengths at a particular intersection. While a certain minimum cycle length is required to service a given traffic demand at a given intersection, cycle length in a coordinated system is usually dictated by the cycle length that will provide the most overall favorable traffic performance. Where a timing plan is constructed, such as by graphical time-space diagrams, it will be a function of typical speeds and of signal spacing. Where a computer program is used, the cycle length may be either an output of the program or the program may be used to determine the cycle length that provides the most favorable traffic performance for the given system. In any case, system needs usually dictate the cycle length used at a particular intersection within a coordinated system.

The cross demand (CD) provides an indication of the need for split changes between the time allocated for north-south movements and the time allocated for east-west movements.

The values of the indices can be used to determine when significant changes occur, changes that could indicate the need for a different timing plan. The magnitude of change in either index must be evaluated based on engineering judgement. Decisions may differ depending on the relative variability of the index over time.

In summary, it may be anticipated that at least two timing plans will be needed, one for peak conditions and one for off-peak conditions. At many intersections three or more timing plans will be needed. An analysis of the demand versus time may be performed to determine whether additional plans are needed and the time of day that each plan would be in effect.

Phase Change Intervals

Phase change intervals consist of a yellow vehicle change interval following each CIRCULAR GREEN or GREEN ARROW interval. The yellow vehicle change interval may be followed by a short all-way red clearance interval. According to the MUTCD, the yellow vehicle change intervals should have a range of 3 to 6 seconds. Since excessively long yellow intervals may encourage driver disrespect, a maximum of about 5 seconds is usually used for the yellow interval if a long yellow interval is required. If a longer phase change interval is needed then the additional time is provided by an all-red interval.

The MUTCD defines the yellow indication as follows:

"Traffic, except pedestrians, facing a steady CIRCULAR YELLOW or YELLOW ARROW signal is thereby warned that the related green movement is being terminated or that a red indication will be exhibited immediately thereafter when vehicular traffic shall not enter the intersection."

Some authorities believe that the timing of a phase change interval should enable a vehicle to clear the intersection before the onset of the green for conflicting movements. The following equation may be used to determine the phase change interval. It includes a reaction time, deceleration element, and an intersection clearing time.

Equation 4–3

$$CP = t + 2a + \frac{V}{64.4g} + \frac{W + L}{V}$$

where:

CP = nondilemma change period (yellow plus all red), seconds

t = perception-reaction time, nominally 1 second

V = approach speed, fps

g = percent grade (positive for upgrade, negative for downgrade)

a = deceleration rate, fps^2

W = width of intersection, feet

L = L ± length of vehicle, feet (normally 20 feet)

The policy of some jurisdictions is to time the phase change interval to allow the outset of the green interval for conflicting movements without the intersection having been cleared. In such cases, the following equation may be used:

Equation 4-4

$$CP = t + \frac{V}{2a \pm 64.4g}$$

In still other jurisdictions the policy is to allow the onset of the green interval for conflicting movements after vehicles have partially cleared the intersection (i.e., the rear of the vehicle has cleared the centerline of the conflicting approach). In such cases, the width in the last term of equation 4-3 should be changed accordingly.

As indicated, a perception-reaction time of 1 second is normally assumed. The 1976 edition of the Transportation and Traffic Engineering Handbook recommended a deceleration rate of 15 feet per second per second. However, the trend has been to use a lower rate. The current edition recommends a value of 10 feet per second.

Because the total change period may consist of both a yellow change and an all-red clearance interval, it is suggested that the yellow change interval be equal to the first two terms of the equation rounded up to the next ½ second, but no less than 3 seconds and no greater than 5 seconds. The remainder of the change period should consist of an all-red interval.

A spot-speed study on an approach to an intersection will produce a range (or distribution) of speeds. Typically, the 85th percentile speed or the prevailing speed limit have been used to determine the yellow change interval. It is important, however, to also consider slower traffic going through the intersection at the 15th percentile speed. Low speeds and wide intersections are a combination that may require a longer clearance time (yellow plus all-red). It may be necessary, therefore, to calculate the equation using both the 85th and 15th percentile speeds and to employ the longer of the two calculations.

Using these equations for approaches with steep downgrades yields such long interval timings that they appear unreasonable to drivers as well as many traffic engineers. The remedy is not to ignore the physics of the situation when an unusually long phase change interval results from a steep grade or high approach speeds. The remedy may be to reduce the interval by lowering the speed limit, or by lowering the approach speeds with warning signs or other such measures. One other option is to apply the concepts discussed under Section 4C-3 of this Handbook.

Pedestrian Timing

At a signalized intersection, pedestrian crossings may be accommodated in one of several ways:

- Concurrent pedestrian movement where pedestrians cross the street during the parallel vehicular green indication (there is no separate pedestrian signal display),

- Concurrent pedestrian movement where pedestrains are controlled by a separate pedestrian signal display, and

- Exclusive pedestrian phase where all vehicular traffic is stopped and pedestrians are allowed to cross the intersection in any direction including diagonally.

Regardless of the phasing or display selected, sufficient time should be provided to allow the pedestrian to enter the intersection (walk interval) and to safely cross the street (pedestrian clearance interval).

When pedestrians cross the street concurrently with traffic on the parallel street and there are no pedestrian displays, the minimum time allocated to traffic should not be less than the time required for pedestrians to react to the signal and cross the street following the procedures set forth below for pedestrian indications.

When pedestrian indications are used, Section 4D-7 of the MUTCD suggests that: ". . . under normal conditions the WALK interval should be at least 4 to 7 seconds . . . . ." Recent research indicates that a WALK interval of 4 seconds is adequate when fewer than 10 pedestrians per cycle are expected.

The MUTCD requires that pedestrian clearance intervals should always be provided where pedestrian indications are used. This interval consists of a flashing DON'T WALK indication. It should be of sufficient duration to allow a pedestrian to leave the curb and travel to the center of the farthest travel lane before the opposing vehicles receive a green indication.

Some jurisdictions terminate the flashing DON'T WALK to a steady DON'T WALK at the onset of the yellow vehicular clearance display to encourage any pedestrians still in the street to hurry up and vacate the crosswalk. This may be especially useful along one-way streets when pedestrians are not facing vehicle signal displays. The yellow change interval is included in the calculation of the pedestrian clearance time (i.e., the pedestrian clearance time is equal to the flashing DON'T WALK plus the yellow change interval).

The time required for the pedestrian clearance interval is a function of pedestrian volume, pedestrian walking speed, and the width of the intersection.

Pedestrian volume affects walking speed. Studies have shown that platoons or groups of pedestrians tend to walk at a slower rate than individual pedestrians. In addition, walking speeds of the very young, the elderly, and the handicapped are significantly slower than the "normal" pedestrian population. Also, female pedestrians, as a group, have a slower walking speed than male pedestrians.

The MUTCD cites an assumed normal walking speed of 4 feet per second. However, research verifies that one-third of all pedestrians cross streets at a rate slower than 4 fps and 15 percent walk at or below 3.5 fps. Those having slower walking speeds have the moral and legal right to complete their crossing once they have lawfully entered the crossing. Vehicular traffic is to yield the right-of-way to pedestrians lawfully within the intersection.

This suggests that the timing of pedestrian signal indications near facilities that serve segments of the population with slower walking speeds should be calculated based on a slower walking speed. Such populations should be anticipated near shopping centers, convalescent or rest homes, therapy centers, etc.

Some traffic engineers tend to resist using the slower walking rate because it may result in less favorable signal splits and longer cycle lengths resulting in longer vehicular delays. Engineering studies and judgment should be exercised for each problem intersection to obtain the optimum balance between pedestrian and vehicular traffic.

Table 4–18 presents typical minimum pedestrian clearance intervals as a function of street width, for walking speeds of 3.5 fps and 4.0 fps.

Traffic Control Signal Cycle Length Calculations

The cycle length is the total time in seconds required to complete a prescribed sequence of phases. The following is one method for calculating cycle lengths for a pretimed isolated intersection.

For each phase, the yellow change interval and any all-red clearance interval are determined as described earlier. In addition, for each phase that includes pedestrian movements, appropriate pedestrian clearance times are calculated.

Next, minimum green times for each phase are then computed. The minimum green time is equal to the pedestrian clearance time minus the yellow (and any all-red) period plus an initial interval when pedestrians may start to cross. For any major through movement, the minimum green should not be less than 15 seconds. The initial interval for pedestrians, as discussed earlier, may be as low as 4 seconds when less than 10 pedestrians

Street Width, feet	Minimum Clearance Intervals*		
	@ 3.5 fps	@ 4.0 fps	Difference, seconds
30	7.1	6.3	0.8
40	10.0	8.8	1.2
50	12.9	11.3	1.6
60	15.7	13.8	1.9
70	18.6	16.3	2.3
80	21.4	18.8	2.6

* Based on street width minus 5 feet for distance to center of farthest lane (assuming no parking)

Table 4-18 Minimum Pedestrian Clearance Intervals

per cycle are anticipated. For moderate pedestrian volumes (say, 10 to 20), 7 seconds is frequently used. Longer intervals may be necessary for heavier pedestrian volumes.

For phases without pedestrian movements, the minimum green time should be estimated by dividing the critical lane volume by 60 and multiplying the results by 2.5. This estimate is based on a 60-second cycle and an average headway of 2.5 seconds.

The next step is to select the critical minimum green. This is usually the longest minimum green with the smallest critical lane volume. Typically, this is the side street green internal since the associated pedestrian movement is crossing a usually wider major street while the side street critical lane volume is generally lower. If there is any doubt as to which is the critical value, the calculation described below should be repeated for the other phases.

Using the critical value selected above, other green phase times are computed in proportion to the approach volumes in the critical lane on each phase during the heaviest hour. Computed green times must be greater than or equal to the minimum green times determined above. Once again, if the computed green is less than the minimum green, the process must be repeated using this minimum green as the critical value.

The cycle length is the sum of the computed green times, yellow times, and all-red times. The cycle length is normally adjusted upward to the next 5 second interval. Any extra green time is distributed among the phases. An example of this timing process for an isolated intersection is given in the top portion of Figure 4-32.

A capacity check should be made of each green time to insure that the critical lane volumes will be serviced. A simple capacity check consists of the following. First, the number of critical lane vehicles per cycle is computed by dividing the hourly volume by the number of cycles per hour.

This value is increased by 10 percent (multiplied by 1.1) to account for fluctuations at near capacity conditions. The resultant value is multiplied by 2.1 seconds (average headway) and added to 3.7 seconds (the time required to start the queue). If this sum is less than the computed green time for that phase, the capacity criteria is met. Otherwise, the cycle length must be increased and the added green time given to those phases requiring additional capacity.

The final step in establishing the signal timing plan is to compute the seconds and percentage values to be used in implementing the timing on the controller in the field. Because one phase (e.g., main street green) may include more than one interval, it is desirable to prepare a chart similar to that shown in the bottom portion of Figure 4–32. In the example shown, eight intervals are used. The various aspects being displayed during each interval are identified. The percent of cycle for each individual interval is calculated. Key settings are then determined using integer percentage values which are required by most types of pretimed controllers which have timing dials. These key settings normally start with zero at the beginning of main street green and are shown on far right column in the example shown.

4F–2 Timing Actuated Controllers

The actuated controller is normally used for isolated (independent) operations, although they are being incorporated into modern computerized systems. The principles involved in determining phase change intervals and pedestrian intervals described earlier for pretimed controller also apply to actuated controllers. Cycle length varies from cycle to cycle and split depends upon relative demand in the various phases. It should be stressed that the effectiveness of the actuated controller is dependent on the operational dependability of the detectors.

Three types of actuated controllers were described earlier in Section 4D—Semi-Actuated, Full-Actuated, and Volume Density. Within these three types, there are three types of phases—nonactuated (used in semi-actuated), actuated, and density. Timing of each type is discussed below.

Nonactuated Phase

The nonactuated phase of a semi-actuated controller guarantees a minimum green time on the major street each time the right-of-way returns to that phase. The green will remain on the major street until there is a vehicular or pedestrian call from the other phase(s). It will then "YIELD" to the other phases. The signal will then go through a phase change interval and transfer right-of-way to the calling phase.

Time an isolated signal with pedestrian indications at the intersection of Pine and Oak: Pine is 56 ft wide, Oak is 40 ft wide. During the peak hour, the critical lane volumes are 300 and 225 veh/h and approach speeds 40 and 25 mph (58.67 and 36.67 ft/sec) for Pine and Oak respectively.

a. Standard yellow change intervals.

Pine: 4 sec. Oak: 3 sec.

b. Calculate nondilemma clearance times.

$$\text{Pine: } 1 + \frac{58.67}{20} + \frac{40 + 20}{58.67} = 4.91 \text{ sec., or } 5 \text{ sec.}$$

$$\text{Oak: } 1 + \frac{36.67}{20} + \frac{56 + 20}{36.67} = 4.96 \text{ sec., or } 5 \text{ sec.}$$

Calculate all-red clearance intervals.

After Pine yellow: $5 - 4 = 1$ sec. After Oak yellow: $5 - 3 = 2$ secs.

c. Pedestrian clearance times.

Pine (crossing Oak): $\frac{40}{4} = 10$ sec. Oak (crossing Pine): $\frac{56}{4} = 14$ sec.

FDW (Pine) $= 10 - 4 = 6$ sec. FDW (Oak) $= 14 - 3 = 11$ sec.

d. Minimum green times (ped. clearance - yellow + Walk minimum).

Pine: $10 - 4 + 7 = 13$ secs. Use 15 secs. minimum. Oak: $14 - 3 + 7 = 18$ secs.*

e. Compute green times (using Oak as critical minimum).

$\frac{300}{225}(18) = 24$sec. (Pine Street green)

f. Adjust cycle length and redistribute extra green time.

Total cycle $= 24 + 5 + 18 + 5 = 52$ sec. Use 55 sec.
Extra green time $= 55 - 52 = 3$ secs. Give 2 sec. to Pine and 1 sec. to Oak.

g. Compute percentage values for all intervals for key settings:

<table>
<tr><th rowspan="2">Interval</th><th colspan="2">Pine Street</th><th colspan="2">Oak Street</th><th rowspan="2">Int. Length</th><th rowspan="2">Key Setting</th></tr>
<tr><th>Veh.</th><th>Ped.</th><th>Veh.</th><th>Ped.</th></tr>
<tr><td>1</td><td rowspan="2">G-26</td><td>W-20</td><td rowspan="4">R-31</td><td rowspan="4">DW-31</td><td>36.4</td><td>→0</td></tr>
<tr><td>2</td><td>FDW-6</td><td>10.9</td><td>→36</td></tr>
<tr><td>3</td><td>Y-4</td><td rowspan="6">DW-29</td><td>7.3</td><td>→47</td></tr>
<tr><td>4†</td><td rowspan="5">R-25</td><td>1.8</td><td>→54</td></tr>
<tr><td>5</td><td rowspan="2">G-19</td><td>W-8</td><td>14.5</td><td>→56</td></tr>
<tr><td>6</td><td>FDW-11</td><td>20.0</td><td>→71</td></tr>
<tr><td>7</td><td>Y-3</td><td rowspan="2">DW-5</td><td>5.5</td><td>→91</td></tr>
<tr><td>8†</td><td>R-2</td><td>3.6</td><td>→96</td></tr>
</table>

G-Green Y-Yellow R-Red W-Walk
DW-Steady Don't Walk FDW-Flashing Don't Walk

† All-red interval.

* Critical value, because it is greater than value for Pine, despite the fact that Oak has the lower critical lane volume.

Figure 4-32 Cycle Length Determination

Actuated Phase

An actuated phase normally has three timing parameters in addition to yellow change and all-red clearance intervals. These are the initial interval, the vehicle interval (sometimes called the extension interval or unit), and the maximum interval. The timing of these intervals depends on the detector configuration at the intersection.

The *initial interval* was established to allow vehicles stopped between the detector and the intersection to get started and move into the intersection. Originally, most detectors were "point" detectors (e.g., treadless in the roadway). Therefore, timing of this interval depends upon the location of the detector and the number of vehicles that can be stored between the detector and the stop line. The initial interval duration is equal to the minimum green to allow vehicles stopped between the detector and the intersection to get started and move into the intersection, minus the vehicle interval duration. Assuming an average distance headway between stopped cars of 20 feet and the average times for vehicles entering the intersection from a queue, the data in Table 4–19 were developed. This timing procedure should be used for "point" detectors only. (Note: A 6-foot square loop detector is essentially a "point" detector.)

Distance between Stop Line and Detector, Feet	*Initial Interval, Seconds*
0 to 40	8
41 to 60	10
61 to 80	12
81 to 100	14
101 to 120	16

Table 4-19 Initial Time as a Function of Distance

The increased use of long loop detectors (or a series of small loops) to provide area and presence detection require a different timing procedure. If the detector ends at the stop line, the initial interval should be set as near zero as possible. Some controllers permit zero settings while others require a minimum time setting. If the detector ends before the stop line, the remaining distance is used in the procedure described above for point detectors.

The *vehicle interval* must be long enough for a vehicle to travel from the detector to the intersection. This is particularly important where point detectors are used and are relatively far from the stop line. The second function of the vehicle interval is to define the maximum gap that can occur without losing the green signal. As long as detections come at shorter intervals than the vehicle interval, the green will be retained on that phase (subject to the maximum interval described later). A third factor to be considered in establishing vehicle interval is the number of lanes being detected. Because all individual detectors on one phase are usually connected together, the controller receives a distorted representation of the actual gaps. There appears to be more shorter gaps than actually occur.

To maximize efficiency, the vehicle gap should be as short as practicable. The green signal should be retained only as long as real demand exists, and stragglers should not be able to keep the green. This "snappy" operation increases capacity and tends to reduce delay by not "wasting" green time to inefficiently serve a few vehicles.

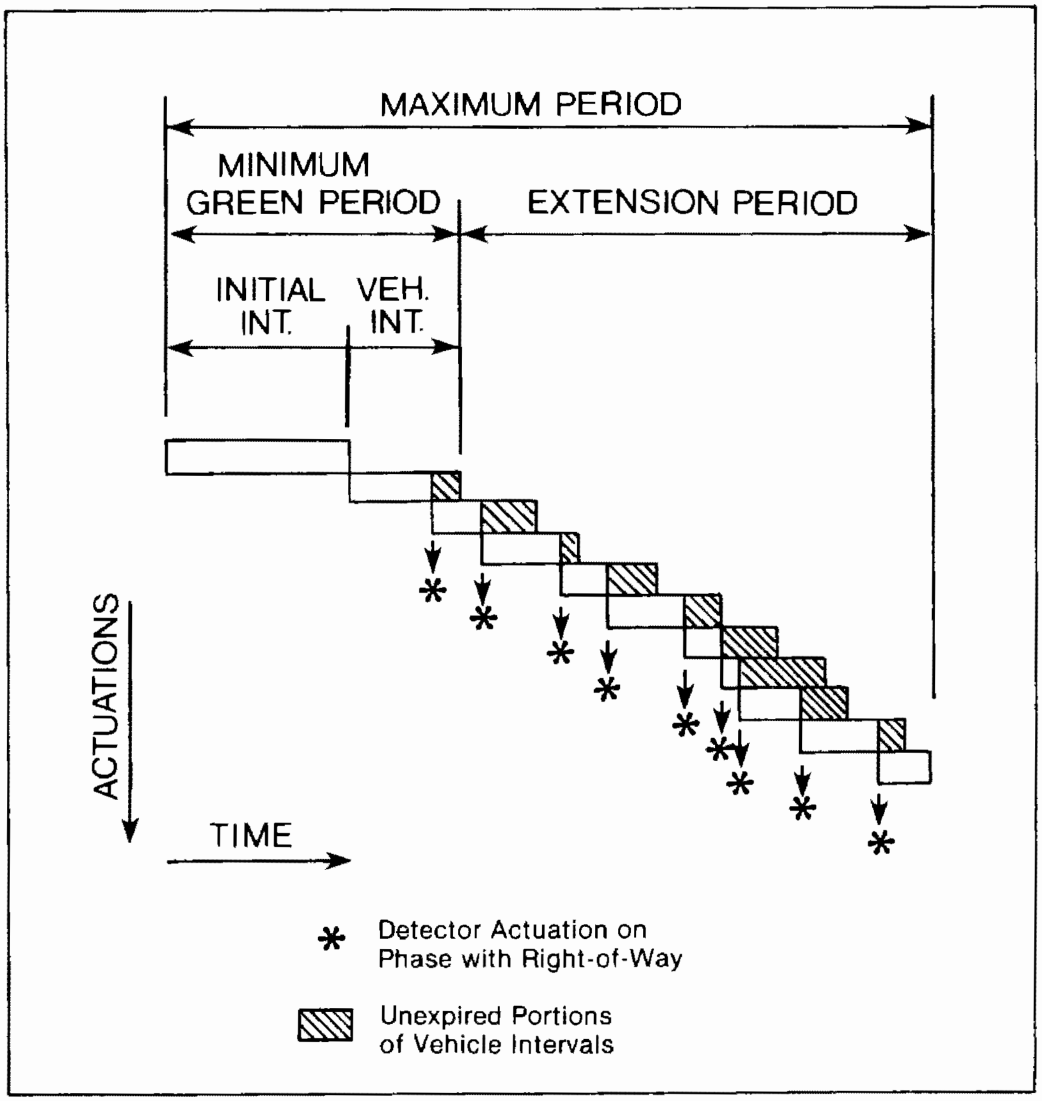


Figure 4-33 Vehicle Extension Intervals

The minimum green period for an actuated phase is the initial interval plus one vehicle interval. A single vehicle will receive this minimum green time. If further detections occur during the vehicle interval, the timer is reset and a new vehicle interval is timed. This process is repeated each time a detection occurs until the gap between detections is greater than the vehicle interval or a preset maximum is reached.

This operation is illustrated in Figure 4-33. In this example, actuation occurred so frequently that no gap greater than the vehicle interval was found. Therefore, the maximum interval timed out and the light changed. Under this circumstance, the controllers will remember that the last vehicle did not necessarily have sufficient time to enter the intersection and will return the green light at the earliest opportunity.

Again, referring to the example, if the first actuation did not occur, the vehicle interval would have timed out and the light would have changed. In this case, the green phase would have been the minimum green time.

Maximum green intervals are established to limit the time any phase can hold the green. Some actuated controllers have the capability to have two maximums per phase. This allows a longer maximum to be used during peak periods when heavy flows are expected on the major street. Normally maximum intervals are set in the range of 30 to 60 seconds. An actuated signal that is properly timed (i.e., short vehicle intervals) should not reach maximum times on a consistent basis unless the intersection is badly overloaded. It should be noted that when an intersection is overloaded and all phases reach the maximum times, the actuated controller is operating as if it were pretimed. Therefore, the selection of the maximum times should be consistant with traffic demands and should not be based on an arbitiary value.

Volume Density Phase

A volume density phase is similar to an actuated phase, but has more timing parameters. Normally, detectors are placed farther in advance of the intersection to provide detection information earlier. Instead of a single value for the initial interval, it allows this interval to be expanded to an assured green time. There is a setting for a minimum initial interval which is enough time for the first few vehicles to get started. On some controllers, after a preset number of vehicles have arrived during the red light, the initial interval is expanded by a preselected number of seconds for each additional detection that occurs during the red light. When the light turns green, the assured green time is the sum of the minimum initial and the expanded increments. On NEMA controllers, each vehicle arriving on the red increments the variable initial. When the light turns green, either the minimum initial or the variable initial governs, whichever is greater.

Instead of a vehicle interval, volume density phases use passage time. This is the time required to travel from the detector to the stop bar. Because this distance is normally substantial, the passage time is greater than the desired maximum gap. Additional settings provide for the length of time to reduce to a preset maximum gap. Older volume density controllers have additional parameters to reduce passage time. Maximum timing normally starts at the end of the initial period.

4G. TRAFFIC SIGNAL CONTROL SYSTEMS

4G-1 General Considerations

A traffic signal control system exists whenever two or more signals operate in a synchronous manner. The major objective of a traffic signal control system is to improve the flow of traffic along an arterial street or throughout a network of streets. A traffic signal control system consists of an appropriate signal timing plan and the hardware components to implement that signal timing plan. The signal timing plan must satisfy traffic demand, traffic flow patterns, and the geometrics that exist at each intersection and in the network as a whole.

Traffic signal control systems may be relatively small and simple or fairly large and complex. A system may merely consist of a series of intersections along an arterial street whose controllers are interconnected. Such a system's purpose is to move platoons of traffic without interruption along the arterial. On the other hand, a system may consist of a network of streets whose intersection controllers are centrally controlled by a digital computer with two-way communication between the computer and the intersection controllers. The purpose of this type of system is to reduce the total amount of delay and the total number of stops occurring to all traffic in the network.

The type of traffic signal control system that is ultimately implemented should reflect the traffic control requirements for the area being controlled. A thorough study of the area should always precede selection of a system design. In addition, the capital and operating budgets available and the technical skills of the operation and maintenance personnel should also be considered. In many instances, the capabilities of signal systems which have been installed have not been used because of the lack of funds and staff to maintain and efficiently operate the system.

4G-2 Types of Traffic Signal Control Systems

There is no universally accepted classification scheme to categorize the different types of traffic signal control systems. The following is a classification of systems according to the type of hardware components that make up the system.

Noninterconnected Systems

The simplest types of system consists of a series of intersections along an arterial or within a small network where the controllers are operating in synchronization but are not interconnected. This is accomplished by relying on the 60-hertz (Hz) cycle of the area's power supply to keep the intersection controllers or coordinating units in synchronization. This type of system is usually limited to a simple timing plan. Therefore, it should only be used in networks with very little fluctuation in traffic conditions.

The advantages of this type of system are the low cost of equipment, installation, and maintenance. Disadvantages include the system's lack of flexibility in adopting to changes in traffic conditions. Since the system is generally limited to one timing plan, controllers are usually timed for the network's worst traffic conditions and this timing plan must operate at all times whether appropriate for all other traffic conditions or not.

The principal disadvantage, however, is the system's lack of ability to firmly hold the offset relationship among the intersections in the system. Since the system is not centrally controlled, whenever a controller goes "out-of-step" it must be reset manually in the field. Because of this inability to hold the offset relationship, systems of this type are not considered an effective means of achieving system control.

Time-Based Coordinated Systems

Time-based coordinated systems are a relatively new means of accomplishing system control. These systems are also noninterconnected. However, each controller is connected to a very accurate digital timing and control device called a time-based coordinator. These devices must be installed in each controller cabinet in the system. The purpose of the devices is to maintain the proper offset relationship among the intersections in the system.

The timing plans are set in each individual intersection controller. The time-based coordinator ensures that each controller keeps proper time. The time-based coordinator normally operates from the area's 60–Hz power supply. However, in the event of a power failure, self-contained batteries permit the device to continue to keep time accurately.

Time-based coordinators can also be programmed with a time-of-day (TOD), day-of-week (DOW) schedule for timing plan implementation. This allows the system to adjust to shifts in traffic conditions by implementing various timing plans. Because of this capability, time-based coordinated systems should be used in networks where traffic conditions change predictably.

The main advantage of a time-based coordinated system is that it provides synchronization without the need for interconnection of controllers. This may result in installation cost savings, especially in cases where the intersections are relatively far apart. The ability to program a schedule of timing plans gives the system a moderate degree of flexibility.

The main disadvantage of a time-based coordinated system is that timing plan and timing plan schedule changes must be made manually in each controller cabinet in the field.

Interconnected, Master Controlled Systems

This is a very broad type of traffic control system. This type is characterized by the interconnection of intersection controllers and the synchronization of each controller during every cycle.

Systems with pretimed controllers are coordinated through the use of a synchronization pulse (synch pulse). The synch pulse is sent out from the master controller at regular intervals of one system cycle length. The offset is set on each controller to establish the proper time relationship for the timing plan in operation. Each controller will dwell at this offset point until it receives the synch pulse from the master controller, thereby ensuring that the proper offset relationship is maintained.

Systems with actuated controllers operate similarly, except that the synch pulse is coordinated with a time zero point set on a device called a coordinating unit. The synch pulse is transmitted at regular intervals of one system cycle length, but since the phase lengths of actuated controllers vary, the synch pulse does not occur at the same point in the cycle at each intersection. Coordination of actuated controllers is accomplished by setting a yield point on each coordinating unit. This point marks the end of the main street green or nonactuated phase, and allows the controller to "yield" control to other phases, establishing the proper point in time for the yield point at each intersection coordinates that intersection with the rest of the system. Because of the manner in which they must be coordinated, actuated traffic control systems must always operate in a semi-actuated mode.

An interconnected master controlled system can be achieved with a variety of different hardware components. The simplest system consists of a series of interconnected controllers with one of the controllers acting as the system master (i.e., the synch pulse is transmitted from this controller). The number of timing plans that may be implemented depends on the capabilities of the individual intersection controllers. Timing plans may be changed on a TOD basis through the use of time clocks or devices called program units in the master controller cabinet. When a timing plan transfer point is reached, a signal is sent out from the master controller instructing the other controllers in the system to also implement the appropriate change in timing plan.

Other types of interconnected master controlled systems contain slight variations in these hardware components. Many systems contain a separate master controller, i.e., the master controller does not control an intersection but merely transmits the synch pulse and timing plan transfer commands. Independent master controllers may be located in the traffic engineer's office, the maintenance shop, or some other convenient location.

Independent master controllers may merely be one or more electromechanical dials that generate synch pulses and use time clocks or program units to determine signal timing plan transfer points. Master controllers may also be fully programmable controllers with timing plan transfer points set on one or more 24-hour or weekly storage devices. An additional option is to use a time-based coordinator as a master controller.

As with the time-based coordinated systems, interconnected, master controlled systems are effective in networks where traffic conditions change predictably. Installation costs vary with the length of cable that must be used. Installation costs are comparable to time-based coordinated systems when the signals are spaced closely together, but would be higher when the signals are relatively far apart. Maintenance costs are similar for both types of systems. The ability to program a schedule of timing plans also gives interconnected, master controlled systems a moderate degree of flexibility.

The main advantages of interconnected, master controlled systems are their simplicity and their ability to change timing plan schedules for many intersections from one location. Interconnected, master controlled systems can be used effectively along arterial streets and in dense networks.

Traffic Adjusted Signal Systems

Traffic adjusted signal systems are characterized by the fact that signal timing plans are adjusted according to changing traffic conditions through the use of an analog computer. These systems are similar to interconnected, master controlled systems except that detectors are added to measure traffic volumes. The analog computer selects a system cycle length from a menu of usually three to six cycle lengths based on the measured traffic demand. An offset, in terms of the percentage of the cycle length, is selected from a menu of three to five offsets based on the directional characteristics of the traffic volume measurements. For example, there may be an offset for AM peak, PM peak, mid-day, light, or congested traffic conditions. One or two different splits (sets of phase lengths) may be established, but splits are assigned to an offset. In other words, the selection of the offset also establishes the splits.

Because of their ability to respond to changing traffic conditions, traffic adjusted signal systems can be used in networks with fluctuating traffic conditions.

The main disadvantage of this type of system is that because the offset is established as a percentage of the cycle length, whenever a different cycle length is selected the implied speed of progression in the system also changes. Thus, when traffic demand rises or falls, implied progression speed falls or rises accordingly. This is a simplistic assumption that fails to consider such things as interference and the amount of turning traffic and their impact on offset and implied progression speed.

Traffic adjusted signal systems are being used along arterial streets or in small, dense networks. Because of the need for detectors, installation and maintenance costs are slightly higher than for interconnected, master controlled systems. Few systems of this type are now oeing installed because digital computerized signal systems offer the same capabilities plus additional capabilities and they operate more effectively.

Computerized Signal Systems

Computerized signal systems are characterized by centralized control by a digital computer and two-way communication capability between the computer and the individual intersection controllers and detectors in the system.

Computer control can be accomplished in two ways. One approach is to utilize the individual intersection controllers to provide the timing function with the computer serving as the master controller. This approach limits the flexibility of the system to the capabilities of the individual intersection controllers. The second and more common approach is to let the computer handle all of the timing functions and use the intersection controllers to merely change the signal display lamps. A much higher degree of flexibility can be achieved with this approach.

Computerized signal systems offer practically unlimited flexibility in implementing signal timing plans. The systems may be operated on a TOD, DOW basis with an unlimited number of timing plans. The systems may be operated on a traffic responsive (TRSP) basis with timing plans selected from a stored library of system plans based on traffic demand measurements. Computerized signal systems can even use the traffic demand measurements to recalculate signal timing plans. However, this has not been often done in practice.

In addition, computerized signal systems offer additional advantages including the ability to monitor system performance in terms of estimates of traffic measures of effectiveness; and the ability to detect controller, detector, and communications system malfunctions.

The disadvantages of computerized signal systems relate to their complexity and to the high costs of installation and maintenance. The traffic surveillance subsystem, the communications subsystem, and the computer itself all require an operating budget and maintenance personnel with specialized technical skills not found in most traffic engineering agencies. Before implementing a highly sophisticated computerized system, the agency should make sure that their budget will provide sufficient funds to operate and maintain the system.

4G-3 Signal System Components

Traffic signal systems usually contain five basic subsystems: the intersection control subsystem, the master control subsystem, the communications subsystem, the detection subsystem, and the control logic subsystem. The relationship of these subsystems to each other is shown in Figure 4-34.

These subsystems work together to implement an appropriate signal timing plan to produce efficient traffic flow. In addition to control, computerized signal systems utilize these subsystems to provide system

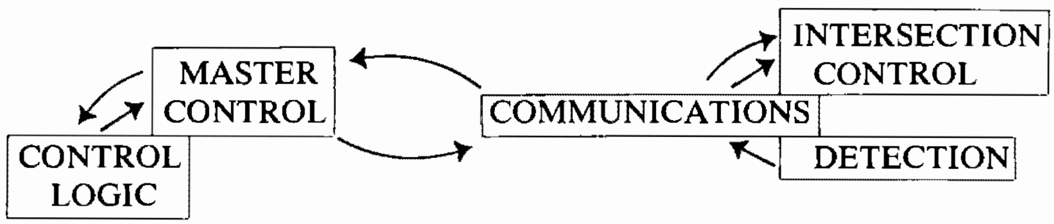


Figure 4-34 Subsystems Relationships

surveillance and malfunction detection and also to permit the operator to interface with the system. These latter functions must be accomplished manually in noncomputerized signal systems.

Control is accomplished by transmitting information from the master control subsystem to the intersection control subsystem through the communications subsystem. This can be done quite simply, as in the case of interconnected, master controlled systems, or can be very complex, as in the case of computerized signal systems.

The system surveillance function begins with the detection subsystem which measures traffic flow information and transmits this information via the communications subsystem to the computer. The control logic subsystem then uses this information to determine the signal timing plan and to estimate various traffic measures of effectiveness. The signal timing information is transmitted back via the communications subsystem to the intersection control subsystem. Also, the measures of effectiveness are either displayed to an operator or routed to a line printer or storage device for later use. The surveillance function is, therefore, used for the dual purpose of control and system monitoring.

Malfunction detection refers to the ability of the control logic subsystem to analyze information transmitted from the intersection control, detection, and communications subsystems to determine whether or not they are operating correctly. This enables operators to detect equipment failures and thereby achieve better system performance.

The ultimate function of operator interface is to provide the operator with information on system performance (system surveillance, and malfunction detection), whereby the operator can make judgments on whether or not to intervene with system operation and what to do. Information is displayed on wall maps, cathode ray tube terminals, teletypewriter terminals, or computer printouts. Operator inputs can be made through a control panel, cathode ray tube terminal typetypewriter terminal, or keypunch and card reader. These devices, collectively known as peripherals, are part of the master control subsystem.

Intersection Control Subsystem

The purpose of the intersection control subsystem is to operate the signal displays according to the signal system timing plan in operation. The controllers may be electromechanical, electronic, or microprocessor based and may operate either pretimed or traffic-actuated. The choice of controller affects the way in which data is transmitted back and forth to the master control subsystem, and the type of interface equipment between the intersection control and communications subsystem.

Master Control Subsystem

The master control subsystem contains the system master controller and, in the case of computerized signal systems, various peripheral devices to provide for operator interface. When using an interconnected, master controlled signal system, the system master provides the synch pulse and the signal timing plan transfer commands. The master controller is usually an adapted intersection controller that is operating with a time clock which establishes timing plan transfer points.

In traffic adjusted systems, the master is an analog computer that provides the synch pulse and also selects a timing plan based on traffic volume measurements.

In computerized systems, the master is a digital computer that may actually control all of the intersection controllers in the system. The computer also stores the various signal timing plans and determines when they are to be implemented and executes the control logic which enables the system to perform a number of valuable functions (system monitoring, malfunction detection, etc.).

The master control subsystem in a computerized signal system includes various peripheral devices that enable the operator to interface with the system. Common peripheral devices include a wall map, CRT terminal, line printer, and control panel.

Communications Subsystem

The communications subsystem is used to transmit information between the master control subsystem and the intersection control and detection subsystems. In interconnected, master controlled systems, the synch pulse and signal timing plan transfer commands are transmitted, via the communications subsystems, from the master controller to the intersection controllers. In traffic adjusted systems, the communications subsystem also transmits traffic volume data to the analog computer. In computerized signal systems, the communications subsystem is used to transmit control data to the intersection controllers and traffic volume and equipment status data to the computer.

The communications subsystem must always ensure that the information being received by one subsystem is exactly the same as what was transmitted from another subsystem. In other words, the communications subsystem must be transparent to all other subsystems of a traffic control system. Communications can be accomplished in a number of ways, the choice depends on the amount and the use of the data that is being transmitted.

In interconnected, master controlled systems, information is usually transmitted over multiple conductor cables. However, in a computerized signal system the amount and use of the information that must be transmitted dictates that the performance requirements of the communications subsystem be significantly better than that required by an interconnected, master controlled system. Multiconductor twisted-pair cable has been commonly used in computerized signal systems. Twisted-pair cable minimizes interference from extraneous electrical sources thereby improving on the performance of the communications subsystem.

Various other methods of communications also exist but have been less commonly used in traffic control systems. One method is coaxial cable (coax) which is also quite effective in minimizing interference. Coaxial cable also has a large bandwidth which permits it to carry a large amount of data. Although coaxial cable offers a significant performance advantage, it is sometimes difficult to run the cable to all of the intersections in the network.

Another method of communication is through the cable television (CATV) systems being installed in communities throughout the United States. Although the location and bandwidth of CATV systems are frequently compatible with traffic signal system control requirements, a number of significant differences exist which should be considered and resolved before CATV systems are included in the design and installation of a traffic signal control system. Other items to be considered include:

- The location of the CATV cables,
- The need for two-way communication for computerized signal system control,
- The need for communication between the signal system control center and the CATV transmitting center, and
- The need for additional amplifiers to handle the extra line drops at each controller.

A final method of communication, not currently being used in traffic control systems, is glass fiber (fiberoptic) cable. This type of cable, which has been used for telephone communications, is proving so effective that widespread use is anticipated. Fiberoptic transmissions offer a number of advantages including:

- Freedom from interference,
- Increased safety, since lightning is not attracted to fiberoptic cables,
- Enormous capacity for data transmission. Thus far, however, fiberoptic communications has been prohibitively expensive for use in traffic control systems.

Detection Subsystem

The purpose of the detection subsystem is to obtain traffic flow information which is transmitted via the communications subsystem to the master control subsystem and then used to select a signal timing plan. Detection subsystems exist only in traffic adjusted and computerized signal systems. In computerized signal systems, the information obtained by the detection subsystem is also used to determine how well the system is operating.

Detectors were discussed in Section 4D-2. Detectors used to measure traffic flow information when using a master control subsystem must be located differently than those that are used with an actuated controller at an intersection. Typically, traffic control system detectors are located in one lane of traffic at a midblock location, free from queue backup from the downstream intersection.

Control Logic Subsystem

The main functions of the control logic subsystem of a traffic signal control system are to select a traffic signal timing plan and to determine when a signal timing plan should be implemented. As described previously, this can be done on a TOD or TRSP basis. Other functions of the control logic subsystem include the determination of when a malfunction of control equipment occurs' the estimation of traffic measures of effectiveness, and the formatting of various system performance reports. Only computerized signal systems contain control logic, which is in the form of a computer program. The UTCS (Urban Traffic Control System) software is an example of a program that provides traffic signal control system logic. This program is available free-of-charge from the Office of Traffic Operations, Federal Highway Administration.

4G-4 Signal System Timing Plans

The purpose of a traffic signal control system is to implement an appropriate signal timing plan that produces efficient traffic flow. As described previously, there are a variety of different ways that this can be accomplished. But, the effectiveness of a traffic control system depends mainly on the quality of the signal timing plans with which the system is operating.

Signal system timing plans are defined by a combination of control parameters and are developed from an analysis of traffic demand and flow patterns and network geometrics. The control parameters which define signal timing plans are:

- *Cycle length*—In a traffic control system, the cycle length is generally the same at all intersections for a particular timing plan. On occasion, some intersections may be double cycled, i.e., they may operate with exactly half of the system cycle length. This allows intersections with relatively low traffic demand to satisfy that demand more efficiently. Actuated systems operate with a background cycle length, the yield point at each intersection occurs at regular intervals of one system cycle length.
- *Phase sequence*—The choice of phase sequence can affect both the operation of individual intersections and the quality of progression in the system. A simple cycle length may be composed of from two to six phases, depending upon the traffic movements that require protection during their respective green periods. The phase sequence is fixed in pretimed controllers, but when there is no demand, phases may be skipped when actuated controllers are used. Phase sequences may consist of numerous combinations of protected and unprotected movements. Engineering judgment should be used to determine which phase sequences are most practical for the signals under consideration. Intersection geometry, length of turn bays, delays to left turning and through traffic, the effect on progression, and pedestrian and vehicle safety should all be considered.
- *Phase lengths (Splits)*—Phase lengths have traditionally been estimated to proportion the green time according to the demand-to-saturation flow ratios on the critical approaches that move during each signal phase. While this approach allocates green time "fairly," it does not guarantee that the system will achieve the best operation in terms of stops and delay. Some signal timing optimization programs design phase lengths to achieve minimum stops and delay.
- *Offset/yield point*—The offset/yield point is the control parameter that enables the intersections in a system to operate in a coordinated manner so that, to the extent possible, platoons of traffic can flow through a number of signals without stopping. The term "offset" applies to pretimed controllers and is defined as the time from a system reference point (e.g., the point in time that the synch pulse is transmitted) to the beginning of the first phase of the cycle at each intersection. The term yield point applies to actuated controllers and is defined as the time from a

system reference point to the end of the main street green phase at each intersection. At this point in the cycle, the actuated controller may "yield" right-of-way to another signal phase where traffic demand exists.

Techniques for Developing Signal Timing Plans

The development of signal timing plans is an off-line process, i.e., signal timing plans are developed by the traffic engineer and then either implemented in the individual signal controllers or input to the central computer in the case of computerized signal systems. Some of the more advanced computerized signal system control logic will calculate signal timing plans on-line, but these systems are rare.

The most commonly used method of signal timing plan development is the time-space diagram. Time-space diagrams are a manual, graphical method in which the system cycle length and intersection phase lengths are precalculated. Offsets are determined by attempting to move bands of traffic through successive intersections, as drawn on a plot of time and distance and accounting for the speed of traffic. Time-space diagrams are relatively easy to prepare for one-way streets. Arterials requiring two-way progression become much more difficult. In addition, time-space diagrams present a very simplified representation of traffic flow, since they do not account for turning movements, queues, or the dispersion of platoons.

A number of computer programs have been successfully applied to develop signal timing plans that produce maximal bandwidth progression along an arterial. These programs include MAXBAND, available from the FHWA, Office of Traffic Operations, and PASSER-II (80), available from the Texas Department of Highways and Public Transportation. These programs can easily accommodate two-way as well as one-way progression and work best on arterials with little turning traffic and good platooning of vehicles. However, because they use the maximal bandwidth approach, these programs do not account for such factors as queuing, turning movements, platoon dispersion or delay to cross-street traffic.

Several computer programs have also been developed to optimize signal timing plans for more complex arterials and networks. Two of these are TRANSYT-7F and SIGOP-III. These programs develop signal timing plans that minimize a combination of vehicle stops and delay occurring in a network or on an arterial. These programs have a sophisticated traffic flow model which allows for realistic modeling of turning movements, queuing, and platooning of vehicles. However, they also have fairly complex input data requirements and at the present time must be run on a large mainframe computer. Information on these programs can be obtained from the Office of Traffic Operations, Federal Highway Administration.

4G-5 Design Considerations

The full value of any traffic signal control system is realized only when it is operated in a manner consistent with traffic requirements. The use of an unduly long cycle length, improper phase lengths, or improper offsets can separately or together result in stop-and-go operation, unreasonably low or high speeds, poor observance of signal indications, poor system efficiency, and greater accident potential.

In any traffic signal control system, knowledge of the demands of traffic must be available in order to select appropriate timing plans and timing plan schedules. Traffic counts and vehicle speed measurement are essential to determine proper cycle lengths, phase lengths, and offsets. In order to take full advantage of any built-in flexibility the signal system has, and to maximize its efficiency, field measurements of traffic should be made and evaluated frequently.

Factors Affecting System Efficiency

Some of the factors that can seriously reduce the efficiency of even the most flexible signal system are:

- Poor signal spacing,
- Inadequate intersection capacity,
- Interference from parking and/or loading operations,
- A high percentage of trucks and/or buses in the system,
- A number of intersections where multiphase operations are required leading to long system cycle lengths,
- Short block lengths or turn bays with limited capacity,
- Intersections that require exclusive pedestrian signal phases,
- Commonly occurring incidents such as lane blockages,
- Poorly operating signal equipment and,
- Out-dated signal timing plans.

4H. MAINTENANCE, SIGNAL TIMING OPTIMIZATION, AND CONTINUING EVALUATION

As with all forms of traffic control devices, to remain effective, traffic control signals must be properly maintained. Immediate traffic problems will result when a signal is not operating or when one malfunctions.

4H-1 Maintenance Activities

There are two types of signal maintenance: preventive (periodic) maintenance and emergency (as needed) maintenance. Both types of maintenance interact; that is, a good preventive maintenance program will substantially reduce the need for more costly emergency maintenance activities.

Preventive maintenance is the systematic and scheduled inspection, cleaning, adjustment, and lubrication of equipment so that it will operate at maximum capability. Maintenance procedures in both the field and shop and the required maintenance are detailed in Ref. 4-2. Some of the more common preventive maintenance activities are summarized below.

Signal Lamp Replacement

Burned-out signal display lamps may create a serious traffic hazard. Immediate replacement of such lamps, and/or scheduled group placement of lamps before the end of their anticipated life, is extremely important.

A regular periodic lamp replacement schedule for groups of signals is advisable since this will reduce the number of lamps that ultimately burn out and, accordingly, the high cost of individual lamp replacement. The schedule should provide for group replacement shortly before the end of lamp life expectancy. The replacement scheduling should reflect the following factors:

- The probability of lamp failure as applied to mass production and manufacturers' mortality curves for signal lamps.
- The effect on lamp life of differences between the applied voltage at the lamp socket and the related lamp voltage.
- The reduction of lamp life expectancy due to normal vibrations and lamp handling.

The actual hours of illumination that can be expected will vary according to the position of the lamp in the signal head. For example, since the yellow lamp is on for a shorter period it will last longer. Nonetheless, it is considered good practice to change all lamps at the same time. The cost of losing the remaining life is offset by the labor and traffic cost of duplicating the activity at a later date, on an emergency basis. Lamps designed for extended life lend themselves to a periodic replacement schedule.

Cleaning Lenses

Schedules for cleaning signals will vary according to the location. Signals in industrial or other areas where the air is dusty, polluted, or subject to chemical fumes will normally require more frequent cleaning than those in residential areas. The abrasive action of wind-blown grit will also reduce the efficiency of the lens.

To the extent practical, the cleaning schedule should be coordinated with the group lamp replacement program. Lenses that have burned or cracked or whose efficiency has been substantially reduced by wind blown grit should be replaced during the cleaning activity. Special nonabrasive cleaners should be used to clean the polished aluminum reflectors. In addition, gaskets should be checked, hinges tightened, and wing nut locks adjusted to seal out water and dirt.

Controller Maintenance

Manufacturer's maintenance recommendations should be followed to protect the equipment warranty. Electromechanical controllers should be lubricated as shown in the manufacturer's instructions. Electrical contacts, bearings, and wiring should be inspected, and any worn or weak parts should be replaced. The accuracy of all timing motors should be checked, including synchronous, induction, and frequency responsive motors.

Loop Detector Maintenance

Loop installations should be inspected to see if the wires are well sealed and have not been pulled up from the pavement. They should be checked to determine if the sealant has cracked. Tests should be made with a "megger" to check for shorts to ground. Inductance meter measurements should be made to determine the inductance level (Ref. 4-14).

When improper operation is observed, the trouble should be isolated either to the loop and lead-in wire system or to the detector amplifier unit. If the amplifier unit malfunctions, it should be replaced, repaired, or retuned. If the loop is faulty, it may have to be replaced as repairs are usually difficult.

Poles

All painted surfaces of steel poles should be checked for condition of paint. All metal poles should be checked for stress cracks in the area of welds and around anchor bolt flanges. Damaged handhole covers and gaskets should be replaced.

At ground level, dry or cracked grout around the base of the pole should be removed and replaced. Metal poles should be examined for evidence of excessive deterioration. If guy guards are used, they should be checked for sharp edges which could represent a hazard to pedestrians.

Mast Arms

Mast arms should be examined for evidence of excessive vertical or horizontal movements. The condition of mounting hardware and paint should also be checked. All pole fittings and nuts should be retightened and painted surfaces showing excess weathering should be sanded, primed, and repainted.

Span Wires

Span wires can be a serious safety hazard if not properly maintained. All span wires should be carefully examined, particularly at the points of attachment to signal heads and poles. The wire should be inspected for signs of fraying or separation and should be replaced when there is evidence of such conditions. Signal hangers, particularly clevices should be checked for wear. All pole hardware nuts should be retightened and compression clamps and vises examined for signs of slippage.

Grounding

Inadequate grounding constitutes a major potential safety hazard at signalized intersections. All controller cabinets and associated metal signal hardware should be grounded in accordance with the National Electrical Code procedures. The grounding lugs on bonding bushings and the cabinet's back panel should be examined and retightened as necessary. The grounding bond of the span wire and the grounding system must be checked to ensure that it is electrically continuous.

Wiring

All overhead wiring should be inspected for breaks, nicks, loose connectors, and bad splices. Wiring attached to span wire should be supported by cable ties or other devices at intervals which will insure a neat appearance and proper support.

Controller cabinets and wiring should be checked with a volt meter to insure that there is no potential problem between the cabinet surface and earth ground. All wiring changes made to a controller cabinet should be marked on the wiring diagram kept in the controller cabinet and/or maintenance shop. Terminal screws should be retightened to assure good connections. All functions of the cabinet should be checked for conformance to specifications.

Painting

Steel poles, posts, controller cabinets, housings, signal heads, and conduits above ground are usually repainted at approximately 5 to 10-year intervals. To prevent corrosion or to maintain a good appearance, they may be repainted at more frequent intervals. The frequency of repainting will vary with the type of paint used, the condition of the surface to which it is applied, chemicals in the atmosphere, presence of salt water, and other related conditions.

Recordkeeping

Complete maintenance records should document all maintenance activities. Typically, the records should indicate the time and cost involved in cleaning, lubrication, retiming, overhauling, lamp replacement, painting, and similar items for each signal installation, controller, and lamp failure.

4H-2 Maintenance Staff Requirements

A well-trained staff of maintenance personnel is essential for any effective maintenance program. Training is a prime requisite of a good maintenance program. The provision of appropriate training opportunities will assure that the staff is well-versed and up-to-date in all aspects of the equipment and proper maintenance procedures. In practice, training may be obtained through equipment/supplier-sponsored schools or on-the-job training.

Once a maintenance program is initiated, every effort should be made to see that it is continued on a regular basis. If additional personnel are needed to implement the program, their cost can be partially offset by the resulting reduction in cost for after-hour emergency repairs.

4H-3 Shop, Tools, and Test Equipment

It is highly desirable to provide a suitable shop area for the repair of equipment that cannot be repaired in the field. There should be adequate tools and testing equipment for quick repairs and adjustments.

Replacement parts for controller components subject to failure should be kept on hand. Up-to-date testing equipment to check the full functional capabilities of controllers should be available.

The small agency may not be in a position to fully staff and operate a signal maintenance shop because of cost and manpower requirements. Contracting maintenance work with a larger agency or private contractor is a possible option. There is conflicting information from cities of various sizes as to the advantages of private signal maintenance. Advantages and disadvantages of using a private maintenance contractor as reported by various agencies are summarized in Table 4-20.

4H-4 Signal Timing Optimization and Continuing Evaluation

After a signal has been installed and operated over a period of time, field evaluations should be conducted to determine whether the signal is operating correctly and efficiently. In addition, the signal, its associated components and operational characteristics (timing plan) should be identified and documented as part of the traffic signal inventory. This section summarizes alternative practices, techniques, and applications associated with operation and evaluation studies, and signal inventories.

Advantages

- Easier to implement minor improvements using maintenance contract without formal bidding process.
- No need to maintain an inventory of replacement parts or equipment. Contractor provides all spares.
- Contractor assumes greater liability role if failure to perform or respond within reasonable limits of time.

Disadvantages

- Poor response time to signal calls due to lack of adequate manpower and distance from contractor's office.
- Approximately 1½ to 3 times as costly than in-house operation.
- May leave intersection in flashing mode for long periods of time.

Table 4-20 Advantages and Disadvantages of Contract Maintenance

Signal Timing Optimization

Traffic signal timing wears out just like anything else. Cities grow and change, and with that change there are alterations in traffic flow patterns. Even small changes in flow patterns require corresponding changes in signal timing if the signal is to operate efficiently; minimizing stops, delay, and fuel consumption. The FHWA estimates that optimizating 2-year-old or older signal timing plans to meet current traffic flow patterns can save motorists approximately 4,500 gallons of fuel per year per signal. This is about a 5 percent reduction in fuel consumption.

Signal timing optimization is a continuing effort requiring periodic measurement of traffic volume patterns along arterials or in networks and the computation and implementation of corresponding optimum timing plans to meet these traffic patterns for different periods of the day. While this effort is assumed to be needed primarily at interconnected and noninterconnected but time-coordinated sets of signals, optimization of the settings used in isolated, actuated traffic signal controllers also can be pursued to significantly reduce stops and delays at individual signals. In particular, the initial interval and vehicle extension interval settings of actuated controllers are often much longer than optimum. Intersection delays and stops are extremely sensitive to the vehicle extension interval setting. If vehicle extension intervals of 4 seconds or longer are used, it may be possible to reduce delay by as much as 50 percent by reducing the settings. Similarly, maximum green time settings are sometimes chosen with little regard for the optimum split requirements during peak flow conditions when the actuated controller behaves more or less like a pretimed controller by timing out to the maximum limit during almost every signal phase.

It is estimated that the typical improvement potential of timing optimization is probably just as great for actuated intersections as for pretimed interconnected intersections. However, such "sharper" operation of actuated signals will often require the upgrading of old detector and controller hardware. This, in turn, may reduce the level of effort required for adequate maintenance because modern traffic control hardware has become more reliable with recent technological advances.

Before and After Studies

Before and after studies should normally be conducted to determine whether established or newly installed signals are operating effectively. These studies serve to define traffic characteristics before and after installation and to document improvements or deficiencies.

The major areas for study for urban and rural traffic signal conditions include:

- Traffic volume,
- Spot Speed,
- Traveltime and Delay,
- Intersection Delay,
- Capacity, and
- Accidents.

The purpose of traffic volume studies is to obtain the actual data on the movement of vehicles and pedestrians at particular points along a street or at an intersection. Data on traffic volume are collected before the improvement was made and after it has been in operation a sufficient time to establish a reasonable pattern. Data collected include:

- Total volume on the street,
- Peak period turning movements,
- Classification of vehicles, (i.e., quantity of trucks, buses, bicycles),
- Pedestrian counts, and
- Cordon and screenline counts at the perimeter of the area under study.

Spot speed studies are used to estimate the prevailing speed distribution at a location for before and after conditions. Speed data are generally used to evaluate detector locations, sight distance adequacy, and signal placement and location. Various techniques for conducting spot speed studies are available in Ref. 4-1 and 4-4, and other major reference sources.

Travel time and delay studies determine the amount of time required to traverse a specific section of street. Travel/time data also provide speed information, but not necessarily delay. A speed and delay study provides information concerning the amount, cause, location, duration, and frequency of delays in addition to the travel time and speed. Study techniques are given in the above references.

Intersection delay studies concerning the delay to vehicles on the approach to an intersection are useful in analyzing the before and after efficiency of an intersection in terms of geometry, loading, and control. Other factors include accidents, operating costs, maintainability, motorist desires, etc.

There are three basic factors affecting intersection delay:

- Physical characteristics such as the number and width of lanes, roadway width, turning lanes, access control, parking, transit stops, cross street geometrics, and intersection angle.
- Traffic factors such as approach volumes, turning movements, peaking characteristics, parking turnover, pedestrians, and approach speeds.
- Traffic controls such as yield and stop signs, signals (type phasing and timing) and markings.

Measures of delay have been studied and primary measures have been defined. Ref. 4-21 identifies these measures and presents techniques for their application in measuring delay at intersections.

Highway capacity studies use data from the above studies to analyze the level of service provided by the intersection. The relationship of overall volume to the capacity of the intersection (V/C) is a primary indicator of the level of service. The Highway Capacity Manual (Ref. 4-22), currently being updated (Ref. 4-9), is the definitive source for calculating capacity.

Accident studies of a specific location indicate the need for careful analysis to determine contributing factors and corrective actions that can be applied. One of the major objectives of a comprehensive accident study program is to evaluate and demonstrate the effectiveness of before and after treatments.

Use of accident record files, especially when computerized, is a primary means of identifying concentrations of accidents or identifying significant changes in accident rates. Together with "Worst Intersection Lists," these and other tabulations can be used to establish a priority of analysis. The procedure used to evaluate problem locations is summarized in Ref. 4-23.

Traffic Signal Inventories

An inventory of traffic signals is a major element of the overall Traffic Control Devices Inventory as discussed in Part I of this Handbook. As with other types of control devices, a number of benefits accrue from maintaining an up-to-date inventory:

- Identification of what is currently in the field,
- Permanent evidence of repairs, changes, modification, and maintenance,
- Access to equipment cost accounting data for historical reference and system costs,
- Legal evidence in case of litigation, and
- Ready response to citizen inquiries.

There are several methods to inventory this equipment. Forms can be developed to provide the information in a graphic and/or a tabular format. Three basic categories of information are usually collected:

- Diagram of the intersection including location of detectors, signals, poles, heads, together with geometric and parking characteristics.
- Equipment details including descriptions of all hardware.
- Timing information including the controller dial settings (verified where possible in the field).

The diagram of the intersection is usually in the form of the "As built" signal design plans or a specially prepared schematic drawing showing details of construction and location of all equipment. Good practice dictates that a copy of this diagram should be placed in the controller cabinet as well as in the office inventory.

The level of detail to be included is a local policy decision. Some agencies inventory literally every facet of the equipment down to the visor length and signal lamp wattage. Others choose to limit the hardware inventory to major components such as controllers, detectors, poles, heads, etc.

Timing data should include all intervals, and/or dial settings for operations throughout the day. Phasing must be defined with sufficient clarity to understand the timing sequences. A separate card or form should be placed within the controller cabinet as well as in the office.

Typical forms for the signal inventory are given in Refs. 4–2, and 4–13. A series of three example forms covering the basic data are shown in Figures 4–35, 4–36, and 4–37.

The inventory should cover all signals within a jurisdiction. The inventory itself may be produced manually or by a computer if the number of signals is high. Desirably, the data should be updated at least annually and should also be updated to reflect any major modifications.

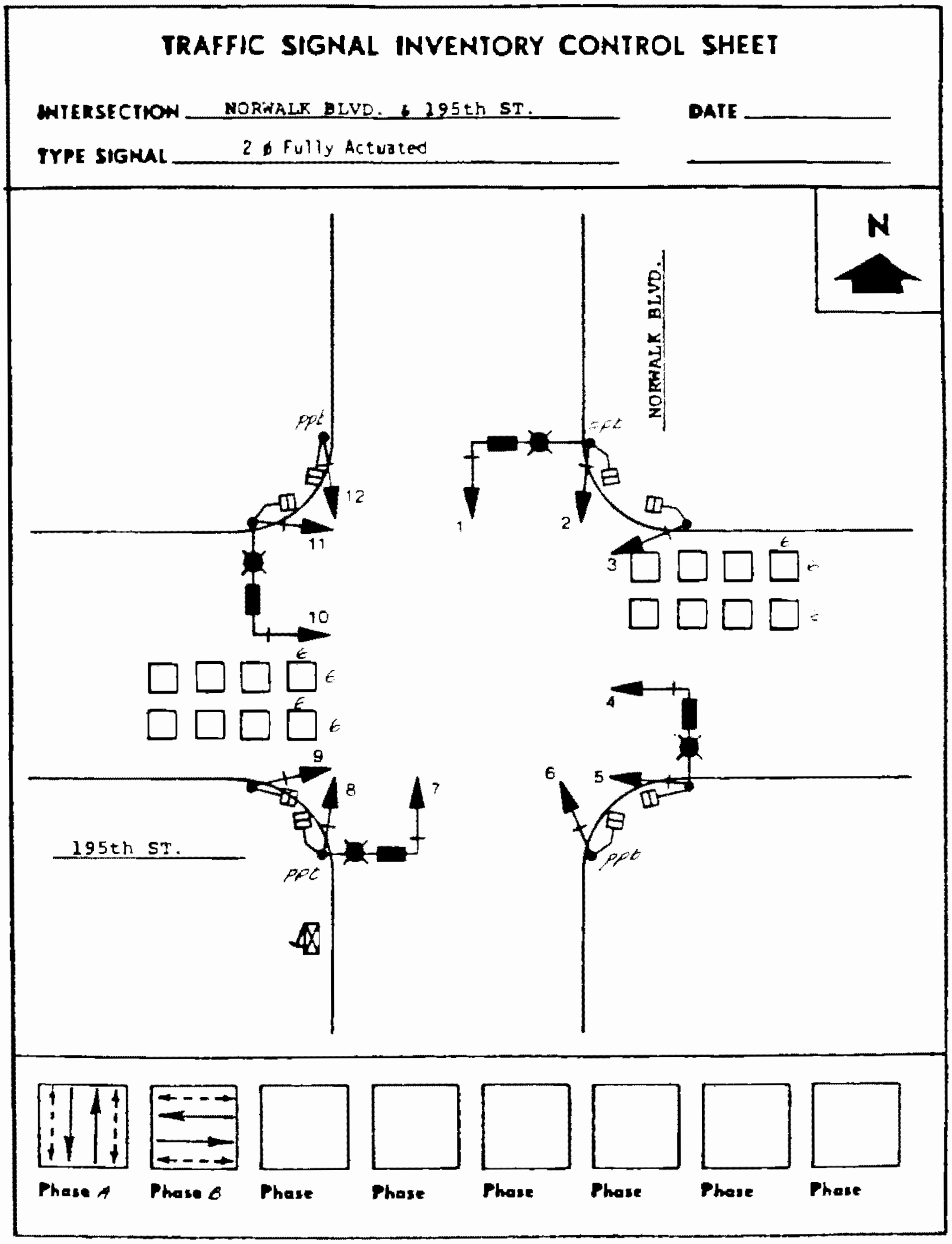


Figure 4-35 Signal Inventory Form

Controller: Type __________

Make __________

Model No. __________

Installed __________

Service Underground __________

Overhead __________

Cabinet __________

FACE NO.	SIGNAL FACE INDICATIONS								PEDESTRIAN SIGNALS	
TOTAL										
LENS LEGEND R-Red Y-Yellow G-Green Arrow WA-Walk WT-Wait DW-Don't Walk 8-8" Lens 12-12" Lens PV-Programmed Visibility PPB-Pedestrian Push Button	R Y G 12	R Y G 8	R ← ← 12 PV	R 8 Y 8 G 12	R Y G PV	R Y G ← ←	R Y G → →	← ← ← 12	W DW White-Orange Green-Orange ___ PPBs	W W

Detectors: Loops __________ Magnetometers __________ Other __________

Sensor Make __________ __________ __________

Model __________ __________ __________

Number __________ __________ __________

Special Equipment __________ __________ __________

R. R. __________ __________ __________

Opticom __________ __________ __________

Fire __________ __________ __________

Internally Illuminated Street Name Signs __________ __________ __________

Figure 4-36 Signal Inventory Form

CITY OF ORANGE INTERSECTION TIMING CHART

INTERSECTION ______________________ CONTROLLER ______________________

PHASE	1	2	3	4	5	6	7	8	COMMENTS
VEHICLE FUNCTIONS									
Initial or Minimum Green									
Vehicle Extension									
Maximum I									
Maximum II									
Yellow									
All Red									
Recall (Min, Max)									
PEDESTRIAN FUNCTIONS									
Walk									
Don't Walk									
Pedestrian Recall									
STANDBY ACTUATION MODULE COMPUTER CONTROLLED CONTROLLERS ONLY									
Initial Green									
Vehicle Unit Extension									
Detector Memory									
Recall									
Overlaps (Yellow Time)									

MULTIPLEX MODULE

MULTIPLEX 1-2	MULTIPLEX 3-4
Receiver Number ______	Receiver Number ______
Standby Program ______	
Transmit Level ______	

DENSITY CONTROL ONLY	1	2	3	4	5	6	7	8	COMMENTS
Minimum Initial									
Added Initial									
Maximum Initial									
Preset Extension									
Minimum Extension									
Time Before Reduction									
Time to Reduce									
Non Locking									

Figure 4-37 Signal Inventory Form

4I. SPECIAL APPLICATIONS

The emphasis in previous sections of this Part of the Handbook has centered around traffic control signals at intersections. While traffic control signals are by far the most common application of signals, they are by no means the only application. This section covers priority control of signals associated with emergency vehicles, bus priority control, and railroad preemption; as well as other applications of highway traffic signal devices.

4I-1 Priority Control of Signals

With priority control capability, signal timing can be altered to provide an appropriate indication for the priority vehicles. The more common applications of priority control presently in use are: preemption for emergency vehicles, preemption or priority control for buses, and signal preemption at or near railroad grade-crossings. Priority control for these applications is discussed below.

Priority Control for Emergency Vehicles

Priority control for emergency vehicles may be included in an intersection traffic control signal installation, or may be included in a midblock emergency traffic signal installed for the express purpose of providing safe and quick access to the street by emergency vehicles.

Intersection Signals

For an intersection signal installation, detection of an emergency vehicle, in most applications, is by a receiver mounted at the signalized intersection. The receiver detects a signal emitted from the emergency vehicle. Typical emitters are radio signals, special light beams, and the sound from a vehicle siren. When the receiver detects the transmission, the phase selector determines whether the signal is green for the approaching emergency vehicle. If the signal shows green, it is maintained in that state until the emergency vehicle has passed and/or the transmission from the emergency vehicle emitter has ceased. If the traffic signal is not green when the first transmission is received, the controller timing is advanced so that a green indication will appear for the oncoming vehicle. It is necessary to first time out the side street green to assure the green has been displayed for some minimum time period, provide an adequate vehicular clearance interval, and provide a pedestrian clearance interval (if pedestrian signals are installed). Pedestrian clearance intervals may assume an accelerated walking pace.

Essentially the same functions may also be achieved in computer-based systems via pushbutton or callup operations. In such instances the emergency vehicle operator pushes a button or otherwise notifies the central control computer of an emergency vehicle run. The computer goes to a table for the timing plan for that pre-programmed run and executes the necessary traffic interval changes at each affected signal to achieve essentially the same results as described above for locally executed preemption routines. Either local preemption execution or central can be utilized in computer-based systems.

The MUTCD provides that traffic signals operating under priority assignment shall be operated in a manner to keep traffic moving. It also states that: "Prolonged all-red or flashing signal sequences are to be avoided." Adherence to these provisions will avoid intersection lock-up with attendant potential delay to the emergency vehicle.

The MUTCD (Section 4B-22) also provides that a distinctive indication may be employed at an intersection to show when an emergency vehicle has achieved control of the traffic signal. A small white light is used in some installations for this purpose. Such an indication may be useful in assuring emergency vehicle drivers that the signal is under their priority control and is not merely going through a regular cycle. Also an emergency vehicle driver who does not receive a green and sees that a signal is under priority control will, thereby, be given notice that an emergency vehicle is probably approaching from a conflicting direction, the conflicting vehicle will receive the green light and that caution should be exercised.

Emergency Traffic Signals

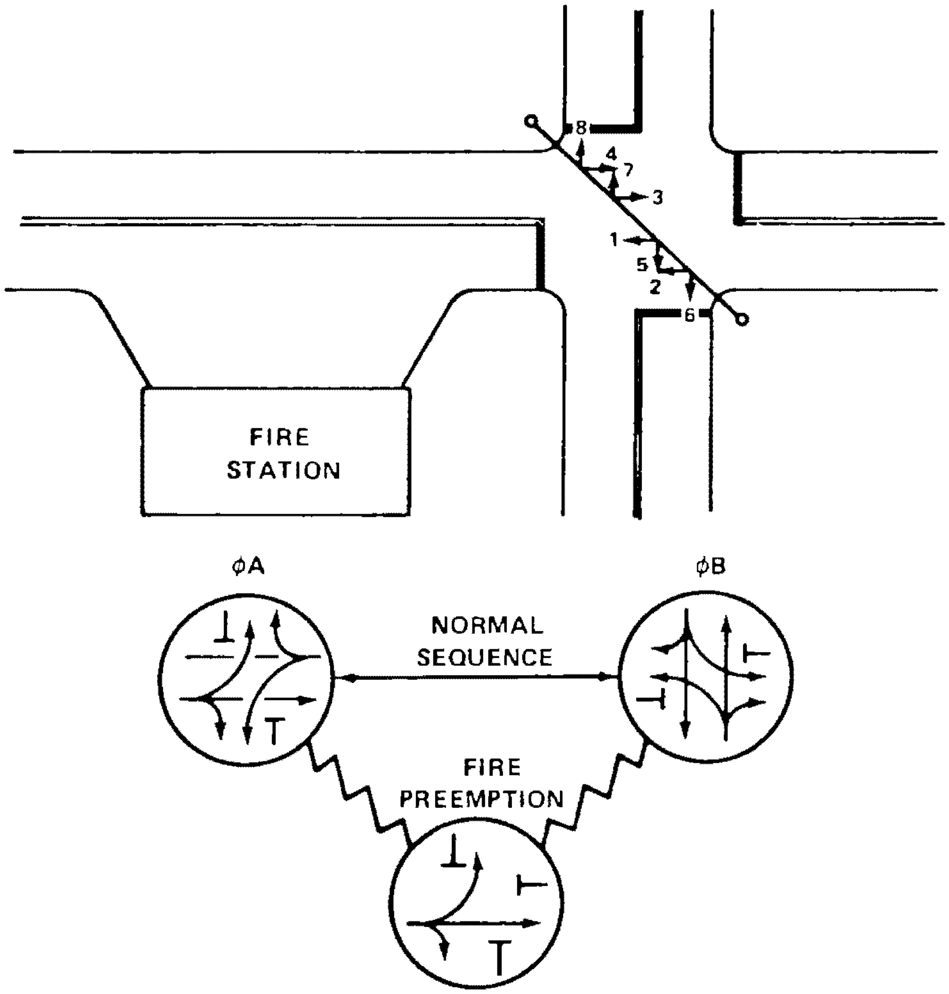
Section 4E-19 through 4E-21 of the MUTCD deals with Emergency Traffic Signals. These are signals in front of or near a building housing emergency equipment where a signal is not warranted by regular warrants, but is needed because adequate gaps in traffic do not exist to permit safe entrance of emergency vehicles, or the stopping sight distance for vehicles approaching on the through street is insufficient to permit safe entrance of emergency vehicles.

At midblock locations, the signal operates to provide continual right of way to the through movement until the preemptive control button in the station is actuated. This permits the emergency vehicle to receive the right of way and enter immediately. Typical phasing sequences for emergency traffic signals are given in Figures 4-38, 4-39, and 4-40.

Bus Transit Priority Control

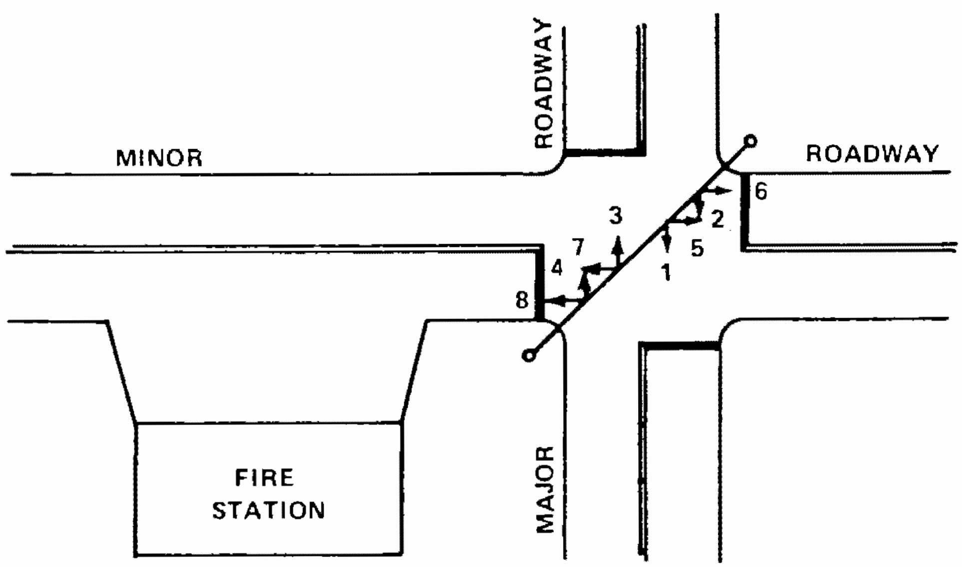
The general method of bus preemption is similar to that described for emergency vehicles. An approaching priority bus identifies its presence to the signal controller which either extends an existing green display or calls for an early green display.

In some cities, the bus priority signal system may be interfaced with a centralized signal control system to provide conditional priority. The central control system monitors other traffic conditions before deciding to allow the priority.



SIGNAL	ϕA		ϕB		FIRE PREEMPTION SEQUENCE			
	R/W	CHANGE	R/W	CHANGE	ϕA CHANGE	ϕB CHANGE	HOLD	RELEASE
1,2	G	Y	R	R	G	R	G	G
3,4	G	Y	R	R	Y	R	R	G
5,6,7,8	R	R	G	Y	R	Y	R	R

Figure 4-38 Typical Phasing Sequence for Emergency Traffic Signals

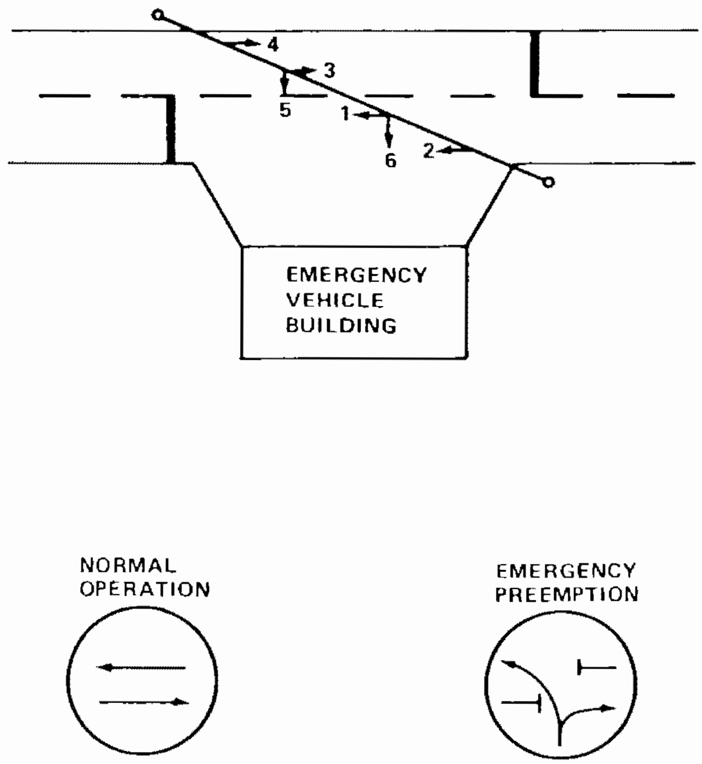


SIGNAL	NORMAL OPERATION	FIRE PREEMPTION SEQUENCE			
		CHANGE	HOLD	CHANGE	RELEASE
1,2,3,4	FY	Y	R	R	FY
5,6	FR	R	R	R	FR
7,8	FR	FR	G	Y	FR

Figure 4-39 Typical Phasing Sequence for Emergency Traffic Signals

When identifying routes where bus priority signal systems would be of benefit, the following major factors should be considered:

- Peak hour traffic volumes on the bus route arterial and on major intersecting arterials.
- The number of buses allocated to the bus corridor.
- The level of transit service within the corridor including:
  - — Route miles,
  - — Bus miles,
  - — Number of trips, headways,
  - — Travel/time, speed, and
  - — Patronage.
- The number of signalized intersections within the corridor at which preemption could be used effectively (e.g., heavy cross traffic or pedestrian movements could reduce the effectiveness of preemption.)
- Travel speed and delay within the corridor.



SIGNAL	NORMAL OPERATION	CHANGE TO EMERG. PREEMPTION	EMERG. PREEMPTION	CHANGE FROM EMERG. PREEMPTION	RELEASE
1,2,3,4	G or FY	Y	R	R	G or FY
5,6	BLANK	BLANK	G	BLANK	BLANK

Figure 4-40 Typical Phasing Sequence for Emergency Traffic Signals

In practice, the following criteria have been used to select candidate bus priority routes:

- Bus signal delay is at least 15 percent of the overall trip time from the start to the end of the route.
- A potential bus time savings from 8 to 20 percent of overall trip time can be assumed with implementation.
- Current bus volumes are from ten to thirty buses per peak hour (from 400 to 900 persons).
- Increases in corridor capacity are limited by heavy auto traffic and/or topography.
- Key bus arterials are limited within the corridor.

Preemption at or Near Railroad Grade Crossings

Highway-railroad grade crossing protection has been the subject of considerable study for over half a century. Criteria, warrants, and formulas have been developed for the various elements of grade crossing protection. Coordination of railroad crossing signals with adjacent highway traffic signals is often required in order that the actions of these separate traffic control devices complement rather than negate each other.

The MUTCD currently specifies:

"When highway intersection traffic control signals are within 200 feet of a grade crossing, control of the traffic flow should be designed to provide the vehicle operators using the crossing a measure of safety at least equal to that which existed prior to the installation of such signals. Accordingly, design, installation and operation should be based upon a total systems approach in order that all relevant features may be considered."

The MUTCD requires (Section 8C-6) that all necessary vehicular clearance intervals shall be provided for traffic signals preempted because of the approach of a train. It further provides that they may not be shortened.

Vehicular clearance intervals can usually be readily provided. However, provision of normal pedestrian clearance intervals, where pedestrian signals are provided near railroad crossings, may greatly complicate the design, installation, and operation of the total system. Thus, pedestrian clearance intervals may be abbreviated, but must still be adequate. In many instances it is reasonable to assume pedestrian clearance intervals can be shortened as the pedestrians become aware of an approaching train. Sometimes minor channelization can reduce the pedestrian clearance requirements. An example would be installation of a pedestrian refuge island in the center of the roadway. Positive treatments are always desirable, however, they cannot always be achieved. Thus, closing of a crosswalk and rerouting of pedestrians via a less direct path may sometimes be the only practical solution.

Typical railroad preemption sequencing for a variety of traffic signals operating adjacent to or at railroad grade crossings are given in Part VIII of this Handbook.

4I-2 Beacons

There are several types of flashing beacons currently being used. The types, design, location, and operation of these beacons are fully described in the MUTCD in Section 4E-1 through 4E-7. The most common usages are to:

- Provide advance warning of intersection controls,
- Warn of hazardous conditions, and
- Complement speed regulation signs.

It is generally agreed that flashing beacons are useful in getting the driver's attention in unusual situations (e.g., where a driver may not be expecting a warning or regulation, or where special emphasis is otherwise required). At the same time, most traffic engineers are concerned that extensive use of flashing beacons will reduce their novelty effect and, therefore, distract from their overall effectiveness. Thus, flashing beacons on advance warning signs and/or regulatory signs are used sparingly and only when there is a true need for additional emphasis.

4I-3 Lane-use Control Signals

According to the MUTCD . . . "Lane-use control signals are special overhead signal shaving indications to permit or prohibit the use of specific lanes of a street or highway or to indicate the impending prohibition of use."

Such signals consist of a red X on an opaque background or a green arrow on an opaque background, with the arrowhead pointing downward. In addition to these two symbols, a yellow X may be used. Only one indication is displayed at a time for each lane in either direction.

Lane-use control signals are most often used for reversible lane control. They may also be used to:

- Clear a freeway lane(s) at any time this is deemed necessary;
- Indicate the termination of a freeway lane;
- Indicate blockage of a lane ahead by an accident or a hazard;
- Permanently operate a two-way street with an unequal lane distribution, or
- Operate a two-way street in a one-way mode during peak periods.

Lane-use control signals are not mandatory for reversible lanes or for their other purposes. Signing has often been used for these purposes. However, properly designed and operated lane-use control signals are generally more effective than signing and for this reason their use is steadily increasing.

In typical reversible lane applications, care must be taken to ensure that when the signal indications are reversed, that there is no traffic proceeding in the wrong direction. There are two alternatives which may be used for this purpose. First, an additional signal head can be provided. This head would display a yellow X which could be continuously illuminated during the period immediately prior to the introduction of the red X, thereby giving motorists using the lane a warning indication before the change occurs. An alternative technique is to display a red X in both directions on the lane for a sufficient clearance period to permit all traffic to vacate the lane.

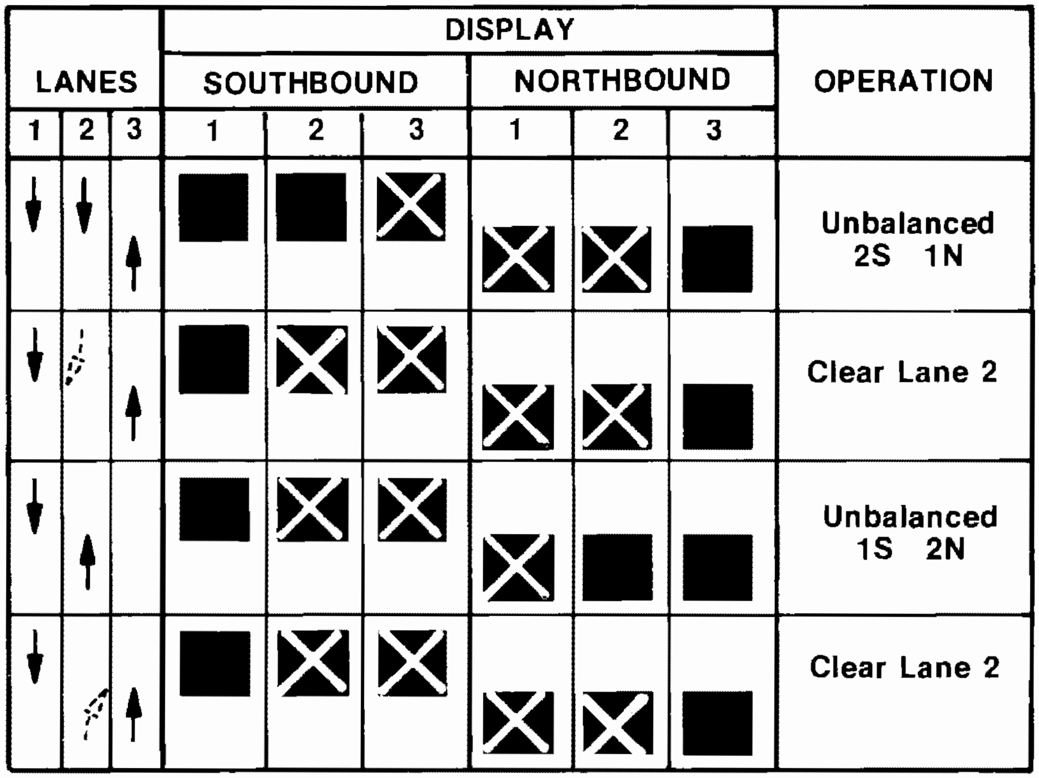
Where a flashing yellow X is displayed for both directions in a lane, the lane may be used by motorists for a left turn. The driver is cautioned that the lane is shared with opposing left-turning vehicles.

The placement of lane-use control signals should not interfere with the motorists' view of intersection traffic control signals. To prevent any confusion between lane-use control signals and the signals at an intersection on the same street, it is advisable to locate the lane-use control signals at least 200 feet from any signalized intersection. It is desirable to use 12-inch lenses for the intersection control signals.

When the division of the lanes is maintained permanently, the lane-use control signals can be illuminated directly from an adjacent power supply. With a reversible lane system, the signals are controlled through a control unit. The control unit should ensure that the green arrows are not displayed on the same lane in both directions at the same time. It should also provide a clearance interval when a lane change is imminent. The lane-use control signals may be switched through a time clock or some other centrally-controlled device. A manual override switch should also be provided. Typical sequencing for lane-use control signals is described below.

The simplest situation consists of a reversible lane where traffic flow is in one direction or the other. This simple type operation is shown in Figure 4-41.

A single lane reversed for morning and evening peak hour traffic may be operated as a two-way left-turn lane during other periods. In this case, the steady yellow X should be used to clear this lane from single-direction flow along with a period when a steady red X is displayed to both directions of traffic followed by the reversible indications. This operation is illustrated in Figure 4-42.



Do Not Enter This Lane

Clear This Lane

Two-Way Left Turn

Use This Lane

Figure 4-41 Reversible Lane

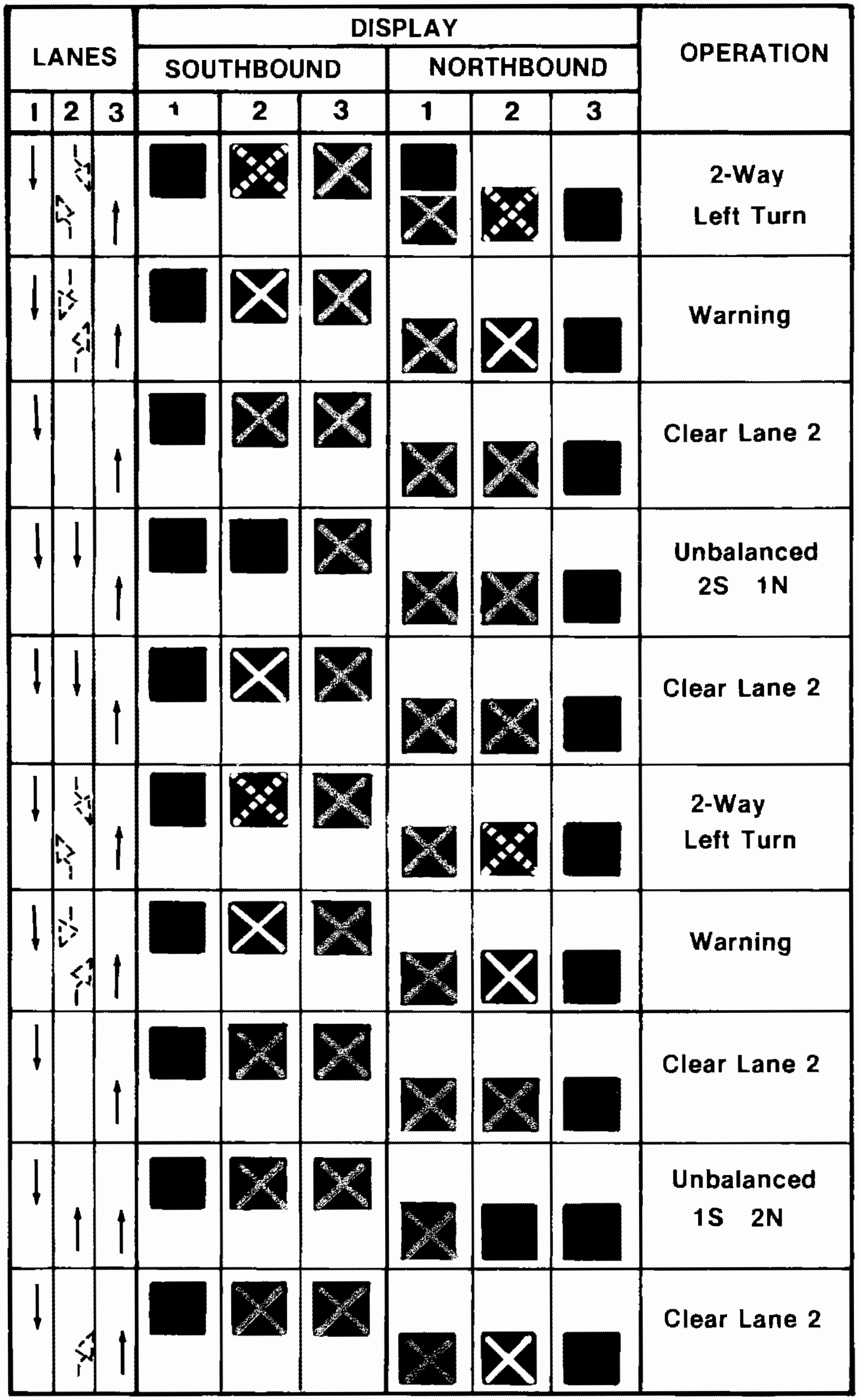


Figure 4-42 Reversible Lane

LANES				DISPLAY								OPERATION
				SOUTHBOUND				NORTHBOUND				
1	2	3	4	1	2	3	4	1	2	3	4	
↓	↓	↑	↑	■	■	⊠	⊠	⊠	⊠	■	■	Normal 2S 2N
↓	↓	⇡	↑	■	■	⊠	⊠	⊠	⊠	⊠	■	Clear Lane 3
↓	↓	↓	↑	■	■	■	⊠	⊠	⊠	⊠	■	Unbalanced 3S 1N
↓	↓	⇣	↑	■	■	⊠	⊠	⊠	⊠	⊠	■	Clear Lane 3
↓	↓	↑	↑	■	■	⊠	⊠	⊠	⊠	■	■	Normal 2S 2N
↓	⇣	↑	↑	■	⊠	⊠	⊠	⊠	⊠	■	■	Clear Lane 2
	↑			■	⊠	⊠	⊠	⊠	■	■	■	Unbalanced 1S 3N
↓	⇡	↑	↑	■	⊠	⊠	⊠	⊠	⊠	■	■	Clear Lane 2

Figure 4-43 Reversible Lane

Where the roadway has an even number of lanes, a different situation occurs. In the morning peak an outbound lane is reversed, while in the evening peak an inbound lane is reversed. During other periods of the day, the street operates as a normal two-way street. The operation of the lane control signals for this operation is shown in Figure 4–43.

4I-4 Ramp Control Signals

Ramp control signals have proved effective in regulating the flow of traffic onto congested freeways, thereby allowing the freeway to operate at a more acceptable level of service. They may also be utilized to control ramp volumes so that the demand on a critical geometric section is reduced sufficiently to allow a more efficient level of service.

It should be recognized, however, that application of ramp control may create bottlenecks at ramp entrances and at adjacent signalized intersections. Techniques for relieving this congestion should be considered prior to implementation of this type of control.

Ramp metering along a section of freeway should only be used when an overall system benefit will be achieved. Figure 4–44 shows a typical ramp metering layout and signal.

The development of ramp metering controls has followed a general pattern of simple control gradually increasing in refinement to include the critical bottlenecks in the network by controlling the inputs to the system at points upstream from the physical bottleneck. A definitive discussion of ramp metering techniques is given in Ref. 4–1.

4I-5 Control at One-Lane, Two-Way Facilities

At a location, which is not wide enough to allow traffic to flow in both directions simultaneously (e.g., bridge, tunnel, construction area), signals can be operated essentially as a two-phase control. Each approach is given one phase, with an all-red clearance period added to the normal cycle. Traffic moves in one direction on one phase and in the opposite direction on the other phase. Between these movements an all-red interval provides time for clearing of traffic in the restricted area.

At isolated locations, pretimed controllers may be used, especially where traffic patterns are predictable and capacity is not critical. However, most authorities agree that traffic-actuated controllers provide superior operations. Loop occupancy detection has been used successfully in the approaches to the one-way section to provide detection of approaching or waiting vehicles. In this operation, when there is an absence of vehicles on the loop, the green signal terminates. A delay timer is used to assure that all the vehicles clear the one way area prior to release of the opposite direction. The timer should be set to accommodate a reasonable speed through the one-way section. On long one-way sections

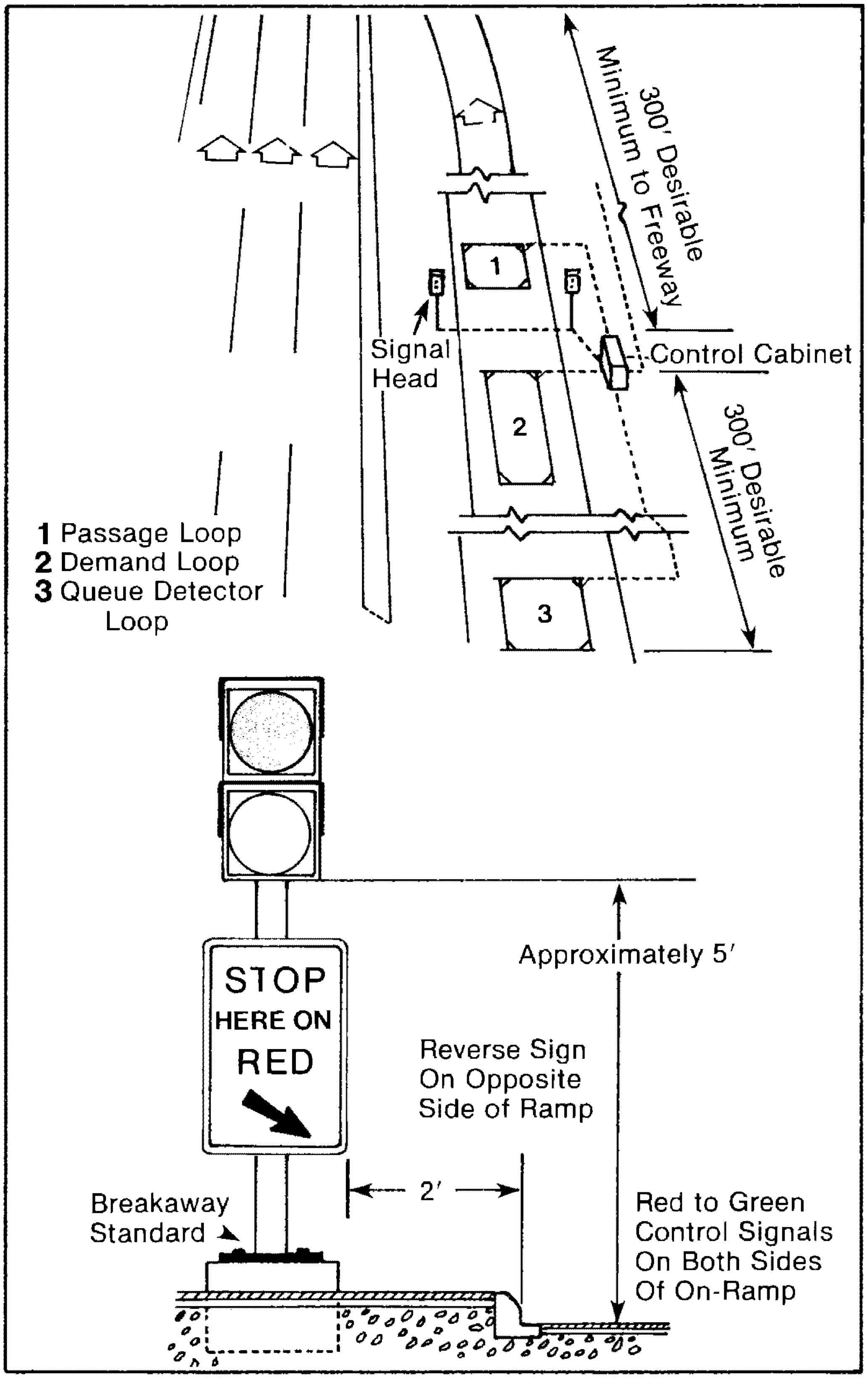


Figure 4-44 Typical Ramp Meterining Layout and Signal

intermediate detection may be provided to assure that "stragglers" are not trapped within the zone upon release of the opposite direction of traffic.

Visibility along the entire length of the restricted section is critical. All efforts should be made to provide the longest possible sight distance.

4I-6 Movable Bridge Signals

On roadway approaches to a movable (draw) bridge, traffic control signals are generally used to stop vehicular traffic when the bridge is open or when it is about to be opened. Signal heads are installed at both approaches to the bridge, often in conjunction with warning gates or other forms of protection. The traffic signal is coordinated with the bridge control and arranged so that adequate warning time is provided in advance of the bridge opening to ensure that the bridge will be clear of all traffic.

Because of the various sytems of traffic control applied under a wide variety of traffic conditions, there are few specific guidelines for the operation of movable bridge signals other than those provided in Sections 4E-13 through 4E-17 of the MUTCD. Generally, the following operational factors should be considered in addition to the recommendations specified in the MUTCD.

- The traffic control devices such as signals and gates should be placed in operation and activated in order starting with the ones farthest from the bridge.
- Sufficient time should be allowed between the activation of devices to permit approaching traffic to respond to each device.
- A bridge tender should wait until approaching vehicles have stopped for the traffic signals before lowering the warning gates. If there are no approaching vehicles, there is no need for a delay between signal and gate operation.
- When the bridge is lowered and again ready for vehicular traffic, the traffic control devices should be deactivated in order from the one closest to the span to the one farthest from the span.
- When a Hazard Identification Beacon is used, it may be desirable to continue flashing the beacon until all stopped vehicles have started to move normally.

4I-7 Portable Traffic Signals

Historically, portable traffic signals were used (and misused) for a number of applications. As traffic control signal requirements and standards have become more definitive and complex, portable signals have become less practical.

Portable signals are still used occasionally under emergency situations such as knockdowns or in construction zones. When used, they are required (see Section 4B-4 of the MUTCD) to conform to the same criteria as permanent signals. Although portable traffic signals are still available, their use is very limited. Wherever possible, other forms of traffic control should be considered.

Portable signals, such as those used in construction areas are often installed at locations where the drivers do not expect to see them. Consequently, the driver is more likely to overlook the signal than in the case where the signal is placed at a conventional location. In such situations, the use of advance warning signs should be considered, perhaps with a flashing beacon, or (in construction zones) a flag.

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Part V. ISLANDS

Part V. ISLANDS

5A. GENERAL

The MUTCD and the AASHTO Policy Design Manual state that an island is a "...defined area between traffic lanes for control of vehicle movements or for pedestrian refuge".

There is some confusion whether an island, per se, is a traffic control device or a roadway design feature which may contain traffic control devices such as signs or signals. For example, a curbed and raised triangular island may be considered a design feature. On the other hand, a triangular island formed by paint can be considered a part of the marking system and, accordingly, a traffic control device.

This Handbook is primarily concerned with the traffic control aspects rather than the geometric design considerations. While some overlap is unavoidable, the following discussion is limited to the application of traffic control devices that form islands particularly including approach end treatments.

5A-1 Purpose and Types of Islands

The major purpose of any island is to control vehicular travel patterns and to discourage random, uncontrolled movements. An island may be *raised* using curbs or *flush* with the pavement and it may be delineated by paint, buttons, or other control devices.

The three basic types of islands are:

- *Pedestrian Refuge Islands:* Primarily used on wide roadways to provide a safety zone for pedestrians.
- *Traffic Divisional Islands:* Narrow elongated islands which follow the course of the roadway to separate conflicting traffic movements.
- *Traffic Channelizing Islands:* Located in the roadway area to define the vehicular path, usually turning movements.

Refuge Islands

Refuge islands are used in urban areas on exceptionally wide roads or at large, irregularly shaped (skewed) intersections where the combination of heavy pedestrian and vehicular volumes can make pedestrian crossing difficult or dangerous. Another typical use is along transit routes on downtown streets where curb loading and discharging of transit passengers may be hazardous.

On wide streets, where the intersection is controlled by a traffic signal, this type of island can be used to reduce the pedestrian clearance interval. The island also provides a stopping point for the slow walker or late starter who cannot cross the entire street in the allocated pedestrian time. At isolated signal locations, the reduced pedestrian clearance time can minimize the signal cycle length and the overall delay to motor vehicle traffic.

Divisional Islands

Divisional islands are an essential design element of major urban thoroughfares. In rural areas, the use of divisional islands (excluding continuous medians on multilane highways) is normally reserved for important intersections. The general objectives of this type of island include:

- Limit interference of opposing traffic. This results in greater convenience and comfort for motorists, and may reduce certain types of accidents.
- Provide protection and control for crossing and turning traffic.
- Provide separate turn lanes for storage and safe maneuvering of turning vehicles.
- Can also provide a refuge for pedestrians (if width is adequate).
- Define alignment and proper vehicle paths, especially at skewed intersections.

Channelizing Islands

Channelizing islands are normally used to guide traffic into the proper path through the intersection area. These islands serve one or more of the following functions (Ref. 5-1):

- Separate conflicting traffic movements,
- Control the angle of conflict,
- Reduce excessive pavement areas,
- Regulate traffic and indicate the proper use of the intersection,
- Protect pedestrians,
- Protect and provide storage for turning and crossing vehicles,
- Locate traffic control devices,
- Prohibit specific movements, and
- Control speed.

Each intersection requires very careful study to determine the appropriate location and shape of islands. It is generally accepted that a few large islands are preferable to many smaller ones.

5A-2 Driver and Pedestrian Needs

Drivers need to see the island installation, and they need to understand the configuration of the desired travel path. At night or during periods of rain, fog, or snow, driver vision may be limited. Therefore, the basic island design should be structured to:

- Make the island and its approach clearly visible to avoid any surprise to the driver,
- Allow sufficient driver time for decisionmaking and reaction, and
- Assure that the island path and approach conditions follow the natural path of movement.

The area used as pedestrian refuge should be free of obstructions such as signs, poles, raised markers, or post-mounted delineators. Also many jurisdictions are now required by law to provide ramps for the handicapped at all crosswalks, including islands.

5A-3 Selection of Island Type

The three primary means of forming an island include:

- The use of curbs or asphalt berms. (Figure 5-1)
- By pavement markings which are often supplemented with raised bars, flexible tubular posts, etc. (Figure 5-2)
- By using nonpaved areas that are formed by pavement edges. These areas are normally supplemented by post-mounted delineators, flexible tubular posts, or pavement markings. (Figure 5-3)

There are advantages and disadvantages associated with each type of island installation. In most instances, the type of island selected is a design decision. Detailed criteria for the design of islands are provided in "A Policy on Geometric Design of Rural Highways" and "A Policy on Design of Urban Highways and Arterial Streets" (Refs. 5-1 and 5-2). The physical characteristics (size, shape, and roadway location) are defined in Part V of the MUTCD.

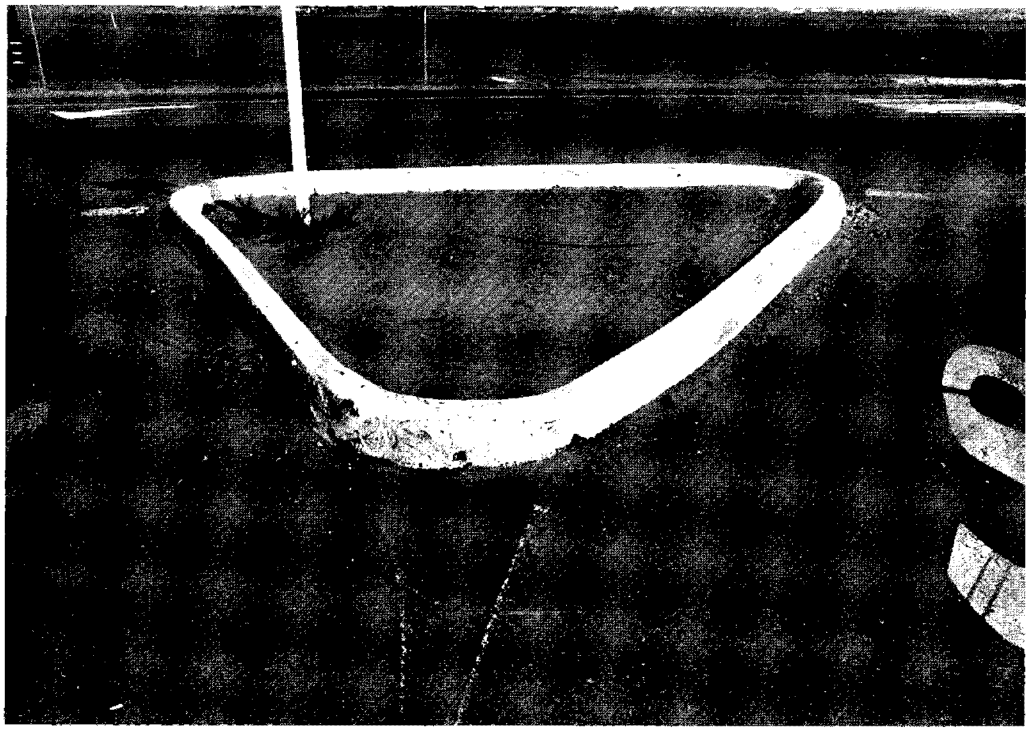


Figure 5-1 Island Formed by Concrete Curb

Figure 5-2 Island Formed by Flexible Tubular Posts

Figure 5-3 Island Formed by Nonpaved Area

5B. APPLICATION

Once the design decision has been made as to the type of island that is needed for a particular roadway situation, it is then necessary to determine the configuration and type of materials to be used in forming the island. To a large extent, the functional purpose of the island may suggest the most appropriate configuration and/or materials.

Small islands are usually raised with curbs. Larger islands may be raised or flush, delineated by color, texture, contrast of the filler material (ground cover, shrubs, bricks, or stones, etc.), post-mounted delineators, raised buttons, paint, tubular markers, or any combination.

5B-1 Materials

There are several conditions that should be considered in determining whether to install a raised island or to use paint, buttons, cones, or other surface materials to delineate the island area. Moreover, if a raised island is selected, decisions must be made involving the type of curb treatment to be used.

There are also many different materials available to construct an island. Raised islands usually consist of concrete or asphalt curbs. The simplest flush islands are formed by reflectorized pavement markings. Combinations of materials (e.g., raised markers, buttons, paint, flexible tubular posts, or delineators) are commonly used. The following discussion highlights the current practices in selecting the most appropriate combination of shape and materials used to form islands.

Islands Formed by Paint

An island defined by paint is often preferred for the following conditions:

- In lightly developed areas
- At intersections with high approach speeds
- Locations with very little pedestrian traffic
- Where fixed source lighting is not available
- Where signs, signals, poles, or lighting standards are not needed in the island.

The painted island is used primarily as a channelizing device. The painted markings are frequently supplemented with raised pavement markers. These markers significantly improve night visibility, particularly under wet weather conditions.

Islands formed by paint should conform to the standard colors and application principles defined in Part III of the MUTCD.

Islands Formed by Raised Traffic Bars

Raised traffic bars (or jiggle bars) are used for three different purposes. First, they may be applied in a relatively continuous line to define the shape of an island. Second, they may be placed transversely or diagonally inside a painted island area to discourage vehicles from crossing over or encroaching on the island. Finally, they are also used to protect the approach end of an island (See Section 5D of this Part). Figure 5–4 illustrates a typical application.

In the first application, the raised bars are placed in sections along the outline of the island area to be defined. Since the bars are usually preformed sections of concrete, they cannot bend around the island corners. Accordingly, different size sections would be required to create a curved design. Concrete bars are currently being used in lieu of the cast iron bars used in the past.

When used with paint as a center island treatment, these bars provide good visual guidance as well as a tactile sensation to discourage encroachment. This application is most effective where the island area is large, and where an occasional encroachment would not damage the violating vehicle. Such islands can provide adequate locations for signs with breakaway or yielding supports but they are not a suitable location for signal standards. They are not used for pedestrian refuge areas.

Figure 5-4 Typical Application of Raised Traffic Bars

Islands Formed by Post-Mounted Delineators

Post-mounted delineators may be used as borders for channelization islands and/or may be installed on raised islands to provide more long-range visibility. The reflective buttons or sheeting materials used to form post-mounted delineators are described in Part III, (Markings) of this Handbook. The post used for mounting the reflective buttons or sheeting should be designed to yield or breakaway upon impact.

Reflectors mounted on white background paddles or on object markers are used for islands in some States. Since a reflector mounted on a 3 ½-inch post is effective only at night, these 2-foot by 8-inch base plates provide better daytime visibility.

Islands Formed by Raised Buttons

Large mushroom-shaped buttons may be used to outline an island configuration. These buttons are up to 6 inches high and are usually reflectorized. Due to their height, these devices are considered hazardous and their indiscriminate use should be discouraged. Their normal application is on low speed facilities where there is a strong need to discourage a vehicle from purposely infringing on the island area.

Islands Formed by Tubular Posts

Flexible rubber or plastic tubular posts are used for configuring channelizing islands and for approach end treatments for either temporary or permanent islands. The design height and reflectivity requirements for tubular posts are specified in Sections 3F-2 and 6C-3 of the MUTCD. The color of the flexible tubular posts should always compliment the color of the pavement markings which they supplement or for which they are substituted.

The use of these posts provides a well-defined island area that is highly visible during both daylight and periods of reduced visibility. However, periodic inspection and replacement are necessary to retain the continuity of island outline.

Tubular posts can be applied to the pavement in a number of ways. Some are epoxied directly to the pavement while others have a base with a hinged connection. This base is epoxied to the pavement. Some tubular posts are merely inserted in holes drilled in the pavement. Most post designs are sufficiently flexible to either spring back after impact or to dislodge. As they are light and flexible, they do not normally become a hazardous flying object if struck by a vehicle.

Concrete or Asphalt Raised Islands

Raised islands constructed of either concrete or asphalt curbs are particularly desirable for large islands (over 100 square feet). They are relatively self-enforcing in that they provide a physical barrier to the passage of vehicles. They are frequently used in urban areas where curbed streets are common. In rural areas, where curbs are not prevelant, raised islands are generally smaller (75 to 100 square feet) and are limited to multilane highways and important intersections.

The type of raised island is defined by the type of curb. Whether the curb is considered a "mountable" or a "barrier" type depends on its height and slope (curb face). The lower mountable curb (under 6 inches) is preferred unless there is a definite need for a barrier.

Barrier curbs (6 inches and higher) can be hazardous on high speed highways where striking the curb will cause loss of control. Crash tests have shown that most "barrier" curbs provide little if any redirection to a vehicle except at very low speeds. The main effects of a barrier curb are causes considerable damage to the impacting vehicle, causes loss of control of the vehicle, and in many cases causes the vehicle to become airborne. In light of the above, barrier curbs should not be used except for low speed facilities.

At times it may be necessary to provide a positive barrier in conjunction with an island. A roadside barrier such as guardrail or the concrete safety shape should be used. The "AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers" should be followed for such installations. (Ref. 5-4)

With respect to pedestrian refuge islands, an important consideration is the recognition of the needs of the handicapped. Pedestrian refuge islands should not constitute a barrier to the handicapped. Thus, any raised pedestrian refuge islands should include appropriate curb cuts and ramps.

Two applications of raised island are shown in Figures 5-5 and 5-6.

Figure 5-5 Raised Concrete Island

Figure 5-6 Raised Asphalt Island

5C. INSTALLATION

The physical installation of the various forms of islands is relatively straightforward. The materials and installation equipment for forming islands by reflectorized paint, thermoplastic, epoxy, raised pavement markers, and post delineators are covered in Part III, Markings. More definitive detail is available from Ref. 5-3, "Roadway Delineation Practices Handbook".

Curbs are essentially constructed of either concrete, asphalt concrete, granite, or other quarried stone. Islands are sometimes installed by constructing the curb first and then placing the pavement against it. Where water is to flow along the gutter, combined one-piece curb and gutter is usually preferred.

Special machines used to form the curb by extruding concrete or asphaltic materials are particularly effective where the curbing is to be placed on existing paving. In other instances, precast curbing sections bonded to the pavement with epoxy resins have been used.

Another alternative involves placing the concrete or asphalt island without a separate curb. The installation must be doweled to the pavement to prevent movement. This method reduces installation cost. It also facilitates removal of the island should that be necessary. In all curb construction related to islands, the provision of handicapped ramps as an integral part of the island should be considered.

More detailed design and installation information on forming curbed islands is provided in the AASHTO design manuals, Ref. 5-1 and 5-2.

5D. APPROACH END TREATMENT

The existence of islands in the roadway can represent a hazard. Therefore, the approach end treatment deserves careful consideration to properly direct traffic along the designated travel path, to alert the driver to a change in the lane configuration or alignment and, in the case of a raised island, to warn approaching traffic of the obstruction. This treatment may involve signs, beacons, markings, and illumination or reflectorization.

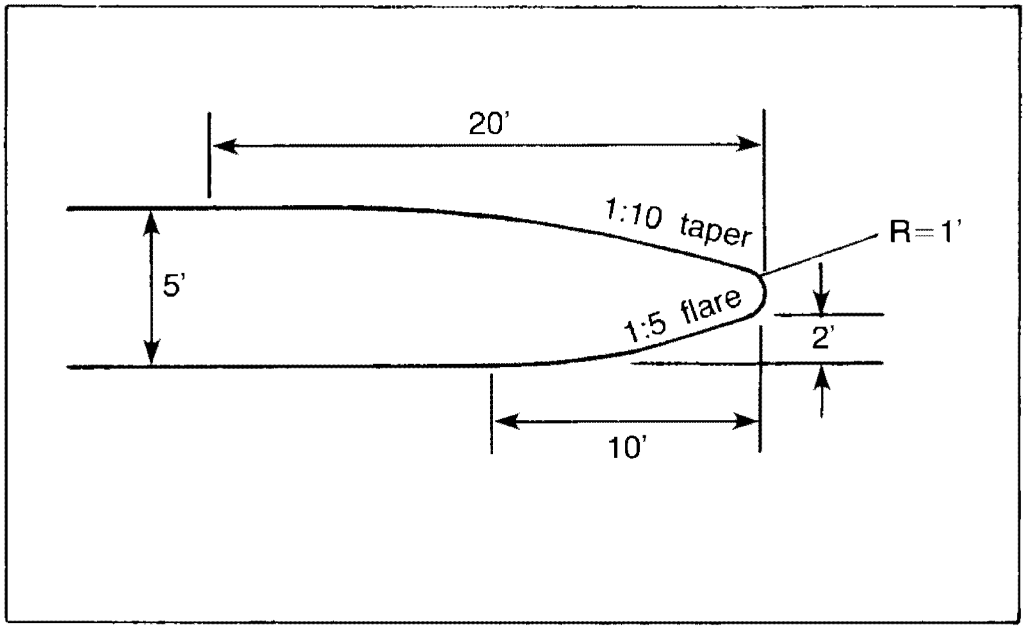
5D-1 Design of Approach End

Typically, the approach end of an island is shaped as shown in Figure 5-7. Ends should be highly visible. This can be accomplished by painting the curb face with reflective paint, applying reflective inserts to the curb face, using retro-reflective delineators, and placing raised pavement markings on top of the curb.

Various approach end treatments are shown in Figure 5-8 and 5-9. The ends of islands on the far side of intersections are usually flared to provide offset distance (usually 2 feet) from the extension of the lane to the edge line (Detail A, Figure 5-9). This increased lane width negates the visual impression that the lane narrows. That is, to the driver across the intersection, the 12-foot mouth of the lane adjacent to a raised island appears to be about 10 feet. By opening up the outbound side by 2 feet, the driver perceives no narrowing of the lane width.

The other side of the nose end of the island is also slightly tapered to ease the left turning movement (Detail B). Normally this is a shorter taper than the opposite side; thus, the nose shape is asymmetrical. The same concepts apply for triangular islands that channel right-turning vehicles. The island is set back 2 feet on both through street sides to avoid the feeling of narrowing lanes (Detail C). On the curving portion of the roadway, the radii and width of the travel path must be adequate for the appropriate design vehicle(s). Although these are design decisions, their application may reduce the number of traffic control devices needed to obtain the same degree of effectiveness.

With islands wider than 18 feet, many agencies stripe an island zone with a chevron pattern to separate the left-turning vehicle from the remaining traffic (Figure 5-10). This improves the visibility for drivers turning from either direction by clearly delineating the through lanes and the turn lanes.



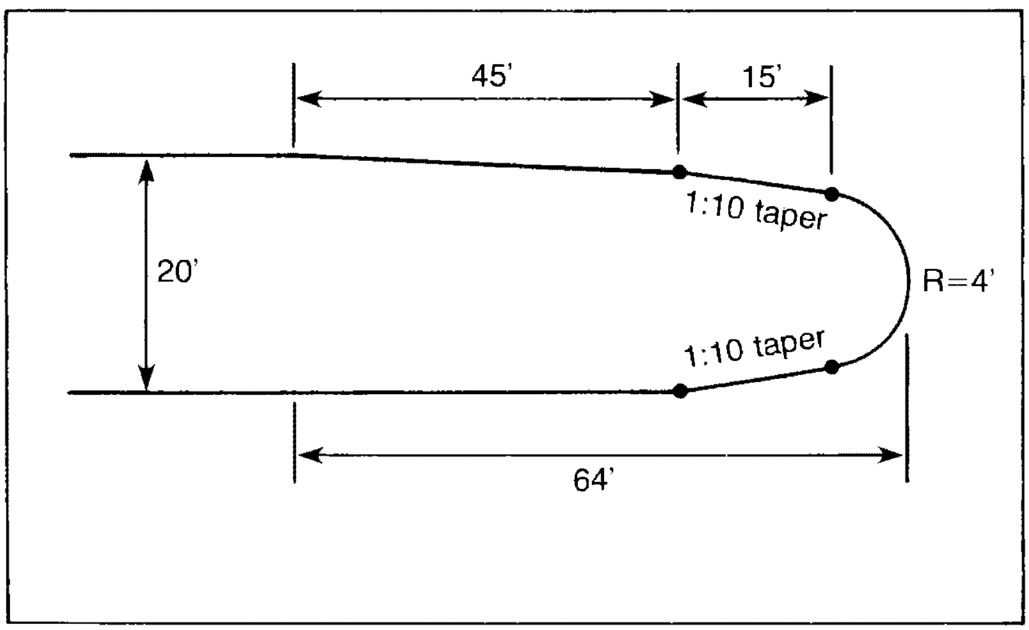


Figure 5-7 Typical Island Approach End Designs

Figure 5-8 Island Approach End Treatment

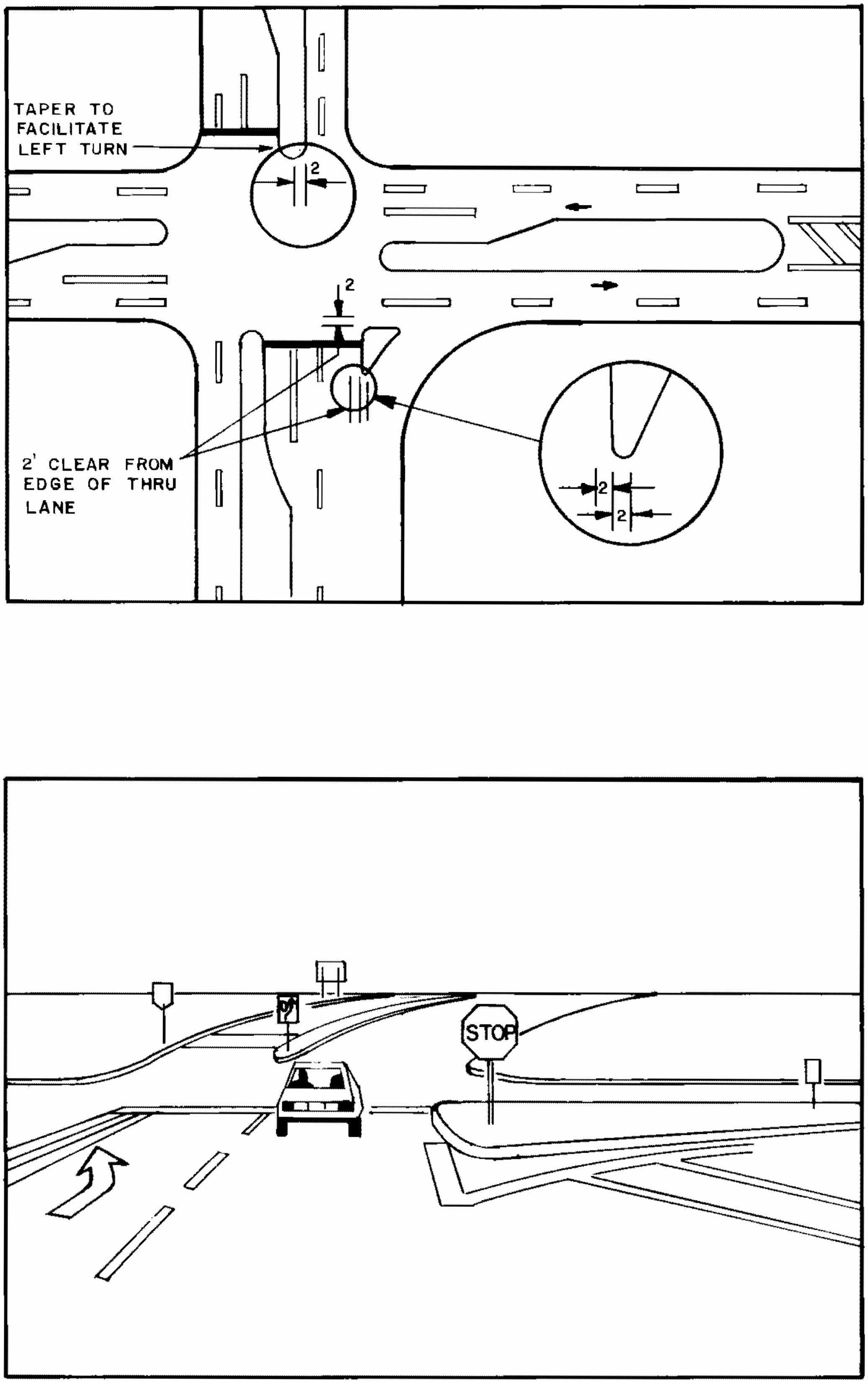


Figure 5-9 Island Approach End Treatment

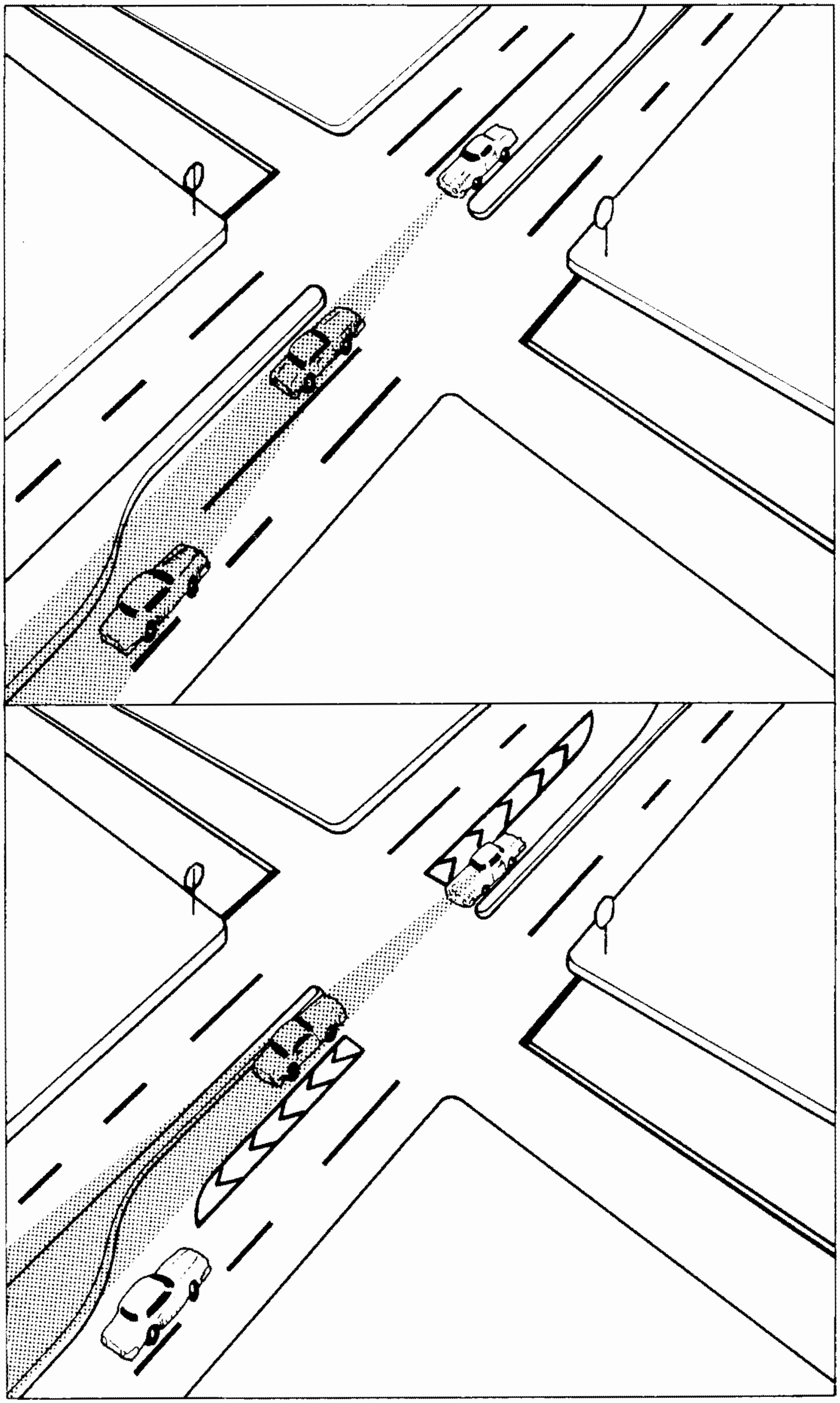


Figure 5-10 Visibility Consideration for Left Turning Vehicles

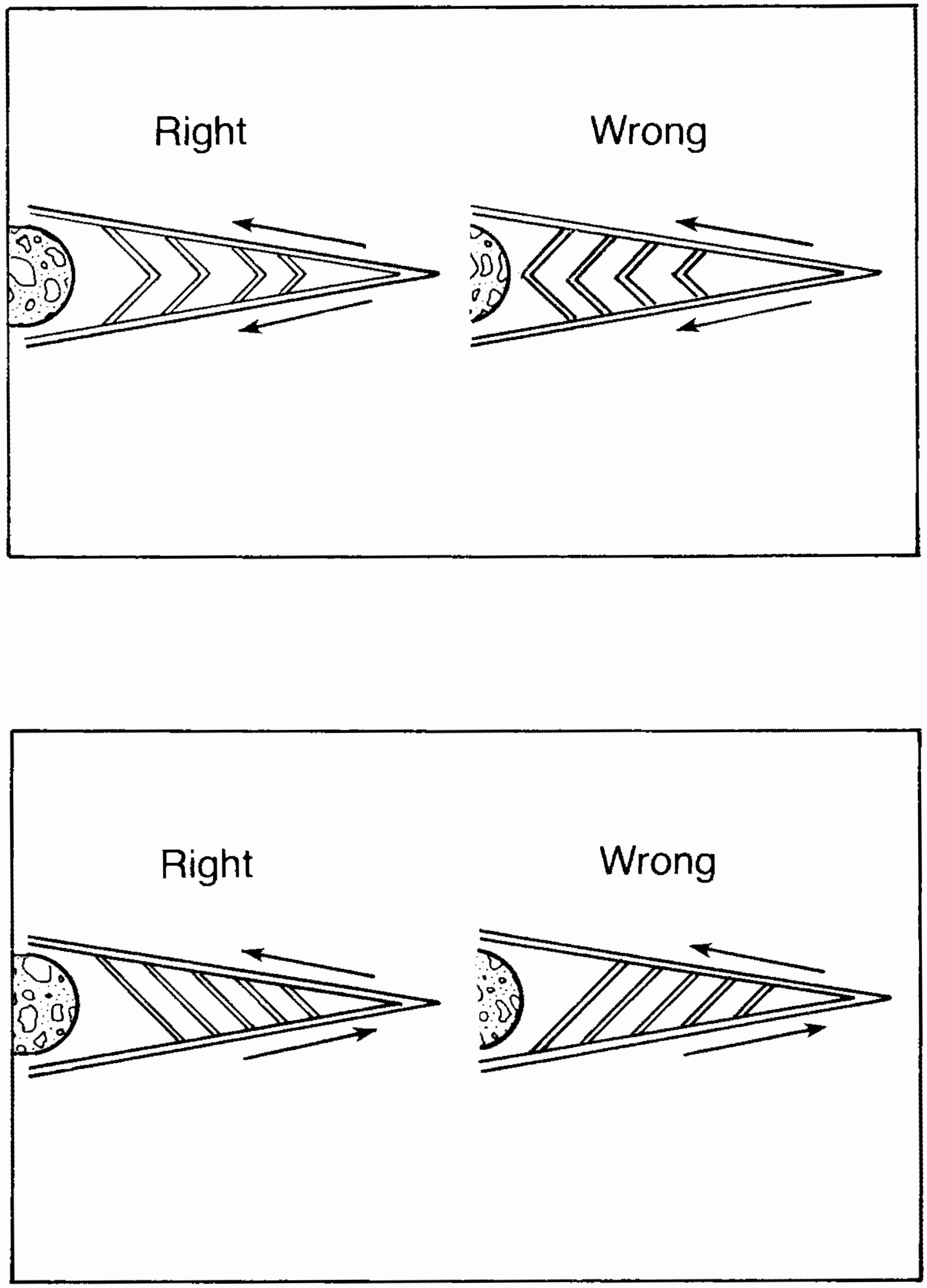


Figure 5-11 Island Approach Striping Patterns

5D-2 Treatment of Approach Area

Since all three types of islands (pedestrian refuge, divisional, channelization) represent departure from the established travel path, advance warning and guidance to the driver is necessary. In general practice, the area immediately preceding the approach end is marked to warn and to guide the driver to the appropriate path of travel.

For most common types of islands, painted cross-hatched striping is frequently used to define the island configuration. The painted striping patterns generally used for various approach end treatments are shown in Figure 5-11. The proper striping patterns are shown on the left. Improper patterns are shown on the right.

The area within the painted island approach may be surfaced with coarse aggregate that is slightly raised or the aggregate can be "mounded" into ¼-to ½-inch high transverse bars. This treatment provides improved visibility of the marked areas and produces an audible warning to vehicles that travel across them. Transverse saw cuts and grooves formed in uncured concrete roadway approaches also produce a similar audible warning.

Raised bars or flexible tubular posts can be used in situations where it would be hazardous for the vehicle to cross into the approach area. The proper treatments of several techniques are defined in the MUTCD Section 5C-2.

5D-3 Use of Signs and Object Markers

The signs and markers that may be used to delineate the approach end of islands (particularly raised islands) are defined in the MUTCD (Parts IIB, IIC, and IIIC). The application of these devices varies among agencies. Some jurisdictions use a full complement of signs and object markers on all major intersection islands or median island ends while others choose to simply install either Type 1 or Type 2 object markers. Typical signs and object markers used for the approach end of islands are shown in Figure 5-12.

Neither the MUTCD nor other engineering handbooks provide definitive guidance as to the extent of signing or markers that should be applied under various situations. Although signs are desirable at the approach end of most raised islands, in general practice, they are used sparingly. Some States require such signing on all State-operated facilities while others, including local jurisdictions, leave it to the discretion of the local Traffic Engineer or follow State guidelines to "some extent". There are no established warrants for use of these signs, but the consensus among practicing engineers indicates that site specific traffic volumes, operating speeds, and fixed object accident histories are their primary criteria for installation of these signs.

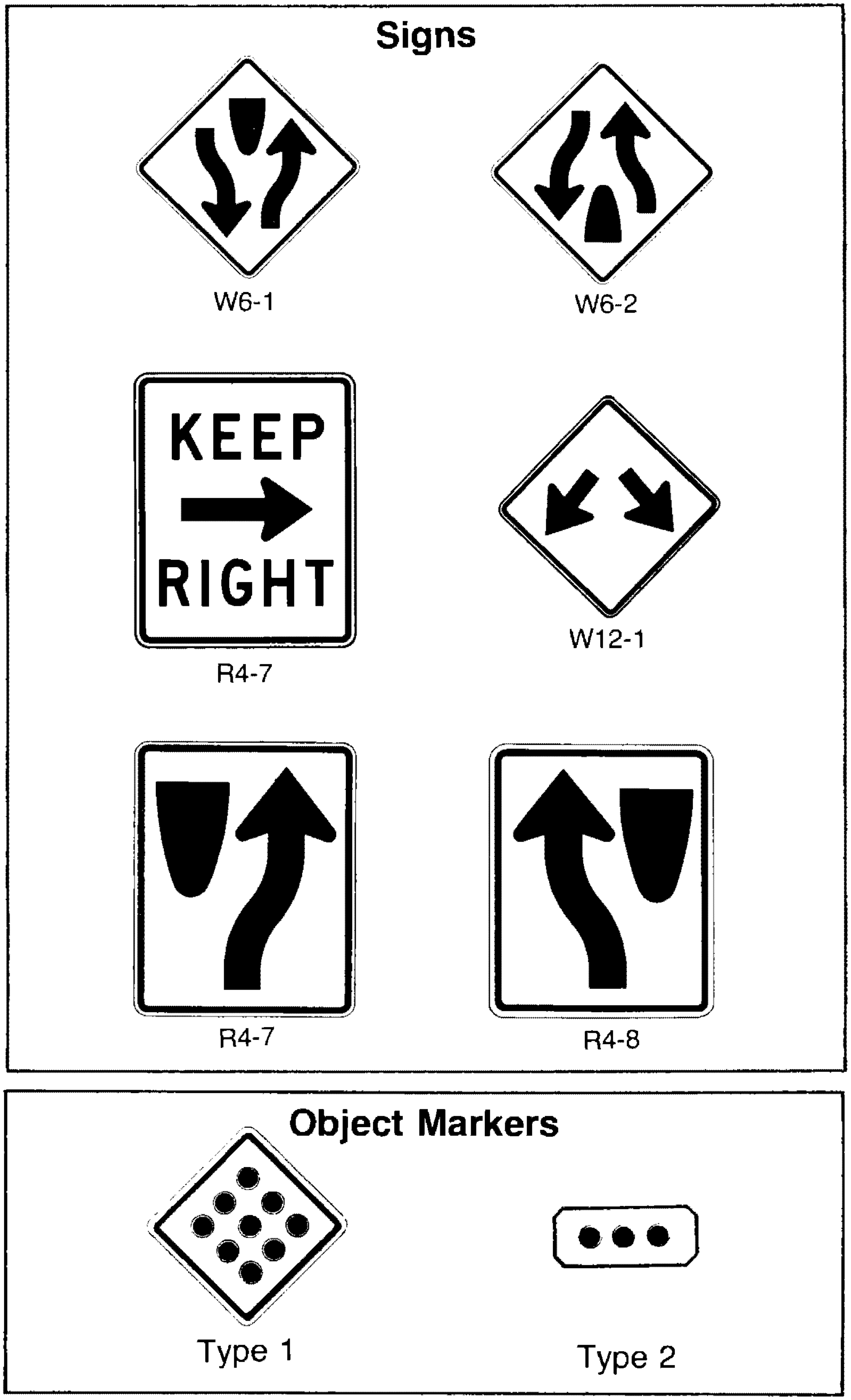


Figure 5-12 Signs and Object Markers for Marking Approach Ends of Islands

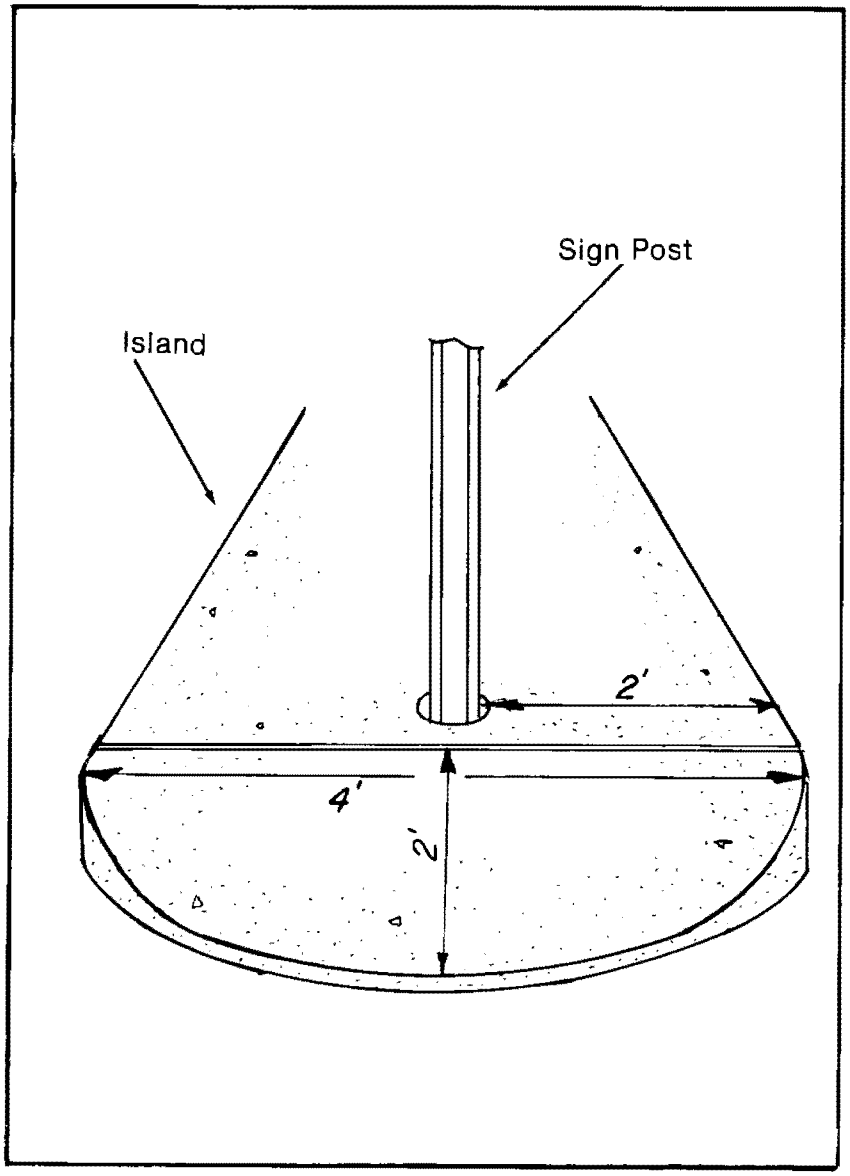


Figure 5-13 Typical Placement of Sign Post on Island Approach End

On raised islands without pedestrian traffic, it is desirable to locate signs at the center point of the circle forming the rounded portion of the island end. (See Figure 5-13). The mounting post is thus located at the maximum island width and as close as possible to the end of the island. The relative size of the island, sign, and turning radii of buses and trucks should also be considered. For example, for a 6-foot wide island with a 4-foot wide sign, the sign should be positioned further back to prevent knockdown by a turning truck overrunning the curb.

In many cases, Type 2 object markers (with three reflective elements) are the only devices used on the approach end of an island. They are inexpensive, easy to install, and do not present a serious hazard if struck.

Such devices mounted 3 to 4 feet above the surface provide a high degree of retroreflectivity from approaching headlights. The MUTCD indicates that Type 2 markers can be installed either horizontally or vertically. In practice, the size of the island and approach area determine the mounting direction.

The Type 1 object marker (with nine reflector elements) has three or more times the reflective power of the Type 2 marker and will, therefore, provide more warning to approaching vehicles. It does, however, cost approximately twice that of the Type 2. The Type 2 markers are preferred on small islands where space is at a premium.

If, in the judgment of the local authorities, a combination of both signs and object markers are required, the treatment should be consistently applied. Combination treatments may cost up to 60% more than the use of object markers only. This cost must be balanced against the increased warning provided particularly since the total costs of these devices is low relative to the overall cost of the roadway facility.

5D-4 Markings

The application and use of pavement markings (paint, thermoplastic, epoxy, raised markers, etc.) to define the travel path around the island approach end is covered in Part III of the MUTCD and is further detailed in Part III of this Handbook.

5E. OPERATIONS AND MAINTENANCE

Once the island has been properly designed and installed, periodic maintenance of the elements that provide the traffic control is required. When plantings are placed in an island regular landscape maintenance is needed to control growth. Also, the problems caused by excessive litter should be considered as part of operations and maintenance. This section briefly discusses the type of operations and maintenance normally required for the various types of islands.

5E–1 Painting

Repainting curb and pavement markings will depend in large measure on the type, durability, and application thickness and characteristics of the materials used. (These factors are discussed in Part III of this Handbook). For the most part, painted island or approach areas are commonly refurbished at the same time that lane lines, center lines, edge lines and other such pavement markings are renewed. However, some agencies prefer to paint island markings on an "as-needed" basis since they receive less wear and therefore last longer than those pavement markings within the travel way.

5E–2 Maintaining Raised Pavement Markers and Reflectors

Maintenance of retroreflective raised pavement markers is covered in Part III. Pavement and object markers should be maintained in conjunction with other maintenance operations as prescribed by agency policy so as to minimize traffic disruption. Most of the larger agencies have determined an appropriate level of effectiveness below which markers are replaced. One State will replace nonreflectorized markers when eight markers are missing from a 100-foot section, or when two or more successive markers are missing and the loss affects the specific configuration.

One problem frequently cited involves the loss of effectiveness (i.e., reflectivity) of object markers due to road film or splash. Several agencies have attempted to clean the reflective faces of the markers, but report that this practice does not appear to be cost-effective. Others have elected to replace the reflective surface when night visibility is significantly degraded.

5E–3 Maintaining Standards and Posts

The knockdown of a sign, lighting, or traffic signal standard placed in an island can create a serious condition. In the past, signs, lights, and signals were protected by vertical posts, concrete pipes, steel pipes, and large concrete pedestals. Such devices are now considered hazardous and their continued use may present a liability situation. These hazards and the traffic control device they are "protecting" should be removed. If removal is not feasible, then they should be shielded by an appropriate barrier or crash cushion or combination of barrier and crash cushion. In the interim, these hazards should be clearly delineated by hazard markers, vertical panels, or other suitable device.

Maintenance of the flexible tubular posts is relatively straightforward in that those that have been dislodged are simply reinstalled and new devices are provided where missing markers disrupt the island's configuration.

REFERENCES

5-1 American Association of State Highway Officials (AASHO), *A Policy on Geometric Design of Rural Highways,* Washington, D.C., 1965.

5-2 American Association of State Highway Officials (AASHO), *A Policy on Design of Urban Highways and Arterial Streets,* Washington, D.C., 1973.

5-3 Niessner, Charles W., *Roadway Delineation Practices Handbook,* Washington, D.C., FHWA, September 1981, 109 p.

5-4 American Association of State Highway and Transportation Officials (AASHO), *Guide for Selecting, Locating, and Designing Traffic Barriers,* Washington, D.C., 1977.

Part VI. WORK ZONE TRAFFIC CONTROL

Part VI. WORK ZONE TRAFFIC CONTROL

6A. GENERAL

Whenever work is done on or near the roadway, drivers are faced with changing and unexpected traffic conditions. These changes may be hazardous for drivers, workers, and pedestrians unless protective measures are taken.

Drivers do not make a distinction between construction, maintenance, or utility operations. Proper traffic control and safety are needed for all types of work.

Part VI of the Manual on Uniform Traffic Control Devices (MUTCD) is the national standard for all traffic control devices used during construction, maintenance, and utility activities. It is applicable to all streets and highways open to public travel and serves as the standard for the several State manuals. It sets forth basic principles and prescribes standards for the design, application, installation, and maintenance of the various types of traffic control devices required for all work activities occurring on public streets and highways. Included are requirements for color, size, shape, location, and need for the devices.

In all cases, the guidelines in this Part of the Handbook and the traffic control plan should conform to, or be of higher standards than, the MUTCD. Adequate protection of the traveling public, workers, and pedestrians will dictate the measures to be taken, consistent with the information presented herein and in the MUTCD.

Two references noted in the MUTCD are of particular importance. Standard Highway Signs (Ref. 6-l) has layout details for each of the standard signs in the MUTCD. The Standard Alphabets (Ref. 6-2) shows the size, shape, and stroke width of the various approved alphabets. These are available from the Federal Highway Administration, HTO-20, Washington, D.C. 20590.

This Part of the Handbook has been designed and written to be used with, not to replace, the MUTCD and explains how to apply the standards to various work situations. It should be useful to anyone involved with planning, designing, installing, maintaining, and inspecting traffic control. The illustrations can be used for a quick guide for various examples of traffic control. Contained in this Part are guidelines varying from planning traffic control to fit the needs of a particular work activity to the reasons for keeping accurate records.

6A-1 Fundamental Principles

Construction and maintenance areas can present to the motorist unexpected or unusual situations as far as traffic operations are concerned. Because of this, special care should be taken in applying traffic control techniques in these areas.

Principles and procedures which experience has shown tend to enhance the safety of motorists and workers in the vicinity of construction and maintenance work areas include the following:

- Traffic safety in construction zones should be an integral and high priority element of every project from planning through design and construction. Similarly, maintenance work should be planned and conducted with the safety of the motorist, pedestrian, and worker kept in mind at all times.
  - The basic safety principles governing the design of permanent roadways and roadsides should also govern the design of construction and maintenance sites. The goal should be to route traffic through such areas with geometrics and traffic control devices as nearly as possible comparable to those for normal highway situations.
  - A traffic control plan, in detail appropriate to the complexity of the work project, should be prepared and understood by all responsible parties before the site is occupied. Any changes in the traffic control plan should be approved by an individual trained in safe traffic control practices.
- Traffic movement should be inhibited as little as practicable.
  - Traffic control in work sites should be designed on the assumption that motorists will only reduce their speeds if they clearly perceive a need to do so. Reduced speed zoning should be avoided as much as practicable.
  - Frequent and abrupt changes in geometrics, such as lane narrowing, dropped lanes, or main roadway transitions which require rapid maneuvers should be avoided.
  - Provisions should be made for the safe operation of work vehicles, particularly on high speed, high volume roadways.
  - Construction time should be minimized to reduce exposure to potential hazards.
- Motorists should be guided in a clear and positive manner while approaching and traversing construction and maintenance work areas.
  - Adequate warning, delineation, and channelization by means of proper pavement marking, signing, and use of other devices which are effective under varying conditions of light and weather should be provided to assure the motorist of positive guidance in advance of and through the work area.

- Inappropriate markings should be removed to eliminate any misleading cues to drivers under all conditions of light and weather. On short term maintenance projects it may be determined that such removal is more hazardous than leaving the existing markings in place; if so, special attention must be paid to providing additional guidance by other traffic control measures.

- Flagging procedures, when used, can provide positive guidance to the motorist traversing the work area. Flagging should only be employed when required to control traffic or when all other methods of traffic control are inadequate to warn and direct drivers.

● To insure acceptable levels of operation, routine inspection of traffic control elements should be performed.

- Individuals who are trained in the principles of safe traffic control should be assigned responsibility for safety at worksites. The most important duty of these individuals is to insure that all traffic control elements of the project are in conformity with the traffic control plan and are effective in providing safe conditions for motorists, pedestrians, and workers.

- Modification in traffic controls or working conditions may be required in order to expedite safe traffic movement and to promote worker safety. It is essential that the individual responsible for safety have the authority to control the progress of work on the project in its relation to obtaining safe conditions, including the authority to modify conditions or halt work until applicable or remedial safety measures are taken.

- Work sites should be carefully monitored under varying conditions of traffic volume, light, and weather, to ensure that traffic control measures are operating effectively and that all devices used are clearly visible, clean, and in good repair.

- When warranted, an engineering analysis should be made (in cooperation with law enforcement officials) of all accidents occurring within work zones. Work zones should be monitored to identify and analyze traffic accidents or conflicts. As examples, skid marks or damaged traffic control devices may indicate needed changes in the traffic control.

- Work-zone accident records should be analyzed periodically to guide officials in improving work zone operations.

- All traffic control devices shall be removed immediately when they are no longer needed.

- The maintenance of roadside safety requires constant attention during the life of the construction zone because of the potential increase in hazards.
  - To accommodate run-off-the-road incidents, disabled vehicles, or other emergency situations, it is desirable to provide an unencumbered roadside recovery area that is as wide as practical.
  - Channelization of traffic should be accomplished by the use of pavement markings and signing, flexible posts, barricades, and other lightweight devices which will yield when hit by an errant vehicle.
  - Whenever practical, construction equipment, materials, and debris should be stored in such a manner as not to be vulnerable to run-off-the-road vehicle impact.

6A-2 Driver Information Needs in Work Zones

The usefulness of traffic control devices intended to assist motorists in guidance and navigation tasks depends on whether the devices satisfy a driver's need for information. Both the message content and the placement of the traffic control device must be carefully considered. Inappropriate messages and/or incorrect placement of signs, markings, and other traffic control devices can mislead and confuse the motorist.

In work zones there are usually three types of traffic control device message content. These include the warning of potential hazards, safe speed, and the lane or shoulder over which a vehicle should be traveling. Positive guidance principles should be considered when determining which traffic control devices will be used and where they will be located.

Research indicates that the more serious failures to meet driver needs result from:

- Providing contradictory or misleading information.
- Presenting a sign with inaccurate distance information, and
- Using nonstandard messages or using inappropriate standard signs.

6A-3 Training

Each person whose actions affect maintenance and construction zone safety, from the upper-level management personnel through construction and maintenance field personnel, should receive training appropriate to the job decisions each individual is required to make. Only those individuals who are qualified by means of adequate training in safe traffic control practices and have a basic understanding of the principles established by applicable standards and regulations, including those of the MUTCD, should supervise the selection, placement, and maintenance of traffic control devices in maintenance and construction areas.

6A-4 Summary

The following list of items can be used as general guidance for those involved with work-zone traffic control activities:

- To keep the motorist's respect and the agency's credibility, don't lie to the public.
- If work is not in progress or a hazard is not there, take down, fold over, or cover signs.
- If there is no need for channelizing devices, remove them.
- Do not tell drivers to expect a hazard that is not there. If you do, they may not believe other signs and devices used on the project.
- Do not assume that drivers and pedestrians will see or recognize the workers or the hazards in the work area.
- Maintain the controls as if every driver were approaching the area for the first time.
- Once you understand the philosophy of good work area traffic control, explain it to your workers or assistants so they can perform their work with a minimum of exposure to traffic, watching for problems, and reporting any damaged or missing devices.

Information provided herein can be used to supplement local, State, and national standards and covers more and different types of worksites than those illustrated in the MUTCD. However, it should be recognized that it is not feasible to cover every conceivable situation. The objective of this Part of the Handbook is to illustrate many of the typical worksites and to describe many common conditions encountered. Good engineering judgment must be used to arrive at the best traffic controls for a particular worksite, depending on the nature of the activity, location and duration of work, type of roadway, traffic volume and speed, and potential hazard.

6B. APPLICATION

6B-1 Traffic Control Zones

When traffic is affected by construction, maintenance, utility, or similar operations, traffic control is needed to safely guide and protect motorists, pedestrians, and workers in a *traffic control zone.* The traffic control zone is the distance between the first advance warning sign and the point beyond the work area where traffic is no longer affected.

Most traffic control zones can be divided into the following parts:

- Advance Warning Area,
- Transition Area,
- Buffer Space,
- Work Area, and
- Termination Area.

If no lane or shoulder closure is involved, the transition area will not be used. In this chapter, each of the "Parts" will be examined for one direction of travel. If the work activity affects more than one direction of travel, the same principles apply to traffic in all directions.

Figure 6-1 illustrates the five parts of a traffic control zone to be discussed in this section. The devices used in these areas, for different types and locations of work, are compared in Table 6-1.

Advance Warning Area

An advance warning area is necessary for all traffic control zones because drivers need to know what to expect. Before reaching the work area, drivers should have enough time to alter their driving patterns. The advance warning area may vary from a series of signs starting a mile in advance of the work area to a single sign or flashing lights on a vehicle.

Advance warning signs may not be needed when the work area, including access to the work area, is entirely off the shoulder and the work does not interfere with traffic. An advance warning sign should be used when any problems or conflicts with the flow of traffic might possibly occur.

Length of the Advance Warning Area

The advance warning area, from the first sign to the start of the next area, should be long enough to give the motorists adequate time to respond to the conditions. For most operations, the length can be:

- One-half mile to one mile for freeways or expressways,
- 1,500 feet for most other roadways or open highway conditions,
- at least one block for urban streets.

For more specific applications, refer to Figures 6-9 through 6-32.

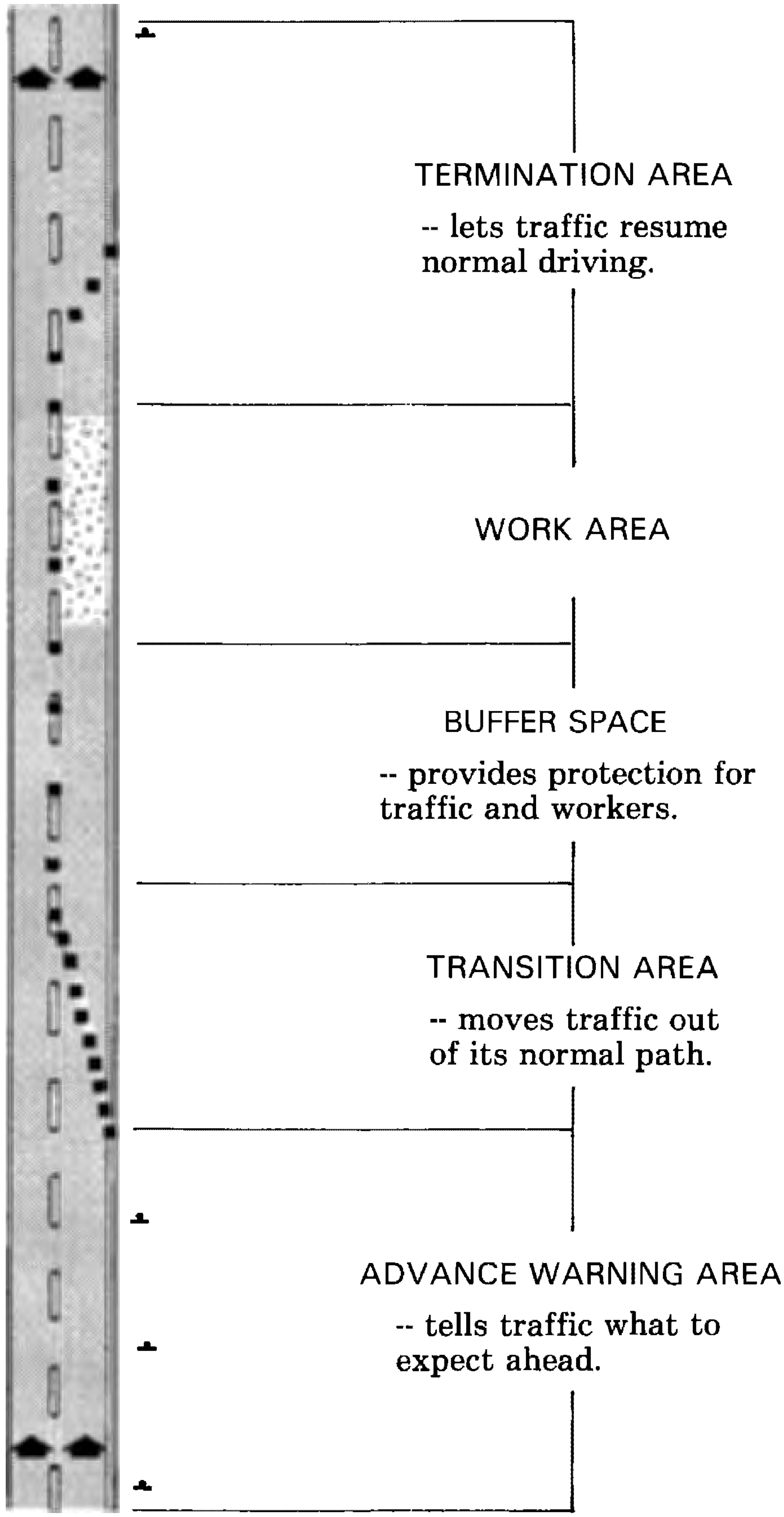
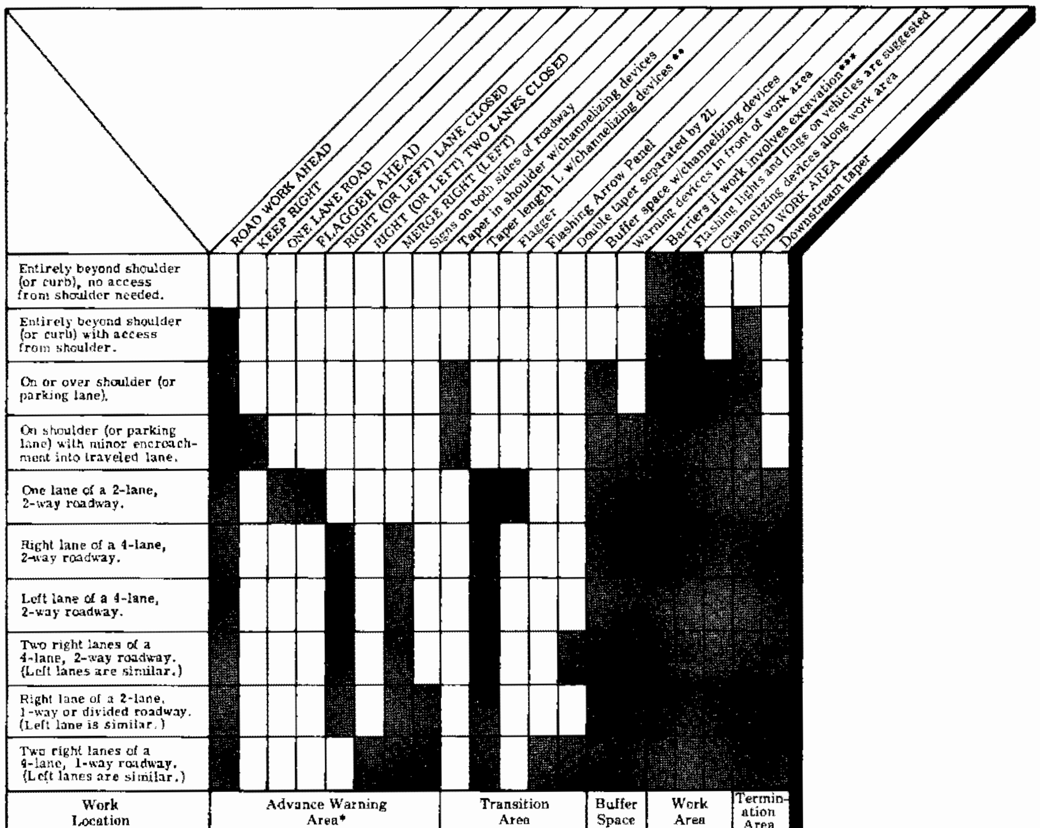


Figure 6-1 Areas in a Traffic Control Zone



* A consistent pattern of messages is shown in this figure. Refer to MUTCD for other acceptable messages or symbol signs.

** Old pavement markings should be removed and new markings placed in transition area for longer-term activities.

***The use of barriers is determined by an engineering analysis of the need for positive protection.

Table 6-1. Traffic Control Devices for various locations of work

Transition Area

When work is performed within one or more traveled lanes, a lane closure(s) is required. In the transition area, traffic is channelized from the normal highway lanes to the path required to move traffic around the work area. The transition area contains the tapers which are used to close lanes.

The transition area should be obvious to drivers. The correct path should be clearly marked with channelizing devices and pavement markings so drivers will not make a mistake and follow the old path. Existing pavement markings need to be removed when they conflict with the transition. New markings should be added. Pavement marking arrows are useful in transition areas.

With moving operations, the transition area moves with the work area. A shadow vehicle may be used to warn and guide traffic into the proper lane. Refer to section 6B-3, Shadow Vehicles, for additional guidance.

Tapers

A taper is a series of channelizing devices and pavement markings placed on an angle to move traffic out of its normal path. An example of a taper is shown in Figure 6-1.

Four general types of tapers used in traffic control zones are:

- Lane closure tapers are those necessary for closing lanes of moving traffic (sometimes referred to as channelizing tapers).
- Two-way traffic tapers are those needed to control two-way traffic where traffic is required to alternately use a single lane (commonly used when flaggers are present).
- Shoulder closure tapers are those needed to close shoulder areas.
- Downstream tapers are those installed to direct traffic back into its normal path.

Lane Closure Taper

The length of taper used to close a lane is determined by the speed of traffic and the width of the lane to be closed (the lateral distance that traffic is shifted). There are two formulas for determining the length of a taper (L) used for lane closures as discussed in Section 6C-2 of the MUTCD. The formulas and their criteria for application are shown in Table 6-2. If restricted sight distance is a problem (e.g., a sharp vertical or horizontal curve), the taper should begin well in advance of the view obstruction. The beginning of tapers should not be hidden behind curves. Table 6-3 shows the taper lengths, the recommended number, and the spacing of channelizing devices for various speeds and widths of closing.

Generally, tapers should be lengthened, not shortened, to increase their effectiveness. Traffic should be observed to see if the taper is working correctly. Frequent use of brakes and evidence of skid marks is an indication that either the taper is too short or the advance warning is inadequate. Section 6B–4 includes several typical applications which illustrate how tapers may be placed in urban areas in the vicinity of intersections.

FORMULAS FOR TAPER LENGTH	
Posted Speed	*Formula*
40 mph or under	$L = \frac{WS^2}{60}$
45 mph or over	$L = WS$

where: L = taper length
W = width of lane or offset
S = posted speed, or off-peak 85 percentile speed

Table 6–2. Formulas for taper length

Speed Limit M.P.H.	*Taper Length — Lane Width in Feet* 10	11	12	*Number of Channelizing Devices for Taper**	*Spacing of Devices Along Taper in Feet*
20	70	75	80	5	20
25	105	115	125	6	25
30	150	165	180	7	30
35	205	225	245	8	35
40	270	295	320	9	40
45	450	495	540	13	45
50	500	550	600	13	50
55	550	605	660	13	55

Table 6–3. Taper Lengths for Lane Closures—Distance L

**** Based on 12-foot wide lane. This column is appropriate for lane widths less than 12 feet.***

Two-Way Traffic Taper

The two-way traffic taper is used in advance of a work area that occupies part of a two-way road in such a way that the remainder of the road is used alternately by traffic in either direction. In this situation, the function of the taper is not to cause traffic to merge, but rather to resolve the potential head-on conflict. A short taper is used to cause traffic to slow down by giving the appearance of restricted alignment. Drivers then have time at reduced speed to decide whether to proceed cautiously past the work space or to wait for opposing traffic to clear. One or more flaggers are usually employed to assign the right-of-way in such situations.

Two-way traffic tapers should be 50 to 100 feet long, with channelizing devices spaced a maximum of 10 to 20 feet, respectively, to provide clear delineation of the taper. Flashing arrows boards (in the arrow mode) should never be used with a two-way traffic taper.

Shoulder Closure Taper

When an improved shoulder is closed on a high-speed roadway, it should be treated as a closure of a portion of the roadway because motorists expect to be able to use the shoulder in the event of an emergency. The work area on the shoulder should be preceded by a taper that may be shorter than for lane closures. One-half of the length from Table 6–3 is suggested as a maximum for shoulder closure tapers, provided the shoulder is not used as a travel lane. If the shoulder is being used as a travel lane, either through practice of through use caused by construction, a lane closure taper should be placed on the shoulder.

Downstream Taper

A downstream taper is used at the downstream end of the work area to indicate to drivers that they can move back into the lane that was closed. It is placed in the termination area. While closing tapers are optional, they may be useful in smoothing traffic flow. They may not be advisable when material trucks move into the work area by backing up from the downstream end of the work area.

Closing tapers are similar in length and spacing to two-way traffic tapers.

Buffer Space

The buffer space is the open or unoccupied space between the transition and work areas (Figure 6–1). With a moving operation, the buffer space is the space between the shadow vehicle, if one is used, and the work vehicle.

The buffer space provides a margin of safety for both traffic and workers. If a driver does not see the advance warning of fails to negotiate the transition, a buffer space provides room to stop before the work area.

It is important for the buffer space to be free of equipment, workers, materials, and workers' vehicles. When designing or setting out a Traffic Control Plan the following guidelines should be considered for buffer spaces:

- Place channelizing devices along the edge of the buffer space. The suggested spacing in feet is equal to two times the posted speed limit.
- Situations occur where opposing streams of traffic are transitioned so one lane of traffic uses a lane that normally flows in the opposite direction. In these situations, a buffer space should be used to separate the two tapers for opposing directions of traffic because it could help prevent head-on collisions. See Figure 6-12 for an example of this type of buffer space.

Work Area

The work area is that portion of the roadway which contains the work activity and is closed to traffic and set aside for exclusive use by workers, equipment, and construction materials. Work areas may remain in fixed locations or may move as work progresses. An empty buffer space may be included at the upstream end. The work area is usually delineated by channelizing devices or shielded by barriers to exclude traffic and pedestrians.

Conflicts and Potential Hazards

Conflicts between traffic and the work activity are potential hazards. These increase as:

- The work area is closer to the traveled lanes;
- Physical deterrents to normal operation exist; such as uneven pavements, vehicles loading or unloading;
- Speed and volume of traffic increase; and
- The change in travel path gets more complex, shifting traffic a few feet in comparison with shifting traffic across the median and into lanes normally used by opposing traffic.

Work areas that remain overnight have a greater need for delineation than daytime operations.

Every feasible effort should be made to minimize conflicts. Some suggestions include:

- Use traffic control devices to make the travel path clearly visible to traffic.
- Place channelizing devices between the work area and the traveled way. Section 6C-2 of the MUTCD states that devices placed on a tangent (along the work area) to keep traffic out of a closed lane should be spaced in accordance with the extent and type of activity,

the speed limit of the roadway, and the vertical and horizontal alignment such that it is apparent that the lane is closed. The MUTCD does not specify a spacing for the devices along the closed lane. For high-speed roadways, a range from 2S to 4S (two to four times the posted speed limit) is suggested. For low-speed or urban streets, a closer spacing may be used.

- Provide a safe entrance and exit for work vehicles.
- Protect mobile and moving operations with adequate warning on the work and/or shadow vehicles.
- Flags and flashing lights should be considered on work vehicles exposed to traffic.

Termination Area

The termination area provides a short distance for traffic to clear the work area and to return to the normal traffic lanes. It extends from the downstream end of the work area to the END CONSTRUCTION or END ROAD WORK sign. A downstream taper may be placed in the termination area.

For some work operations, such as single location utility or maintenance repair, it may not be necessary to display a sign as it will be obvious to drivers that they have passed the work area.

There are occasions where the termination area could include a transition. For example, if a taper were used to shift traffic into opposing lanes around the work area, then the termination area should have a taper to shift traffic back to its normal path. This taper would then be in the transition area for the opposing direction of traffic. It is advisable to use a buffer space between the tapers for opposing traffic, as shown in Figure 6-12.

Avoid "gaps" in the traffic control that may falsely indicate to drivers that they have passed the work area. For example, if the work area includes intermittent activity throughout a 1-mile section, the drivers should be reminded periodically that they are still in the work area. The primary purpose of the guide sign ROAD CONSTRUCTION NEXT— MILES is to inform the drivers of the length of the work area. It should not be erected until work begins.

6B-2 Planning for Traffic Control

During planning for work zones, one should strive for the greatest payoff in terms of safety and convenience at a cost commensurate with the hazards and problems involved. A properly installed traffic control zone will allow traffic to pass through or around a work zone safely. It requires time and effort for planning, installation, and maintenance. All employees involved with work-zone safety should be properly trained. These include design, traffic, and construction engineers, inspectors, superintendents, and foremen.

All work-zone traffic-control planning centers around an analysis of the work activity and relating it to the provision of adequate safety and capacity. What is the likelihood of motorists failing to negotiate the work zone safely? What are the consequences of such action on pedestrians, workers, or other motorists?

Planning for traffic control through a construction zone may be more involved than for maintenance or utility zones because of the differences in traffic disruption and duration of the work. Although the requirement for safety in all zones is the same, planning for the three types of work operations will be discussed separately. The exposure of traffic to potential hazards is a function of the traffic volume and the length of time that the closure will be in effect. The goals common to all traffic control zones are:

- to minimize accidents and accident severity; and
- to minimize inconvenience and conflicts as a result of the work. It should be recognized that these goals may at times be at odds.

Minimize Accidents

For all work zones, the first fundamental principle, according to Section 6A–5 of the MUTCD, is that safety should have a high priority through all stages of the work. The following list is a set of guidelines that may be helpful in achieving this goal:

- Use traffic control devices that are visible and effective.
- Follow the standards in the MUTCD on the use and location of tapers and transitions. Avoid introducing severely reduced travel path geometrics at the approaches to or within the work area.
- Minimize fixed object hazards. For example, use lightweight channelizing devices and use crash cushions to protect barrier ends. Sand bags should be placed on the bottom of supports for various devices so that they do not become a projectile as a result of a collision.
- Minimize traffic conflicts with workers and equipment. Consider using a portable barrier.
- Provide night visibility with illumination, reflectorized devices, warning lights, and pavement markings. Consider floodlighting hazardous areas. However, care should be taken to insure that the floodlights are not aimed in a way that would adversely affect motorist's vision.
- Provide safe pedestrian walkways by separating pedestrians from vehicular traffic and work activities. Provide safe pedestrian and vehicular access across or through driveways.

- Store equipment and materials outside the clear recovery zone as defined in the Guide for Selecting, Locating, and Designing Traffic Barriers (Ref. 6-3).
- Provide a buffer space between traffic and workers.
- Provide safe employee access to work, storage areas, businesses, residences, and within the work area. Provide a safe entrance and exit for work vehicles. This may require the use of temporary traffic signals, flaggers, or temporary portable barriers.
- Plan for the safety of workers on the project as required by safety and health regulations. (e.g., safety clothing, hardhats, etc.)
- Flags and flashing lights should be utilized on work vehicles exposed to traffic. To protect mobile and moving operations, shadow vehicles may be used and equipped with signs, flags, flashing lights, and/or crash cushions as appropriate.

Minimize Inconvenience

Work in or near traveled lanes often causes confusion and disruption of normal traffic. The traffic control plan should be aimed at reducing inconvenience and conflicts, as stated above and in Section 6A-5, Principle 2, of the MUTCD. The following list is a set of guidelines that may be helpful in achieving this goal:

- Close only those lanes that must be closed, and reopen them as soon as practicable to maintain maximum roadway capacity.
- Avoid severe speed reductions.
- Avoid traffic delays that could cause backups.
- Avoid scheduling work during peak hours and holidays.
- Prepare an alternate route or plan in case of an accident or other emergency. If an alternate route is not feasible, be prepared to use signs, flaggers, and radio announcements to warn traffic of the backup and to explain the delay.
- Reduce inconveniences for pedestrians and bicyclists by providing the shortest and safest path, safe clearances, and minimum grades, steps, and curbs.
- Emergency organizations, such as police, fire, and ambulance services, should be notified prior to the start of work. This will allow them to adjust their routes and/or work schedules accordingly.
- Emergency vehicles should have a high priority in passing through a work zone or using an alternate route.
- Access to police and fire stations, fire hydrants, and hospitals should be maintained at all times.

Utility Work Zones

Utility work may be divided into three classifications; emergency, maintenance, and new construction. The guidelines for traffic control listed here are for normal situations and additional protection should be provided when special complexities and hazards exist.

Emergency Work

- Can occur at any time of day or night;
- May be caused by storm damage;
- May involve disruptions of utility service to customers;
- Work operation usually involves a small crew and a work vehicle for a short period of time;
- The work vehicle should be equipped with a yellow flashing light, a limited number of portable signs and channelizing devices in good condition, and equipment for flaggers in the event they are needed; and
- The extent of traffic control may be less than longer term construction or maintenance, yet the safety of pedestrians, motorists, and workers should be provided.

Maintenance and New Construction for Utilities

The public will not easily make a distinction between maintenance and new construction so the type of traffic control used should be adequate for the nature, location, and duration of work, type of roadway, traffic volume and speed, and potential hazard. New construction and some maintenance activities are planned (as opposed to emergency activities) so the following guidelines should be considered:

- In urban areas, consider avoiding the hours of peak traffic when scheduling work.
- Maintain street and road work areas for only as long as is necessary to safely move in, finish the work, remove all utility work signs, and move out.
- Take special care to clearly mark suitable boundaries for the work space with channelizing devices so pedestrians and drivers can see the work space. If any of the traveled lanes are closed, tapers shall be used as required by the MUTCD. If a shoulder is closed, a shoulder taper is suggested.
- Pedestrians should not be expected to walk on a path which is inferior to the previous path. Loose dirt, mud, broken concrete, or steep slopes may force pedestrians to walk on the roadway rather than the sidewalk. Repairs (temporary or permanent) to damaged sidewalks should be made quickly. This may include bridging with steel plates or good quality wood supports.

- Any work which cannot be completed during the day and which impedes traffic or presents a hazard overnight may need additional attention. Reflectorized signs and channelizing devices are required by the MUTCD. Warning lights are optional but should be considered.
- Any member of the crew who serves as a flagger should be equipped with a red flag or a STOP-SLOW paddle, a reflective vest, and should be trained for proper flagging procedures.
- Work areas involving excavations on the roadway generally should not exceed the width of one traffic lane at a time. The work should be staged and, if needed, approved bridging should be utilized. This type of activity should be fully coordinated with the traffic or public works department having jurisdiction over the street or highway.

Highway Maintenance Work Zones

Maintenance operations are needed to preserve, repair, and restore the streets and highways and include those activities performed on travelway surfaces, shoulders, roadsides, drainage facilities, bridges, signs, markings, and signals.

These operations may be emergencies (as a result of storms or accidents), or planned activities. They may be stationary, mobile, or moving operations. The traffic control needed will vary according to the nature, location and duration of work, type of roadway and speed of traffic, and potential hazard.

Traffic Control Plans for Construction Projects

A formal Traffic Control Plan (TCP) is required to be included in the plans, specifications and estimates (PS&E) for all Federal-aid projects by Federal-Aid Highway Program Manual 6-4-2-12. (Ref. 6-4.) Other construction projects should also have a TCP, as indicated in Section 6A-3 of the MUTCD. These plans may range in scope from a very detailed TCP designed solely for a specific project, to a reference to standard plans, a section of the MUTCD, or a standard highway agency manual. The degree of detail in the TCP will depend on the complexity of the project and on the interaction of traffic needs and construction activities.

Highway agency design and traffic engineers will develop the TCP and include it in the PS&E. The contractor can develop a TCP, but may use it only if it is equal to or better than the TCP in the plans, and is approved by the highway agency.

The following people and organizations should be involved in the development of a TCP:

- Transportation officials from local, State, and Federal levels, including design, traffic, and construction engineers;
- Police and fire officials at the State and local levels; and
- Utility companies.

Once the TCP has been developed and approved, but before construction starts, others should be notified, as follows:

- Businesses in the area;
- Affected public groups, such as homeowners' organizations;
- School officials, so they can change bus schedules if necessary;
- Local government officials, including the Chamber of Commerce; and
- Tow truck services.

The following factors need to be considered for the TCP:

- Economic and community
  - commercial business districts,
  - residential locations,
  - recreation areas,
  - shopping centers,
  - railroad crossings,
  - rural areas, and
  - other work planned adjacent to or within the area of the project;
- Traffic
  - volumes,
  - peak hours, including holiday, special event and recreation traffic,
  - pedestrian traffic,
  - bicycles,
  - large vehicles such as trucks and buses,
  - speed of traffic,
  - capacity of roadway,
  - traffic signal operation (effect on existing vehicle detectors); and
- Seasonal changes and weather, including
  - maintaining traffic control during seasonal shutdowns,
  - loss of visibility and damage to devices during rain or snow,
  - temperature restrictions for some phases of construction, and
  - maintenance of traffic control devices (cleaning, cutting vegetation away from signs).

A 24-hour workday may be desirable as it allows the total number of working days to be decreased. Consideration should include:

- Neighborhood objection to nighttime noise;
- Higher cost, for labor and lighting;
- Higher percentage of drinking drivers at night; and
- Limited available commercial services, such as supply of ready-mix concrete or aggregate.

The controlled staging of construction should be considered, including:

- The location of work (on roadway, shoulders, or sidewalks);
- The number of lanes required for the work activity;
- Hours of a day during which a lane may be closed;
- Whether work may progress simultaneously in both directions of traffic;
- The length of the work area (controlled staging such as guardrail removal and immediate replacement);
- Minimize time of exposure to hazards such as dropoffs;
- Time involved, such as curing of pavement or bridge decks;
- Remove or shield the motorist from hazards created by the work activity within the recovery area such as boulders, drainage basins, pipe, headwalls, blunt ends of guardrail, and sign supports; and
- Delays during traffic control set-up and take-down time (preferably during low traffic volume periods).

Traffic control planning should consider the inclusion of unit pay items in the construction contract to cover the furnishing, application, installation, and maintenance of traffic control devices of acceptable quality to comply with the agency's specifications.

Materials developed for the TCP may include but are not limited to:

- Scaled drawings of the control zone;
- List of devices selected for installation;
- Special manpower needs, such as flaggers;
- Copies of permits;
- Phone numbers of officials to be contacted in an emergency;
- Scaled drawings of construction stages, including detours; and
- Schedules for times during the day when work is permitted or when certain lanes should remain open.

Speed Control for Detours, Transitions, and Median Crossovers

Studies have shown that reliance upon speed zone signing solely is not an effective method of reducing travel speeds in work zones. This should be recognized during the design of the project and the following are some guidelines for determining speed limits in detours, transitions, and median crossovers:

- Detours and crossovers should be designed for speeds equal to the existing speed limit if at all possible. Speed reductions should not be more than 10 m.p.h. below the limit of the entering roadway.
- Where a speed reduction greater than 10 m.p.h. is unavoidable, the transition to the lower limit should be made in steps of not more than 10 m.p.h.
- Where severe speed reductions are necessary, police or flaggers may be used in addition to advance signing. The conditions requiring the reduced speed should be alleviated as soon as possible.

Transitional Areas from Construction Zones to Sections of Older Roadways

Transitional areas from construction zones to sections of older highways should be carefully designed and located so that the driver can adjust to the reduced standards or changed conditions. It should be recognized that these transitional areas may remain in place for a period of time until the adjacent section of roadway is improved. The following factors should be considered when designing, constructing, and operating these transitional areas:

- Provide adequate sight distance and geometrics consistent with the roadway having the higher design speed.
- If channelizing devices, other than portable barriers, are used, they should be lightweight or yielding.
- Sign supports should be yielding or breakaway. Pavement markings should be used to provide a well defined path.
- Transitional areas should be kept clear of unnecessary hazards.

Pavement Dropoffs

Highway agencies have varying opinions as to which depth of pavement dropoff needs some type of treatment. They also have varying opinions as to the type of treatment that should be used. A research project is underway that may provide guidance as to where and what type of devices to use for dropoffs of different depths with varying roadway conditions.

Dropoffs should be kept to a minimum in frequency, duration, and depth. When they are inevitable, good judgment should be used to determine the treatment that will be employed. The following items should be considered when developing a TCP for a project that will have a pavement dropoff condition:

- Where possible, the contract should limit the amount of difference in elevation between adjacent lanes.

- The time that a difference in elevation will be allowed should be limited.
- Signs can be used to advise motorists of the dropoff condition.
- A fillet or wedge of gravel or paving material can be placed as shown in Figure 6-8.
- Where excessive dropoffs are necessary it may be possible to close the adjacent lane with appropriate channelizing devices. If the adjacent lane can not be closed it may be necessary to install longitudinal roadside barriers such as guardrail or portable concrete barrier.

6B-3 Function of Devices

Traffic control devices include signs, signals, lighting units, pavement markings, delineators, channelizing units, hand signaling signs or flags, and portable barriers which are used to warn, guide, or regulate traffic. This chapter discusses elements of design, proper application, and placement for various devices used. Table 6-4 notes how several devices may be attached to other devices and supports.

The examples of devices portrayed in this handbook are those commonly used. They follow the MUTCD standards in dimension, copy size, and message. Alternates that are available are given in the MUTCD.

Signs

Typical signs that are available are shown in Part VI of the MUTCD. They are classified as regulatory, warning, and guide signs.

Regulatory Signs

Regulatory signs impose legal restrictions and may not be used without permission from the authority having jurisdiction over the roadway.

- *Design*—Regulatory signs are typically rectangular in shape with the long dimension vertical. The standard color scheme is black lettering on a white background. A red circle with a diagonal slash may be used in conjunction with a black diagram to indicate a prohibited maneuver.
- *Exceptions*—Red is used as a predominant color for STOP, YIELD, DO NOT ENTER and WRONG WAY signs. Unique shapes and color schemes increase the target value for these important signs.

Warning Signs

Warning signs are used to give notice of conditions that are potentially hazardous to traffic. They should be used when such conditions are real, particularly when the danger is not obvious or cannot be seen by the

Attachments \ Supports	Signs	Cones & Tubes	Vertical Panels	Barricades, Types I, II	Barricades, Type III	Drums	Barriers	High-Level Warning Device	Shadow Vehicle	Work Vehicle	Post, Single Support
Signs					■	■		■	■	■	■
Flags	■	■				■		■	■	■	
Delineators		■					■				■
Flashing Light, Type A			■	■	■	■					
Flashing Light, Type B	■				■						
Steady Burn Light, Type C		■	■	■		■	■				
High-Level Warning Device									■	■	■
Arrow Panel									■	■	
Crash Cushion							■		■	■	

NOTE: Shaded blocks indicate appropriate devices which may be attached to other devices or supports.

Table 6-4 Signs and devices that may be mounted on or used in combination with other devices

motorist. They should not be overused or they will lose their attention-getting value. Likewise, they should not overwarn or be overly restrictive or they will lose credibility with motorists.

- *Design*—Warning signs are typically diamond-shaped with one diagonal vertical. Permanent warning signs have a black legend on a yellow background. Construction and maintenance warning signs are a special series with the black legend on an orange background. The orange color is used to indicate the temporary nature of the condition and the additional potential hazard of the worksite. Traditionally, work activities have included construction, maintenance, and utility operations. However, orange color warning signs may have application for all work activities within the right of way such as survey crews (other than for C & M projects) or temporary weighing stations.
- *Exceptions*—Two warning signs have unique shapes which make them easily distinguishable:
  - — The railroad crossing warning sign is round with a yellow background only; and
  - — The NO PASSING ZONE sign is pennant shaped.

  The TURN OFF 2-WAY RADIO and END BLASTING ZONE warning signs are rectangular with their long dimension horizontal to better accommodate the message.

  The Large Arrow sign, because of its shape, is placed on a rectangular background with the long dimension horizontal.

  Mounting considerations for large warning signs on freeways and expressways may justify a change to the rectangular shape; however, such variances should have prior approval of the appropriate highway authority (Section 6B-13, MUTCD).
- *Placement*—Warning signs should be placed sufficiently in advance of the condition for which warning is given to permit the motorist time to understand the information and make any required response. Exceptions to this principle include the Large Arrow and the TWO WAY TRAFFIC signs.

Guide Signs (Informational Signs)

Guide signs show destinations, directions, distances, services, points of interest and other geographical or cultural information. They may be used if their placement does not distract from the more important regulatory and warning signs.

Section 6B-35 of the MUTCD states that informational signs are required at work zones as follows:

- Standard route markings, to the extent that temporary route changes are necessary.

- Directional signs and street name signs, when used with detour routing, may have a black legend on an orange background.
- Special information signs relating to the work being done shall have a black message on an orange background. Examples are ROAD CONSTRUCTION NEXT 5 MILES, END CONSTRUCTION, DETOUR, PILOT CAR FOLLOW ME.

Choosing Signs

Standard signs and messages, as shown in the MUTCD, should be used. Drivers are familiar with those signs and know how to react. Nonstandard sign messages may be confusing. All signs should be made in a quality sign shop or purchased from a reputable business. "Home-made" signs are immediately suspect and do not command any driver respect.

When choosing signs, the following should be considered:

- Choose signs that are appropriate; signs that accurately describe the work situation.
- Choose the message on signs according to what action the driver needs to take. Use larger signs when greater visibility is desired, as with high speed or volume. Avoid messages having only a local meaning since it may not be clear to strangers.
- Start with a common sign at the beginning of the work area. Then use signs with more specific messages, with the most specific sign, stating what action should be taken, closest to the work area. Drivers sometimes forget what they are told, so the last sign in the advance warning area should tell them specifically what to look for or expect, such as a flagger or a one-lane road.
- The message "AHEAD," or an appropriate distance, is used on the warning signs. Use the end of the advance warning area as the point for deciding on the measurement on warning signs. For example, ROAD WORK 1 MILE means that the advance warning area ends in one mile, and the transition or work area starts.
- The overall effect of the signs should be to make the driver aware of what he is approaching and what action may be required.

The warning area length for moving operations will vary according to geometrics and sight distance.

Sign Spacing

Section 6B-3 of the MUTCD states "Where a series of advance warning signs are used, the warning sign nearest the worksite should be approximately 500 feet from the point of restriction with the additional signs at 500–1000 foot intervals."

A "rule-of-thumb" for the spacing between signs in a series is:

- 250 feet for urban, residential, or business districts, or with speeds under 40 m.p.h.;
- 500 feet for urban arterials and rural roads, or with speeds over 40 m.p.h.; and
- 1000 feet for expressways and freeways.

Other Considerations

The location of the advance warning area may need to be adjusted when special problems are encountered. Typical situations include:

- Urban: distance restrictions can be imposed by the length of city blocks; additional advance warning may be necessary due to "extra" intersections created by alleys, shopping centers, and side streets.
- Rural, open highway: there is a need for greater warning distances and larger signs.
- Divided roadways and one-way streets with two or more lanes in one direction: signing on both sides of the roadway should be considered if a median is available. Existing overhead sign structures may be used for warning signs.
- Signs should be high enough to be seen over parked cars or traffic.
- Signs should not block the view of vehicles entering the area from gas stations, restaurants, cross roads, etc.
- All signs should be carefully placed for best visibility. Existing signs which are not needed during the work activity should be removed or covered.

Speed-zone signing, either advisory or regulatory, is usually not an effective way to control traffic. Posting severely reduced speed limits that cannot be enforced is particularly ineffective. The need for speed reduction must be obvious to drivers. Drivers will slow down only if they see that they need to.

If traffic is heavy and becomes backed up, additional warning signs should be placed in advance of the backup.

A drive-through check, both day and night, should be made periodically to determine if signs have been properly spaced to allow adequate driver response time. Project personnel are normally quite familiar with the project. They should try to look at the work area as through the eyes of a stranger.

Sign Supports

Signs may be attached to posts or portable supports. Fixed sign supports should be used on long-term projects. Portable supports are more practical for short-term projects or changing activities such as flagging.

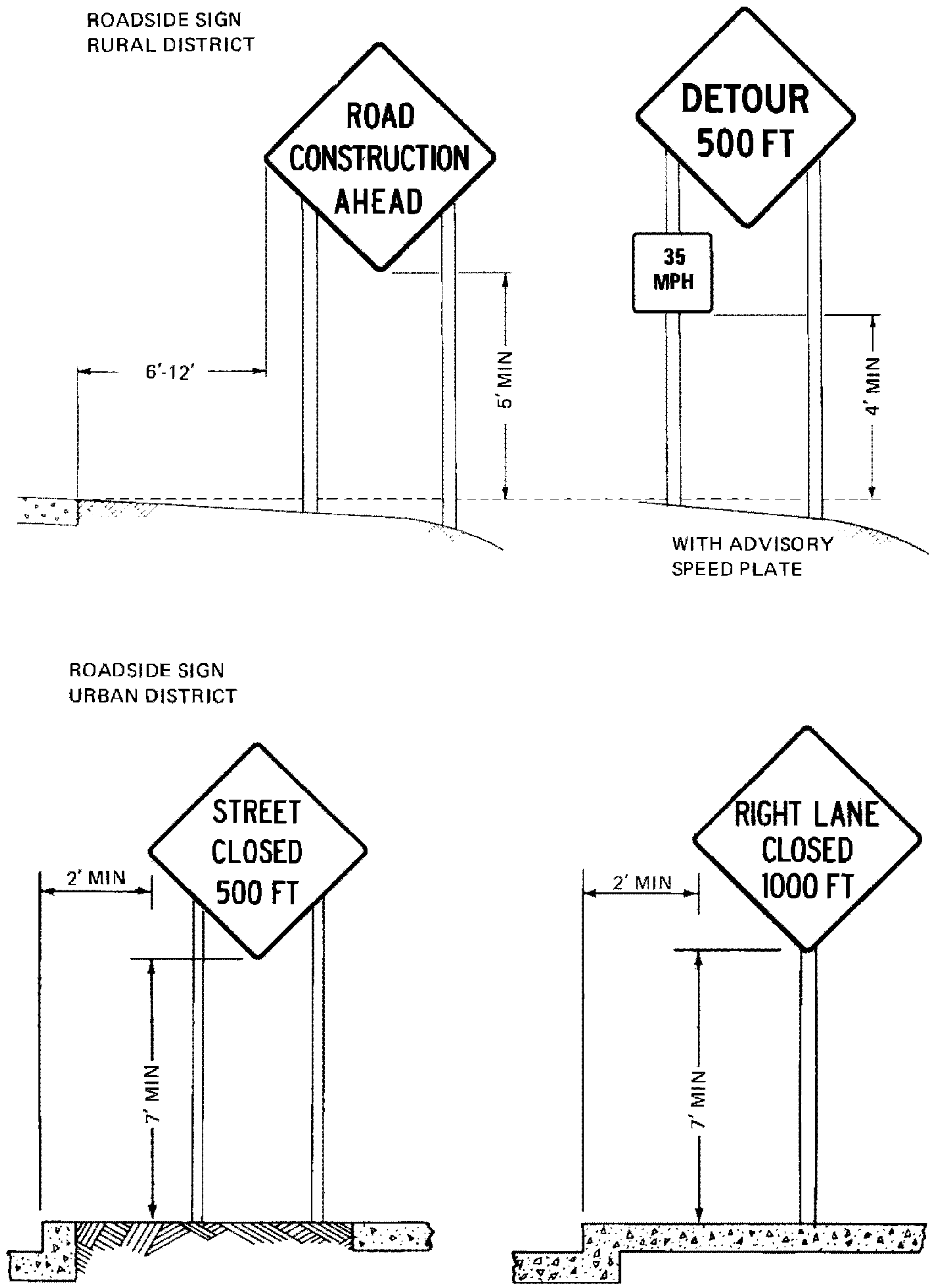


Figure 6-2 Height and Lateral Locations of Signs—Typical Installation (MUTCD, Figure 6-1)

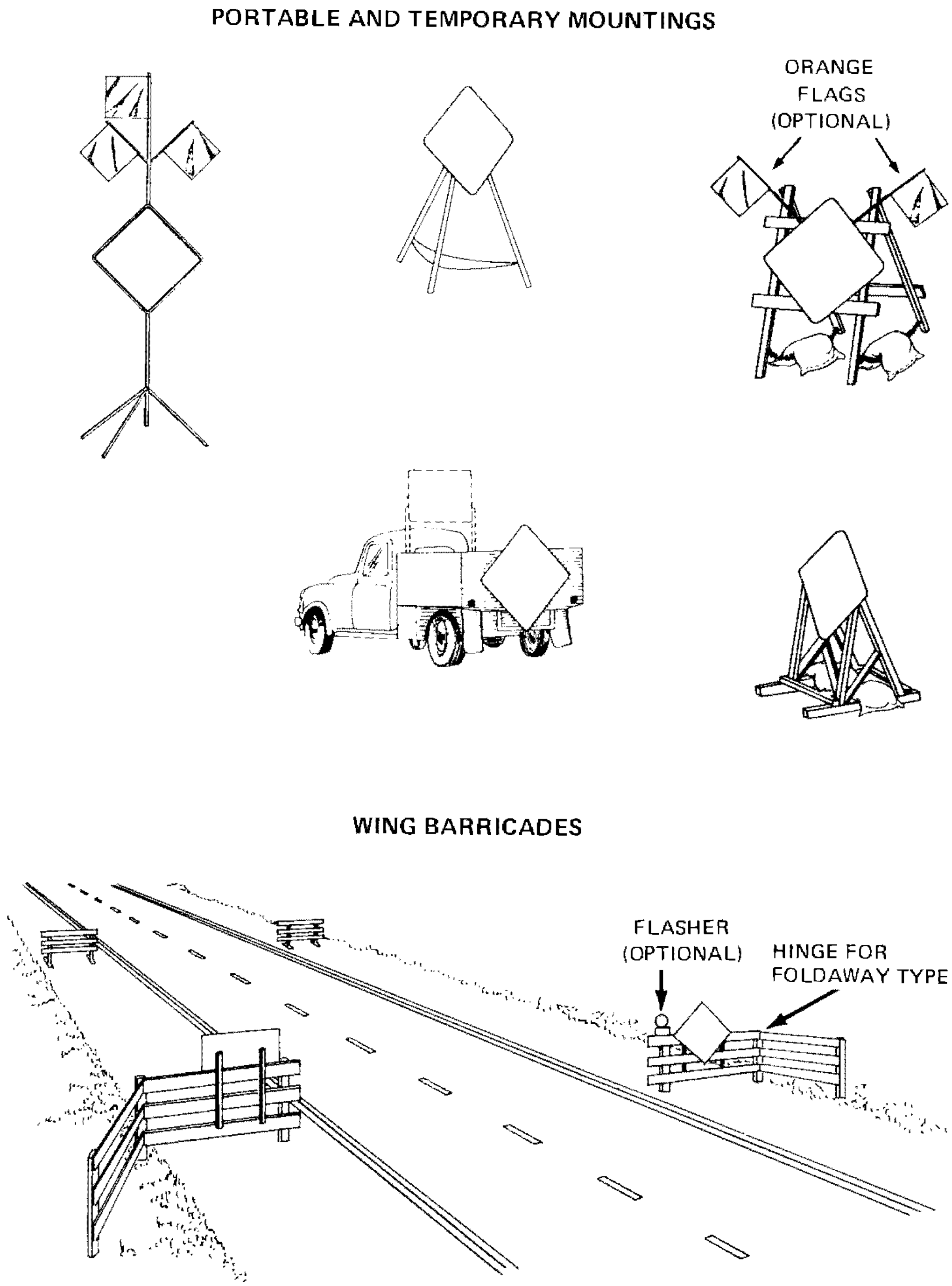


Figure 6-3 Methods of Mounting Signs Other than on Posts (MUTCD, Figure 6-11)

Lightweight, yielding, or breakaway supports should be used for all sign installations. Construction zone sign supports should meet the breakaway requirements for permanent installations as discussed in Part II, Signs. To avoid glare from headlights, signs may be tilted back and slightly away from the roadway.

Figure 6–2 shows the minimum height requirements for signs attached to posts. Signs on portable supports are required by the MUTCD to be at least 1 foot above the roadway, Figure 6–3. Sign locations and mounting heights may be adjusted above the minimum requirements to obtain good visibility.

Single sign supports are usually adequate for signs up to 36 $\times$36 in. Larger signs normally require two supports to preclude twisting and turning of the assembly, caused by wind or air movement resulting from trucks passing close to the sign.

Signs at Night

All signs used at night are required by the MUTCD to be reflectorized or illuminated.

- *Reflectorized* signs should be checked periodically for proper reflectivity and cleanliness. One method is to drive through the work zone at night using low-beam headlights. Another method is for the inspector to use a piece of reflectorized sign material (inspector's guide) which has been predetermined by the agency to be of minimum acceptable quality for reflectivity. Place the inspector's guide on the sign to be inspected. Step back about 30 feet, view the sign and inspector's guide with a flashlight held close to the eye. If the inspector's guide is brighter than the sign, the sign should be cleaned and/or replaced.

  Experience has shown that beads on paint are not effective for reflectorizing signs or channelizing devices. The beads are easily worn off and they do not reflect when the surface is wet. Reflectorized sheeting having a smooth, sealed outer surface should be used for signs and other traffic control devices. Reflectorized material should meet the agency's specifications for new material.

- *Illuminated* signs should be considered when a reflectorized sign is not effective, as when the sign is overhead or when background light sources reduce the sign's visibility. Refer to Section 6B–2 of the MUTCD for additional details on signs.

Markings

Pavement markings are very important in guiding traffic through work zones. Pavement markings and delineators outline the vehicular path to lead traffic around a work area.

Pavement Markings

Drivers use pavement markings as a primary means of guidance. Pavement markings include lane stripes, edge stripes, centerline stripes, pavement arrows and word messages. Markings are made of paint (with bead reflectorization), raised reflectorized markers, preformed adhesive-backed reflectorized tape, cold preformed reflectorized plastics, hot reflectorized plastics, epoxies, and other materials placed by heating and spraying.

The standard markings planned for the road should be in place before opening a new facility to traffic. Also, if revised lane patterns are planned for the work zone, temporary markings should be placed before the traffic is changed. Where this is not feasible, such as during the process of making a traffic shift or carrying traffic through surfacing operations, temporary delineation may be accomplished with lines of traffic cones, other channelizing devices, or strips of adhesive-backed reflectorized tape.

When pavement placed during the day is to be opened to traffic at night and permanent striping cannot be placed before the end of work, a temporary stripe should be applied to provide an indication to the driver of the location of the lane or centerline. Standard marking patterns are most desirable for this use. On rock-screened seal coats, striping should be applied following removal of excess screenings.

For relatively long-term use or when the surface is to be covered later with another layer, reflectorized traffic paint, or preformed adhesive-backed tape, with or without raised pavement markers should be considered. For relatively short-term use, and when frequent shifts are to be made, adhesive-backed reflectorized tape is useful. Raised pavement markers may be used to form the pavement markings or may be used to supplement marked stripes. High speeds and volumes of traffic may justify raised markers for even comparatively short periods. They are particularly valuable at points of curvature and transition.

Pavement arrows are useful in guiding traffic when the traveled way does not coincide with the configuration of the exposed surface area, such as when the color of the transition pavement is different from the existing pavement. Pavement arrows are especially useful on a two-way, undivided roadway to remind the driver of opposing traffic. TWO-WAY TRAFFIC signs should be used in conjunction with the arrows for the application. The arrows should be completely removed once the two-way traffic condition is no longer needed.

Whenever traffic is shifted from its normal path, whether a lane is closed, lanes are narrowed, or traffic is shifted onto another roadway or a detour, conflicting pavement markings should be removed. Exceptions to this may be made for short-term operations, such as a work zone under flaggers' control, moving or mobile operations. Use of raised pavement markings or removable markings may be economical since they are usually easier to remove when no longer needed. A discussion on pavement stripe removal techniques is included in Part III, Markings.

Delineators

Delineators are reflective units with a minimum dimension of approximately 3 inches. The reflector units can be seen up to 1,000 feet under normal conditions, when reflecting the high beams of a car. The delineator should be installed about 4 feet above the roadway on lightweight posts.

Delineators should not be used alone as channelizing devices in work zones but may be used to supplement these channelizing devices in outlining the correct vehicle path. They are not to be used as a warning device. To be effective, several delineators need to be seen at the same time. The color of the delineator should be the same as the pavement marking that it supplements.

Channelizing Devices

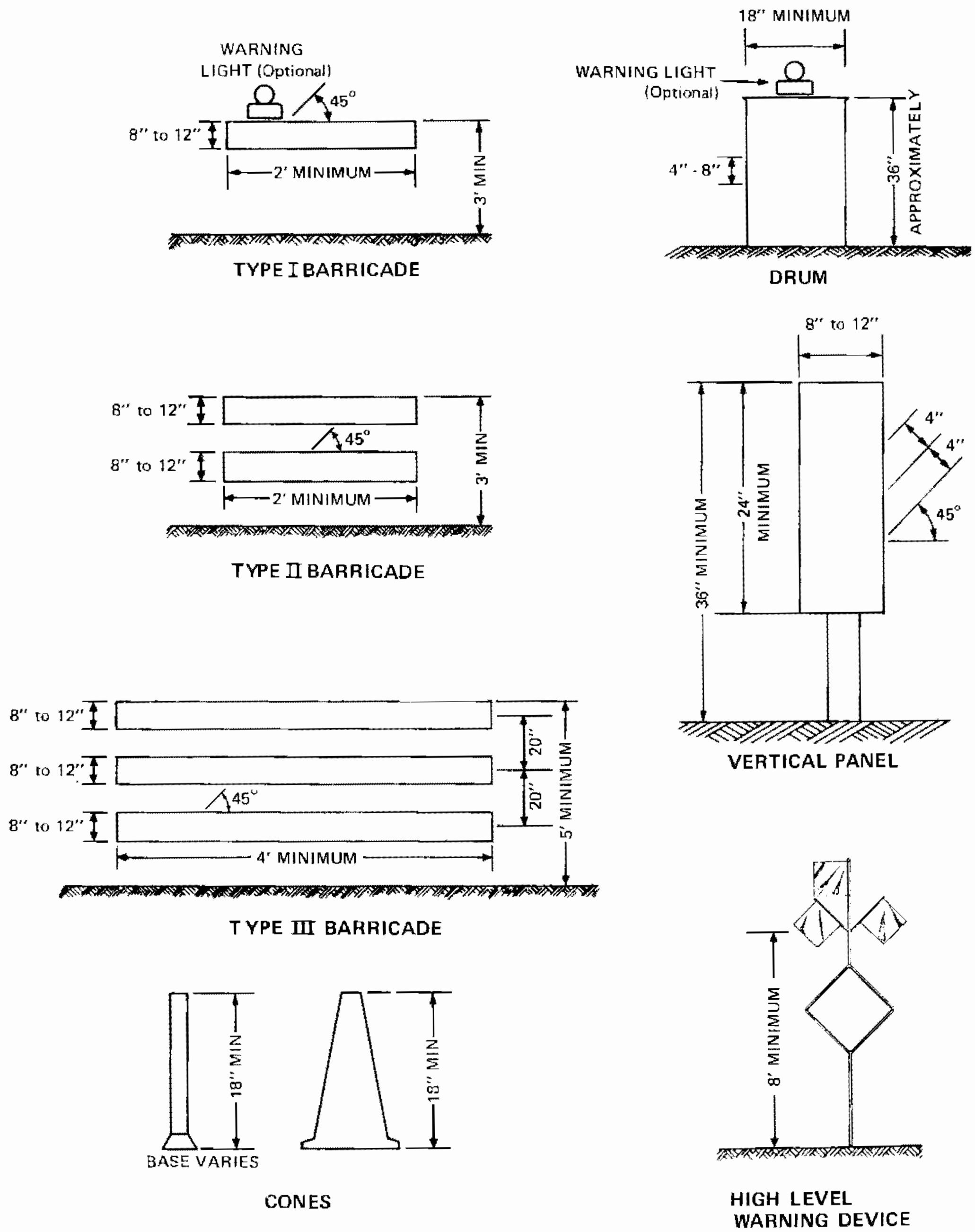
Channelizing devices are used to warn and direct traffic away from or around a work area. They also control the flow of traffic when separating two directions of travel. Several types, including barricades, vertical panels, cones, and drums, are shown in Figure 6-4. Each type has distinct visibility characteristics and advantages.

The MUTCD requires that channelizing devices to be used at night shall be reflectorized with a material having a smooth, sealed outer surface. This includes commercially available reflectorized sheeting and tape strips. All channelizing devices used should be a lesser hazard, if struck by an errant vehicle, than the hazard marked.

Some devices require a weight, such as a sand bag, because they are easily knocked or blown over. These weights should be placed at the bottom of the device for stability and to keep the weight from being thrown as a result of a collision. Neither the device nor the weight should cause excessive damage when struck by a vehicle. Also, sand bags should not be placed in a way that will limit the motorist's view of the device.

Cones

Cones are lightweight channelizing devices that may be stacked for storage, are easy to place and remove, and are a minor impedence to traffic flow. For stability, a rubber or sand collar or specially weighted base may be added. Cones cause little or no damage when hit. They shall be at least 18 inches high, but taller cones should be used on freeways and other roadways where speeds are relatively high, or wherever more conspicuous guidance is needed. Taller cones (up to 36 inches high) have good daytime visibility.



Note: Flashing or steady burn warning lights should be used on barricades, panels, and drums as needed.

Figure 6-4 Channelizing Devices and High Level Warning Devices (MUTCD, Figure 6-14)

Cones can be made more effective by:

- Using fluorescent colors (daytime);
- Adding flags (daytime);
- Supplementing with other devices, such as a high-level warning device (daytime);
- Supplementing with flashing arrow panels when lane closures are involved (day and night); and
- Using wider reflectorized bands (night).

If used at night, the MUTCD requires that they be reflectorized with a 6-inch wide reflectorized band, no more than 3 inches from the top, or that they be equipped with a lighting device.

The disadvantages of cones are that drivers have less respect for them and they are easily displaced or knocked over unless properly ballasted. When cones are used they should be checked periodically and those that have been either displaced or knocked over should be reset.

Tubular Markers

Tubular markers are similar to cones in that they are lightweight, easy to install, and are a minor impedence to traffic flow. Tubular markers may be set in special weighted bases or fastened directly to the pavement. They offer a particular advantage, due to the narrow size, to form new lanes or separate two-way traffic for a short-term activity.

Tubular markers shall be at least 18 inches high, with taller devices preferred for better visibility. If used at night, the MUTCD requires at least two 3-inch wide reflectorized bands, no more than 2 inches from the top, and no more than 6 inches between the bands. Under many conditions wider bands should be used. Tubular markers have the same disadvantages as cones with the addition that tubular markers have less visible area.

Vertical Panels

Vertical panels are used as either channelizing or warning devices but are not as portable or easy to install as cones or tubular markers. They are advantageous in narrow areas, where barricades and drums would be too wide. Vertical panels should be mounted on lightweight posts driven into the ground or placed on lightweight portable supports. They may be mounted back to back and used between opposing lanes of traffic.

The orange and white stripes on vertical panels shall slope down toward the side that traffic is to pass, and shall be reflectorized, as required by Section 6C-5 of the MUTCD.

Drums

Drums are used as either channelizing or warning devices. These devices may be highly visible, give the appearance of being formidable objects and, therefore, command the respect of drivers. Due to their size and weight, metal drums are usually limited to longer-term work operations. For stability, a small amount of sand may be placed in the drum. Where the potential for freezing exists, drain holes should be made in the bottom to permit draining to lessen the hazard if struck by a vehicle.

The MUTCD requires that markings on a drum be horizontal orange and white stripes that are reflectorized, 4 to 8 inches wide. The drum must have at least two sets of orange and white stripes but can also have nonreflectorized spaces up to 2 incheswide between the stripes. Disadvantages of metal drums are the possibility of rolling across the road when hit and difficulties of storage and placement. Plastic drums are available. They are lighter than the metal drums and pose less hazard to a vehicle. Plastic drums can be nested allowing for easy transportation and storage. Many of the commercially available plastic drums have one or more flat sides to preclude rolling and have recesses for warning lights and sand bags.

Barricades

Barricades should be constructed of lightweight materials. Barricades are classified as Types I, II, and III. (The type is determined by the number of rails facing traffic.) Types I and II are portable and can be used for either channelizing or marking hazards. Type III barricades are used for road closures. See Figure 6-4.

Types I and II have rails on both sides and may be used to separate opposing lanes of traffic. Type III usually faces one direction of traffic, so the rails are on one side. The barricade rails shall have alternating orange and white reflectorized stripes, that slope down toward the side traffic is to pass.

For road closures, a ROAD CLOSED sign, R11-2, and a Detour Arrow sign, M4-10 (if a detour is used), shall be used and may be mounted on a Type III barricade. If local traffic will be allowed to use the closed roadway, the ROAD CLOSED TO THRU TRAFFIC sign (R11-4) may be used. Adequate signing, marking, and protection from hazards should be used even though the roadway carries only local traffic. Sections 6B-8, 6B-9, and 6C-9 of the MUTCD provide additional information on road closures.

Barricades may be highly visible due to the large amount of reflective area, they offer a means of supporting signs, and are useful for pedestrian control. They may, however, be cumbersome for short-term projects and if the barricades are heavy and rigid, may cause excessive damage to an impacting vehicle.

Barriers

The terms barrier and barricade are frequently confused. A barricade, as discussed above, is an item that provides a visual indication of a

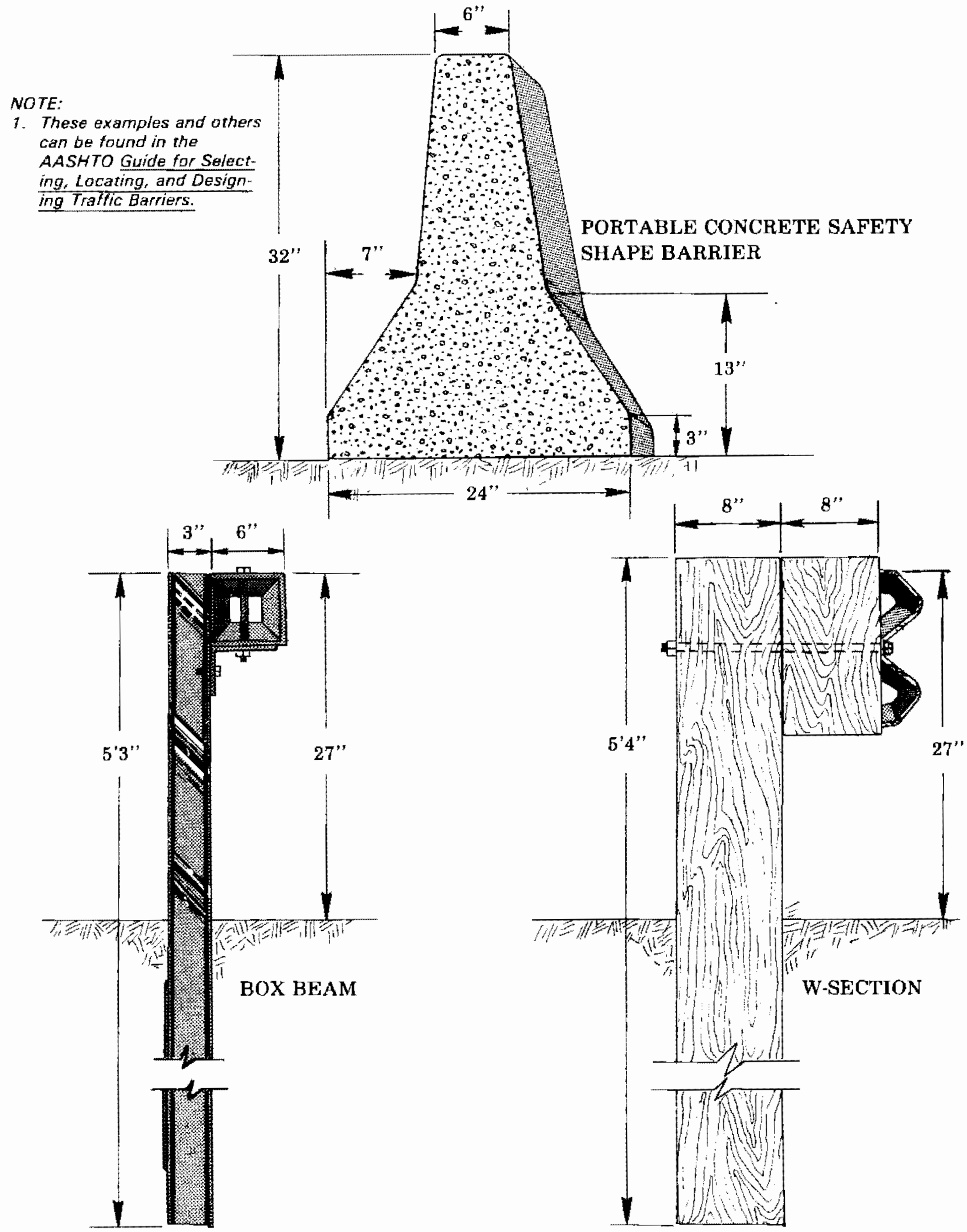


Figure 6-5 Examples of Three Types of Barriers

hazardous location or of the desired path a motorist should take. On the other hand, a barrier provides a physical limitation through which a vehicle would not normally pass.

There are four primary functions of barriers:

- Keep traffic from entering a work area or from hitting an exposed object or excavation.
- Provide positive protection for workers.
- Separate two-way traffic.
- Protect construction such as falsework for bridges.

Portable roadside barriers are usually made of concrete or metal. They are designed to contain and redirect an errant vehicle. An example is shown in Figure 6–5. Portable concrete barriers may be precast sections with built-in connecting devices. The connecting devices must be strong enough to insure that the individual elements act as a smooth continuous barrier. For some applications it may be necessary to anchor the concrete barrier to prevent lateral movement if hit by a vehicle. This can be accomplished with drift pins or anchor bolts placed in holes drilled in the pavement or bridge structure.

Barriers may serve the additional function of channelizing traffic. When used as channelizing devices, barriers should be light in color for increased visibility. Delineators or steady-burn warning lights may be attached to the barrier for channelization. A solid edgeline may be placed on the pavement adjacent to the barrier.

The need for barriers should be based on an engineering analysis. Portable concrete barriers are designed to minimize damage when they are hit. When a barrier is used in a lane closing situation, the barrier should be preceded with channelizing devices placed along a standard lane closing taper (Figure 6–32).

On construction projects, particular attention is needed for connecting portable or temporary barriers to adjacent existing barriers or guardrails. The construction plans should provide details for this. All connections should develop the full strength of the barrier system(s). Also, proper transitions must be used. For additional information see the "Guide for Selecting, Locating and Designing Traffic Barriers" (Ref. 6–3).

Exposed ends of barriers should have crash cushions to protect traffic. Another way to protect traffic is to flare the ends away from the roadway by extending the barrier beyond the clear roadside recovery area (Figure 6–12).

High-Level Warning Devices

High-level warning devices are tall, portable stands with flags and/or flashing lights that are visible above traffic and parked cars. They have three flags, 16-inch square or larger, at least 8 feet above the roadway (Figure 6–4).

The devices may be used with flags only, may have a sign or flashing light attached, or may be attached to vehicles used in moving or mobile work operations.

Lighting Devices

Warning Lights

Most of the warning lights in use are portable, lens directed, enclosed units and may be used on channelizing devices, barriers, and signs. Detailed discussions on the use and operating requirements of warning lights are contained in Section 6E-5 of the MUTCD.

The principal types and uses of warning lights are:

- Flashing lights, Type A, are appropriate for use on a channelizing device to warn of an isolated hazard at night or to call attention to warning signs at night;
- High intensity lights, Type B, are appropriate to use on advance warning lights day and night; and
- Steady-burn lights, Type C, are appropriate for use on a series of channelizing devices or on barriers which either form the taper to close a lane or shoulder or keep a section of lane or shoulder closed, and are also appropriate on the channelizing devices alongside of the work area at night (see Figure 6-1).

Warning lights should be secured to the channelizing device or sign in such a way that they will not separate from the channelizing device or sign if impacted by a vehicle. Warning lights that come loose during an accident may become a dangerous flying object.

Flashing Vehicle Lights

Work vehicles in or near the traffic areas are hazards and should be equipped with flashing lights. The vehicle warning lights may be emergency flashers, flashing, strobe, or rotating beacons. High intensity lights are effective both day and night. The laws of the agency having jurisdiction over the street or highway should be checked concerning requirements for flashing vehicle lights.

These lights should be used in addition to other channelizing and warning devices. However, in some emergency situations, where the work will be in progress for a short time, these lights may be the only warning device.

Flashing Arrow Panels

Arrow panels are signs with a matrix of lights capable of either flashing or sequential displays. Flashing arrow panels are effective day and night, for moving traffic out of a lane to the left, to the right, and may be used for tapered lane closures and moving operations.

There are two types of arrow panels, flashing and sequencing. Flashing arrow panels have three basic operating modes:

- left arrow,
- right arrow,
- caution mode (four or more lamps arranged in a pattern which does not indicate a direction).

Sequencing arrow panels have several arrowheads that flash in a series, directing traffic to the right or left.

The minimum sizes for arrow panels are shown in Table 6-5. The flash rate should be between 25 and 40 flashes per minute. The minimum lamp "on time" should be 50 percent for the flashing arrow and 25 percent for the sequential chevron.

Type	*Minimum Size*	*Minimum Number of Panel Lamps*	*Minimum Legibility Distance*
A	24" x 48"	12	½ mile
B	30" x 54"	13	¾ mile
C	48" x 96"	15	1 mile

Table 6-5. Arrow panel sizes and dimensions (MUTCD, Table VI-3)

The flashing or sequencing arrow modes should NOT BE USED under the following conditions:

- When the location of the work does not require any lanes to be closed.
- When all of the work is on or outside the shoulder and there is no interference which requires the adjacent traveled lane to be closed.
- When the flagger is controlling traffic on a normal two-lane, two-way road.

Use of the arrow modes under the above conditions will lead to the loss of credibility when the arrow mode is used for lane closures or moving operations.

The caution modes may be used for stationary or moving work operations on or outside of the shoulder. The caution mode may be used in addition to other devices such as signs, channelizing devices, or flashing vehicle lights.

As large arrow panels can be seen from a mile away, they are especially effective in high-volume or high-speed areas and for moving operations either on the work or shadow vehicle. For day and night use, arrow panels should be equipped with both an automatic and manual dimming device capable of 50 percent dimming. Flashing arrow panels that are used at night should be checked to insure that the device is properly dimmed, otherwise, motorists may be temporarily blinded. Circular hoods are recommended around each of the lenses to prevent side distraction at night. For more information, see Section 6E-7 of the MUTCD.

Hazard Identification Beacons

Flashing hazard identification beacons are used in work areas both day and night to alert drivers of a critical point in the highway, such as a truck crossing, and have the same meaning as permanently mounted beacons. Flashing beacons are not used for channelization. Flashing beacons with a yellow lens that is a minimum of 8 inches in diameter are brighter than flashing warning lights, Types A and B.

Floodlights

Floodlights are used to light work activities, flagger stations and other restricted or hazardous areas at night when area lighting is not sufficient. Floodlights should be positioned or shielded to prevent glare to the drivers. The increased visibility provided by floodlighting may enable the driver to see distracting portions of the work area. In this case, steady-burning warning lights mounted on channelizing devices may be advisable. Floodlighting the work area cannot be considered as illuminating signs or devices. Each illuminated sign or device should have its own light source.

During the planning and design of a street improvement project, consideration may be given to specifying that proposed street lighting be completed as one of the earlier stages during construction. Consideration should also be given for providing temporary luminaires at certain locations such as the work activity, certain crossroads, and transitions.

Shadow Vehicles

Moving operations, such as lane striping or sweeping, need traffic controls that move with the work operations. Shadow vehicles may be used to assist traffic control for moving operations. Signs and other warning devices may be placed on the work vehicle (depending on the type of work) or the shadow vehicle, or both. Need for a shadow vehicle depends on the speed of traffic compared to the speed of the work vehicle, exposure to traffic of workers and the type of work activity. Portable crash cushions can be attached to the shadow vehicle to protect motorists and workers from a collision. Signs, flags, flashing lights, or arrow panels may be attached to shadow vehicles to warn traffic. Arrow panels may be used on multilane highways but should not be used on a two-lane, two-way road .

Flagging Procedures

One of the fundamental principles in the MUTCD, Section 6A-5, paragraph 3-C, states in part, "Flagging should only be employed when required to control traffic or when all other methods of traffic control are inadequate to warn and direct drivers."

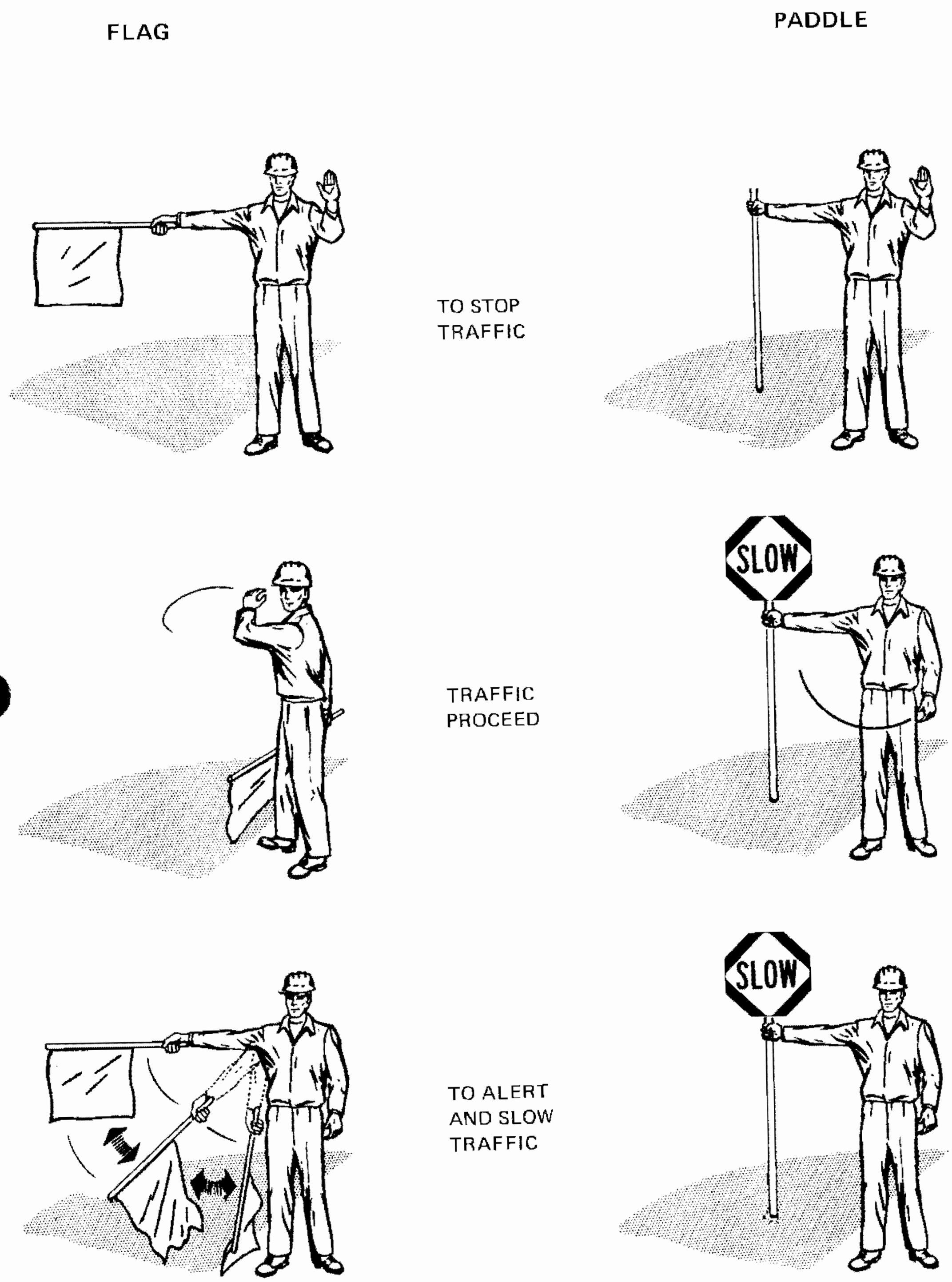


Figure 6-6 Use of Hand Signaling Devices by Flagger (MUTCD, Figure 6-15)

The procedures for flagging traffic are contained in Sections 6F-2 through 6F-7 of the MUTCD. Those procedures were developed over a period of time and are workable. The standard signals to be used by flaggers are illustrated in Figure 6-6. In addition, Figures 6-10 and 6-11 show the proper positioning of the flagger. It should be noted that both figures show the use of channelizing devices to form a lane closure behind the flagger.

Flagger Training

Attention should be given to the proper instruction of all personnel who are flaggers, starting with the basics of flagging. New flaggers should have a special introductory training session and all flaggers need periodic reminders as well as close supervision.

Flaggers need to know the correct ways to stop, slow down, or keep traffic moving. They should also know how to be courteous to the public, to explain delays or to help motorists. Some agencies give the flagger a pocket instruction card that shows the proper methods for controlling traffic.

Flagger Guidelines

Flaggers are responsible for the safety of traffic and workers; their job is important. They can promote good public relations because they have close public contact. The image they project is often responsible for the public's attitude toward the entire work operation.

For short work areas where both ends can be seen at the same time one flagger may suffice. Both directions of traffic must be able to see the flagger and to recognize the person as a flagger. If this is not possible with one flagger, then two or more must be used.

Flaggers should be visible, should always face traffic, and should be prepared to warn workers to get out of the way if necessary. Other workers should not be allowed to gather near the flagger. During lunch or other breaks, flaggers should leave their station so that drivers will know that the flaggers are not on duty, and not think they are ignoring their duties.

Whenever a flagger is on duty, the advance flagger sign should be displayed to traffic. When a flagger is not on duty, the sign, should be removed or covered. The responsibility for placing and removing the Flagger Ahead signs should be assigned to a specific person.

A schedule of work and relief hours for flaggers, and replacement flaggers should be available. Flaggers should be alert, have good eyesight, quick reflexes, and a thorough understanding of their job.

Orange or fluorescent orange clothing such as a vest, shirt, or jacket is required by the MUTCD. For nighttime conditions, similar garments shall be reflectorized. Flaggers may use either a red, 24-inch flag or an 18-inch STOP-SLOW paddle, Figure 6-6.

On longer work areas, two or more flaggers are often needed. One of them should be designated as chief flagger. The chief flagger's job is to provide coordination. A two-way radio may be needed for communication between them. A flag or other token may be used where the flaggers cannot see each other. The flag or token is given to the last driver in line going through the work zone and turned over to the flagger at the other end to indicate that it is clear to send traffic through in the other direction.

Traffic Signals

Standard traffic signals may be used for work zone traffic control for these types of applications: (1) a highway intersection with a temporary "haul road" or equipment crossing; (2) through short sections of road when opposing directions of traffic use the same lane for travel alternately. The traffic signal shall be installed in accordance with the standards set forth in Part IV of the MUTCD. Their use should be based upon a traffic engineering study.

Miscellaneous

Crash Cushions

Crash cushions are devices designed to absorb the energy of an impacting vehicle in a controlled manner such that the impact forces on the passengers are tolerable. Two types of crash cushions commonly used in work zones are shown in Figure 6-7, sand-filled plastic barrels and "Guard Rail Energy Absorbing Terminal."

Crash cushions should be designed to meet the needs of each location, depending on the type, length and width of the hazard and this information should be included on the highway construction plans. They are used to protect traffic from hazards, such as exposed barrier ends or bridge parapets. Crash cushions may be mounted on shadow vehicles and work vehicles to protect traffic during construction, maintenance, and utility operations.

Care should be taken, throughout the time that crash cushions are used, that:

- Crash cushions be installed and maintained in accordance with the manufacturers' recommendations.
- Crash cushions that are impacted should be promptly inspected and repaired or replaced.
- Sufficient spare parts are on hand to repair the crash cushions. Repairs should not have to be delayed while parts are being ordered and delivered.

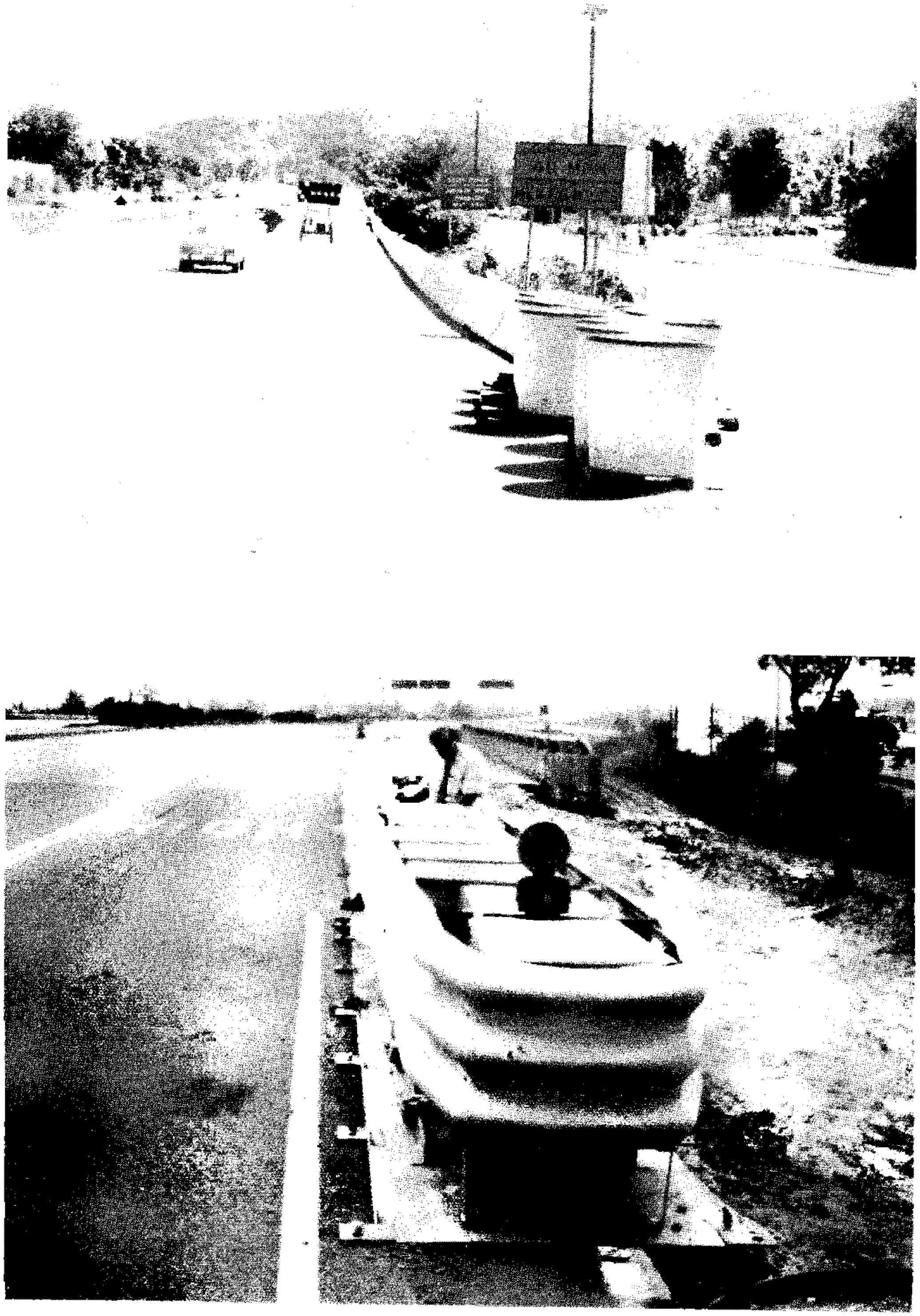


Figure 6-7 Crash Cushions, Sand-filled Plastic Barrel, and Energy Absorbing Terminal

Fillet of Material

A fillet of material is a "wedge" of gravel, or other material placed in a manner that will provide stability for errant vehicle and is used to reduce the dropoff as a result of an excavation, as illustrated in Figure 6–8. It can be used when work in the excavation is discontinued for a short period of time, as at night, and removed when work will start again. Frequently, this wedge is composed of the same material which is either being excavated or back filled (such as crushed rock base course).

Variable Message Signs

Portable variable message sign devices capable of displaying various messages to the motorist will sometimes facilitate construction zone signing. These devices are normally trailer or truck mounted and have their own power system. As they are expensive to buy and operate variable message signs are normally used for the more complex traffic control plans.

Messages, or series of messages can be preprogramed into the device or can be added with an additional memory device. Some variable message signs can be programed in the field. Display panels may have one, two, or three lines of copy.

When using a variable message sign care should be taken to insure that the message is clear. A lengthy message may distract the motorist from his driving task for too long a time. The sequencing of the words in a message can also cause problems. For example, RIGHT LANE CLOSED MERGE would get a different driver response than LANE CLOSED MERGE RIGHT. Yet, the messages are similar except for the beginning point.

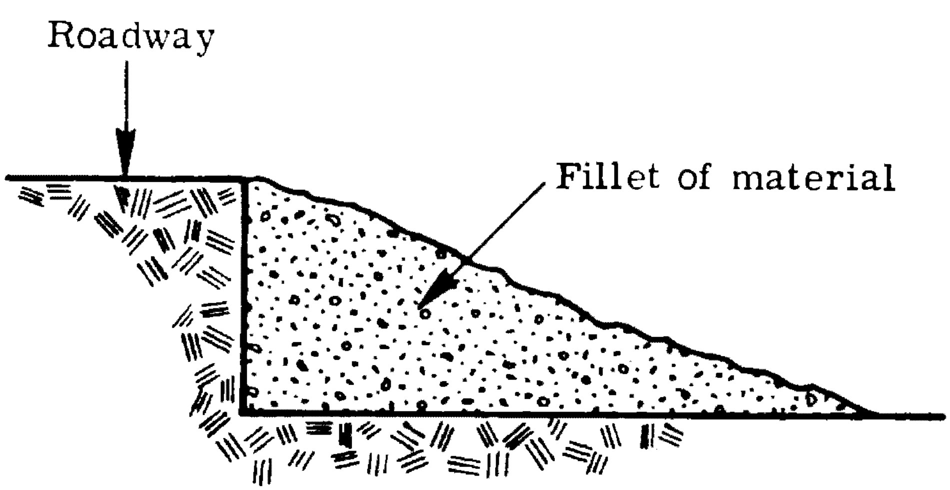


Figure 6–8 Cross Section View of a Material Fillet Used to Decrease the Hazard of an Excavation Adjacent to the Roadway

Variable message signs are especially useful in the following situations:

- When different messages are needed during the day due to changing work operations.
- For upstream traffic diversion when instructions vary with traffic conditions.
- For emergency conditions.

6B-4 Typical Applications (Layouts)

Each traffic control zone is different, with variables such as speed, volume, location of work, pedestrians, and intersections changing the needs for each zone. The goal of a traffic control zone is safety, and the key factor in making the control zone work is the application of proper judgment. The examples in this chapter are guides showing how to apply the standards.

The typical applications include the use of various traffic control methods, although they do not include a layout for every conceivable work situation. Typical applications may be altered to fit the conditions of a particular work area.

The layouts in the MUTCD and this handbook represent minimum requirements. Other devices may be added to supplement the devices shown in the layout and sign spacings and taper lengths can be increased to provide additional time or space for driver response. When difficult situations or potentially hazardous conditions are encountered, typical designs may be modified to a higher-type treatment as indicated by the following:

- Additional devices
  —additional signs
  —flashing arrow panels
  —more channelizing devices
  —high-level warning devices

- Upgrading of devices
  —improved pavement markings
  —larger signs
  —higher-type channelizing devices
  —barriers in place of channelizing devices
  —variable message signs

- Improved geometrics at detours or crossovers

- Increased distances
  —longer advance warning area
  —longer tapers

- Lighting
  —steady-burn lights for channelization
  —flashing lights for isolated hazards
  —illuminated signs
  —floodlights

Nine of the typical applications used in this handbook are taken from the MUTCD. On many of the typical applications, the existing pavement markings have been either marked or changed to indicate those that should be changed for long-term projects. If the project is short-term, such as 1-day maintenance operations, the pavement markings may not need to be removed and replaced although guidance should be provided with channelizing devices.

Table 6-1 shows the typical traffic control devices needed for various work zones. It indicates how traffic control increases as work approaches the traveled lane and as conflict with traffic increases. Some of the less complicated work zones are not illustrated. The typical traffic control devices for such zones are given in Table 6-1.

Work Entirely Beyond Shoulder or Parking Lane

Traffic control depends primarily on devices such as advance warning signs, flashing vehicle lights, and flags. An advance warning sign should be used when any of the following conditions occur:

- Work will be performed immediately adjacent to the roadway at certain stages of the activity,
- Equipment may be moved along or across the highway, and
- Motorists may be distracted by the work activity.

A typical sign for this situation could be MOWING AHEAD. If the equipment travels on or crosses the roadway, it should be equipped with appropriate flags, flashing lights and/or a Slow Moving Vehicle symbol.

Work On or Over Shoulder or Parking Lane

No Encroachment in Traveled Lane

There is no direct interference with traffic. When the shoulder is occupied or closed, the motorist should be advised and the workers should be protected. Usually, the single warning sign SHOULDER WORK is adequate. When an improved shoulder is closed on a high-speed roadway, it should be treated as a closure of a portion of the road system as the motorist expects to be able to use it in an emergency. The work area on the shoulder should be closed off by a taper of channelizing devices. However, flashing arrow panels should not be used, except in the caution mode.

Minor Encroachment in Traveled Lane

When work is on the shoulder or takes up part of a lane, traffic volumes, type of traffic (buses, trucks and cars), speed, and capacity should be analyzed to determine whether the affected lane should be closed. Figure 6–9 illustrates a method for handling traffic where the work area encroaches slightly into the travelway. Conflicts with traffic will be reduced and the additional protection provided by using portable concrete barrier along the work area similar to Figure 6–32. For high-speed traffic conditions, a lane closure should be considered.

Work on Two-Lane Roadway

When one lane is closed on a two-lane, two-way road, the remaining lane must be used by traffic traveling in both directions. The short two-way traffic taper (50 feet minimum) is used to slow traffic as it approaches the work space. Alternate one-way traffic control may be affected by the following means:

- Two flaggers, one at each end of the work area;
- One flagger can assign right-of-way at a short work area with low volumes;
- For very short work areas at a spot location where traffic volumes and speeds are very low, the movements *may* be self-regulating. This method is not satisfactory when the work area is near sharp hills and curves;
- A pilot car; and
- Temporary traffic signals for long-duration projects.

Curved Roadway and Hill

If the work area ends near the curve or hill, a flagger should be stationed at both ends of the work area. The transition area should be adjusted so that the flagger and the entire taper will be visible before the curve or hill for an adequate stopping sight distance. Figure 6–10 applies to short-term flagging operations and Figure 6–11 applies to longer-term flagging operations.

Work on Four-Lane, Two-Way Roadway (Undivided)

Right Lane Closed

Traffic controls similar to Figure 6–15 may be used for four-lane roads, either undivided or divided. If traffic volumes are high, traffic may back up as a result. If morning and evening peak hourly traffic volumes in the two directions are uneven and the greater volume is on the side where the work is being done, the inside lane for opposing traffic may be closed and made available to the side with heavier traffic. A volume check in both directions should be made before this method is used, Figure 6–12.

NOTE:
1. *Additional advance warning may be necessary.*
2. *At least 10 feet on urban streets should remain in the travel lane. If a greater encroachment is needed, close the lane.*
3. *Portable concrete barrier may be used along the work area.*
4. *For high speed traffic conditions, a lane closure should be considered.*
5. *A buffer space may be used.*
6. *Metric conversion: 500 ft. = 150 m.*
7. *L = lenght of taper—refer to Table 6-3.*

KEY:

Channelizing Devices ■

Flashing vehicle light

Pavement markings that should be removed for long term projects. Temporary markings to be placed as needed. ////

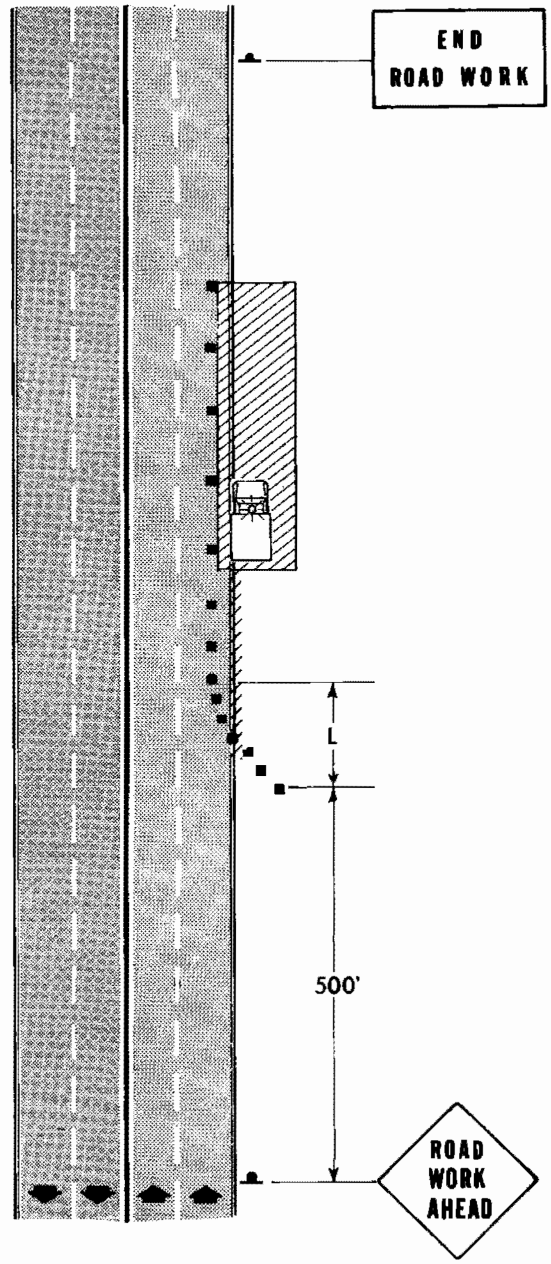


Figure 6-9 Typical Application of Traffic Control Devices for a Minor Encroachment onto Travel Lane on Urban Streets

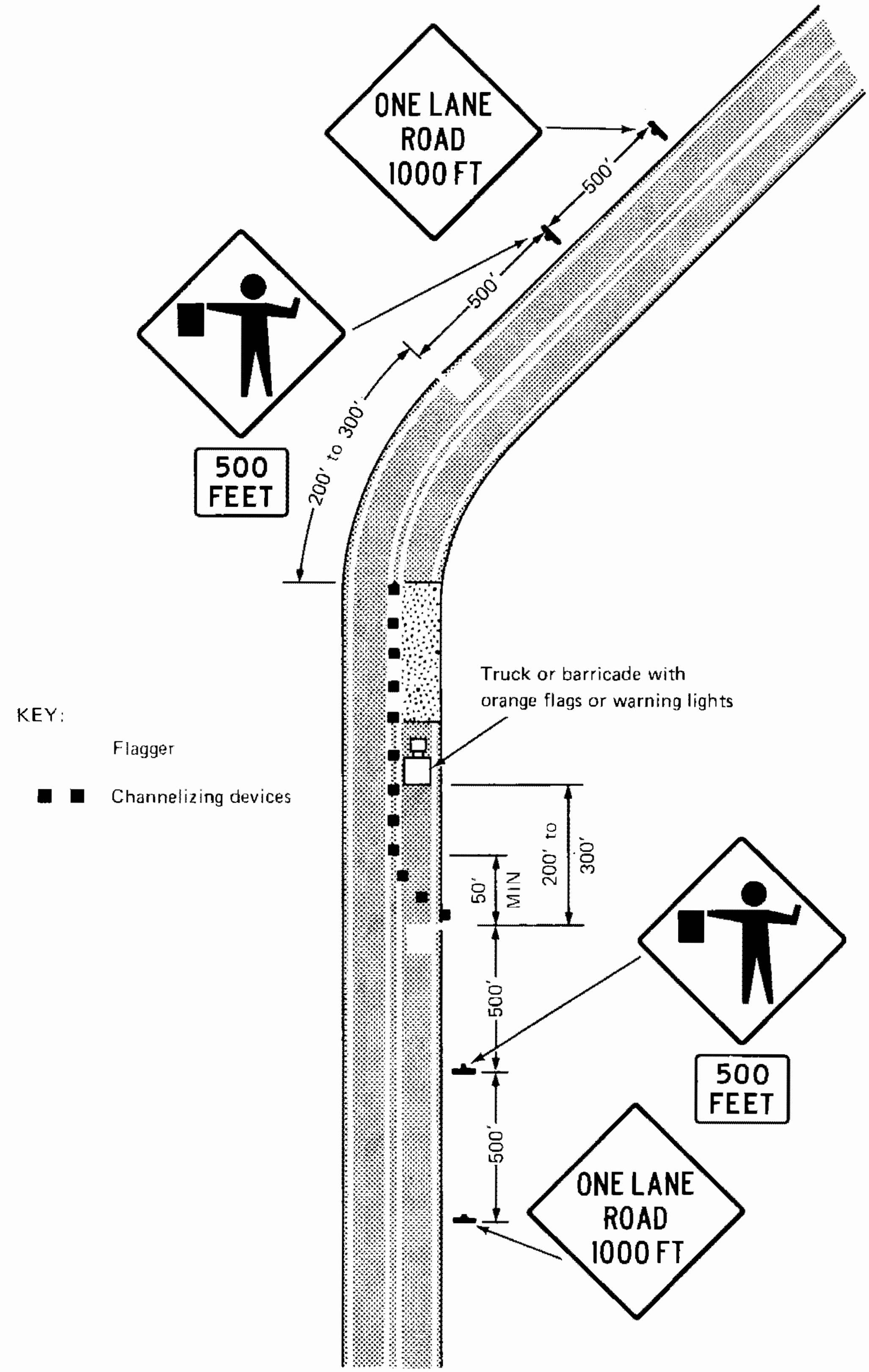
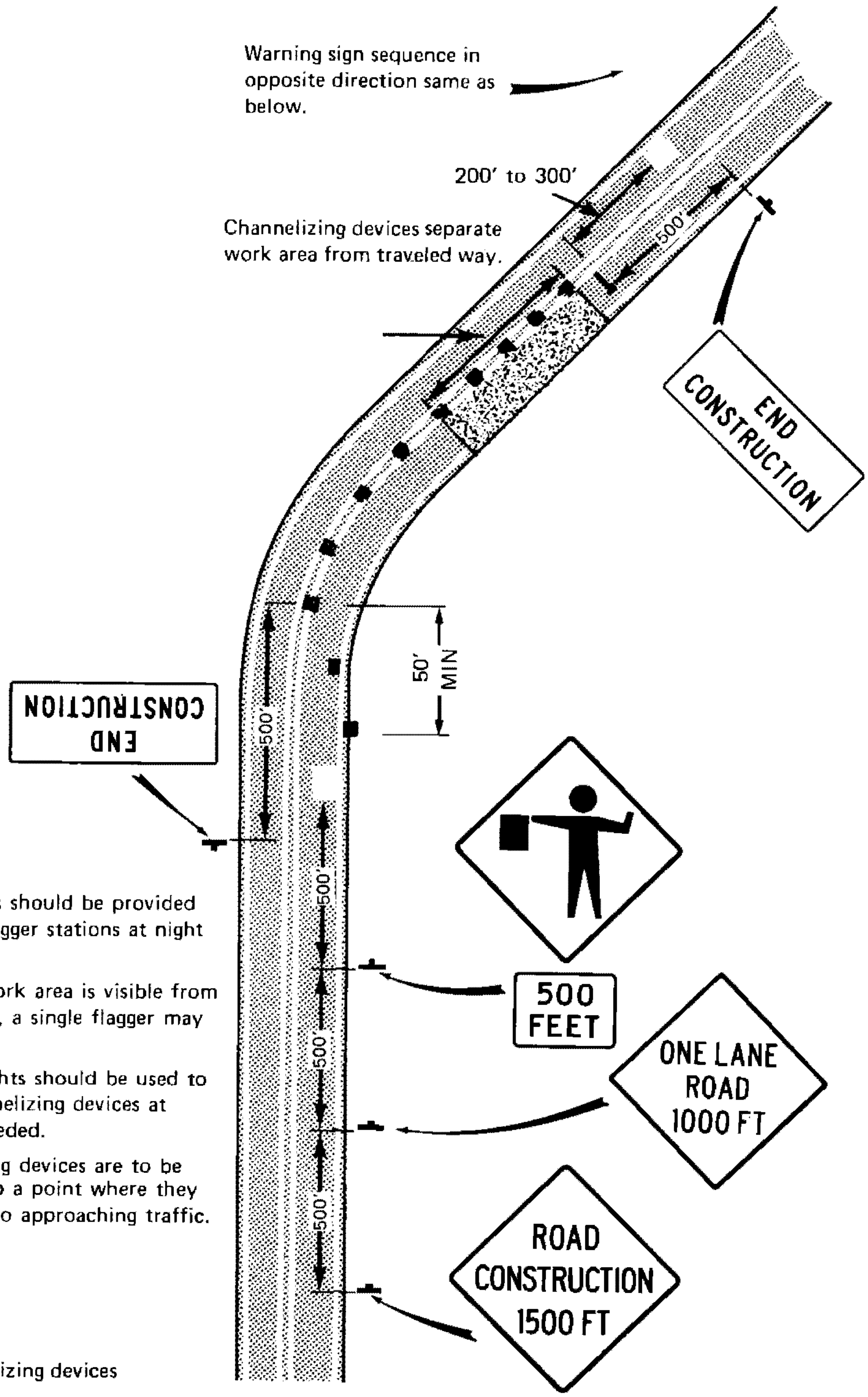


Figure 6-10 Typical Application—Daytime Maintenance Operations of Short Duration on a Two-lane Roadway and Flagging is provided (MUTCD, Figure 6-6)



Note:

1. Flood lights should be provided to mark flagger stations at night as needed.
2. If entire work area is visible from one station, a single flagger may be used.
3. Warning lights should be used to mark channelizing devices at night as needed.
4. Channelizing devices are to be extended to a point where they are visible to approaching traffic.

Key:

Flagger

■ ■ Channelizing devices

Figure 6-11 Typical Application of Traffic Control Devices on a Two-lane Highway Where one Lane is Closed and Flagging is Provided (MUTCD, Figure 6-5)

NOTES:

1. Taper Formula:
   L=SXW for speeds of 45 or more.
   $L=\frac{WS^2}{60}$ for speeds of 40 or less.

   Where:
   L=Minimum length of taper.
   S=Numerical value of posted speed limit prior to work or 85 percentile speed.
   W=Width of offset.

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

KEY:
■ ■ Channelizing devices

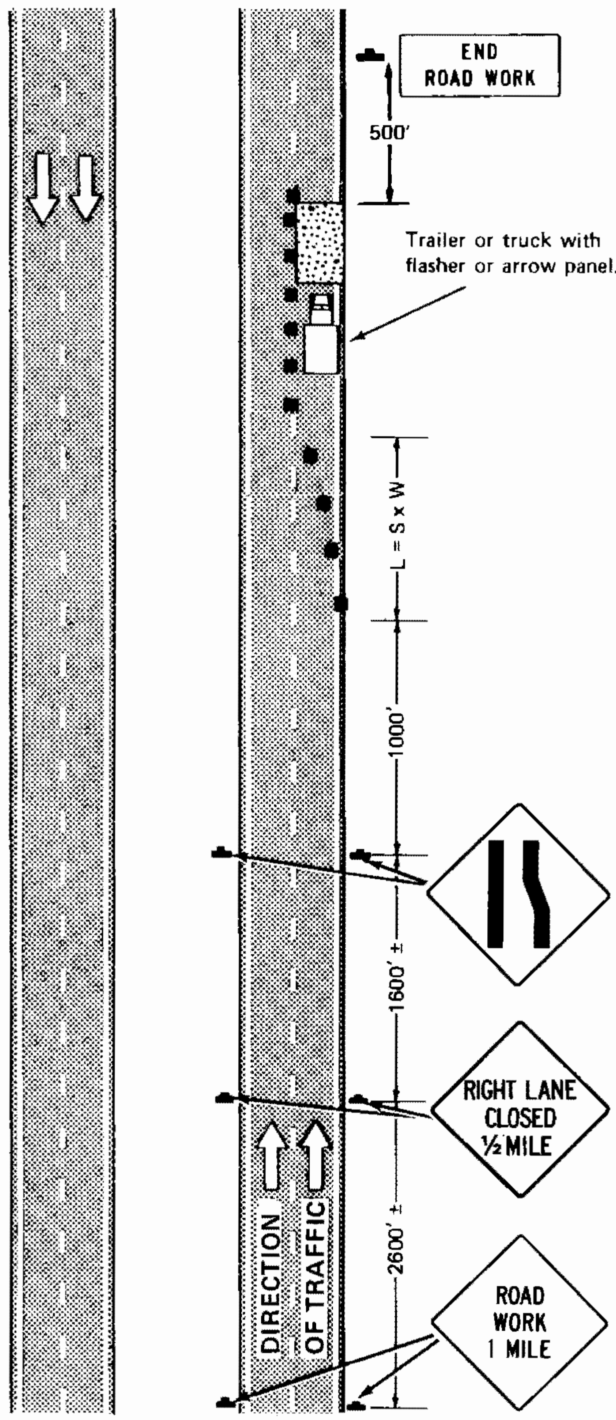


Figure 6-12 Typical Application of Traffic Control Devices Where Directional Traffic Volumes are Uneven

If the heavier traffic changes to the opposite direction, the traffic control in Figure 6–12 can be changed to allow two lanes for opposing traffic by moving the devices from the opposing lane back to the centerline. (If these changes occur frequently, cones or tubes should be used at close spacing to emphasize lane lines and the centerline.)

Left Lane Closed

If the work activity can be contained entirely within the left (or inside) lane, it may be appropriate to close only that lane. Channelizing devices should be placed along the centerline and outside of the work activity to give advance warning to the opposing traffic. An alternative is to close the two center lanes, as shown in Figure 6–13, to give traffic and workers additional protection and to provide easier access to the work area. Overall safety, considered with existing traffic volumes in each direction, are the main factors for determining alternates.

Two Lanes Closed

When the work occupies both lanes for one direction of traffic, the number of lanes remaining open may be reduced to one for each direction, Figure 6–14. A capacity analysis is necessary before this method is initiated. Traffic should be moved over one lane at a time and the tapers should be separated by a distance of 2L. When both center lanes are closed, traffic controls may be used as indicated in Figure 6–13.

Work on a One-Way or Divided Roadway

One Lane Closed

An example of a right lane closure is shown in Figure 6–15 for a four-lane divided roadway. If the work is near an access ramp on a four-lane divided roadway, refer to Figure 6–25.

Two Lanes Closed on a Four-Lane Roadway

Two lanes of a multiple lane roadway can be closed by using two tapers and separating them by a distance of 2L (Figure 6–16). Careful analysis of roadway capacity should be made first. This type of closure is usually limited to non-peak hours of traffic.

Center Lane Closed on a Three-Lane Roadway

To close the center lane traffic must first be channelized out of the left lane (or right lane) and into the center lane. Then, traffic in the center lane can be directed around the work area by a second taper. This is illustrated in Figure 6–17.

NOTE:
1. Additional advance warning signs may be necessary.
2. A buffer space may be used.
3. The lane closure for opposing traffic is optional, depending on the need for access to the work space and protection of traffic.
4. Length of advance warning area shown is for urban streets. For rural or open highway conditions, the advance warning area should be at least 1500 ft. long.
5. Metric conversion: 500 ft. = 150 m.
6. L = length of taper — refer to Table 6-3.

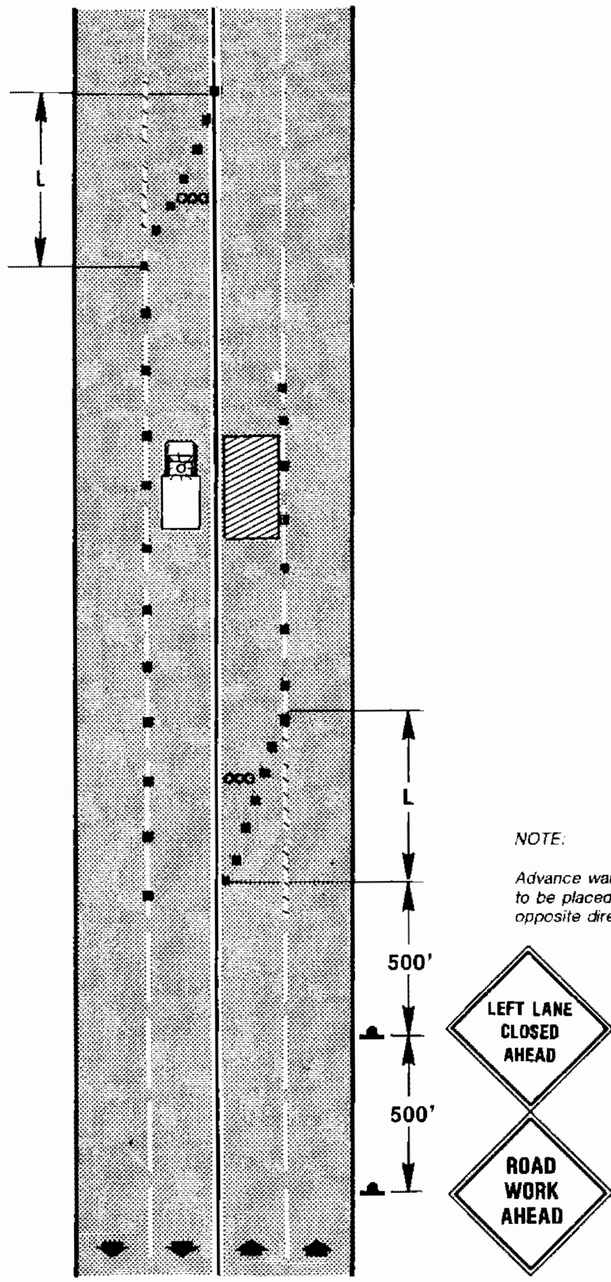
KEY:

Channelizing devices ■

Arrow panel ooo

Flashing vehicle light

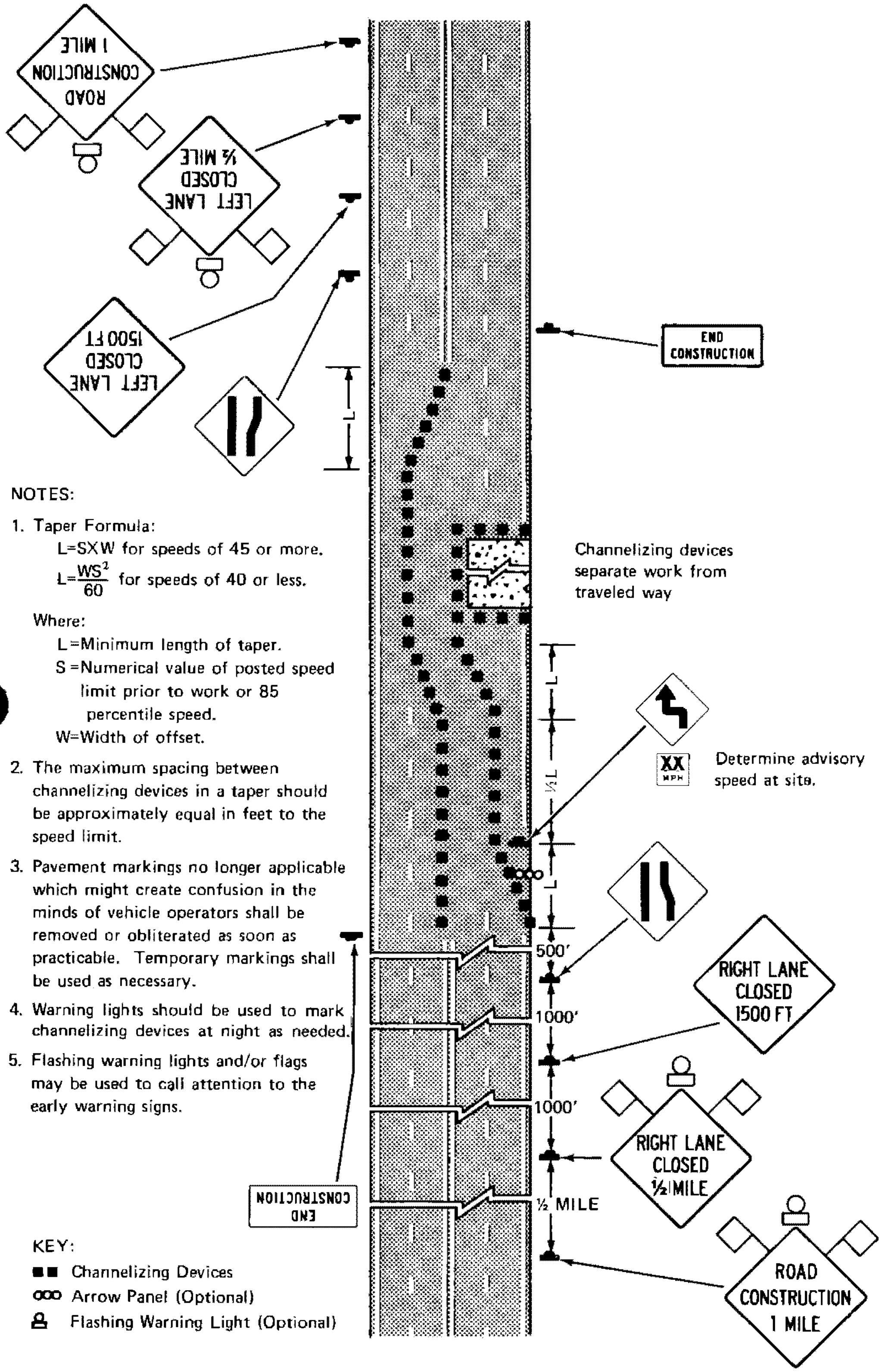
Pavement markings that should be removed for a long-term project. Temporary markings to be placed as needed. ///////



NOTE:

Advance warning signs to be placed in opposite direction also.

Figure 6-13 Typical Application—Work Area Within Left Lane, Allowing Access to Work Areas from Adjacent Lane



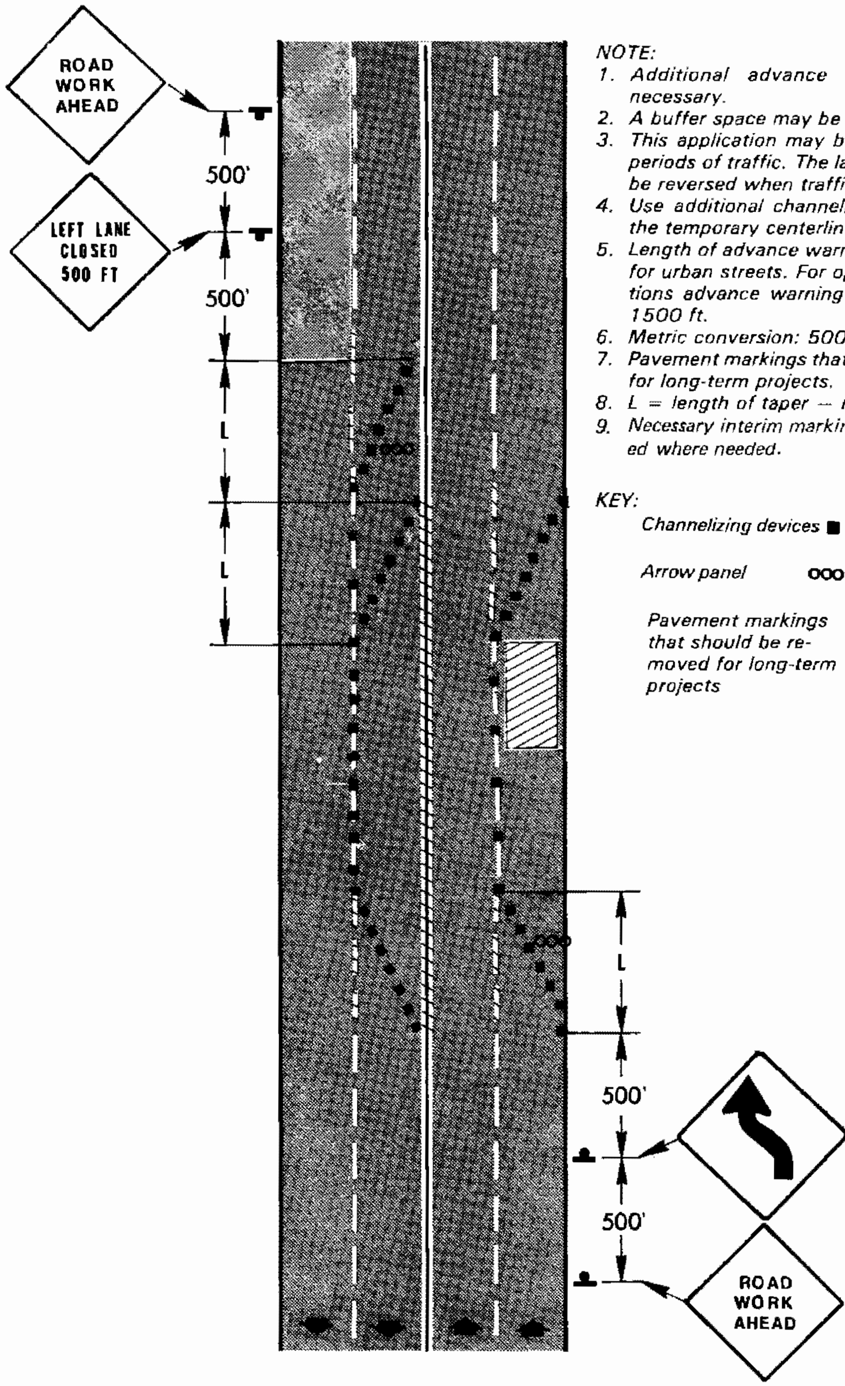
NOTES:

1. Taper Formula:
   L=SXW for speeds of 45 or more.
   $L=\frac{WS^2}{60}$ for speeds of 40 or less.

   Where:
   L=Minimum length of taper.
   S=Numerical value of posted speed limit prior to work or 85 percentile speed.
   W=Width of offset.
2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.
3. Pavement markings no longer applicable which might create confusion in the minds of vehicle operators shall be removed or obliterated as soon as practicable. Temporary markings shall be used as necessary.
4. Warning lights should be used to mark channelizing devices at night as needed.
5. Flashing warning lights and/or flags may be used to call attention to the early warning signs.

KEY:
- ■■ Channelizing Devices
- ooo Arrow Panel (Optional)
- Flashing Warning Light (Optional)

Figure 6-14 Typical Application—Four-lane Undivided Roadway, Where Half the Roadway is Closed (MUTCD, Figure 6-7)



NOTE:

1. *Additional advance warning may be necessary.*
2. *A buffer space may be used.*
3. *This application may be used during peak periods of traffic. The lane distribution may be reversed when traffic flow changes.*
4. *Use additional channelizing devices along the temporary centerline.*
5. *Length of advance warning area shown is for urban streets. For open highway conditions advance warning area to be at least 1500 ft.*
6. *Metric conversion: 500 ft. = 150m.*
7. *Pavement markings that should be removed for long-term projects.*
8. *L = length of taper — refer to* Table 6-3.
9. *Necessary interim markings should be installed where needed.*

KEY:

Channelizing devices ■

Arrow panel ooo

Pavement markings that should be removed for long-term projects ////////

Figure 6-15 Typical Application—Daytime Maintenance Operations of Short Duration on a Four-lane Divided Roadway Where One Lane is Closed (MUTCD, Figure 6-9)

NOTES:

1. Taper Formula:
   L=SXW for speeds of 45 or more.
   $L=\frac{WS^2}{60}$ for speeds of 40 or less.

   Where:
   L=Minimum length of taper.
   S=Numerical value of posted speed limit prior to work or 85 percentile speed.
   W=Width of offset.
2. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.
3. Flashing warning lights and/or flags may be used to call attention to the early warning signs.

KEY:

- ■ ■ Channelizing devices
- ooo Arrow Panel (Optional)
- Flashing Warning Light (Optional)

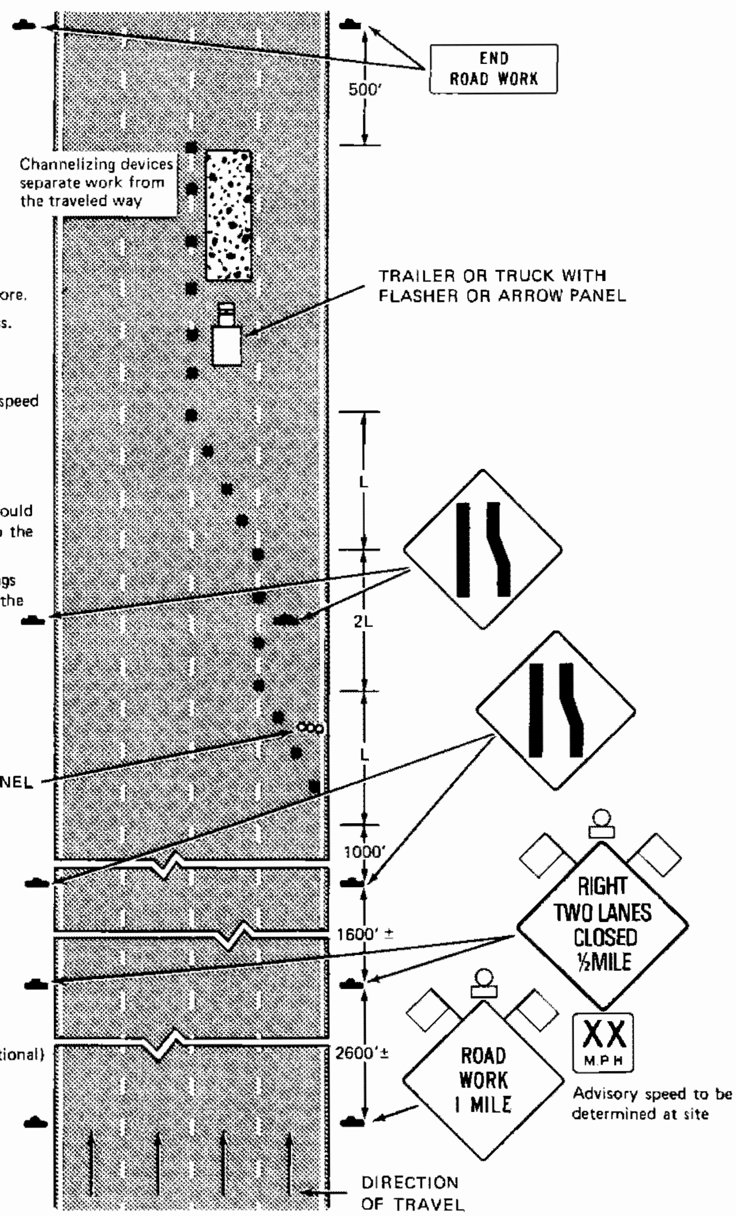


Figure 6-16 Typical Application—Closing Multiple Lanes of a Multi-lane Highway (MUTCD, Figure 6-10)

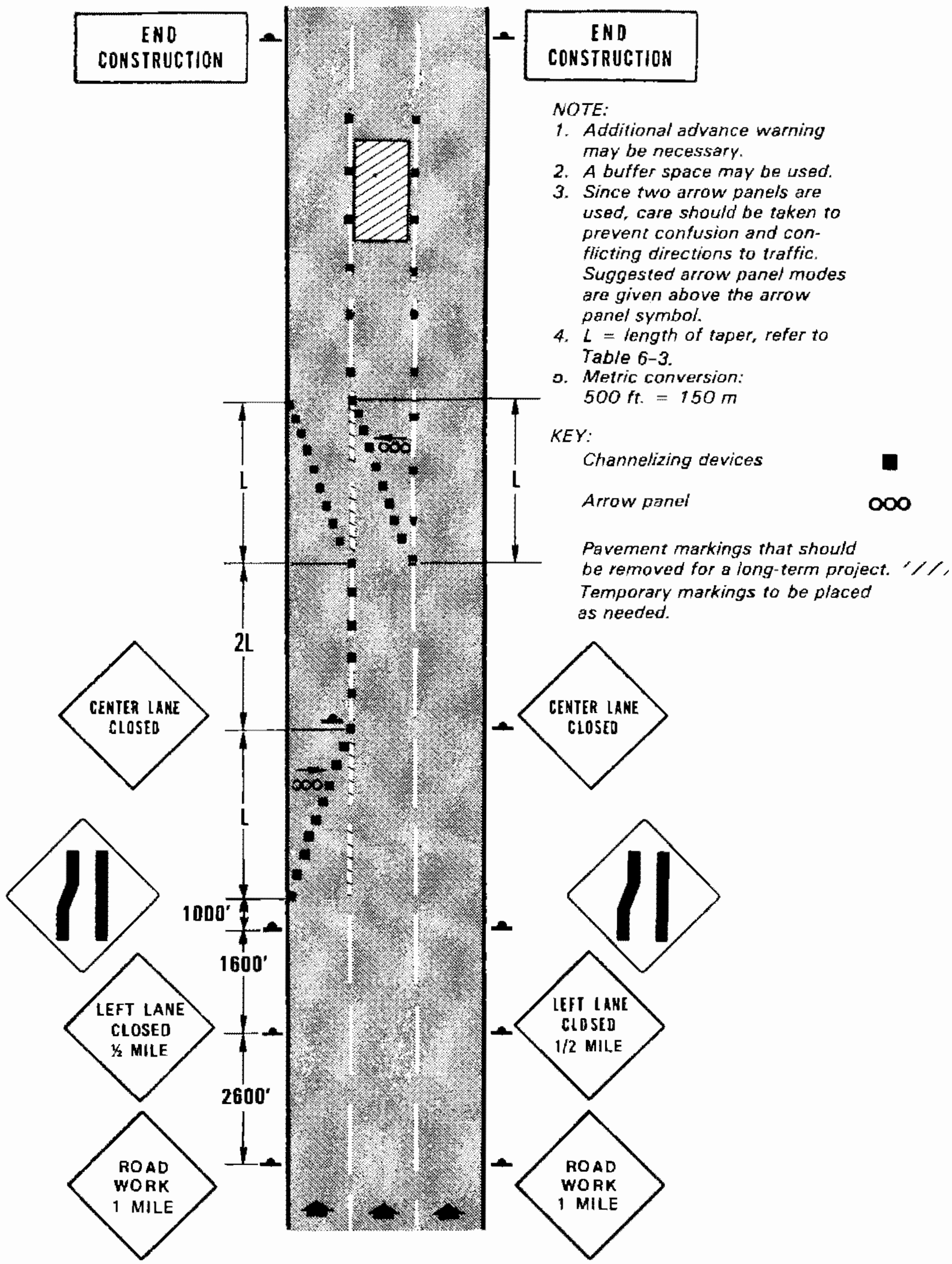


Figure 6-17 Typical Application of Traffic Control Devices Used with Work Area in Center Lane of a Three-lane, One-way Roadway

Two-Lane, Two-Way Traffic on One Roadway of a Normally Divided Highway

The two-lane, two-way traffic on one roadway of a normally divided highway (TLTWO) is a typical application that requires special consideration in the planning, design, and construction phases (Figure 6–18). As unique operational problems (typically serious head-on collisions) can arise with the TLTWO, this typical application will be discussed with a greater level of detail than the other typical applications.

Determining Appropriateness of TLTWO

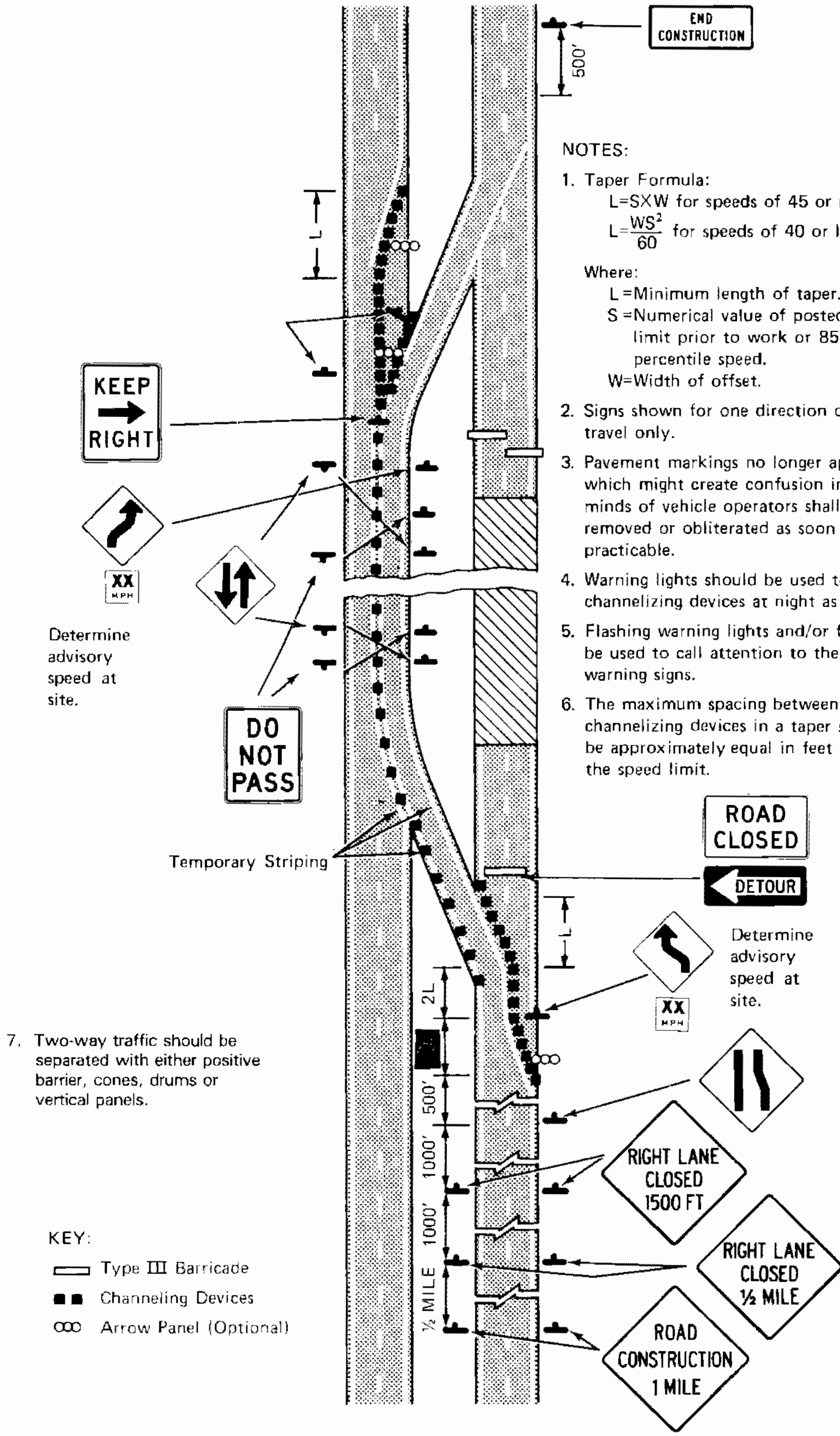
Before including a TLTWO in the TCP for a project careful consideration should be given as to the appropriateness of a TLTWO. The following items should be considered in the decisionmaking process:

- Is a suitable detour available?
- What are the characteristics of the traffic?
- Can traffic be maintained on the shoulder?
- Can temporary lanes be constructed in the median?
- Can the work be accomplished by closing only one directional lane? If this option is selected for consideration will it result in additional hazard to construction personnel?
- If a TLTWO is selected will this result in a shorter contract time?
- If a TLTWO is selected will it allow a contractor to perform the work more efficiently and thus result in a substantial decrease in contract cost?
- What is the "track record" of similar installations?
- Are there any width or height restrictions that would preclude the TLTWO or the use of a shoulder for use of temporary lanes in the median?
- What is the condition of the pavement and the shoulders in the proposed TLTWO section? Due to width restriction, traffic may drive on the sholders which must be structurally adequate.

Selection of Separation Devices

Should it be determined that a TLTWO is to be used then a decision must be made as to the type of separation device that will be required. The following devices and factors should be considered:

- *Portable Concrete Barrier* is often the most costly but provides the greatest protection from the potential head on collision. This is the preferred treatment for many TLTWO applications.
- *Raised Islands* can be constructed of concrete or bituminous material. Their cross section should be such that if contacted by a vehicle they would alert the driver without causing the driver to loose control of the vehicle. Islands would normally be less expensive than



NOTES:

1. Taper Formula:
   L=SXW for speeds of 45 or more.
   $L=\frac{WS^2}{60}$ for speeds of 40 or less.

   Where:
   L = Minimum length of taper.
   S = Numerical value of posted speed limit prior to work or 85 percentile speed.
   W=Width of offset.
2. Signs shown for one direction of travel only.
3. Pavement markings no longer applicable which might create confusion in the minds of vehicle operators shall be removed or obliterated as soon as practicable.
4. Warning lights should be used to mark channelizing devices at night as needed.
5. Flashing warning lights and/or flags may be used to call attention to the early warning signs.
6. The maximum spacing between channelizing devices in a taper should be approximately equal in feet to the speed limit.
7. Two-way traffic should be separated with either positive barrier, cones, drums or vertical panels.

KEY:

- Type III Barricade
- Channeling Devices
- Arrow Panel (Optional)

Figure 6-18 Typical Application—Four Lane Divided Highway Where One Roadway is Closed.

portable concrete barrier. Also, they can be designed to be narrower than portable concrete barriers. They should be supplemented by other channelizing devices.

- Roadway drainage and snow and ice removal must be considered when either the portable concrete barrier or raised island are used.
- *Drums,* either steel or plastic, are somewhat effective in controlling traffic. Steel drums, due to their weight and bulkiness, can cause considerable damage to an impacting vehicle. In addition, a drum that is hit by a vehicle can be knocked into traffic in the opposing roadway.
- *Barricades* can also be effective in controlling traffic. They are susceptible to being blown over or out of position by large vehicles passing close to them. Like drums, they can be a dangerous projectile if hit into opposing traffic.
- *Vertical Panels* have the advantage of being up high where they can be easily seen and they are narrow. Some agencies use them in conjunction with drums. They are usually mounted on lightweight posts that are driven into the pavement or that are set in holes drilled in the pavement.
- *Tubular Markers* are the narrowest device. Self-restoring tubular devices are commercially available. They can be epoxied or bolted to the pavement or are sometimes set in holes drilled in the pavement.
- *Cones* have the advantage of being easy to place and their initial purchase price is comparatively low.
- Many motorists recognize that cones and tubular markers can be driven over without damage to a vehicle. For this reason they are somewhat ineffective in TLTWO applications. Also, although their initial cost is low, they require continual maintenance.
- Drums, barricades, vertical panels, tubular markers, and cones will require varying degrees of maintenance. Sometimes these devices are hit so frequently that the cost of repositioning and replacing them with new devices makes them more expensive than the portable concrete barrier.
- The repositioning or replacement of impacted devices will entail a certain amount of risk for the workers involved.

Crash Cushions

If a portable concrete barrier is used, the ends of the barrier pose a serious hazard to the motorist. The following treatments are acceptable ways of beginning or ending a portable concrete barrier:

- The barrier can be physically connected to an existing longitudinal barrier.

- The barrier can be flared away from traffic until it is outside the recommended clear recovery zone. See page 64 of the Guide for Selecting, Locating, and Designing Traffic Barriers (Ref. 6-2) for appropriate flare rates and page 15 for clear zone criteria.

- Crash Cushions can be used. Two types have yielded good results.

  —The GREAT System

  —Sand Filled Plastic Barrel System

Determining the Length of the TLTWO

In the early planning stages, while analyzing the appropriateness of the TLTWO and the type of separation devices for a TLTWO, the length of the two-way section needs to be considered as length may affect cost and safety. A study entitled, "Optimum Length of Two-Lane, Two-Way No-Passing Traffic Operations in Construction/Maintenence Zones on Rural Four-Lane Divided Highways," sponsored by the Engineering Research Center of the University of Nebraska in cooperation with FHWA was published in 1979. An equation was developed for the sum of road user and traffic control costs as a function of the length or segment of two-lane, two-way operations. Road user costs included accident, delay, and operating costs. Traffic control costs included cost of crossovers, signs, pavement markings, and separation devices. Cost of devices and crossovers in the examples were based on Nebraska's experience. The optimum segment length in the study varied but did not exceed 3½ miles. Certain assumptions were made that may not be valid for all situations. For instance, some type of work activity may require a minimum length so as to be reasonably cost efficient from the standpoint of contractor productivity. This may control the minimum segment length of a TLTWO on a project. When segments of TLTWO exceed 3 to 5 miles, there may be operational problems due to lower speed vehicles which can make a section more prone to rear end accidents. Also emergency vehicles may have more difficulty getting through a longer section. Where separation devices are other than positive barrier, there is a high probability of illegal passing maneuvers on longer sections due to frustration and impatience. Also maintenance of devices may be more difficult. Therefore, from a safety standpoint short segments are desirable.

Independent roadway alignment or rough terrain may dictate long sections of TLTWO. Passing sections may be a possible solution in these cases. Where operational problems are not anticipated and contractor productivity will be substantially reduced by unduly short sections of TLTWO, engineering judgment is necessary to determine the appropriate length of the TLTWO by weighing carefully all the factors involved.

Crossover Design for TLTWO

The following statements are considered good guidance in the design of crossovers:

- It is better to use flat diagonal crossovers rather than reverse curves with superelevation.
- Lateral obstructions located closer than 6 feet from the edge of a traffic lane reduce its effective width. Reasonable shoulder widths should be constructed with crossovers.
- Tapers for lane drops should not be contiguous with crossovers.
- It is desirable that crossovers be designed for speeds not less than 10 miles per hour below the speed limit or 85 percentile speed of the facility unless required by unusual site conditions.
- A good array of channelizing devices and full, properly placed pavement markings are important in providing drivers with a clearly defined travel path.
- Portable concrete barrier should not be used to compensate for poor geometric design
- The design of the crossover should provide for the truck traffic of the roadway.
- A clear area should be provided adjacent to the crossover.

Supplemental Signing and Pavement Markings

The signing and pavement markings shown in Figure 6-18 are considered to be minimum requirements for all TLTWO applications. Other items that may be considered include:

- The use of variable message signs,
- The use of oversize signs,
- The use of signs to advise motorists the length of TLTWO remaining, and
- The use of pavement lane arrows.

Mobile Operations

Mobile operations are work activities that make frequent short stops, up to a 15-minute period, such as litter cleanup or pothole patching and are similar to stationary operations. Warning signs, flashing vehicle lights, flags, and/or channelizing devices should be used.

Safety should not be compromised by using fewer devices simply because the operation will change its location frequently. Portable devices should be used. Flaggers may be used but caution must be taken so they are not exposed to unnecessary hazards. The control devices should be moved periodically to keep them near the work area. If mobile operations are in effect on a high speed travel lane, flashing arrow panels should be used.

Moving Operations

Moving operations are work activities where workers and equipment move along the road without stopping, usually at slow speeds. The advance warning area moves with the work area. Traffic should be directed to pass safely. Parking may be prohibited and work should be scheduled during off-peak hours. For some moving operations, such as street sweeping, if volumes are light and sight distances are good, a well marked and signed vehicle may suffice. If volumes and/or speeds are higher, a shadow or backup vehicle equipped as a sign truck, preferably equipped with a flashing arrow panel, should follow the work vehicle. Where feasible, warning signs should be placed along the road and periodically moved as the work progresses. In addition, vehicles may be equipped with flags, flashing vehicle lights, and appropriate signs. See Figure 6–19 for one example of using a shadow vehicle for a moving operation. Actual conditions may change the signs and devices needed.

Short-Term Utility Operations

Despite the shortness of "short-term" operations, certain traffic controls are necessary.

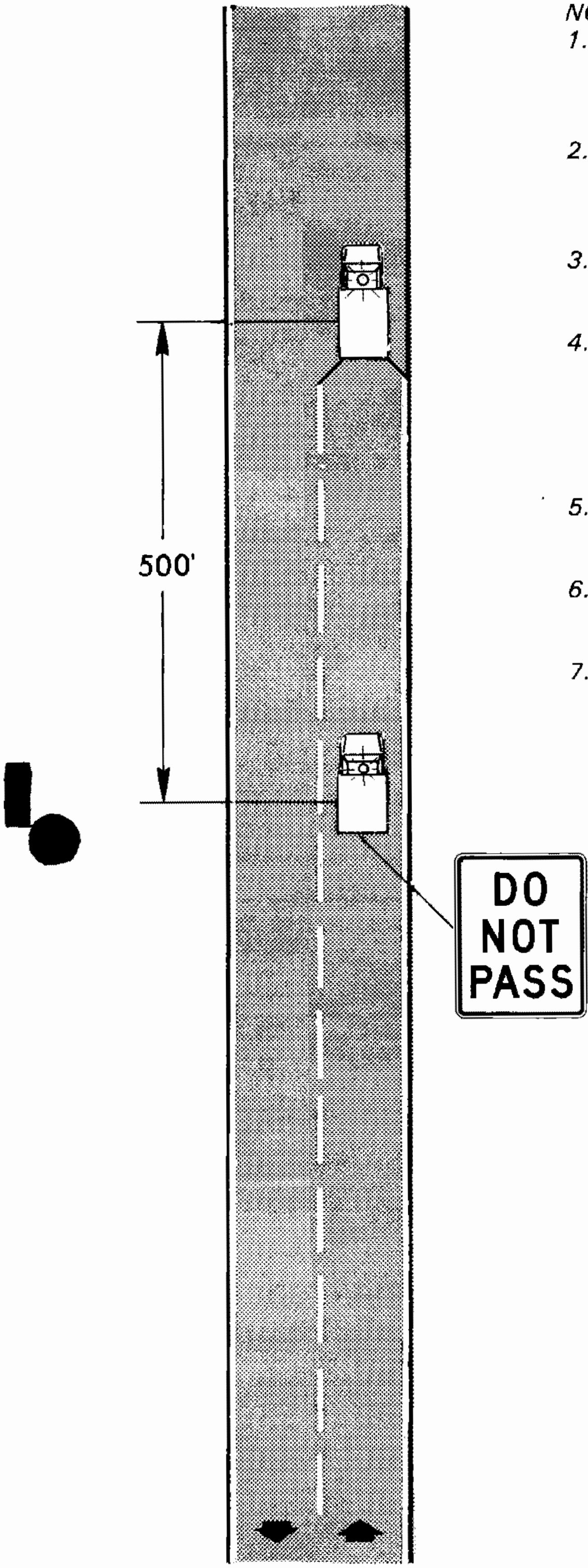
In urban areas, the work vehicle may be used for warning if it is equipped with flashing lights, rotating beacons, or flags.

Figures 6–20, 6–21, 6–22, and 6–23 are specifically included as typical applications for utility operations. Other typical applications may apply as well. Refer to section 6B–2, Utility Work Zones, for additional discussion of utility operations.

When entering or leaving a manhole, workers should always face oncoming traffic, so that they can get out of the way if necessary. Materials or equipment should be stored away from the manhole opening.

Urban Areas

Urban traffic control zones may be subdivided into segments. Decisions must be reached as to how to control vehicular traffic; how many lanes are required; or whether any turns should be prohibited at intersections. Pedestrian traffic must be considered. If work will be done on the sidewalk, will it be necessary to close the sidewalk and assign the pedestrians to another path? (See Figure 6–24 for an example.) Next, decisions must be reached as to how to maintain access to business, industrial and residential areas. Even if the road is closed to vehicles, pedestrian access and walkways should be provided.



NOTE:
1. *With this type of control, the work and shadow vehicles should pull over frequently to allow traffic to pass.*
2. *The distance between the work and shadow vehicles may vary according to terrain, paint drying time and other factors.*
3. *Additional shadow vehicles to warn and reduce speed of oncoming traffic may be used.*
4. *Another method for traffic control is to perform the edge striping from the shoulders and to place the center line with the work and shadow vehicles directly over the centerline.*
5. *Crash cushions mounted on the rear of the vehicles should be considered.*
6. *Two high-intensity flashing lights should be mounted on rear of vehicles adjacent to sign.*
7. *Metric conversion: 500 ft. = 150 m.*

KEY:
Flashing vehicle light

or

Figure 6-19 Typical Application—Using a Shadow Vehicle for Advance Warning

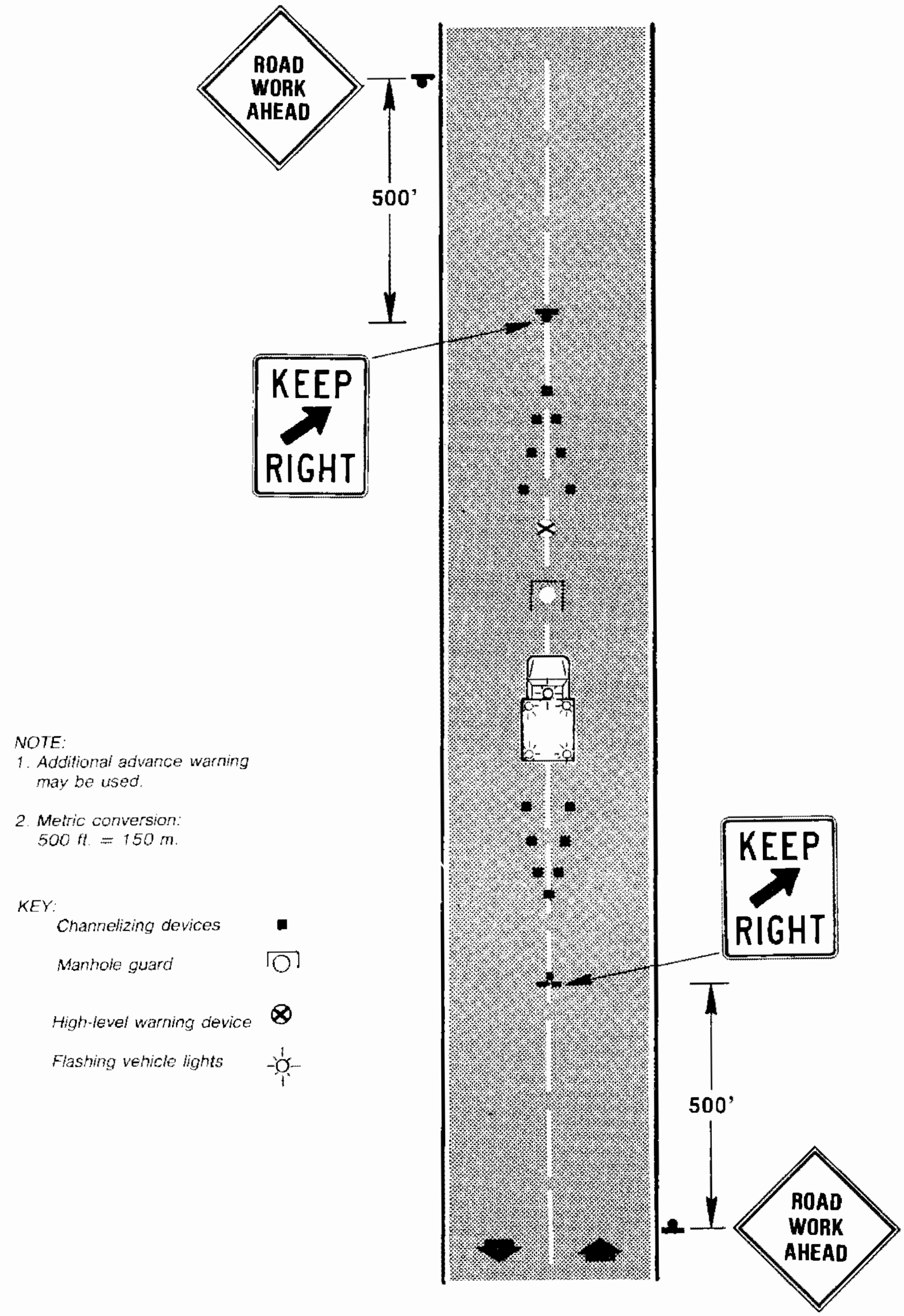
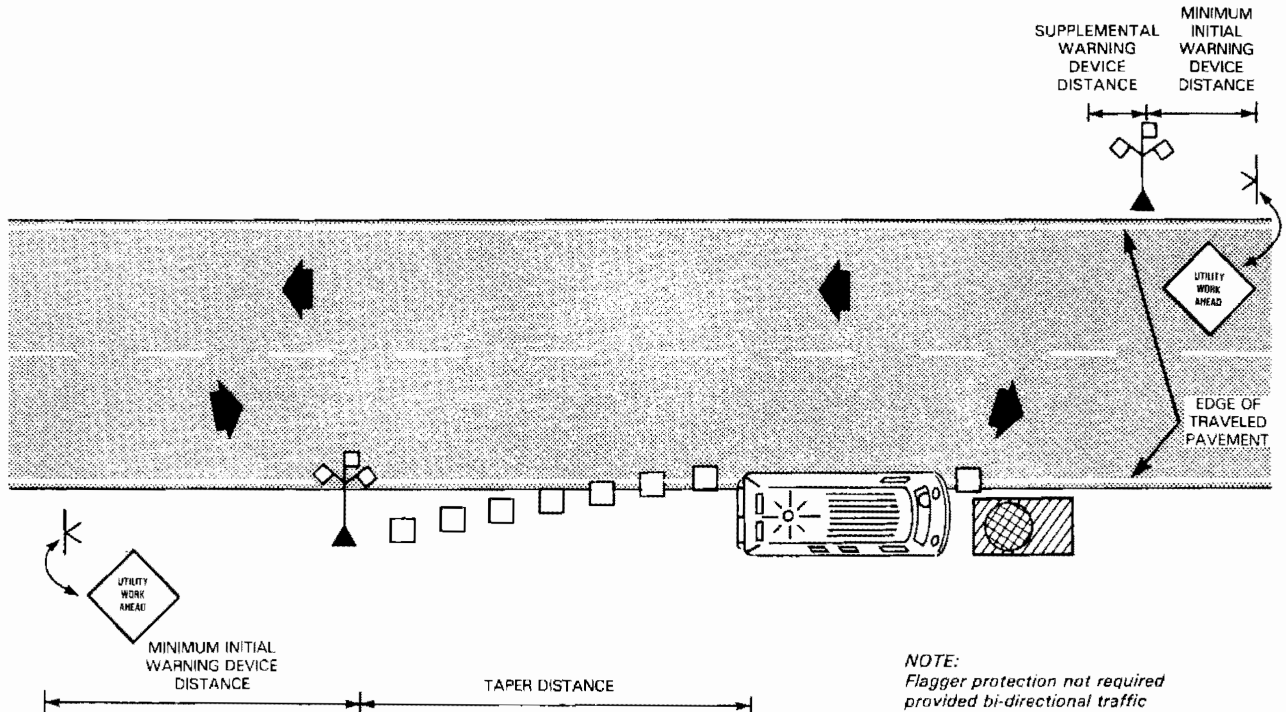


Figure 6-20 Typical Application of Traffic Control Devices or a Short-term Utility Operation in an Urban Location



SPEED LIMIT M.P.H.	MINIMUM* INITIAL WARNING DEVICE DISTANCE	SUPPLEMENTAL WARNING DEVICE DISTANCE	TAPER DISTANCE
0-25	200 ft.	200 ft.	125 ft.
26-35	300 ft.	300 ft.	250 ft.
36-50	500 ft.	400 ft.	600 ft.
OVER 50	1000 ft.	500 ft.	660 ft.

*MUTCD requires an advance warning distance of 1500 ft. on rural or open highway conditions.

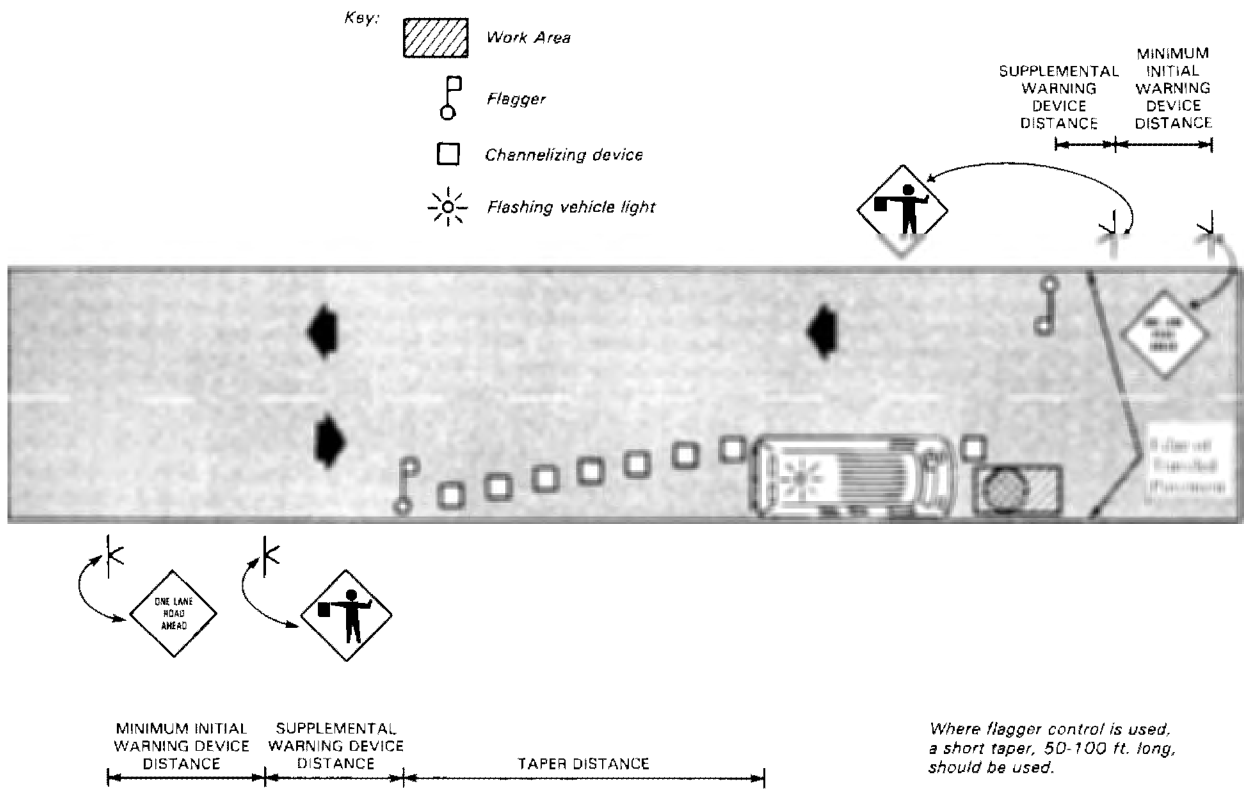
NOTE:
Flagger protection not required provided bi-directional traffic can move freely at reduced speed through the work area.

Refer to Figure 6-22 where above conditioning cannot be obtained.

Key:
- *Work area* \\\\\\\\
- *Channelizing Device* □
- *Flashing vehicle light*

Figure 6-21 Typical Application for a Utility Work Zone on a Two-lane Roadway with Low Traffic Volume

Figure 6-22 Typical Application for a Utility Work Zone on a Two-lane Roadway

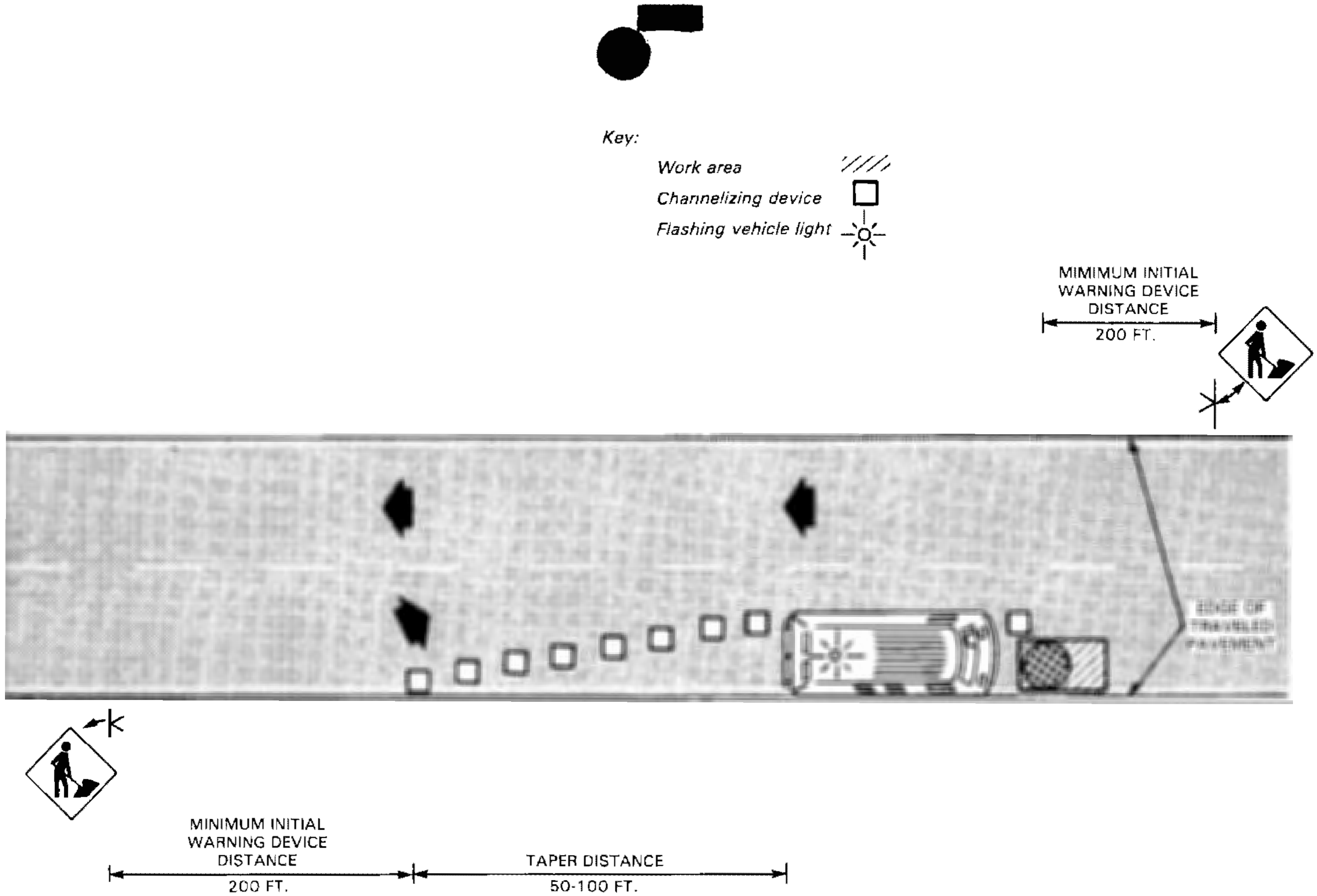


SPEED LIMIT M.P.H.	MINIMUM* INITIAL WARNING DEVICE DISTANCE	SUPPLEMENTAL WARNING DEVICE DISTANCE
0-25	200 ft.	200 ft.
26-35	300 ft.	300 ft.
36-50	500 ft.	400 ft.
OVER 50	1000 ft.	500 ft.

*MUTCD requires an advance warning distance of 1500 ft. on rural or open highway conditions.

Where flagger control is used, a short taper, 50-100 ft. long, should be used.

A flagger ahead message sign may be used as an alternate.



NOTE 1: *Where a flagger is required because of traffic volume or visibility, refer to Figure 6-22 for set up.*

NOTE 2: *With very few exceptions, this control device set-up is not to be used in rural areas. Typical applications of traffic control devices on other roadways are shown on Figures 6-21 and 6-22.*

Figure 6-23 Typical Application for a Utility Work Zone on a Two-lane Residential Street (Low Traffic Volume)

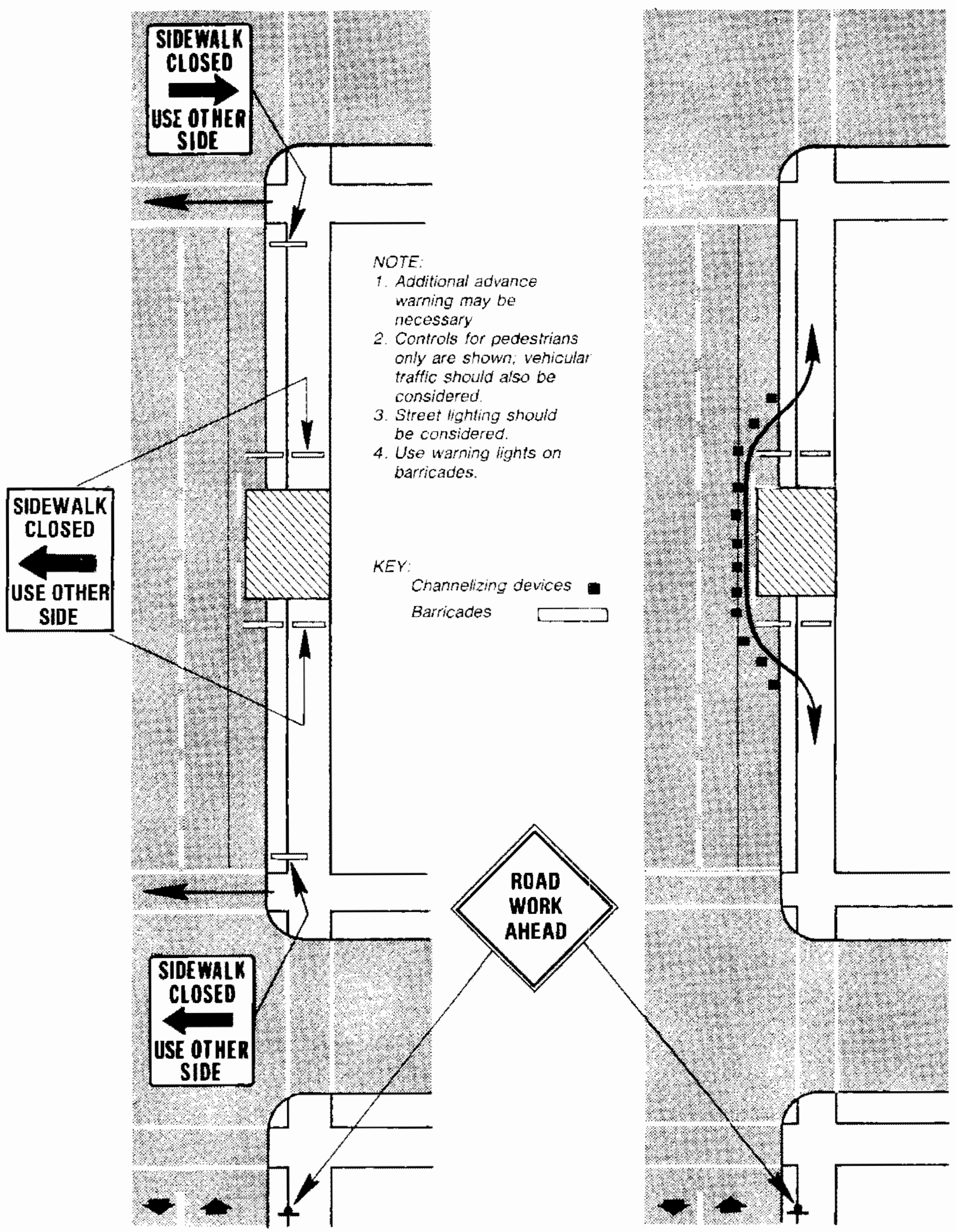


Figure 6-24 Typical Applications—Two Methods for Controlling Pedestrian Traffic by Either Directing Pedestrians to Another Route or Providing a Walkway

Pedestrians

When there is pedestrian traffic in the area, walkways should be provided. (Figure 6–24) The following situations would normally warrant including walkways in the TCP:

- Where sidewalks traverse the work zone,
- Where a designated school route traverses the work zone,
- Where significant pedestrian activity or evidence of such activity exists (i.e, a worn path), and
- Where existing land use generates pedestrian activity.

The following principles should be considered in designing or constructing pedestrian facilities:

- Pedestrians and vehicles should be physically separated (i.e., by barrier, barricade, or similar items). See Figure 6–24.
- Pedestrian walkways should be maintained free of any obstructions and hazards such as holes, debris, mud, construction equipment, stored materials, etc.
- Temporary lighting should be considered for all walkways that are used at night, particularly if adjacent walkways are lighted.
- Walkways should be at least 4 or 5 feet wide, and should be wider in areas of high pedestrian activity.
- All hazards (ditches, trenches, excavations, etc.) near or adjacent to walkways should be clearly delineated.
- Walkways under or adjacent to elevated work activities such as bridges or retaining walls may require covered walkways.
- Where safe pedestrian passage can not be provided, then pedestrians should be directed to the other side of the street by appropriate traffic control devices. See Figure 6–24.
- Signs and traffic control devices should not be a hazard to pedestrians.
- Signs located near or adjacent to a sidewalk should have a 7-foot clearance.
- Where construction activities involve sidewalks on both sides of the street efforts should be made to stage the work so that both sidewalks are not out of service at the same time.
- In the event that sidewalks on both sides of the street are closed, then pedestrians should be guided around the construction site.
- Reflectorized traffic control devices are of little value to pedestrians. Warning lights should be used to delineate the pedestrians pathway and to mark hazards as appropriate.

Bicycles

Bicycles also need protection and access to the roadway. If a bicycle path is closed because of the work being done, an alternate route should be provided and signed for if appropriate. Bicycles should not be directed into the same path being used by pedestrians. For more details on controlling bicycle traffic, see Part IX of the MUTCD and Part IX of this Handbook.

Interchanges

On limited access highways, with interchange ramps, access to these ramps should be maintained even if the work area is in the lane adjacent to the ramps. If access is not possible the ramp may be closed by using signs and Type III barricades. Early coordination with officials having jurisdiction over the affected cross streets is needed prior to ramp closures.

The access to the exit ramp should be clearly marked and outlined with channelizing devices. For long-term projects, old markings should be removed and new ones placed. As the work area changes, the access area may be changed, as shown in Figure 6–25.

Intersections

Use advance warning signs, devices, and markings as appropriate on all cross streets. The effect of the work upon signal operation should be considered such as signal phasing for adequate capacity and for maintaining or adjusting detectors in the pavement. Three examples of intersection traffic control are given in Figures 6–26, 6–27, and 6–28.

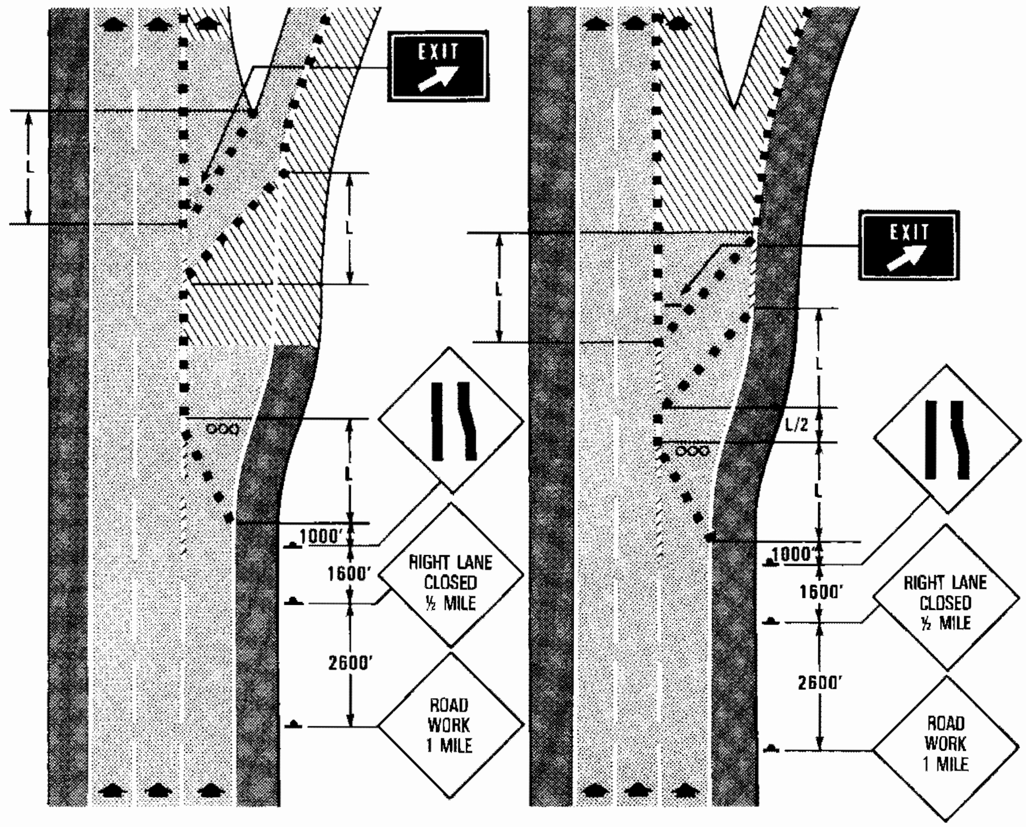
Detours

Detour signing is usually handled by the traffic engineer with authority over the roadway because it is considered a traffic routing problem. Detour signs are used to direct traffic onto another roadway. When the detour is long, signs should be installed to periodically remind and reassure drivers that they are still on a detour. This is done by using the Detour Marker (M4–8) or Detour (M4–9) signs.

When an entire roadway is closed, as illustrated in Figure 6–29, a detour should be provided and traffic should be warned of the closure in advance. This illustration is an example for a closure 10 miles from the intersection. If local traffic is allowed to use the roadway up to the closure, the ROAD CLOSED TO THRU TRAFFIC sign should be used. The portion of the road open to local traffic should have adequate signing, marking, and protection.

Figure 6–30 illustrates a road closure in a city with typical detour signing.

Detours should be signed so that traffic will be able to get through the entire area and back to the original roadway.



NOTE:

1. *Additional advance warning may be necessary.*
2. *A buffer space may be used.*
3. *The right shoulder may be used as an exit ramp if it has been designed appropriately.*
4. *Another alternative is to channelize exiting traffic onto the shoulder, and close the lane as necessary.*
5. *L = length of taper — refer to Table 6-3.*
6. *Metric conversion: 500 ft. = 150 m., 1000 ft. = 300 m.*

KEY:

Arrow Panel ooo

Channelizing devices ■

\\\\\ *Pavement markings that should be removed for a long term project. Temporary markings to be placed as needed.*

Figure 6-25 Typical Applications of Traffic Control on Freeway Allowing Access to Exit Ramp

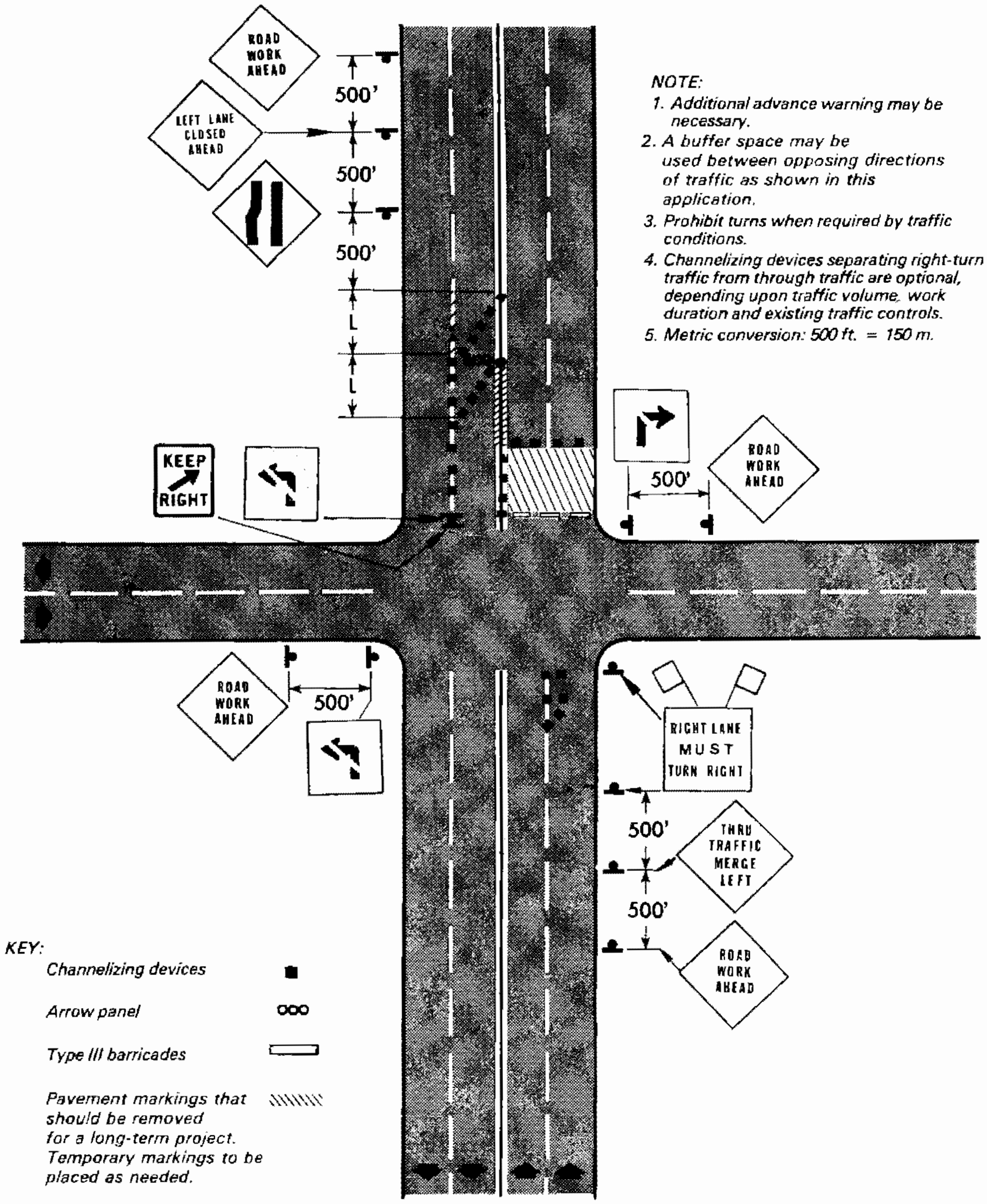


Figure 6-26 Typical Application of Control Around a Work Area Near an Intersection, Allowing Right Turns

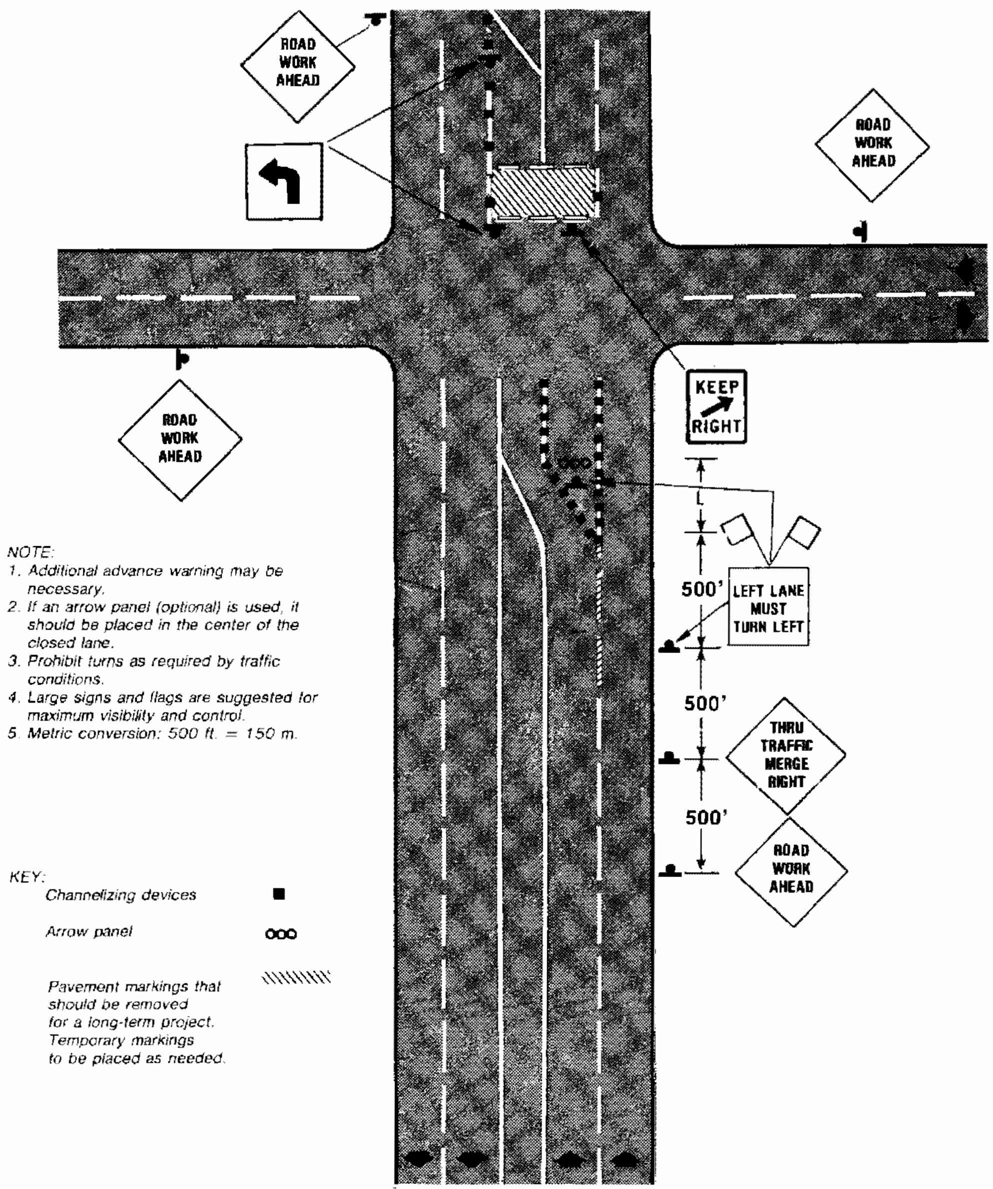
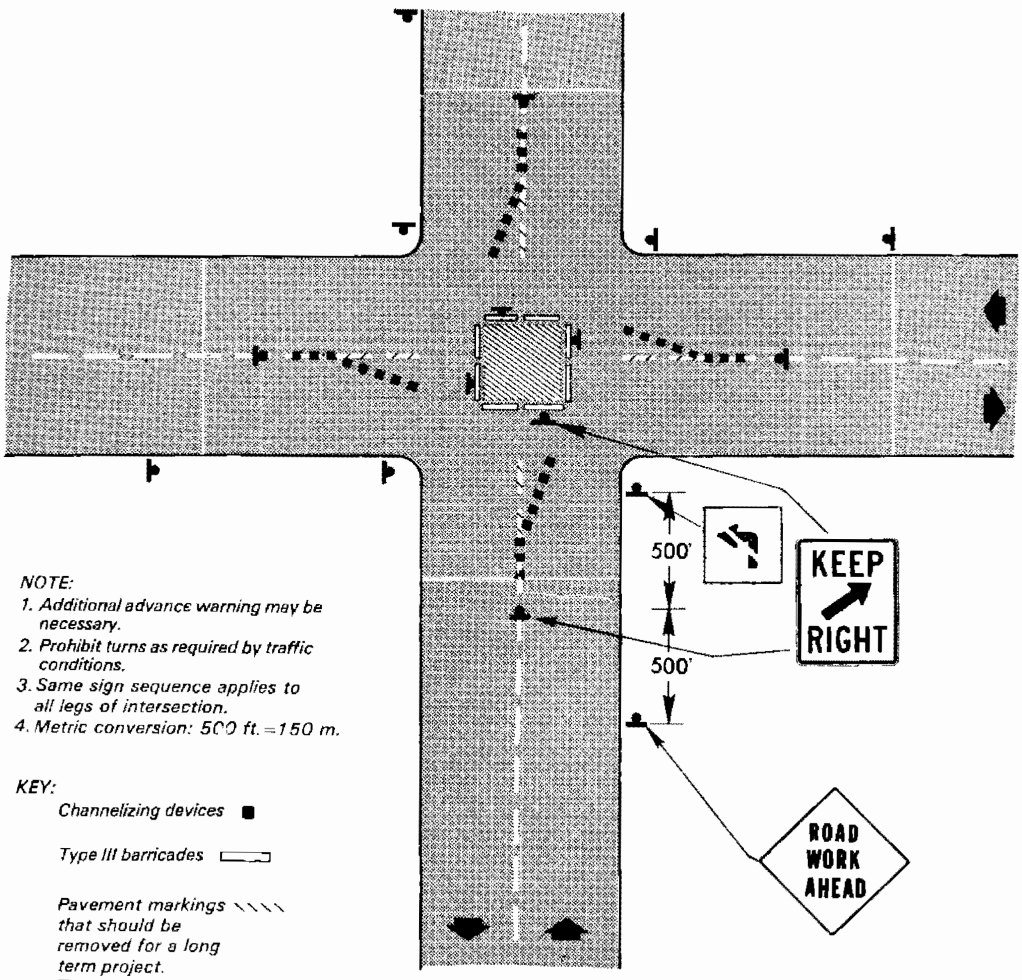


Figure 6-27 Typical Application of Traffic Control Devices Used for a Work Area Near an Intersection, Providing Access to Left-turn Lane



NOTE:

1. *Additional advance warning may be necessary.*
2. *Prohibit turns as required by traffic conditions.*
3. *Same sign sequence applies to all legs of intersection.*
4. *Metric conversion: 500 ft. = 150 m.*

KEY:

Channelizing devices ■

Type III barricades

Pavement markings \\\\ *that should be removed for a long term project. Temporary markings to be placed as needed.*

Figure 6-28 Typical Application of Traffic Control Devices when the Work Area is in the Center of an Intersection

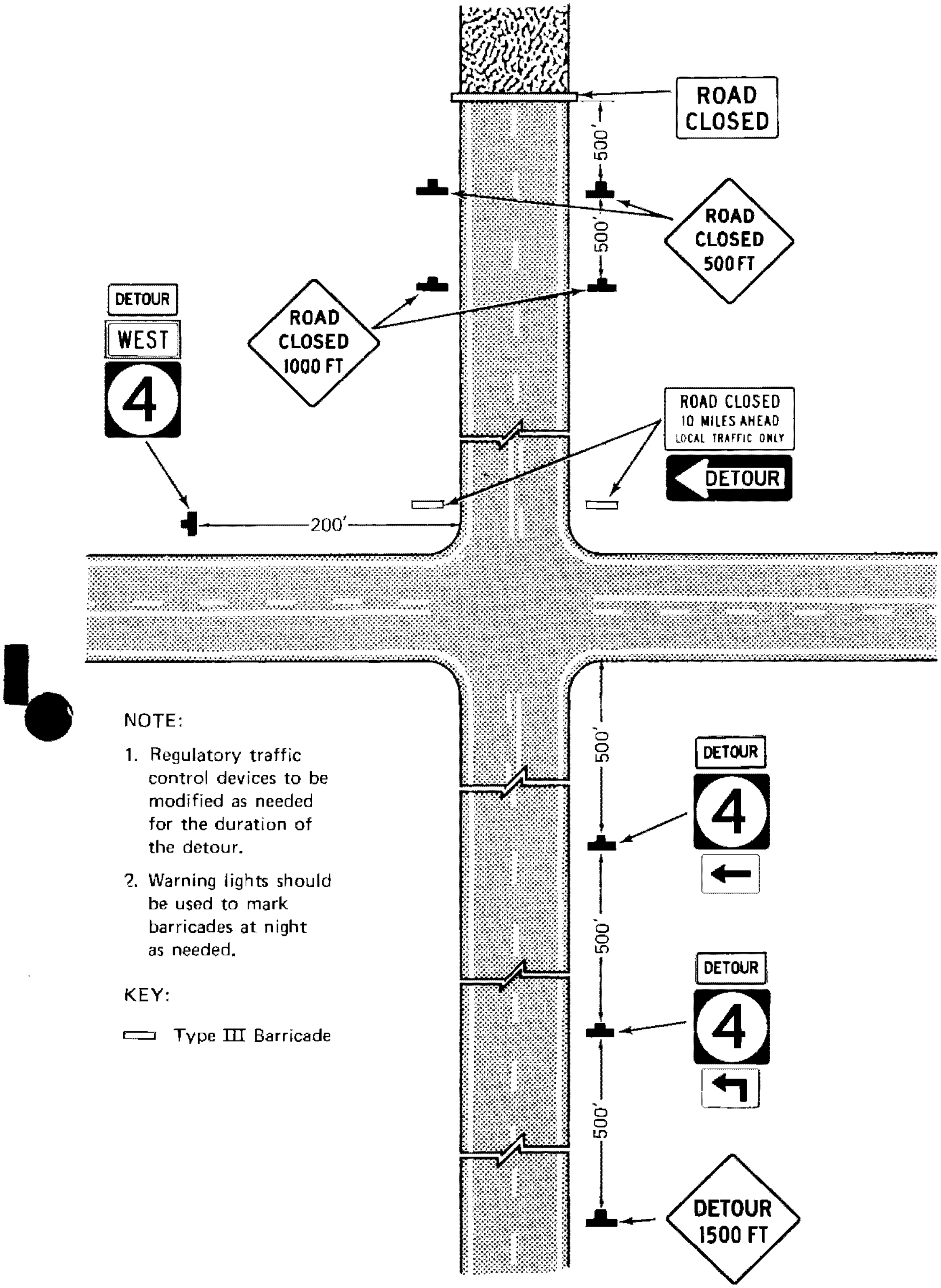
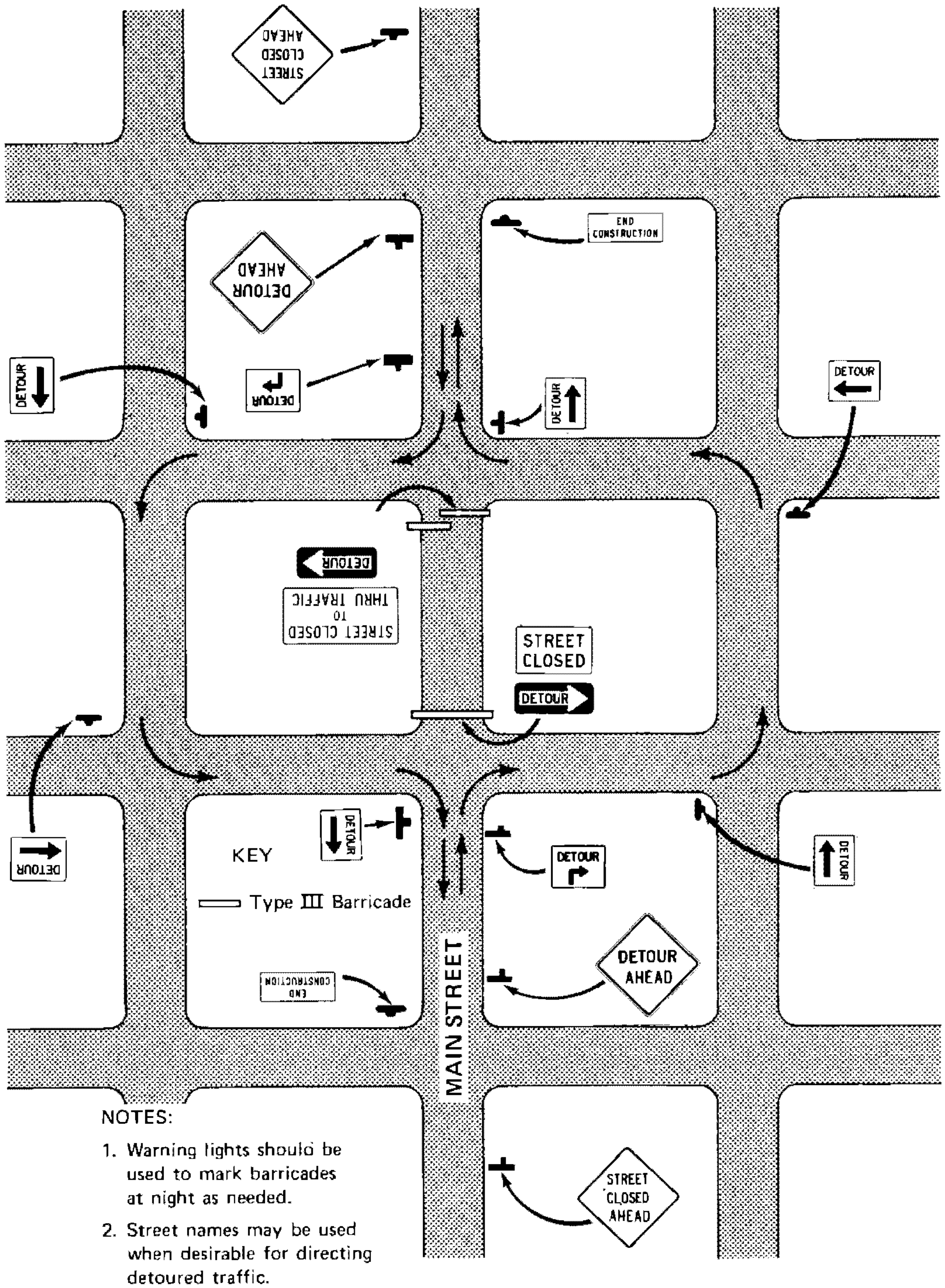


Figure 6-29 Typical Application—Roadway Closed Beyond Detour Point (MUTCD, Figure 6-3)



NOTES:

1. Warning lights should be used to mark barricades at night as needed.
2. Street names may be used when desirable for directing detoured traffic.

Figure 6-30 Typical Application—Detour Signing for Street Construction Project in a Street Grid (MUTCD, Figure 6-4)

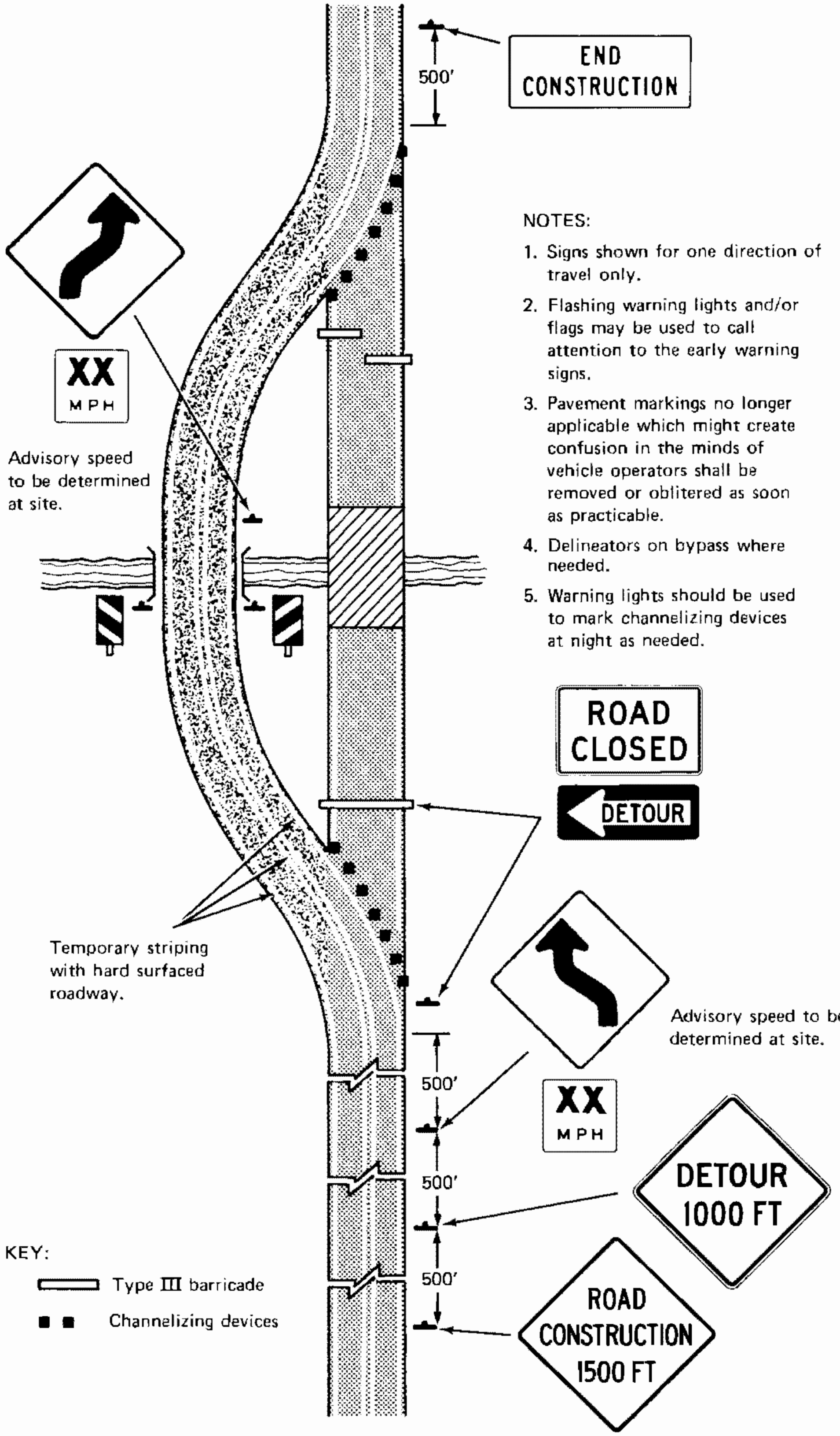


Figure 6-31 Typical Applications of Traffic Control Devices on a Two-lane Highway Where the Entire Roadway is Closed and a Bypass Detour is Provided (MUTCD, Figure 6-2)

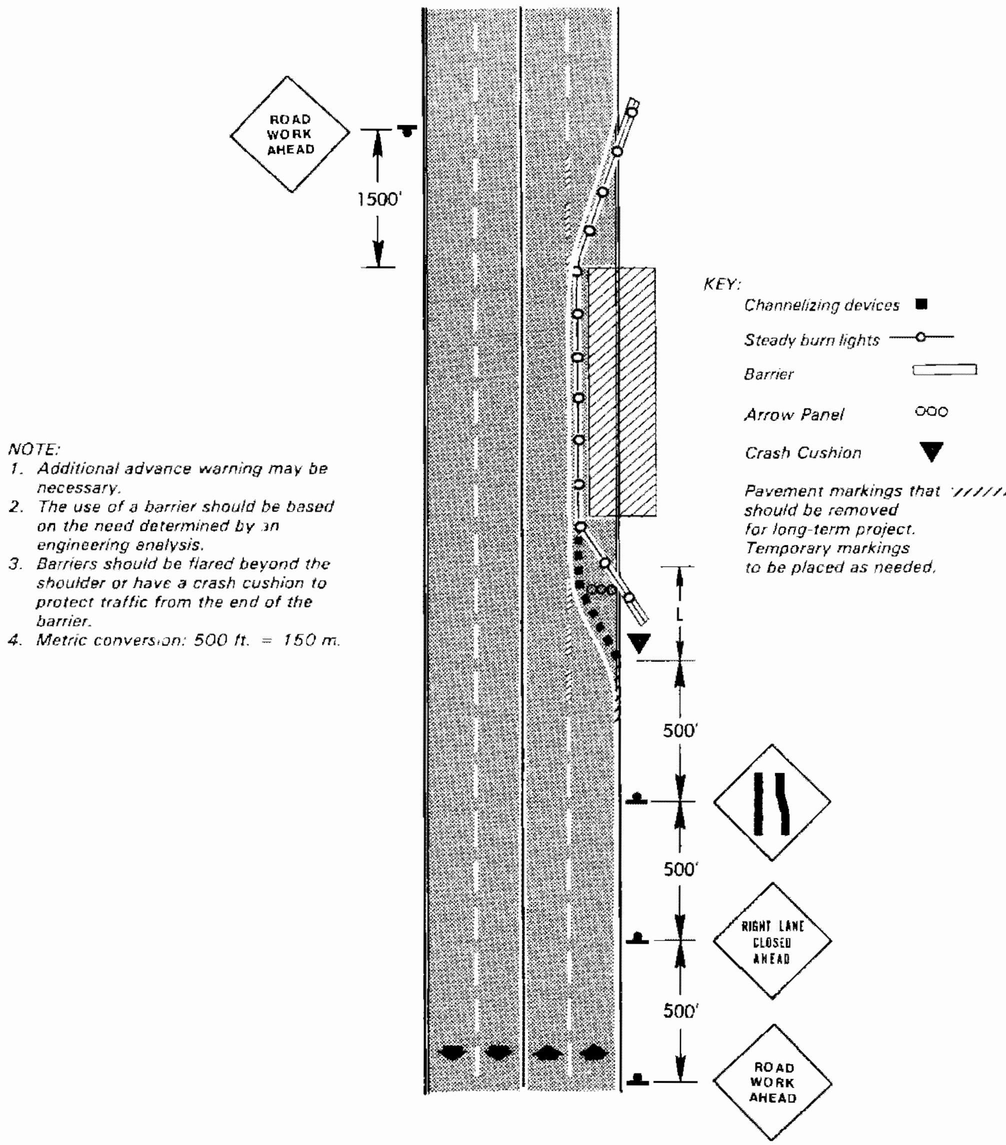


Figure 6-32 Typical Application of Traffic Control Using a Portable Barrier Around a Work Area

Temporary Roadway

Figure 6-31 illustrates the controls around an area where a section of roadway has been closed. Channelizing devices and pavement markings are used to indicate the transition to the temporary roadway.

Portable Concrete Barrier

Figure 6-32 illustrates the use of a portable concrete barrier around a work area which also includes a lane closure. When determined necessary by an engineering analysis, barriers should be used for added safety. There are four primary functions of barriers:

- Keep traffic from entering work areas, such as excavations or material storage sites;
- Provide positive protection for workers;
- Separate two-way traffic; and
- Protect construction such as falsework for bridges and other exposed objects.

6C. INSTALLATION, MAINTENANCE AND INSPECTION

Before the work is scheduled to begin, the foreman and/or inspector should check all signs, pavement marking material, and channelizing devices that are to be used. All devices should be:

- Standard in size, shape, color, or message;
- In good condition, not needing repair;
- Reflectorized.

If a particular device does not meet all of the above requirements it should be replaced with one that does. Additional devices should be available to replace any that may be damaged while the work is in progress. On construction, the inspector and foreman should be in agreement that the devices are satisfactory before they are placed on the roadway.

Reflectorized devices need extra care when handling and transporting to ensure that the reflectorizing elements are not damaged.

Existing signs that do not apply during construction, maintenance, or utility work should be removed or completely covered. Burlap or other materials that are not opaque are not acceptable. At night, non-opaque materials let the messages be seen because headlights reflect the message through the material.

Work area signs that are installed before traffic patterns are changed should be covered, rotated, or folded in half so drivers cannot read the message.

As many maintenance, utility, and emergency operations require the same devices for each job, vehicles should be equipped with an adequate supply of commonly used portable devices.

6C-1 Installation and Removal

Order of Placement

Traffic control devices should be placed in the order that drivers will see them, starting with the sign or device that is farthest from the work area and place the others as the work area is approached. If traffic in both directions will be affected, such as with work in the center lanes, the devices can be placed in both directions at the same time, starting at each end farthest from the work area.

When one direction of traffic will be directed into opposing traffic lanes, such as Figures 6-12 and 6-29, the signs, devices, and pavement markings for the opposing traffic should be placed first. When the signs and devices are across from or at the work area, the devices for the oncoming direction can then be set up. (It is essential to channelize opposing traffic out of its lane before moving the oncoming traffic into the lane.)

When signs or channelizing devices are to be installed and removed several times during the work operation, a spot should be painted where the devices are located, so that the installation can be repeated quickly and so that proper placement is assured. The devices should be stored off the roadway, out of sight, or transported to another location.

Motorists do not expect to encounter workers in the roadway setting up a traffic control zone. Since the goal is to make the entire operation safe, high-level warning devices, flaggers, or flashing vehicle lights should be used to warn the drivers of the presence of workers. Flashing arrow panels are valuable to assist the workers during placement or removal of channelizing devices for lane closures.

Removal of Devices

As soon as the work is completed and the devices are no longer needed, they should be removed. Devices should be removed in the opposite order of installation by starting with the devices closest to the work area and continuing away from the area. Flashing arrow panels, high-level warning devices, flaggers, and/or flashing vehicle lights should be used for the removal process.

Pavement Marking Removal

Motorists use pavement markings as a primary source of guidance. Temporary pavement markings, such as pressure-sensitive traffic tape or raised pavement markings can be used with other devices in a traffic control zone. Any pavement markings that are no longer applicable or that may confuse drivers should be removed as soon as practicable.

Traditionally, methods of removal include grinding, burning, chemical treatment, sandblasting, hydroblastic, and high pressure water jetting (Ref. 6-5). Over-painting no longer appropriate markings with black paint and bituminous solutions is specifically disallowed by the MUTCD. This treatment has proved unsatisfactory as the original lines eventually reappear as the overlying material wears away under traffic. In addition, lines which are covered in this way are still visible under certain conditions (low angles of illumination). See section 3D-2 for a more thorough discussion of pavement marking removal.

6C-2 Inspection and Maintenance Program

Purpose

Once the traffic control zone is established, it is important to ensure that it continues to function as it was intended and installed—and perhaps subsequently modified as a result of the evaluation process.

Maintenance is needed to service the equipment and make corrections which may be required due to any combination of the following factors.

On highway construction projects, this is normally the responsibility of the contractor.

- Traffic accidents
- Device displacement
  —vehicular contact
  —slip stream from trucks
  —workers
  —wind
- Damage caused by construction activities
- Weather created damage
- Malfunctions and burn outs
- Consumption of energy
  —battery-operated lights
  —gasoline generators
- Physical deterioration
- Dust and grime
  —on sign faces
  —on reflectorized rails
- Dirt and debris
  —on roadways
- Vandalism

Elements of an Inspection Program

A comprehensive inspection and maintenance program should include the following elements:

- A formalized plan;
- Defined inspection procedures;
- A form on which the findings of the field inspection are recorded;
- A repair program;
- Assurance of an adequate inventory of devices for emergency replacements or repairs;
- Check procedures to assure that specified repairs are made;
- Identify possible causes of accidents or skid marks;
- A review to insure that the travel path is clearly marked through the entire work zone, both day and night; and
- Formal documentation of inspections and repairs made.

The inspector will be faced with the need to make decisions during the inspection and must exercise judgment in establishing appropriate practices.

A key element of the program is the procedure which insures that the required maintenance is performed. When the corrective action is taken, it should be so noted in order that documentation is complete.

Responsibility

For each project, an individual should be assigned the responsibility for traffic control. On construction projects, the contractor should designate a specific person by name and telephone number. In addition, on large projects the traffic control responsibility should be assigned to an employee in the agency's organization. Routine inspections of the traffic control installation should be carried out by these individuals.

Less frequent but periodic inspections should be performed by senior staff of the contractor (typically the superintendent) and the agency (the resident engineer and/or the traffic engineer).

Lines of communication and responsibility should be clearly established between individuals in control of routine maintenance activities and those with greater authority, so that urgent problems that arise from time to time can be brought promptly to the attention of officials who are in a position to respond immediately.

Frequency

To determine the frequency with which inspections should be performed, the following factors should be considered:

- Project size and duration,
- Nature of work activity,
- Complexity of traffic control,
- Frequency at which damage is occurring, and
- Number of deficiencies observed during previous inspections.

Traffic controls that are left in place overnight should be inspected during hours of darkness at the same frequency as during the daylight hours. Holiday and weekend inspections should be made as needed.

Recordkeeping

Good recordkeeping procedures suggest that the time and location of the installation and removal of traffic control devices be noted. Although this can be time consuming for a moving maintenance operation, it is important to record significant traffic control actions taken by the field crew. It is desirable that this include:

- Starting and ending time of work;
- Location of work;
- Type, condition and position of traffic control devices;

- Names of personnel;
- Type of equipment used; and
- Any change in temporary or permanent regulatory devices.

Major projects will require more detailed recordkeeping since they may involve greater amounts of funds, outside (Federal or State aid) funding sources, and longer distances and times of physical exposure to the workers, motorists, or pedestrians.

Several methods of recording traffic controls are available. These include:

- Use of photologging;
- Photographs either keyed to a diary or containing a brief description of
  —time,
  —location,
  —direction, and
  —photographer's name.
- Special notes on construction plans (preferably the traffic control plan sheet); and
- Daily diary entries of times, location, and names of individuals (when known) involved in the
  —installation,
  —change, and
  —removal of traffic control devices.

Change orders or work orders also serve as a reference, and should be keyed to the diary when used.

When the inspection process reveals a condition that requires correction, the documentation should include:

- Description of the correction needed, when it was noted, and by whom;
- Corrections made or deferred and why;
- Replacements made or deferred and why; and
- Any other needed actions.

6C-3 Legal Liability

Highway personnel should anticipate the likelihood of lawsuits in the event of an accident or other grievance suffered by an injured citizen. To prevent or minimize such litigation, and to help defend lawsuits, the following steps are recommended:

- Know and comply with the traffic control for street and highway construction and maintenance operations set forth in the State, local or national MUTCD and other nationally accepted engineering standards and practices.

- Provide properly working devices at the site particularly when unattended (nights, weekends, etc.).
- Document all actions taken on or related to traffic controls that are placed in effect at the worksite.
- Inspect the worksite at frequent intervals with a view to detecting and immediately correcting deficiencies in traffic control.
- Remove all material and equipment not needed at the site as soon as possible. (This applies also to traffic control devices that cease to be needed.)
- Provide warning and protection to motorists, pedestrians, and workers for potential conflicts and hazards that may result from the work being done at the site or from a vehicle striking a device.

6C–4 Documentation for Protection

Since it is not known when an accident will occur, the key to defending cases in courts of law is advanced preparation. Highway personnel and the contractors should maintain a careful record of job-related activities so they may document their efforts to provide good traffic control at the worksite. The record system should reflect priorities and a planned safety program.

The following steps are recommended as a means of establishing effective project documentation:

- Maintain up-to-date engineering drawings.
- File all pertinent memoranda and correspondence.
- Reference standards and specifications.
- Keep daily project diary.
- Perform and document routine inspections.
- Follow all safety regulations.
- Conduct personnel safety training.
- Document all instructions to contractors or subcontractors.
- Take photographs at key project stages and for unusual situations.

In case of an accident, project personnel should promptly record and document the circumstances and pertinent factors. Photographs are recommended.

REFERENCES

6-1 Federal Highway Administration (FHWA) *Standard Highway Signs*, Washington D.C., U.S. Department of Transportation 1979; vp.

6-2 Federal Highway Administration (FHWA) *Standard Alphabets for Highway Signs and Pavement Markings*, Washington D.C., U.S. Department of Transportation 1977; 56p.

6-3 American Association of State Highway and Transportation Officials (AASHTO), *Guide for Selecting, Locating, and Designing Traffic Barriers*, Washington D.C., 1977; 322p.

6-4 Federal Highway Administration (FHWA), *Federal Aid Highway Program Manual Volume 6*, Chapter 4, Section 2 Subsection 12, Washingtion D.C., U.S. Department of Transportation.

6-5 Niessner, Charles W., *Traffic Stripe Removal*, Washington D.C., Federal Highway Administration, July 1979; 60p.

PART VII
School Areas

Part VII. TRAFFIC CONTROL FOR SCHOOL AREAS

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7A. GENERAL

Traffic accidents involving the injury or death of pedestrians are one of the most critical problems confronting Traffic Engineers. This traffic issue arouses significant emotion and public indignation when the pedestrians are school-age children. Parents and civic leaders are persistent in their demands for more and better applications of signs, markings, signals, and crossing protection in and around school areas and other locations which attract children.

According to national statistics, young pedestrians under 15 years of age experience twice as many accidents as any other age group. Moreover, pedestrian traffic accidents are generally severe. The young pedestrians are more vulnerable than the mature pedestrian because of their lack of experience and judgment in traffic situations. Added to this is a lack of perception and reading skills which can be expected of adult pedestrians.

Accident statistics further indicate that the children are more often involved in nonschool related accidents. This may be indicative that the standard treatments prescribed for traffic control around school facilities are effective. Adherence to these uniform standards and safety provisions are apparently a critical contributing factor to improving the overall pedestrian accident problem.

The MUTCD standards and the guidelines presented below relate to the school pedestrian (and the environs in which they operate). They are presented as separate and distinct from the general application and design of traffic control devices because of the special nature and need of the school-age pedestrian. It would be misleading to infer that greater attention to traffic control solely in the school corridor will completely solve the youth accident problem. In reality, the same fundamentals applicable to school areas are of equal importance near playgrounds and other areas which attract a number of young pedestrians.

7A-1 Need for Standards

As with other forms of traffic control, uniformity in application and operation of traffic control devices around school facilities promotes the orderly and predictable movement of traffic. It is especially significant that motorists understand and comprehend their responsibilities as they are typically more mature, aware, and experienced in traffic situations than the young pedestrian.

There are many instances where existing school zone controls were installed as a result of emotional requests from parents or school officials.

Many of these controls are not only unnecessary, but costly to maintain. More importantly, the lack of respect accorded the unwarranted controls lessens the respect for traffic control devices in general. Thus, it is necessary to stress that traffic controls for pedestrians in school areas must be uniformly applied on the basis of established standards combined with sound engineering studies. Care must be exercised to avoid the pitfalls of over-reacting to the emotional demands for excessive traffic control devices.

From an engineering standpoint, the problem of traffic control and operation in school areas is one of evaluating approved devices while taking into consideration child-pedestrian behavior and driver reaction. To fully appreciate the fundamental criteria for school zone protection, it is necessary to understand the behavior of both the young pedestrian and the adult driver.

7A–2 Characteristics of Young Pedestrians

Research on the behavior of children as pedestrians and the extent of their perception and judgment in a traffic situation shows that children from 6 to 16 years of age are generally inattentive and careless in crossing streets (Ref. 7–1). Behavior studies indicate the following general characteristics of this age group:

- Physical Perception: Peripheral vision is not as well developed in children as in adults.
- Physical Stature: The small stature of children under 9 years old (3.6 feet average) presents difficulties in their seeing oncoming vehicles beyond parked cars as well as difficulties for the drivers in seeing these small pedestrians.
- Use of Crosswalks: About two-thirds of the children will use a marked crosswalk at an uncontrolled intersection. The percentage increases at signalized intersections. When crossing guards are present, almost all children use the crosswalk.
- Use of Traffic Signals: Only two-thirds of the young pedestrians will cross on the green indication where crossing guards are not present. With crossing guards, nearly all young pedestrians cross on green. With pedestrian-actuated signals, less than half will actuate the signal and cross during gaps in traffic if crossing guards are not present.
- Use of Over or Underpasses: Children between age 5 and 16 will generally use overpasses when a crossing guard is nearby or when fences channel them to the crossing.

Accident data (Ref. 7–1) show that the lack of attention to the traffic situation is a major factor in accidents involving children. Sixty percent of the children involved in accidents did not see the vehicle. Seventeen percent of the accident victims under 14 years of age had either run into the roadway, appeared suddenly in the path of a vehicle, or crossed from between parked vehicles.

From another viewpoint, the young pedestrian that is not generally involved in accidents may be characterized as follows: goes to school with friends, goes the same way every day, selects the route taken because it is short, and would change the route if told to by parents. In the trip to school, this type youth crosses three or more streets at nonsignalized crossings; crosses one or more streets with a policeman, crossing guard, or student patrol present; does not cross in the middle of the block; crosses when there are no cars in sight; was told how to cross the street safely by parents; knows it is safer to walk across the street than to run; would run out into the street to save a child or animal; would cross a signalized intersection when the light is green; thinks a marked crosswalk at the corner is a safer place to cross than midblock or an unmarked crosswalk; feels safer going home from school than to school; and is more worried about being hit by a car when it is dark.

The youngest pedestrians, 9 and under, are involved in more than their share of accidents. Kindergarten through third grade students have considerable difficulty understanding and properly using school area traffic signals and crosswalks. They are more likely to cross midblock or against a red signal than older students. The young pedestrian at each age level considers the location with a crossing guard or student patrol the safest place to cross.

7A-3 Driver Behavioral Characteristics

Usually, the driver using roadways surrounding school facilities is a local resident driving to work. A typical composite shows that the driver has a child between the ages of 5 and 9 and is aware of the school area—not because of signing but because of familiarity with the area. The driver knows that the legal speed limit through the school zone is between 15 and 25 miles per hour, but is nevertheless driving through the area between 31 and 35 miles per hour. The driver does not perceive the existing signs unless there is a flashing beacon associated with a speed sign, and is not aware of the intent of the traffic signs. Even though the driver is aware of the flashing beacon and speed sign, he will not slow down for the school zone unless he perceives a potential hazard. Driver behavior studies have concluded that vehicular speeds in school zones are reduced only when children are visible, crossing guards are visible, the flashing beacons are activated, or when police enforcement is evident.

Given the characteristics of the young pedestrians and the attitudes and perceptions of the typical driver traveling through school zones, it becomes obvious that uniform traffic control devices properly applied and enforced are needed to protect young pedestrians.

7A-4 Protective Measures

The protection of the school age pedestrian is the shared responsibility of parents, school administrators, traffic officials, civic leaders, and vehicle drivers. There is little doubt that programs in the home and school to train the child as a responsible pedestrian are an important factor in improving safety. The following sections in this Part of the Handbook address the current practices in applying standard measures to safeguard young pedestrians. Such protective measures include safe walking routes, signs, markings, signals, pedestrian separation structures, adult crossing guards and school safety patrols.

7B. ESTABLISHING SCHOOL ROUTES

For elementary and kindergarten students, a "Suggested Route to School Plan" is highly desirable to develop good walking patterns and to promote conformance to school zone traffic controls. The procedure used to develop a Suggested Route to School Plan starts with the preparation of a route map for each elementary school in the district. Guidelines for development of suggested trip maps are presented in various publications (Refs. 7-2, 7-3 and 7-4.) A synopsis of the procedures is given below.

7B-1 Locational Factors

An initial meeting between the Board of Education and the local Traffic Engineering Department (or Division) is usually conducted to assure mutual understanding and agreement and to assign responsibility for the various steps in the procedure.

For example, the school board should provide data or a map that indicates the following:

- List of all elementary schools in the district,
- List or map showing each school boundary,
- Names of all elementary school principals, and
- List or map showing all school bus routes and bus stops.

The following information should be obtained from the school principal, the Parent/Teacher Association, or any organized citizen group involved in pedestrian safety:

- Student walking areas,
- Safety patrol and/or crossing guard locations,
- Problem locations (i.e. areas of concern to parents/public or areas of actual, potential, or perceived safety problems),
- Student enrollment, age profiles, and volume of student pedestrians,
- PTA contacts (or equivalent),
- School hours, and
- Verification of school boundary.

A base (street) map is usually prepared showing the boundary of the school attendance areas surrounding the school. Right-of-way maps, zoning maps and street maps, all to scale (1 inch = 200 feet to 1 inch = 1000 feet) can be used as base maps (Figure 7-1). The necessary data obtained from the sources listed above can then be transferred to the base map.

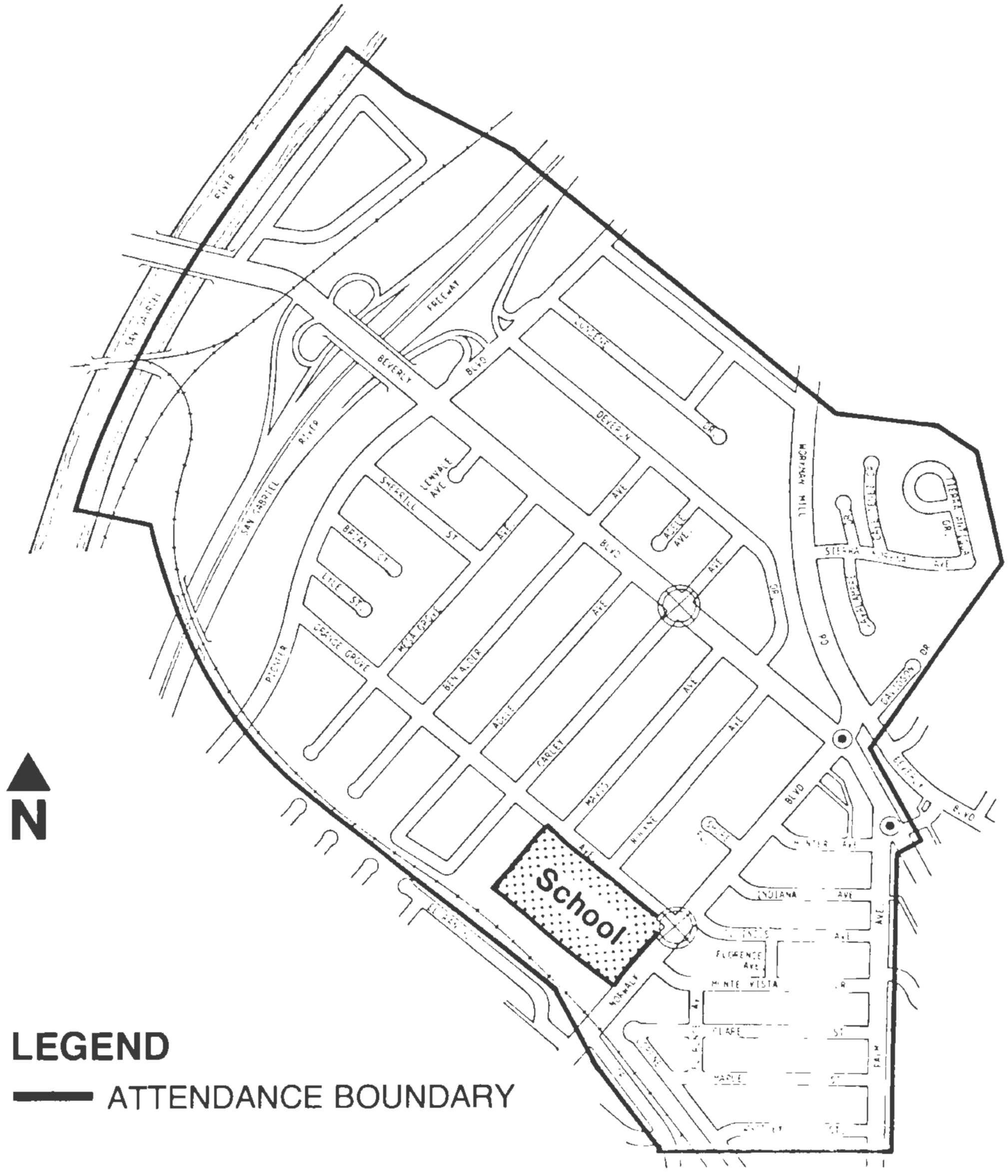


Figure 7-1 Typical School Area Base Map

7B-2 Traffic Characteristics

The walking areas should be reviewed to identify the location of traffic signs, pavement markings, signals, sidewalks, posted speed limits, and specific locations that might be hazardous to school-age pedestrians. This can be done by driving through the area and recording data directly on the base map. Photologging of principal routes from a moving vehicle using time-lapse or distance-lapse photography is another inventory technique.

Traffic volume data on major streets within the school attendance boundaries are usually collected to determine which routes exhibit high vehicular travel. Traffic volumes on minor streets close to school grounds should also be collected to determine the magnitude of potential conflicts at points of heaviest pedestrian concentrations. This data should be collected during school pedestrian traffic periods.

All of the field inventory data should be consolidated to assist in the final preparation of the safe or suggested routes.

7B-3 Map Layout and Route Design

Before developing the safest walking routes, the map layout should be checked to assure that the following data are included:

- School location and boundary;
- All stop and yield signs, traffic signals, crossing guard locations, and school safety patrol locations;
- Location of all crosswalks;
- North arrow, scale of map;
- Sidewalk or path locations; and
- Bicycle lane or path locations.

This information and pedestrian and vehicular volumes should be coupled with engineering judgment to develop the suggested safest routes. The routes should be identified by sequential arrows. Generally, the route should be designed to assure that the school-age pedestrians:

- Form into a group as soon as possible to be more readily visible to motorists.
- Cross the fewest number of streets to reduce vehicle-pedestrian exposures.
- Walk on sidewalks or paths where available.
- Walk the shortest possible distance on streets without sidewalks or wide shoulders.
- Walk facing traffic on streets where there are no sidewalks or shoulders.
- Avoid high speed, high volume roadways.
- Make maximum use of protective techniques, (crossing guards, school patrols, traffic control devices).
- Use easements with walkways through parks or other available areas where student safety is maximized.

In determining the safest crossing locations, the following factors should be considered:

- Approach speeds,
- Traffic and pedestrian volumes,

Locate and mark with a colored pencil your residence on the map.

Select and mark a route to the school with the most traffic control devices (signals, stop signs and crossing guards). Try to select those streets with sidewalks.

Walk the route with your child so that he or she becomes familiar with the route. Emphasize the need for safe walking habits such as: look both ways before crossing a street; cross at the intersections only; do not walk or run from a parked car; etc.

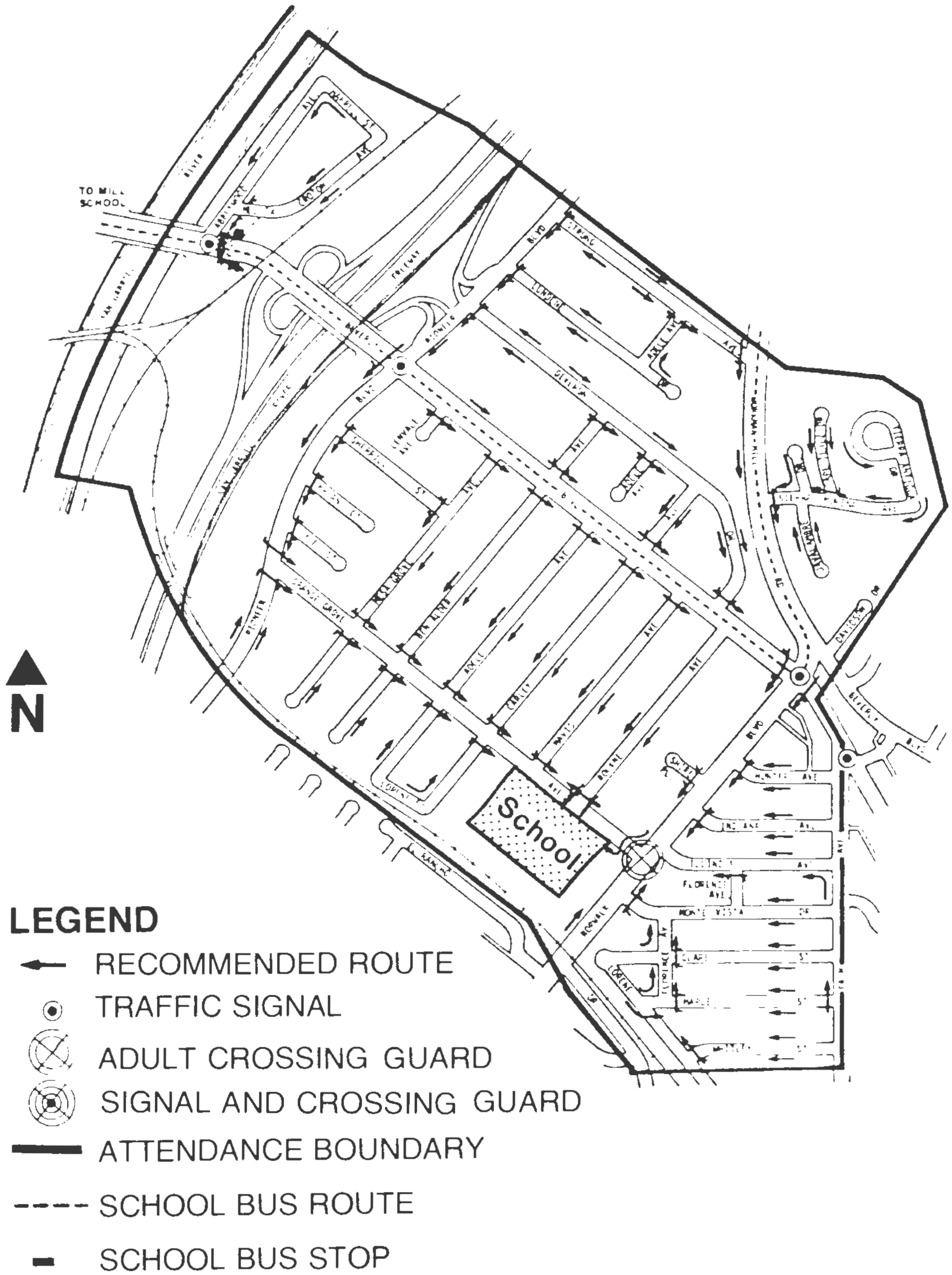


Figure 7-2 Typical Safest Route Plan

- Road geometry (sight distance, curvature),
- Type of area (residential, commercial, industrial),
- Traffic control devices,
- Adequacy of signal displays and timing for children, and
- Availability of assistance measures (crossing guards, school patrols).

A common procedure in developing the map is to begin with the streets near the outer school boundary lines and end at the school. Some existing traffic control devices may not be properly located to accommodate the safest route to school. Consequently, the routes need not be made to conform to the existing devices if engineering judgment determines that there is a safer alternative. In many cases, adjustments to existing traffic control devices may be warranted.

Midblock crossings have been used by many agencies when:

- Supervised by an adult crossing guard or police officer,
- The crossing is signalized, and
- Proper signs and markings together with enforced curb parking restrictions are provided to assure sufficient visibility in the crossing area.

The location where the pedestrian routes terminate at the school site should be well separated from car and bus loading and unloading zones. Consideration should also be given to the route home from school as well as the route to school. These routes may differ to accommodate after-school activities. Other routes such as to favorite lunch areas, libraries, sports centers, and others, should also be considered.

Figure 7-2 illustrates a safest route plan superimposed on a typical street system base map. Developing the map and route system should not merely be an office exercise. The safest route plan should be reviewed by walking the route while looking for unique traffic characteristics and potential conflict points.

7B-4 Usage

Prior to the distribution of the safe route maps, a series of meetings should be conducted with the PTA, principal, and police and engineering staff to assure understanding and agreement among responsible parties. During these meetings a set of instructions for the use of the maps should be agreed on. The instructions will be addressed to parents and/or children and should include specific safety rules. These explanations, instruction, and safety rules are usually an integral part of the map.

After the maps have been distributed to the school children, the program should be evaluated to determine whether the map and the instructions are being used properly by the parents and students. In addition, the maps should be updated periodically. It is also important to define who will update, print, and disseminate the maps each year.

7C. APPLICATION

The standard guidelines and warrants for the application of signs, markings, and signals that would ordinarily be installed on roadways near school sites as part of an overall traffic control system are covered in Parts II, III and IV of the MUTCD and this Handbook. Those special devices and techniques unique to the control of traffic through school zones where young pedestrians are vulnerable to vehicular conflicts are provided in Part VII of the MUTCD and are discussed below.

An overview of pedestrian separation structures, adult crossing guards, and student patrol programs is also included. Although these elements are not generally considered traffic control devices, their use complements the application of signs, markings, and signals.

7C-1 Signs

Uniformity of the physical characteristics of signs (size, shape, color) is especially critical near school areas and care should be exercised to assure conformance to the standards outlined in the MUTCD. Nonuniform signs such as "CAUTION—CHILDREN AT PLAY," "SLOW—CHILDREN," or similar legends should not be permitted on any roadway at any time. While these signs may serve to alert drivers, they could be interpreted by others to infer that children are permitted to play in roadways. On the contrary, every means should be used to point out that children should not play on or near any road, street or alley, no matter how remote or "safe" the roadway appears. Consequently, the removal of any nonstandard signs should carry a high priority.

Although the MUTCD (Section 7B-5) calls for reflectorized or illuminated signs only if "regularly scheduled classes begin or end during periods of darkness," the majority of agencies routinely use reflectorized signs. In fact, commercial sign fabricators report that unreflectorized signs must be special ordered since the demand is so small. The relatively small cost differential (6% more for reflectorization) is justified considering: 1) the seasonal changes in the sunrise-sunset cycle which will usually produce some periods of near darkness around school hours; 2) the use of school grounds as an after hours playground; and 3) periodic school activities scheduled for early evening hours.

The application of the School Advance Sign (S1-1) and the School Crossing Sign (S2-1) is defined in the MUTCD. The School Advance Sign is required in advance of the School Crossing Sign. Where pedestrians are prohibited from crossing the roadway and where the school grounds are separated from the street by a fence, or other physical barrier, it may not be necessary to provide either the School Advance Sign or the School Crossing Sign.

The School Bus Stop Ahead Sign (S3-1) has been modified by some agencies to indicate the actual distance to the bus stop location.

For example,

This is particularly effective in situations where sight distance may be a problem or where drivers appear to disregard the less specific notice.

The use of School Speed Limit Signs (S4-1, -2, -3, -4) are generally established by State or local law or regulation. When installed, they are essential where the average observed speed is consistently higher than that considered safe for existing conditions. Driver awareness and observance of these posted speed limits through the school zone should be sought through every means possible. These signs are one method of control.

One of the major issues involves identifying the time periods when the school speed limit is to be in force. This is especially important when the appropriate speed during school hours is 10 to 15 mph or more below the posted speed limit. Along busy arterials, this large differential between the slow school speed limit and the posted speed can cause excessive delay, driver hostility, and rapid acceleration at the termination of the zone. To obtain driver compliance, additional signing may be needed to step down the posted speed in advance of the school zone. In these cases, blank-out messages, variable message signs or other methods should be considered to identify the time in which the school speed limit sign is in force. Where blank-out or variable message signs are used, it is imperative that the reduced speed limits be displayed only when children are likely to be present. Otherwise, drivers will be unnecessarily delayed and will lose respect for the signs.

An even more critical issue is establishing and enforcing an appropriate speed limit. Some cities have successfully used aggressive enforcement of school speed limits by continually citing violators and attaching a high cost to the citation. This has served to train drivers to observe the posted school speed limits.

Flashing yellow beacons are often used with the school speed limit (Figure 7-3). Many agencies have found this to be an effective application, especially for critical locations. Although the use of the beacon with a sign

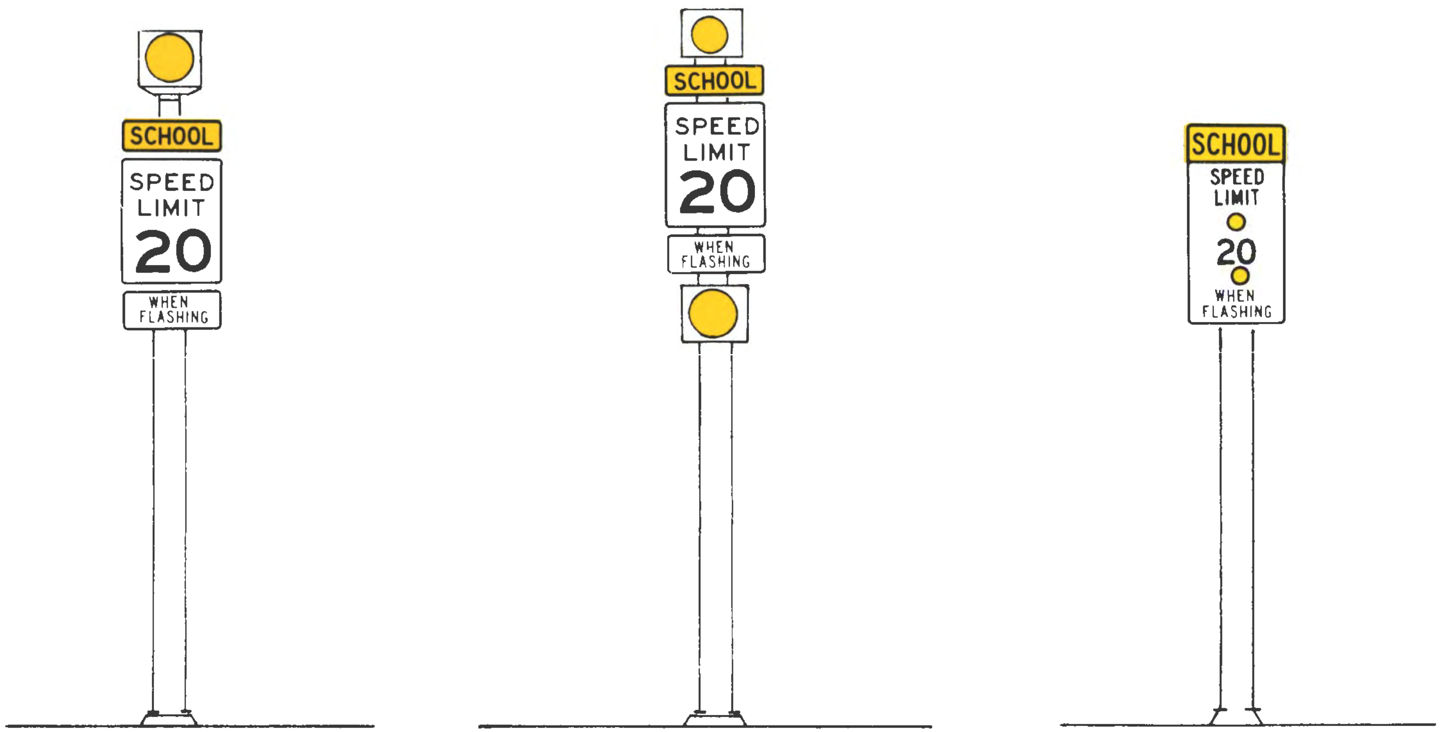


Figure 7-3 Speed Limit Signs with Flashing Beacons

is approximately four times as costly as reduced speed limit signing, the flashing beacon attracts more driver attention and has a higher probability of driver compliance.

The decision to use a flashing beacon is usually based on vehicular and pedestrian volumes, approach speeds, roadway geometrics, and sight distance. The following representative range of values has been used by a number of agencies as a guideline for the use of a flashing yellow beacon (with both the advance warning sign and/or the school speed zone signing):

- Pedestrian Volume: Forty to 60 school age pedestrains crossing during a 2-hour period of a normal school.
- Vehicle Volume: Two hundred to 600 vehicles per hour during the period that students cross the street.
- Vehicle speed: Where the 85th percentile speed is in excess of 35 mph. (Note: Vehicle speed refers to that of vehicles approaching the beacon).
- Roadway Geometrics: There is no other crossing controlled by a signal, stop sign, or crossing guard within 250 to 800 feet of the proposed location.

7C-2 Markings

The roadway markings used around or through school areas are identical to those ordinarily used to delineate center lanes, lane lines, edge lines, etc. The policies and standards governing the use of these markings are covered in Part III of the MUTCD and this Handbook. Part 7-C of the MUTCD describes the markings typically used in school areas and their requirements.

7C-3 Crosswalks

Because of their importance in school zones, a general discussion of crosswalks is included below.

Crosswalks are marked in both rural and urban areas whenever there is a clear need for increased visibility and designation of the crossing area. Crosswalks are usually marked at:

- School crossings approved by the local agency, governing body, safety commission, school principal, etc.
- Arterial crossings manned by adult crossing guards.
- Signalized intersections equipped with pedestrian signals.
- Crossings on recommended safest route to school.
- Crossings at two-way and four-way stop intersections.
- Intersection crossings with unusual geometric design where the pedestrian path is confusing and could lead to potential conflict.

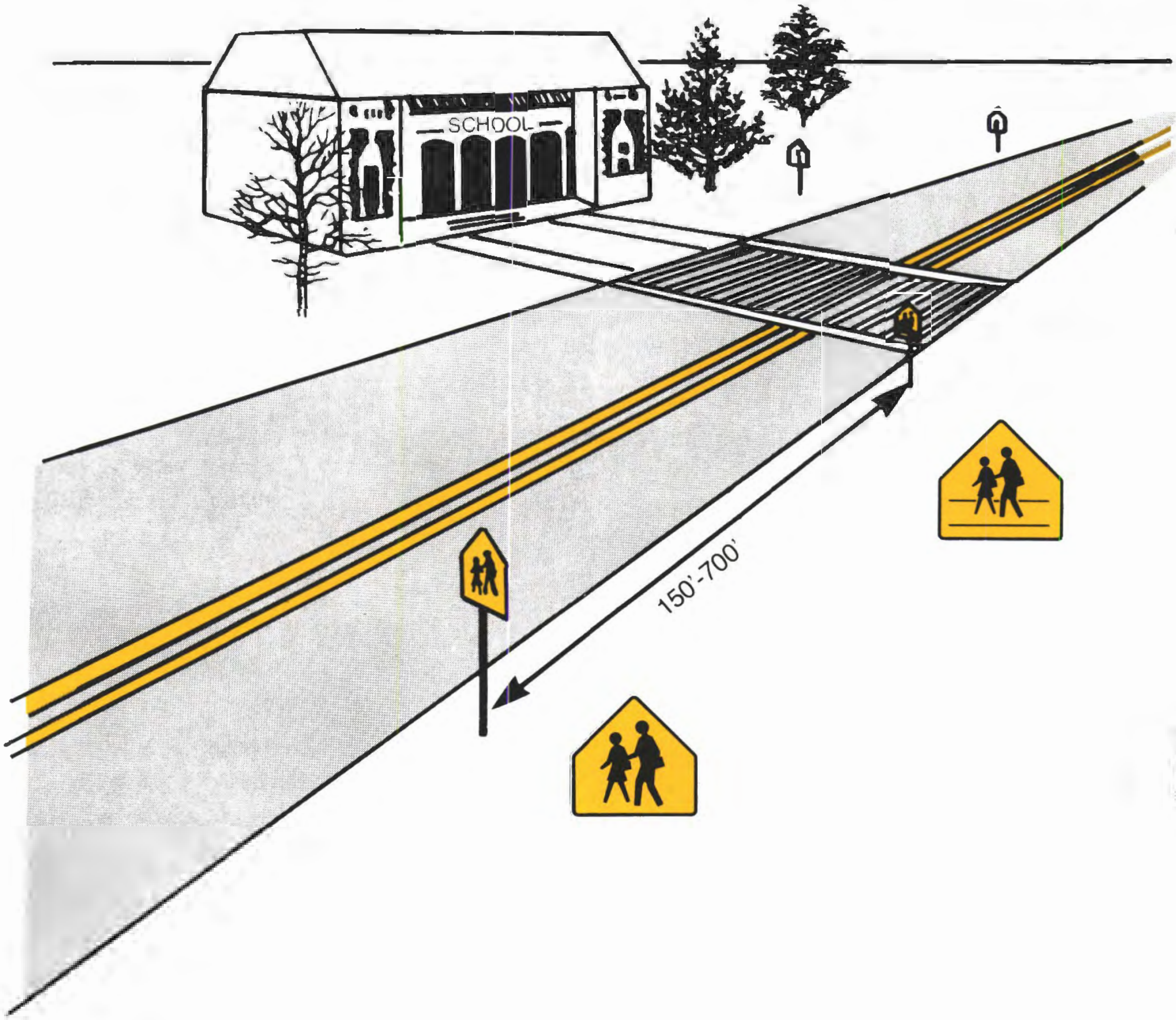


Figure 7-4 Typical School Area Crossing Signing

Many larger agencies have produced guidelines to assist in determining the need to provide a painted crosswalk. These guidelines consider major street vehicular volume, pedestrian crossing volume, speed limit along the approach to the crossing and existing controls at the crossing.

It is probable that smaller communities may never reach the magnitude of volume levels that a larger city would experience. In these cases, communities should relate their objective engineering judgment to their needs and should lower the guideline volume levels accordingly.

Midblock crosswalks have been avoided by a number of agencies based on the premise that drivers do not expect them in such locations. Other agencies feel that a properly marked and signed midblock crosswalk where parking restrictions are enforced can be safer than the intersection crosswalk as there is no side street turning traffic.

If midblock crosswalks are to be used, the first requirement is that they be highly visible. Longitudinal or diagonal lines should supplement the typical parallel lines defining the crossing area. Advance signing and pavement markings should also supplement the painted crosswalks.

Curb parking prohibitions necessary for adequate visibility of the crossing should be stringently enforced. Normally, midblock crossings are not installed if an intersection is nearby (250 to 400 feet).

The majority of State Administrative or Vehicle Codes call for the School Advance Sign in advance of the school grounds or school crossings. The MUTCD specifies the use of a School Advance Sign (S1-1) in advance of every School Crossing Sign (S2-1). In general, these signs should be separated by not more than 700 feet and not less than 150 feet as shown in Figure 7-4. The lesser value is used when there is a nearby intersection.

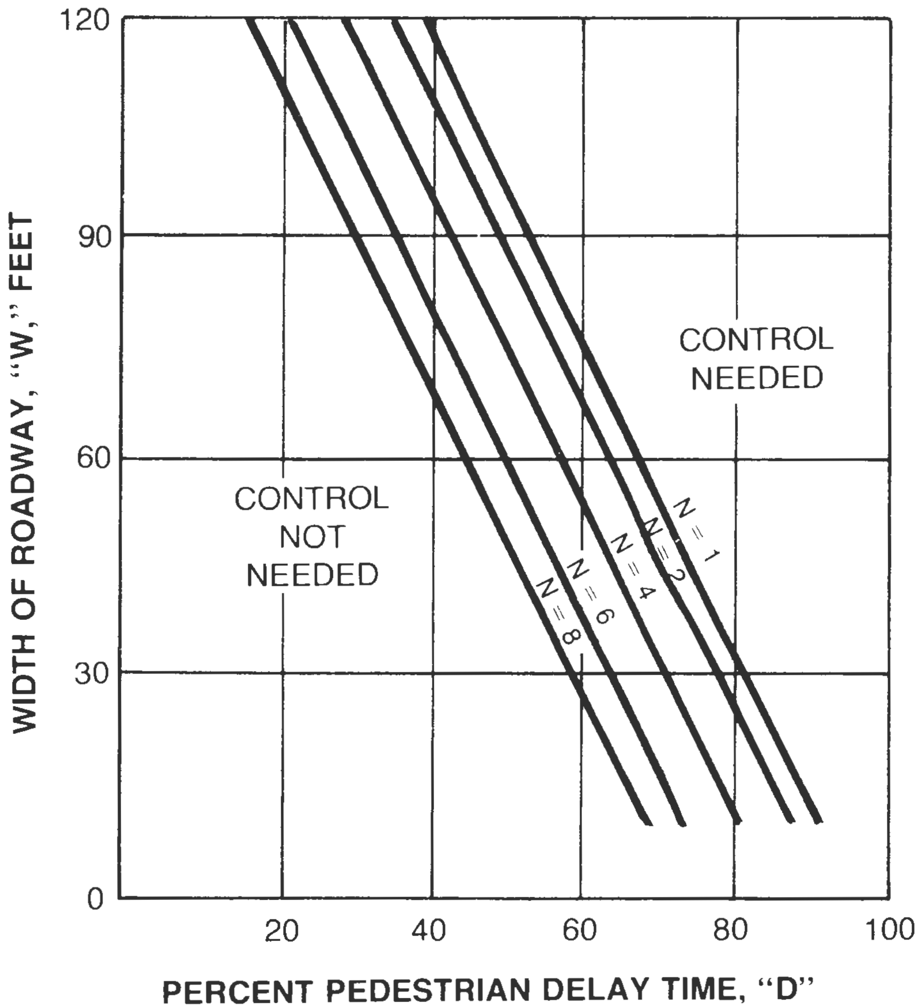
Word pavement markings are frequently used in advance of a school crossing or within the area of a school except where the crossing is controlled by a STOP or YIELD sign or traffic signal. In remote locations outside the school zone, the pavement word markings are less frequently used. Stop lines are not required at marked crosswalks. The crosswalk line closest to the vehicle approaching the intersection serves to define the stopping or yielding point.

7C-4 Traffic Signals

According to the MUTCD (Sec. 7D), standard traffic signals may be warranted at established school crossings where there is a need to create adequate gaps in vehicular traffic for pedestrian crossings. Section 4C-1 of the MUTCD defines the advanced engineering data needed to perform the signal study. In school areas, the number and distribution of gaps in vehicular traffic on the major street is fundamental to the study together with pedestrian delay time and basic data such as pedestrian and vehicle volume, speeds, accident histories and physical conditions.

The pattern of adequate vehicular gaps in the traffic stream are unique to each crossing and form the basis for determining the proper control device or technique. Methods used in the selection process vary across the country. The most widely used is that provided in the Institute of Transportation Engineers (ITE) publication, "A Program for School Crossing Protection." (Ref. 7-4) This technique is applicable when the vehicle arrivals are random. Actual gap studies are recommended.

Basically, after collection of field gap data, the chart from the ITE publication is used to determine if control is really needed (Figure 7-5). If the plot of points falls to the right of the appropriate N line, then some control is needed to create the necessary gaps in the traffic stream.



N – No. of rows of pedestrians walking 5 abreast

Figure 7-5 Determination of Need for Traffic Control at School Crossings

The ITE method does not directly consider all factors such as speed of traffic, safety record of crossing, sight distance and other local factors. Thus, several jurisdictions have developed a rating system that assists in determining what measures to use. Points are assigned for certain ranges of values in each specific category (e.g. "X" points for 85th percentile speeds between 10 to 20 mph, 20 to 30 mph, etc.). The points are totaled and compared for the various available improvement measures (signs, signals, crossing guards, etc.).

Some of the criteria other than pedestrian volume and available gaps considered in these rating systems include:

- 85th percentile speed along the street under study.
- The ratio of available sight distance to safe stopping distance.

- Previous accident history at crossing.
- Percentage of school children by grade (more points for kindergarten or grade 1 students).
- Complexity of intersection or crossing geometrics.

Traffic signal control for school crossings is not the only remedy nor is it necessarily a safe solution. While traffic signals can effectively assign intersection right-of-way and promote the safe, orderly movement of both pedestrians and vehicles, they may not be practical in all situations. Moreover, the response of very young pedestrians (kindergarten to 3rd grade) to traffic signals is frequently so inadequate as to create a hazard rather than a solution. In these cases, officer control or adult crossing guards should be used.

As a general rule, signals should be limited to those locations that meet the criteria given in Part IV of the MUTCD and when the gap studies discussed in Part VII indicate a warranted need. Where signals are installed, an instructional program for the school children should be initiated. Children should be warned against relying too heavily on the WALK or green light indication as well as the hazard of turning vehicles at signalized intersections. They should be instructed on the proper use (and misuse) of signals and of the safety consequences.

In current practice, some key considerations expressed by many of the larger jurisdictions with respect to school traffic signal implementation are summarized below:

- Traffic control signals should be planned to minimize delay and hazard to vehicular traffic. Such planning should take into account signal visibility for motorists, suitability of the location to fit into the progression of a system of traffic signals, the desirability of pedestrian push-button signals, and the use of signals by pedestrians other than children.

- Traffic signals placed in a flashing mode should not be used to control traffic at school crossings. If school crossings warrant signal control, then uniform signal design is also warranted. The use of flashing signals should be limited to functions of advance warning where a school crossing is not easily recognized, and at signalized school crossings when school is not in session. They may, however, be operated in a flash mode when not required for pedestrian or vehicular traffic. Signals must be operated at all times and not left dark during periods of nonschool use.

- Pedestrian WALK-DON'T WALK indications must be installed when an intersection is to be signalized under the MUTCD pedestrian volume or school crossing warrants.

7C-5 Pedestrian Separation Structures

While pedestrian separation structures eliminate vehicular-pedestrian conflicts, they are limited to selected locations where the safety benefits clearly justify the substantial public investment. Separation structures are generally considered as supplemental techniques for providing school pedestrian safety and, as such, are not traffic control devices. However, the following criteria used in evaluating the installation of such a structure is included here as one of the options available for problem locations. Pedestrian separation structure may be an effective alternative under the following conditions:

- The school crossing is permanent and is located in a substantially developed area with established traffic patterns and stable volume levels.
- An economic analysis based on a traffic signal measureable life of 10 years indicates that a pedestrian structure will be less costly to install and maintain.
- The 85th percentile speeds along the major street are in excess of 30 mph and pedestrian and vehicle volume levels are high. (At least 700 vehicles and 75 pedestrians per hour for a 4-hour period)
- There is no existing plan for a traffic signal within a reasonable distance from the proposed structure location (400 to 750 feet).
- The structure will serve other pedestrians (including the handicapped) and bicyclists.

7C-6 Crossing Supervision

There are many school crossings that involve traffic situations hazardous to young pedestrians despite the proper application of traditional traffic control devices (signs, markings, signals). In these cases, school crossings may be supervised by adult crossing guards, police officers, or student patrols.

The MUTCD provides general guidelines for the functional requirements and duties of these types of crossing supervision. Recommended practices in terms of organization, operation and administration of an adult crossing guard program are given in Civilian Guards For School Crossings (Ref. 7-5). Recommended practices involving student patrols are given in Policies and Practices for School Safety Patrols (Ref. 7-6). Some of the general characteristics of adult or student patrol programs are summarized below.

Adult Crossing Guards

On-site supervision of a school crossing may be appropriate where walking routes to elementary schools cross major, high volume, roadways. Specifically, adult crossing guards should be considered when special problems exist which make it necessary to assist the children in crossing the street, such as at an unusually complicated intersection with heavy vehicular turning movements and/or high vehicular speeds.

Various agencies have established warrants for the use of adult crossing guards. An example of such warrants as given below may be of value in developing local criteria. Adult crossing guards may be warranted under the following conditions:

- At uncontrolled crossings where there is no alternate controlled crossing within 600 feet; and
  - In urban areas where the vehicular traffic volume exceeds 350 in each of any two daily hours during which 40 or more school children cross while going to or from school whenever the critical approach speed exceeds 40 mph, the warrants for rural areas should be applied; or
  - In rural areas where the vehicular traffic volume exceeds 300 in each of any two daily hours during which 30 or more school children cross while going to or from school.
- At stop sign controlled intersection crossings:
  - Where the vehicular traffic volume on undivided highways of four or more lanes exceeds 500 per hour during any period when the children are going to or from school.
- At traffic signal-controlled intersection crossings:
  - Where the number of vehicular turning movements through the school crosswalk exceeds 300 per hour while children are going to or from school.
  - Where there are circumstances not normally present at a signalized intersection, such as crosswalks more than 80 feet long with no intermediate refuge, or an abnormally high proportion of heavy commercial vehicles.

The MUTCD implies that crossing guards should be considered to ". . . . provide gaps in traffic at school crossings where an engineering study has shown that adequate gaps must be created." Although the example warrant is based on traffic volume and pedestrian volumes, it is assumed that "adequate gaps" would not be available under these conditions; hence, an adult crossing guard may be desirable.

Should the volume numbers given in the example warrant appear too high or low for local conditions, a gap study should be conducted to establish the parameters defining the site-specific conditions that do not provide "adequate" gaps. Procedures for conducting gap studies are provided in Ref. 7-4.

Adult guards are usually civilians under the jurisdiction of the local police agency. Although they may be considered as special police officers, they do not have the same regulatory authority as the uniform police officer. It is recommended that crossing guards wear an easily recognized uniform. In practice, civilian guards seldom wear uniforms identical to the police department officers. In some instances, a distinctive colored vest worn over civilian clothes is a common practice. The vest should be reflectorized for use during reduced visibility conditions.

Regular police officers are normally used to supervise school crossing in emergency situations or on a temporary basis. Some agencies in small communities have found it economically advantageous to use regular police crossing guards in lieu of civilian adult guards where time and duties permit.

Student Patrols

Student patrols are comprised of older students (fifth grade or higher) who are selected and authorized by the governing school board to assist children in crossing roadways bordering the school area. They do not attempt to direct vehicular traffic but function to identify adequate gaps for crossing. That is, they serve to control and restrain children at the curb and permit them to cross when it is safe to do so. Members of the patrol are generally used where large numbers of children cross streets having relatively light traffic; at signalized intersections where turning movements are not a problem; and to assist adult crossing guards or police officers at complicated intersections where the control of large numbers of children is difficult for one person.

REFERENCES:

7-1 *"School Trip Safety & Urban Play Areas,"* Reiss, M.L. et al, FHWA RD 75-105, Volume I.

7-2 *"Planning Guide for the Development of Pedestrian & Bicycle Facilities,"* JHK & Associates, August, 1977.

7-3 *"Guidelines for The Development of Safe Walking Trip Maps"*, Volume II, U.S. DOT, FHWA RD 75-108, Reiss, M.L. et al, November 1975.

7-4 *"A Program for School Crossing Protection,"* A Recommended Practice of the Institute of Traffic Engineers, August, 1962. Institute of Transportation Engineers, 1815 North Ft. Myer Drive, Suite 905, Arlington, Virginia 22209.

7-5 *"Civilian Guards for School Crossings,"* Traffic Institute of Northwestern University, 405 Church Street, Evanston, Illinois 60204.

7-6 *"Policies and Practices for School Safety Patrols."* American Automobile Association, Falls Church, VA 22042.

Part VIII· TRAFFIC CONTROL SYSTEMS FOR RAILROAD-HIGHWAY GRADE CROSSINGS

PART VIII
Grade Crossings

PART VIII
Grade Crossings

Part VIII.
TRAFFIC CONTROL SYSTEMS FOR RAILROAD-HIGHWAY GRADE CROSSINGS

8A. GENERAL

The railroad-highway grade crossing is a unique environment. Two modes of transportation are involved, the railroad train and the motor vehicle. This Part discusses the traffic control employed for the highway user.

To select the appropriate traffic control devices it is important to understand the interrelationships of highway traffic control devices, railroad track circuitry, conditions existing at the grade crossing, and the behavior of the driver within the grade crossing environment. Often, the highway engineer and the railroad engineer will share responsibilities at the grade crossing. The extent of their responsibilities will vary depending upon State laws and practices; however, both must be involved in the decisionmaking process and both must have an understanding of the interaction between train, motor vehicle, and control devices.

This Part of the Handbook addresses the selection, operation, installation, and maintenance of railroad-highway grade crossing traffic control devices. Its purpose is to assist the personnel involved so as to ensure safety and efficiency within the railroad crossing environment.

8A-1 Introduction

The purpose of traffic control systems at railroad-highway grade crossings is to permit safe and efficient operation of rail and highway traffic over grade crossings. The function of traffic control systems at railroad-highway grade crossings is to provide appropriate information and sufficient time to permit roadway users to make relatively uncomplicated decisions that will allow them to safely pass over the crossing.

Traffic control messages are communicated by various signals, signs, and pavement markings. The types, purpose, and application of these various devices are discussed within this part of the Handbook. The need for uniform application of standard devices cannot be over-emphasized. To assure the safe operation of a traffic control system at a railroad-highway grade crossing it is important that each particular traffic control device look the same, have the same meaning, and be applied in the same manner, regardless of which highway agency or railroad company installs or maintains it. Uniform standards provide motorists with a reasonable opportunity to learn the meaning of all devices through experience and to satisfy the motorists' expectation that the meaning is consistent. They also enable highway agencies, railroads, and industry to benefit economically from the standardized design and construction of traffic control devices.

8A-2 Types and Purposes of Devices

The various signals, signs, and pavement markings used to convey traffic control messages to highway users are classified as either passive or active. *Passive crossing* devices provide static messages of warning, guidance, and in some instances, mandatory action. *Active crossing devices* are those which give notice of the approach or presence of a train. They are activated by the train passing over a detection circuit or in a few situations, by manual control, and occasionally involve the use of a flagger.

Passive railroad crossing control devices consist of Regulatory, Warning, and Guide signs, and supplemental pavement markings. The MUTCD (Part II and Part VIII) specifies the use of these various devices under given situations.

When used by themselves, passive crossing devices provide the minimum level of warning and/or control. Their use is also necessary in conjunction with active crossing devices, to provide increased levels of warning and/or control.

Active traffic control devices include flashing light signals and automatic gates, with bells sometimes used as an audible supplement. In addition, highway traffic signals at or near grade crossings are sometimes connected to track circuitry to preempt certain highway intersection signal indications upon the approach of trains. Also, train activated yellow hazard identification beacons are sometimes mounted on the Advance Warning Sign (W10-1) to create an Active Advance Warning Sign. Section 8B-1 of this Handbook provides a detailed discussion on the application of both passive and active traffic control devices.

8A-3 Driver Behavior and Needs

The track crossing maneuver consists of three basic stages (Ref. 8-5): Stage I—Approaching the Crossing; Stage II—Within the Critical Stopping Distance Zone; and Stage III—Crossing the Tracks.

Stage I—Approaching the Crossing

The vehicle operator is informed of the presence of a crossing by advance signing, by pavement markings, and sometimes through the visual observation of the crossing or of the train itself. The efficiency of motorist perception of warning devices depends upon such factors as visual acuity, familiarity with the area, visibility of control devices, and the condition of the vehicle operator in terms of fatigue, attitude, and physical and mental condition.

Visual acuity, the resolving power of the human eye, is related to visual contrast, which is the brightness and color differences between objects and their backgrounds. This factor is discussed in Part II of this Handbook.

A sign or marking is not isolated within the motorist's field of vision. In fact, signs and markings are easily camouflaged by other elements in the environment which compete with, and distract from, their clear visibility.

The advance warning treatment must compete for the attention of a motorist who may be bored, listening to the car radio, or conversing with passengers. Based on past experience, drivers familiar with the crossing may be very cautious when they know train traffic is heavy or irregular. In other situations, a driver may give little thought to a crossing if experience has shown that a train rarely operates over it.

The advance warning treatment should satisfy the needs of both the familiar and unfamiliar motorist. It must alert them to the present circumstances at the grade crossing. For example, an infrequently used spur track that suddenly becomes active because of plant expansion requires a different warning treatment than the treatment used before the plant expansion.

Stage II—Within the Critical Stopping Distance Zone

A driver approaching a crossing will reach a critical point at which a decision must be made to stop if a train is approaching or passing through the crossing. In daytime, with good visibility and adequate stopping distance, a train passing through the crossing usually provides all the information the driver needs to make the decision to stop. During periods of darkness or poor visibility, the driver's task becomes more difficult, especially at crossings equipped with only passive traffic control devices. In some cases, it may be difficult to detect the train on the crossing because of the low reflectance of dirty, dark-colored, rail cars. Active traffic control devices are especially beneficial at crossings with night visibility problems. Illumination of the crossings is another alternative.

A train in the vicinity of a crossing exerts the greatest demands on the driver. The train, itself, through the use of horns and/or headlights provides the principal warning at a passive-controlled crossing. While it is vital for the motorist to perceive these warnings, there are several factors that may limit the motorist's ability to detect an approaching train:

- Noise such as from a truck exhaust or a car radio can mask a train's horn warning.
- Under adverse weather conditions the field of view may be greatly limited.

- There may be inadequate sight distance caused by highway alignment or by obstacles in the sight triangle (e.g., buildings, other vehicles, vegetation, signs, etc.)

The most critical element within the critical stopping distance zone is for the motorist to be able to see the train or to be alerted by traffic control devices, far enough from the grade crossing, to be able to react and stop safety.

Stage III—Crossing the Tracks

In this final stage, the motorist must safely cross the tracks. This stage can be divided into driver actions at crossings with passive crossing devices and those with active crossing devices.

At crossings with passive crossing devices, even a driver who has seen the approaching train may encounter several dangerous situations. First, the motorist may fail to make a definite decision. In this case, they may slow or stop, but then decide to "beat the train" and attempt to proceed across the crossing. On the other hand, after first deciding to proceed, the motorist may decide it is more prudent to stop, but may stop too close to the tracks. In both instances, such indecisiveness can result in a severe or fatal incident.

At crossings with active crossing devices, the flashing signal is a message to the motorist that it is not safe to proceed. The credibility of this message must be maintained. A motorist arriving at a track near a switching yard may proceed, anticipating only slow-moving switching operations. This driver would obviously not be prepared for a high speed train.

To increase respect for signals, railroad operations should minimize inadvertent activation of signals when no train is present. It is recognized, however, that these devices must be fail-safe; that is, they must provide the proper indication whenever a train is present. Where active control devices are present, the motorist will generally rely on them and follow their indication.

Driver Detection of an Approaching Train

At railroad-highway grade crossings with only passive control devices it is imperative that the motorist detect the presence of an approaching train as early as possible. This is accomplished through visual and/or audible means.

Conspicuity is the property of attracting attention by visual means. It is a vital element at grade crossings where so much of the burden for safe performance is placed on the driver's ability to detect the train by visual means. Train conspicuity is of particular concern at crossings with passive crossing devices. Assuming adequate sight distance, the motorist must be able to see the train and estimate its speed throughout a wide range of backgrounds and visual distractions. To increase train conspicuity, it has been suggested that highly visible panels be installed on the side of trains. Another treatment is to provide movement in the locomotive headlamp. Some lamps currently have a movement that sweeps the tracks. Other railroad companies are utilizing strobe lights or rotating beacons mounted on lead locomotives. However, none of these concepts have been adopted for general use.

All locomotives include horns, whistles, and/or bells as audible warning devices. The Federal Railroad Administration (FRA) has established 96 db, at 100 feet forward of the locomotive, as the minimum level of warning for an engine horn or whistle. Bells are primarily used to warn pedestrians. They are used mostly in switching operations in railroad yards and on the approach to passenger station platforms.

Various factors may influence the motorist's ability to hear an audible signal. Motorists with impaired hearing or operating vehicles with closed windows, air-conditioning, a radio or stereo, may not hear warning signals in time to react. Therefore, although an audible signal system may be desirable or even necessary, it should be considered as a supplemental system, and not as a substitute for other devices.

8A-4 Pedestrian Behavior and Needs

Although pedestrian accidents account for only 1 percent of the total accidents at grade crossings, a majority of these accidents result in fatalities. At grade crossings controlled by gates, the activated gates are quite easily circumvented by a pedestrian who goes under or around the barricade. There are three preventive measures that are commonly employed at crossings where this is a problem.

Fencing may be used to enclose the right-of-way, restricting pedestrian access to the crossing. However, fencing is generally ineffective at most grade crossings. One alternative is to provide a pedestrian grade crossing and to erect a fence to channelize pedestrians to the crossing. Such a crossing can be controlled with a train activated gate and appropriate signing.

Grade-separated pedestrian overpasses can be used at reasonable intervals. However, pedestrian use of such structures will depend on their accessibility and ease of use. Underground tunnels are discouraged because they tend to encourage and provide cover for acts of crime.

Pedestrian education is an effective method of reducing the incidence of pedestrian accidents. Individual railroads, the National Safety Council, and the Association of American Railroads have conducted active railroad safety programs through the schools. However, no form of pedestrian protection can be effective without some level of surveillance and enforcement.

8A-5 Railroad Operations

Train operations at or in the vicinity of a grade crossing are a critical factor in determining the most appropriate type of traffic control system. Train movements, characteristics, and relevant railroad company operational procedures are reviewed in this section.

Types of Train Movements

The driver's perception/expectation of what is about to occur on the tracks is as important as what is actually occurring because most drivers react on the basis of their perception. For example, a local driver may become aware that a freight train travels through a crossing at approximately the same time and speed each day. This can create the dangerous impression that the grade crossing will be occupied only during certain times. In this situation, the driver may ignore physical indications that other train activity is underway.

Mixed train traffic can present an even more complex situation to the driver. Passenger trains may be moving at a high rate of speed while freight trains move slower. The various types of trains also have large acceleration differentials. These variations often increase the driver's waiting time by 20 seconds or more. The speed and time variation is even more pronounced when some trains stop at nearby stations or sidings while other trains proceed through at maximum speed.

Switching operations within the limits of a train detection track circuit, which has no speed detection or motion sensing capability, can result in a 4-to 5-minute wait by the driver before the train arrives at the crossing. When an operation consists of picking up or setting out cars, the train may not cross the highway, but may still activate the grade crossing control signals. At some locations, such an operation will leave railcars on both sides of the crossing.

All of these operations can result in a variance in train arrival times after activation of the flashing lights. This variance induces motorists to risk driving through the red flashing signals without realizing how difficult it is to judge the closing rate of a train. When the flashing lights are activated too far in advance of the arrival of a train, driver compliance is reduced and the credibility of all grade crossing traffic control devices is degraded.

"The Standard Code of Operating Rules" developed by the Association of American Railroads (Ref. 8-4), only addresses switching at grade crossings for the purpose of requiring a member of the train crew to act as a flagger during certain operations. Most railroad companies recognize the need to minimize unnecessary activation of flashing lights and issue instructions to that effect. Two methods are often used. First, whenever possible, switching operations are conducted outside the track circuit. Second, the track circuitry may be manually bypassed. This, however, introduces the potential for human error in that the track circuit could remain cut off when a train passes through the crossing. One solution to the unnecessary activation of flashing lights problem is to upgrade the track circuitry to include motion sensing or train speed monitors where feasible.

Train Speed

The maximum allowable speed of trains is controlled in part by the type and condition of the track. This involves track curve radius and superelevation, the track gauge, the strength of the rail, and the condition of the supporting roadbed. Minimum standards for the above elements and others are specified in track safety standards issued by the Federal Railroad Administration (FRA). The FRA specifies maximum train speeds for each class of track and inspects the track conditions to assure compliance with the standards. Maximum train speeds for each class of track are given in Table 8-1.

Track Class	Passenger	Freight
6	110 mph	110 mph
5	90	80
4	80	60
3	60	40
2	30	25
1	15	10
Excepted	None	10

Table 8-1. Maximum Train Speed as a Function of Track Class

8A-6 Grade—Crossing Responsibility

Jurisdiction

Jurisdiction over railroad-highway grade crossings resides almost exclusively in the States. Within some States, responsibility is frequently divided among several public agencies and the railroad. In a number of States, jurisdiction over the crossing is assigned to a regulatory agency referred to as a Public Utilities Commission, Public Service Commission, or similar designation. In other States, the authority is divided among the public administrative agencies of the State, county, and city having jurisdiction and responsibility for their respective highway systems. It is important to remember that several agencies, both public and private can be involved when improvements are considered at a railroad highway grade crossing. These include:

- The railroad,
- The State agency responsible for regulating railroad-highway grade crossings, and

- The agency responsible for the roadway crossing the railroad (State, county, or city).

When a new railroad-highway grade crossing is contemplated or when an existing grade crossing is proposed for closing, these agencies should be involved as early as possible in the planning and decisionmaking process.

Legal Considerations

There have been significant changes in the old concept of total railroad responsibility for improvements at railroad-highway grade crossings. The present trend is toward public agency assumption of greater responsibility for the improvement of grade crossings.

Many States have laws which allow the State to be sued for any negligence on the part of its officers or employees. Potential liability exists where the State or local jurisdiction is responsible for determining whether or not crossings are equipped with adequate warning devices.

8B. APPLICATION

This section discusses the application of various passive and active traffic control devices to develop traffic control systems for railroad-highway grade crossings. Comprehensive examples of passive systems, active systems, and active systems with traffic signal preemption are presented. Also included is a discussion on improvement choices.

8B-1 Passive Devices

Passive railroad highway grade crossing traffic control devices consist of regulatory, warning, and guidance signs, and supplemental pavement markings. They provide static messages of warning, guidance, and in some instances, mandatory action.

It should be emphasized that while signs and markings are considered passive crossing devices, they are also used with and to supplement active crossing devices. Thc most common signs used with railroad-highway grade crossings are shown in Figure 8-1.

Signs

The Railroad Crossing (Crossbuck) sign (R15-1) is required on each roadway approach at all grade crossings. The Supplemental Number of Track signs (R15-2) must be mounted below the Crossbuck at crossings with two or more tracks that are not controlled by automatic gates. Where automatic gates are present, the Supplemental Number of Tracks sign (R15-2) is optional. The location of signs R15-1 and R15-2 with respect to the roadway pavement and railroad track are discussed in Section 8B-2 of the MUTCD. These signs are usually installed and maintained by the railroad company.

The agency responsible for maintenance of the roadway is normally responsible for the Advance Warning sign (W10-1). This round black and yellow warning sign is located in advance of the crossing and serves to alert the motorist that a railroad crossing is ahead. The distance from this sign to the track(s) is dependent upon the highway speed, but it should be at least 100 feet in advance of the nearest rail. The recommended range in urban areas is 175 to 550 feet; in rural areas, it is 550 to 900 feet. Table 2-3 in Part II of this Handbook provides a full range of recommended distances as a function of vehicle speed.

The Advance Warning sign is required in advance of all grade crossings with few exceptions. These exceptions include (1) low volume roadways (ADT below 500) with approach speeds below 40 mph which cross minor spurs or other tracks which are infrequently used and which are flagged by train crews; (2) in the business district of large cities where active grade crossing traffic control devices are being used; and (3) in situations where physical conditions do not permit even a partially effective display of the sign.

Figure 8-1 Typical Signs Frequently Used for Railroad—Highway Grade Crossing

When the grade crossing roadway is a divided highway it is desirable to place an additional sign on the left side of each approach roadway. It may also be desirable to place an additional sign on the left side of an approach roadway when the roadway alignment limits the visibility of signs mounted on the right side.

Where a road runs parallel to a railroad and the perpendicular distance between the two is relatively short (less than 100 feet) there may not be enough distance to display the Advance Warning sign (W10-1) to warn turning motorists of a downstream railroad crossing. Three warning signs designated as W10-2, W10-3, and W10-4 (W10-3 and 4 are variations of the W10-2) can be installed when their need has been determined based on an engineering study. Typical applications of the Advance Warning sign (W-10 Series) and the Railroad Crossing (Crossbuck) sign (R-15-1) are shown in figures 8-2, 8-3, and 8-4.

The Advisory Speed Plate (W13-1) should be used when sight or geometric conditions require a speed lower than the posted speed limit. The Advisory Speed Plate should not be erected until the recommended speed has been determined by an engineering study of the specific crossing. If this plate is used, the recommended speed should be periodically reviewed and corrected if necessary. When used, the Advisory Speed Plate must be mounted on the same assembly and is normally below the Advance Warning sign (W-10 Series). Should it be determined that the Advisory Speed Plate is not effective in reducing speeds then it may be appropriate to use a regulatory speed limit sign (R2-1).

The use of the STOP sign (R1-1) at railroad-highway grade crossings should be limited to selected crossings where the need has been determined by a detailed traffic engineering study. Crossings considered for installation of STOP signs should be limited to those having the following characteristics:

- The highway should be secondary in character with low traffic counts (400 ADT-rural and 1,500 ADT urban)
- Train traffic should be substantial (i.e., 10 trains per day).
- A restricted line of sight exists such that approaching traffic is required to reduce speed to 10 miles an hour or less in order to stop safely.

It should be noted that at the stop bar, there must be sufficient sight distance down the track, to afford ample time for a stopped vehicle to start and cross the track before the arrival of a train. An engineering study may determine other compelling reasons, such as accident history, to install a STOP sign. In these cases, use of the STOP sign should be considered an interim measure until active traffic control devices can be installed. A STOP sign shall never be used at a crossing with train activated signals.

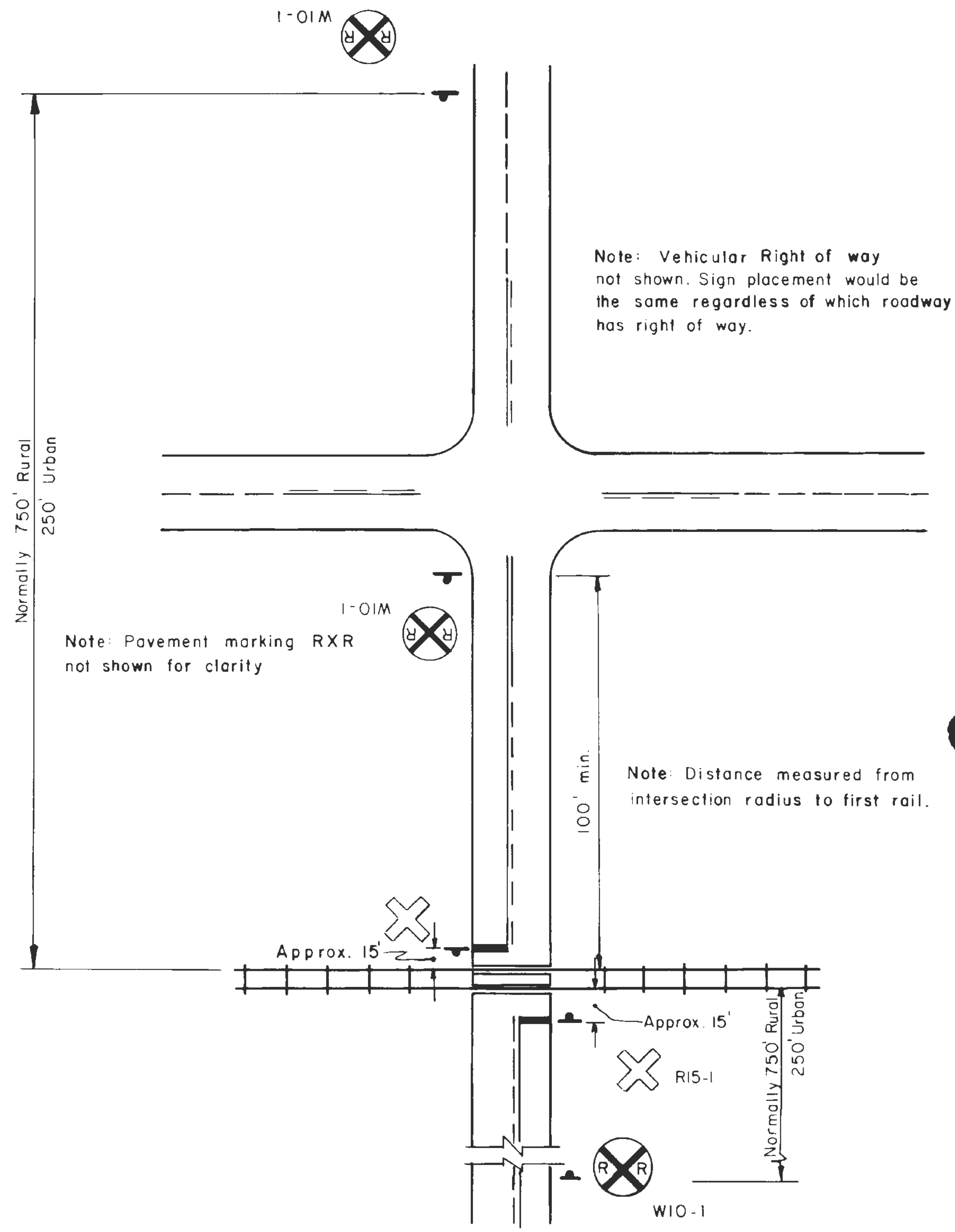


Figure 8-2 Typical Sign Placement Where Parallel Road is Over 100 Feet From Crossing

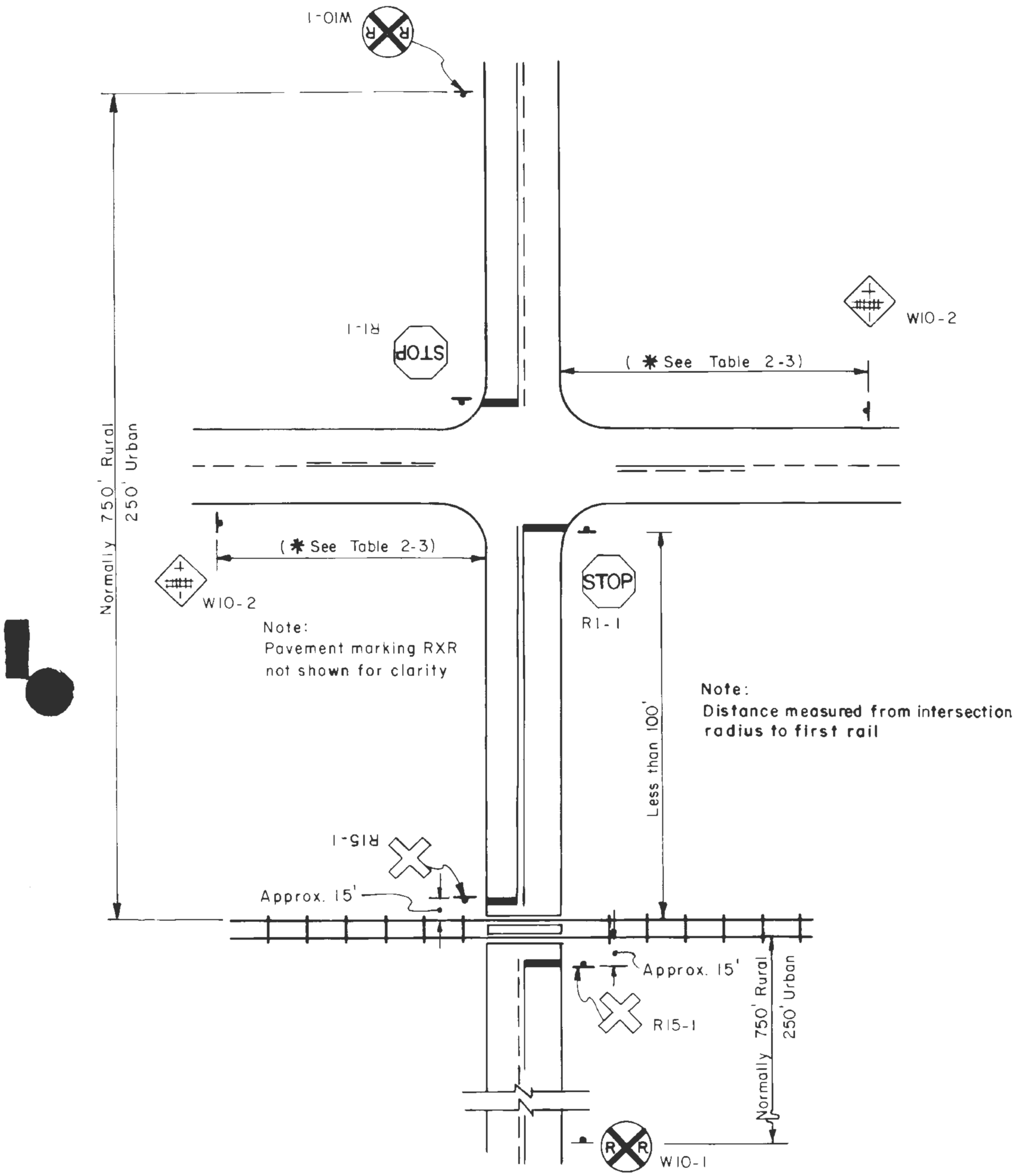


Figure 8-3 Typical Sign Placement Where Parallel Road is Within 100 Feet of Crossing and Intersecting Road Traffic Must Stop

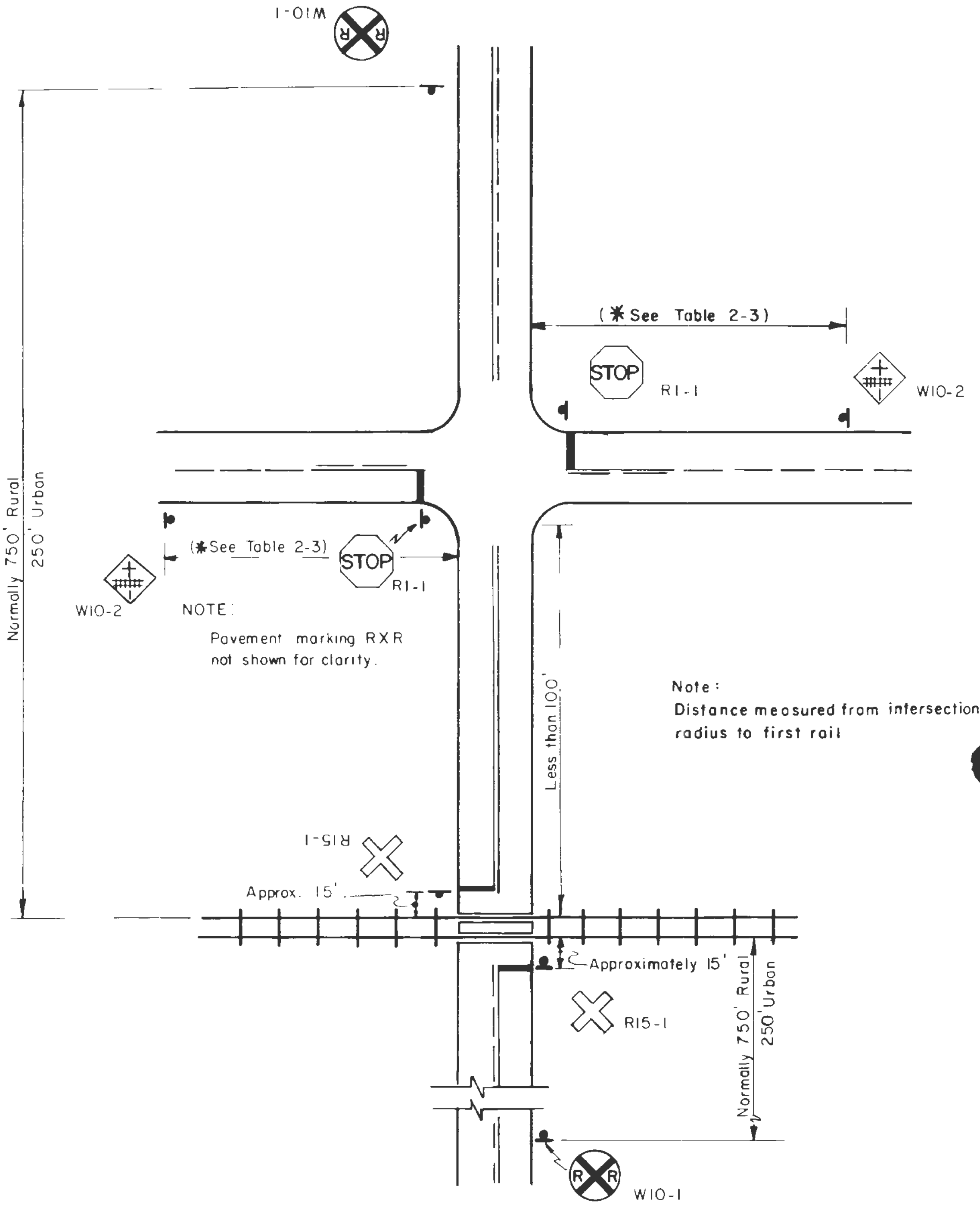


Figure 8-4 Typical Sign Placement Where Parallel Road is Within 100 Feet of Crossing and Parallel Road Traffic Must Stop

Whenever a STOP sign is installed at a grade crossing, a STOP AHEAD sign (W3-1a) shall be installed in advance of the STOP sign. Figure 8-5 shows a typical STOP sign instalation.

In situations where an engineering study has indicated the possibility that vehicles may stop on the tracks, a DO NOT STOP ON TRACKS sign (R8-8) should be considered. Typically, this situation can occur where there is a crossroad near the grade crossing controlled by a STOP sign or a traffic control signal that might cause vehicles to queue up on the tracks. The DO NOT STOP ON TRACKS sign is usually located near the crossbuck. However, it may also be effective to locate this sign on the far side of the tracks.

The Exempt Crossing sign (R15-3, W10-1a) is only used when authorized by law or regulation. It's purpose is to inform drivers of vehicles normally required to stop at all railroad highway grade crossings that a stop is not required at a specific crossing unless a train, locomotive, or other railroad equipment is approaching or occupying the crossing. In considering the use of EXEMPT signs, the crossing should generally be characterized by one or both of the following conditions:

- Trains are not currently using the tracks.
- No more than one train per week crosses the road and that train stops prior to crossing and is flagged over the crossing after roadway traffic is safely stopped.

When used, the EXEMPT sign (R15-3) is placed under the Crossbuck (R15-1) sign. A supplemental EXEMPT sign (W10-1a) may be placed under the Advance Warning sign (W10-1).

At signalized highway intersections within 200 feet of a grade crossing, where and when the intersection's traffic signal control is preempted by the approach of a train, all turning movements toward the crossing should be prohibited. Turn Prohibition signs NO RIGHT TURN (R3-1a) and/or NO LEFT TURN (R3-2a) should be used as appropriate. These signs are to be visible only when the turn prohibition is in effect. A blank-out, internally illuminated, or other type sign may be used to accomplish this objective. Since these signs are only displayed upon activation by an approaching train, they could be considered an active warning device.

Pavement Markings

Section 8B-4 of the MUTCD discusses the requirements for pavement markings in advance of a grade crossing. These markings are shown in Figure 8-5 and in Figure 8-2, page 8B-4 of the MUTCD. The following pavement markings shall be placed in each approach lane where grade crossing signals or automotive gates are located, and at all other grade

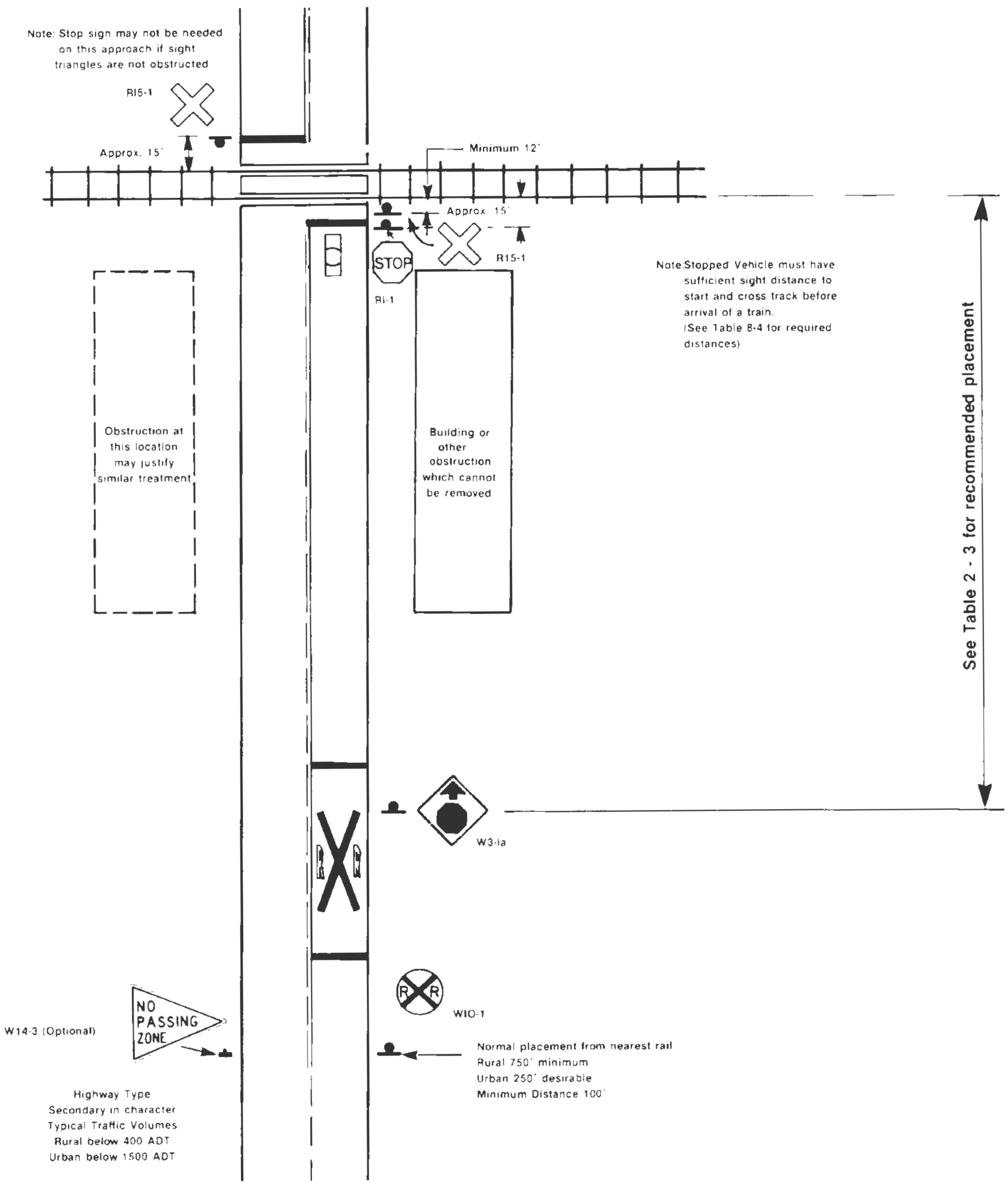


Figure 8-5 Typical Application of a STOP sign at a Railroad-Highway Grade Crossing

crossings where the prevailing speed of highway traffic is 40 mph or greater:

- an X,
- the letters RR,
- a no passing marking (2 lane roads), and
- certain transverse lines.

These markings shall also be placed at other crossings where engineering studies indicate there is a significant potential conflict between vehicles and trains. On the other hand, at minor crossings or in urban areas, if an engineering study indicates that other devices would provide suitable control, then the pavement markings may be omitted.

Raised reflective pavement markers can be used to supplement pavement markings in advance of a grade crossing. The pavement marking "X," lane lines, and the stop line can be delineated by raised reflective markers. They provide improved guidance at night and during periods of rain and fog.

The positioning of the various signs and pavement markings used as part of traffic control systems for railroad highway grade crossings are specified throughout the MUTCD, sometimes as minimum and sometimes with ranges. It is important to note that the placement of all signs and pavement markings should provide the motorist a clear message in sufficient time to react properly.

8B-2 Active Devices

Active grade crossing control devices are those which give warning of the approach or presence of a train. They are activated by the passage of a train over a detection circuit in the track except in those few situations where manual control or manual operation are used. Active control systems utilize the same signs and pavement markings that are used in passive control installations.

Flashing Light Signals

Flashing light signals constitute the minimum level of active control currently being installed at railroad-highway grade crossings. This control device consists of two alternately flashing red light units mounted 30 inches apart on a horizontal crossarm. Flashing light signals are generally post-mounted, but where improved visibility is required, cantilevered flashing light signals are used. Flashing light signals are described in sections 8C-2 and 8C-3 and are shown in Figures 8-3 and 8-4 of the MUTCD.

Cantilever-mounted flashing light signals may be appropriate when any of the following conditions exist:

- Multilane highways (two or more lanes in one direction).
- Highways with paved shoulders or a parking lane which would require a post-mounted light to be more than 10 feet from the edge of the travel lane.
- Roadside foliage obstructs the view of post mounted flashing light signals.
- Line of roadside obstacles such as utility poles (when minor lateral adjustment of the poles would not solve the problem).
- Distracting backgrounds such as excessive number of neon signs (Conversely, cantilever-mounted grade crossing flashing lights should not distract from nearby traffic signals).
- Horizontal curves at locations where extending the flashing lights over the traffic lane will provide line of sight for the required stopping sight distance.

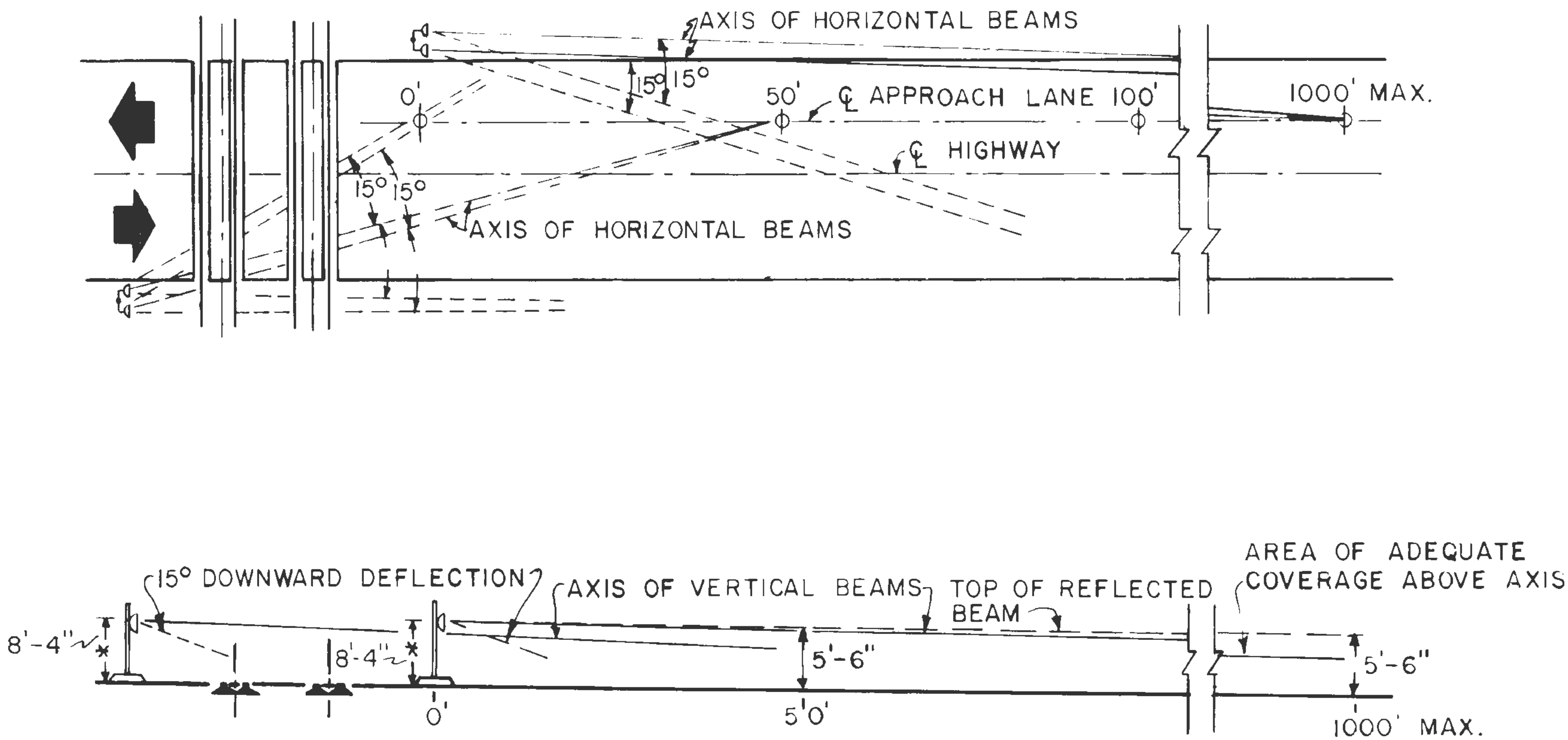
Flashing light signals are always located within the railroad right-of-way and their installation and maintenance are usually the responsibility of the railroad.

The major objective in locating the flashing light assembly is to allow the light units to be clearly seen by the motorist. If, under this criterion, it is necessary to locate the flashing lights in a potentially hazardous position, crash cushions should be considered. Placing flashing lights in a median should be avoided.

Of equal importance with the location of the flashing light signal is the proper alignment of the flashing light unit to provide the desired range and visibility. The light power specification indicates that the light should be visible from approximately 1,000 to 3,000 candelas at the axis, but drops away quickly from the center. This is particularly true of the long range "hot spot" 15-30 degrees roundels. With these roundels, effectiveness is limited to 5 to 10 degrees from center. Figures 8-6 and 8-7 show typical alignment patterns for flashing light signals for a two lane, two-way roadway and for a multilane roadway.

Additional pairs of light units can also be installed to cover side roads entering the approach highway. At T-intersections, a pair of lights can be directed toward the approach lanes that parallel the tracks. Figure 8-8 shows the use of multiple pairs of lights to cover a horizontal curve to the left on the approach roadway. A horizontal curve to the right may be covered by placing another roadside flashing light on the opposite side of the highway (Figure 8-9).

Each light of any pair should be aimed at the same approach target. If the roadway alignment requires coverage of an additional approach area, then an additional pair of lights should be included in the installation.



* MINIMUM, MEASURED FROM CROWN
OF ROADWAY TO CENTER OF LENS.

Figure 8-6 Typical Alignment Pattern for Flashing Light Signals, 2 Lane, 2-Way Roadway

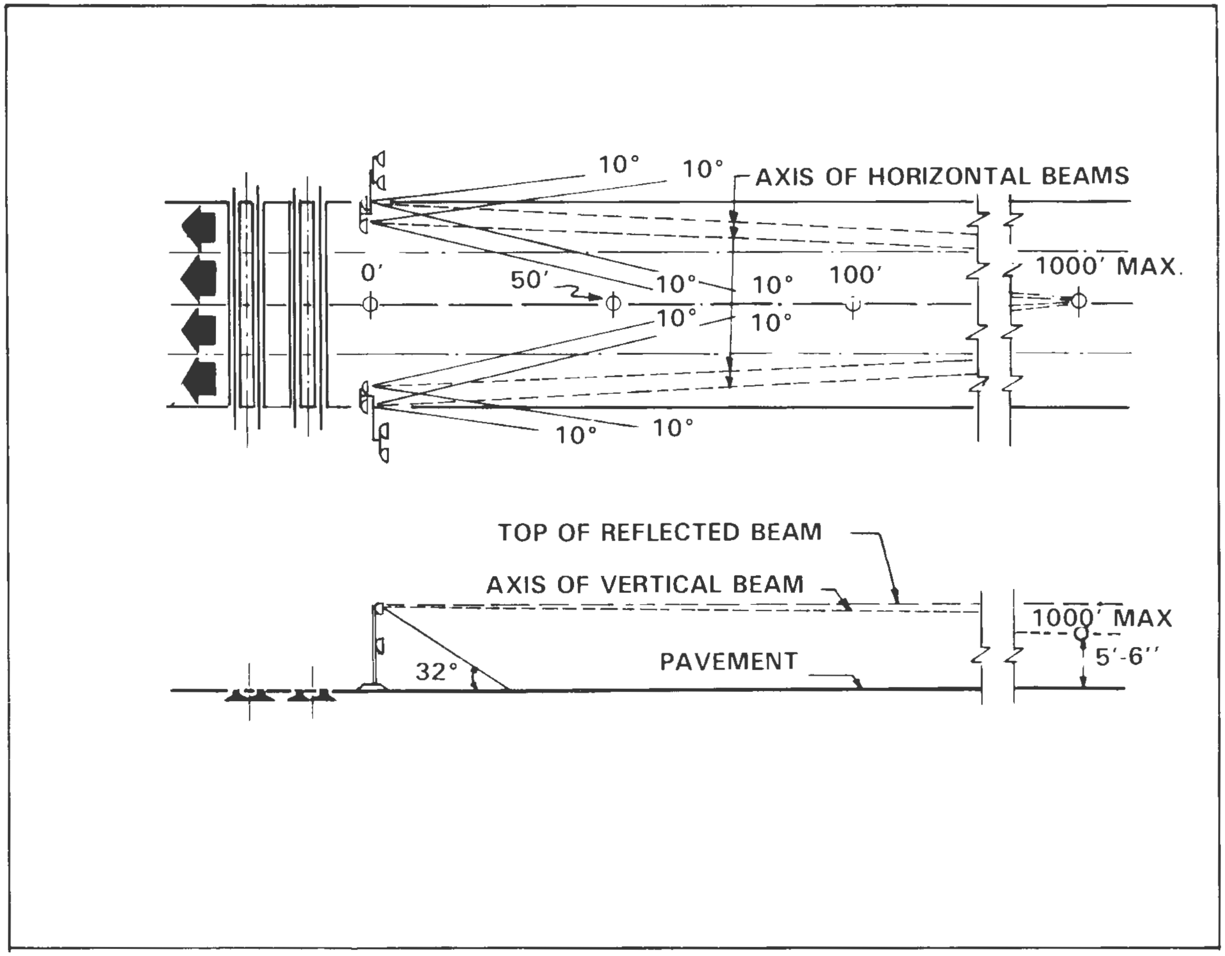


Figure 8-7 Typical Alignment Pattern for Flashing Light Signals, Multi-lane Roadway

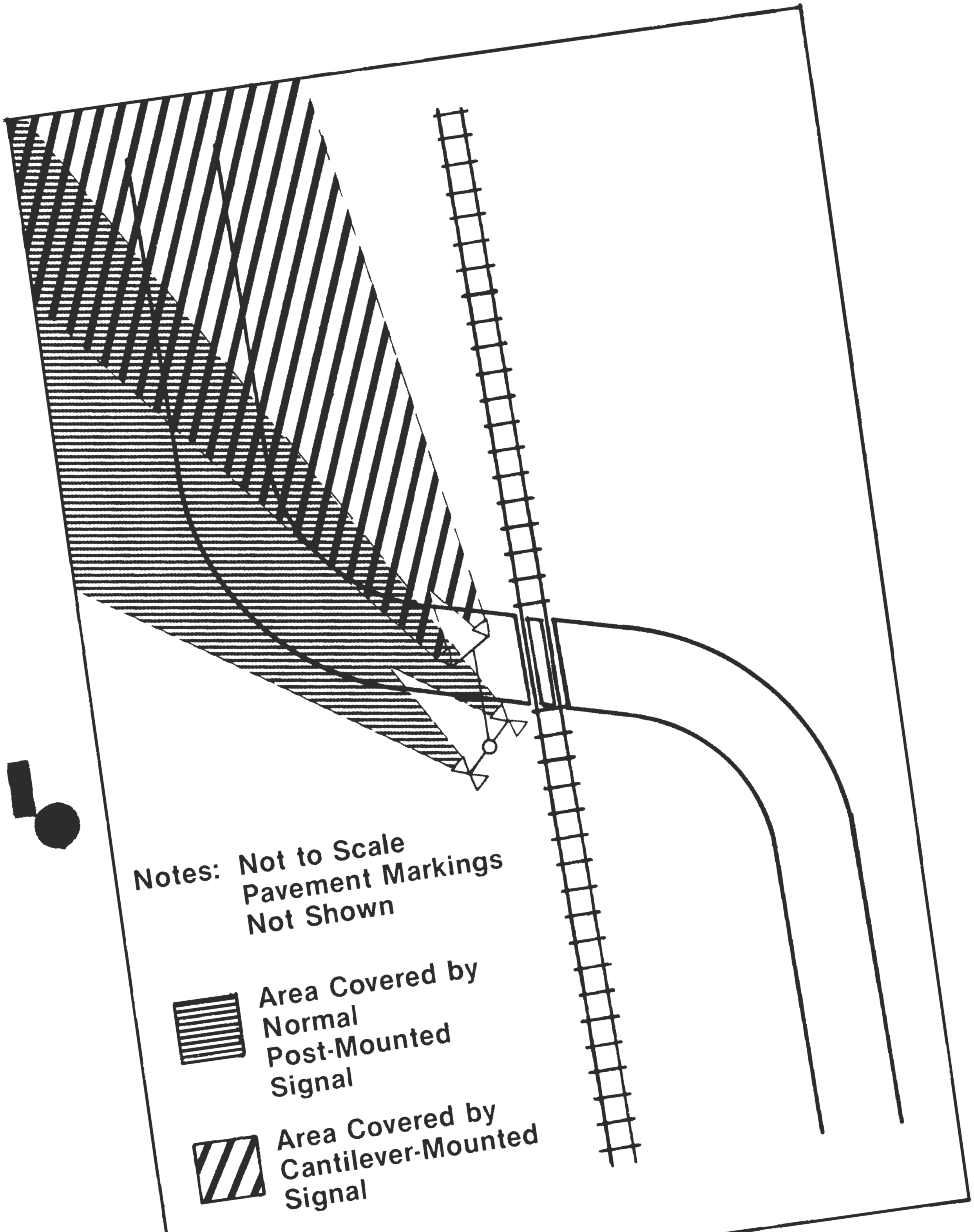


Figure 8-8 Use of Multiple Flashing Light Signals for Adequate Visibility
Horizontal Curve LEFT

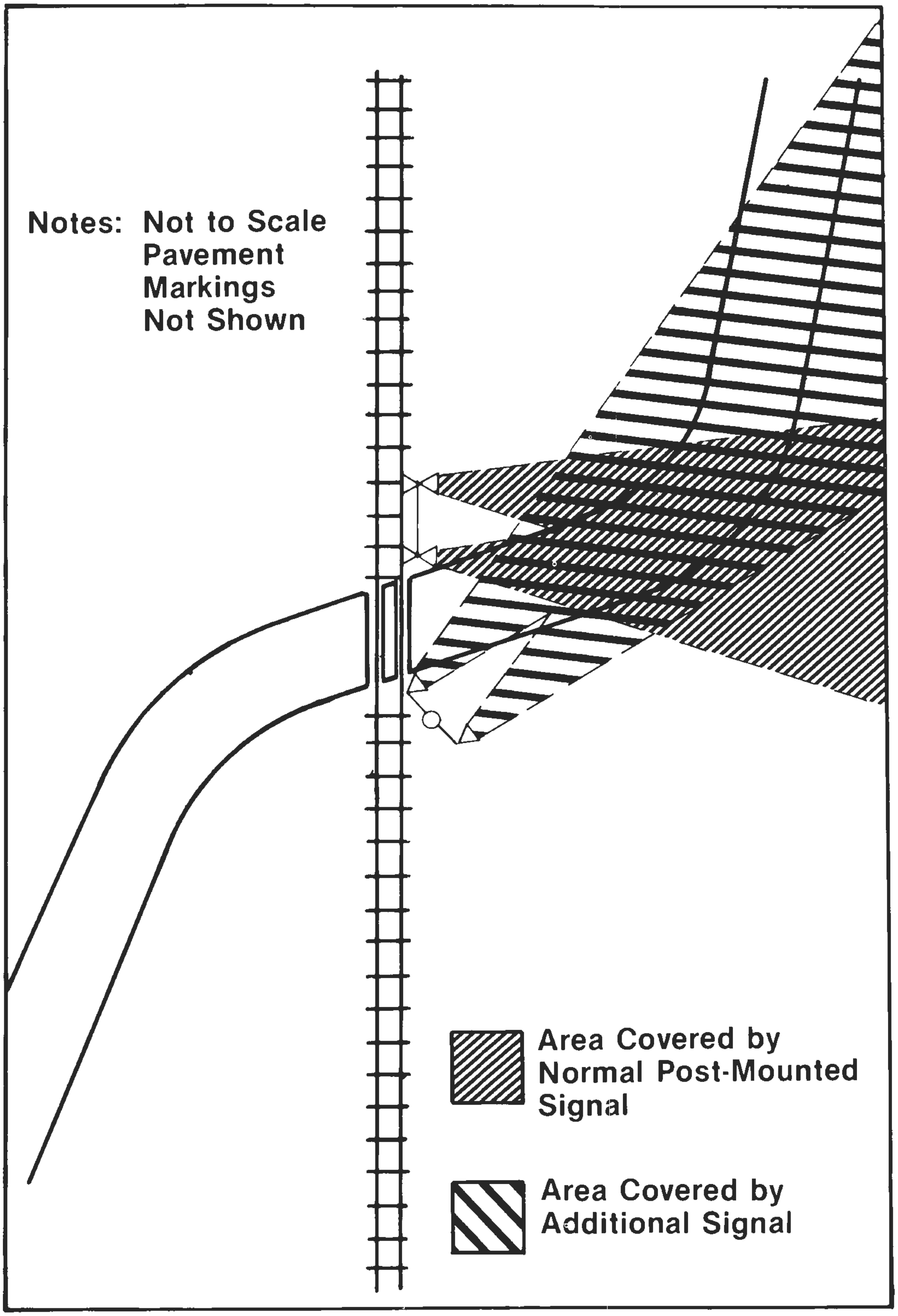
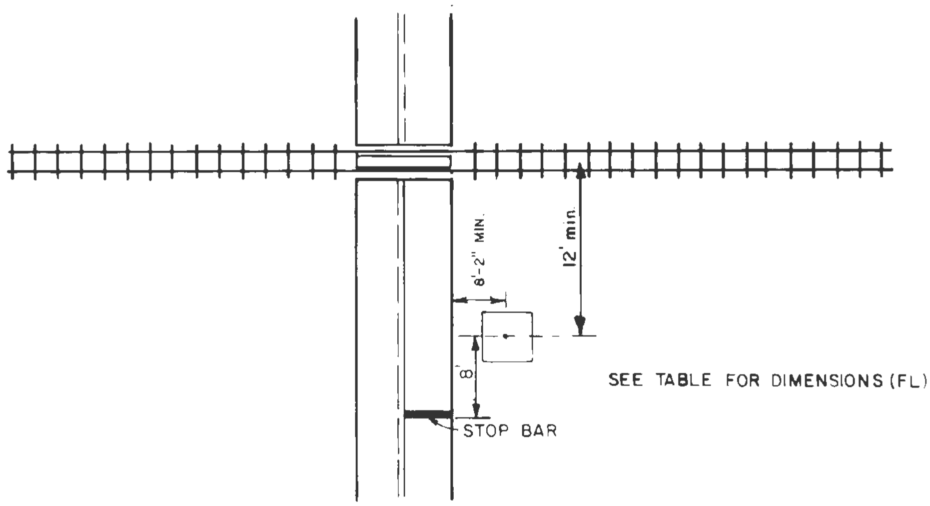
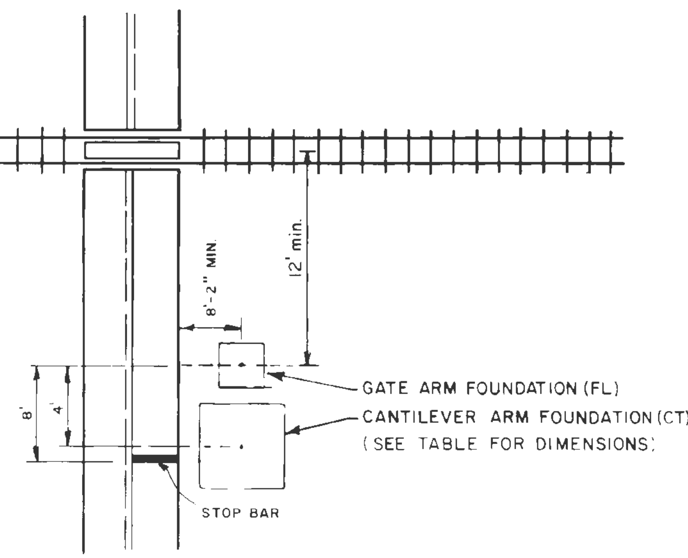


Figure 8-9 Use of Multiple Flashing Light Signals for Adequate Visibility
Horizontal Curve Right



a. Flashing Light with or without Gate

b. Cantilever Flashing Lights and Gates



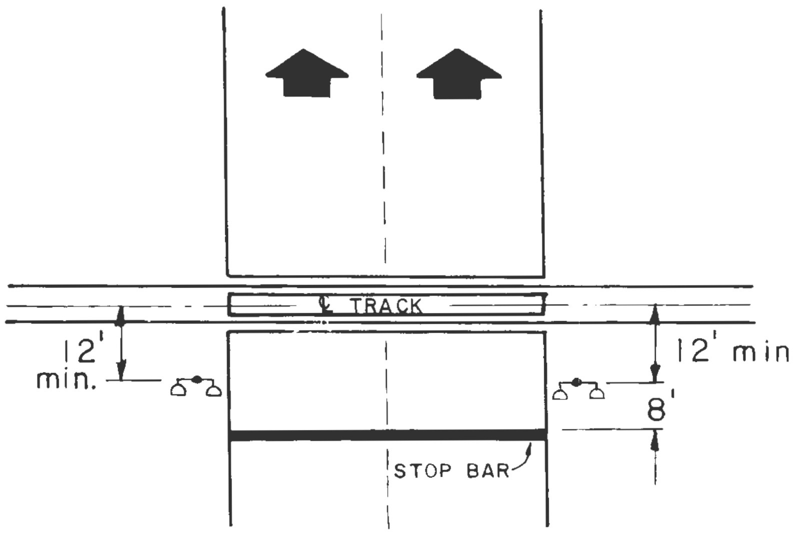
FOUNDATION TABLE			
TYPE		WITH GATE	DIMENSION
FL	POURED	NO	29" X 29"
FL	POURED	YES	34" X 34"
FL	PRE CAST	YES	30" X 30"
10' CT	PRE CAST	NO	78" X 78"
28' CT	PRE CAST	NO	90" X 90"
10' CT	POURED	NO	48" X 48"
28' CT	POURED	NO	66" X 66"
40' CT	POURED	NO	66" X 66"
40' CT	PRECAST	NO	90" X 90"

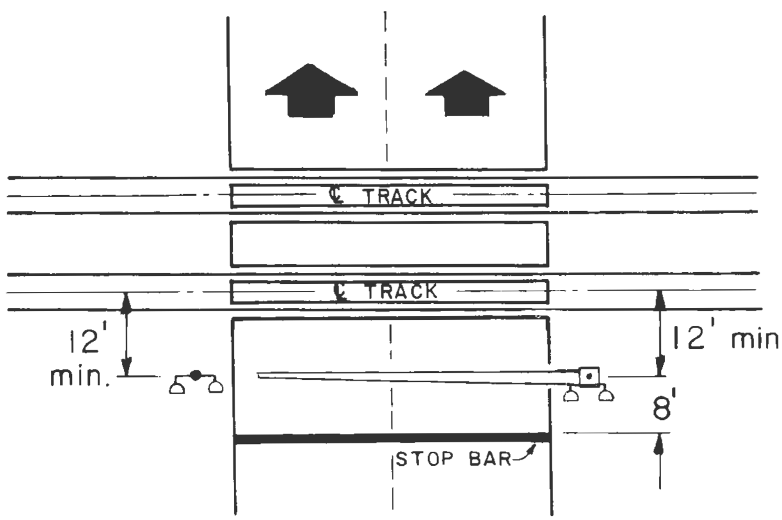
Figure 8-10 Typical Location of Signal Devices

The location of flashing light assemblies must also provide adequate lateral clearances from the track as well as space for construction of the foundations. The Association of American Railroads' (AAR) Signal Manual (Ref. 8-1) provides detailed plans of typical locations for a variety of situations. Figure 8-10 shows typical requirements for the area of the foundation, plus excavation limits for flashing lights, automatic gates, and cantilevered flashing lights. The area required for the foundation and excavation must be analyzed to determine the effect on sidewalks, utility facilities, and drainage.

Figures 8-11 through 8-17 show a series of typical location plans for railroad-highway crossing signals both with and without gates. It should be noted that while these plans indicate a 12-foot minimum clearance between the center of the flashing light assembly and the center of the tracks, some railroads prefer a 15-foot minimum clearance. Also, a cantilever would eliminate the need to place Signals on the median (Figures 8-13, 8-14, 8-16, 8-17). The minimum median width of 8′ 2″ is an operating requirement and is not an AASHTO recommendation for median width (Fig 8-13, 8-14, 8-16, and 8-17).

a. Flashing Lights

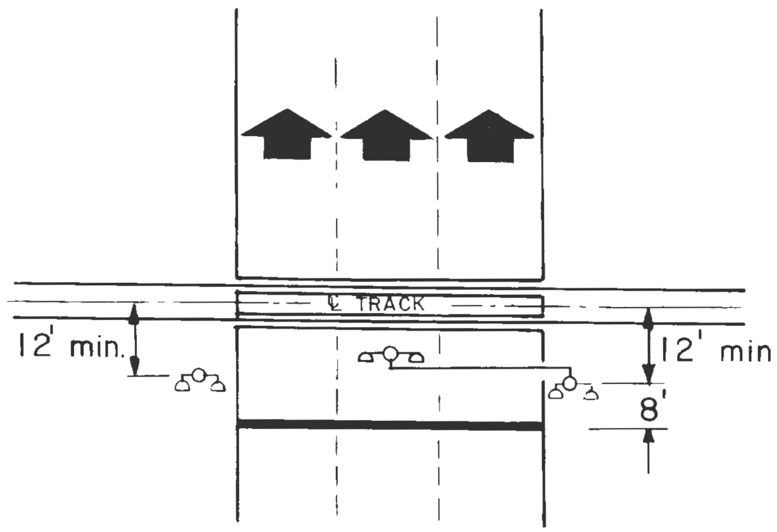


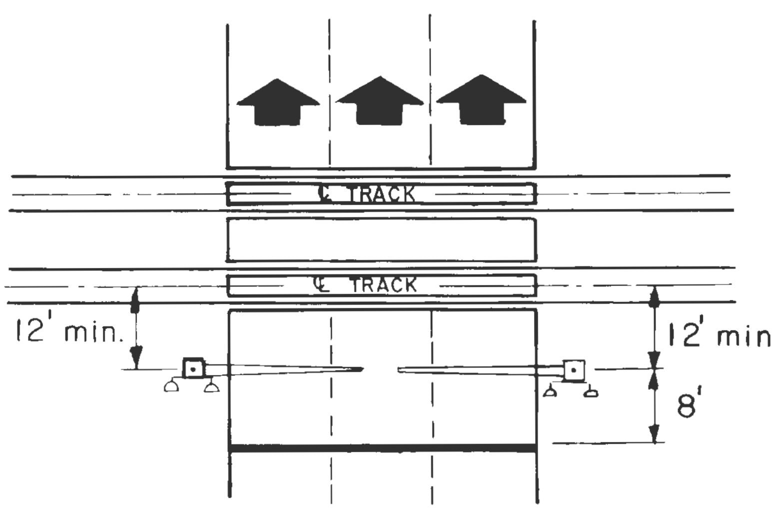


b. Flashing Lights and Gates

Figure 8-11 Typical Right Angle Crossing for One-Way Vehicular Traffic—2 Lanes

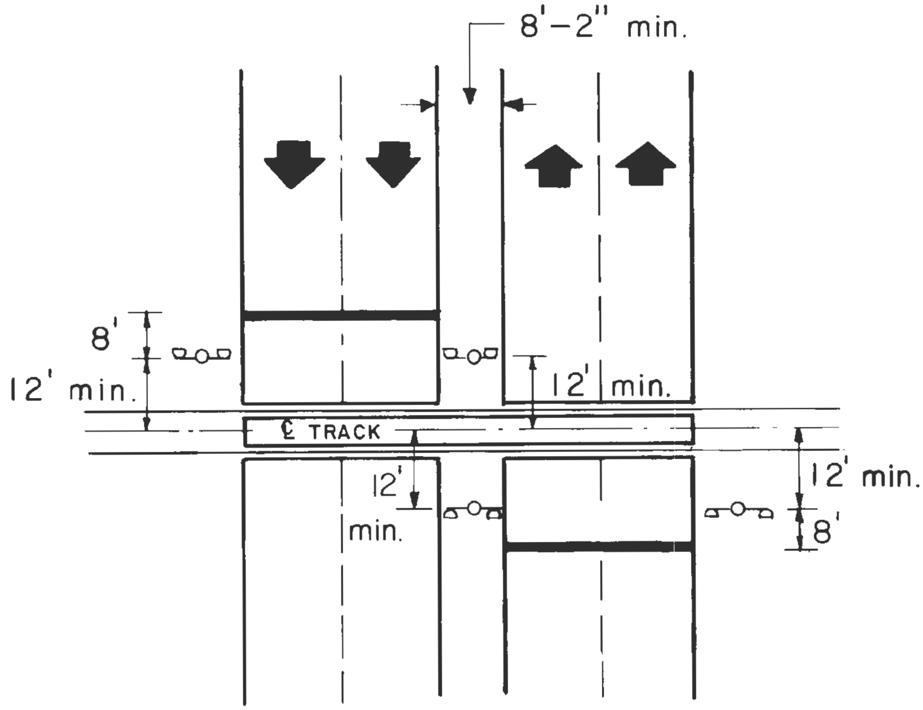
a. Flashing Lights





b. Flashing Lights and Gates

Figure 8-12 Typical Right Angle Crossing for One-Way Vehicular Traffic—3 Lanes



a. Flashing Lights

b. Flashing Lights and Gates

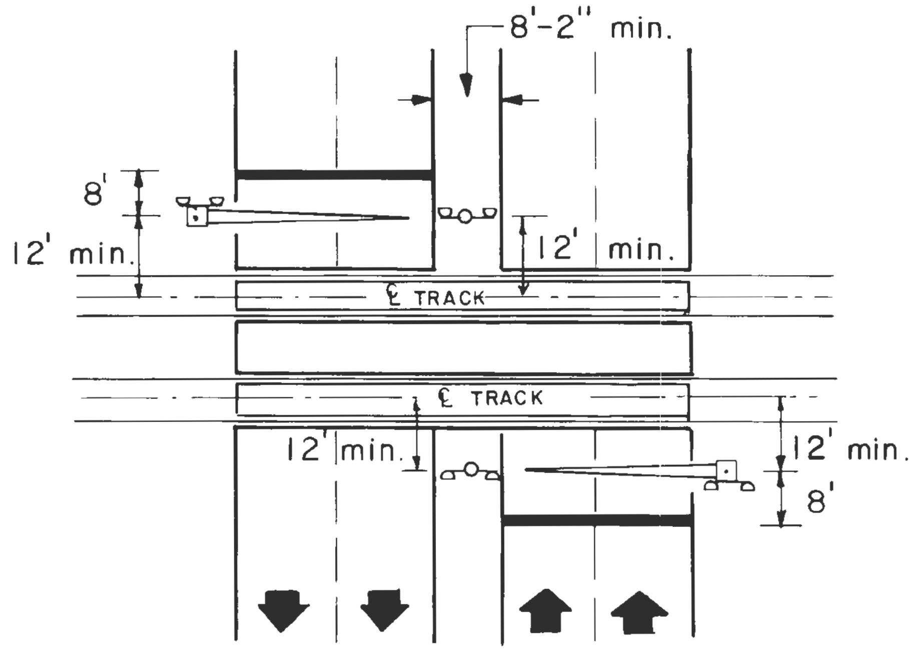


Figure 8-13 Typical Right Angle Crossing for Divided Highway with Signals in Median—2 Lanes Each Way

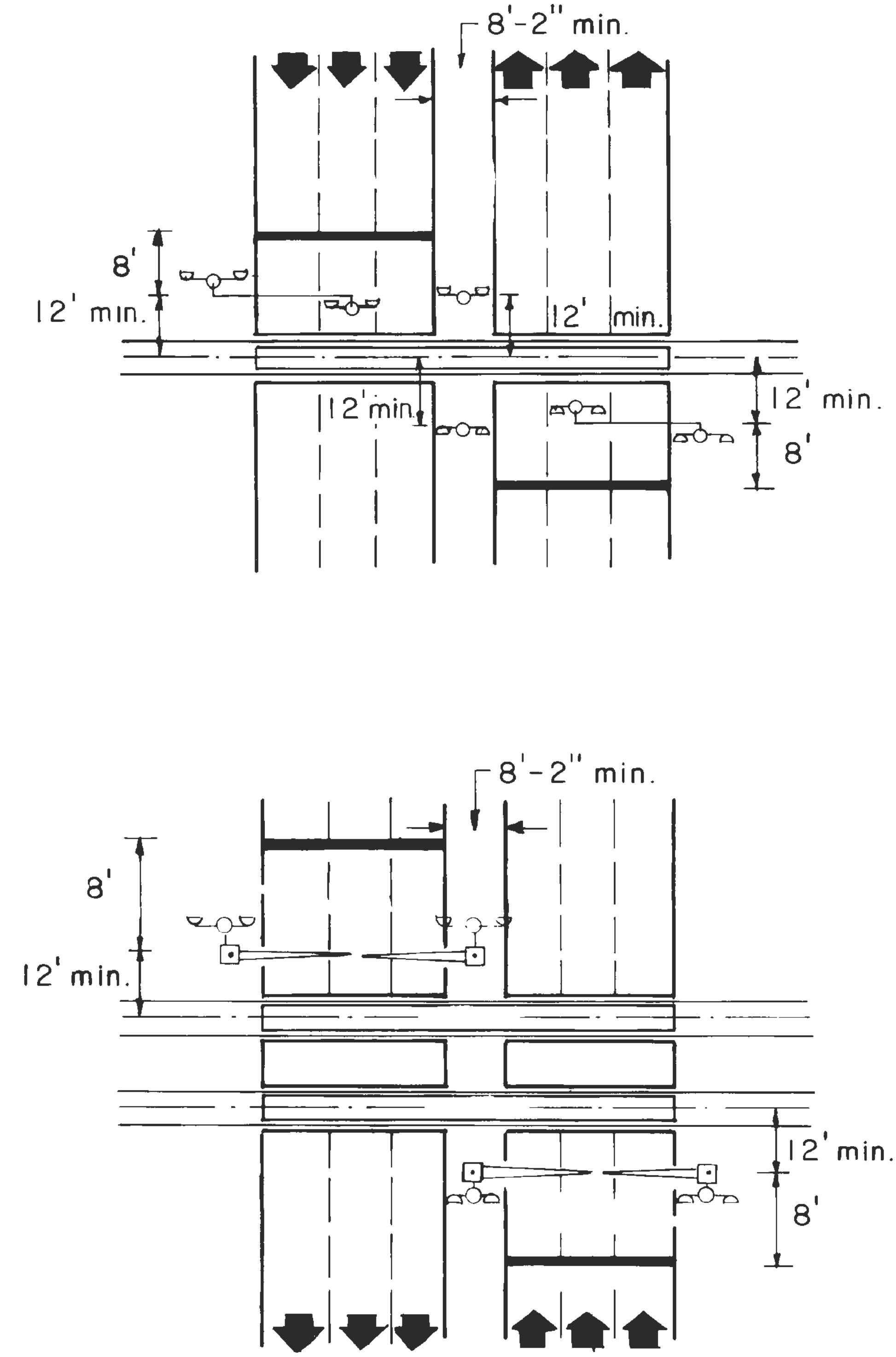
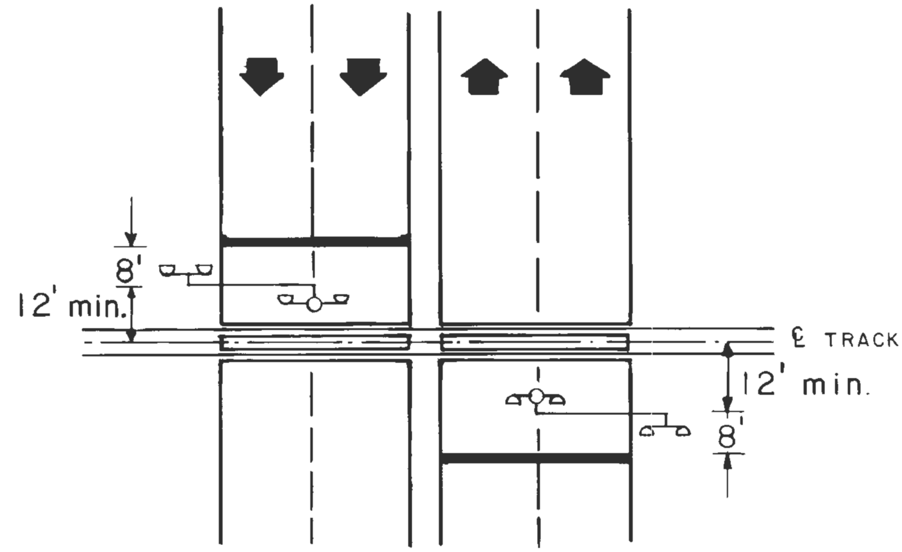


Figure 8-14 Typical Right Angle Crossing for Divided Highway with Signals in Median—3 Lanes Each Way



a. Flashing Lights

b. Flashing Lights and Gates

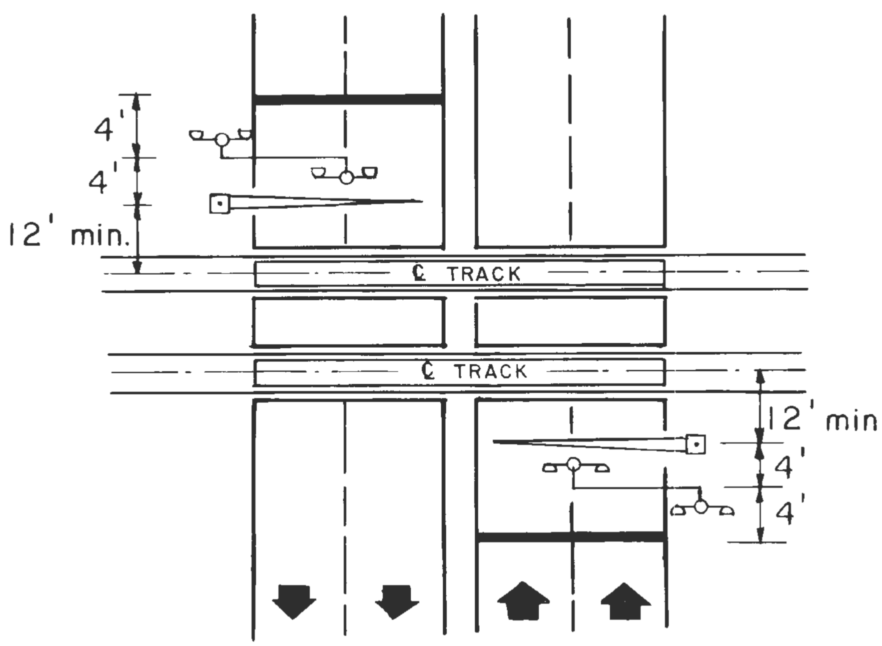


Figure 8-15 Typical Right Angle Crossing for Divided Highway with Insufficient Median for Signals—2 Lanes Each Way

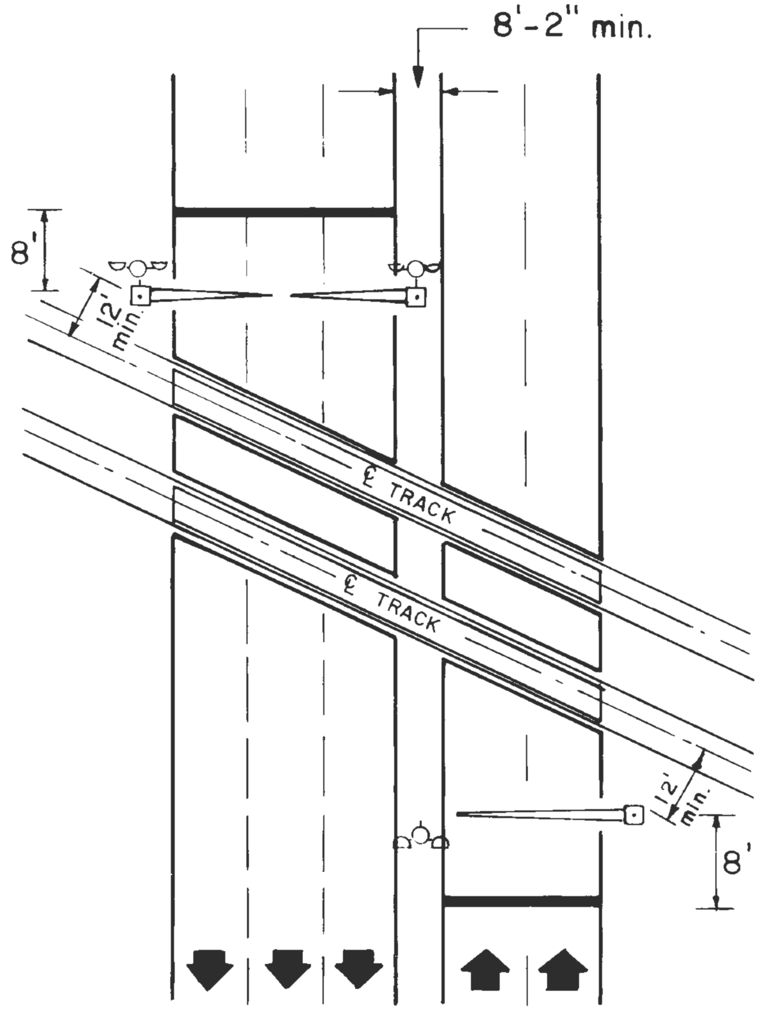


Figure 8-16 Typical Acute Angle Crossing for Divided Highway with Signals in Median—Two or Three Lanes Each Way

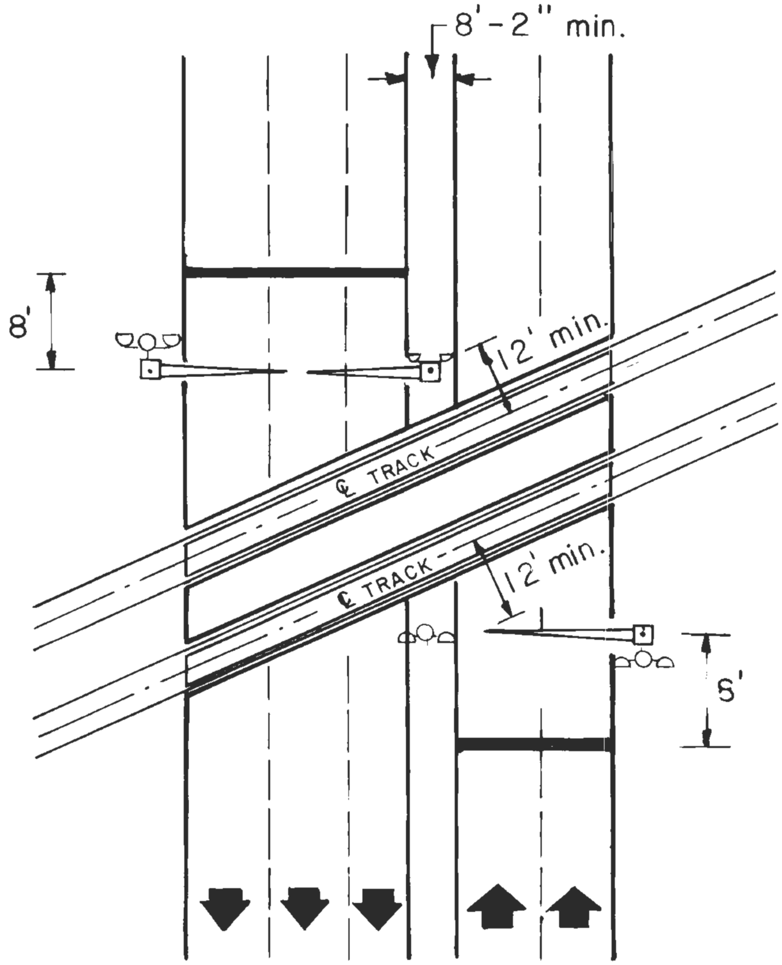


Figure 8-17 Typical Obtuse Angle Crossing for Divided Highway with Signals in Median-Two or Three Lanes Each Way

Automatic Gate

The automatic gate is a reflectorized red and white striped barricade held in a vertical position until the approach of a train. At that time, it is released to descend to a horizontal position across the traffic lanes. Lights are mounted on the gate arms. The gate mechanism is either supported on the same post with the flashing light signal or separately mounted. In either case, the flashing light signal is required when an automatic gate is used.

With the exception of a grade-separated crossing, the use of an automatic gate is the most effective method to control approaching vehicles. When the lights are flashing and the gate is in place across the approach lane, the Uniform Vehicle Code requires that the motorist stop and not drive around the lowered gate.

In determining the need for automatic gates the following factors are usually considered:

- Multiple main line railroad tracks,
- Multiple tracks where a train on or near the crossing can obscure the movement of another train approaching the crossing,
- High speed train operation combined with limited sight distance,
- A combination of high speed and moderately high volume highway and railroad traffic,
- Presence of school buses, transit buses, farm worker vehicles in the traffic flow,
- Presence of trucks carrying hazardous materials, particularly when the view down the track from a stopped vehicle is obstructed (curve in track, etc.), and
- Continuance of accidents after installation of flashing lights.

On two-way streets, the gates should cover enough of the approach roadway to physically block the motorist from driving around the gate without going into the opposing traffic lane. On multilane divided highways, an opening of approximately 6 feet may be provided for emergency vehicles.

The length of the gate arm extension is limited by weight of the materials used and should be limited to 38 feet according to the Association of American Railroads (AAR). However, wood gate arms can have a maximum effective length of 42 feet (44 feet total); while fiberglass and aluminum gate arms have a maximum effective length of 38 feet.

To increase night visibility of the barricade three red lights are placed on the gate arm. The light nearest to the tip burns steadily while the other two flash alternately. Some States require one light per traffic lane plus the tip light. The lens is the same color red as the flashing light signal.

Given the maximum effective length of the gate arm of 42 feet, to obtain full lane coverage it may be necessary to place gate assemblies in the median. In these cases crash cushions may be desirable. Under no circumstances should signals or gate assemblies be placed in an unprotected painted median.

Various clearance and location plans for the installation of automatic gates in typical situations are provided in Figures 8-5, 8-6, 8-7 (Section 8C-4) of the MUTCD. Figures 8-10 through 8-17 of this Handbook also show typical location plans for gates.

Signal Bells

The crossing bell is an audible warning signal used to supplement other active warning devices. Although some States require that a bell be installed with all flashing light signals, the bell's effectiveness as a warning to motorists is limited because today's motor vehicles are well insulated from outside noise. Its present day value is to warn pedestrians and bicyclists. Bells are also used to warn passengers at commuter stations that a train is arriving.

When used, the bell is usually mounted on top of the supporting mast of one of the flashing light signals. The bell is positioned so that the gong is parallel to the sidewalk or street.

The bell may interact with the flashing light in various ways. The most common application is for the bell to sound whenever the flashing light signals are operating. The bell circuitry may be designed so that the bell stops ringing when the lead end of the train reaches the crossing. When gates are used, the bell may be silenced when the gate arms descend to within 10 degrees of the horizontal position. Silencing the bell when the train reaches the crossing or when the gates are down may be desired to accommodate residents of suburban areas.

Active Advance Warning Sign

A train-activated advance warning sign should be considered at locations where the grade crossing flashing light signals cannot be seen until an approaching motorist has passed the decision point (the distance to the track from which a safe stop can be made). These distances are further discussed in section 8D of this Handbook. An activated signal consists of one or two 8-inch yellow Hazard Identification Beacons mounted above the Advance Warning sign. The beacons are connected to the railroad track circuitry and should be activated prior to the flashing lights so that a driver would not pass a dark beacon and then encounter an activated flashing light. Use of activated advance warning signs requires some modification of the track circuitry.

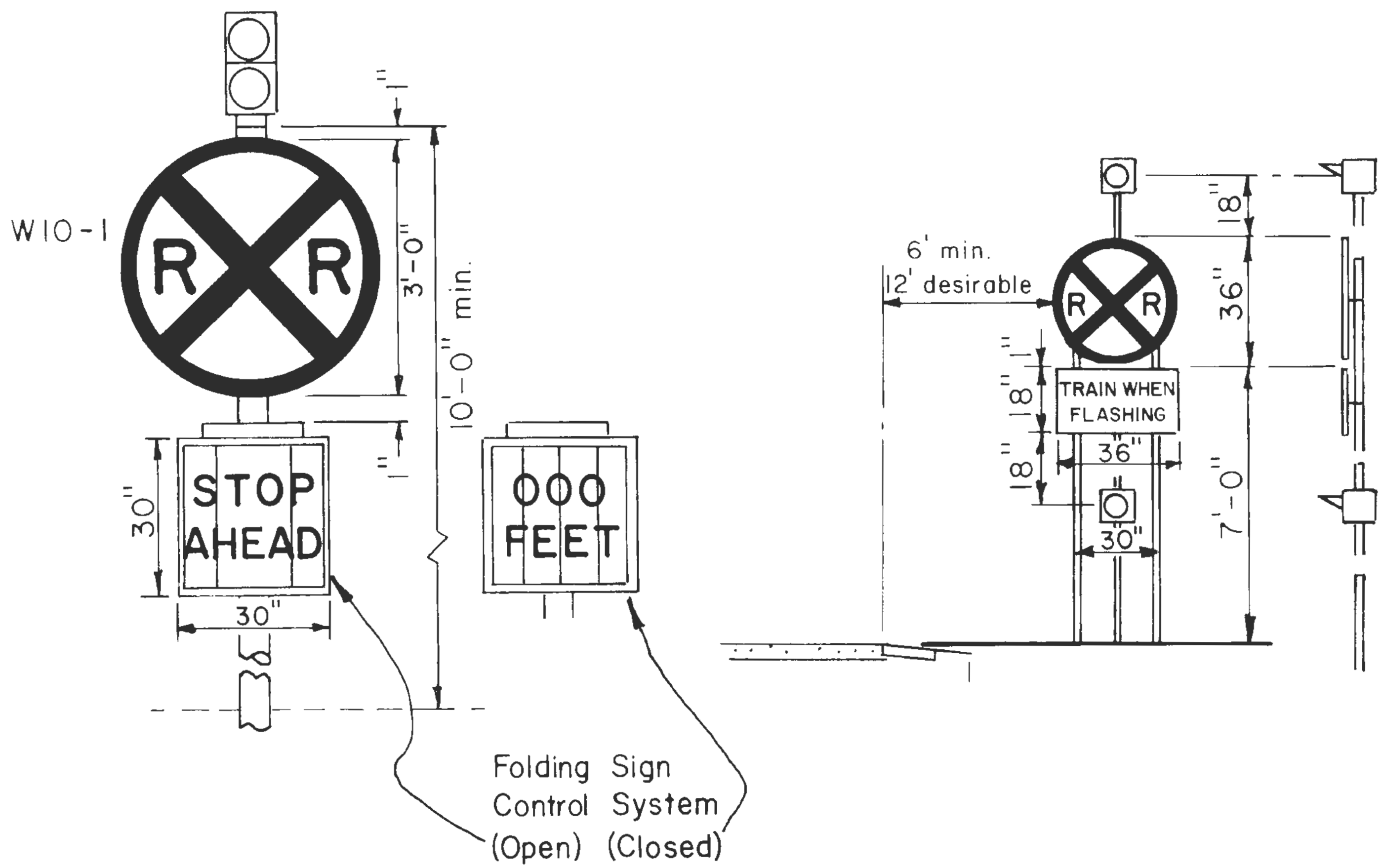


Figure 8-18 Examples of Active Warning Signs

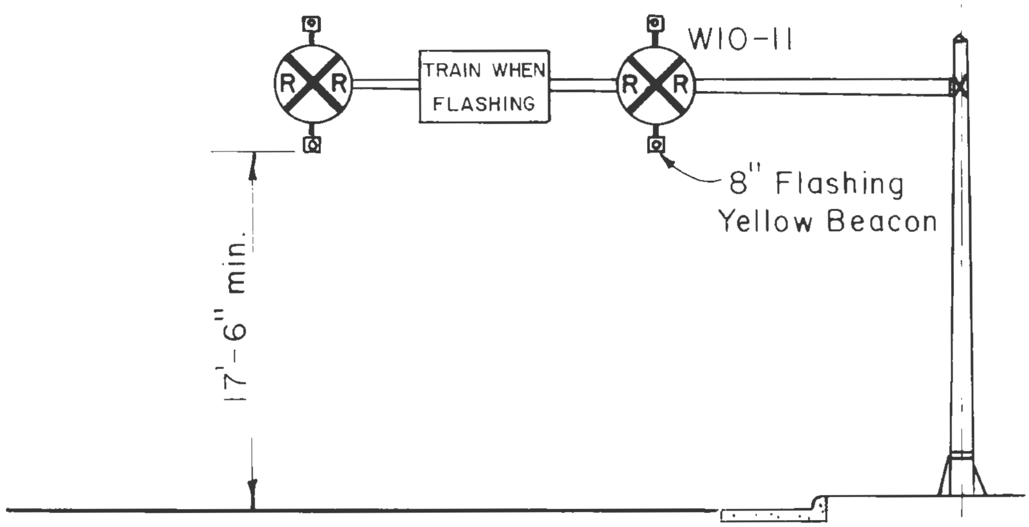


Figure 8-18 Examples of Active Advance Warning Signs

A few States employing train activated beacons also use a supplementary message (either active or passive) with the beacon such as TRAIN WHEN FLASHING. The disadvantage of the passive message is that should the beacon fail, then the motorist would not be alerted to the hazardous situation.

Figure 8-18 shows three examples of Active Advance Warning signs.

Flagging

At certain grade crossings, railroad companies may have a policy to use a flagger to stop highway vehicles and pedestrians before allowing a train to move over the crossing. These crossings typically have only the passive warning signs. The Standard Code of Operating Rules, Rule 103 (Ref. 8-4) states that flaggers should be employed at crossings which do not have active control devices " . . . when (the railroad) cars are not headed by an engine." The flagger may operate "stationed on the ground" or "located on the leading end of the movement." Some railroad companies require flagging when the train has been split or when switching operations necessitate numerous movements across the roadway.

There are no specific instructions on how a railroad flagger is to stop highway vehicles or on the use of fusees (flares). However, Rule 12 (Ref. 8-4) establishes a standard flag or lamp signal for train operations.

The appearance of the flagger is important. The ideal flagger is highly conspicuous and easily identified as a person who is to provide traffic directions (authoritative). Not all railroad-highway grade crossings have traffic or environmental conditons that would facilitate flagging. If flagging is to be conducted at night, it is important that the crossing be illuminated so that both the flagger and the train can be seen. One State's rule for determining the type of grade crossing that should utilize flagging reads as follows:

"A new (opening) grade crossing may be considered for a delay in the installation of active grade crossing traffic control devices provided that the operating railroad company specifies that the grade crossing will be manually flagged and that the characteristics of the highway traffic is conducive to stopping (e.g.: highway is two lanes or less, less than 4,000 ADT, less than 30 mph operating speed, and if train movements are at night, the grade crossing must be illuminated.)"

Traffic Signals at or Near Grade Crossings

A prime consideration for motorist safety is the preemption of highway intersection traffic control signals located within 200 feet of a railroad highway grade crossing or where vehicle queues reach the track. Grade crossing signals are coordinated with adjacent highway traffic control signals so that the operation of these separate control devices will at all times complement rather than negate each other. The MUTCD (Section 8C-6) stresses that " . . . design, installation, and operation should be based upon a total system approach in order that all relevant features may be considered." A primary criterion is to avoid the entrapment of vehicles on the crossing by conflicting aspects of the highway signal and the grade crossing signal. The best way to do this is to prevent vehicle queues onto the tracks by the proper design and operation of the dual signal systems.

The pre-emption feature requires an electrical circuit between the control relay of the grade crossing warning system and the traffic controller. The circuit shall be on the closed circuit principle, that is, the traffic signal controller is normally energized and the circuit is wired through a closed contact of the energized control relay of the grade crossing warning system. This is to establish and maintain the preempted condition during the time that the grade crossing signals are in operation. Where multiple or successive preemption may occur from differing modes, train actuation should receive first priority and emergency vehicles second priority.

The various elements that should be considered include: intersection geometrics, vehicular volume, queue lengths and dissipation rate, proximity of the crossing to the intersection, train movements, approach speeds for train and motor vehicles, public transportation vehicles, and trucks carrying large or hazardous cargoes.

Principles that characterize adequate grade crossing preemption and coordination include (Ref. 8-18):

- Every green signal indication is terminated with a yellow indication as specified in the MUTCD.

- When preempted by train movements, the traffic control signal (after provision of the proper phase change intervals) will immediately provide a short green interval to the approach crossing the track. This is done to clear any vehicles that may be on, or so close to the track as to be in danger, or where vehicles may interfere with the operation of crossing gates. The traffic signal will subsequently display indications to prevent vehicles from entering the track area, while at the same time traffic movements which do not conflict with the railroad movement may be permitted. If, at the time of preemption, the green interval is on an approach that does not cross the track, the green interval would be immediately terminated with a standard yellow phase change interval in order that green time may be given to the approach crossing the track.
- Conflicting indications are not presented.
- ''Blank-out signs that display ''NO RIGHT TURN'' or ''NO LEFT TURN'' should be used as appropriate.
- Optically limiting devices may be employed for traffic signal indications to preclude driver observance of conflicting or misleading indications.

The layout of the preemption sequences should state specifically what phase change interval is to occur no matter when the preemption begins in relation to the normal phasing sequence.

There are an infinite number of railroad-highway grade crossing configurations. Figures 8-19 through 8-30 illustrate how the basic principles discussed above may be applied.

Special Situations

In some cases, geometric and/or operational characteristics may call for a traffic signalization strategy other than the typical ones previously mentioned. This is especially true when the grade crossing is: extremely close to the signalized intersection; is rather far from a signalized intersection, but peak-hour queues develop across the track; or the crossing is located between two closely spaced signalized intersections.

When a grade crossing is located only a few car lengths from a signalized intersection stop line, it is likely that vehicles will queue across the tracks during the red interval of each cycle. Although the track clearance interval of the preemption sequence may provide sufficient time to allow vehicles in the track area to proceed through the intersection, occasionally an anxious driver may stall the vehicle and feel forced to abandon it on the tracks in the face of an oncoming train. The potential for this situation can be reduced if the intersection stop line is removed from its normal location and the stop line in advance of the crossing is allowed to function as the intersection stop line. This configuration

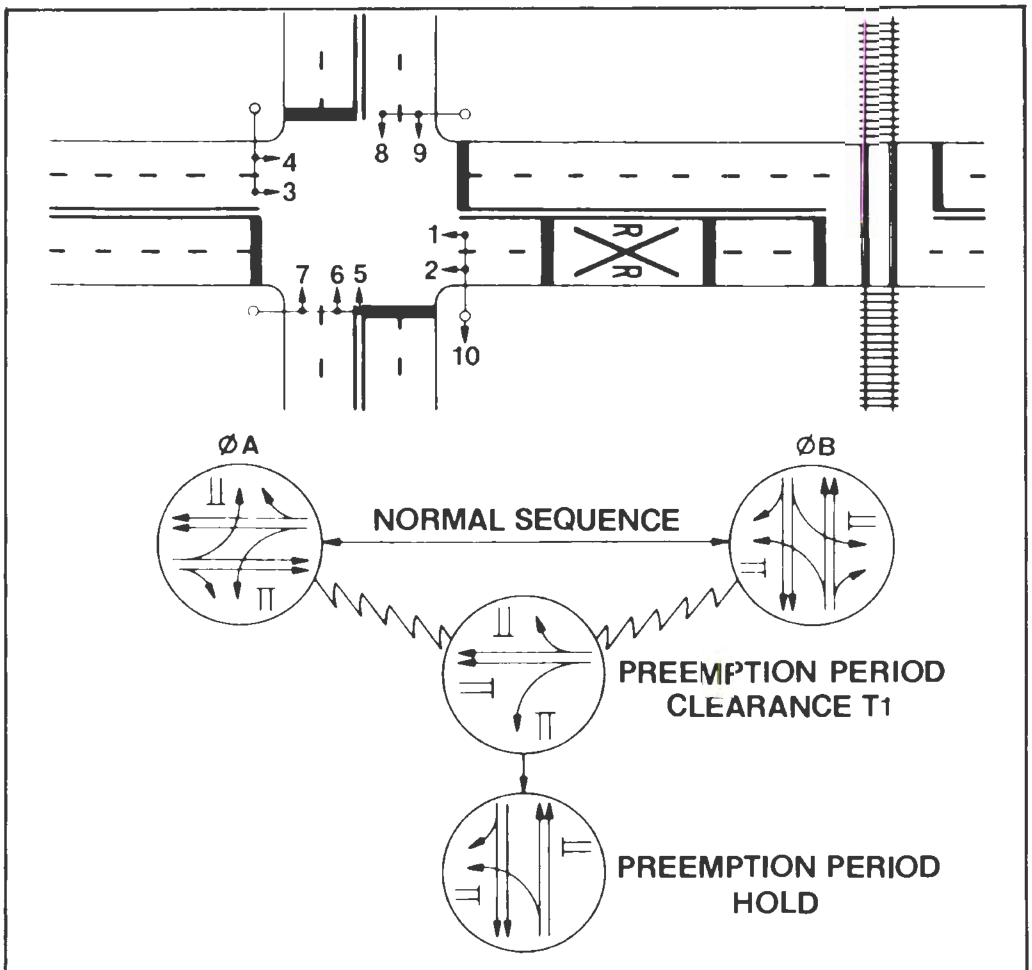
FIGURE KEY

Ø	Signal Phase
●—▶	Overhead Mounted Signal Head
o- ▶	Pedestal Mounted Signal Head
R	Circular Steady Red Indication
FR	Circular Flashing Red Indication
Y	Circular Steady Yellow Indication
FY	Circular Flashing Yellow Indication
G	Circular Steady Green Indication
—▶	Steady Green Arrow Indication
Y—▶	Steady Yellow Arrow Indication
W	Steady Lunar White Walk Indication
FDW	Flashing Portland Orange Don't Walk Indication
DW	Steady Portland Orange Don't Walk Indication
R/W	Green Interval
CHANGE	Yellow Change Interval
T_1, T_{1A}, T_{1B},	Preemption Clearance Intervals Prior to Train Approach
T_2	Yellow Change Interval Following T_1 Interval
T_{2A}	Yellow Change Interval Following T_{1A} Interval
T_{2B}	Yellow Change Interval Following T_{1B} Interval
HOLD	Signal Indications During Train Passage
RELEASE	Signal Indications Immediately After Train Passage
BLANK	Signal Indication Extinguished

NOTES

1. Turn prohibition signals are blank-out type and shall conform to the *Manual on Uniform Traffic Control Devices*
2. Turn prohibition messages shown herein may have to be modified to conform to applicable state or local law concerning right turn on red

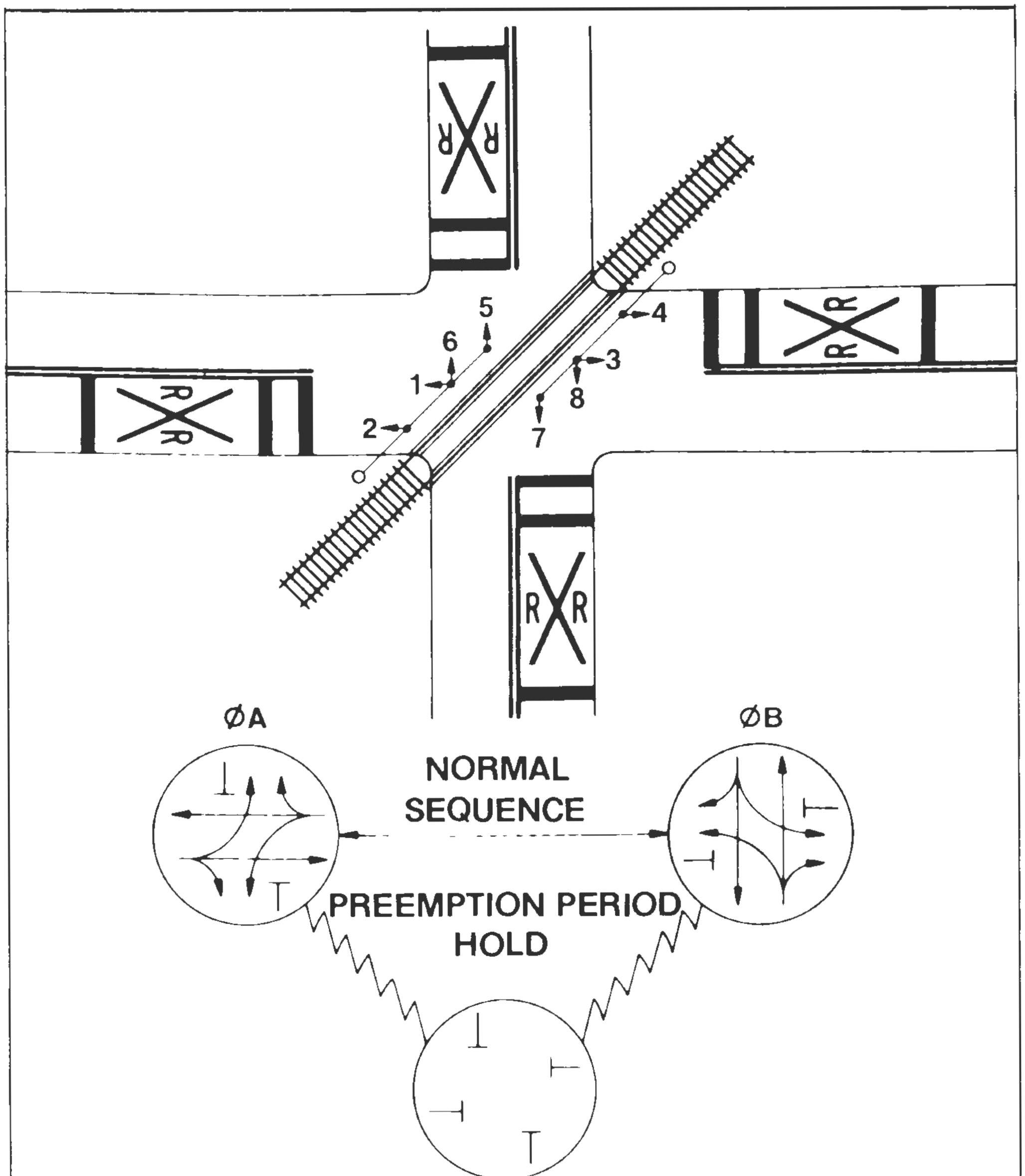
Figure 8-19 Figure Key to be Used with Figures 8-20 through 8-32



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE						
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE	ØB CHANGE	T_1	T_2	HOLD	CHANGE	RELEASE
1,2	G	Y	R	R	Y	R	R	R	R	R	G
3,4	G	Y	R	R	G	R	G	Y	R	R	G
5 *	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	NO LEFT TURN	BLANK
6,7,8,9	R	R	G	Y	R	Y	R	R	G	Y	R
10 *	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	BLANK

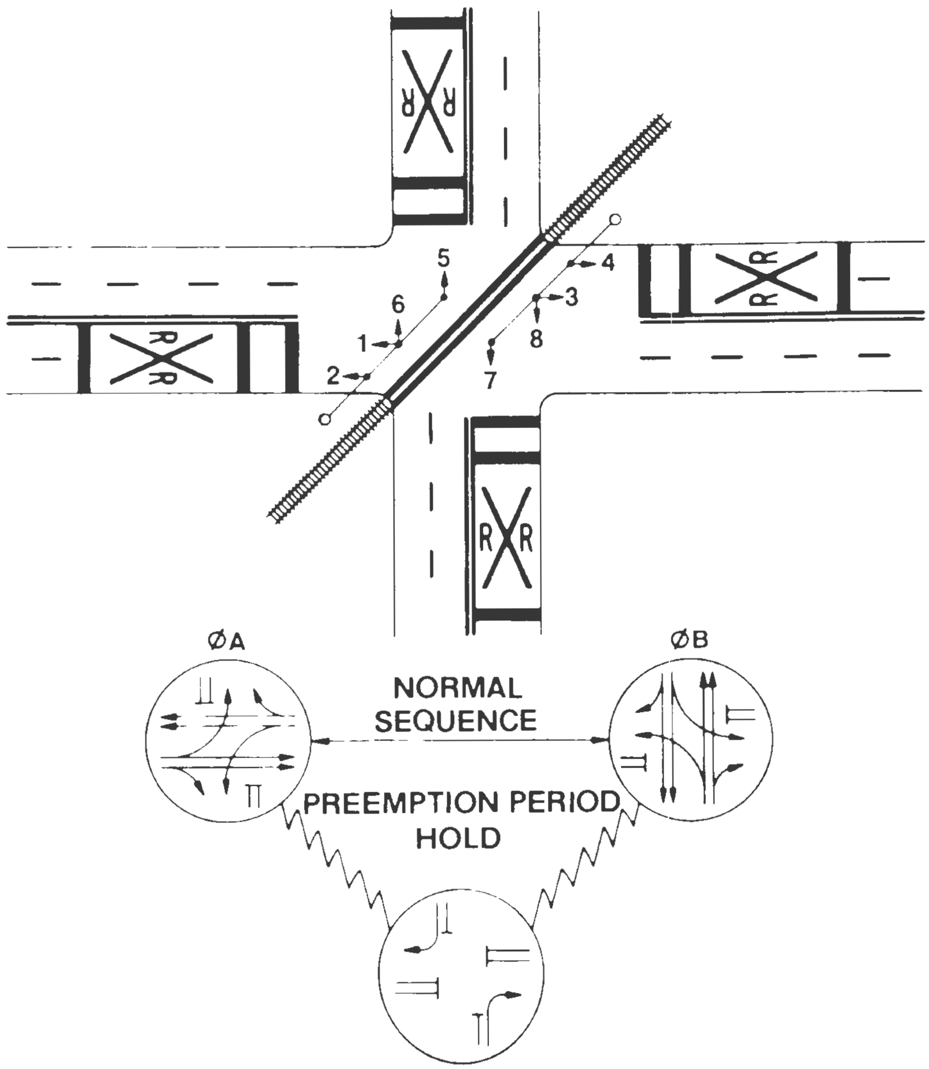
* OPTIONAL

Figure 8-20 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Undivided Roadways, Two-Phase Operation



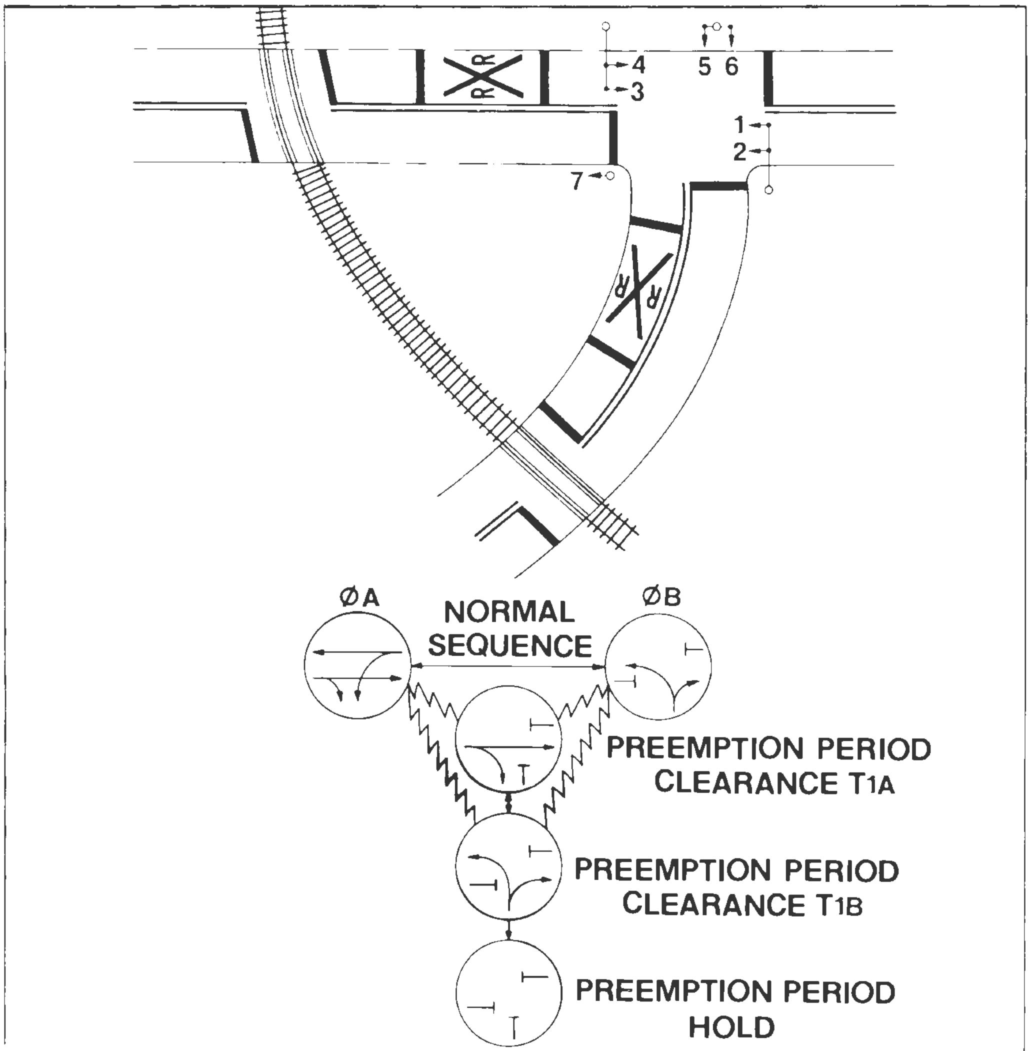
SIGNAL	ØA R/W	ØA CHANGE	ØB R/W	ØB CHANGE	PREEMPTION SEQUENCE ØA CHANGE	PREEMPTION SEQUENCE ØB CHANGE	PREEMPTION SEQUENCE HOLD	PREEMPTION SEQUENCE RELEASE
1,2,3,4	G	Y	R	R	Y	R	R	G
5,6,7,8	R	R	G	Y	R	Y	R	R

Figure 8-21 Typical Railroad Preemption Sequence, Signalized Intersection of 2 Lane Roadways with Railroad Bisecting Intersection, Two-Phase Operation



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE				
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE	ØB CHANGE	HOLD	CHANGE	RELEASE
1,2,3,4	G	Y	R	R	Y	R	R	R	G
5,7	R	R	G	Y	R	Y	R	R	R
6,8	R	R	G	Y	R	Y	R	Y R	R

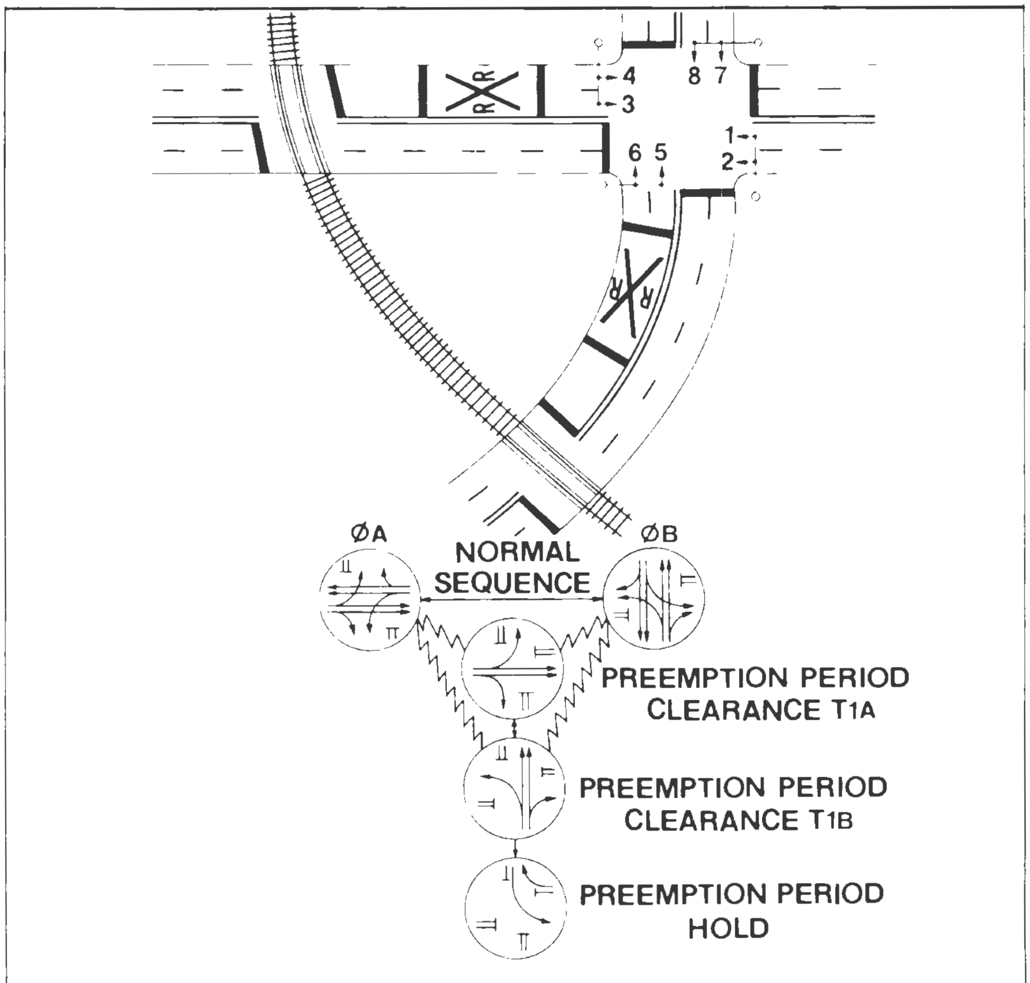
Figure 8-22 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Undivided Roadways with Railroad Bisecting Intersection, Two-Phase Operation



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE									
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE FOR T_{1A}	ØB CHANGE FOR T_{1A}	ØA CHANGE FOR T_{1B}	ØB CHANGE FOR T_{1B}	T_{1A}	T_{1B}	T_{1A}	T_{1B}	HOLD	RELEASE
1.2	G	Y	R	R	G	R	Y	R	G	R	Y	R	R	G
3.4	G	Y	R	R	Y	R	Y	R	R	R	R	R	R	G
5.6	R	R	G	Y	R	Y	R	G	R	G	R	Y	R	R
7 *	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	BLANK

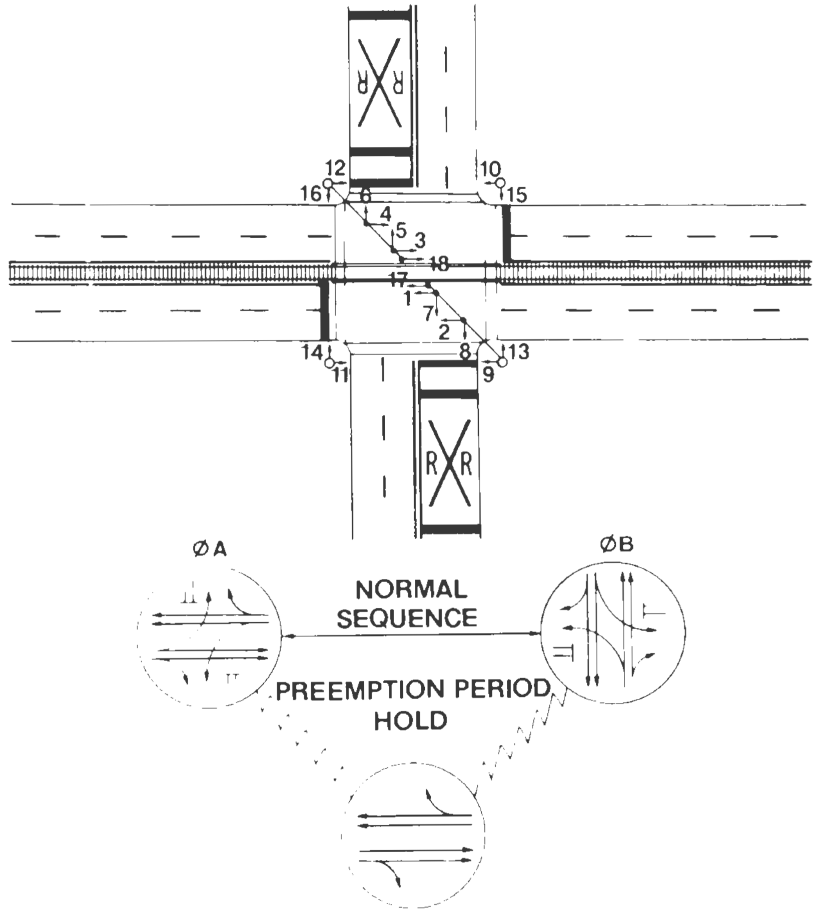
* OPTIONAL

Figure 8-23 Typical Railroad Preemption Sequence, Signalized Intersection of 2 Lane Roadways with Railroad Crossings on Two Approaches, Two-Phase Operation



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE										
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE FOR T_{1A}	ØB CHANGE FOR T_{1A}	ØA CHANGE FOR T_{1B}	ØB CHANGE FOR T_{1B}	T_{1A}	T_{1B}	T_{2A}	T_{2B}	HOLD	CHANGE	RELEASE
1,2	G	Y	R	R	G	R	Y	R	G	R	Y	R	R	R	G
3	G	Y	R	R	Y	R	Y	R	R	R	R	R	R	R	G
4	G	Y	R	R	Y	R	Y	R	R	R	R	R	R →	R →	G
5	R	R	G	Y	R	Y	R	Y	R	R	R	R	← R	← R Y	R
6	R	R	G	Y	R	Y	R	Y	R	R	R	R	R	R	R
7,8	R	R	G	Y	R	Y	R	G	R	G	R	Y	R	R	R

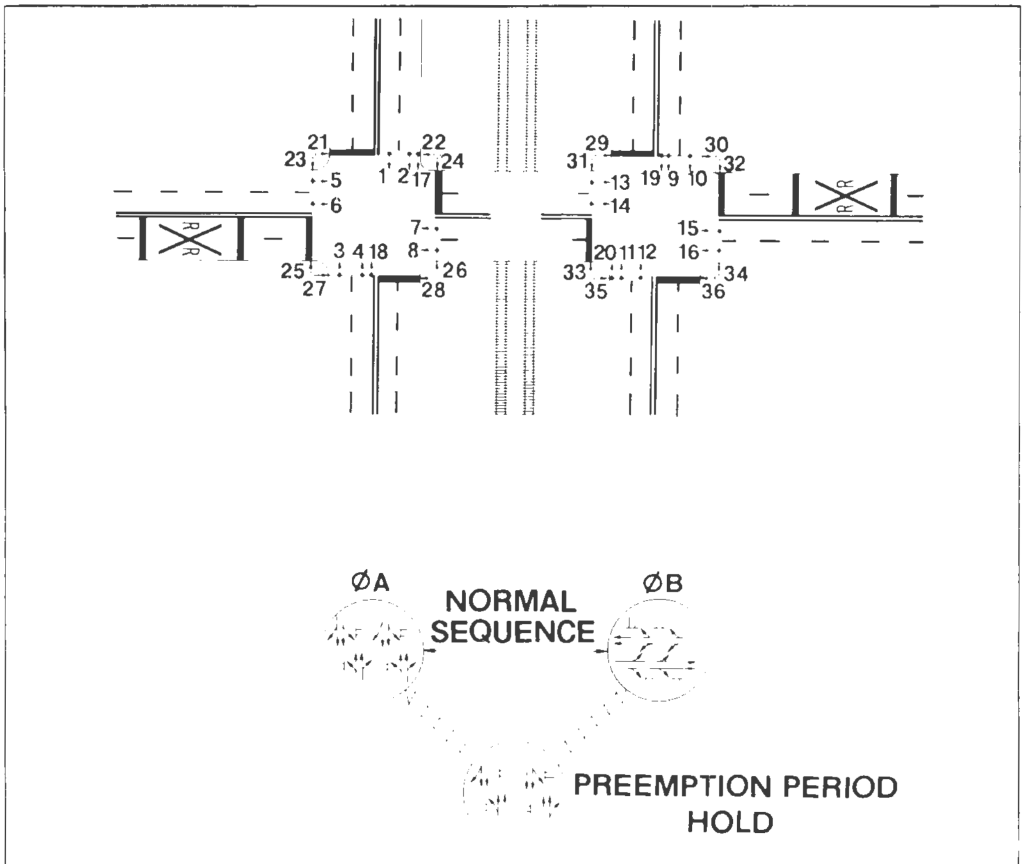
Figure 8-24 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Undivided Roadways with Railroad Crossing on Two Approaches, Two-Phase Operation



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE				
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE	ØB CHANGE	HOLD	CHANGE	RELEASE
1,2,3,4	G	Y	R	R	G	R	G	Y	R
5,6,7,8	R	R	G	Y	R	Y	R	R	G
9,10,11,12	W/DW	DW	DW	DW	W	DW	W/DW	DW	DW
13,14,15,16	DW	DW	W/DW	DW	DW	DW	DW	DW	W
17,18*	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	NO LEFT TURN	BLANK

* OPTIONAL

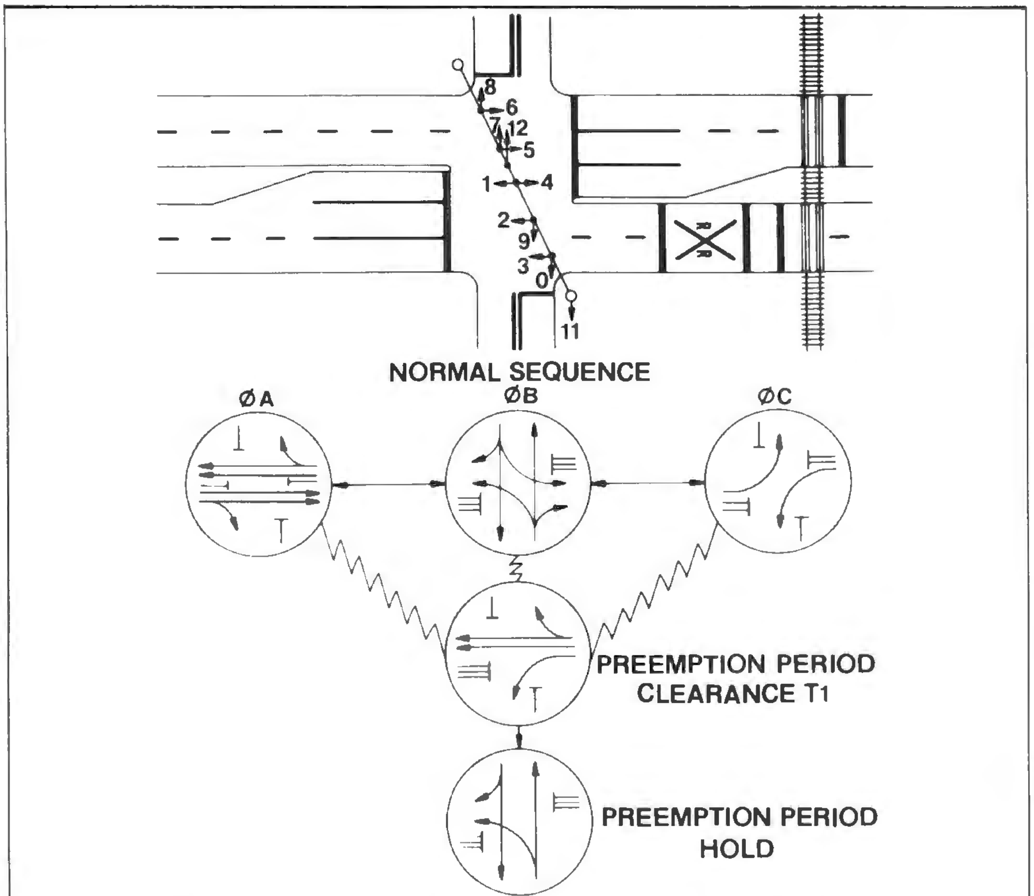
Figure 8-25 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Roadways with Railroad Bisecting One Roadway, Two Phase Operation with Pedestrian Signals



SIGNAL	ØA R/W	ØA CHANGE	ØB R/W	ØB CHANGE	PREEMPTION SEQUENCE ØA CHANGE	ØB CHANGE 1	CHANGE ØB 2	HOLD	CHANGE	RELEASE
1.2.3.4. 9.10.11.12	G	Y	R	R	Y	R	R	G	Y	R
5.6.15.16	R	R	G	Y	R	G	Y	R	R	G
7.8.13.14	R	R	G	Y	R	Y	R	R	R	G
17.20*	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	NO RIGHT TURN	BLANK
18.19*	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	NO LEFT TURN	BLANK
21.22.27.28 29.30.35.36	DW	DW	W/DW	DW	DW	DW	DW	DW	DW	W/DW
23.24.25.26 31.32.33.34	W/DW	DW	DW	DW	DW	DW	DW	DW	DW	DW

* OPTIONAL

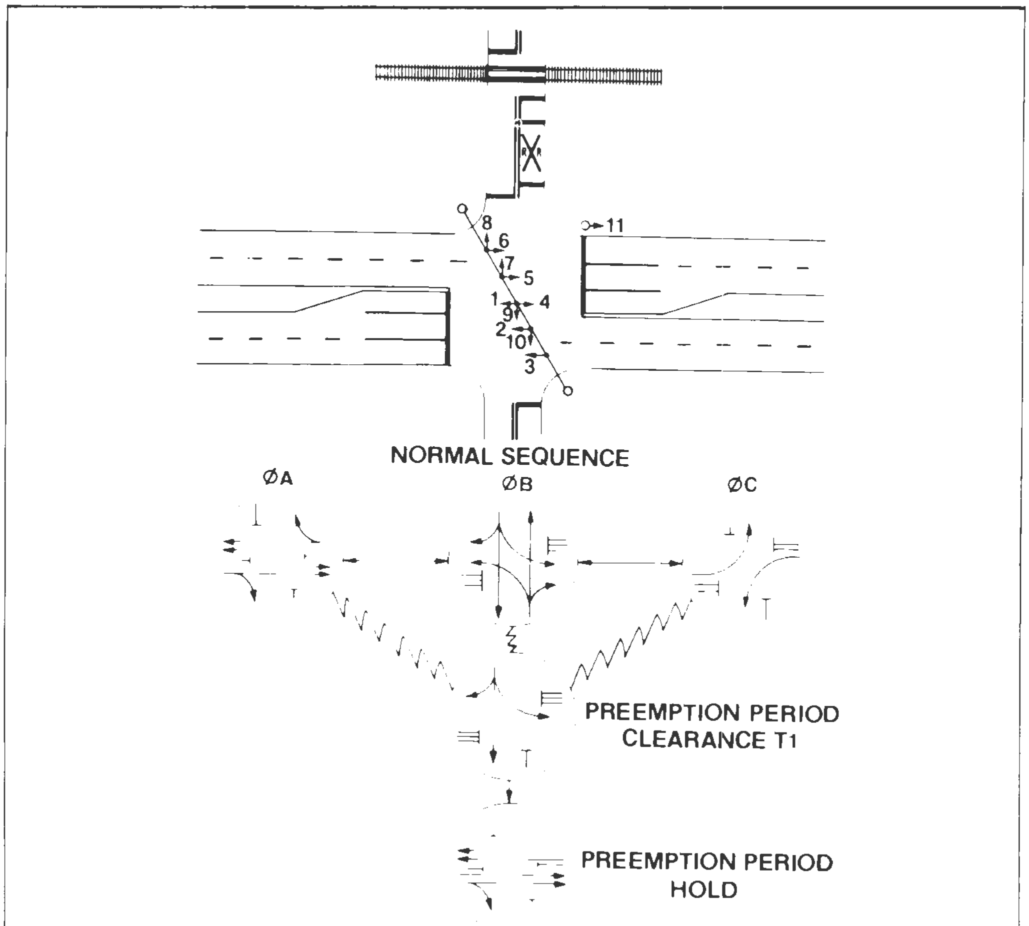
Figure 8-26 Typical Railroad Preemption Sequence, Railroad Crossing Between Two Signalized Intersections, Two Phase Operation with Pedestrian Signals



SIGNAL	ØA R/W	ØA CHANGE	ØB R/W	ØB CHANGE	ØC R/W	ØC CHANGE	PREEMPTION SEQUENCE ØA CHANGE	ØB CHANGE	ØC CHANGE	T.	T_2	HOLD	CHANGE	RELEASE
1	R	R	R	R	←	Y	R	R	Y	R	R	R	R	R
2	↑	Y	R	R	R	R	Y	R	R	R	R	R	R	↑
3	↑→	Y	R	R	R	R	Y	R	R	R	R	R	R	↑→
4	R	R	R	R	←	Y	R	R	←	←	Y	R	R	R
5	↑	Y	R	R	R	R	↑	R	R	↑	Y	R	R	↑
6	↑→	Y	R	R	R	R	↑→	R	R	↑→	Y	R	R	↑→
7,8,9,10	R	R	G	Y	R	R	R	Y	R	R	R	G	Y	R
11*	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	NO RIGHT TURN	BLANK
12*	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	NO LEFT TURN	BLANK

* OPTIONAL

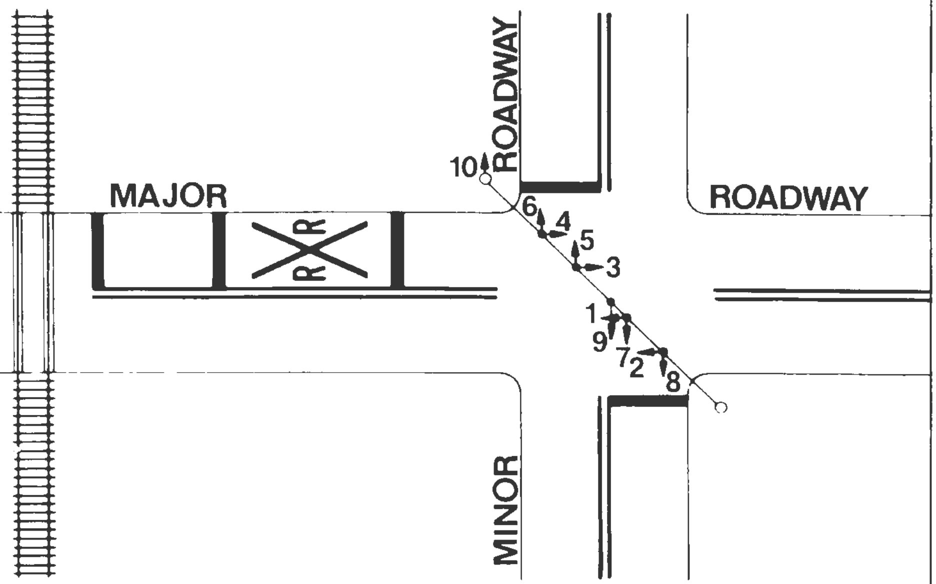
Figure 8-27 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Divided and 2 Lane Roadways with Railroad Crossing on Major Approach—Three Phase Operation



SIGNAL*	ØA R/W	ØA CHANGE	ØB R/W	ØB CHANGE	ØC R/W	ØC CHANGE	PREEMPTION SEQUENCE ØA CHANGE	ØB CHANGE	ØC CHANGE	T.	T	HOLD	RELEASE
1,4	R	R	R	R	←	Y	R	R	Y	R	R	R	R
2,5	↑	Y	R	R	R	R	Y	R	R	R	R	↑	↑
3	↑→	Y	R	R	R	R	Y	R	R	R	R	↑→	↑→
6	↑→	Y	R	R	R	R	Y	R	R	R	R	↑	↑→
7,8	R	R	G	Y	R	R	R	G	R	G	Y	R	R
9,10	R	R	G	Y	R	R	R	Y	R	R	R	R	R
"1"	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	BLANK

* OPTIONAL

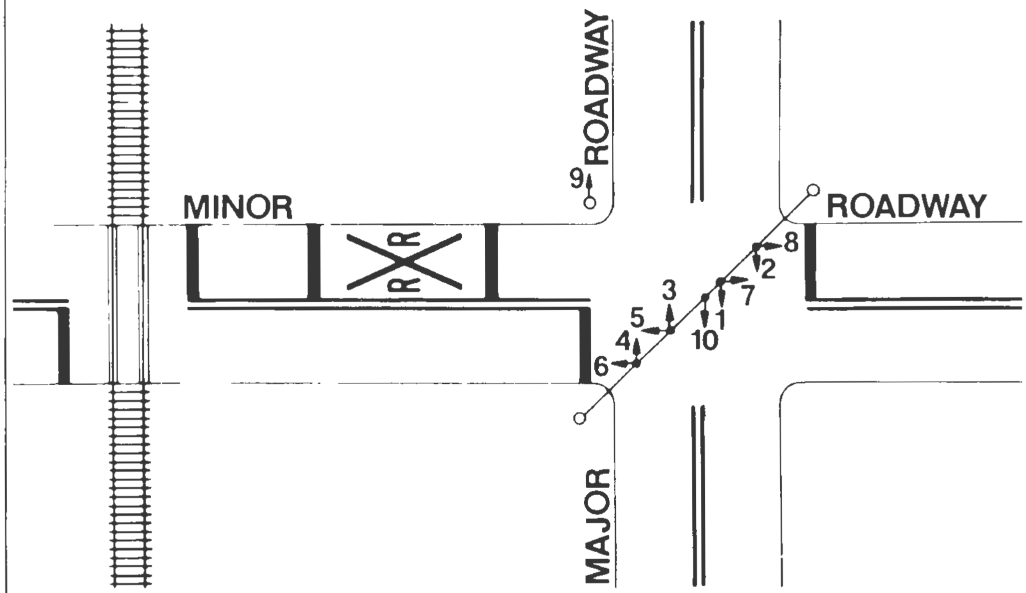
Figure 8-28 Typical Railroad Preemption Sequence, Signalized Intersection of 4 Lane Divided and 2 Lane Roadways with Railroad Crossing on Minor Approach Three Phase Operation



SIGNAL	NORMAL OPERATION	PREEMPTION SEQUENCE				
		CHANGE	T_1	T_2	HOLD	RELEASE
1,2	FY	FY	G	Y	R	FY
3,4	FY	Y	R	R	R	FY
5,6,7,8	FR	R	R	R	FR	FR
9*	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	BLANK
10*	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	BLANK

* OPTIONAL

Figure 8-29 Typical Railroad Preemption Sequence, Intersection with Flashing Beacon Control, Railroad Crossing on Major Approach



SIGNAL	NORMAL OPERATION	PREEMPTION SEQUENCE				
		CHANGE	T_1	T_2	HOLD	RELEASE
1,2,3,4	FY	Y	R	R	FY	FY
5,6	FR	FR	G	Y	R	FR
7,8	FR	R	R	R	R	FR
9*	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	BLANK
10*	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	BLANK

* OPTIONAL

Figure 8-30 Typical Railroad Preemption Sequence, Intersection with Flashing Beacon Control, Railroad Crossing on Minor Approach

effectively incorporates the crossing area into the width of the intersection. The yellow clearance interval should be extended accordingly to compensate for the added travel distance (Figure 8-31a).

Sometimes the grade crossing stop line is greater than 120 feet from the farthest intersection signal face which governs that approach. When this occurs, the faces should either be relocated to the near side of the intersection or supplemental faces should be used. This is accomplished more economically if box span wire assemblies or mast arms are employed at the intersection. Then, a separate span wire assembly may be used on the near side of the intersection (Figure 8-31b). To enhance the effectiveness of these alternatives, permanent right-turn-on-red prohibitions would be appropriate for the track approach with a STOP HERE ON RED sign (R10-6) installed at the stop line.

Optically programmable signal faces should be considered for the far side of the intersection for the track approach. View of these signal faces should be limited to that portion of the approach from the tracks to the intersection. The supplemental heads should operate in unison with the primary signals during normal conditions. Upon detection of an approaching train and after appropriate phase change intervals the programmable signal faces would display a green indication to clear the tracks while the primary signals would display a red indication in conjunction with the railroad flashing light signals to hold subsequent traffic at the crossing stop line.

When the distance between a grade crossing and a signalized intersection is approximately 150 feet or more and traffic volumes are such that vehicle queues routinely develop onto the tracks, the typical preemption strategies may not be capable of clearing the tracks within the normal warning time provided by the train detection circuit. One solution, lengthening the track detection circuit may not be feasible. Another option is to employ traffic control signals at the crossing in addition to the ones at the intersection. The additional traffic control signals are located on the intersection side of the railroad crossing and control the track approach only. (Figure 8-32)

A STOP HERE ON RED sign (R10-6) should be placed at the crossing stop line which also serves as the stop line for the traffic control signals. Using this option during normal signal operation, the exclusive signals would operate in coordination with intersection signals. For the track approach movements, a double clearance interval is provided to terminate green indications at the crossing signals prior to the termination of green at the intersection signals. In this manner, the two sets of signals effectively prevent queueing onto the tracks by not requiring vehicles to stop between the crossing and the intersection. Upon train arrival, the normal track clearance interval is dispensed with and red indications are displayed to hold traffic in advance of the crossing.

a. Relocated Stopline

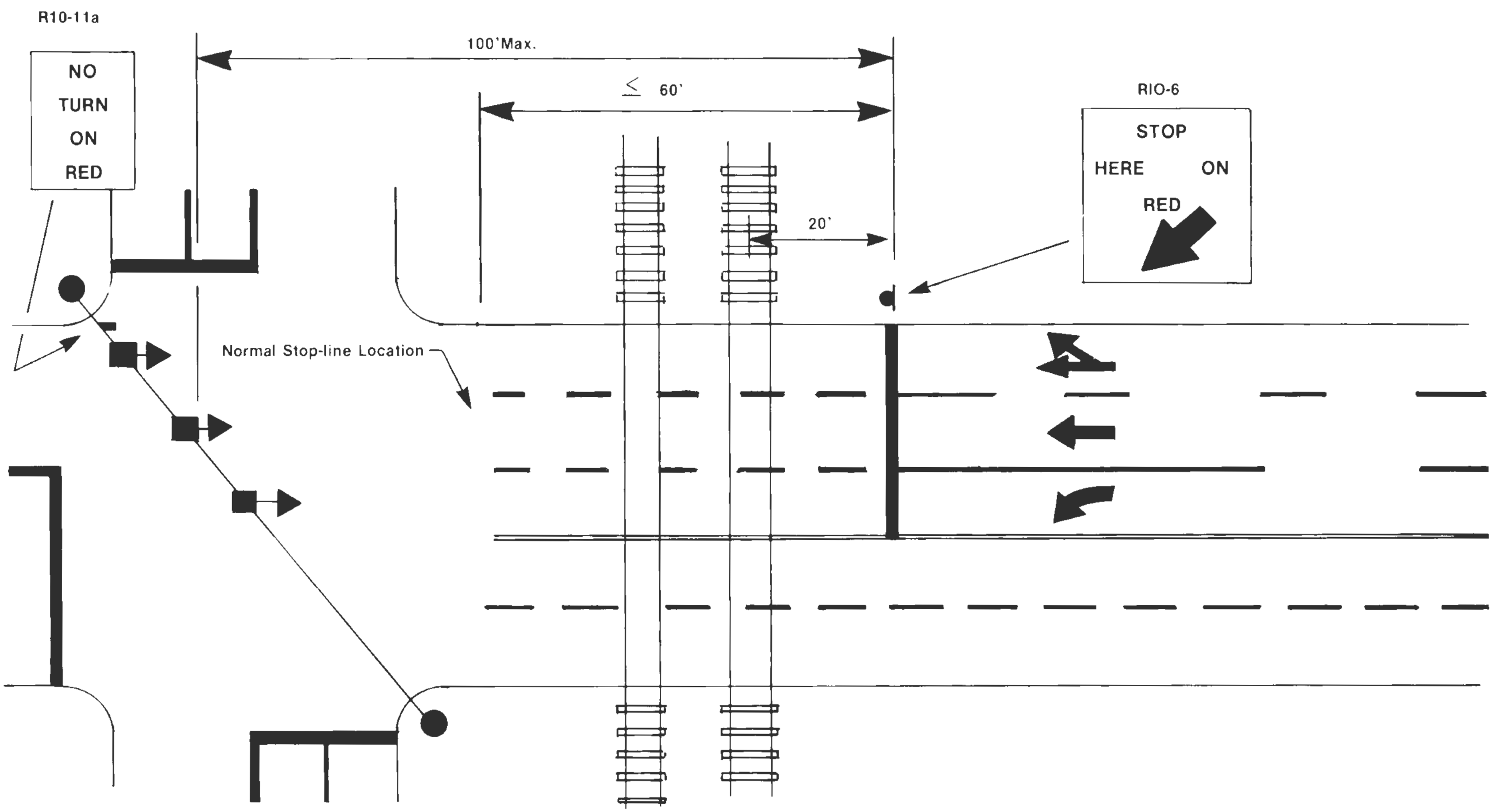
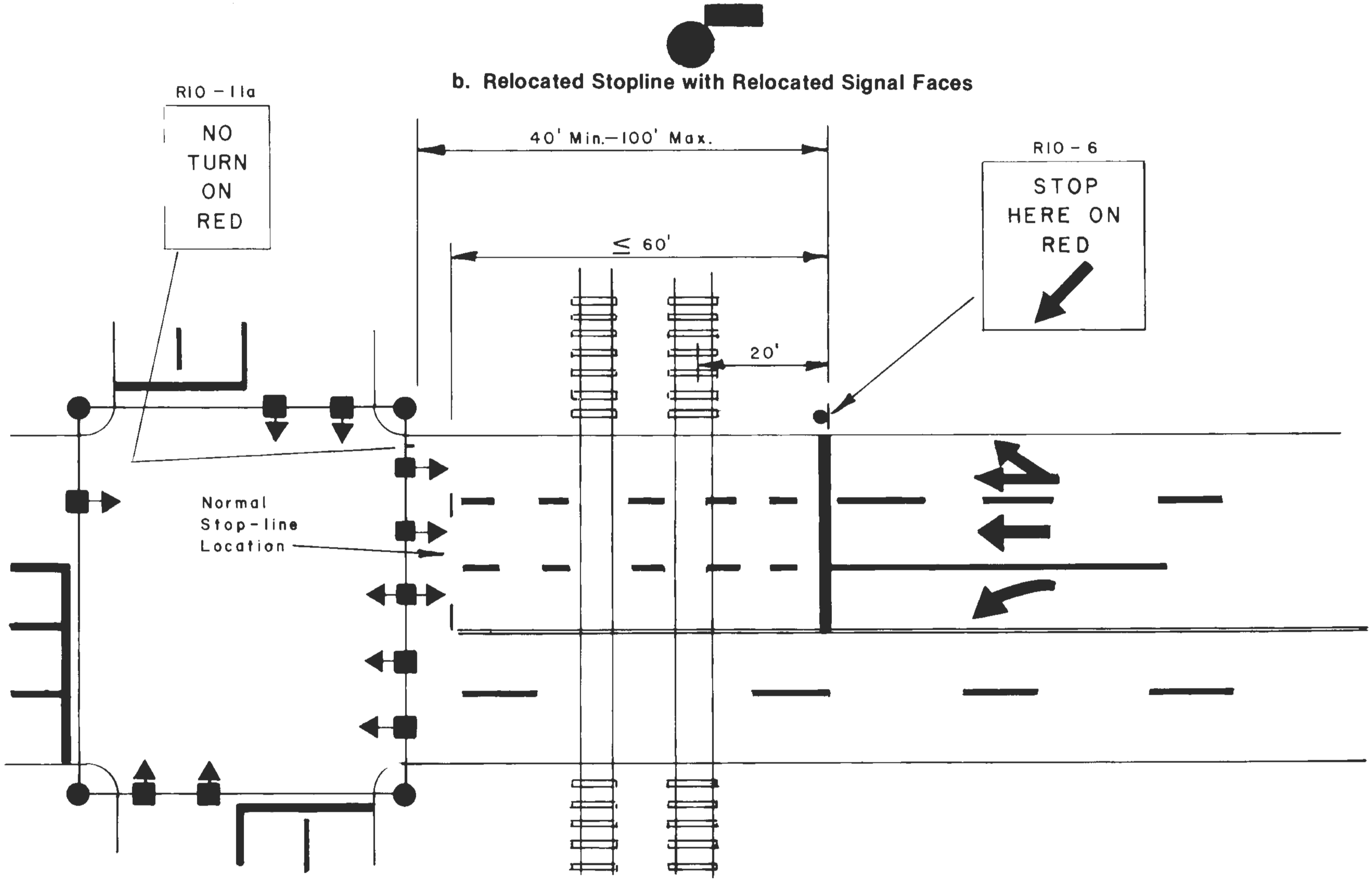
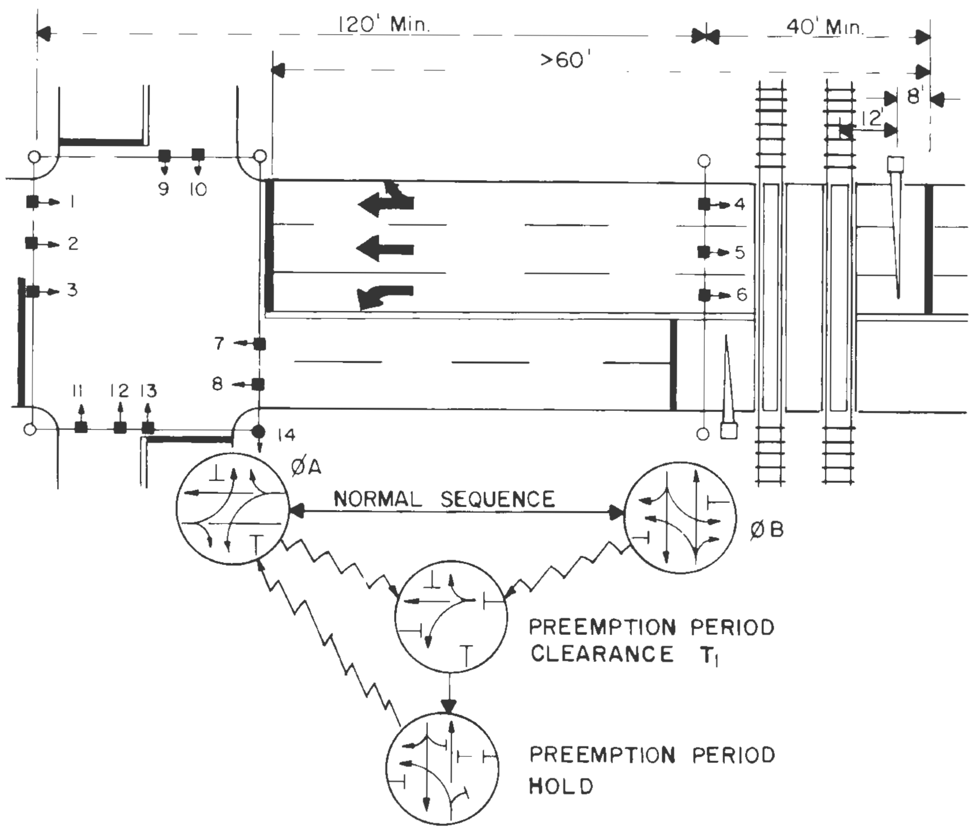


Figure 8-31 Relocation of Intersection Stop Line to Reduce Possibility of Vehicles Stopping On Tracks



b. Relocated Stopline with Relocated Signal Faces

Figure 8-31 Relocation of Intersection Stop Line to Reduce Possibility of Vehicles Stopping On Tracks



SIGNAL	ØA		ØB		PREEMPTION SEQUENCE						
	R/W	CHANGE	R/W	CHANGE	ØA CHANGE	ØB CHANGE	T_1	T_2	HOLD	CHANGE	RELEASE
1, 2, 3	G	Y	R	R	G	R	G	Y	R	R	G
4,5,6	G	Y	R	R	Y	R	R	R	R	R	G
7,8	G	Y	R	R	Y	R	R	R	R	R	G
9,10,11,12	R	R	G	Y	R	Y	R	R	G	Y	R
13	BLANK	BLANK	BLANK	BLANK	NO LEFT TURN	BLANK	NO LEFT TURN	NO LEFT TURN	NO LEFT TURN	NO LEFT TURN	BLANK
14	BLANK	BLANK	BLANK	BLANK	NO RIGHT TURN	BLANK	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	NO RIGHT TURN	BLANK

Figure 8-32 Use of Additional Traffic Control Signals At Crossing

Train Detection

The operation of a train activated active railroad-highway grade crossing control system depends on some form of train detection. The design, installation, and maintenance of active control systems are usually performed by railroad personnel.

On tracks where trains operate at speeds of 20 mph or higher, the MUTCD (Section 8C-5) requires that "circuits controlling automatic flashing light signals shall provide for a minimum operation of 20 seconds before arrival of any train on such track." It should be emphasized that this 20 second operation time is a MINIMUM. The length of operation of flashing light signals before arrival of any train should be extended beyond the 20 second minimum to ensure clearance of any vehicle which might have stopped at the crossing and then proceeded to cross just before the automatic flashing light circuit was energized. Factors which can affect this time include: width of the crossing (i.e., number of tracks to cross), acceleration capabilities of vehicles using the crossing, length of vehicles using the crossing, roadway grades, and the condition of the crossing surface.

Factors which must be considered in the design and installation of a train detection system include; existing rail and ballast conditions, volume and speed of highway and rail traffic, and other types of train detection circuits that may be in use on the same pair of rails for the control of train movements for other signaling purposes. In addition, train propulsion currents on electrified lines, track switch locations within the approach warning distances of a crossing, and train detection circuits used for other highway crossings within the approaches (overlapping) will affect the design at specific crossings. The application of train detection circuits requires the knowledge and participation of the railroad signal engineer.

Most train detection systems employ some type of electrical circuit that uses the rails as conductors in such a way that the presence of a solid electrical path as provided by the wheels and axles of a locomotive or railroad car shunts the circuit.

8B-3 Improvement Choices

Although an active warning device may be desirable from a safety standpoint for all grade crossings, this is realistically not feasible. Available funds should be used in a cost-effective manner to ensure the motorist is provided safe and efficient crossings.

Hazard Identification

Most organizations (generally a State highway department or public utility commission) use some type of priority ranking to identify crossings exhibiting the greatest need for improvement. The methods used to establish priorities vary considerably. One method is based on a 3-to 5-year accident history. Another method uses the traffic volume at the crossing factored by the accident history. Although different States may use a variety of factors in establishing their Hazard Index, most indices recognize that the most influential factors are vehicular traffic volumes, number of trains per day, and type of warning devices at the crossings.

A more detailed discussion of the data elements used by the various States is provided in "Criteria Used by State Highway Agencies to Determine Warrants and Priorities for Warning Devices at Rail-Highway Crossings" (Ref. 8–12).

The values of the various warning devices in reducing the hazard at crossings were developed by the California Public Utilities Commission (Ref. 8–14) and more recently by the U.S. Department of Transportation (DOT) (Ref. 8–13). The findings of the two studies are summarized in Table 8–2.

Two recently developed hazard index formulas are based on accident prediction models using a regression analysis. The first of these is a State-developed model (Ref. 8–15) which uses the sight triangle as one of the factors. The second of these newer methods was developed by the U.S. DOT (Ref. 8–16) and uses data available from the National Railroad-Highway Grade Crossing Inventory (Ref. 8–8, 8–9, and 8–10). An advantage in an accident prediction equation is that cost values can be more easily applied for evaluation. Further detail on ranking methods, both manual and computerized, are provided in Section 4 of the Railroad-Highway Grade Crossing Handbook (Ref. 8–5).

Upgrade Category	*U.S. DOT Findings* Effectiveness Factor (percent)	*U.S. DOT Findings* 95 Percent Confidence Interval (percent)	*1974 California Findings (percent)*
Passive to flashing Lights (1165)[1]	65	57–73	64
Passive to flashing Lights With Gates (985)[1]	84	80–89	88
Flashing Lights to Flashing Lights With Gates (844)[1]	64	56–71	66

[1] Indicates the total number of rail-highway crossings considered.

Table 8–2 EFFECTIVENESS FACTORS FOR UPGRADING CROSSING DEVICES

Many States use a hazard index as a tool to select a group of crossings that will be further analyzed as candidates for improvement. This group may also include problem crossings as identified by railroad companies, local governments, and other agencies.

The group of railroad-highway grade crossings identified as candidates for improvement, should be individually subjected to a thorough analysis of potential improvement alternatives. An on-site field review by a "diagnostic team" is an essential part of this analysis.

Improvement Alternatives

Crossing Elimination

The first alternative to be investigated for improvement of a grade crossing is whether or not the crossing can be eliminated by either removing the roadway or the railroad. The following discussion addresses the factors which may influence the decision to eliminate a crossing.

- Each railroad company operating over a candidate crossing should indicate their intent for future utilization of that section of track. If track abandonment is anticipated, roadway closure or any crossing improvements should be held in abeyance pending resolution of the track abandonment proposal.
- A roadway closure should not exert a negative impact on the local transportation system. Alternative public crossings should be within a reasonable travel time and distance. The alternate crossings and connecting roadways should have sufficient capacity to accommodate the diverted traffic safely and efficiently.
- No roadway crossing should be closed that serves as a direct route for vital traffic such as ambulances, fire trucks, or other emergency vehicles.
- The economic impact to existing or planned businesses located nearby should be considered.
- The accident experience or hazard potential for the crossing under study should be carefully evaluated. Items which should be reviewed include: number and severity of accidents, type and number of trains, train speed range, and time periods that the crossing is blocked by a train.

Criteria for identifying candidate crossings for closure must relate directly to existing operational and geometric characteristics. The number of vehicles using the crossing and the accessability of alternate crossings are significant criteria in determining whether the elimination of a particular crossing is practical. Although criteria and values differ among agencies, the following are some suggestions:

- Criteria for Crossings on Branch Lines
  - Less than 2,000 ADT
  - More than two train crossings per day
  - Alternate crossing within 0.25 miles with less than 5,000 ADT if two-lane, or less than 15,000 ADT if four-lane.
- Criteria for Crossings on Spur Tracks
  - Less than 2,000 ADT
  - More than 15 train crossings per day
  - Alternate crossing within 0.25 miles with less than 5,000 ADT if two-lane, or less than 15,000 ADT if four-lane.
- Criteria for Crossing on Main Lines
  - Any main line section with more than five crossings within a 1.0-mile segment.

The numerical values expressed above should be modified to reflect local conditions and policies. In this way, crossings of least value to the specific community can be identified.

An additional alternative for improvement, which includes closure, is railroad relocation and consolidation. Planning for such projects is complex and often controversial. Because of the widespread impact of railroad relocation, long-range plans for relocation and consolidation of railroads in urbanized areas should be reviewed prior to making any decisions relating to crossing improvement either through grade separation or through traffic control systems. Urbanized area transportation plans and railroad studies for mergers and consolidation are two sources of information which should be checked and analyzed whenever considering improvement alternatives.

Abandoned Grade Crossings

Federal safety regulations and State laws require buses carrying passengers and trucks transporting hazardous materials to stop at most railroad-highway grade crossings. The practice of leaving traffic control devices in place at abandoned crossings tends to reduce the credibility of similar devices at crossings currently in use.

Records of rail line abandonment hearings conducted by the Interstate Commerce Commission can be utilized to determine where crossings may be abandoned. However, before proceeding with any physical removal, confirmation of the abandonment should be sought from the former owner (if the company is still in business) and/or the State railroad regulatory agency. Even though a rail line has been identified as abandoned, it is possible that another railroad company or a subsidiary of the original owner may now be serving the line.

When it has been determined that a railroad track has been abandoned, all related traffic control devices including pavement markings should be removed, the track should be removed and the roadway restored to the appearance of a continuous section.

Also, there are numerous rail lines which are not being used by the railroads, but which have not been ruled officially abandoned by ICC action. It may be possible to close the unused grade crossings on these lines by paving over the tracks and removing the warning devices until such time as rail service might be resumed. Such an action would require an agreement between the appropriate highway agency and railroad. This has already been accomplished at unused crossings in several States. Highway authorities should solicit help in identifying unused crossings. Sources of help include the railroads, State and local police agencies, commercial bus companies, school bus operators, hazardous materials carriers, and local public officials.

Grade Separation

The optimum improvement to a grade crossing is separation of the railroad and highway grades. Although this alternative requires a large expenditure of funds, the benefits that may result include reduced highway congestion and motorist delay, and improved safety. The grade separation alternative should be considered specifically in the design of new highway routes, and in improvements to railroad facilities. Lines used for high speed railroad passenger service should have no grade crossings.

Traffic Control Devices

In the development of a grade crossing improvement program, each level of available traffic control should be given consideration. The choice of devices should be made on the basis of the anticipated reduction in accidents and casualties compared to the cost of the device plus its annual operating and maintenance cost. The operational effect on vehicular traffic and accidents can be stated in terms of cost. Benefit/cost ratios can then be computed for each level of traffic control.

In addition to traffic control devices, the improvement of the roadway surface across the track(s) can contribute significantly to the reductions of accidents at grade crossings. A motorist's concern for the roughness of the crossing, rather than the possibility of an approaching train or the warning message from traffic control devices, may distract a driver's attention to the extent that warning systems will be ignored. Grade crossing surface improvements will also add to the comfort and convenience of motor vehicle users at many locations.

Diagnostic Team

The final analysis and recommendation should not be made until a field review by a "diagnostic team" has been completed. As a minimum, this team should consist of a traffic engineer, a utility engineer, and a railroad signal engineer. Other members of the team could include representatives of the FHWA, highway design and maintenance agencies, and local government.

The diagnostic study team approach provides an excellent means of focusing the attention of all concerned agencies on a particular problem. Such an approach brings together representatives of the various agencies involved and immediately establishes lines of communication so that a functional system may be provided. The "diagnostic study team" is a somewhat sophisticated term used to describe a very simple procedure of utilizing experienced individuals from various agencies and disciplines, bringing their attention to bear on a common problem.

The primary factors to be considered in the assignment of people to the diagnostic team are first, that the team is interdisciplinary in nature, and second, that it is representative of all groups having responsibility for the safe operation of grade crossings.

In order that each of the vital factors relating to the operational and physical characteristics of the crossing may be properly identified, it is necessary that individual team members be selected on the basis of their specific expertise and experience. The overall structure of the team should be built upon three complimentary attributes (l) local responsibility, (2) administrative responsibility, and (3) advisory ability. The diagnostic team should have experience in the following areas:

- *Traffic operations* (Includes both vehicular and train traffic operation.) Knowledge of highway safety, vehicular and train volume, peak period characteristics, operating speeds, types of vehicles, and train class and length.
- *Signals* (Both railroad and highway signals.) Knowledge of grade crossing active traffic control signal systems, interconnection with adjacent signalized highway intersections, traffic control devices for vehicle operations, traffic control devices for railroad-highway grade crossings, and highway signs and pavement markings.
- *Administration*—It is important to recognize that many of the problems relating to grade crossing safety involve the apportionment of administrative and financial responsibility. This importance should be reflected in the membership of the diagnostic team. Members of the team representing the administration area should be carefully selected from policy making echelons of both highway department and railroad company management. The primary responsibility of these representatives is to advise the team of

specific policy and administrative rules applicable to any decision to modify or upgrade grade crossing traffic control devices. One of these members may well be the leader of the team.

To ensure appropriate representation on the diagnostic team, it is suggested that a team be composed of members chosen from the following:

- Traffic engineer with safety experience (desirable on all teams).
- Railroad signal engineer (desirable where active traffic control devices are involved).
- Railroad administrative official.
- Highway or street administrative official.
- Human factors engineer.
- Law enforcement officer.
- Regulatory agency official (where applicable).

The collection of physical data to support and supplement the diagnostic study of railroad-highway grade crossings may be classified into two categories, operational and site characteristics. Operational characteristics include the following factors:

- Train and vehicle speed, volume, types and distributions, including passenger trains and buses.
- Accident records.
- Signalization and signing.
- Adjacent roadway and railroad vehicle and train operations.

Site characteristics include the following factors:

- Road and track geometrics.
- Location of buildings, trees, and other structures near the crossing.
- Location of adjacent streets, roadways, and railroads.
- Topography of the immediate area.
- Population density.

The diagnostic team should study each crossing with a group review of all available data and a group inspection of the crossing and its surrounding area. The objective is to determine the conditions at the grade crossing which affect safety and traffic operations. The following list of items should be considered:

- Driver awareness.
- Visibility.
- Effectiveness of advance warning signs and signals.
- Geometric features of the roadway.
- "Repeat driver" regard for the crossing.
- Awareness of approaching trains.

- Driver dependence on crossing signals.
- Obstruction of view of train approach.
- Roadway geometrics diverting driver attention.
- Location of standing railroad cars or trains.
- Removal of sight obstruction.
- Availability of information for proper stop or go decisions.
- Pavement markings.
- Conditions conducive to vehicle becoming stalled.
- Other traffic control devices contributing to vehicles stopping on the crossing.
- Hazards presented by vehicles required by law to stop at the crossing.
- Signs and signals that are fixed object hazards.
- Opportunity for evasive action by driver.
- List major features of the crossing which contribute to safety.
- List features which reduce crossing safety.
- Suggest methods for improving safety at the crossing.
- Give an overall evaluation of the crossing.

When the diagnostic study of a crossing has been completed, the results and recommendations should be documented. Implementation of these recommendations should follow as soon as possible. The implementing step of the improvement process may require any of the following:

- Site Improvements—Removal of obstructions in the sight triangle, highway realignment, improved cross section, drainage, or illumination of the crossing.
- Crossing Surfaces—Rehabilitation of the highway structure, the track structure, or both; or installation of drainage and subgrade filter fabric.
- Traffic Control Devices—Installation of passive or active control devices, or upgrading of existing control system.

Recommendations should be forwarded through appropriate channels emphasizing that they are the result of a diagnostic team study.

Additional information on the role and activities of the diagnostic team is discussed in Section 4.5 of Ref. 8-5.

Program Development and Implementation

Program development is that portion of the total process concerned with selecting the specific improvement projects (including the type of improvement to be made along with the estimated cost of such improvements) to be included in a railroad-highway grade crossing improvement program. Program implementation is that portion of the total process concerned with making specific improvements at specific railroad-highway grade crossings.

Some method should be used to establish a priority ranking of crossings to be considered for improvement. The prioritizing of a crossing for improvement can either be done individually or using the corridor approach.

The corridor approach considers a number of crossings along a railroad line. Utilizing this method, the potential of improving the efficiency of railroad operations as well as highway operations may be considered.

The total program should include more projects than can reasonably be funded. This is to insure that substitutions can be made in the priority list following field evaluation of the crossings by a diagnostic team.

To aid in the programming of projects a resource allocation model (Ref. 8–6) has been developed to assist in making allocation decisions. The methodology, using a railroad-highway crossing accident prediction formula, warning system effectiveness, and cost parameters, provides a funding priority ranking of projects. On the State and local level it can be used to prioritize crossing projects and options by their benefit/cost ratio.

It should be emphasized that in the use of ranking procedures (i.e., hazard indices, resource allocation, etc.) that the algorithm does not dictate the final decision. These tools should be considered only as an aid to State and local officials and railroad management for making decisions. Local conditions, and the judgment of State and local officials, should play a major role in this evaluation process.

8C. OPERATIONS AND MAINTENANCE

8C–1 Operations

The operation of railroad-highway grade crossing traffic control systems is generally shared between the railroad and the public agency with jurisdiction over the roadway. The usual situation has the railroad responsible for all active and passive devices adjacent to the tracks, the crossing surfaces in and between the tracks, and maintaining sight distance along the tracks within the railroad right-of-way. The highway agency is generally responsible for the advance signs, signals, illumination, pavement markings, and the sight triangles outside of the railroad right-of-way. When active advance warning devices or traffic signal preemption is employed, these devices are the responsibility of the highway agency. Train detection and track circuitry for the detection devices is the responsibility of the railroad.

8C–2 Maintenance

The highway agency and the railroad company jointly occupy the right-of-way in the conduct of their assigned duties. Although maintenance of grade crossing traffic control devices and their circuitry is performed by railroad personnel, highway authorities share a concern about the quality of maintenance performed.

Usually, the railroad company maintains the crossbucks, bells, signals, gates, associated control equipment, and the crossing surface within the outer limits of the track structure. Highway agency maintenance responsibility includes all advance warning signs, illumination, pavement markings and the approach roadway. The preemption equipment for nearby signalized highway intersections is usually maintained by the highway agency with jurisdiction over that intersection.

Specific inspection intervals for proper maintenance of control devices at grade crossings are difficult to establish because of the wide variations in environmental and traffic conditions. In general, periodic nighttime inspection of signs, illumination, and pavement markings should be conducted. Any deficiencies should be immediately reported and scheduled for correction.

Because of the severity of rail-highway accidents when they occur, sign maintenance at or near railroad crossings should carry a high priority. The level of maintenance should be equal to or greater than that established for other forms of roadway signing. Vandalism and inadvertent damage or knockdowns are serious concerns. While choice of material and mounting technique can reduce damage from vandalism, damage caused by accidents is difficult to control. Frequent reviews by both railroad and highway personnel are necessary to assure that warning devices have not been vandalized or damaged.

It is essential that maintenance activities be coordinated between the railroad and the agency responsible for the roadway. Highway maintenance activities do not always require the presence of railroad personnel. The notable exception is when such activities take place on or in the immediate vicinity of the tracks. Conversely, railroad activities which involve the testing and operation of warning devices often require some form of highway traffic control.

To successfully coordinate these maintenance activities, an open channel of communication must be established between railroad and highway maintenance supervisors. Those supervisors and foremen responsible for maintenance should contact their counterparts prior to maintenance activities to agree on the scope and level of participation by each agency.

Traffic Control

Traffic control for railroad-highway grade crossing maintenance and reconstruction is very similar to traffic control for roadway construction and maintenance. The major difference is that the work area is in joint use right-of-way and the possibility of conflict exists between rail and highway traffic as well as the construction operations.

During track resurfacing or crossing reconstruction operations, requiring the entire crossing to be removed, the crossing should be closed and traffic should be detoured over an alternate route or temporary bypass. All traffic controls for crossing closures shall conform to the requirements for road closures in Part VI of the MUTCD. Crossings should not be closed on high volume rural and urban highways during week days or peak hours. Maintenance of crossings should not be performed during peak hours.

Traffic control for the construction of new crossings should be the same as that used for roadway construction and maintenance and shall comply with the applicable requirements of the MUTCD.

Figures 8–33 through 8–36 show typical applications of traffic control devices for railroad-highway grade crossing maintenance and reconstruction activities.

The following general notes apply to Figures 8–33 through 8–36:

- Dimensions may be adjusted to fit field conditions.
- All applicable requirements for traffic control in work areas set forth in the MUTCD shall apply to construction and maintenance of railroad-highway grade crossings.

- When numerical distances are shown for sign spacing, the distances are intended for rural areas and urban areas with a posted speed limit of 45 mph or greater. For urban areas with a posted speed limit of 40 mph or less, the sign spacing should be in conformance with the following table:

	Sign Spacing	
Speed Limit	X	Y
30 mph or less	300 ft.	200 ft.
35 mph or 40 mph	450 ft.	300 ft.

Table 8-3 Maintenance and Construction Sign Spacing for Urban Areas

- All construction warning signs should be mounted so as to be clearly visible to the motorist.
- Signs with specific distances shown shall not be used if the actual distance varies significantly from that shown. The word message AHEAD should be used in urban areas and in other areas where a specific distance is not applicable.
- Standard railroad crossing pavement markings are not shown in the figures for clarity.
- Additional traffic control devices other than those shown in the figures should be provided when roadway and traffic conditions warrant. These devices shall conform to the requirements of the MUTCD.
- Flaggers shall be in sight of each other or have direct communication at all times.
- All traffic control devices that are not applicable at any specific time shall be covered or removed or turned so as to not be visible to the motorist.

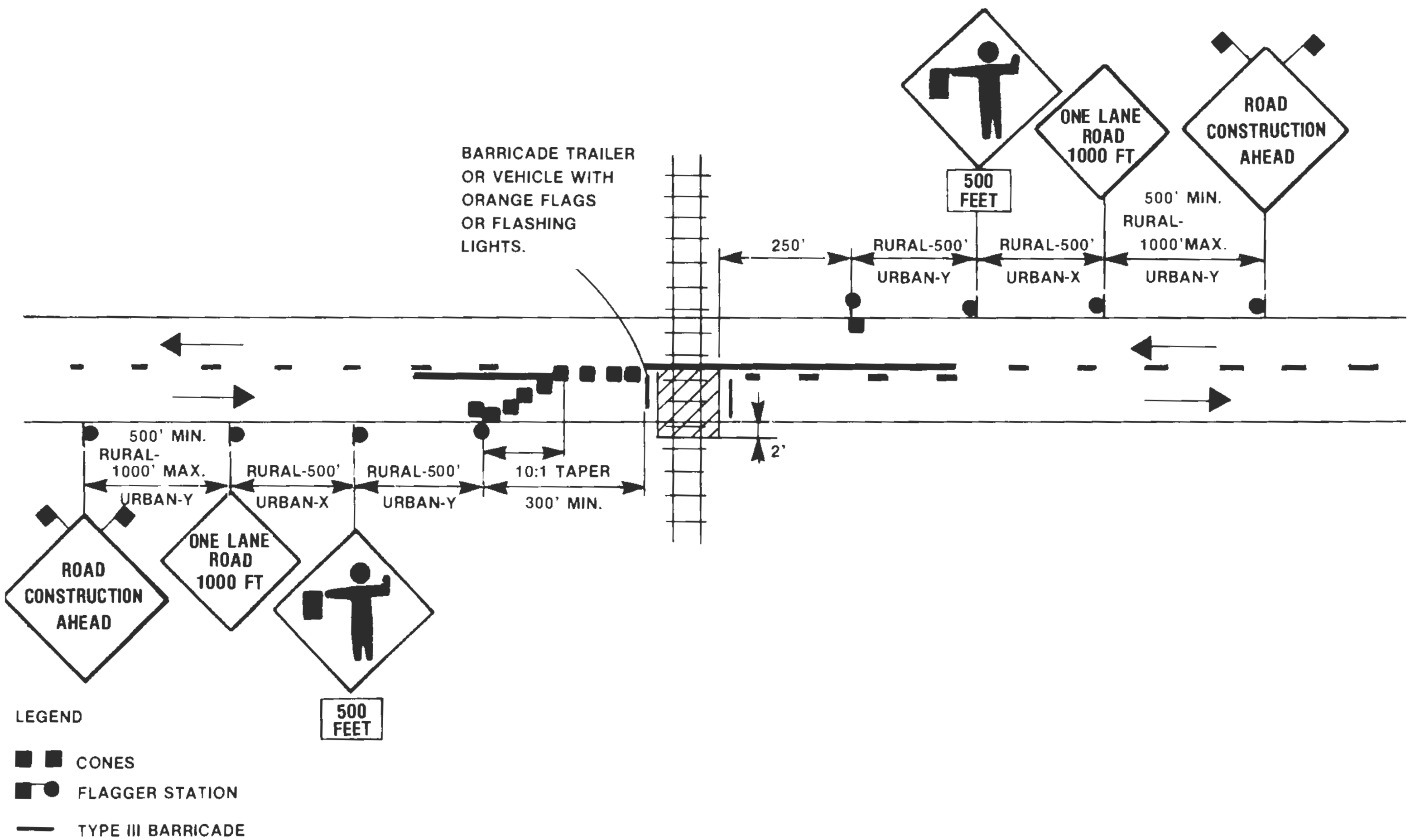


Figure 8-33 Work Activities, Railroad Highway Grade Crossing, Two Lane Highway, One Lane Closed

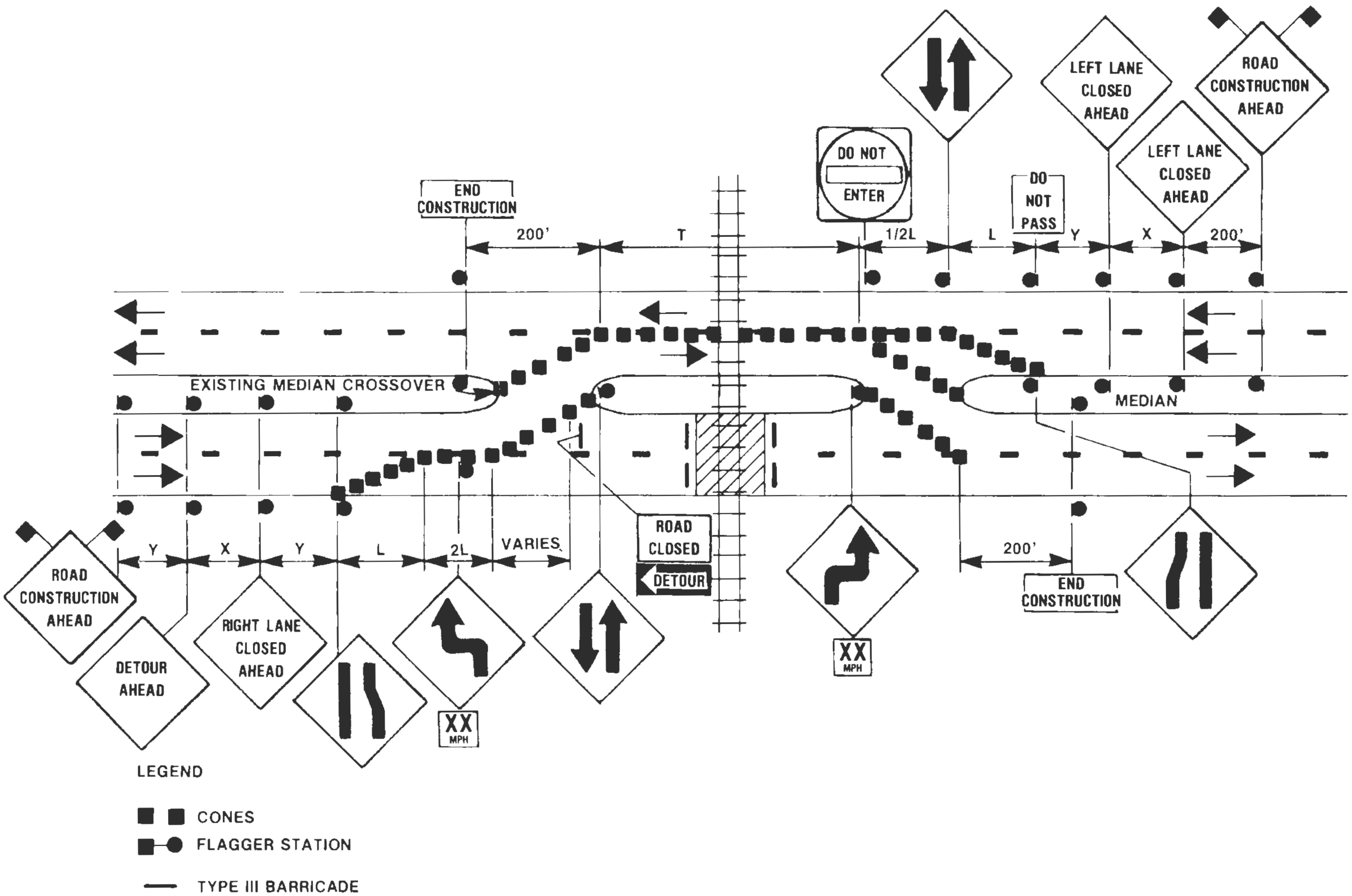
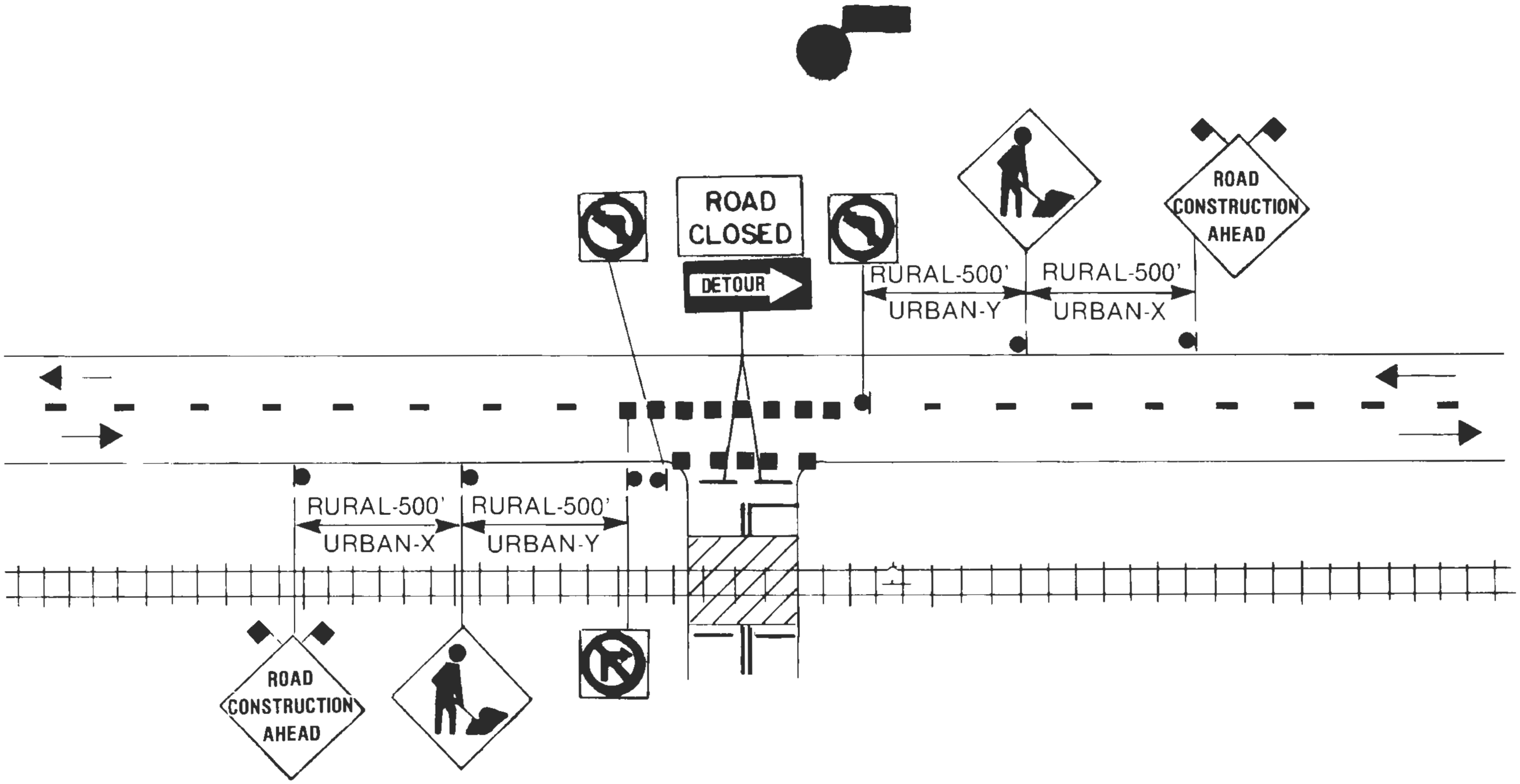


Figure 8-34 Work Activities, Railroad Highway Grade Crossing, Multi-lane Urban Divided Highway, One Roadway Closed, Two Way Traffic



LEGEND

CONES

FLAGGER STATION

TYPE III BARRICADE

Figure 8-35 Work Activities, Railroad Highway Grade Crossing, Closure of Side Road Crossing

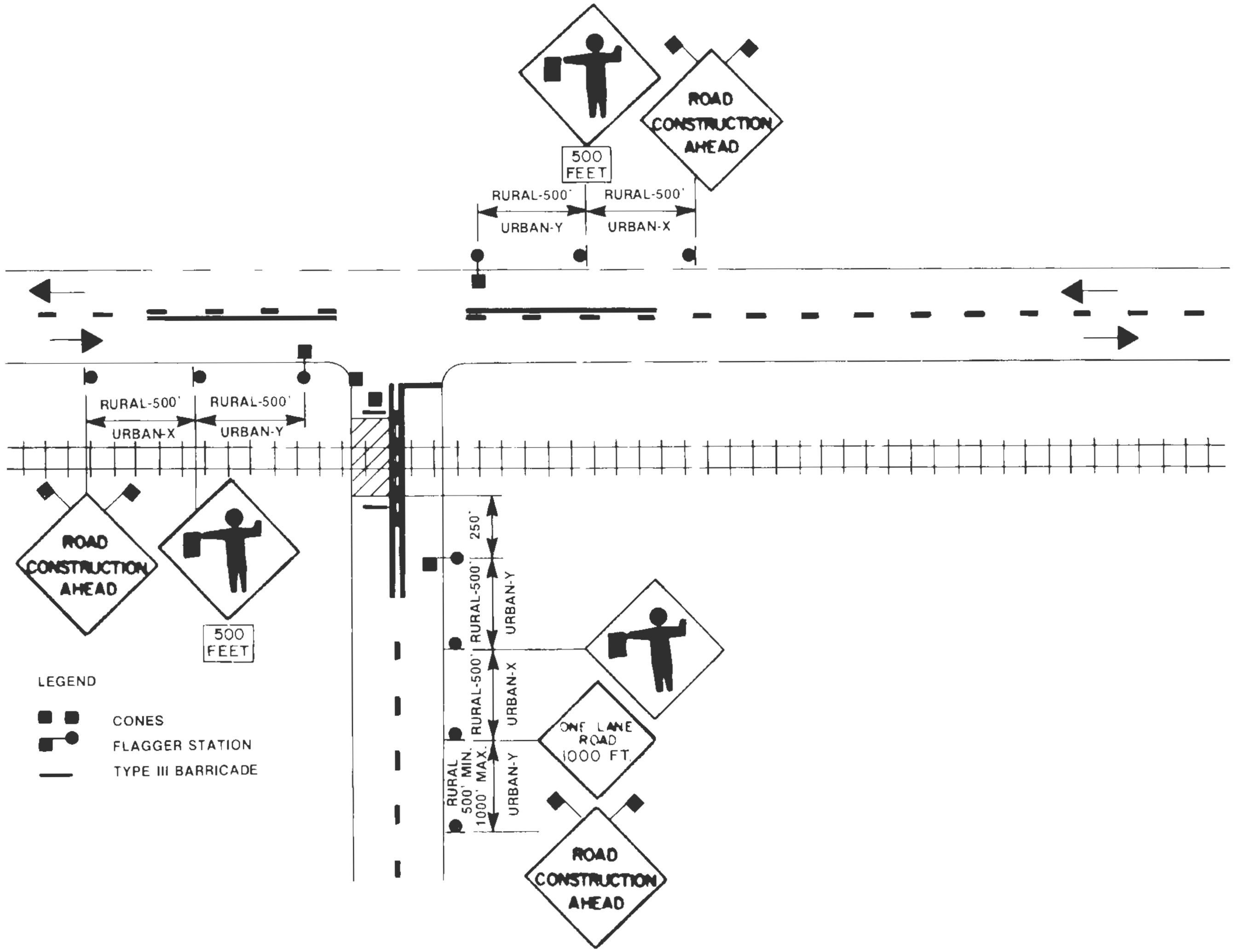


Figure 8-36 Work Activities, Railroad Highway Grade Crossing, One Lane of Side Road Crossing Closed

8D. OTHER CONSIDERATIONS

Many times, low cost improvements can be made at a crossing which will enhance motorist safety. Such improvements as removing obstructions from sight triangles, increasing drainage capabilities or illuminating the crossing, may be undertaken without excessive investment. Other site improvements such as highway realignment and changing the cross section are more expensive and must be weighed against alternative improvements. This section details considerations that should, and in some cases must, be made to permit safe and efficient operation of the grade crossing.

8D-1 Sight Distance

The primary objective in designing a grade crossing is to provide adequate sight distance for the motorist to make an appropriate decision as to whether to stop or to proceed. Also, when a vehicle, particularly a truck, is stopped at the crossing, a clear line of sight must be provided to insure that the vehicle will have adequate time to clear the crossing. The sight distance will be controlled by roadside sight obstructions, horizontal alignment, and vertical alignment.

Minimum Sight Triangle

Speeds of the two vehicles (train and motor vehicle) define the distances at which a driver must be able to see a train. Distances measured along the track and along the roadway establish a minimum sight triangle. Distances along the roadway must, as a minimum, be the safe stopping sight distance for a given approach speed. Distances along the track are those which result in a train, traveling a given speed, arriving at the crossing at approximately the same time as the motor vehicle comes to a stop.

As in the case of a highway intersection, there are several events which can occur at a highway-railroad grade intersection. These events are:

- The motorist moving at highway speed can observe the approaching train in a sight line which will safely allow the highway vehicle to pass through the grade crossing prior to the train's arrival at the crossing.
- The motorist can observe the approaching train in a sight line which will permit the highway vehicle to be brought to a stop prior to encroachment in the crossing area.
- The motorist has stopped and can observe the approaching train in a line of sight that will safely allow the highway vehicle to accelerate and clear the crossing prior to the arrival of the train.

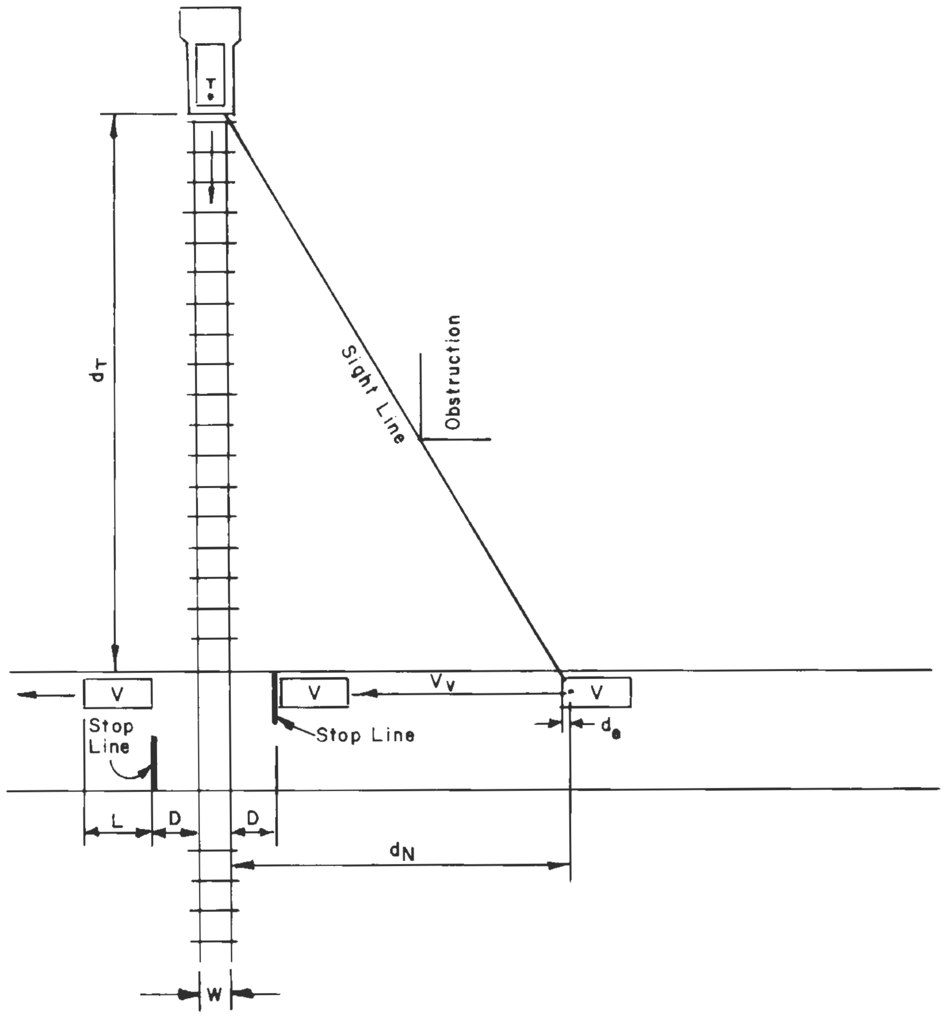


Figure 8-37 Sight Triangle, Moving Vehicle to Safely Cross or Stop at Crossing

The first two events are shown in Figure 8-37. The sight triangle consists of the two major legs, that is the sight distance (d_H) along the highway and the sight distance (d_T) along the railroad tracks. Table 8-4 indicates sight distance values for various approach speeds of the vehicle and the train. These distances are developed from two basic formulas:

$$d_H = 1.4667\ V_V\ t + \frac{V_V{}^2}{30\ f} + D + d_e$$

and

$$d_T = \frac{V_T}{V_V}\left(1.4667\ V_V\ t + \frac{V_V{}^2}{30\ f} + 2D + L + W\right)$$

Where:

d_H = sight distance along the highway for a vehicle to cross tracks safely even though a train is observed at the same instant, or to safely stop the vehicle without encroachment of the crossing area (feet).

d_T = sight distance along the railroad tracks to permit the same vehicle maneuvers as for d_H (feet).

V_V = assumed velocity of the vehicle (mph).

V_T = velocity of the train (mph).

t = perception/reaction time (sec.). This is assumed to be 2.5 sec.

f = coefficient of friction (Table 8-5).

D = distance from the stop line or front of the vehicle to the nearest rail (feet). This value is assumed to be 15 feet.

d = distance from the driver to the front of the vehicle (feet). This value is assumed to be 10 feet.

L = length of vehicle (feet). This is assumed to be 65 feet.

W = distance between outer rails (feet). For a single track this value is 5 feet.

When a vehicle has stopped at a railroad crossing, the next maneuver is to depart from the stopped position. It is necessary that the vehicle operator have a sight distance along the tracks which will permit sufficient time to accelerate the vehicle and clear the crossing prior to the arrival of a train, even though the train might come into view as the vehicle is beginning its departure process. Figure 8-38 indicates this maneuver. Table 8-4 contains various values of departure sight distance for a range of train speeds. These values are obtained from the formula:

$$d_T = 1.4667\ V_T \left[\frac{V_G}{a_1} + \frac{L + 2D + W - d_a}{V_G} + J \right]$$

Where:

d_T = sight distance along railroad tracks (feet).

V_T = velocity of the train (mph).

V_G = maximum speed of vehicle in first gear (assumed 8.8 fps).

a_1 = acceleration of vehicle in first gear (assumed 1.47 ft/s^2).

L = length of vehicle (assumed 65 feet).

D = distance from stop line to nearest rail (assumed 15 feet).

W = distance between outer rails (for single track, W = 5 feet).

J = Sum of the perception time and the time required to activate the clutch or an automatic shift (assumed 2 sec.).

d_a = distance vehicle travels while accelerating to maximum speed in first gear; or:

$$d_a = \frac{V_G^2}{2a_1} \quad \text{or:} \quad \frac{8.8^2}{(2)\,(1.47)} = 26.4 \text{ feet}$$

	Assumed Vehicle Speed (mph)							
	0	10	20	30	40	50	60	70
Train Speed (mph)	Distance (d_T) Along Railroad From Crossing (ft.)							
10	240	145	105	100	105	115	125	135
20	480	290	210	200	210	225	245	270
30	720	435	310	300	310	340	370	405
40	960	580	415	395	415	450	490	540
50	1200	725	520	495	520	565	615	675
60	1440	870	620	595	620	675	735	810
70	1680	1015	725	690	725	790	860	940
80	1920	1160	830	790	830	900	980	1075
90	2160	1305	930	890	930	1010	1105	1210
		Distance (d_H) Along Highway From Crossing (ft.)						
		70	135	225	340	490	660	865

NOTE: All calculated distances rounded up to next higher 5-foot increment.

ASSUMPTIONS: Sixty-five foot truck crossing a single set of tracks at 90°; flat terrain. Adjustments should be made for unusal vehicle lengths and acceleration capabilities, multiple tracks, skewed crossings, and grades.

Table 8-4 Required sight distance for combination of highway and train vehicle speeds.

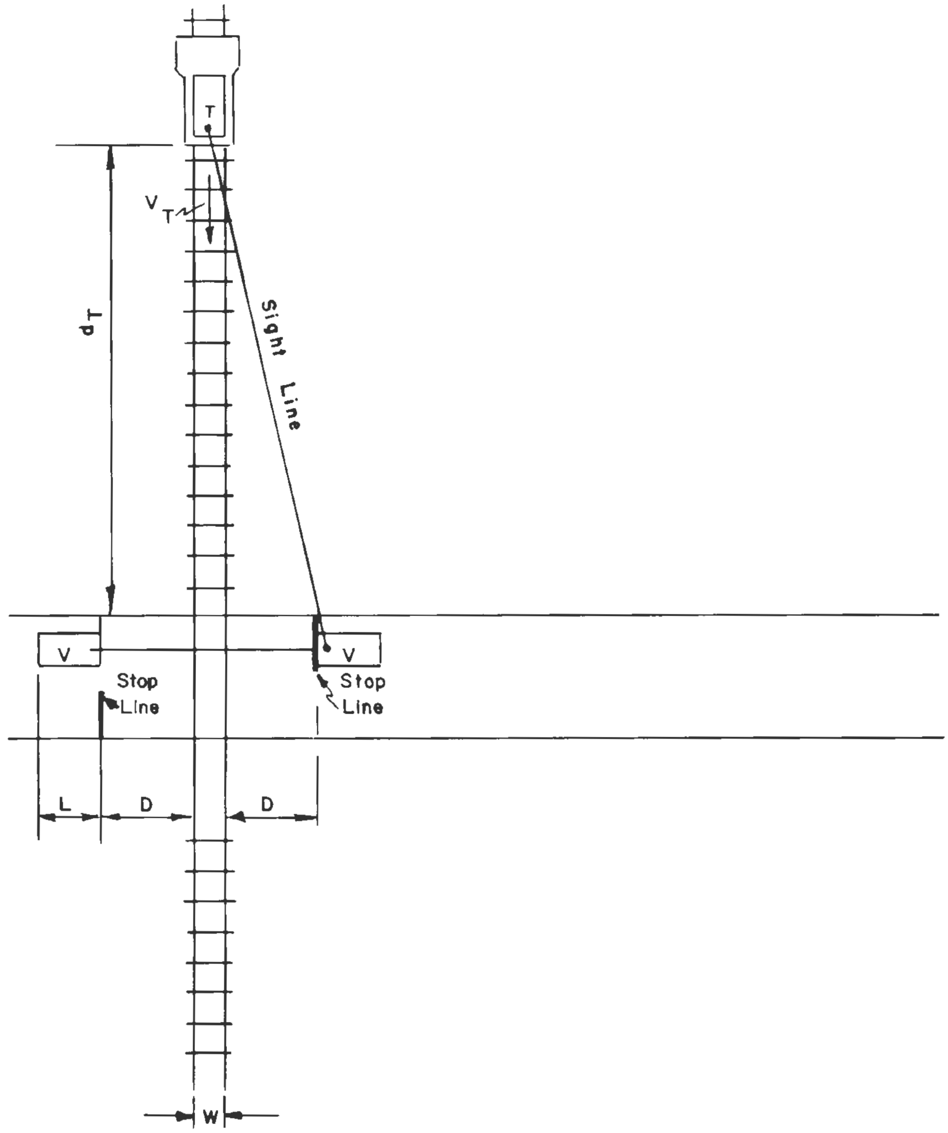


Figure 8-38 Sight Triangle, Stopped Vehicle to Cross Single Railroad Track

Adjustments for skew crossings and for other than flat highway grades are necessary. The formulas in this section may be used with proper adjustments to the appropriate dimensional values.

In the event that it is impossible to achieve the minimum sight triangle, consideration should be given to the installation of active crossing devices.

Speed (mph)	f
10	0.40
20	0.40
30	0.35
40	0.32
50	0.30
60	0.29
70	0.28

Table 8-5 Coefficents of Friction

Obstructions

On the approaches to rail-highway grade crossings an area for railroad related devices should be established and maintained. This area should extend longitudinally along both approaches to the crossing. Where possible, all other roadside appurtenances such as highway signs, utility poles, and lighting poles should be located in advance of, or beyond, this area. In this manner the information presented to the approaching driver is limited to railroad warning and controls; thus, enhancing the conspicuity and effectiveness of these devices.

Obstructions in the sight triangle in any of the four quadrants can result in restricted sight distance for at least one approach roadway. If such obstructions are vegetation or other natural features, they should be removed. It may not be feasible to remove other obstructions such as buildings. If such is the case, other alternatives are available.

The first alternative, is the installation of active crossing devices. Another alternative is to reduce motor vehicle speeds, through the use of regulatory or warning signs, to a level which conforms to the minimum sight triangle available. However, this reduced speed should generally not be less than 20 mph. The speed restriction may only be required in one direction depending on the quadrants in which sufficient sight triangles cannot be established. The use of signing to reduce speeds should be limited to crossings with low exposure rates. These crossings should be monitored on a regular basis to ensure speed reductions are adequate.

When severe sight restrictions are encountered, such as in heavily industrialized areas, STOP signs can be considered as an alternative.

However, STOP signs at railroad-highway grade crossings shall be used only in accordance with MUTCD warrants.

Prior to taking any action beyond reestablishing an adequate sight triangle by removing vegetation or other natural features, it is desirable to conduct an engineering study of the location by a diagnostic team as discussed in Section B of this Part.

Situations can arise where active crossing devices are necessary. However, due to the horizontal and vertical alignment of the highway, there is not sufficient sight distance for motorists to properly respond. Although such cases may be rare, proper treatment is important. Where conditions are such, that neither the minimum sight triangle nor stopping sight distance to the active devices is attainable, flashing yellow beacons may be added to the advance warning sign. Active advance warning signs are discussed in Section B of this Part.

8D–2 Geometrics

The horizontal and vertical alignment of a highway at a grade crossing are usually determined by railroad conditions and availability of highway right-of-way. Highway designers attempt to locate the highway centerline perpendicular to the track centerline. However, for a variety of reasons, many skewed crossings and crossings on curves have been constructed; and in some cases it has been necessary to construct crossings where both the highway and track are on curves. This latter situation produces poor rideability for highway traffic when either the track or highway radii require superelevation.

Horizontal Alignment

A grade crossing is an intersection of two carriers which have differing operational characteristics. This fact must be kept in mind when planning improvements. Horizontal alignment should permit drivers to operate their vehicles at posted speeds without unexpected intersections with railroads or other highways. Good geometric design requires:

- Elimination of sharp curves near an intersection,
- Right angle crossings whenever possible,
- Where skewed crossings are required the angle of skew should be minimized.

Site improvements may require purchase of additional right-of-way. Relocation of one or both traveled ways may be required. The total cost and benefits of such improvements must be compared with the cost and benefits of installing active control devices.

Vertical Alignment

Careful consideration should be given to revising grades on both the highway and the railroad, to improve sight distance, approach characteristics, drainage, and intersection conditions. Wherever possible, approach grades should be relatively flat. If vertical curves are required, they should be as long as necessary to insure a good view of the crossing. Once again, speed, sight distance, and the elimination of unexpected conflicts with railroad traffic are the prime considerations.

Cross Section

Requirements for the cross section of the highway at grade crossings differ little from that for highway intersections. Detailed design requirements are contained in "A Policy on Geometric Design of Rural Highways" (Ref. 8-3). A few important considerations are:

- The cross section should be designed to ensure that the driver always has some escape route available.
- The pavement surface adjacent to the track should be at the same elevation as the track. This will often require warping the pavement from its normal cross slope to a plane even with the track. When such warping is required the rate of change in elevation of the pavement edges should not exceed those rates shown in Table 8-6.

Design Speed (mph)	Distance Required for 1.0-foot Change in Elevation (feet)
40	175
50	200
60	225
70	250
80	275

Table 8-6

8D-3 Drainage

Drainage requirements of grade crossings would be satisfied through good highway and railroad design and maintenance practices. However, drainage problems frequently arise. Slope and ditch maintenance and debris removal should always be included in maintenance activities around railroad-highway grade crossings. Also subgrade drainage is often required when highway construction blocks normal ballast and side ditch drainage along the railroad.

8D-4 Illumination

The lighting of a grade crossing can be effective in reducing nighttime accidents. Illuminating most crossings is feasible since commercial power is available at approximately 90 percent of all public crossings. The decision to illuminate a crossing should be made only after an engineering analysis of crossing conditions has been completed. Illumination may be effective under the following crossing conditions:

- Substantial nighttime train operations,
- Train speeds are low,
- Crossings are blocked for long periods,
- Accident history indicates motorists have difficulty in detecting the train or grade crossing control devices at night,
- Poor alignment of roadway approach so that the vehicle headlight beam does not fall on the train, or
- Low ambient light levels.

Recommendations for the placement and type of luminaires are available in the AASHTO Lighting Guide (Ref. 8-20) and from the Illuminating Engineering Society's "American National Standard Practice for Roadway Lighting" (Ref. 8-21).

On uncurbed roadways, luminaire supports should be erected as far as practical from the traveled way (20 feet is desirable). On curbed roadways, 4 feet from the curb is desirable, 2 feet is minimum. When located within the clear zone defined in the "Guide for Selecting, Locating and Designing Traffic Barriers," (GSLDTB) (Ref. 8-19), luminaire supports should have breakaway bases. If possible, luminaires should also be located to insure damaged poles will not fall on the tracks.

The luminaires should be carefully positioned to ensure that the motorist or railroad operator is not subjected to glare from the light source. If glare cannot be eliminated, cutoffs should be provided to shield the cone of vision of the motorist or train operator. In rural areas with high train speeds, some lighting should be directed down the tracks to illuminate the sides of an approaching train. Trains and grade crossing devices should not be backlighted.

Train-activated illumination circuitry can be designed, but should not be used as a substitute for active control devices. Whether the illumination should be activated by an approaching train or should operate continuously during the night depends upon the characteristics of the individual crossing.

8D-5 Barriers

The use of barriers with grade crossing control devices is generally discouraged. The purpose of a longitudinal barrier, such as guardrail, is to protect the motorist (by containing and redirecting the vehicle), not the traffic control device. Their use should be limited to situations where hitting the object (i.e., control device) is more hazardous than hitting the guardrail and possibly redirecting the vehicle into a train. The following general guidelines reflect some of the limitations and criteria for the use of barriers.

- Longitudinal guardrails should not be used for railroad traffic control devices unless the guardrail is otherwise warranted, as for a steep embankment. The reason for not using longitudinal guardrail is that it might redirect a vehicle into a train.
- The round guardrail installations used by some railroad companies create the same type of hazard to the driver as the signal mast (only a larger one). They do, however, serve to protect the signal mast. Since functioning warning devices are vital to the safety of highway grade crossings, the round guardrail may be used in locations of heavy industrial traffic (trucks). Their use should be limited to low speed roadways.
- When installing guardrail around two adjacent masts (flashing lights and gates). The guardrail should be installed according to the requirement of the GSLDTB.
- On some crossings it may be possible to use crash cushions to protect the motorist from the hazard of the railroad traffic control devices. As crash cushions are designed to capture rather than redirect a vehicle, they will not normally redirect a vehicle into a train.

8D-6 Crossing Surfaces

It is important that each grade crossing be provided with a surface suitable for its situation, consistent with overall economic considerations. Of the materials most commonly used in constructing grade crossings, bituminous surfaces have the lowest initial cost and are entirely suitable for those situations where highway traffic is light and where the riding quality of the bituminous crossing can be maintained. By contrast, a crossing constructed with one of several types of manufactured crossing surfaces, although much higher in initial cost, will provide superior riding quality for high speed and high density vehicular traffic. If the original installation of a manufactured crossing surface is made on a well prepared track structure with good subgrade conditions a minimum of maintenance is generally required. Panel-type crossings can be removed and replaced to permit periodic track resurfacing work, while bituminous crossings must be torn up and reconstructed when track resurfacing is performed. The additional cost of a proprietary crossing surface may well be warranted by the longer life of the material, lower maintenance costs, superior riding quality, or a combination of these features. Materials used in manufactured panels include treated timber, concrete, steel, rubber, and polyethylene. Some of the products are patented.

There are considerable variations in the application of the several materials in the construction of railroad-highway grade crossings. Generally each of the manufactured products has some unique features. Under the combination of circumstances existing at a specific grade crossing, one or another of its unique features may make a particular manufactured product the most suitable. Under another set of circumstances, another product may be uniquely suitable. However, at many crossings there are no particular circumstances that make one product a better choice than any of several others.

Regardless of the type of surface material used, adequate preparations of the track structure and the subgrade, including adequate drainage, is essential. For a detailed discussion on crossing surfaces see "Railroad-Highway Grade Crossing Surfaces." (Ref. 8-7)

8D-7 Driver Education

Nearly all grade crossing accidents involve some degree of driver error. One of the objectives of driver education is to impart the knowledge, skills, habits, and attitudes to enable a driver to perform in a manner that will minimize the probability of his causing or being involved in a traffic accident. Education can be divided into three parts: General Public Education, Driver Education, and Elementary School Education.

Over the years there have been many programs aimed at educating the public about the inherent hazards of grade crossings. To be successful, a public education effort must be carefully planned and executed and aimed at the driving public via the most attractive media possible. The messages should be presented in prime time, and in the most popular magazines and newspapers. The highest public officials should endorse and support a public information campaign. The campaign should be coordinated with other traffic safety messages and activities of the State or local communities. Above all, the messages should be positive and informative, with the crossings depicted as dangerous, but necessary.

Driver education is an area that has considerable potential for improving crossing safety. Unfortunately, as presently taught, driver education does not increase the driver's safety potential with respect to grade crossings. The instruction generally consists of teaching recognition of the standard railroad grade crossing signs and pointing out the legal requirement to stop at a flashing light signal or barrier. At the very least, a student driver should traverse a grade crossing as part of his behind-the-wheel training.

8D-8 Enforcement

Law enforcement, in the broadest sense of the term, has often been cited as one means of improving grade crossing safety. Law enforcement agencies and associations recognize their potential, and many have taken an active interest in promoting grade crossing safety. However, these law enforcement practices throughout the Nation vary widely, ranging from excellent programs to total inattention.

Accident data have shown that a majority of drivers involved in grade crossing accidents are familiar with the crossing at which the accident occurred. It seems that in spite of a driver's perception of a potential hazard at a grade crossing, a habit of inattention develops after repeated crossings without the presence of a train.

Enforcement can positively affect driver safety potential at grade crossings, but analysis is required to determine whether the benefits justify the costs. The expense of increased patrols, especially at high accident locations, might be cost-effective, since accident data show the frequency of collisions to peak at the times of the greatest commuter traffic. Police patrols could effectively cover a number of high accident locations at peak traffic periods.

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Part IX. TRAFFIC CONTROL DEVICES FOR BICYCLE FACILITIES

PART IX
Bicycle Facilities

Part IX.

TRAFFIC CONTROL DEVICES FOR BICYCLE FACILITIES

9A. GENERAL

It is apparent from national, State, and local accident statistics that there is a critical need to provide safe and convenient bicycle facilities for the growing number of bicyclists on the Nation's roadways. This requires careful consideration of planning, engineering, education, and enforcement criteria applied to a wide range of local conditions and specific site characteristics. A prime element in providing a safe bicycle environment is the application of uniform traffic control devices.

Bicycle facilities are unique in that they must accommodate a wide assortment of users of different ages, skills, educational levels, and attitudes. Furthermore, these users operate their vehicles for different type trips in a mixed traffic stream (e.g. cars, trucks, buses, pedestrians, etc.) This problem is compounded by the nonuniformity of roadway and bikeway design, the number and quality of educational and enforcement programs in use, and the variations in codes and laws.

This part of the Handbook addresses the design, placement, operation, and maintenance of traffic control devices used for bicycle facilities.

9A-1 Characteristics and Needs of Bicyclists

Trip purposes for the bicycle mode of transportation are as varied as the differences among the bicyclist's abilities. In general, bicycle trip purposes can be divided into two broad types, utilitarian and recreational. The primary objective of a utilitarian trip is simply reaching a specific destination quickly with few interruptions. From a functional standpoint, the utilitarian trips are predominantly used for the following trip purposes:

- Commuting to and from work
- Travel to and from school
- Shopping and short errands

On the other hand, a recreational trip is riding for pleasure. The destination is not the primary objective. Recreational trips can be grouped as either or both of the following:

- Touring
- Exercise

These trip purposes do not necessarily define the personal traits of the bicycling population nor the type of traffic control devices that are required. Rather, understanding the differences among bicyclists' abilities and purposes for riding are an important element of locating and designing a bicycle facility that is responsive to the users' needs. Whether a specific facility primarily serves the utilitarian or recreational bicyclist, there is a wide variation in the characteristics of the people who use it. This diversity in user characteristics creates a number of problems in determining the type, physical requirements, and operations of traffic control devices for bicycle facilities.

The bicycling population includes a broad range in age, physical ability, skill, experience, judgment, attitude, and knowledge. Many of these characteristic differences are primarily a function of the age of the user.

The very young bicyclists have little knowledge of rules of the road and little or no experience involving traffic judgment. Their motor skills, necessary to propel and control a bicycle, are not fully developed. In many cases, children are operating bicycles too large for their small stature.

At the other end of the age spectrum is the senior citizen who may be mature in knowledge and judgment, but whose motor skills may be impaired by age. People in this age group may be unsure of their ability to maneuver in the traffic stream.

One other extreme is the highly sophisticated bicyclist. They often use specially designed equipment and are secure in their physical and judgmental skills. They are confident that they can successfully maneuver in all types of traffic situations and are often opposed to traffic control directed specifically to restricting bicycle operation. They generally prefer to abide by the rules and regulations for motor vehicles as they feel able to compete effectively for their share of the roadway.

There remains a large body of bicyclists in between these extremes. This group cannot be easily defined in terms of levels of skills, judgment, attitudes, experience, and physical capabilities. Due to this high variance in user characteristics, the application of traffic control devices should be based on the standards and recommendations provided in the MUTCD, on local knowledge of the site, and engineering judgment. The objective is to provide the highest level of safety consistent with the characteristics of bicyclists using a particular facility.

9B. APPLICATION

9B-1 Signs for Bicycle Facilities

Signs which provide information, warnings, etc., to both the motorist and the bicyclist should conform to the criteria specified in the MUTCD, Part II, Signs. When signs are intended exclusively for bicyclists they may be smaller in size than those intended for motorists since the operating speed of bicycles is usually below the speed of motor vehicles. Consequently, more time is available to the bicyclist to see and comprehend the bicycle sign message.

In terms of placement of signs, bicycle signs are normally placed on the right hand side of the bicycle facility. They should be placed within the cone of vision of a typical bicyclist, but offset sufficiently to the right (lateral clearance) so that the sign does not present a physical obstruction or hazard to bicyclists or pedestrians.

In urban areas bicycle route signs are usually spaced 350 to 500 feet apart to provide a continuous guide to the bicyclist. In rural areas, they may be spaced up to 1,000 feet apart. On the approaches to major rural intersections, bicycle signing should be provided to clearly define the bicycle route.

Over the years, many agencies have attempted to provide signing for bicyclists. As standards had not yet been established, these well intentioned efforts have resulted in a variety of bicycle related signs. Now that standards have been established, these older signs are nonstandard signs and should be replaced with conforming traffic control devices. With the increase in the number of bicyclists (and bicycle related accidents), the need for consistent application of uniform standards is becoming more crucial. Local policies, standards, and guidelines should be developed or revised so as to be in compliance with the MUTCD. Uniformity and consistency in application within a local area are highly desirable with national uniformity an appropriate long-term objective.

Sign Height

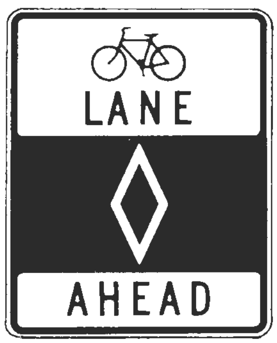
Section 9B-2 of the MUTCD states that "where signs are to serve both bicyclists and motorists, mounting height and lateral placement shall be as specified in Part II, Signs." The specifications of Part II are based in part on the field of vision of the motor vehicle driver. The bicyclist's head is "normally" inclined forward. This results in a somewhat lower field of vision for the bicyclist. Therefore, signs along bicycle paths can be mounted slightly lower than signs directed specifically to motor vehicle drivers. Bicycle path signs are frequently mounted 4 to 5 feet above the pavement surface.

Signs that are specifically directed to bicyclists using bicycle lanes may also be mounted at the lower height. However, all signs that apply to bicyclists and motorists or signs that might not be visible at the lower height, due to sight obstructions such as parked cars, should be mounted at the heights perscribed in Part II. (Ref. 9-1)

Regulatory Signs

The regulatory signs for bicycle facilities are primarily concerned with access to the roadway. For example, supplementary regulatory bikeway signing is largely directed toward emphasizing the exclusiveness of the bikeway by restricting motor vehicle usage.

The MUTCD standard symbol and word bike lane signs are recommended for designating the presence of a bike lane. (Figure 9-1) A supplemental plate "BEGIN" or "ENDS" may be added to denote the limits of the bike lane.



R3-16

R3-17

Figure 9-1 Bike Lane Signs

The R3-16 sign should be placed 100 to 250 feet in advance of the start of the bicycle lane. Typical application of these signs and supplemental pavement markings are shown in Figure 9-3, page 9B-12 of the MUTCD.

Along urban streets and highways where there are closely spaced side street intersections or where complex situations exist, the bicycle lane signing is usually spaced every 250 to 500 feet. In rural areas, the spacing may be up to 1,000 feet. Placing the signs too close together should be avoided as excessive signing is not only costly, but tends to reduce overall sign effectiveness. Signs should be placed so as to assure that the users can clearly see, interpret, and react to the message displayed.

Where local laws and ordinances allow bicyclists to share the sidewalk with pedestrians, the R9-7 sign (Figure 9-2) is used to define the proper positions of both bicyclists and pedestrians. The Uniform Vehicle Code

(Sec. 11–1209) and most local ordinances and laws include statements such as the following examples:

- A bicyclist upon and along a sidewalk, or across a roadway upon and along a crosswalk shall yield the right-of-way to any pedestrian and shall give audible signal before overtaking and passing such pedestrian.
- A bicyclist operating upon or along a sidewalk, or across a roadway upon and along a crosswalk shall have all the rights and duties applicable to a pedestrian under the same circumstances.

R9-7

Figure 9-2 Shared Sidewalk Sign

YIELD and STOP Signs

Yield and stop controls pose a number of problems for bicyclists. Motorists often travel without hesitation through yield-controlled intersections, giving only a cursory glance toward cross traffic. Because of their low profile, bicyclists are frequently overlooked by motorists and this can result in serious accidents.

Bicyclists, on the other hand, motivated by their desire to maintain momentum, frequently violate stop controls. They depend on their maneuverability and senses of hearing and sight to avoid conflicts. Unfortunately, STOP sign violations by the bicyclist are a major cause of bike-motor vehicle collisions. Realistically, stop controls do not protect bicyclists from right-of-way conflicts.

STOP signs may be used to assign the right-of-way to bicyclists using high volume, established bikeways at the intersection with low volume roads. Such applications may be particularly effective where sight obstructions exist. The decision to install such a STOP sign must take into account the relative traffic volumes, possible sight distance improvements, and normal operating speeds on the highway.

Warning Signs

The standard warning signs, symbols, shapes, and messages specified in Part II and IX of the MUTCD are used extensively on bicycle facilities.

Because of the different operating characteristics of bicycles, sign location and placement are different from signs primarily intended for motorists. However, the fundamental principles governing their use are the same.

Warning signs should be considered wherever a bicycle route crosses a major roadway, when a bicycle route begins or ends, or at any other points where large numbers of bicycles may be encountered. In urban areas, warning signs directed to the motorist are usually positioned a minimum of one-half block in advance of any point where bicycles may be encountered. Signs warning bicyclists of potential hazards such as drains or grates should be positioned along all types of bikeways not less than 50 feet in advance of the condition.

Bicycle lanes or routes on shared roadways normally follow the roadway alignment. Warning signs for curves, turns, stop ahead, etc., will normally serve both the motorist and the bicyclist.

On separate bicycle paths where it is necessary to warn bicyclists of unexpected changes in path direction, the appropriate curve sign or signs should be used. Choice of the W1-1 or W1-2 is a function of the speed approaching and traveling through the curve.

The speed that a bicyclist travels is dependent on several factors: the type and condition of bicycle, the purpose of the trip, the geometry and location of the bicycle path, environmental conditions, and the physical condition of the bicyclist. Bicycle paths are normally designed for a selected speed that is at least as high as the preferred speed of the faster riders. Table 9-1 shows general speed conditions for different types of bicycle use.

Design Speed, mph	*Conditions*
15	Primarily for recreational bicycle paths that are not paved
20	Basic design speed, flat conditions
25	Primarily for recreational paths, not paved with grades in excess of 4 percent
30	Used when downgrades exceed 4 percent

Table 9-1 Design Speeds for Bicycle Paths

Table 9-2 provides the AASHTO design radii for horizontal curves on bicycle paths (Ref. 9-1). When the existing bicycle path curvature falls below these values for a given operating or design speed, the W1-1 or W1-2 sign should be installed.

Another warning sign is the "BIKE XING" symbol/sign (W11-1). The MUTCD recognizes that this sign may not be necessary in advance of all intersections where bicyclists may be present. However, the sign has considerable merit at intersections where STOP or YIELD signs are

Design Speed, mph	Minimum Design Radius, feet
15	50
20	95
25	155
30	250

Table 9-2 Design Radius for Horizontal Curves on Bike Paths

frequently ignored. In this case, the motorist would be alerted in advance of the possible presence of bicyclists.

On bicycle paths with long steep downgrades (4 percent or greater), some agencies have chosen to use the HILL sign (W7-1) to warn the bicyclist of the prevailing conditions. The bicycle symbol is substituted for the truck in this sign.

Guide Signs

Guide signs are placed where needed to inform bicyclists of route destination and continuity. Typically, guide signs are of most value to the bicyclist unfamiliar with the route. Standard guide signs specified in the MUTCD include the BIKE ROUTE sign, (D11-1), supplementary message plates (BEGIN, ENDS, and TO), directional plates with a variety of arrow designations (M7-1 through M7-7), and destination plates with the destination and an arrow or the street name (D1-1b and D1-1c).

Guide signs may also be used to inform cyclists of the nearby bikeway. If distances are large between major decision points, some intermediate guide signs are appropriate. Placement of bikeway guide signs on each block as a matter of routine, is an unnecessarily wasteful practice. The criteria usually followed in guide signing are summarized below:

- Signing should be provided at all decision points along the route. Such signing may consist of signs informing the bicyclist of upcoming directional changes and confirmation signs to insure that route direction has been properly comprehended.
- Route or guide signs should be provided at regular intervals so that unfamiliar users are informed that they are traveling on an officially designated bicycle route.

Care should be exercised to avoid mixing guide signs with regulatory signing along a particular bicycle facility. For example, a section of bikeway that is signed as a bicycle lane does not need to include the bicycle route sign since the higher level bicycle lane sign takes precedence.

Bicycle routes used by touring bicyclists that extend for long distances should be given numerical designations. The MUTCD recommends a coordinated effort among States for numbering such routes passing through two or more States. The M1-8 and M1-9 route markers have been adopted for use in these cases.

Construction Signs

Construction signs fall into the same three categories as do other signs—namely, Regulatory, Warning, and Guide signs. Construction signs used for motorists are generally satisfactory for bikeways. The critical need is that the proper signs are used to warn of hazardous conditions and that detours are provided when construction equipment, materials, debris and excavations obstruct a bikeway. Bicyclists must be considered when construction activity poses a hazard or interruption to the bicycle travel path.

9B-2 Markings

Pavement markings are generally employed to reinforce and supplement signing and to provide direct communication to the user. Pavement markings are particularly effective for the bicyclist as their placement on the pavement is directly in front of the bicyclist and in their normal cone of vision. This section discusses those markings of specific relevance to bikeways.

Bike Lane Lines

Bike lane lines identify a specified lane as a travel path for bicyclists. Normally, a single white solid line provides delineation between the bike lane and motor vehicle travel lanes. Other typical lane line applications are shown on Figures 9-4 through 9-6 of the MUTCD. As with bikeway signing, a number of unique treatments were devised before the uniform standards were implemented. New and upgraded facilities should conform to the MUTCD requirements.

Except for centerlines on bicycle paths, the standard color for bikeway pavement markings is white. Some agencies have experimented with different colors to increase bike lane recognition. Those special color schemes have proved ineffective because they were hard to see.

Practices related to the application of specific markings are summarized below:

- Edge lines are seldom used on bike paths except to delineate special features such an area of restricted horizontal clearance or along a route to improve nighttime visibility. Solid white 2- or 4-inch lines are normally used.
- Yellow centerlines on two-way bicycle paths are desirable especially where volumes are high and on curves or at approaches to intersections.

- Raised pavement markers, mushroom buttons, or thermoplastic stripes are not advisable for bike lane delineation. They can cause the bicyclist to lose control of his vehicle and fall or encroach on adjacent traffic lanes.

Pavement Word Messages and Symbols

The diamond preferential lane symbol and BIKE LANE legend together with an arrow indicating direction of travel are used to supplement signing. A bicycle symbol is also used to supplement the legend, but is not recommended for use alone. The legend, BIKE ONLY, may be substituted for BIKE LANE where prescribed by local ordinance.

Pavement legends should be white and should have a minimum letter height of 4 feet. This height is also suggested as a minimum for directional arrows; however, longer arrows may be desirable to increase visibility and to emphasize the proper direction of travel by bicyclists at critical locations.

When wet, narrow bicycle tires may slip or skid on thermoplastic or heavily painted pavement markings. In addition, because of the application thickness of thermoplastic (approximately ten times the thickness of paint) the bicyclist's wheels can scrape against the edge and cause loss of control; consequently, this material should be avoided for bicycle markings. Pavement markings at critical stopping areas should also be discouraged. Markings in all cases should be limited to those considered vital for safety or control purposes.

Intersection Approach Treatments

Bicycle lanes tend to complicate both bicycle and motor vehicle turning movements at intersections. Bicycle lanes encourage bicyclists to keep to the right and motorists to keep to the left. Both operators are somewhat discouraged from merging in advance of turns. Thus, some bicyclists will begin left turns from the right-side bicycle lane, and some motorists will begin right turns from the lane to the left at the bicycle lane. Both maneuvers are contrary to established rules of the road and result in conflicts. There are many markings and striping configurations used for the treatment of intersection approaches where on-street bicycle lanes are provided. The most typical treatments include:

- The lane striping is continued through the intersection as either solid lines, dotted lines, or as a set of one dotted and one solid line (Figure 9-3).
- The lane stripe is continued up to the intersection as a solid or as a dotted line (Figure 9-4).
- The lane stripe is terminated at a point prior to the intersection (Figure 9-5).

Figure 9-5, page 9C-3 of the MUTCD presents details of pavement markings for bike lanes approaching Right Turn Only lanes for motorists. In considering marking for left turns at intersections, it is important to recognize the various ways that bicyclists make left turns. Some bicyclists merge across one or more lanes of traffic to use the inside lane or left-turn lane provided for motor vehicles. However, some bicyclists feel uncomfortable with this maneuver and will make a two-legged left turn by either riding a course similar to that followed by pedestrians, or by dismounting and walking in the pedestrian crosswalk. Where there are numerous left-turning bicyclists, a separate turning lane, as indicated in Figure 9-5 of the MUTCD can be considered.

None of these treatments can be expected to satisfy all needs and situations. Some of the factors to be considered in selecting a particular treatment are summarized below:

Bicycle lane striping carried through the intersection.(Figure 9-3)

- Appropriate where bicycle lane on major street crosses minor street.
- Reinforces bicyclist right-of-way over traffic emerging from the minor street.

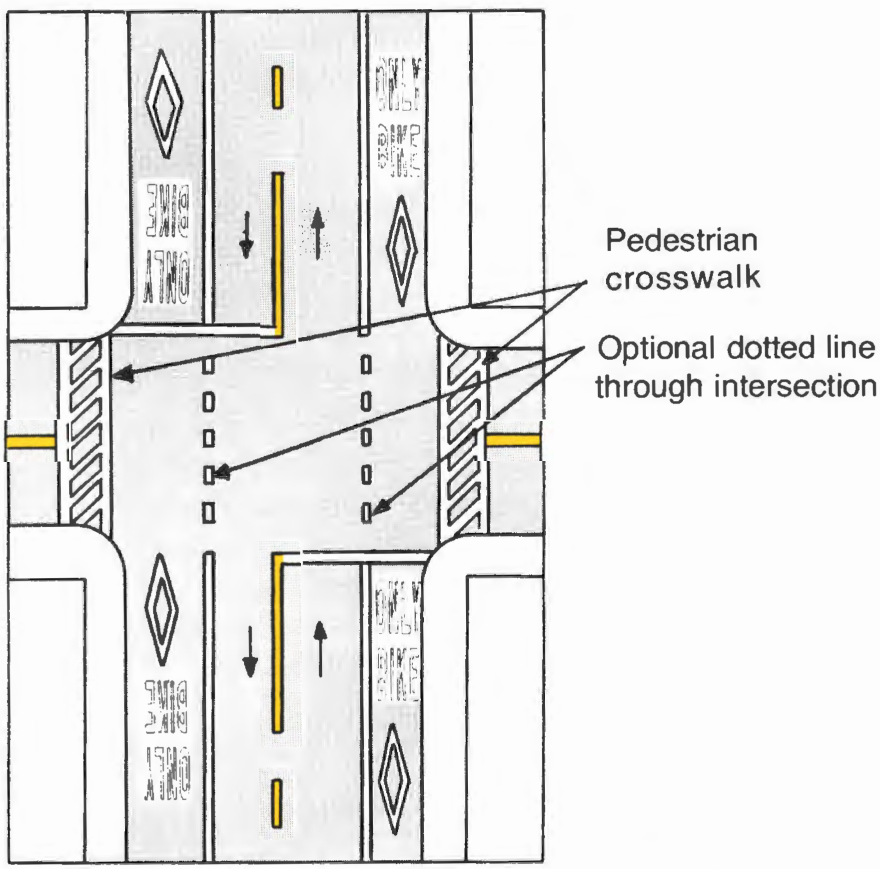


Figure 9-3 Intersection Approach Treatment, Bicycle Lane Striping Carried Through the Intersection

- Alerts right-turning motorists on the major street of the possibility of bicyclists on their right.
- Not desirable at signalized intersections when right turns on red are permitted. Motorists looking to the left may not expect bicyclists on the right.

Bicycle lane striping terminated at the intersection. (Figure 9–4)

- Used for locations where motorists' right turn movements are light.
- Not desirable at signalized intersection when right turns on red are permitted. Motorists looking to the left may not expect bicyclists on the right.
- A solid line is intended to encourage the bicyclist into a two-stage left turn when it would be difficult for the bicyclist to weave into the left-turn lane. The broken stripe provides a defined area for bicyclists but may allow right turning motorists to legally enco-rach.

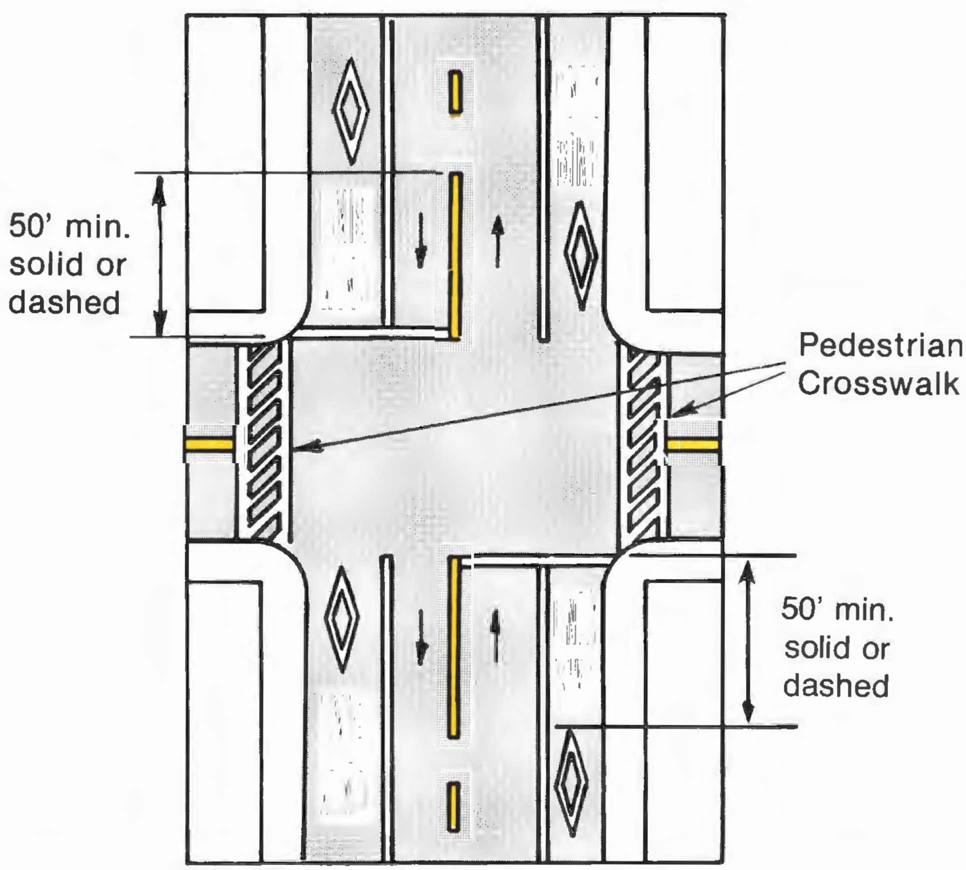


Figure 9-4 Intersection Approach Treatment, Bicycle Lane Striping Terminated at the Intersection

Bicycle lane striping terminated prior to the intersection. (Figure 9-5)

- Appropriate treatment to use with motorists' Right Turn Only lanes
- Right-turning motorists must merge with through bicyclists.
- This common treatment leaves the bicyclist on his own in maneuvering for left or right turns.

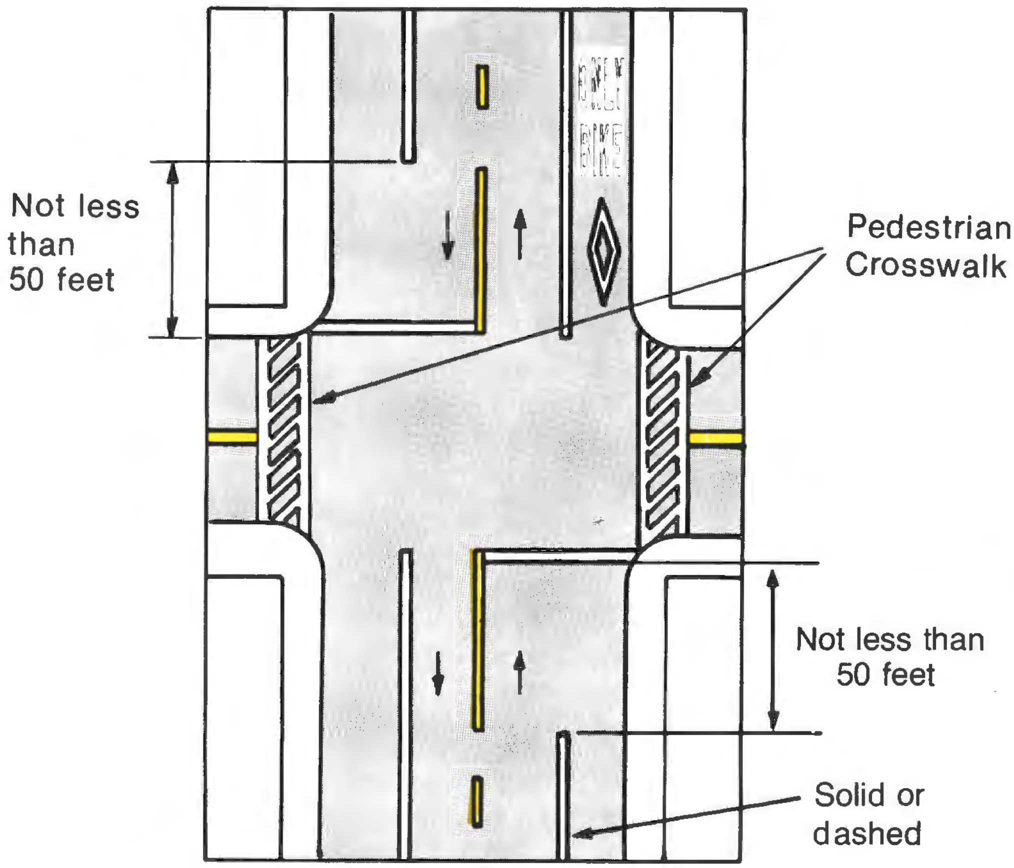


Figure 9-5 Intersection Approach Treatment, Bicycle Lane Striping Terminated Prior to the Intersection

Regardless of what treatment is used, its effectiveness depends on both motorists and bicyclists understanding the meaning of the striping and responding appropriately. For this reason, proper public education and enforcement is a critical part of traffic control on bicycle facilities.

In all of the bicycle lane striping treatments at intersections, the pedestrian has the right-of-way once he has entered the crosswalk area. Where crosswalks are marked, this area is well defined. The lane-thru-intersection striping treatment would stop at the crosswalk as would the broken stripe treatment.

With the presence of handicapped ramps at intersection curbs, the bicyclist may choose to "skirt" the lane by using the sidewalk ramp and then the crosswalk as he traverses the intersection or turns right. This situation creates conflicts between pedestrians and bicyclists. Every effort should be made to design ramp configurations that would discourage this practice.

Object Markers

At locations where objects and obstructions hazardous to bicyclists are adjacent to or in the path of the bicycle (e.g., drainage grates), Type I, II, or III object markers (Sec 3c of the MUTCD) and/or supplemental striping should be used to clearly delineate the presence of the object or obstruction. Object markings are typically used around or on:

- Utility poles,
- Parallel drainage bar grates or drop inlets,
- At grade railroad tracks,
- Uneven pavement/curb joints,
- Tree trunks, and
- Water or electric meters, junction boxes, etc.

9B–3 Signals

The use of bicycles as a mode of transportation is not always considered in the design or operation of a signal installation. As a consequence, signal operations at many locations create problems for the bicyclist. Typical problems, promising solutions, and the relation of bicycle traffic to the application/installation of traffic signals are covered in this section.

At intersections where significant bicycle travel exists or is anticipated, the timing of the traffic signal cycle, as well as the traffic detection system, should consider bicycle traffic. Normally, a bicyclist can cross an intersection under the same signal phasing arrangements as motor vehicles. However, on multilane streets special consideration should be given to ensure that clearance intervals are sufficient. If necessary, an all-red clearance may be used. Traffic engineers must weigh the possible adverse consequences of an overly prolonged clearance interval. These may degrade intersection traffic-carrying capacity and possibly good signal progression. It is, nonetheless, more realistic than the possible alternative of providing separate signal heads for bikes with an advanced yellow setting.

The clearance time required for bicycles should be evaluated as standard practice for each signalized intersection along a heavily used bikeway. A bicyclist's speed of 10 mph (14.7 feet per second) and a perception/reaction/ braking time of 2.5 seconds is generally used in the calculation to determine the number of seconds required to ride across a given street.

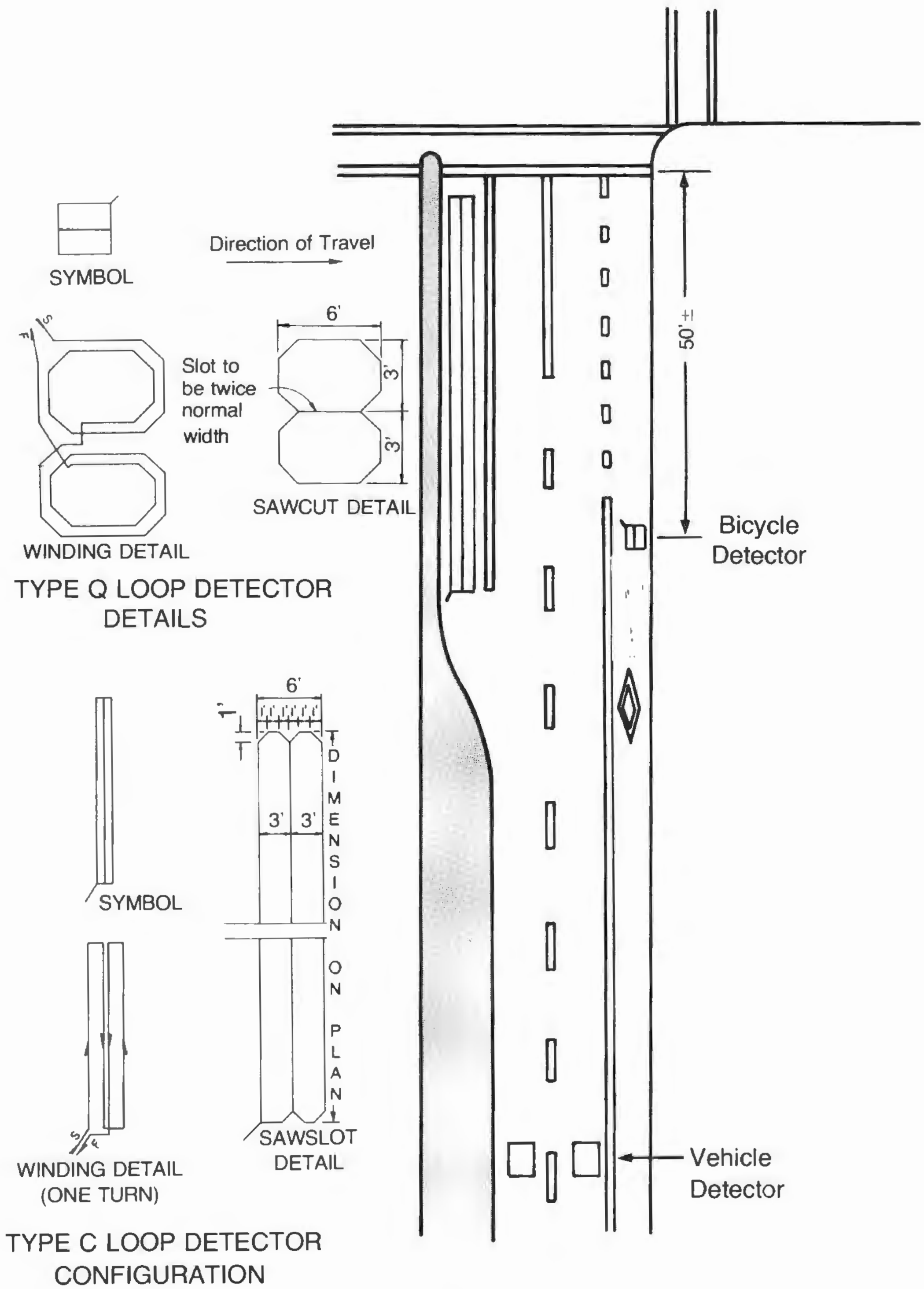


Figure 9-6 Bicycle Detection System—Quadrapole Loops

Signal timing modifications to improve overall traffic service are possible if separate detection of bicyclists are included with traffic-actuated signal installations. Normally, when a curbside mounted button is provided for bicyclist's use, actuations are simply treated as a pedestrian "call." The phase length allocated for pedestrian actuations are significantly longer than those provided for motor vehicles or the actual crossing time required for bicyclists.

The installation of a curbside pedestrian actuation button within the reach of bicyclists will solve part of the problem for through bicycle traffic. It is obviously of no use to a bicyclist turning left from the center of the street. The curbside pushbutton installation and sign should be large enough and positioned so the bicyclist can easily see it. The R10–3 sign has been used on the pedestrian pushbutton equipment while the R9–5 also advises the bicyclist to use the device.

Several manufacturers have successfully developed and produced the "quadapole"-type inductive loop detector configuration shown in Figure 9–6. It is capable of detecting the presence of bicycles. Depending upon the length of lead-in cable and conduit needed, the cost to cut and lay the wire amounts to approximately $500 to $700 per installation. This type of detection has proved effective for bicycle paths, bicycle turn lanes, and bicycle approach lanes to signals. To be effective, the detector must be within the expected path of travel of the bicyclist. Several communities are experimenting with markings to identify to the bicyclist the exact location of the detector.

The inductive loop method of detection is preferred to the pushbutton because it is a passive device. That is, it does not require any action on the part of the bicyclist.

9C. OPERATIONS AND MAINTENANCE

As with any other traffic control or safety program, the operating effectiveness of bicycle facilities should be evaluated after installation to ascertain that the facility is serving the intended purpose. Evaluation techniques that have been used by various agencies include time lapse photography, video, field observations, user survey (interviews and/or questionnaires), and the compilation and analysis of accident histories. As a minimum, accidents involving bicyclists should be monitored to identify the potential conflict points and to determine how these problem areas can be improved.

Probably the most important effort that could be undertaken to enhance bicycle travel would be improved maintenance and upgrading of existing roads that are used by bicyclists, regardless of whether or not bikeways are designated. This effort requires that increased attention be given to the right-hand portion of roadways where bicyclists can be expected to ride. An attempt should be made to improve the width and quality of the surface and to maintain the right-hand portion in a condition suitable for bicycle riding.

Also important is the consideration of bicycle needs in the implementation of major construction projects and normal safety and operational improvements. For example, in constructing new roads, adequate width should be provided to permit shared use by motorists and bicyclists. When resurfacing, full shoulders should be resurfaced, as well as traffic lanes, uneven joints with the gutter should be avoided. When constructing truck passing lanes, the paved shoulders should not be sacrificed as this would cause bicyclists to ride within truck lanes.

When restriping a roadway after an overlay has been applied, an attempt should be made to provide sufficient room outside the stripe for bicyclists. When considering the restriping of roadways for more traffic lanes, the impact on bicycle travel should be assessed. These efforts, to preserve or improve an area for bicyclists to ride, can benefit motorists as well as bicyclists.

Under most circumstances, maintenance of bike routes require no special maintenance activities. That is, normal street cleaning, restriping, etc., as established foı the overall roadway usually provides adequate maintenance of shared roadway facilities. As with roadways, bicycle lanes and paths need a regular schedule of maintenance to insure that the riding surface is free of debris and potholes. This will involve sweeping activities and possible patching.

A properly striped bike lane is not intended for use by motor vehicles. It, therefore, does not experience the "sweeping action" of traffic. In fact, traffic in the adjacent traveled way tends to sweep debris into the bike lane. This accumulation of glass, gravel, and other debris reduces the effective width of the bike lane and causes the bicyclist to ride on the extreme left, i.e., closer to moving traffic. Where there is a large accumulation of debris, the bicyclist will frequently choose to ride in the motor vehicle lane, thus eliminating the usefulness of the bike lane entirely. Frequent machine sweeping of the bike lane may be necessary to keep certain bike lanes free of debris.

Bicycle paths must also be maintained. These separate facilities can be easily overlooked by maintenance forces that rely on motorized vehicles to perform inspections to determine maintenance needs.

Bicycle signs and markings should be inspected regularly and kept in good condition. A periodic sign inventory should involve all bicycle-oriented control device features.

9D. OTHER CONSIDERATIONS

The bicycle as a viable mode of transportation is becoming an integral part of the traffic stream. This has led to a new group of signs and markings to assist bicycle operation. There are some standards and uniform applications that have been accepted almost totally. However, there are other considerations regarding the application and installation of traffic control devices on bicycle facilities that have yet to be resolved.

Special bicycle operations problems such as the use of on-street two-way bicycle lanes, allowing bicycles to travel on freeways or sidewalks are still being evaluated. Another emerging problem involves the use of bike lanes by motorized pedal cycles (mopeds) and the use of bikeways by other than bicyclists (e.g., rollerskaters, joggers, skateboarders.) This section discusses some of the unique considerations and the experimental traffic control approaches that have been devised to deal with these new problem areas.

9D-1 On-Street Two-Way Bicycle Lanes

Bicycle lane signing and marking typically provides for one-way travel in bicycle lanes; that is, the bicyclist travels in the same direction as adjacent motor vehicle traffic. This requires designating a bicycle lane on each side of a two-way street to accommodate both directions of bicycle travel. Some agencies have chosen to allow two-way bicycle travel in one designated lane on the street, but many of these agencies have subsequently eliminated these facilities and prohibited their use by local ordinances.

There are a number of operational and safety problems associated with two-way bicycle lanes on the street. The severity of some of these problems indicates that the use of on-street, two-way bike lanes should not be allowed. Some of these problems are summarized below:

- The increased closing speed between opposing motorists and bicyclists reduces the available maneuver time and increases the likelihood of serious accidents.
- Many State motor vehicle code laws prohibit bicyclists from traveling on the street in an opposite direction to motor vehicles. Accordingly, such lanes would violate State codes.
- The various conflict points between motor vehicles and bicycles at intersections become significant with the two-way bicycle lane, as the motorist would not expect bicyclists coming from both directions.
- Motorists exiting driveways in midblock may not be aware of two-way bicycle traffic and not look in both directions, thus, increasing accident potential.

- Where the two-way bike lane is wide enough, (10 feet or more) motorists might use the lane to pass to the right. This increases the potential for head-on collisions with bicyclists.
- Special provisions must be made to return the "wrong-way" bicyclist to the appropriate side at the termini of the two-way facility.

9D-2 Bicycle Operation on Freeways

Bicycle travel in the urban area is usually via the city street system. In the suburbs and rural areas, the bicyclist may have no convenient or available alternative roadway to travel on but a freeway. Several States allow bicyclists to operate on the freeways under special circumstances to retain the continuity of a specific bikeway. In almost all cases, the bicyclist uses the paved shoulder which may vary in width from 8 to 10 feet and will allow sufficient lateral clearance from mainline vehicles and large trucks.

Signing at the entrance to the freeway ramp is used to notify both motorist and bicyclist that bicyclists are allowed to use a defined section of the freeway. In the observed cases, there are very few (if any) pavement markings, symbols, or signing on the freeway specifically for the bicyclist. The freeway bikeway usually terminates at a point where a suitable alternate surface road is available for use.

Bicyclists entering the freeway ramp are expected to use the paved section of the ramp on the right-hand side. At the entrance to the freeway mainline, bicyclists should be directed to the right-hand shoulder with pavement striping. Exit signing should be provided well in advance of the terminal point and at the exit point of the off ramp. Directional signing should guide bicyclists to the connecting facility.

In cases where bicyclists must cross interchange areas where motor vehicles are entering and/or exiting, the bicyclist is in an extremely vulnerable position. Where possible, the bicyclist should be guided off the freeway via the exit ramp and then signed to enter the on ramp on the opposite side of the interchange. Although somewhat inconvenient, it avoids the direct freeway mainline conflict between motor vehicles and bicycles. Conflicts introduced at the crossroad can be more easily accommodated with normal traffic control devices.

The use of freeways by bicyclists is a very special consideration and should be approached with extreme caution. The States known to allow this practice for unique situations are monitoring this usage closely. Until significant data are available, this practice should not be considered routine.

9D-3 Sidewalk Bikeway Criteria (Ref. 9-1)

In general, the use of sidewalks for bicycle travel creates problems for the following reasons:

- Sidewalks tend to be used in both directions, despite any signing to the contrary. As such, bicycles coming from the right may be unnoticed by motorists emerging or entering driveways.
- At approaches to intersections, parked cars interfere with the visual relationships between motorists and bicyclists. At driveways, sight distances are often impaired by property fences and shrubs, etc.
- At intersections, motorists are not looking for bicyclists (which are traveling at higher speeds than pedestrians) entering the crosswalk area.
- Sidewalks are typically designed for pedestrian speeds, and may not be safe for higher-speed use. Due to the speed differential, conflicts between bicyclists and pedestrains are common. Fixed objects such as parking meters, utility poles, sign posts, bus benches, trees, hydrants, and mail boxes also pose a hazard to bicyclists. Also, bicyclists riding on the curb side of sidewalks may accidentally drop off the sidewalk and into the path of motor vehicle traffic.

The development of extremely wide sidewalks does not necessarily add to the safety of sidewalk bicycle travel, as wide sidewalks will encourage higher speed bicycle use and can increase the potential for conflicts with motor vehicles at intersections as well as with pedestrians and fixed objects.

Sidewalk bikeways should be considered only under special circumstances, such as:

- To provide bikeway continuity along high speed or heavily traveled roadways having inadequate space for bicyclists. These should be relatively uninterrupted by driveways and intersections.
- On long, narrow bridges. In such cases, ramps should be installed at the sidewalk approaches. If approach bikeways are two-way, sidewalk facilities should also be two-way. A positive barrier such as the concrete safety shape should be used to separate bicycle and motor vehicle traffic.

Whenever sidewalk bikeways are established, a special effort should be made to remove obstacles that will be hazardous to bicycle travel. Whenever bicyclists are directed from bike lanes to sidewalks, curb cuts should be wide and flush with the street to assure that bicyclists are not subjected to the hazards of a vertical lip crossed at a flat angle. Also, curb cuts at each intersection are necessary, as well as bikeway YIELD or STOP signs at uncontrolled intersections. Curb cuts should be wide enough to accommodate adult tricycles and two-wheel bicycle trailers.

In residential areas, sidewalk riding by young children too inexperienced to ride in the street is common. With lower bicycle speeds and lower auto speeds, potential conflicts are somewhat lessened, but still exist. Nevertheless, this type of sidewalk bicycle use is accepted. However, it is inappropriate to sign these facilities as bikeways. Bicyclists should not be encouraged, through signing, to ride facilities that are not designed to accommodate bicycle travel.

9D-4 Two-Way Bicycle Path at Intersections

There are three methods currently employed for accommodating the bicyclist on a two-way bicycle path when it reaches an intersection with a painted crosswalk. The typical treatment allows the bicyclist to cross the street on the approach side at the crosswalk. A crossing lane is defined by the back crosswalk line and a dotted striped line. (Fig. 9-7). In this method, approaching motor vehicles must stop further back from the intersection area as prescribed by an appropriately placed stop bar. In some cases, the intersection sight distance for vehicles is restricted at the

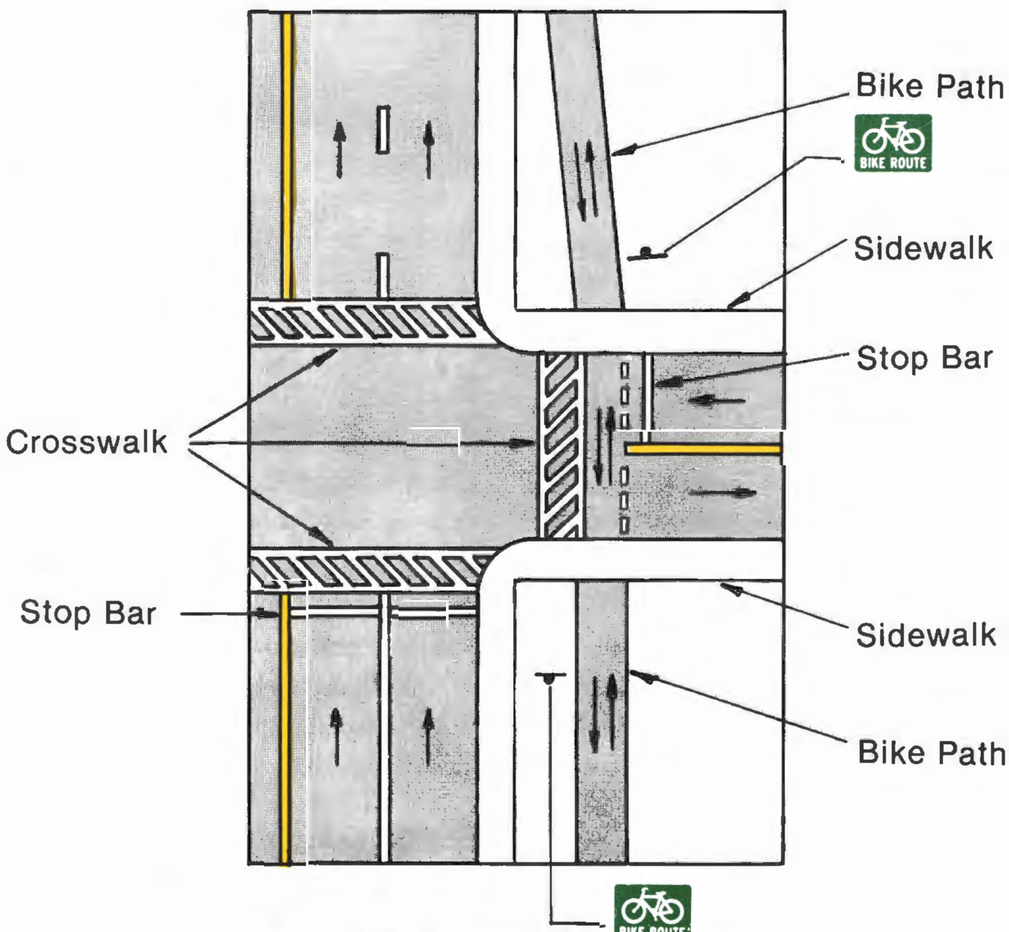


Figure 9-7 Approach Side Crosswalk

new stopping location because it is further from the intersection. In this situation, observations show that motor vehicles tend to infringe upon both the bicycle crossing area and pedestrian crosswalk. Although this method provides separate travel paths for pedestrians and bicyclists, conflicts may occur at the curb returns. There are, however, fewer conflicts than for the other two treatments.

The next treatment allows the bicyclist to share the painted crosswalk. (Fig. 9-8) There is much greater conflict between bicyclists and pedestrians within the crosswalk as well as at the curb return. This frequently used treatment is the least desirable since the crosswalk area is normally designated for pedestrians. When used, it is desirable to install a bicycle YIELD sign (R9-6).

The third treatment allows the bicyclist to travel on the outside (intersection side) of the crosswalk (Fig. 9-9). A dotted line is striped on the outside of the crosswalk to combine with the front crosswalk line to form the crossing lane. Conflicts in this treatment may occur at the curb

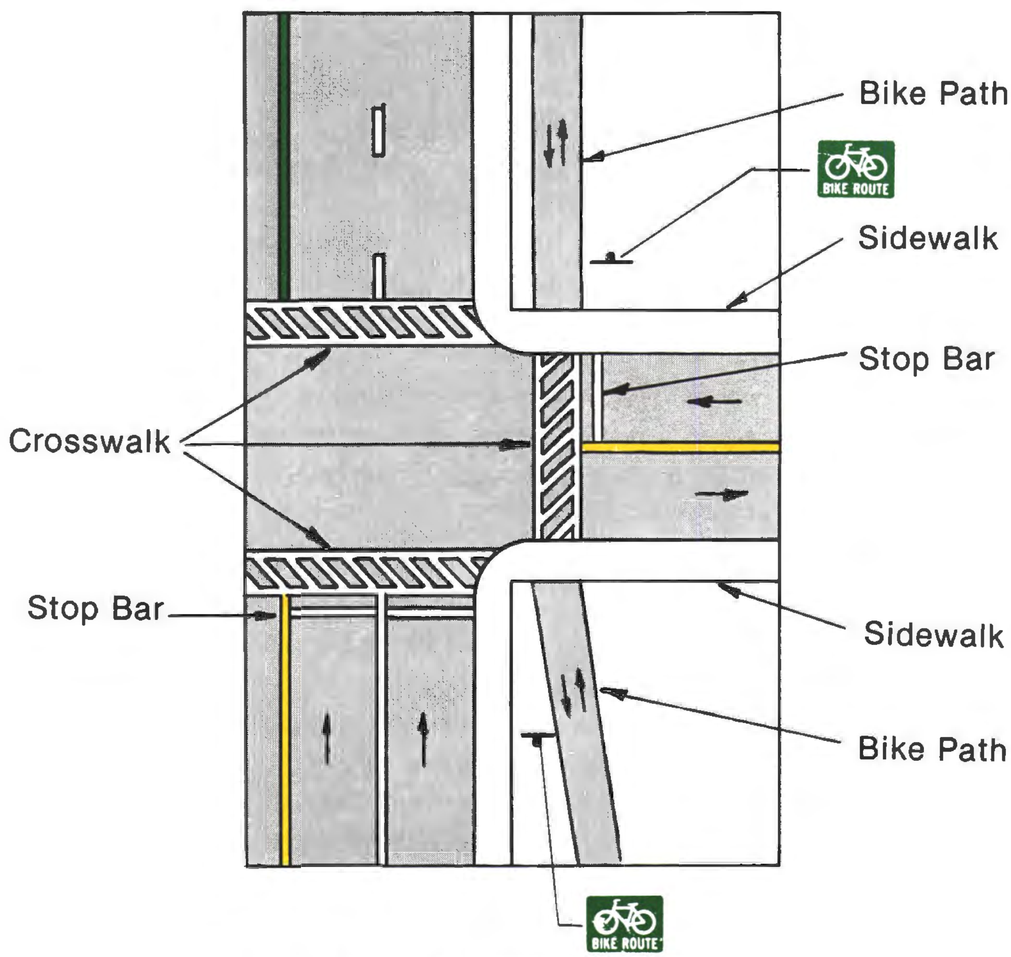


Figure 9-8 Shared Crosswalk

return where the bicyclist on the path must cross in the curb return area to reach street crossing. This treatment is used when a two-way bicycle path terminates and a one-way bicycle lane begins. The bicyclist entering the one-way lane is almost directly in line with the bicycle lane whereas in the previously described treatments there would be a need to cross the crosswalk and opposite side curb return.

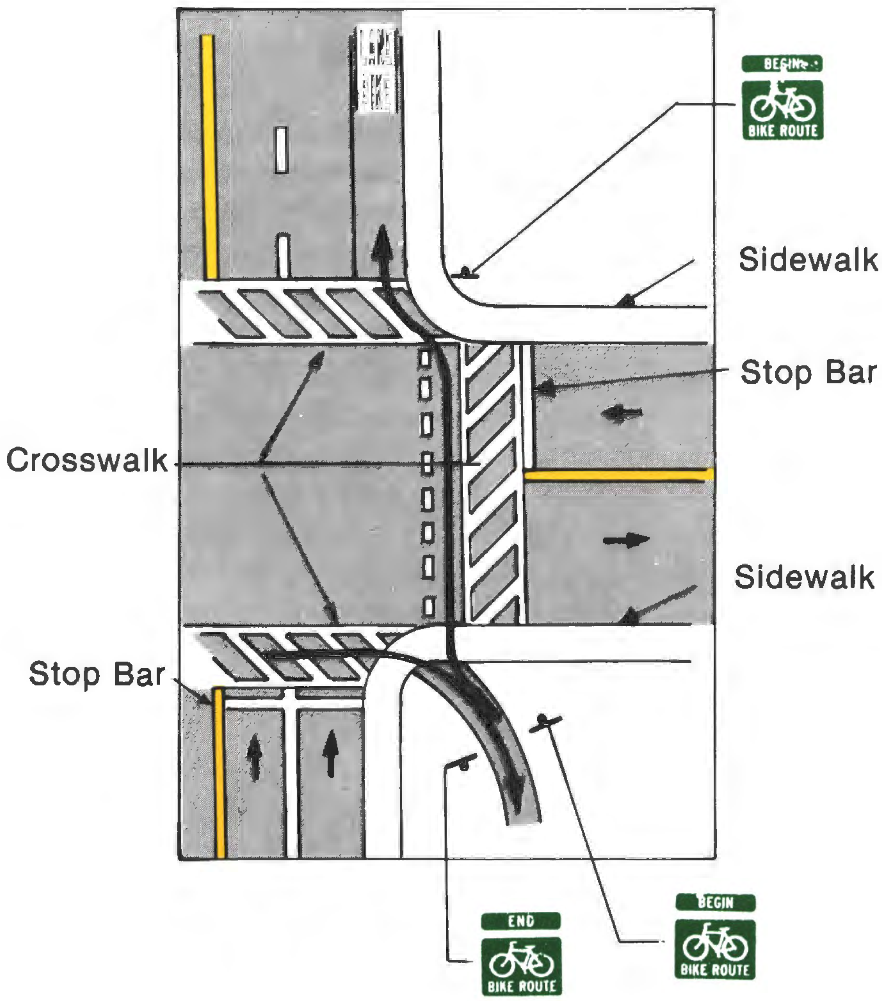


Figure 9-9 Intersection Side Crosswalk

9D-5 Bikeway Use by Other Than Bicycles

Bicyclists on bicycle paths and sidewalks frequently share the facility with pedestrians. In addition, bicycle lanes as well as trails have recently been utilized by motorized pedal cycle or "moped" riders as well as roller skaters, skateboarders, and joggers.

The moped problem on the bikeway centers around the difference in average speeds; the moped can reach speeds up to 35 and 40 mph while the bicyclist normally operates at 10 to 20 mph. The moped's higher speeds may exceed the design speed of the bikeway. Although most States limit moped speeds to 20 mph or less, the potential speed differential has prompted several agencies to prohibit mopeds from using bicycle lanes. This is particularly desirable where elementary school age bicyclists operate in a bicycle lane. Conversely, some agencies support the concept that the moped should operate in the bicycle lane based on the following rationale:

- Bicycle volume is usually very low and the moped has the mobility to react to the few bicyclists it encounters.
- Mopeds operating in the street (outside of the designated bikeway) can be a hindrance to smooth traffic flow as they travel more slowly than the average auto and moped operators are not generally experienced enough to operate in the heart of the traffic stream.
- A moped/motor vehicle accident is usually more severe than a bicycle/moped accident.

The other users of the bicycle path involve varying age groups with different operating characteristics that clash with the bicycle operator as well as each other. The roller skater and skateboarder can travel at speeds closer to the bicyclist, but may have less control than the bicyclist.

The jogger represents another problem in that he is moving slower than any of the "wheeled" operators. Although actually a pedestrian, the jogger may be less aware of his surroundings than a typical pedestrian as he concentrates on the physical aspects of his activity. It is difficult to predict the movements of a jogger who may change directions without warning and dart into the bicyclist's path. The travel path restriction sign (R9-7) should be used where joggers are a problem.

Many local agencies are investigating the need for ordinances to prohibit the use of bicycle facilities for other than bicycle travel.

9D-6 At-Grade Railroad Crossing and Cattleguards

Whenever a bikeway crosses metal tracks or parallel bars, special problems exist for the bicyclist. First, there is the safety considerations involving potential conflicts at these crossings. Therefore, the presence of the hazard along, any bikeway should be clearly marked with appropriate advance warning devices.

In addition, depending on the orientation and type of crossing, the crossing itself may be hazardous. To reduce the accident potential, the bicycle path should be at a right angle to the crossing.

For railroad crossings, the materials of the crossing surface and the flangeway depth and width must be evaluated. The more the crossing deviates from the ideal 90-degree crossing, the greater the potential for a bicycle wheel to be trapped in the flangeway. If the crossing angle is less than 45 degrees, then consideration should be given to widening the bikeway. This would allow bicyclists adequate room to cross the tracks at a safer angle. (Fig. 9-10)

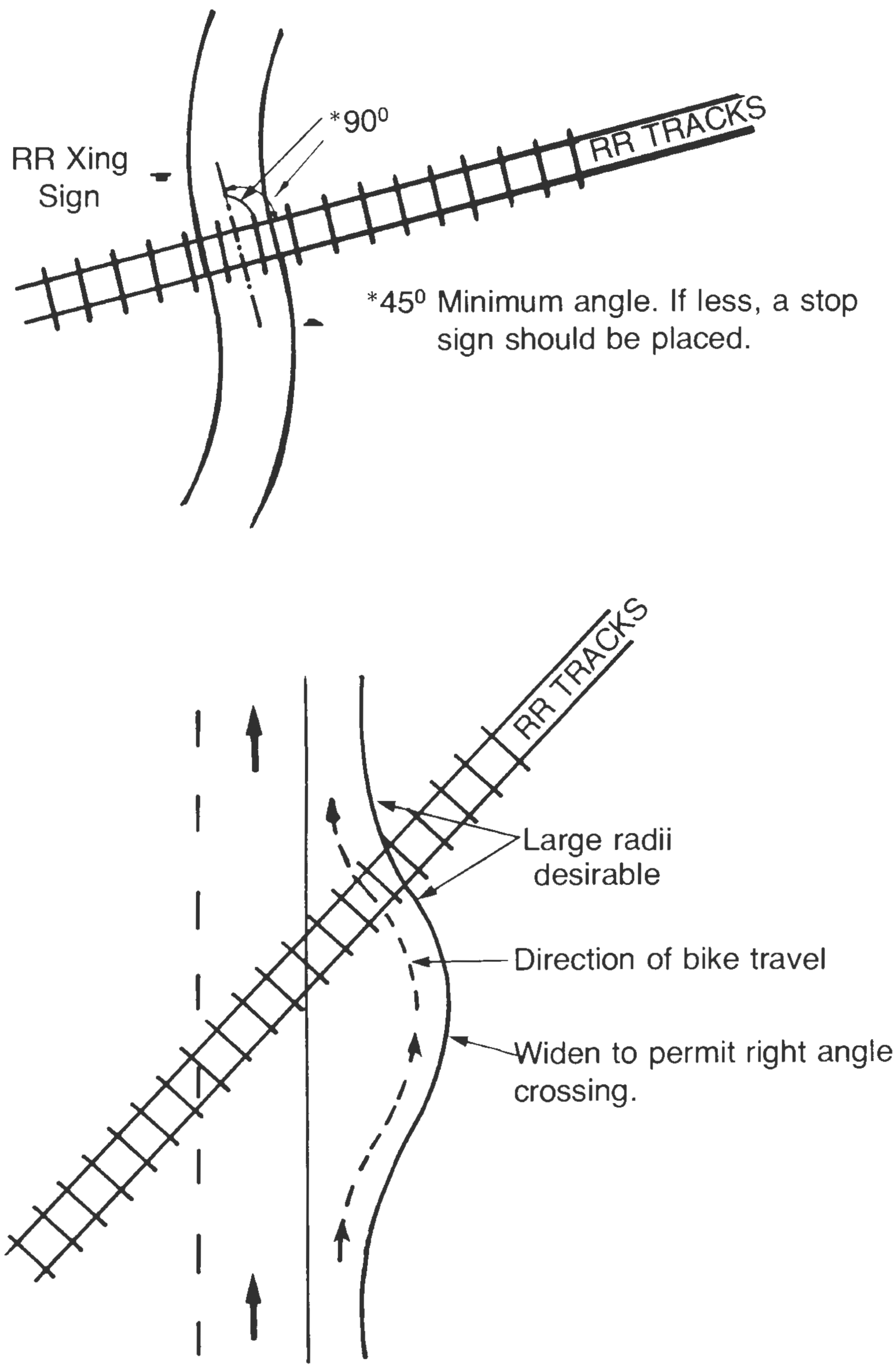


Figure 9-10 Bikeway/Railroad Grade Crossing

Where the bikeway approach is not at the same elevation as the railroad or when the crossing angle is less than 45 degrees, flangeway fillers can be installed to enhance bicyclist safety. In any case, appropriate advance warning signs should be used.

REFERENCE

9-1 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Development of New Bicycle Facilities* 1981, Washington, D.C. 1981.

* U.S. GOVERNMENT PRINTING OFFICE : 1983 O - 409-573