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NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

REPORT 476

Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction

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SUBJECT AREAS
Maintenance

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in Cooperation with the Federal Highway Administration

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Several highway agencies contributed to this effort by providing agency procedures and materials to the researchers, by participating in seminars with the research staff during development of the project materials, and by allowing the researchers access to project records. In addition, arrangements were made for the researchers to visit a number of project sites to observe night construction and maintenance procedures and traffic control and to obtain photographs for the seminars and reports.

Highway agencies that cooperated in this research effort include the following:

- California Department of Transportation
- Florida Department of Transportation
- Iowa Department of Transportation
- Maryland Department of Transportation
- New York State Department of Transportation
- Oregon Department of Transportation
- Pennsylvania Department of Transportation

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- Barrier Systems, Inc.—Rio Vista, California
- Carsonite International—Early Branch, South Carolina
- Energy Absorption Systems, Inc.—Chicago, Illinois
- Rifenburg Construction Company, Inc.—Troy, New York
- United Rentals Highway Technologies—Villa Park, Illinois
- Walter S. Pratt and Sons, Inc.—Rensselaer, New York

KAL Graphics Design Studios, Inc., of Fort Lauderdale, Florida, prepared the typical application drawings in Appendix A.

Robert Attaway (North Carolina State University) was responsible for conducting telephone surveys with state highway agencies, which yielded valuable information for these guidelines. Robert Hostetter (LRI, Inc.) performed the literature review; Richard J. Porter (LRI, Inc.) developed the lighting plan in Section 2.9, and Patricia Senior (LRI, Inc.) contributed many hours of word processing support.

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

This report presents guidelines to assist highway agencies in developing and implementing a plan for night work that will provide for public and worker safety and satisfy the community while minimizing waste and other problems associated with the supply of materials and capable workers. The guidelines also contain a number of innovative procedures suggested by state DOTs to respond to special nighttime problems, such as control of glare, visibility of workers, and the need to improve conspicuity of traffic control devices. This report will be of particular interest to engineers responsible for development and maintenance of traffic control plans for construction and maintenance projects.

Work zones pose safety problems for both motorists and workers. Although work zones result in significant amounts of congestion and associated delay, lead to accidents and related losses, cause adverse impacts on communities and businesses, and increase driver frustration, the need to construct new highway facilities, preserve existing roadways, and perform maintenance make work zones unavoidable. Growth in traffic volumes has led many agencies to defer roadwork activities to off-peak hours to avoid congestion. Nighttime work, however, raises additional safety problems.

The objectives of NCHRP Projects 17-17 and 17-17(2) were to (1) develop guidelines for nighttime road work to improve safety and operations and (2) formulate procedures to facilitate making decisions about undertaking nighttime work. This report presents guidelines for design and operation of nighttime traffic control for highway construction and maintenance. *NCHRP Report 475* contains the procedures to assist highway agencies in determining whether to perform nighttime construction or maintenance.

A research team from The Last Resource, Inc., was selected to undertake this research. This report suggests methods that can help maintain the quality of work, ameliorate community complaints, stress the importance of minimum performance standards for traffic control devices, and ensure the quality of these devices. The report is presented in three chapters. Chapter 1 contains information to help the user identify the minimum specification, setup, and maintenance of each work zone design element, including traffic control devices, barriers, lighting, and other safety features. Chapter 2 includes information pertaining to the design of traffic control devices, other safety devices, and types of work zone lighting. Chapter 3 provides guidance for the implementation and operation of night work zones.

The guidelines are directed toward professional staff and skilled, well-trained technicians. The guidelines language follows accepted terminology, such as that used in the *Manual on Uniform Traffic Control Devices* (MUTCD). Seven typical application diagrams (TADs) for night work, based on TADs currently in the MUTCD, are included in Appendix A, illustrating recommended enhancements to accommodate the added risks inherent in working at night.

CONTENTS

INTRODUCTION

Night road construction has increased dramatically over the last few years and will continue to grow out of necessity. The fact that so many roads operate near or beyond capacity has resulted in a more frequent need to conduct road maintenance and repair at night. Not only are more roads operating near capacity, but an ever-increasing percentage of roadways has become in need of significant repair. The combination of road deterioration and congestion will result in a continued increase in the amount of roadwork done at night.

Although the 2000 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*) provides current national standards and guidelines for traffic control devices and numerous illustrations of how to apply these devices in typical work zone plans, the MUTCD offers limited guidance to address the special problems that night work presents. These special problems include problems associated with visibility; community impact; and the supply of labor, materials, and administrative support.

The first, and most obvious, problem is that nighttime brings a reduction in visibility for both workers and drivers. The loss of visibility for workers results in the need for supplemental lighting that satisfies the visibility requirements of workers. These requirements are determined by the work task and available contrast. The loss of visibility for drivers results not only from the absence of daylight and the inefficiency of headlighting, but also from the negative effects of glare produced by other vehicles, illuminated signs and other visual clutter, and possibly the illumination of the work zone itself. This loss of visibility affects not only the detection distance and conspicuity of traffic control devices, but also the visual detail from the road and the surrounding area that provides information about road alignment. Accompanying this loss in visibility at night is the presence of drivers who need greater visibility to have adequate time to react to the unexpected situations that night work activity presents. At night, there is a higher percentage of impaired drivers (e.g., drivers who are either fatigued or driving under the influence of alcohol or drugs). A significant problem with night work, then, is that drivers need more visibility at a time when conditions reduce visibility.

The second problem associated with night work is that night work often has a negative impact on the community, particularly residential areas where residents expect peace and quiet. Night work often is accompanied by a disturbing level of noise, an increase in light and particularly glare, and sometimes a rerouting that is an inconvenience to some local residents or businesses. Some businesses, such as restaurants, may lose more business when the work is done at night than when the work is done during the day.

The final problem with night work is the limited supply of labor and materials. There is a natural resistance to night work by contractors, and contractors that accept night work are also more likely to suffer fatigue at night than during the day. At night, there is a more likely chance than during the day of having problems with the availability of materials and support personnel to fix things that break, whether the problem is damaged traffic control devices, a loss of lighting, or a breakdown of equipment. Because the offices of the contractor and the agency are closed at night, there may be problems with having important decisions made in a timely manner.

The problems with visibility need to be addressed by a well-designed traffic control and lighting plan with properly designed and maintained devices and equipment. Community impact needs to be mitigated by advance public relations work and continuous and accurate real-time information disseminated throughout the work cycle. Responding to the problems with labor and materials requires much more planning and attention to detail than would otherwise be required for day work. The guidelines in this report are intended to help an agency develop and implement a plan for night work that will provide for the safety of the public and the worker and the satisfaction of the community while minimizing waste and other problems associated with an insufficient supply of capable and alert workers, materials, maintenance, and administrative support.

In spite of all the problems, night work may still have significant advantages, including the reduction of congestion and delay and often an increase in productivity. Anyone using the guidelines in this report will have decided (possibly with the assistance of *NCHRP Report 475: A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance* [*2*]) that the benefits of night work outweigh the costs. The goal of these guidelines is, therefore, to bridge the gap between the standards provided by the MUTCD and the need to sensitize planners of night work activity to the issues that must be addressed if night work is to be conducted safely and efficiently. These guidelines were developed with the assumption that the guidance provided by the

MUTCD, state departments of transportation (DOTs), and local governments contain only minimum requirements and that the special problems associated with night work require additional steps to be taken to ensure safety. One of the recommendations in a report from the Wisconsin DOT suggested that a chapter on traffic control is needed for the Wisconsin DOT's facilities development manual (*3*), which will supplement and cross-reference the MUTCD. Much of what the Wisconsin DOT envisions for this chapter is contained in this report.

The most common problems with night road work operations reported by agencies include quality of work, additional cost, community resistance, and the fact that traffic control devices are frequently misused and poorly maintained. The need to adjust the work zone setup during the night and to satisfy productivity goals so that the facility can open on time the next day increases the number of risks and level of stress that often accompany working at night.

The guidelines in this report suggest methods that can help maintain the quality of work, ameliorate community complaints, stress the importance of minimum performance standards for traffic control devices, and ensure the quality of these devices. The guidelines also contain a number of innovative procedures suggested by state DOTs to respond to special nighttime problems, such as the control of glare, the visibility of workers, and the need to improve conspicuity for traffic control devices.

This report has three chapters: Chapter 1 contains guidelines to help the user identify the minimum specification, setup, and maintenance of each work zone design element, including traffic control devices, barriers, lighting, and other safety features. Chapter 2 contains the guidelines pertaining to the design of traffic control devices, other safety devices, and types of work zone lighting. Chapter 3 contains guidelines for implementation and operation of night work zones.

The guidelines are as brief as possible, with additional references given where appropriate. The guidelines are directed toward professional staff and skilled, well-trained technicians. The guidelines use the same terminology as that used in the MUTCD.

Many guidelines have technical notes. Technical notes provide references for the guidelines, as well as additional detail, including an explanation of any research and a summary of relevant results as they relate to the guidelines. These notes may provide some discussion of the research conclusions. Some technical notes explain the limitations of a guideline, such as conditions under which it was or was not tested. Other technical notes simply define terminology or explain a basic concept or principle. Technical notes are numbered and appear at the end of this report.

Except for very minor efforts, a traffic control plan (TCP) is normally prepared for most construction or maintenance projects. The TCP focuses on work zone traffic control, specific detour routes, and construction procedures. Traffic demand on the facility under construction is accommodated either within the roadway or through detours that carry traffic around the work area. Traditional TCPs consist of (1) sharing the roadway between traffic and construction or (2) rerouting traffic onto other facilities using conventional traffic control devices and setups. Nontraditional TCPs typically may add contractual requirements to accelerate the work, introduce techniques to reduce the work space and time needed to complete the work, or shift the work to periods with less traffic (i.e., nights or weekends).

A conceptual framework of a TCP will have been developed within the process that resulted in the decision to work at night (see *NCHRP Report 475*). The detailed TCP must then be developed following the principles of the MUTCD and the guidelines provided in Chapters 1, 2, and, to some extent, 3 of this document. When the detailed TCP is finalized, an operational plan must be developed that will address the issues of staffing, training, oversight, accessibility of site, setup and takedown, and emergencies and contingencies. The development and implementation of this operational plan is the subject of Chapter 3.

Seven typical application diagrams (TADs) for night work are included in Appendix A. They illustrate recommended enhancements to accommodate the added risks inherent in working at night. These TADs are based on TADs currently in the MUTCD.

CHAPTER 1

DESIGN REQUIREMENTS FOR VARIOUS TRAFFIC CONTROL OPTIONS

1.1 ROAD CLOSURE AND DETOUR

Because traffic volumes are typically lower at night, it is often feasible to completely detour traffic from a facility to allow full access to the roadway for the construction or maintenance. The advantages of this approach are discussed in *NCHRP Report 475: A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance* (*2*). However, a number of factors discussed in *NCHRP Report 475* pose special concerns for the design of closures and detours for use in conjunction with nighttime construction. These factors require the use of enhanced designs and devices to ensure that drivers can safely and easily traverse detours at night and that the roadway closures are completely effective in keeping traffic out of the closed facility. Because workers and equipment are less visible at night, any vehicle that circumvents a roadway closure and reaches the area of construction activity represents a potential for a catastrophic accident. This concern is magnified at night by the increase in the number of impaired drivers.

Depending on the nature of the facility where the work is performed and on the highway system available in the area, different detour options may be available, including the following:

- Traffic may be detoured off the facility onto other roadways using a fully designated detour route.
- Traffic may be detoured onto a service road adjacent to the primary facility.
- Traffic may be detoured onto a street or highway, such as an arterial, that parallels a freeway but shares the same corridor.
- Traffic may be restricted from a facility without the designation of a specific detour. This option is normally limited to arterials and local streets that do not carry significant nonlocal traffic and to areas where parallel streets provide obvious alternate routes for the detoured traffic.

Designated or undesignated detour diversions may be provided to remove a portion of the traffic in advance of the work area or the primary. Such diversions may permit the remaining traffic to be carried through the work area or on a detour that cannot carry the entire traffic volume.

The guidelines in this chapter provide specific recommendations to enhance the design and performance of the various roadway closures and detours at night.

Specific information on design requirements for traffic control devices, including safety issues, is contained in Chapter 2. Examples of roadway and ramp closures are provided in night work typical application drawings 2 and 3 (NWTA-2 and -3) in Appendix A.

1.1.1 Advance Warning Signs

Because drivers are often less alert and are more likely to be impaired at night, the use of advance warning signs in advance of roadway closures and detours is especially important.

1.1.1.1 Content of Signs for High-Speed Roads

For high-speed roadways, the DETOUR (W20-2) or ROAD CLOSED (W20-3) signs are typically used.

Where the construction activity will be a distraction to traffic, or where construction vehicles may be entering or exiting the roadway to access the work site, the ROAD WORK (W20-1) sign should be placed upstream from the DETOUR or ROAD CLOSED sign.

1.1.1.2 Spacing of Signs for High-Speed Roads

For most situations, the warning should be repeated at appropriate distances (see Table 6C-1 in the MUTCD) to ensure that drivers see one or more of the signs and comprehend the warning. For facilities with higher speeds, a total advance warning distance of 0.80 km (0.5 mi.) for conventional highways and 1.6 km (1 mi.) for expressways and freeways normally provides adequate time for drivers to prepare for the upcoming maneuver. Because speeds are often higher and drivers less alert at night, the spacings in Table 6C-1 from the MUTCD may need to be lengthened.

1.1.1.3 Content of Signs for Low-Speed Roads

For low-speed roadways carrying light traffic volumes, a single advance warning sign using the AHEAD legend instead of a specific distance may be appropriate.

1.1.1.4 Spacing of Signs for Low-Speed Roads

As shown in Table 6C-1 in the MUTCD, spacings as small as 30 m (100 ft) between signs are reasonable for urban facilities with low speeds.

1.1.1.5 High-Speed Roads with Long-Distance Traffic

In extreme cases where long-distance traffic must be detoured from freeways, longer advance warning distances provided by additional warning signs or supplemental devices, such as changeable message signs (CMSs), may be considered (see Section 2.3)

1.1.1.6 Voluntary Diversions

Standard advance warning signs are normally not required for voluntary diversions, even if the alternate route is signed. However, some sort of advance notice is desirable. Regardless, advance information and advance notice are both important, as discussed in Section 1.1.8.

1.1.1.7 Mandatory Diversions

Where diversions are actually mandatory detours for a portion of the traffic stream, such as trucks, advance warning must be provided according to the previous guidelines.

1.1.2 Route Signs

Detour signs and markers, as discussed in Section 6F.50 of the MUTCD, are critical components of nighttime detours to guide drivers along the temporary route and back to the highway beyond the temporary traffic control zone. Basic principles for route signing, including detours, are provided in Section 2D of the MUTCD. Several examples of route sign layouts are provided in Section 6H.01. Those principles remain valid at night and are not repeated here. However, because of the added difficulties and uncertainties involved in navigating an unfamiliar detour at night, the following recommendations for route guidance are offered as enhancements to improve the effectiveness of detour signing at night. It is most important that when the detour is active only at night, all temporary signing must be removed or covered during the removal of the temporary traffic control devices when normal traffic flow is restored.

1.1.2.1 Route Marker Assemblies

Standard route marker assemblies with the DETOUR (M4-8) marker should be used whenever possible when the closed highway is a numbered route. Use of the DETOUR sign *alone* on numbered routes should be limited to emergencies or for confirmation on very short detours where the route is apparent.

Strict adherence to the use of advance route turn assemblies, directional assemblies, and confirming or reassurance assemblies is especially important. Frequent use of reassurance assemblies at any point that may potentially raise a question for a driver is more essential for nighttime construction detours, since other visual clues are missing and many of the drivers may be unfamiliar with the route.

1.1.2.2 Route Marker Size

Increasing the size of the route detour markers should be considered for routes carrying substantial traffic volumes, especially where truck traffic and multilane roadways may require enhanced legibility to ensure that drivers see the signs far enough in advance of turn points.

1.1.2.3 Posting on Multilane Roads

Posting route assemblies on both sides of multilane roadways offers increased assurance that drivers will see the route assemblies in advance of turns, especially where truck traffic is high or roadside lighting from nonhighway sources makes the route assemblies difficult to see.

1.1.2.4 Intersecting Roadways

In addition to route assemblies along the detour route itself, route assemblies should be provided on intersecting roadways to assist drivers who may need to enter the detour and follow it to the reopened roadway at the end of the detour. This provision is especially important if the intersecting roadway leads to a closed entrance or to another intersection with the closed roadway.

1.1.2.5 Closure Spanning More than One Exit or Interchange

If the closure spans more than one exit or intersection of the closed roadway, it will be essential to provide detour signing from any closed intermediate entrances or intersections. These secondary detours may lead to the main detour or may lead directly to the reopened roadway at the end of the main detour.

1.1.2.6 Detour Arrows at Closure Points

The detour arrow (M4-10) sign should be provided at the actual points of closure or start of the detour, mounted on or above the barricades. On freeways and expressways, where barricades are used to channelize traffic onto a ramp at the closure point, the sign should be mounted above the barricades and perpendicular to traffic. Placing the sign on a separate support behind the barricades may be most effective.

1.1.2.7 Streets and Minor Roads

The normal DETOUR (M4-9) sign may be used for streets and other minor roads, but use of a street name DETOUR sign with this sign will enhance driver confidence and may help to smooth traffic flow.

1.1.2.8 Diversions or Alternate Routes

Designated diversions, or alternate routes, should be provided with route signing as necessary to ensure that traffic can easily return to the main route. Where the alternate route carries traffic directly back to the intended route, no further signing may be necessary. If, however, the intended diversion is not clear, it may be desirable to sign the alternate route using black-on-orange ALTERNATE (M4-1) panels in place of DETOUR panels.

1.1.3 Barricades and Channelizing Devices

A combination of devices is necessary to form road closures at detour points. Type III barricades are required by the MUTCD to form closures. In addition, other types of channelizing devices may be necessary to form lane closures in advance of roadway closures or to otherwise channelize traffic in preparation for the detour movement. The following guidelines are provided for the use and layout of these devices at closure points.

1.1.3.1 Closures at Intersections or Entrance Ramps

For closures at intersections or at the start of entrance ramps, Type III barricades must be extended completely across the roadway. If local traffic is allowed beyond the point, however, adequate gaps must be left between barricades to permit traffic access. Where space permits, it is desirable to place at least one device in the center of the road, and one on each shoulder.

1.1.3.2 Passage for Construction Traffic

Where only construction traffic is permitted past the closure point, access for the construction traffic should be provided in a manner that discourages other traffic from entering the closed roadway. This may be done by leaving the construction traffic opening on the shoulder or even requiring construction traffic to go over a mountable curb.

To further discourage impaired drivers from entering closed roadways using openings left for construction vehicles, Type III barricades or other large channelizing devices may be used to form a chicane, forcing traffic to move from one side of the road to the other to maneuver around the devices.

1.1.3.3 Sight Distance at Intersections

Placement of the Type III barricades must consider intersection sight distance for vehicles that must pass the barricades when exiting the closed facility, such as local traffic, construction vehicles, or exiting traffic on two-way ramps or roadways. An increase in sight distance can generally be accomplished by setting the barricades back several feet from the edge of the through lanes.

1.1.3.4 Redundancy

Redundancy (in the form of backup devices) is desirable for all road closures to stop vehicles that either unintentionally or intentionally circumvent the primary closures. At a minimum, an additional set of Type III barricades should be provided at some distance beyond the primary closure. Other backup measures are discussed in Section 1.1.6.

1.1.3.5 Expressway and Freeway Closures

Detours on expressways and freeways are accomplished by first closing lanes to restrict traffic to the number of lanes available on the exit ramp or other transition to the detour facility. Lane closures are addressed in detail in Section 1.2. Channelizing devices used to form the lane closures should follow the same criteria as for other lane closures. However, at the point where the final taper is formed to direct traffic off the closed roadway onto the exit ramp or transition roadway, Type III barricades are typically necessary to effect closure. These devices should be closely spaced to form a continuous array such that vehicles cannot pass between them. See MUTCD Section 6F.60. Depending on the geometry of the taper, the retroreflectivity of closely spaced barrels (or other large, three-dimensional channelizing devices) with a one-directional large arrow (W1-6) sign may provide greater target value at night than the two-dimensional barricade would.

A second set of Type III barricades should be provided completely across the closed roadway just beyond the exit ramp gore or closure point, leaving room along the far shoulder for construction traffic to pass.

1.1.3.6 Channelization on Deceleration Lanes and on Off-Ramps

It may be necessary to provide a second row of channeling devices along the shoulder of the deceleration lane and along the off-ramp approaching the exit point if the width is such that the exiting traffic might attempt to pass slower traffic or form two lanes. The width between the Type III barricades and the supplemental devices should be sufficient for trucks and other large vehicles to negotiate the lane change, but not sufficient to allow passing. Four and a half meters (15 ft) is often an appropriate width, but an adjustment to meet actual conditions may be necessary.

1.1.3.7 Ramp Closed, Main Line Open

In some cases, exit ramps may be closed in areas where traffic is present on the main line. If the travel lane adjacent to the ramp is closed, the channeling devices along the deceleration lane and ramp area should be closely spaced to emphasize the closure and to prevent traffic from crossing through the channelizing devices onto the ramp. If the adjacent lane is not closed, channeling devices should be used to form a shoulder closure upstream of the ramp and then should continue past the ramp. Type III barricades ought to be placed completely across the exit lane just past the exit gore. To further discourage traffic from attempting to use the exit, Type III barricades may also be placed at intervals across the deceleration lane and behind the row of channelizing devices. A spacing of 76 m (250 ft) is adequate for most situations, but adjustments should be made as needed.

1.1.4 Regulatory Signs at Closures

Sections 6F.08 and 6F.09 of the MUTCD identify the appropriate regulatory signs for road closures. RAMP CLOSED signs may also be appropriate. Placement of the signs is described in the same section. In cases where only a portion of the traffic is detoured, regulatory signs must be provided to address the specific situation. An example would be TRUCKS MUST EXIT. The following guidelines are provided to enhance the use of these signs for nighttime activities.

1.1.4.1 Placement on High-Speed Roads

Where traffic is diverted from expressways or exit ramps are closed, signs must be adequately sized to permit them to be read in advance of the decision point at the prevailing speeds. For higher approach speeds, especially where traffic is approaching the signs head-on, mounting these signs on separate supports just above the barricades may facilitate setup and handling and make the signs more noticeable to drivers.

1.1.4.2 Placement for Low-Approach Speeds

At intersections where traffic speeds are low, and especially if traffic is approaching parallel to the signs and barricades, mounting the signs on the face of the barricades, rather than above them, will improve their legibility, since they will be observed at much closer distances, and often under low-beam illumination.

1.1.5 Warning Lights

Warning lights offer excellent enhancement to channelizing devices and barricades, especially at night, by attracting attention to the devices and improving delineation under adverse conditions. The following guidelines are offered for the use of warning lights at nighttime closures and detours. Further discussion is presented in Section 2.1.6.

1.1.5.1 Flashing Lights on Barricades

Flashing warning lights are recommended on Type III barricades at closure points to attract attention to the closure. These devices may be especially helpful where reflectorized devices are frequently encountered by drivers throughout the temporary traffic control zone, and added emphasis on closures is desirable. Two flashers, one at each end of a 1.5-m (5-ft) barricade, provide good conspicuity for Type III barricades. Similar 1.2-m (4-ft) spacings may be used on longer barricades.

1.1.5.2 Type A or Type B Lights

Type A (low-intensity) flashing lights are generally adequate for night use if the batteries are kept in good condition. If the closure is placed before dark or extends into daylight, Type B (high-intensity) flashing lights may be needed if visibility in daylight is necessary. Type A lights are not effective in daylight.

1.1.5.3 Steady-Burn (Type C) Lights

Steady-burn (Type C) warning lights are discussed in depth in Section 2.1.6. These lights are intended to supplement delineation. However, because they are less effective than flashing lights in gaining attention, their hazard potential if impacted negates any benefit from their use.

1.1.5.4 When to Avoid Flashing Warning Lights

Because flashing warning lights create a potentially confusing "firefly" effect when installed in a longitudinal display, or when multiple transverse rows of flashers are visible to a driver, they should not be used for delineation. Flashers thus provide the greatest benefit when arranged in a single row across the closed roadway—generally perpendicular to the intended travel path.

1.1.6 Safeguards to Prevent Intrusion

Even well-designed closures may not be immune to intrusions into the closed roadway. This concern becomes more acute at night because driver impairment is more likely, darkness reduces visibility, and reduced traffic volumes may make drivers prone to ignoring regulations. Several methods are available to prevent either deliberate or inadvertent intrusions.

1.1.6.1 Intrusion Risk Assessment

The decision to employ any of the following intrusion safeguards must be based on a consideration of site conditions and of the potential danger of an intrusion. In suburban areas where impaired drivers may be traveling home late at night, the risk of intrusions may be higher. A history of impairment-involved accidents or arrests in the area may indicate the potential need for these safeguards. Closure points remote from the work area may pose greater risk because drivers cannot see lights or work activity and are, therefore, less aware of the construction activities, or they may believe they can use the closed roadway as a short cut. This situation is especially hazardous because the driver may travel for some distance at a high speed before encountering individual workers or the work operation.

1.1.6.2 Arrestor Nets

Commercially available arrester nets are installed across a closed roadway to prevent vehicles from entering. These devices consist of a chain-link fence attached to energy-absorbing anchors at each end. On impact, the fence entraps the front of the vehicle and brings it to a controlled stop. Deceleration rates of about 1 g are typical for passenger cars. A variety of anchorage systems that permit rapid deployment and removal for most situations are available. Depending on the approach speed, a deflection space of 30 m (100 ft) or more is required beyond the net to stop the vehicle. If construction traffic is allowed to enter, adequate room must be available outside the shoulder to permit vehicles to bypass the net and anchors. Full details on arrestor nets are provided in Section 2.6.8.

When nets are used, the preferred location is several hundred feet beyond the primary barricades. This permits the installation of a secondary row of barricades prior to the net, with sufficient braking distance for drivers to stop before striking the net if the intrusion is unintentional.

1.1.6.3 Impact Attenuator

Even though they are quickly removed and installed, arrestor nets may not be practical at some sites, especially if the closure is very short term. For such locations, a shadow vehicle equipped with a portable impact attenuator may be used in each of the closed lanes. This unit must be designed to safely stop vehicles under the expected range of approach speed and vehicle sizes. Warning lights and signs on these vehicles are essential to alert drivers prior to impact. Typical positioning at closures is beyond the secondary barricades, allowing adequate space for errant drivers to stop prior to impact with the attenuator.

1.1.6.4 Guards or Police

If space is provided for construction traffic to enter the closed roadway, determined drivers may attempt to circumvent the closure and arrestor net or impact attenuator. The deployment of civilian guards, or even of uniformed police officers, may become necessary. When used, the guard or police officer should be provided with clearly marked vehicles equipped with warning lights. Radio communication systems are also essential to communicate with other police units and with the construction staff in the event of an intrusion.

If a guard is used in conjunction with or instead of an arrestor net or impact attenuator vehicle, the guard vehicle must be stationed in a safe location where it is readily visible, but not at risk of being impacted in the case of an intrusion. In no case should the patrol guard vehicle be parked within the deflection space of the safety net or in the roll-ahead distance of the attenuator vehicle. The use of enforcement for speed control is discussed in Section 3.3.11.

1.1.7 Improvements to Detour Routes

It is important to ensure that detour routes can accommodate the traffic demands placed on them at an acceptable level of service and safety. Night work can be expected to place added demands on detours because of higher-than-normal traffic volumes, reduced visibility, and impaired drivers. The following guidelines address the safe, efficient operation of nighttime detours.

1.1.7.1 Detour Geometrics

The basic geometrics of the detour must allow safe accommodation of the anticipated traffic. Although it is rarely feasible to widen the pavement or improve alignment along an entire detour, it may be feasible to make spot improvements to eliminate problem locations on a detour route that is otherwise acceptable. Such improvements may include minor widening at intersections, eliminating parking to effectively increase roadway width, or even reconstructing isolated bottlenecks.

1.1.7.2 Pavement Markings

High-quality pavement markings are essential for unfamiliar drivers at night. Unless the detour is very short, operates at a very low speed, or includes a high level of roadway illumination, highly visible pavement markings should be added to the detour route if not already present. This addition should include edge lines, centerlines, and lane lines. The addition of raised pavement markers to pavement stripes provides an added benefit at night, especially in areas subject to fog or frequent rainfall.

1.1.7.3 Warning Signs

The size and retroreflectivity of warning signs along the detour may need to be upgraded, additional signs may need to be added, or both because of the increase in traffic volume along this route.

1.1.7.4 Intersection Control

Intersection controls must be adequate to accommodate the added detoured traffic. If existing controls are inadequate, it may become necessary to add STOP or YIELD signs or even traffic signals. The design of such controls must consider both the normal daytime flows and the increased detour volumes at night. In some cases, existing signal systems may require upgrading or different signal phasing to efficiently handle the different flow conditions between day and night.

1.1.7.5 Fixed Roadway Lighting

Roadway lighting at selected intersections or even along the entire detour may be considered, especially if the closed roadway is fully lighted or if the detour route includes difficult alignment or intersections. Temporary lighting may be very effective in reassuring drivers that they are following the correct detour route and in assisting them to correctly navigate complex or potentially confusing decision points.

1.1.7.6 Pavement

The pavement structure must be able to accommodate the increased detour traffic. In some cases, the owner of a potential detour facility may require overlaying the detour route as a condition for approval to use the facility as a detour. Where the pavement surface is already in poor condition or where the detour traffic may result in pavement deterioration, a pavement overlay may be necessary prior to placing traffic on the detour.

1.1.8 Detours and Diversions

Detours and diversions function most effectively when drivers are alerted in advance concerning the nature of and the reason for the detour or diversion. Guidelines for related public awareness activities are provided in detail in Section 3.6.

Diverting a portion of the traffic away from a temporary traffic control zone often eases the task of accommodating the remaining traffic. Likewise, a partial diversion may make it feasible to accommodate the remaining traffic on a detour route that could not otherwise safely or efficiently carry the entire traffic flow.

1.1.8.1 Truck Diversions

In some cases, diversions of trucks may permit a detour to carry the remaining passenger vehicle traffic. A typical example is a detour route through or adjacent to residential areas where truck traffic would be especially objectionable at night.

1.1.8.2 Advance Signing

To work effectively and to help drivers willingly follow diversions, diversions must be signed well in advance. If presented with a last-minute decision, drivers may choose to stay on the primary route. CMSs, highway advisory radio, or both can be particularly effective for this purpose.

1.1.8.3 Advance Notice

Providing notice in advance of the start date of the night work allows commuters and other drivers who frequent the route to plan an alternate route in advance. Such notice should clearly specify the location, dates, and times of the planned work, as well as the other routes affected. Methods and guidelines for providing advance notice are discussed in Section 3.6.

1.2 LANE AND SHOULDER CLOSURES

Night work operations frequently involve the temporary closure of traffic lanes or shoulders to permit work operations to occur during periods of reduced travel, with the lanes reopened during the day to restore full capacity. Occasionally, long-term lane or shoulder closures are used during night work to permit multiple work shifts or to permit operations such as concrete placement to proceed during cooler night hours. Basic considerations for lane closures are presented in the MUTCD (Chapter 6C and other chapters). These considerations include the definition of the basic temporary traffic control zone components: the advance warning, transition, activity, and termination areas. Buffer spaces are a key part of the activity space. Figures 6C-1 and 6C-2 in the MUTCD display the basic components of temporary traffic control zones.

This section provides an overview of related information from the MUTCD, as well as additional considerations that are especially applicable to nighttime work operations. Different types of operations involving lane or shoulder closures that may be used at night include the following:

- Short-term, relatively long closures for paving and pavement work (such closures are typically relocated on a nightly basis or even during a night);
- Short-term, shorter closures for localized operations, such as bridge work;
- Long-term closures of various lengths for major construction, such as bridge replacement or full-depth pavement reconstruction; and
- Nightly closures at a fixed location that are removed daily to restore capacity during peak or daytime travel periods.

Although these situations share many common problems, different approaches provide specific advantages in certain situations. Reduced visibility and driver/worker impairment introduce special concerns at night. Enhanced advance warning, larger buffer space, better separation of successive or conflicting traffic movements, and positive driver guidance at decision points all become more critical. These approaches will be discussed in the subsections that follow.

Examples of lane and shoulder closures for night work are shown in NWTA-1A, -2, -4A, -4B, -5, and -7, in Appendix A. NWTA-1B and -1C show setup and adjustment details.

1.2.1 Starting Points for Closures

A key decision in designing lane or shoulder closures is selecting the best possible location to start the closure. The advance warning area discussed in Section 6C.04 of the MUTCD includes features that must be provided to alert drivers prior to the actual start of a lane or shoulder closure. To be effective, the devices in the advance warning area must attract driver attention and convey the necessary information. Because drivers are frequently less alert or not expecting to encounter closures at night, approaches that are acceptable during daylight may need enhancement to ensure effectiveness at night. The following guidelines are offered to address nighttime concerns relative to locating the start of lane and shoulder closures.

1.2.1.1 Conflict Points

Closures should be started as far away from other conflict points as possible so that drivers can focus attention more directly on the closure. Potential conflicts include on- or off-ramps, intersections, major traffic guide signs, or CMSs. Any of these features may distract a driver's attention from the closure such that a potential for a conflict arises.

The MUTCD suggests a minimum distance between successive closures equal to twice the normal lane closure taper length (see Section 1.2.2 for a discussion of taper lengths). Considering reduced visibility and the effects of driver impairment at night, considerably longer separations reduce the potential for drivers missing critical information and conflicts arising. When site conditions permit, placing the actual start of the lane or shoulder closure (defined in the MUTCD as the start of the transition area) 30–60 s travel time beyond other decision points provides time for a driver to adjust to the upstream pattern and focus on the upcoming closure. When conditions are such that drivers will be faced with potential conflicts or driver decision points downstream of the taper, it is likewise helpful to provide 30–60 s for traffic to acclimate.

1.2.1.2 Sight Distance

Locating closure points to provide good sight distance to the taper is especially important at night. Locating tapers downstream of horizontal curves or vertical crests makes it difficult or impossible for drivers to see the approaching transition. Roadside features such as traffic barriers, roadside vegetation, bridge piers and abutments, or various other features may reduce sight distance even on relatively flat or straight road alignments. When project conditions permit, locating transitions away from features that restrict sight distance improves merges and shifts as drivers approach the transition, thus reducing the potential for forced or late merges, sudden speed reductions, and other potential conflicts. Providing the driver with decision sight distance (DSD) to transition points is helpful in smoothing operation during higher traffic periods. DSD is the distance at which drivers can detect a hazard or a signal in a cluttered roadway environment, recognize the threat potential, select an appropriate speed and path, and perform the required maneuver safely (*4*).

1.2.1.3 Recovery Areas

In addition to buffer spaces to separate the travel lane and work spaces (see Section 1.2.3), roadside recovery areas upstream of and through the transition area of lane and shoulder closures are important. These recovery areas provide drivers with an area to regain control of the vehicle and to safely stop or return to the travel lane when a conflict or driver error occurs. Because the transition area requires driver responses, such as merging or slowing, the potential for conflicts and errors leading into and within the transition area increases.

Locating the transition area to take advantage of an available roadside recovery area is the easiest way to address this concern. Transition area locations that include bridges, large sign structures, nontraversable side slopes, and other roadside features that represent potential hazards reduce the likelihood of a driver recovering from a conflict or driving error. Often, moving a transition area by a few hundred feet can place the transition maneuver where improved roadside recovery area is available.

As with existing roadway features, construction features may also detract from the availability of roadside recovery areas. Locating transitions away from material stockpiles, roadside construction operations, vehicle or equipment staging areas, and parking areas for workers' vehicles may improve available recovery area.

1.2.2 Layout of Transition Area

Within the transition area, the normal traffic pattern is changed to provide for both travel and work spaces within the activity area. Typical changes include merges for lane closures, speed reductions as drivers react to construction activities adjacent to the travel lane, increased congestion, and momentary stops.

1.2.2.1 Taper Lengths

Tapers are used to provide gradual merges and lateral path changes where lanes are closed or shifted, or drivers react to activity on the shoulder. Use of large, closely spaced channelizing devices and an arrow panel in lane closure tapers (see Figure 1) provides adequate guidance for drivers at night work sites. Recommended taper length criteria are provided in Table 6C-2 of the MUTCD, which is reproduced in Tech Note 1.

As discussed in Section 6C.08 of the MUTCD, adjustment of taper lengths to accommodate site conditions is important. For high-speed, free-flow conditions, the recommended lengths are desirable minimums, with shorter lengths likely to result in forced merges and abrupt braking. When other roadway features such as intersections and ramps interfere with taper layouts, some shortening of the taper may provide acceptable results, especially if speeds are not high. However, for free-flow conditions with higher speeds, relocating the taper to provide greater length may improve operation. Where speeds are low, especially with higher traffic volumes, longer tapers may result in sluggish flow by encouraging drivers to compete for position in the open lane beyond the taper. (See Tech Note 2.)

Figure 1. Lane closure taper.

1.2.2.2 Adjustment of Taper Lengths for Night Work

Longer taper lengths may be needed to accommodate reduced driver alertness and slower response times at night. Especially for high-speed roads, taper lengths longer than those in Table 6C-2 of the MUTCD may reduce conflicts at merge and shift points. When tapers are left in place for several hours, traffic volume may decrease and speeds may increase markedly later in the night. In such cases, partly lengthening the taper through the night may be worth considering. When the taper is established, an adjustment of the taper length can normally be accomplished easily by a lateral adjustment of the channelizing devices. However, this adjustment must be planned in advance so that the adjusted taper length does not encroach on or taper beyond the activity area.

1.2.2.3 Monitoring Transition Operations

Regardless of traffic changes during the course of the work, operational characteristics of the transition must be monitored and adjustment in the taper length made in response to problems or conflicts. Shortening a taper under low-speed conditions may improve operations, encouraging drivers to merge sooner and more smoothly rather than attempting a forced merge at the downstream end. On the other hand, if maneuvers such as abrupt braking are observed under high-speed, free-flow conditions, a longer taper may result in smoother merges.

1.2.2.4 Shoulder Tapers

Because work operations or equipment and vehicles on shoulders may startle inattentive drivers, adequate tapers are especially important for shoulder closures at night. Criteria for shoulder taper lengths are provided in Table 6C-2 of the MUTCD.

1.2.2.5 Separation Between Tapers

Where successive tapers or other changes are introduced within a transition area, the principles for reducing conflicts (discussed in Section 1.2.1) are important. A separation of twice the normal taper length between successive tapers or between other decision or conflict points provides time for drivers to acclimate to the first change and observe traffic control devices for the second change.

1.2.3 Layout of Activity Area

The layout of the activity area must provide a clear separation between the travel and work activity spaces and should provide buffer spaces to provide added protection when drivers or workers inadvertently stray from their intended areas.

The conceptual layout of the activity area is defined in Figure 6C-1 of the MUTCD. Considering the higher risk of driver error at night combined with the presence of workers in the work space, the inclusion of longitudinal and lateral buffer spaces in the activity area is especially desirable.

1.2.3.1 Longitudinal Buffer Space

Additional length of closed lane or shoulder between the downstream end of the taper and the start of the work space provides a recovery area for drivers who fail to merge or fail to stay in the proper driving lane. To be effective, this buffer space must be kept completely free of workers, vehicles, equipment, and any other obstructions or hazards. Although any length of buffer space is helpful, the increased risks associated with night work make it especially desirable to provide adequate length for drivers to recover or stop at the anticipated operating speeds. Section 6C.06 of the MUTCD provides guidelines for the use of longitudinal buffer spaces. The length may be based on the braking distance portion of AASHTO stopping distance guidelines, although shorter lengths are still worthwhile if longer buffer spaces cannot be provided.

When a shadow vehicle with impact attenuator is placed in advance of the work space, it defines the downstream end of the buffer space. An errant vehicle can breach the taper anywhere through the taper length. Although the taper itself is not included in the length of the buffer space, the closed portion of the lane or shoulder within the taper must also be kept clear of potential hazards.

1.2.3.2 Lateral Buffer Space

Reduced visibility, combined with poor driver performance, increases the importance of lateral buffer spaces in night work operations. The lateral buffer space may be provided to separate traffic and workers or to separate vehicles from other hazards and obstructions adjacent to the travel lane. On undivided roadways, lateral buffer space may also separate opposing traffic flows.

No established criteria address the width of lateral buffer space. The width should be based on engineering judgment and on an analysis of work site characteristics. However, devices used to create a buffer space should not reduce the lane width to less than 10 ft. When the work space occupies the shoulder of a multiple-lane roadway or an outer lane of a three-or-more-lane roadway, consideration should be given to closing the lane adjacent to the work space to provide a lateral buffer. This option is suitable when traffic demand does not exceed the capacity of the remaining open lanes such that congestion occurs and queues develop. Closing an additional lane to form a lateral buffer when objectionable congestion does not occur may reduce speeds somewhat and have a calming effect on traffic through the activity area.

When a lane adjacent to the work space can be closed, the closing provides the added advantage of allowing the channelizing devices or portable barrier used to form the closure to be placed in the closed lane. This placement maintains the full width of the open lane and permits smoother traffic flow past the work space, which may reduce the potential for conflicts on the opposite side of the travel lane.

When an additional travel lane cannot be closed as a lateral buffer, the need for a buffer remains, especially if workers or equipment are present in the lane adjacent to the open travel lane. When only a single travel lane remains open and a shoulder is available on the opposite side, placing the channelizing devices on the travel side of the lane line provides a small amount of buffer by moving traffic laterally toward the shoulder.

1.2.3.3 Lateral Buffer Space with Barriers

Drivers tend to move away from roadside obstructions, especially at the obstructions' point of introduction. This effect applies to positive traffic barriers, whether permanent or portable, and may be more pronounced at night because the barrier may be less visible. Shy-line offsets, intended to reduce driver reaction to the introduction of such hazards, are discussed in the AASHTO *Roadside Design Guide* (*5*) and may be used to assess lateral buffer space widths. Suggested shy-line offsets for various speeds are given in Table 5.4 of the AASHTO *Roadside Design Guide*.

Typically, positive barriers should be placed as far away from the travel path as conditions permit, providing the lateral buffer between the travel space and the barrier. Because the barrier provides positive control of errant vehicles, additional buffer space is normally not needed between the barrier and work space or roadside hazard, except as necessary to accommodate dynamic barrier deflection. For channelizing devices, however, it is necessary to place the devices immediately adjacent to the travel space, providing the buffer space beyond the devices.

When space permits, especially if reflective pavement markings or other positive delineation cannot be provided, placing channelizing devices to form a lateral buffer between the travel space and the barrier provides added protection against drivers impacting the barrier.

1.2.3.4 Flagger Use for Lateral Buffers

When restricted site conditions make it impractical to provide a reasonable width of lateral buffer adjacent to the work space, it may be possible to shift traffic away from concentrations of workers and equipment, such as a paver operation, using flaggers. Guidelines for flagger use in nighttime operations are discussed at length in Section 2.5. When used, flaggers must be located upstream of the work operation and be made as visible as possible to approaching traffic. The flagger signal should be intended to encourage drivers to slow down and shift away from the work space. For this application, it is helpful for the flagger to carry an audible warning device that can be activated if a vehicle appears to present a threat to workers in the work space. This audible warning device is one form of an intrusion alarm. Others are discussed in Section 2.6.9.

1.2.4 Intrusion Protection for Lane and Shoulder Closures

When feasible, intrusion protection is desirable to protect workers from errant vehicles that may enter the work space. Section 2.6 provides details of some safety features that may be used to prevent intrusions. Because most nighttime lane and shoulder closures must be quickly set up and removed, devices that can be quickly deployed are most useful. Shadow vehicles equipped with truck-mounted attenuators are especially good choices.

1.2.4.1 Temporary Barrier

Temporary barriers greatly reduce the risk of errant vehicles intruding into the work space or contacting other hazards. Although most nighttime work operations would benefit from the positive protection that a barrier provides, considerations of setup time and width restrictions often make barrier use impractical or impossible. Even lightweight plastic barriers require some time to deploy and entail an exposure of the setup operation to traffic. When lanes must be reopened on a daily basis to accommodate traffic demands, the nightly deployment of portable traffic barriers is rarely practical. However, a moveable concrete barrier fitted with retroreflective markers may be applicable for such situations.

Fixed temporary barriers may also be suitable to separate shoulder work spaces from traffic. Contractor access to the work space must be considered. In some cases, access may be available from outside the shoulder or from the ends of the work space. In other cases, it may be possible to provide access during nighttime work periods by temporarily closing the lane adjacent to the shoulder. In these latter cases, the barrier provides protection of the work space, with activity in the closed lane limited to material deliveries and similar operations.

1.2.4.2 Barrier Warrants

Established warrants to guide decisions on temporary barrier application in work zones are not available. Such decisions must be made on the basis of an analysis of the comparative costs and benefits of performing the work with and without the barrier. Factors considered include the nature of the hazard if a work space intrusion occurs, traffic speed and volume, availability of lateral buffer space, duration of the work activity, and accident history of the facility. Conventional portable concrete barrier is most likely to be cost-effective to protect shoulder closures when traffic volumes and speeds are relatively high, because workers will frequently be present in the closure and the closure will be in effect for an extended period.

A moveable concrete barrier can be easily and quickly shifted laterally to close or reopen travel lanes with minimal traffic impact during the shift. This barrier is, thus, suitable for use when lane closures must be implemented and removed on a regular basis. Although this barrier is easily shifted laterally, longitudinal relocation entails extensive time and effort. This type of barrier is, therefore, generally suitable when the work space remains in a fixed location for some time. The cost of the movable barrier and transporter machine is relatively high—typical recent applications in New York State were on the order of $1 million. However, for facilities carrying high volumes of high-speed traffic, where the setup will be in place for some time, a movable barrier may be cost-effective (*6*).

1.2.4.3 Barrier Length

Even though it is a safety feature, a portable traffic barrier represents a potential hazard in that it may be impacted by errant vehicles. Furthermore, its use adds to traffic control costs and requires time to install and remove. The length of the temporary barrier must, therefore, be limited to only that length needed to protect the work space or other hazards. Because the primary function of a portable barrier is intrusion protection and not channelization, one must first form lane or shoulder closure tapers using channelizing devices and then form an appropriate longitudinal buffer space prior to introducing the barrier.

1.2.4.4 Barrier Layout and End Treatments

Ends of portable barriers represent a significant hazard if impacted, even at low speeds. One must, therefore, either install the upstream ends of the portable barrier to minimize the chances of vehicle impact or protect the barrier end by means of an acceptable barrier terminal. The risks of end impacts and adverse driver reaction to the barrier end are both reduced by flaring the barrier end away from traffic. Low flare rates produce longer flared sections and may increase the number of impacts with the temporary barrier. Higher flare rates produce shorter flared sections and fewer impacts, but may result in an increase in the severity of redirection accidents and may increase the number of barrier penetration accidents. Benefit-cost analyses of temporary concrete barriers indicate that total accident costs may be minimized for flare rates ranging from 4 : 1 to 8 : 1. A flare rate of 5 : 1 or 6 : 1 may be slightly more favorable for urban streets with high traffic volumes where speeds are lower and impact angles are higher (*6*).

The AASHTO *Roadside Design Guide* discusses a number of treatments for barrier ends, including shielding behind existing barrier, burying the end in an embankment backslope, or installing a crash cushion. Whatever the treatment selected, it is essential to consider the need for access to the work site when designing the barrier layout.

1.2.5 Channelizing Device Characteristics

Channelizing devices are an essential part of lane and shoulder closures, even when portable traffic barriers are used to separate the travel and work spaces. Channelizing devices are required to form the closure taper and buffer spaces and to provide delineation throughout the temporary traffic control zone. To accommodate the added visibility requirements of night work, channelizing devices that are larger and more visible than those used in comparable daytime applications are desirable. When these devices are used by themselves to separate the traffic and work spaces, it is especially important that they provide a highly visible and clearly defined separation. Section 2.1 provides guidelines for the selection of channelization devices.

1.2.6 Channelizing Device Layout

To clearly guide drivers through the temporary traffic control zone and to reduce the risk of drivers straying into the work space or other areas not intended for traffic, devices must be spaced closely enough to discourage both inadvertent and deliberate intrusions. The MUTCD recommends a device spacing in feet equal to the travel speed in miles per hour in tapers, and double the travel speed in tangents. From nighttime work experience, the New York State DOT (NYSDOT) found that frequent intrusions occurred in nighttime work areas using these spacings and subsequently reduced spacings to discourage intrusions (*6*). Guidelines for device spacings follow.

1.2.6.1 Taper and Tangent Spacings

As traffic speeds decrease, closer device spacings are needed to provide the same visual effect as drivers pass the devices. Large, closely spaced channelizing devices, such as the drums in Figure 2, clearly define closed lanes at night. Based on successful experience by NYSDOT, the spacings in Table 1 appear to discourage intrusions in tapers and tangent sections of lane and shoulder closures.

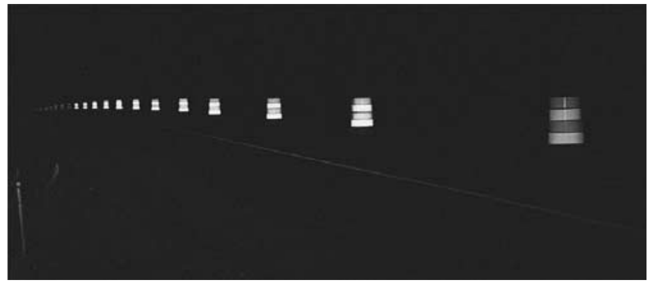


Figure 2. Large, closely spaced channelizing devices.

The longest allowable spacing is equal to the broken lane-line spacing and is, thus, easy to follow during setup. When conditions indicate the need to more clearly define the travel path or further discourage intrusions, even closer spacings may be used, especially if smaller devices such as cones or tubular markers are used.

Especially with the larger devices—drums, barricades, and 30-cm (12-in.)-wide vertical panels—the device spacings in Table 1 appear to create a nearly solid wall of orange and white reflectorized material as a vehicle traverses the traffic control zone.

When positive traffic barriers are employed, thus eliminating the risk of work space intrusions, device spacings on the order of those recommended in the MUTCD may be effective and will reduce setup and takedown time.

1.2.6.2 Spacing at Ramps and Intersections

Risks of drivers leaving the intended travel lanes are greater at decision points where a driver must select between two or more options, such as ramps and intersections. This is especially true if the normal path through the intersection or on the ramp is relocated or restricted. Ramps or intersections that are temporarily closed may be especially troublesome. To further clarify the correct travel paths in such areas, and to distinguish them from tangent sections, closer device spacings are effective. The channelizing device spacing should be reduced to half the normal tangent spacing or less to provide enhanced guidance through these critical areas (*6*).

1.2.6.3 Midlane Devices

Paving, pavement repairs, and other operations frequently involve long lane closures with the work operation moving

TABLE 1 Taper and tangent spacings

Estimated Operating Speed		Maximum Spacing	
km/h	mph	m	ft
30	20	6	20
50	30	9	30
70	40 or higher	12	40

throughout the closure during the night. Part of the time, long sections of the closed lane may appear to be unoccupied. This appearance presents a risk of impaired or careless drivers entering the closed lane and traveling some distance until encountering a work operation or some other hazard. This risk can be reduced by placing extra channelizing devices transversely across the lane at regular intervals to alert drivers who enter the lane. Placement of either (1) two drums, vertical panels, or Type II barricades or (2) one Type III barricade per lane is sufficient to effectively close off the lane. A spacing of approximately 225 m (750 ft) presents an obstacle approximately every 10 s for vehicles traveling 45–50 mph (72–80 km/h), but provides sufficient distance for a driver to stop or return to the proper lane.

Where contractors are using the closed lane for work vehicles, sufficient access must be retained. In some cases, work vehicles can pass the transverse devices on the shoulder. If multiple lanes are closed, device locations can be staggered between the adjacent lanes to provide a chicane effect. Where width is restricted and shoulder width is insufficient, some benefit can still be gained by placing the devices near each edge of the lane, leaving just enough width for work vehicles to pass between.

In the case of paving or similar operations, the transverse devices cannot be used through the active work area. However, it may still be possible to use the devices beyond the immediate work area, with the devices relocated throughout the night as the work progresses.

Finally, all open dig-outs and other excavations should be clearly marked.

1.2.6.4 Lateral Clearance Between Devices

It is often necessary to use two or more longitudinal rows of channelizing devices to define both sides of a travel lane or for exit and entrance lanes. In these locations, it is essential to control the width between rows of devices to restrict traffic to the intended number of lanes while providing adequate width to accomplish turning maneuvers required by the traffic pattern. Where excessive width is available, aggressive drivers may attempt to pass slower traffic, creating confusion and a potential conflict when the lane again narrows. Typical problem areas are locations where a single open lane shifts from one side of the roadway to the other, at on- and off-ramps. For tangent sections and flat curves, the normal lane width of 4 m (12 ft) is normally sufficient to permit smooth flow while discouraging high speeds. In shifts and other locations where some turning is necessary, especially if articulated vehicles are present, increasing the width between devices to 4.3 m or 4.9 m (14 ft or 16 ft) will smooth flow and reduce abrupt driver reactions. Except where severe alignment necessitates, more width, greater than 4.9 m (16 ft) between devices, may encourage drivers to form two lanes or attempt to pass.

1.2.6.5 Warning Lights

The use of warning lights to enhance the visibility of channelizing devices is covered in Section 2.1. Installing Type A, low-intensity, flashing warning lights on the first two channelizing devices at the start of a taper may be helpful to alert drivers to the change in traffic pattern. Type A lights may also be effective at other critical locations, such as exit ramp locations and on midlane devices. To avoid driver confusion, it is essential to limit Type A lights to only one or two at a specific location.

Because temporary lighting is typically present and large reflectorized channelizing devices are used, Type C, steady-burn lights are rarely necessary or effective for these applications.

1.2.7 Arrow Panels

Application of arrow panels is addressed at length in Section 6F.53 of the MUTCD. Because of arrow panels' demonstrated effectiveness in alerting drivers to lane closures and because of the higher risk to workers at night, arrow panels are highly recommended for all night lane closures.

1.2.7.1 When Not to Use Arrow Panels

Because an arrow panel operating in an arrow or chevron mode may encourage unnecessary lane changes, these devices are not recommended for functional traffic control for shoulder closures. Arrow panels operated in a caution mode may help to alert drivers at shoulder closures. However, the presence of the other devices discussed in these guidelines are effective by themselves. Adding the arrow panel detracts from available buffer space and adds little to the traffic control.

1.2.7.2 Location

To provide the earliest advance warning and to preserve the buffer space beyond the taper, the preferred location for the arrow panel is on the shoulder at the start of the taper. When shoulder width does not permit or when work site access must be maintained on the shoulder, placing the arrow panel some distance into the taper to permit locating the device partly or fully in the closed lane is an acceptable alternative, although not the preferred choice.

1.2.7.3 Size and Operating Mode

To provide the clearest and most visible message to drivers, the Type C panel is most effective, especially for expressway and freeway sites. Type B panels may be suitable for mobile operations or on lower-speed facilities if the panels' use offers operational advantages compared with the larger

Type C panels. Recommendations for arrow panels are contained in Section 2.4.

1.2.7.4 Brightness

Glare from arrow panels is a concern at night. Recommended brightness values for arrow panels to avoid glare problems at night are provided in Section 2.4.

1.2.8 Traffic Signs

General guidelines for traffic signs in night work zones are discussed in Section 2.2. Guidelines for specific sign messages and sign placement associated with lane and shoulder closures at night are provided in the following sections.

1.2.8.1 Advance Warning Signs

The ROAD WORK (W20-1) sign combined with two or more LANE CLOSED (W20-5) or SHOULDER CLOSED (W21-5a or 5b) signs provide the typical advance warning. Suggested advance warning sign spacings provided in Table 6C-1 of the MUTCD may be increased at night for added effectiveness, especially on high-speed freeways and expressways. Placement of the first advance warning sign 1 mi. or more upstream from the closure provides extra time for drivers to prepare for lane closures. Use of 0.80-km (0.5-mi.) and 457-m or 305-m (1,500-ft or 1,000-ft) distances on the LANE CLOSED/RIGHT SHOULDER CLOSED signs are generally used with the 1-mi. advance warning sign.

When there is a possibility of queues developing, longer spacings may be desirable and a BE PREPARED TO STOP (W20-7b) sign may also be needed. Placement of a lane reduction (W4-2) symbol or a RIGHT SHOULDER CLOSED sign 152 m (500 ft) upstream of the tapers is often used to further reinforce the start of the taper.

An advance CMS placed about 1 mi. upstream of the beginning of the transition can serve as a useful supplement to the lane closure signs and result in smoother lane change profiles. The CMS should be a supplement to and not a substitution for an arrow panel. Where a permanent CMS operated by a traffic management center is available, the CMS can provide drivers with advance warning during the day and the work period.

1.2.8.2 Static Arrows

The large arrow (W1-6) sign may be used within the taper to reinforce lane closures. Placement of one arrow sign midway along the taper reinforces the need to merge. When the arrow panel cannot be placed at the start of the taper because of space limitations, use of a large arrow sign may be helpful. This sign is not recommended at shoulder closures because it may encourage unwanted lane changes.

1.2.8.3 No-Passing Signs

When long lane closures are set up for night work, especially when the work activities occur only at scattered locations throughout the closure, it may be helpful to reinforce the closure. The DO NOT PASS (R4-1) regulatory sign may be placed periodically throughout lane closures where traffic is restricted to a single lane and there is a concern that vehicles may momentarily enter a closed lane to pass slower vehicles. Placement on the left and right side of the closed lane adds reinforcement. Spacing at 0.5-mi. increments is generally adequate.

1.2.9 Adjusting Lane Closures

Operations such as paving and pavement repairs often require work in each lane at a given location as the work progresses during the night. For certain other operations, the work may progress throughout the night such that the longitudinal location of the activity area changes. When the work operation changes from one lane to another, the lane or lanes closed to traffic must be changed as the night progresses. When the work moves longitudinally within the same lane, it is sometimes desirable to adjust the start and end point of the closure to minimize traffic delays. The following sections provide guidelines to address both situations.

1.2.9.1 Selecting Lanes to Close First

The decision of which lane or lanes to close first for paving and similar operations is based on consideration of requirements of the work operation, the number of lanes required to accommodate traffic at an acceptable level of service, and site characteristics. On a three-lane roadway with a wide shoulder on the right side, it may be preferable to first close the right lane, allowing the contractor to use the right shoulder for access while paving the right lane. Later in the night, when traffic demand has diminished, it is possible to adjust the setup to close the center and left lane, with the slower traffic flow confined to the right lane.

On two-lane roadways when traffic is heaviest, closing the left lane first may provide an advantage if the right shoulder is wider, the advantage being the wider buffer space that can be provided when traffic is heaviest.

1.2.9.2 Selecting Lane for Taper

It is generally preferable to place the lane closure taper in the lane that is to be closed first and to continue the closure through the activity area. This method avoids the need to shift traffic from one lane to another when traffic is heaviest. Later at night when traffic is lighter, a shift can be installed to move traffic back to the lane that was closed earlier. However, sight distance and traffic split between lanes should also be considered. All other things being equal, it is generally preferable (because of lower volume and fewer trucks) to place the taper in the left lane. This placement corresponds with paving the left lane first on two-lane roadways.

1.2.9.3 Shifting Closure Between Lanes

When it becomes necessary to change the travel lane from one lane to another, a momentary delay in traffic is necessary to allow workers to quickly adjust the channelizing devices to form the shift from one lane to the other. This delay can be accomplished by a police vehicle or work vehicle proceeding slowly or momentarily stopping in the lane upstream of the shift and then slowly leading the traffic through the shift into the new pattern.

If a police vehicle is used, the warning lights on the vehicle must be in operation. If a work vehicle is used, it must be equipped with warning lights and sign stating WORK VEHICLE—DO NOT PASS or a similar appropriate message.

To minimize the time needed for the shift to be accomplished, it is essential for the channelizing devices to be in place along the new traffic lane downstream of the shift in advance of the changeover. During the changeover, only the devices along both sides of the taper need to be adjusted. Sufficient workers must be present to make the change as quickly as possible.

When a lane closure change is planned during the night, it is essential to provide additional length of closure upstream of the activity area to accommodate the shift taper and to provide at least $0.5L$ tangent length between the initial closure taper and the shift taper.

For speed limits of 60 km/h (40 mph) or less,

L (in meters) = $WS^2/155$ and

L (in feet) = $WS^2/60$

where

W = width of offset and
S = posted speed, or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed.

For speed limits of 70 km/h (45 mph) or greater,

L (in meters) = $WS/1.6$ and

L (in feet) = WS

Longer separations between tapers—up to $2L$—may be helpful in smoothing traffic flow where space is available within the work zone.

1.2.9.4 Shift Signing

A large arrow (W1-6) sign should be placed in the new closed lane just beyond the start of the shift to direct traffic into the new lane. However, no arrow panel should be used for the shift because no lane change or merge is necessary.

1.2.9.5 Adjusting Closure Length

A lane closure can be easily extended from within the closed lane by simply extending the line of channelizing devices and adding supplemental signs and transverse channelizing devices as needed. However, it is essential that the work vehicle and workers not move beyond the end of the closure where they may be exposed to vehicles abruptly returning to the opened lane. A police vehicle or lighted and marked work vehicle ahead of the workers setting the channelizing devices provides protection against this risk.

1.2.9.6 Adjusting Start of Closure

Unless traffic delays necessitate the shortest possible length of closure, it may be preferable to leave the lane closure taper at its original location and simply extend the closure length as the work progresses. However, when traffic needs dictate that the taper be moved with the progress of the work, this move can be accomplished safely by setting up a second taper within the first closure at the new downstream location, working completely within the closed lane. After the second taper is fully in place, including the new set of advance warning signs, the previous channelizing devices are then picked up from within the closed lane, proceeding upstream against traffic from the new taper to the previous one. Finally, the first arrow panel and advance warning signs are removed.

To avoid confusion for motorists, it is important that the relocated taper is far enough downstream from the first one that the advance warning signs do not overlap and that drivers do not observe both arrow panels at once.

It is also much safer to make the adjustment under traffic when there is sufficient width on the shoulders upstream of the first taper for the work crew (1) to remove the arrow panel and (2) to pick up or cover the first set of signs. When these adjustments cannot be made safely, it may be preferable to simply leave the extended closure length in place throughout the night.

1.2.9.7 Middle-Lane Closures

For middle-lane closures on three-lane highways, closure of both the middle lane and one of the adjacent exterior lanes is the typical practice. However, if considerations of capacity and congestion do not permit the closure of two lanes, the available options are to either use a shoulder lane to replace the lost lane of traffic or split traffic to both sides of the middle lane, which results in the loss of only one lane.

If the middle closure is on a section where capacity requires two open lanes but shoulders cannot be used to maintain traffic, traffic must be split to either side of the work area. Signing and channelization for splitting traffic to both sides of the middle lane is described in the MUTCD TA-38. There is no standard advance signing for a traffic split.

In implementing the traffic split strategy, traffic should be reduced to two lanes well upstream of the split using a standard freeway lane closure. To discourage lane changing in the vicinity of the split, cones may be placed on the lane line beginning at the split and extending 300 m (1,000 ft) upstream. Closely spaced cones or other suitable devices are used to channelize traffic to both sides of the middle-lane work zone and to keep traffic out of the work area. An arrow panel may be placed in the closed middle lane just downstream of the split area. One or more shadow vehicles with truck-mounted attenuators should be parked in the closed middle lane to protect the work crew and to discourage traffic from weaving through the work area. See Section 2.6.7 for guidelines on the use of shadow vehicles. For middle-lane closures near exit ramps, signing may be needed in advance of the closure to indicate that the exiting traffic must use the right lane at the closure in order to use the exit. All other guidelines identified for single- or multiple-lane closures apply in the case of the middle-lane closure as well. (See Tech Note 3.)

1.3 LANE SHIFTS, DIVERSIONS, AND CROSSOVERS

Lane shifts, diversions, and crossovers used by themselves, or in addition to lane and shoulder closures may be used to provide additional work space in the activity area while providing an adequate number of lanes and lane widths to maintain traffic capacity at an acceptable level. Because traffic volumes are frequently lower at night, it is often possible to reduce the number of lanes through the temporary traffic control zone. Thus, lane shifts, diversions, and crossovers are often used in combination with a lane closure.

Several examples of temporary traffic control zones using shifts, diversions, and crossovers are provided in the MUTCD. An example of a median crossover for night work is shown in NWTA-5 in Appendix A. The following sections discuss appropriate applications of these techniques, with specific guidelines to address nighttime applications.

1.3.1 Lane Shifts

Lane shifts are relatively minor temporary lateral changes in travel path, with the shift generally taking place within or close to the lateral confines of the original travel lane or shoulder. Lane shifts are differentiated from diversions on the basis of the degree of the change in path from the original roadway. The lane shift may or may not involve the construction of a temporary roadway lane or section. Basic signing and channelization for a lane shift is shown in TA-36 of Part 6 of the MUTCD.

1.3.1.1 Advance Warning Signs

The ROAD WORK (W20-1) sign, either with the AHEAD legend or with specific distances, is appropriate for advance warning when the lane shift is at the start of the temporary traffic control zone. For night work on high-speed roads, especially on freeways and expressways, this sign should be repeated at various distances upstream. The advance warning sign spacings and distances recommended for lane closures are also appropriate for lane shifts when the shift is the first feature encountered. Refer to Section 1.2.8 for recommended sign placement.

1.3.1.2 When Not to Use Advance Warning Signs

When a lane shift occurs beyond the start of the temporary traffic control zone, such as within a lane closure, repeating the general ROAD WORK sign series is unnecessary and may be confusing. Adding unneeded signs is never a good idea. Considering the added difficulty of night work zones, it is especially important to avoid the use of any signs that do not fulfill a specific need.

1.3.1.3 Alignment Signs

The principal information needed for drivers as they traverse a lane shift area is the alignment of the temporary travel path. Appropriate roadway alignment signs should, therefore, be posted the appropriate distance upstream of the alignment change. On tangent sections of roadway, the shift generally approximates the form of a reverse curve as the lane is moved laterally and then runs parallel to the original alignment. A second reverse curve returns the lane to its normal alignment beyond the activity area. In this case, a pair of reverse curve (W1-4) signs are appropriate. A large arrow (W1-6) sign may also be useful for traffic entering the shift, especially at the upstream end of the work zone.

When the shift is located on a horizontal curve, the revised alignment normally follows a simple curve rather than a reverse curve, and use of the curve (W1-2) sign is appropriate.

Where two or three lanes are open through the shift, the double lane shift (W1-4b) or triple lane shift (W1-4c) signs may be effective in conveying to drivers not only the alignment, but also the fact that all lanes continue through.

The advisory speed plaque (W13-1) may also be appropriate on the alignment signs at a lane shift. These signs are discussed in Section 6F.45 of the MUTCD.

1.3.1.4 Lane Use Signs

When more than one lane is available through a shift, it is usually desirable to discourage lane changes within the shift. This can be done by posting a regulatory STAY IN LANE (R4-9) sign in advance of the shift. To ensure maximum effectiveness, this sign should be posted on both sides of the roadway.

1.3.1.5 Taper Layout

Recommended shift taper lengths are provided in Table 6C-2 of the MUTCD, which is reproduced in Tech Note 1. The recommended taper length of 0.5L is generally appropriate for night work, although longer tapers may be needed if speeds are very high and there is a high percentage of large trucks. It is also important to provide adequate distance between successive alignment changes. The MUTCD recommends 0.5L between successive shifts or between merge and shift tapers. This recommendation is generally adequate, although somewhat shorter separations may be used if space is limited within the work zone and the lateral shift is only a few feet wide. Separations should be lengthened if drivers appear to be experiencing difficulty with the maneuvers, such as sudden braking or swerving.

For sites where drivers are failing to merge or are not staying in the proper lane, additional longitudinal buffer space may have to be provided between the end of the taper and the beginning of the lane shift. A discussion of longitudinal buffer space and other requirements is included in Section 1.2.3.

1.3.1.6 Channelization

The guidelines for channelizing lane and shoulder closures are also applicable for lane shifts. Refer to Section 1.2.6 for specific details. Lane shifts used for night work are typically set up and removed on a nightly basis, thus making it impractical to revise the pavement markings to follow the temporary lane alignment. It is, therefore, essential to provide channelizing devices along both sides of the travel space through the entire length of the shifted alignment.

When more than one lane must be carried through the shift area to maintain capacity and the existing pavement markings remain in place, it becomes necessary to provide devices between the lanes to prevent lane encroachments through the shift. Typically, narrower devices such as cones or tubular markers are effective for this purpose. These devices must begin before the start of the shift and be carried throughout the entire shift area. Typically, these devices must be placed from a work vehicle as a moving operation.

1.3.1.7 Shift Width

The width of a temporary shift is determined on the basis of the work activity, the available width to accommodate the shift, and the need for lateral buffer adjacent to the work space. The total width is usually limited by the width of shoulder or median onto which traffic is shifted. Splitting the available width to provide reasonable lateral buffer spaces adjoining the work space on one side and roadside hazards (such as traffic barrier or opposing traffic) on the other side of the realigned lane is often a reasonable approach.

1.3.1.8 Intrusion Protection

Refer to Section 1.2.4 for information on intrusion protection.

1.3.2 Diversions

Diversions are similar to lane shifts, except the temporary travel lanes are shifted beyond the original travel lanes and shoulders. As long as the temporary travel path remains within or immediately adjacent to the original roadway, the traffic pattern is considered a diversion rather than a detour. A diversion may take the form of a temporary roadway constructed adjacent to the original roadway. Another common diversion is rerouting traffic onto a service road to permit work to occur on the main line.

Although any number of diversion types may be used to temporarily carry traffic around a work site, diversions involved in night work are typically set up and removed on a nightly basis. All the lanes on the approach roadway may be diverted when adequate width is available through the diversion. Otherwise, one or more lanes will have to be closed first.

1.3.2.1 Signing

Advance warning, lane use, and alignment signs for diversions should typically follow the same general guidelines as for lane shifts. However, the addition of the ROAD CLOSED (R11-2) sign is recommended on the original roadway. It should be placed beyond the channelizing devices forming the diversion, as shown in TA-7 of the MUTCD. Because the alignment on diversions is typically more severe than the shifts, the addition of large arrow (W1-6) signs or Chevron (W1-8) signs may also be effective in guiding drivers through the alignment.

1.3.2.2 Layout of Diversion

Ideally, the geometric layout of a diversion should accommodate traffic at the prevailing approach speed. The use of standard shift taper lengths are suitable to accommodate traffic at the speed used in the taper length calculation. However, the resulting length of the taper may become exceedingly long when traffic is diverted completely off the roadway. Therefore, it is more typical to design the diversion using standard highway curves, basing the radius on the design speed selected. AASHTO's *A Policy on the Geometric Design of Highways and Streets* provides design criteria (*7*).

Regardless of whether tapers or horizontal curves are used, it is essential to provide separation between successive movements. When the diversion follows a lane closure, the diversion should begin a distance of at least 2*L* beyond the end of the closure taper, with a shorter separation of at least 0.5*L* used only when space within the work zone is limited.

When long-term diversions are installed, it is often possible to adjust pavement cross slopes and provide pavement banking to match the design speed of the diversion. Because nighttime diversions are typically installed and removed nightly, it is normally not possible to adjust cross slopes, at least at the point where the temporary roadway leaves and rejoins the existing roadway.

It is also more likely that nighttime diversions will use existing pavement, such as a service road, adjacent to the normal roadway. To the extent that additional pavement is constructed or resurfaced to accommodate nighttime diversions, horizontal alignment and pavement cross slope should be based on the anticipated operating speed.

1.3.2.3 Channelization

When traffic is diverted from its normal path, channelization for a taper or horizontal curve should follow the same guidelines as those provided in previous sections for lane closures and shifts. Normally, this level of channelization is needed on the side adjoining the existing roadway. It may be possible to greatly reduce or even eliminate channelizing devices on this side when traffic is completely separated from the original roadway. On the far side of the roadway, it may be acceptable to use reduced spacing or even no devices throughout much, if not all, of the diversion.

The need for channelizing devices beyond the taper area is based on the need for driver guidance rather than on the need to provide a physical separation between the travel and work spaces. When existing or temporary pavement markings provide a satisfactory level of delineation, channelizing devices are not needed, especially if the alignment is not severe and the diversion is extensive in length. For short diversions, especially if the alignment is curvilinear, devices along both sides of the temporary roadway provide very positive guidance. The normal daytime spacing (in feet) of twice the speed (in mph) normally provides excellent guidance, with a reduced spacing used for curves where a speed reduction is desirable.

When more than one lane is carried through the diversion, it is usually impractical to adjust the pavement markings on a nightly basis. The guidelines provided for lane delineation through shifts are also important for diversions. Some type of lane delineation is essential through diversions, especially through the area where the traffic is transitioned from the normal path to the temporary-lane position. For such situations, channelizing devices to separate adjoining lanes is often the only feasible solution.

At the return to the existing roadway, the reduced device spacing used at the departure taper should again be provided to separate traffic from the closed roadway.

In addition to the devices used to form the diversion and to provide guidance along its length, Type III barricades should be placed across the existing roadway downstream of the taper area. The ROAD CLOSED (R11-2) sign should be placed above the barricade nearest to the center of the closed lanes. These devices should be arranged to preclude errant drivers from entering the work space, as discussed in Section 1.1.3. On roadways with two-way traffic, these devices should be provided at each end. Where sufficient longitudinal buffer space is available beyond the diversion point, it is desirable to install these barricades well beyond the taper so drivers following the diversion are not distracted or misled by the barricades and ROAD CLOSED sign. These protection devices are unnecessary for drivers who are properly following the diversion, and they will only add to the visual clutter at night.

1.3.2.4 Advisory Speed

To the extent possible, the diversion should be designed for the prevailing approach speed. Because nighttime diversions must frequently use available existing pavement, normal cross sections often cannot be provided, and, in some cases, abrupt changes in pavement elevation may be encountered where the diverted lanes leave the normal roadway. In such cases, it is essential to provide information to drivers in terms of advisory speeds for the actual geometric conditions to be encountered. This information should be posted as advisory speed plaques (W13-1) on the roadway alignment signs (W1-1 through W1-4) at the approach to the diversion. A portable or fixed CMS may also be used to provide this information.

When possible, ball-bank measurements should be used to determine the appropriate advisory speed prior to installing the diversion. In many cases, it may not be possible to obtain ball-bank measurements, and, therefore, it is necessary to base the advisory speed on experience or on calculations using the actual geometry.

1.3.2.5 Roadside Design

In addition to the geometric design of the diversion and the selection of the traffic control devices to be used, consideration should be given to roadside design of the diversion. This consideration becomes especially important when speeds through the diversion are high and the roadside does not provide good recovery area. When the diversion is to be used for an extended period, the roadside design should be checked following the guidance in the AASHTO *Roadside Design Guide*. When a diversion is only used for a short period, especially when it is changed on a nightly basis, addressing roadside hazards using normal design approaches may be impractical or even impossible. In such cases, the use of channelizing devices to provide positive driver guidance is essential.

Regardless of the existing roadside features along the diversion, it is important that the work activities do not impose additional hazards. Storage of materials, equipment, and work vehicles should not detract from roadside recovery space through the diversion.

1.3.2.6 Intrusion Protection

Refer to Section 1.2.4 for information on intrusion protection.

1.3.3 Diversion through Diamond Interchange

Another option should be considered when work is performed within a simple diamond interchange. In such cases, it may be possible to detour traffic onto the off-ramp, across the intersecting highway, and back on the on-ramp. This option depends on having adequate capacity on the ramps and through the intersection. The option may require a revision of the traffic control procedures normally used at the intersection.

1.3.4 Crossovers

Crossovers are a special form of diversion in which traffic from the roadway where the work is to occur is diverted onto the opposing roadway. Depending on the width and number of travel lanes and available shoulder width, it is normally necessary to close one or more lanes on each roadway prior to the crossover. The decision of how many lanes to close in each direction should be based on a comparison of the expected traffic volumes through the night work period. An example of a crossover on a divided highway is shown in Figure TA-39 of the MUTCD, with crossovers on undivided roadways shown in Figures TA-24, -31, and -32.

1.3.4.1 Signing

Guidelines for signing of diversions in the preceding section are also generally applicable to crossovers. In addition, two-way traffic (W6-3) signs and DO NOT PASS (R4-1) signs should be posted near the start of the two-way traffic section and repeated periodically for long sections. Finally, keep right (R4-7) and DO NOT ENTER (R5-1) signs should be posted at the end of the two-way traffic section. However, these signs are not needed if positive traffic barriers are used throughout the two-way traffic section to separate the opposing traffic.

1.3.4.2 Layout of Crossover

The general layout of the crossover should follow the same guidelines given for diversions. The guidelines in Section 1.2.1 should also be applied to selecting the location for crossovers.

On undivided highways, traffic is simply shifted across the centerline or flush median. Such shifts can generally be located as needed to accommodate the planned work activity and may be relocated from night to night. The length of the diverted roadway section should be limited to only that needed for the night's activities.

On divided highways, temporary pavement must be provided at the median crossover point, and a preexisting median barrier may require removal. Because these requirements represent a significant construction effort and cost, crossover points are normally limited to a fixed location at each end of the project. For long projects, consideration may be given to adding one or more additional crossover points throughout the project such that the length of the diverted roadway section used on any night can be limited to that which is needed for that night's activity. Avoiding unnecessarily long crossovers minimizes traffic delays, reduces setup and takedown time, and reduces accident risk, especially if positive traffic barriers are not used.

1.3.4.3 Channelization

The channelization guidelines for diversions (see Section 1.3.2) also apply to crossovers. Because installation of positive barriers is impractical for nighttime operations, channelizing devices should be used to separate opposing traffic. Also, if the distance is sufficiently short that motorists can see the far end of the section, the motorists are less likely to forget that there is opposing traffic, and channelization may provide adequate separation. At a minimum, closely spaced channelizing devices are needed to separate opposing traffic between the two median crossovers. When used to separate opposing traffic, device spacing must be used to avoid drivers' cutting between devices into the opposing lane. The spacing guidelines provided for lane closures (see Section 1.2.6) may be applied in this case; however, a further reduction in the spacing should be considered.

In addition to conventional channelizing devices, the opposing-lane traffic divider is also appropriate for separating opposing traffic lanes in two-lane, two-way operations. These devices, which are discussed in detail in Section 2.6.6, are especially effective in alerting drivers to the presence of two-way traffic where the driver does not expect to encounter opposing vehicles. Both portable and fixed versions are available, with the portable ones especially suited to nighttime operations requiring daily setup and removal.

Type III barricades beyond the diversion point are desirable to prevent drivers from entering the work space if they fail to follow the crossover. Guidelines for diversions (see Section 1.3.2) are applicable for crossovers as well.

When more than one lane is diverted across the median, the concern for lane demarcation must be addressed in the same way as other diversions. The guidelines for diversions should be applied in this case.

1.3.4.4 Traffic Barrier

Because crossovers for night work must typically be installed and removed on a nightly basis, the use of portable traffic barriers is rarely feasible. The time and traffic exposure necessary to complete the installation and removal usually outweigh any advantages associated with use of the barrier, especially for portable concrete barriers. Methods to protect workers from errant vehicles that may enter the work space are discussed in Section 1.2.4.

Lightweight portable plastic barriers that have been approved by FHWA for various test levels of *NCHRP Report 350* are available (*8*). These barriers offer some advantage compared with concrete barriers in terms of setup and take-down time and effort. Use of these barriers for night operations may be feasible, especially for short lengths of diverted roadway sections where the amount of barrier needed is small. The primary concern for these lightweight barriers is the relatively large lateral barrier deflection upon impact. Even when filled with water as ballast, deflections of several feet may occur, depending on impact speed and angle. Any decision to use these barriers must, therefore, consider the probable impact conditions and the available width separating opposing traffic.

Moveable concrete barrier, which is shifted laterally by a transporter machine, offers a potential solution for crossovers that will be installed nightly at the same location for an extended construction period. The high cost of this barrier and transporter make its use impractical for brief construction periods. However, for longer periods, especially where traffic volumes and speeds are high, the positive protection provided against crossover accidents involving opposing vehicles often outweighs this cost.

In a typical application, the movable barrier is set up in advance of the start of night operations on the median shoulder of the roadway that will carry both streams of traffic. To start the setup of the nightly crossover, the median lane of that roadway is first closed using a standard lane closure. This closure should begin upstream of the start of the barrier, providing an adequate buffer space. It is not necessary to close the lane throughout the entire crossover section, because the lateral transfer of the barrier continues to the downstream end of the closure. When the barrier to separate the crossover lane from the remaining lanes is in place, the lane closures and diversion are set up in the other roadway and traffic is diverted into the crossover. The resulting traffic pattern provides positive separation between the opposing traffic streams with minimum exposure and delay associated with deployment of the barrier. At the end of the night shift, the procedure is simply reversed to restore the highway to normal flow.

The only significant impact on traffic during nonwork hours is the storage of the barrier on the median shoulder. Typically, the transfer vehicle is stored at either end of the barrier in the median and standard portable barriers can be provided, if necessary, to protect against impacts by vehicles that encroach into the median. When movable barriers are to be stored near an active lane of traffic, consideration should be given to protecting the blunt end of the barriers.

1.3.4.5 Other Considerations

Guidelines for advisory speed, as well as roadside design (see Section 1.3.2) for diversions, may also apply to crossovers. Those guidelines should be reviewed and applied to crossovers as necessary.

1.4 RAMP CONTROL

Night work on limited access highways often involves the use of (1) road closures with detours; (2) lane and shoulder closures; or (3) shifts, diversions, and crossovers. Each of these basic approaches, especially when two or more are used in combination, typically affect traffic flow on entrance and exit ramps in the vicinity of the temporary traffic control pattern. Several different situations involving ramps may require consideration—ramps that must be temporarily closed and ramps that are left open but must be reconfigured to accommodate the temporary traffic pattern on the main line. In addition, it may be desirable to close (1) entrance ramps that are a short distance upstream from a full closure of the main line or (2) ramps that add significant traffic volume to the main line such that it is difficult to accommodate the added volume through the temporary traffic control zone.

The MUTCD shows several examples of temporary traffic control involving both entrance and exit ramps—TA-40, -41, -42, -43, and -44. Those examples, combined with guidelines provided in earlier sections of this report, provide the primary guidelines for ramp control. Additional guidance, with consideration of nighttime operations, is provided in the following sections.

1.4.1 Decision to Leave Open or to Close

The decision to leave ramps open or have a temporary closure is based on several factors: available detours, effort required to set up and remove detours, traffic demand on ramp, configuration of main line temporary traffic pattern, main line traffic volume, and nature of the work operation. No single solution is best for every situation, and a small shift in any one of these factors may indicate the need to use a different ramp-control approach.

In urban areas where interchanges are closely spaced and detour routes are available, the preferred choice is often to close entrance and exit ramps that would otherwise require the ramp traffic to cross through the work space. Guidelines for closing ramps and establishing detours are provided in Section 1.1.

When detour or alternate routes with an acceptable increase in travel time and distance are not available to handle the expected ramp traffic, it will be necessary to leave the ramp open and to provide a temporary traffic pattern through the work space to accommodate both the ramp traffic and the work activity.

1.4.2 Ramp Traffic Patterns

Figures TA40 through TA44 of the MUTCD provide several examples of temporary traffic control involving ramps. These examples and several other situations involving ramps require attention to a number of considerations.

1.4.2.1 Lane Open Adjacent to the Exit Ramp

When the work space occupies the median lane, leaving a single lane adjacent to the exit ramp open, no additional provisions are typically needed for traffic to continue to use the ramp. However, if storage space on the ramp is limited to the degree that traffic backs up onto the main line, conflicts may result. In such cases, consideration should be given to making adjustments at the downstream end of the ramp to move traffic off the ramp more quickly. These adjustments could involve re-timing the signal or, as a last resort, adding a flagger.

1.4.2.2 Lane Open Adjacent to the Entrance Ramp

The primary concern for when a lane is open adjacent to the entrance ramp is the availability of adequate gaps in the open travel lane to permit the ramp traffic to merge smoothly. When main line traffic is confined to fewer lanes, headways decrease and fewer acceptable gaps are available. If adequate room is available on the shoulder, it may be possible to lengthen the acceleration lane to facilitate merging. Such a change should be implemented prior to the start of night work, including adjustment of the pavement markings to provide the added length needed.

1.4.2.3 Lane Closed Adjacent to the Exit Ramp

When the lane adjacent to the exit ramp is closed, the ramp traffic must pass through or around the work space. Example traffic patterns are shown in TA-41 and TA-42 of the MUTCD. In these situations, it is essential to clearly define the travel path through the work space using highly visible channelizing devices. Guidelines for device type and layout are provided in Section 2.1. When the width of the shoulder adjacent to the ramp is adequate, it may be possible to divert the ramp traffic onto the shoulder upstream of the work space and then carry the traffic past the work space on the shoulder. In other cases, especially when speeds through the work area are low, it may be acceptable to eliminate the deceleration lane and provide a more direct temporary route onto the ramp, passing in front of the work space. Regardless of the configuration selected, the use of temporary signs to clearly identify the location and path of the realigned ramp is essential. This use is particularly necessary for night operations, since drivers do not expect configurations such as more direct routes onto a ramp and, therefore, require information that is adequate to overcome the effects of such an expectancy violation.

1.4.2.4 Lane Closed Adjacent to the Entrance Ramp

The most difficult situation to handle often results when entering traffic must be carried through or around the work space to merge with main line traffic on the opposite side of the roadway. If the shoulder provides adequate width and is not occupied by the work activity, the preferred solution is often to carry the entering traffic on the shoulder until it is beyond the entire work space, or at least beyond the actual activity. After the ramp traffic is beyond the work activity, the ramp traffic can merge with traffic in the open lane.

If the lane closure extends some distance beyond the actual activity area, it may be desirable to direct the ramp traffic across the lane closed to through traffic to merge with the open lane traffic. In this situation, an adequate acceleration lane should be provided to facilitate merging.

When carrying ramp traffic past the activity area is not possible, providing a path through the activity space is necessary. In this situation, the temporary path for the ramp traffic must be clearly defined using channelizing devices according to the guidelines provided in Section 2.1. To the extent that conditions allow, an acceleration lane should be provided to facilitate merging. However, this provision is often not feasible, and one of the other controls discussed below may become necessary.

Depending on the type of work operation underway, it may be necessary to adjust the entrance ramp layout as the work progresses. The layout may start out with the entering traffic proceeding along the shoulder to merge with the through lanes beyond the work space. Then, as the work progresses past the ramp, the temporary pattern is moved back to carry the entering traffic across the work space upstream of the activity area. In some cases, several adjustments may be necessary over the course of the night.

1.4.2.5 Temporary Traffic Stoppage

Even with the best possible layout of temporary ramps, there may be occasional brief periods where it becomes impossible to accommodate the ramp traffic through the work space. Typical situations include paving or milling operations as they pass the actual terminus of a ramp or brief periods when a temporary ramp alignment must be revised. In these situations, it is sometimes necessary to briefly stop the ramp traffic until the work operation moves ahead or the ramp alignment is revised. The lower traffic volumes typically encountered at night often make it possible to stop traffic for a few minutes without producing long queues.

For entrance ramps, the stopped traffic can normally be accommodated on the ramp as long as the delay does not result in a queue length longer than the ramp. For exit ramps, space should be provided if possible to hold the queue without interfering with the through traffic.

It is essential to follow the guidelines in Section 2.5 for flagging operations when stopping traffic. If police patrols are available at the project, they should be used to assist.

1.4.3 Control of Entering Traffic

When adequate acceleration lane length can be provided for a temporary ramp alignment, the entering traffic can be allowed to merge normally. However, because the entrance ramp must often be carried through the work space, it is frequently not feasible to provide an acceleration lane adequate to permit safe merging. In these situations, some form of control is essential so that entering traffic can wait until an acceptable gap is available and then merge. The following approaches are available.

1.4.3.1 Stop Control

When sight distance is limited on the ramp, traffic must stop and wait for an acceptable gap before merging. Because longer gaps are needed for a stopped vehicle to accelerate and merge, stop control should be limited to those situations where the MUTCD guidelines require use of stop control.

1.4.3.2 Yield Control

Because traffic is not required to stop if an acceptable gap is available, yield control may reduce delays and queue formation compared with stop control. However, yield control can only be used safely when sight distance is adequate and the other guidelines of the MUTCD are satisfied.

1.4.3.3 Flagger Control

When sight distance for the through lane entry is very limited or when long delays may be encountered between acceptable gaps, flagger control may be necessary. In such cases, the flagger holds the entering traffic until a gap is available and then directs the driver to proceed. The flagger can provide two advantages over stop and yield control. First, the flagger provides much greater assurance that the driver waits for a safe gap, even if a substantial delay is required. Second, the flagger usually has better visibility and, thus, can more readily identify safe gaps where sight distance is restricted for entering drivers.

Flagging is a high-risk operation at any time, made even worse by nighttime conditions. Even when temporary lighting is provided and other guidelines to enhance safety are observed, flagging operations are best avoided at night when alternate approaches can be used. Except where stop and yield control cannot safely control entering traffic, flagger control at entrance ramps should be avoided at night. Section 2.5 discusses night flagging operations.

1.4.4 Ramp Metering

For facilities with existing ramp metering equipment, it may be possible to adjust the ramp metering cycle to better match the actual traffic conditions on the main line during the work period. In cases where traffic flow is severely restricted on the ramp, the metering equipment should be turned off during the work period.

1.4.5 Channelizing Devices

Temporary ramp traffic patterns may become very confusing for drivers at night. Therefore, the guidelines for the selection and spacing of channelizing devices provided in Sections 1.2 and 2.1 are essential to ensure that drivers can follow the intended path, especially when the ramp traffic must be carried through the work space. The use of closer device spacings at the intersections of ramps and the through lanes is particularly helpful to drivers in distinguishing the ramp path from the through lanes.

Ramps that must pass through the work space must frequently be realigned during the course of the night. It is, therefore, important to consider the ease of repositioning the devices when the device selection is determined. Furthermore, sight distance for drivers entering the through lanes may be affected by channelizing devices placed at the intersection of the entrance ramp and main line. To restrict sight distance as little as possible, consideration must be given to the height and overall size of the devices placed at this location. Larger devices may be suitable at the temporary gore of an exit ramp to make it easier for drivers to identify the correct point to depart the main line. These large devices, however, may not be desirable at the throat of the entrance ramp, where they restrict sight distance for entering traffic.

1.4.6 Signing for Temporary Ramps

Adequate signing is an essential element in the effective operation of temporary entrance and exit ramps. The guidelines in Section 1.1 provide information with regard to signing ramps that are closed, including detour signing for closed ramps. General signing guidelines given in Section 2.2 apply to all ramps. Clear signing for closed or relocated exit ramps are essential so that drivers do not become confused and encroach into the work space when attempting to use a ramp.

1.4.6.1 Relocated Ramp Sign

Whenever the exit ramp gore is relocated, it is essential to provide a temporary EXIT (E5-1) sign in the relocated gore. The temporary sign should be sized to meet the traffic conditions at the site according to the guidelines in Section 2.2. It is essential that the sign is positioned above the channelizing devices and any other potential obstructions so that it is clearly visible to approaching drivers. Figure 3 shows a relocated exit gore at night with temporary lighting, closely spaced drums, and a relocated gore sign.

1.4.6.2 Ramp Closed Signs

When an exit ramp is closed, temporary guide signs and advance warning signs placed upstream of the ramp are essential to alert drivers to the closure and to provide drivers with information on the alternate or detour route. A regulatory RAMP CLOSED (R11-2) sign should then be placed at the normal or apparent exit ramp location to alert drivers to the closure. In addition, if an entrance ramp is closed, route assemblies should be provided on intersecting roadways, as well to assist drivers who must follow a detour to the reopened roadway.

1.4.6.3 Stop and Yield Signs

Temporary STOP (R1-1) and YIELD (R1-2) signs that may be required at the end of entrance ramps may be unexpected by drivers. It is essential that these signs be appropriately placed and sized to ensure that they are seen by drivers on the ramp. Posting of signs on both sides of the ramp is recommended to increase the certainty that they will be seen. However, care is necessary in locating the sign on the left such that it does not act to reduce available sight distance. STOP AHEAD (W3-1a) and YIELD AHEAD (W3-2a) signs provide added warning to drivers who do not normally encounter signs at that location. These signs should be added even when sight distance to the STOP (R1-1) or YIELD (R1-2) sign is not limited. When added assurance is required, flashing warning lights may be added to the advance warning signs.

1.4.6.4 Flagger Sign

Whenever a flagger is used for ramp control, a flagger (W20-7a) advance warning sign is essential.

Figure 3. Relocated gore sign.

1.4.6.5 Other Ramp Signs

Temporary ramp alignments may introduce the need for additional signs to alert drivers to the changed alignment. The large arrow (W1-6) sign and other appropriate signs should be provided to alert drivers to the alignment on temporary ramps.

1.4.7 Changeable Message Signs

CMSs are especially adaptable to conveying information on ramp closures and changes. They can be used to provide advance information on ramp closures and route alternates or detours. They may also be useful on realigned entrance ramps to inform drivers of temporary ramp controls such as STOP (R1-1) signs, flaggers, or other controls that may not be expected. Because messages can be quickly revised, CMSs are especially useful when ramp patterns are changed over the course of the night.

1.5 PEDESTRIAN PROTECTION AND ACCOMMODATIONS

The MUTCD provides relatively little in the way of standards for pedestrian protection. The only statement in the document that is related to pedestrians in night operations is a reference to maintenance of adequate lighting of covered walkways (Section 6D.01). However there is no operational definition of "adequate." The development of a TCP, which requires the accommodation of pedestrians during night operations, should separate pedestrians from both traffic and construction as much as possible. Whenever possible, pedestrians should be rerouted using traffic-controlled intersections onto alternative safe sidewalks away from any danger. When pedestrians must be routed onto a new path, which exposes them to vehicular conflicts on the traffic side and/or the danger and interference from construction on the other side, adequate guidance and delineation of path and positive protection from any potential hazard are essential. An assessment of the visibility of any possible hazards that can be expected to exist during the construction and maintenance period is essential to maintaining a safe passageway for pedestrians.

Some accommodation for pedestrians in work zones is necessary whenever pedestrians must travel through the work zone or when the existing pathway will be either closed or made more hazardous by the work activity. An assessment of pedestrian safety in work zones should consider the level of pedestrian activity, the duration of the project, and the level of hazard that exists. Guidelines for pedestrian safety that are applicable to both day and night work activity have been provided in an *ITE Journal* article (*9*). This chapter focuses on additional problems that occur when the need to accommodate pedestrians extends overnight. Also, any construction location that had accommodation for people with disabilities prior to construction will have to be given special consideration (*10*).

The following sections give guidelines for the protection of pedestrians.

1.5.1 Pedestrian Routing

Pedestrian routes should not be circuitous because such routes may encourage pedestrians to take routes that do not provide adequate protection. Pedestrians often look for the shortest route, and the dangers along such a route, which are visible in daylight, may not be visible at night. Positive protection, such as fencing, should be used to protect pedestrians from hazards that may be difficult to see at night or may occur at unexpected times. Fencing can also be used to ensure that pedestrians follow the intended route and do not initiate otherwise dangerous short cuts. Temporary pedestrian paths should be clearly marked using signs and channelizing devices (see Figure 4). Typical pedestrian accommodations are shown in TA-28 and TA-29 of the MUTCD.

1.5.2 Pathways

Pathways should be at least 1.2 m (4 ft) wide, constructed of a stabilized nonskid material, and free of any obstructions (*9*). Placement of temporary traffic control devices on sidewalks or temporary pedestrian paths should be avoided (see Figure 5).

1.5.3 Temporary Lighting

Proper lighting is essential for all walkways and bikeways that are adjacent to open lanes of travel moving through or adjacent to night construction. The ambient lighting condition should be evaluated with regard to all potential hazards. Ambient lighting may be provided by an existing fixed lighting system on the roadway or extraneous off-roadway sources. If it is expected that one or more hazards will not be fully visible, either a temporary lighting system should be installed or a device such as a steady-burn light should be used to mark each hazard.

Figure 4. Clearly marked, temporary pedestrian paths.

Figure 5. Avoid placing devices on sidewalks or temporary pedestrian paths.

It should be kept in mind that factors such as slight changes in level or roughness of the walking surface can induce trips and falls; therefore, surfaces must be lighted in such a way that shadows or light patterns do not conceal irregularities. Furthermore, with regard to an assessment of the lighting, the designer or inspector should be aware that pedestrians generally will be looking ahead while walking and not looking down at their feet. This characteristic must be taken into consideration in evaluations and inspections. Also, temporary lighting should be evaluated with regard to creation of glare. Lights shining into the eyes of a pedestrian may produce disability glare, which will make path or surface hazards less visible.

A minimum level of 10 lux is recommended for horizontal illumination, with an average-to-minimum uniformity of 5 to 1. The method for achieving this minimum illumination should be specified in the lighting plan (see Section 3.4). As with all work zone lighting, care must be taken to ensure that this lighting does not produce significant glare for through traffic or for pedestrians (see Section 3.2.4 and Tech Note 4).

1.5.4 Warning Lights

Retroreflectorized traffic control devices are of little value to pedestrians. Type C warning lights may be used to delineate pedestrian pathways, and Type A warning lights may be used to mark isolated hazards if sufficient lighting has not been provided. It is important that these warning devices not create a distraction to motorists (*11*).

1.5.5 Pedestrian Signals

For signalized intersections in urban arterial work zones, the most efficient way to accommodate pedestrians is to use pedestrian push-buttons for crossings, particularly if pedestrian traffic is not expected to be high enough at night to merit a full crossing cycle. When pedestrians are required to cross a roadway at anywhere other than a signalized crossing, then pedestrian signals, a flagger, or police may be required, depending on traffic speed and volume (*12*).

Because pedestrians are far less visible at night, signal cycles should not require walking speeds in excess of 1.22 m (4 ft) per second. The potential use of signals by older pedestrians or pedestrians with disabilities may require longer signal intervals based on walking speeds as slow as 0.91 m (3 ft) per second. (See Tech Note 5.)

1.5.6 Interactions with Work Vehicles

When work vehicles must cross the pedestrian walkway, a positive means of preventing the pedestrians from crossing the work vehicle path must be used. If volume is extremely light and the periods between vehicle crossings are long, it may be feasible to use flagger personnel to perform the pedestrian control task. However, if the crossings are expected to occur frequently, a portable pedestrian crossing signal should be considered (*13*).

1.5.7 Special Considerations for Senior Pedestrians and Pedestrians with Disabilities

Special attention to the needs of senior pedestrians and pedestrians with disabilities becomes more critical at night, when drivers are less likely to see these pedestrians.

Special attention and consideration for improvement include the following (*10*):

- Assume lower walking speed criterion at signalized intersections.
- Provide refuge islands at wide intersections. (The definition of "wide" should be more conservative at night.)
- Use flared curbs at intersections.
- Provide oversized signs and signals.
- Provide lighting.
- Reduce glare from any offensive source.

CHAPTER **2**

DESIGN REQUIREMENTS FOR VARIOUS TRAFFIC CONTROL DEVICES AND SAFETY FEATURES

2.1 CHANNELIZING AND GUIDING DEVICES

Sections 6F.55 through 6F.68 of the MUTCD provide guidelines for the application of channelizing devices, pavement markings, and other guidance devices in temporary traffic control zones. Those guidelines apply to all situations, including night work. However, because of reduced visibility and the increase in the number of impaired drivers, as well as the need to set up and remove most of the devices on a nightly basis, night work zones present special considerations in terms of channelizing and guidance devices. Enhanced channelization and guidance is essential to protect workers and the public from intrusions into work spaces or other areas not intended for travel. Devices that must be set up and removed nightly should be selected, with consideration of ease of handling as well as visibility and other traffic control characteristics. The limited space available in some activity areas may require that the width of the channelizing devices selected be kept as narrow as possible to provide adequate space for travel lanes and the work space.

Previous research established that increasing the amount of reflective material improved driver performance at night in terms of speed reduction, detection distance, and lane-changing behavior (*14*). Retroreflective devices must be inspected at night under headlamp illumination. Devices that have lost reflectivity may be satisfactory in daylight, but close to invisible at night.

Detection distance is the most important measure of performance for devices used to mark isolated hazards. Detection distance is also important for lane closures and other transition tapers, but advance signing, arrow panels, temporary lighting, and other devices reduce the dependence on long detection distances for drivers to properly negotiate a transition. Once into the taper, a driver needs to be able to follow the intended alignment through the temporary traffic pattern, but that task does not depend on long detection distance for the channelizing devices.

The guidelines that follow discuss numerous characteristics of channelizing devices, pavement markings, and other guidance devices to enhance effectiveness for night work operations. State DOTs report that the misuse and improper maintenance of traffic control devices is a common problem that reduces the safety of night work.

2.1.1 Channelizing Device Types

Figure 6F-4 of the MUTCD provides the basic characteristics of channelizing devices available for use on public highways. Regardless of where they are used, channelizing devices must meet these basic requirements. In addition, the opposing traffic lane divider may also be used for separating opposing traffic flows. The following guidelines are provided to select devices for night work. Indiscriminate mixing of devices may create confusion, particularly at night, and should be avoided. However, controlled mixing, such as alternating cones with drums, does not seem to present a confusing situation and may be an excellent way to discourage drivers from cutting between devices while still keeping the quantity of large devices to a manageable number. Controlled mixing can be particularly helpful when very close spacing is needed.

2.1.1.1 Type III Barricades

Type III barricades are the largest channelizing device available (see Figure 6). Because of their greater size—1.5 m by 1.25 m (5 ft high by 4 ft wide) minimum—portable Type III barricades offer the greatest target value and appear the most imposing to drivers. However, they are much less convenient to handle than other devices, such as drums, vertical panels, and cones. Type III barricades are typically used to close roadways when all traffic is diverted or when only local traffic or construction traffic is permitted to pass. Because of their large and imposing appearance, the barricades minimize the risk of drivers intruding into the closed area and are, thus, the preferred device for roadway closures (see Section 1.1.3).

Type III barricades may be used to channelize lane closures and other temporary traffic patterns. Although their large size provides excellent visibility and target value, they require more time and effort to handle and deploy. Other channelizing devices, such as drums and vertical panels, appear to provide essentially equivalent performance, especially when they are closely spaced and used as part of a well-designed TCP. Except when vehicle intrusions have been a problem, the use of Type III barricades in tapers and longitudinal arrays may not be worth the added time and effort for setup and removal on a nightly basis. However, for

Figure 6. Type III barricades.

Figure 7. Type II barricades.

setups left in place for extended periods and not deployed on a nightly basis, these devices should be considered if maximum protection against intrusions is essential.

Application of Type III barricades as midlane devices in closed lanes is a good way to reinforce that the lane is closed. A further advantage is that signs can be mounted above the barricade as needed throughout a lane closure or other temporary traffic pattern. See Section 1.2.6.3 for further discussion of midlane devices.

Type III barricades may be used as a portable support for temporary signs. While the barricade adds to the target value of the sign, these devices may be more difficult to move on a nightly basis than other supports. Unless the barricade itself is needed as part of the TCP, its use solely as a sign support or to enhance the target value of a sign may not be worth the added effort to handle the barricade on a nightly basis.

2.1.1.2 When to Avoid Using Type III Barricades

The greater height of Type III barricades compared with other channelizing devices increases the risk of restricting sight distance for drivers at intersections, ramps, and driveways. The 1.5-m (5-ft) height of the barricades is above driver eye height for passenger cars. The use of Type III barricades should therefore be avoided whenever it would restrict the sight distance needed.

2.1.1.3 Type I and II Barricades

The smaller size and height of Type I and II barricades make these barricades more convenient to use when nightly deployment is necessary. The size of the Type II barricade provides target value equivalent to drums and vertical panels, and this barricade is an acceptable alternative to those devices for tapers and longitudinal arrays. Type II barricades provide clear definition of travel lanes (see Figure 7). Because its smaller size provides less target value, the Type I barrier is normally limited to low-speed local streets or pedestrian applications.

Type I and II barricades may be used to form road closures. However, the larger size of the Type III makes the Type III a much better choice for nighttime closures when the risk and consequences of intrusions is greater.

A wide variety of commercially available Type I and II devices are available. An important criterion for night use is ease of handling and deployment. If a Type II barricade is selected for longitudinal channelization where many devices must be deployed, it is important that the device be light enough to handle easily and that it can quickly be placed in its proper position on the roadway.

2.1.1.4 Drums

The relatively large size and imposing appearance of drums make drums an excellent choice for longitudinal arrays where many devices are required. Because they are light in weight and can be stacked, drums are easy to handle and deploy. Because of their large size, drums provide very clear definition of the traffic space and discourage drivers from intruding into the work space (see Figure 8). Most drums are easily ballasted to guard against displacement by wind gusts from traffic. Either drums or vertical panels are an excellent choice for tapers and longitudinal arrays for temporary traffic patterns, especially where width is not restricted.

Because drums provide the same appearance from any viewing angle, they are especially appropriate for channelizing at intersections, driveways, and other locations where traffic approaches from various directions.

2.1.1.5 Vertical Panels

Vertical panels provide good visibility and are suitable for lane-closure tapers (see Figure 9). Vertical panels, especially the 30-cm (12-in.)-wide version, provide similar advantages to drums for night use. Although vertical panels are narrower

Figure 8. Drums.

than drums are, their height is the same and the 30-cm (12-in.) panels include more reflective sheeting per side than the drum panels include. When used in closely spaced arrays, vertical panels are thought to be equivalent to drums. Their relatively compact size facilitates handling, and when equipped with a weighted base, they are easy to place on the roadway and are stable under traffic-induced wind gusts.

Because vertical panels are a two-dimensional device, they are less appropriate than drums for use at intersections, driveways, and other locations where they must be visible over a wide range of approach angles.

Figure 9. Vertical panels.

2.1.1.6 Cones

Traffic cones are typically used for longitudinal arrays that are deployed and removed on a daily basis (see Figure 10). Because the reflectorized portion of the cone provides a much smaller target at night, they are not as appropriate for lane closures and similar traffic control setups at night as drums, vertical panels, or Type II and III barricades. Although cones are the fastest and easiest devices to set up and remove, that advantage is outweighed at night, where the risk and consequences of intrusions are greater. If cones are selected for night work, use of the larger 914-mm (36-in.) cones enhances their target value and places the reflective material higher, where it is more directly in the driver's line of sight. Depending on their ease of setting and removal, 914-mm (36-in.) cones may be used in tangent sections of lane closures and so forth, but they should not be permitted in tapers where target value is more critical.

Because of their narrower width, cones sometimes provide an advantage over drums and panels and may be applicable in very narrow work zones or between opposing or adjoining traffic lanes, where wider devices require too much space. Alternating between drums or panels at intersections, ramps, and other locations where the spacing of the channelizing devices is revised to half the normal tangent spacing may be appropriate. (See Tech Note 6.)

2.1.1.7 Tubular Markers

Tubular markers offer the least target value of any of the devices available. Their narrow width makes them an appropriate candidate for very narrow situations to separate traffic

Figure 10. Closely spaced cones during the day.

lanes or to mark the edge of pavement dropoffs or similar situations (see Figure 11). When used, a minimum 914-mm (36-in.) height is necessary to place the reflective material more directly in the driver's field of view. The most retroreflective material should also be used to offset the limitation of the small target area. Because of their limited target value, tubular markers should be used for night operations only when larger devices cannot be accommodated because of width limitations. (See Tech Note 7.)

2.1.1.8 Opposing Traffic Lane Dividers

In addition to conventional channelizing devices, the opposing traffic lane divider is also appropriate for separating opposing traffic lanes in two-lane, two-way operations. These devices, which are discussed in detail in Section 2.6.6, are especially effective in alerting drivers to the presence of two-way traffic where the driver does not expect to encounter opposing vehicles. Both portable and fixed versions are available, with the portable ones especially suited to nighttime operations requiring daily setup and removal. (See Tech Note 8.)

2.1.2 Device Spacing

When used for longitudinal channelization at night, close device spacing provides the appearance of an orange and white barrier and, thus, reduces the risk of drivers encroaching into the work space or other closed areas, either intentionally or accidentally. The MUTCD recommends a maximum spacing in feet equal to the speed in miles per hour for tapers and twice that distance in tangent sections.

Previous research on urban arterial work zones recommended a spacing in feet equal to speed in miles per hour to discourage encroachments (*11*). On the basis of experience with night work, NYSDOT requires a spacing in feet equal to the actual operating speed, both in tapers and in tangents, but with a maximum spacing of 12-m (40-ft). At intersections, ramps, and other potential problem areas, this spacing is cut in half. A maximum 12 m (40 ft) spacing, with reduced spacing of 6 m (20 ft), facilitates setup by matching device spacing to the normal lane line marking spacing.

Figure 11. Tubular markings.

When drums or 305-mm (12-in.)-wide vertical panels are used in tapers, a 12-m (40-ft) spacing results in an apparent lateral overlap of the devices as viewed from the approach lane as long as the taper rate is based on a speed of 40 mph or greater. The resulting visual effect of a continuous and uniform array of retroreflectorized devices reduces the risk of a driver attempting to drive into the closed lane. Past the taper, where devices are viewed from the adjacent lane, the 12-m (40-ft) maximum spacing appears to present a nearly impenetrable array, especially for the larger devices. As speed decreases, reducing the spacing tends to maintain a similar apparent spacing as drivers pass the devices and, thus, reduces the risk of slower traffic attempting to cut through the line of devices.

2.1.3 Retroreflectivity

For effective visibility and detection, it is essential for all channelizing devices to be equipped with retroreflective materials at night. The MUTCD describes the required area and pattern of reflectivity for all channelizing devices, and those requirements have generally been accepted as providing good visibility. However, there are no accepted guidelines on the level of brightness of the retroreflective sheeting needed to provide acceptable performance.

Research has shown that brighter sheeting increases the recognition and detection distance of channelizing devices (*15*). However, considering initial cost and durability, the brightest sheetings were not found to be most cost-effective. When closely spaced, large devices are used to define the travel lane through the work area, the added brightness of the premium grades of reflective sheeting does not appear to offer any advantage, provided the devices are kept in good condition. The smaller tubular devices, and perhaps cones, should benefit most from better retroreflectivity. (See Tech Note 9.)

For individual or small groups of devices used to mark isolated hazards, especially on dark roadways with high approach speeds, increased target value provides more assurance that drivers will recognize and avoid the hazard. In such cases, consideration should be given to the use of Type II or III sheeting (*16*). However, for closely spaced devices used to define travel lanes, there is no consensus that these premium materials provide any advantage over engineer-grade sheeting.

2.1.4 Device Condition

To provide good performance, channelizing devices must remain in good physical condition such that they display the intended shape and remain in position on the roadway. Equally important, the devices must be clean and the reflective material must be in good condition to ensure good visibility with the intended shape under headlamp illumination. The American Traffic Safety Services Association (ATSSA) has prepared condition guidelines, called “Quality Standards For Work Zone Traffic Control Devices” (*17*). These guidelines illustrate suggested acceptable levels of condition, including reflective sheeting on channelizing devices. Devices used in nighttime projects should be inspected on a regular basis. Any devices that are dirty or damaged such that they are noticeably less visible than devices in good condition under actual field conditions should be replaced as soon as possible. Because inspection staff is present on the project at night, regular night inspections can identify marginal devices before they become a problem. The ATSSA guidelines can be used for daytime inspection to identify devices that may be candidates for replacement. However, devices that appear satisfactory during daylight may not have adequate visibility under headlamp illumination at night.

2.1.5 Impact Performance and Ballast

The MUTCD requires that channelizing devices be constructed and ballasted to perform predictably when impacted and to minimize risks to vehicle occupants and workers.

2.1.5.1 Impact Performance

NCHRP Report 350 provides nationally accepted criteria for evaluating the safety performance of work zone devices, including channelizing devices (*8*). Although few formal evaluations have been performed, it is generally accepted that small devices (including cones, tubular markers, and drums without lights) present little risks when impacted. However, some larger devices may present a risk if impacted, especially if lights or signs are attached to the device.

FHWA recently issued rulemaking to identify acceptable highway safety features that meet the *NCHRP Report 350* recommendations, including work zone traffic control devices. FHWA guidelines are available for assessing the performance of channelizing devices and other work zone traffic control devices (*18, 19*). FHWA lists products that have been identified by FHWA as meeting these requirements and this list is expected to be updated on a regular basis (*20*). Other agencies are also expected to compile lists of devices that have been identified as meeting these requirements. A Texas DOT memo (*21*) lists devices accepted by Texas DOT as compliant with *NCHRP Report 350* recommendations. In some cases, it is expected that individual manufacturers or industry associations will certify compliance with the *NCHRP Report 350* criteria.

To ensure safe impact performance, channelizing devices should meet *NCHRP Report 350* performance criteria. When test data or manufacturer’s certification is not available, performance should be assessed according to the guidelines in FHWA HNG-14 (*18, 19*). Fortunately, for many channelizing devices, compliance with the NCHRP criteria can be inferred by comparison with similar devices that have been tested, accepted by FHWA, or certified by a manufacturer.

2.1.5.2 Ballast

Ballast may be necessary to prevent channelizing devices from being displaced by traffic-induced wind gusts. When used, ballast must not create safety concerns if impacted. In addition, it is desirable for ballast to remain intact for most impacts to minimize cleanup and reduce risks from scattered ballast on the roadway. Equally important, the ballast configuration must facilitate handling for devices that must be deployed nightly.

To reduce risks on impacts, it is essential that all ballast be placed at ground level. Ballast more than a few inches above ground is at greater risk of becoming a projectile or penetrating a windshield. Ballast containers may be broken and scattered if snagged by vehicles passing over the device. Limiting container height for sand and other loose ballast to 4 in. reduces the risk of snagging by passenger cars.

Suitable ballast may consist of bagged sand, integral ballast compartments for sand incorporated into the base of the device, weighted ballast rings, weighted bases, and other concepts. The best performance is achieved when the channelizing device separates cleanly from the ballast when impacted. This clean separation permits the ballast to remain at the impact point in most cases, minimizing the weight of the device thrown by the impact.

2.1.5.3 Beware of Impacted Ballast

Any form of ballast placed on top of a drum or above the pavement surface poses a risk of windshield penetration if impacted. Nonstandard forms of ballast—such as pieces of wood, chunks of pavement or concrete, or other such material—attached to or placed on top of or inside channelizing devices may be thrown on impact and pose a severe threat to vehicle occupants, workers, and other traffic (*22*).

2.1.6 Warning Lights on Channelizing Devices

Both flashing and steady-burn warning lights may be used to improve the detection and visibility of channelizing devices. Section 6F.72 of the MUTCD provides specific requirements for warning lights.

2.1.6.1 Flashing Lights

Flashing lights are generally considered to be effective for attracting driver attention. When channelizing devices are used to mark isolated hazards or features, the addition of flashing lights may improve the likelihood of being noticed by drivers, and this effect may be greater at night when drivers are drowsy or otherwise impaired. Increased driver attention at the start of tapers is especially important, and flashing lights on the first two devices may help to ensure detection by approaching drivers. Likewise, flashing lights should be provided on barricades at road and ramp closures to improve driver attention to the barricades.

Flashing lights are not to be used in longitudinal displays because they provide to drivers a potentially confusing pattern that may obscure the actual vehicle path.

2.1.6.2 Steady-Burn Lights

Steady-burn lights are intended to define the edge of the travel path. Because the brightness and size of the light is overpowered by large reflectorized channelizing devices, the value of steady-burn lights to supplement large retroreflectorized channelizing devices is questionable. Studies in Ohio concluded that these lights did not enhance driver performance when attached to channelizing devices equipped with high-intensity sheeting (*23, 24*). Considering the large device size and close spacing recommended by these guidelines and the experience of states such as New York and Iowa, it is doubtful that steady-burn lights on channelizing devices will provide any value in night work zones (*6*).

In addition to the questionable value for visibility, earlier research has shown that lights attached to channelizing devices may break windshields when impacted and may increase the risk of the channelizing device being thrown on impact rather than pushed down by the impacting vehicle (*22*).

2.1.6.3 Light Attachment

When the decision is made to use lights on channelizing devices, it is essential that the attachment is sufficiently strong to resist impact forces. Lights torn loose from a channelizing device present a greater risk of windshield breakage or becoming a potentially lethal projectile. Batteries used to power warning lights, especially the heavy-duty batteries used with Type B lights, present a risk in terms of broken windshields and passenger compartment intrusion and may present a risk to workers if dislodged on impact. The preferred mounting, especially for heavy-duty batteries, is at ground level to eliminate the risk of windshield contact and being thrown into the work space. The lightweight batteries used in Type A lights may be attached directly to the barricade or channelizing device. However, it is essential for the attachment to be secure to reduce the risk of becoming dislodged on impact and to discourage theft by vandals.

2.1.7 Pavement Markings

Pavement markings are an essential part of work zone traffic control devices, especially at night, when drivers require additional guidance to safely traverse temporary traffic patterns during periods of reduced visibility when the driver may be fatigued or otherwise impaired. Unfortunately, the short-term nature of most nighttime operations makes it impossible to deploy and remove temporary pavement markings on a nightly basis.

2.1.7.1 Marking Applications

Temporary pavement markings are very effective in delineating travel lanes at crossovers and diversions (see Figure 12); however, in lane closures and shifts that are set up and removed on a nightly basis, and for the portion of diversions that are within the normal travel lanes it is normally impossible to provide temporary pavement markings on a nightly basis. In those situations, it is necessary to provide channelizing devices to mark the outer limits of the travel lanes and to separate adjoining and opposing lanes.

Diversions and crossovers beyond the normal travel lanes should be provided with standard pavement markings, including lane lines, edge lines, and centerlines where two-way traffic is present. Likewise, night detours should be provided with standard pavement marking if not already present on the detour route.

2.1.7.2 Marking Materials

A variety of pavement marking materials are suitable for temporary use, and all of them are capable of providing excel-

Figure 12. Temporary pavement markings.

lent night visibility when maintained in good condition. These materials include traffic paint, permanent and removable tape, durable striping materials (such as epoxy and thermoplastic), and reflective pavement markers. Because they are easily installed with minimal equipment, can be removed when no longer needed, and provide excellent night visibility, temporary raised markers and removable marking tapes often provide excellent choices for short-term marking applications.

2.1.7.3 Marking Pattern

When pavement markings are installed in conjunction with night work, marking patterns should meet the requirements of Section 6F.66 of the MUTCD. When it is not practical to place and remove markings to coincide with nightly traffic pattern changes, channelizing devices should be used to define travel lanes, following the guidance in Section 2.1.

2.1.7.4 Marking Brightness

Temporary pavement marking materials are available in a variety of different brightness levels, approximately 100–550 mcd/m^2/lux for white markings and 70–450 mcd/m^2/lux for yellow markings. The materials are also available in a number of different thicknesses in the form of thermoplastic and structured tapes. The advantage of the thicker applications is the ability to maintain brightness during rain conditions and ponding. Because the brighter and thicker marking materials are more expensive, it is necessary to make judgments for various parts of the work zone as to the criticality of more clearly defining the driver path. That is, materials of lower retroreflectivity might be considered for sections of the work zone that do not involve any substantial path changes, and the brighter materials might be used for more critical sections. However, if the work zone is in a geographic area where a large proportion of older drivers are expected, brighter markings throughout the work zone may be beneficial. (See Tech Note 10.)

2.1.7.5 Marking Removal

In addition to providing visible markings, removing conflicting markings may be necessary in some cases. Because scars from marking removal are potentially misleading at night, especially on wet pavement, care to reduce scarring is essential. There are commercially available removable masking tapes that can completely obscure existing markings without creating a visible scar. A range of colors and textures are available to match the road surface, which improves the results. These removable masking tapes may be a good choice for short-term traffic pattern changes because the original markings are easily restored with no damage to the marking or pavement at the completion of the work. The relatively high cost of these materials, however, may limit their application to small-quantity situations.

2.1.8 Delineation

In addition to channelizing devices and pavement markings, other delineation devices may be helpful in marking the travel path through night work areas. The following are typical applications for delineation devices.

2.1.8.1 Concrete Barrier Delineation

Concrete barrier placed close to travel lanes is difficult to see at night, especially during rainy conditions. Requiring the barrier to be light colored, or painting it white, may enhance night visibility somewhat, but does not eliminate the need for delineation. Pavement edge lines placed at the base of the barrier may help define the travel path. However, markings frequently become covered with dirt or water and, thus, are ineffective when needed most. When movable barrier is shifted on a nightly basis, it may be impossible to provide a lane line at the base of the barrier. Reflective markings, raised pavement markers, or steady-burn warning lights placed near the top or on top of temporary barrier enhance the visibility of the barriers under adverse conditions and should be provided whenever the barrier is placed closer than a few feet from the travel lane.

Although steady-burn lights are generally considered to be effective for enhancing the visibility of the barriers, maintaining the batteries in operable condition may be expensive and difficult under high-volume traffic conditions. Panels with reflective sheeting have been shown to be effective. Another treatment that has been used is orange or white reflective tape placed along the barrier (*25*).

For movable barriers, one must place the delineation system and, if used, the glare screen on the barrier such that the delineation system and glare screen do not interfere with the transfer machine.

2.1.8.2 Post-Mounted Delineators

Although channelizing devices are typically used to mark the edge of travel lanes and to provide guidance (1) adjacent to work spaces, (2) in tapers, and (3) in other critical areas, they may be unnecessary along the full length of temporary roadways, such as diversions or detours. For such situations, post-mounted delineators may be helpful to indicate the roadway alignment, especially when that alignment is unfamiliar to drivers. Section 3D of the MUTCD provides guidelines for the use of delineators, with suggested spacings on curves in Table 3D.1. On tangents, the MUTCD suggests spacings of 60–160 m (200–530 ft). To obtain the maximum value from delineators on unfamiliar temporary alignments, consideration should be given to placing delineators on tangents using the closer spacings of 200 ft.

2.1.8.3 Object Markers

When fixed objects and other hazards are adjacent to temporary roadways and when the edge of the roadway is not provided with channelizing devices, object markers placed according to the guidelines of Section 3C of the MUTCD should be considered.

2.2 FIXED SIGNING

With regard to night work activity, there is little difference among various guidelines for the design of warning, regulatory, or guide signing. Because drivers are not accustomed to encountering construction activities at night and warning signs are not expected, extra care is needed to ensure that warning signs provide adequate nighttime visibility and legibility. An increase in the advance warning distance is important, particularly for the first advance warning sign. When guide signs are used to alert drivers to night operations and to provide information on road and ramp closures, the sign messages must be designed to ensure legibility at a distance that does not compromise safety.

State DOTs report that the misuse and improper maintenance of traffic control devices is a common problem that reduces the safety of night work. As with warning signs, any unneeded or inapplicable signs are distracting and misleading and must be completely covered or removed. Signs must be kept clean and visible with good retroreflectivity, the same as for channelizing devices, delineators, and other guiding devices.

To provide adequate visibility of these signs, one must (1) provide adequate sign size for the amount of message content; (2) place the sign so that it receives sufficient illumination from headlamp beam patterns or provide external lighting; and (3) if retroreflective, replace signs that have degraded beyond their service life.

2.2.1 Location

Because drivers are unaccustomed to encountering construction activities at night, enhanced advance warning distances are important. Warning signs must be located to provide adequate visibility distance to drivers. They must not be blocked by foliage, roadway features, or other signs or traffic control devices. Also, warning signs should not be located where glare from light sources behind the sign may reduce visibility.

2.2.1.1 High-Speed Roads

A minimum of 0.8–1.6 km (0.5–1.0 mi) advance warning should be provided on roadways with operating speeds of 80 km/h (50 mph) or higher, except as noted for exits and entrances below.

2.2.1.2 Low-Speed Roads

Distances may be shortened to 450 m (1,500 ft) on roadways with speeds of 60 km/h (40 mph) or less.

2.2.1.3 Exits and Entrances

Exiting and entering traffic should be considered when locating advance warning signs. It is generally not desirable to start a warning sign series upstream from a major exit or intersection, except when it is desirable to divert traffic off the route at that point.

2.2.2 Distance

Actual distance from a warning sign to the condition should be close to the stated distance on the sign. However, positioning of the sign to enhance visibility and avoid conflicts with other traffic control devices and roadway features is more important than precise agreement with the stated distance.

Standard distances to be used on a series of warning signs include 1,600 m, 800 m, 450 m, 300 m, and 150 m (1 mi, 0.5 mi, 1,500 ft, 1,000 ft, and 500 ft). Generally, three signs are adequate for a series with the specific distances selected to fit site conditions. Nonstandard distances—such as 240 m, 180 m, and 90 m (800 ft, 600 ft, and 300 ft)—should not be used on signs unless it is imperative to provide precise distance information to drivers.

Where single advance warning signs are provided on ramps or minor intersecting roads, the “Ahead” wording rather than a specific distance is preferred because this wording allows drivers to more easily adapt to site conditions and reduces sign inventory needs for the contractor.

2.2.3 Spacing

Both construction signs and permanent signs must be adequately spaced to provide recognition and legibility. On high-speed roadways, signs must be spaced at least 150 m (500 ft) apart. This spacing may be reduced to 110 m (350 ft) on low-speed roads. (See Tech Note 11.)

2.2.4 Placement

Reflectorized signs must be oriented away from drivers (about –4 deg from perpendicular to the direction of traffic) to reduce specular glare. Supports that result in tilted signs are unacceptable. Also, the brightness of a retroreflective sign becomes significantly reduced when it is more than 10 deg in any direction from perpendicular. The reader is referred to the MUTCD Section 6F.03 and Tech Note 12 for further information.

Sign placement must consider several factors, including low-beam headlight patterns, blockage, and dirt accumulation. Signs that are on short-radius curves or are mounted higher than necessary may be less visible at night because of insufficient illumination. However, signs mounted too low may be blocked by other vehicles and interfere with pedestrians in urban areas. For temporary post-mounted signs, the MUTCD requires a minimum height of 5 ft (1.5 m) in rural districts and 7 ft (2.1 m) in urban districts measured to the bottom of the primary panel 4 ft (1.2 m) and measured to the bottom of secondary panels 6 ft (1.8 m). Signs mounted on portable supports may be as low as 0.3 m (1 ft). Considering these requirements and the considerations mentioned previously, the following recommendations are suggested for sign heights in nighttime work zones:

- Post-mounted signs should follow the MUTCD guideline of 5 ft (1.5 m) for primary panels in rural districts and 7 ft (2.1 m) for primary panels in urban districts (4 ft [1.2 m] and 6 ft [1.8 m] for secondary panels).
- Signs on portable supports should normally be at least 5 ft high to enhance visibility and reduce blockage by other vehicles.
- In some situations, it may be desirable to locate portable signs lower than 5 ft. For rigid sign panels, this location may entail a risk of windshield penetration if impacted (*22*). This practice should be allowed only for sign-support combinations that have been shown to perform acceptably through full-scale crash testing.
- Rollup sign panels generally do not present a risk of windshield penetration and, thus, may be used safely at heights below 5 ft. However, Section 2.2.8 should be consulted for legibility concerns for rollup sign panels.

When signs cannot be located to be visible under headlight illumination (i.e., they are mounted very high), artificial illumination should be considered to enhance visibility and legibility, or the sign must be moved.

2.2.5 Sign Supports

Warning signs on one-way roads should be double-posted on both sides of the roadway for all nighttime operations, regardless of the number of lanes.

Sign supports used for night work must address the same general concerns as for other work zone applications. The supports used must place the sign where it will be visible and legible, the sign must be maintained in the proper position without displacement by wind and traffic, and the sign must not present an undue hazard if impacted. In addition, signs used at night must often be installed and removed on a nightly basis, so portability and ease of handling become important criteria, as well.

See Section 2.1.5 for a discussion of current requirements for impact performance for work zone traffic control devices and references for devices meeting *NCHRP Report 350* criteria.

Either fixed or portable supports may be used to mount work zone signs. For devices that must be relocated frequently, and especially for signs that are located in closed travel lanes or on the shoulder, portable supports offer a substantial advantage. For signs that will remain at one location over an extended period, fixed supports offer better assurance that the sign will remain in the proper position. Fixed supports should include features to facilitate covering or removal of the sign panel when the temporary operation is not active. Supports not folded flat present a roadside hazard, especially if left on or near the shoulder; therefore, portable sign supports not in use should be either removed or folded flat and placed beyond the shoulder (see Figure 13).

In addition to acceptable impact performance, good visibility is a desirable feature for temporary sign supports used at night, especially for supports located on or close to the

(a)

(b)

Figure 13. A hazardous roadside situation because unused support is not folded flat and is left near shoulder (a) and a safe roadside situation because unused support is folded flat and placed beyond shoulder (b).

pavement or in other locations where they may be easily impacted by errant vehicles or construction traffic. Simply painting supports white improves visibility. Reflectivity may be added where there are special concerns about the visibility of a sign support.

2.2.6 Content

Messages on warning signs should identify specific conditions to the greatest extent possible. Appropriate messages include lane and shoulder closure, alignment and intersection signs, flagger and worker symbol signs, road or bridge closed, detour, and other appropriate texts as described in the MUTCD.

General warning signs, such as ROAD WORK XX FT, should be limited to the first sign in a countdown series. ROAD WORK AHEAD may be used separately when a more specific message is inappropriate or as the first sign in a warning sign series on minor side roads where distance information is not necessary.

Messages must be simple and concise so that drivers can read the messages at prevailing operating speeds. Long or involved messages cannot be rapidly read and may distract drivers from other tasks. If it is necessary to provide messages of more than a few words in length, the messages must be split between two or more signs placed at least 150 m (500 ft) apart. Rules for split messages are given in Section 2.3.3. To ensure that drivers comprehend the total message, no intervening signs should be placed between the two, and the distance between the signs should not be extended such that the connection between the two is lost.

2.2.6.1 Avoid Poor Legend Quality

Poor legend quality reduces legibility, especially at night. Makeshift legends such as temporary overlays or hand-painted legends should not be permitted.

2.2.6.2 Avoid Unnecessary Signs

Unneeded or inapplicable signs are especially distracting to drivers at night and must be completely covered or removed (see Figure 14). Partially visible signs distract drivers and may divert attention away from traffic and other devices that are critical for drivers to see. Sign covers must be opaque and must completely cover the sign face.

2.2.7 Color

The color of all signs should be as specified by the MUTCD. Fluorescent red-orange or fluorescent yellow-orange may be substituted whenever the color orange is specified. These fluorescent colors provide greater conspicuity than standard orange does, especially during twilight (*26*).

Figure 14. Covered sign.

2.2.8 Size

Larger sign sizes enhance sign legibility, especially at night. The standard size for advance warning signs is 122 cm (48 in.). Signs this size typically have a 15–20-cm (6–8-in.) Series C or D letter, which provides between 60 m and 120 m (200 ft and 400 ft) of legibility, depending on the letter height, the series letter, and the visual ability of the driver. Whenever possible, Series D or even Series E letters should be used to maximize legibility. Oversized signs (e.g., ROAD WORK NEXT XX MILES) may be installed to increase legibility distance. If truck blockage is a problem, oversized signs may be installed on overhead structures or duplicated on both the left and right sides of the road. (See Tech Note 13.)

Sign sizes of 90 cm (36 in.) and less that limit letter height to 13 cm (5 in.) or less should not be used except on low-speed, low-volume roads.

2.2.9 Retroreflectivity of Warning Signs

If not severely degraded, Type I material (also referred to as engineering grade) provides sufficient sign detection and recognition for standard 48-in. signs in all but very complex visual backgrounds. However, because the service life of this material is relatively short and high speeds and complex areas may require greater retroreflectivity for conspicuity, more reflective materials should be used. Considering service life and the need for greater conspicuity, a high-intensity material such as Type III (also referred to microprismatic) or a material of greater retroreflectivity should be used for all warning signs except when standard-size signs are used on low-speed, low-volume roads. (See Tech Note 14.) The fluorescent material often used today will satisfy this requirement. Painted sign panels are not to be used, and flexible panels (i.e., rollup signs) should be avoided if possible. (See Tech Note 15.)

2.2.10 Conspicuity of Warning Signs

Type B, flashing, high-intensity warning lights may be considered to enhance the visibility of isolated warning signs, or of the first sign in a series of signs, for nighttime operations where high-speed, free-flowing traffic raises concerns that drivers will fail to notice the advance warning signs. The lights are to be mounted above the sign panel such that the battery and lens do not obscure any part of the sign panel. If remote batteries are used, they must be placed at ground level.

2.2.11 Maintenance

Warning signs must be kept clean and in good condition to provide good legibility, as shown in "Quality Standards for Work Zone Traffic Control Devices" (*17*).

2.2.12 Retroreflectivity for Guide and Regulatory Signs

FHWA is in the process of publishing recommendations for minimum retroreflectivity for all traffic signs (*27*). Guide and regulatory signs that satisfy these recommendations for normal conditions will be satisfactory under conditions where speeds are reduced because of work activity. Until these minimum requirements are adopted, any recognized retroreflective material covered by ASTM specifications is acceptable. Because some materials wear more quickly than others do, a visual inspection at night is necessary to ensure that signs have adequate legibility and conspicuity. A drive-through inspection will reveal whether signs have at least 6 s of exposure time and, under high-speed, high-volume conditions, 150 m (500 ft) of legibility. (See Tech Note 16.)

2.3 CHANGEABLE MESSAGE SIGNS

Highway CMSs are traffic control devices that can be used for warning, regulation, path control, and traffic management (see Figure 15). CMSs improve the flow of traffic by providing real-time, highway-related information. However, because the legibility of fixed signing is generally superior to all types of CMSs, the use of CMSs for nighttime construction and maintenance operations, as in daylight, should be limited to information that cannot be practically provided by fixed signing. Among CMS technologies, fiber-optic designs have been found to provide greater legibility than other technologies. Flip-disk designs should not be

Figure 15. Changeable message signs communicating night work schedule.

used on high-speed roads at night (*28*). Because the characteristics of new technologies are constantly changing, this section offers guidelines in choosing among competing technologies.

As with other traffic control devices, CMSs require greater visibility at night because night construction is generally unexpected and, thus, requires longer legibility distance and because sign legibility is reduced, which requires larger letter heights to maintain legibility. The reduction in legibility at night suggests the importance of minimizing the length and complexity of CMS messages so that the demand for legibility distance is not as great.

The guidelines in this section for CMSs summarize the purpose and message content of CMSs in work zones, as well as design considerations for maximum nighttime conspicuity and legibility. With regard to purpose, a CMS may not be a cost-effective method for supplying information that can be conveyed by fixed signing. A CMS may not be justified if its sole purpose is an advance warning of construction activity ahead. Similarly, warning commuter traffic of impending lane closures and construction a week ahead of time can be accomplished by fixed signing, as well. However, a CMS might be the most cost-effective means of notifying traffic of road detours or lane closures when the hours of operation are not consistent from night to night or when the location changes from week to week.

The visibility of CMSs is determined by the design of the matrix elements, the design of message components, and the sign luminance and luminance contrast of message and background. Although the cost and available supply of CMSs may limit flexibility in choosing the CMS design for any specific situation, some CMS designs are clearly inappropriate for high-speed, heavy-traffic situations.

It is very important to understand that message content and visibility interact in two ways. First, the more content there is in a message, the more time it takes to read and process the information. This extra time translates into additional needed visibility distance and, therefore, a larger sign with larger letters. Second, signs designed to enable the display of long messages are less likely to provide large letter heights and adequate visibility.

The principles for the selection of CMS and the design of messages are contained in the following sections.

2.3.1 Credibility of CMSs

The information presented on a CMS will only be effective if drivers have confidence that the information is accurate, is current, and applies to them. Unlike with fixed signing, drivers expect the information on a CMS to be current. Therefore, the operation of a CMS requires proper planning to ensure that the correct message is displayed at the correct time.

2.3.1.1 Avoid Inaccurate or Untimely Information

It is better to display less or no information than to display information that may not be timely or accurate. When no message is required, the CMS should be turned off. Turning the sign face away from traffic minimizes driver distraction. Channelizing devices alert drivers to the CMS trailer at the shoulder edge (see Figure 16). Also, it is imperative that trained personnel be available to operate and monitor the system; otherwise, the CMS should be shut down.

2.3.1.2. Avoid Trivial Information

Display a message only when it provides potentially useful information. Do not use a CMS to tell drivers something they already know, such as DRIVE SAFELY.

2.3.2 Message Content

Because of reduced visibility at night, it is most important that messages be short and clearly understood. Long or confusing messages require more time to read or comprehend and, therefore, require larger letter size to provide the required visibility distance.

Figure 16. Properly shut down changeable message sign.

2.3.2.1 Advisory Sign Message Elements

Advisory messages may consist of two or, at most (for reasons cited in Section 2.3.6), three of the following components:

- Problem statement (e.g., accident, maintenance, or road work),
- Effect statement (e.g., delay, lane closure, or detour),
- Attention statement (e.g., group being addressed),
- Action statement (e.g., exit, move left or prepare to stop), and
- Location statement (e.g., distance ahead, exit number, or shoulder or lane).

The following example shows a possible advisory sign.

Example A:

LANE CLOSURE
STADIUM TRAFFIC
EXIT 25th STREET

2.3.2.2 Advance Sign Message Elements

Advance signing messages used in conjunction with advisory displays will consist of two or, at most, three of the following elements (not necessarily in the order shown):

- Information alert,
- Nature of information (e.g., best route or traffic conditions),
- Destination for which the information applies, and
- Location of the information (e.g., ahead or specific distance).

The following example shows a possible advance sign message used in conjunction with advisory displays.

Example B:

STADIUM ROUTE
INFORMATION
1000 FEET

2.3.3 Message Format

"Message format" refers to both the order of information units and the chunking of information units on each line of text.

2.3.3.1 Order of Units of Information

Although the order of units may vary, not every order is acceptable. For example, the following order would be inappropriate for the Example B sign:

STADIUM ROUTE 1000 FEET INFORMATION

2.3.3.2 Chunking of Information Units

The physical characteristics of the sign may determine how the information units may or may not be chunked. A sign that presents only a single line (e.g., as may be necessary in a tunnel) must have all of the units of information contained on one line. A sign that is too narrow to display many characters in width may have to present a word on each line. Generally, the display of a unit of information per line, as shown in Examples A and B (or, at most, two units per line), is considered ideal for reading. When traffic volume and speeds are low, any format may provide sufficient time for reading. (See Tech Note 17.)

2.3.3.3 Avoid Run-On Format

The run-on format (also called "moving" or "continuous" message display) displays messages as a train of words moving continuously across a display from right to left. This type of display should *not* be used for drivers traveling at high freeway speeds.

2.3.3.4 Split Messages

Incident management and point diversion situations frequently require more information than drivers can process or that can fit on a sign. Drivers can read and recall an eight-word message better if it is broken up into two displays of two to four words each. A message can be displayed by sequencing message chunks on a sign or displaying chunks of information across two signs. When chunking information, the information must be split into compatible units of information (e.g., BEST ROUTE TO STADIUM and INFORMATION 1000 FT).

2.3.4 Redundancy

Useful redundancy can be achieved by the repetition of key words or the use of coded information.

2.3.4.1 Repetition

If space permits, key words can be repeated in both segments of a split message (e.g., BEST ROUTE TO STADIUM and STADIUM INFORMATION 1000 FT).

2.3.4.2 Coded Information

Trailblazer logos and interstate shields have redundancy in that their components of color or shape may communicate most of the same information presented in text. Although not essential, using a CMS that provides graphic capability that can display these shapes and symbols could be advantageous.

2.3.4.3 Avoid Unnecessary Words

Some words that are often used may be understood from the context and, therefore, may be unnecessary. Examples are words like "avenue," "boulevard," and "street." Also, "accident ahead" and "accident" mean the same thing, as drivers do not expect to be notified about any other accidents than the ones ahead. Removal of unnecessary words reduces reading time and may allow for larger, more visible letters.

2.3.5 Exposure Time

Exposure time is the length of time the sign is legible to the driver. The exposure time will depend on the legibility of the letter (including letter height) and the speed of travel. Letter legibility determines where the sign first becomes readable and exposure begins, and speed determines when the exposure ends. It is necessary that exposure time be greater than the time required to read a sign. For older drivers, it is recommended that an unobstructed sign have sufficient exposure time to be read twice (*29*). It is also recommended that exposure time be long enough to permit the driver to make any decision about what action to take.

2.3.6 Minimum Required Legibility Distance (MRLD)

The longer or more complex the message, the more time it takes to read and understand and the longer the exposure time required. The exposure time required must be translated into a distance (based on approach speed) before sign design and placement parameters can be established. Whereas exposure time is a measure of supply (i.e., how much time is available to read a sign), MRLD is a measure of demand (i.e., how much distance drivers require to read a sign). MRLD is affected by driver work load, message load, message length, message familiarity, decision complexity, and display format. The way each of these factors affects MRLD is discussed in Tech Note 18.

As a general rule, one should assume a reading time of 2 s for one or two words, 3 s for three or four words, 4 s for five to seven words, and 5 s for eight to ten words, when drivers are familiar with the words or place names displayed. When drivers are not likely to be familiar with the words displayed, allow 1 s for each short word (four to eight characters) or 2 s per unit of information, whichever is longer. The sign shown in Example B would require 4 s (six words) for familiar drivers and 8 s (four units of information) for unfamiliar drivers.

On two-sequence displays of four words or two units of information each, messages may be displayed at rates as fast as 0.5 s per word, as long as the rate permits two cycles of viewing per driver. On longer messages, slower rates, as previously suggested, should be used.

2.3.7 Visibility and Flashing

The variety of technologies being used to build CMSs has resulted in signs that provide a range of sizes, fonts, message capability, photometrics, and cost. Factors that affect the visibility of CMSs can be grouped into character components, message components, and photometric variables.

In general, conspicuity is not a problem for any CMS, although traffic blockage may result in failure to notice a device. The attention value of a roadside CMS may be increased by slowly flashing (two cycles per phase) a single piece of information, such as CAUTION or WORK AHEAD. Other elements of information should not be flashed, as flashing decreases legibility (*29*).

2.3.8 Character Components

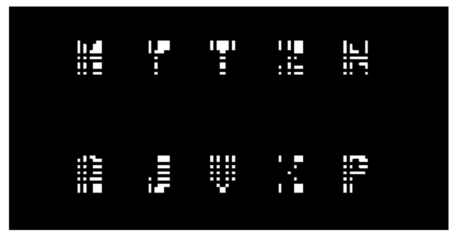
Character components include both element variables and character variables. Element variables include the shape, size, number, and spacing of the individual elements that make up the characters on a CMS. Character variables include the height, width, and font of the alphanumeric characters. (See Tech Note 19.)

2.3.8.1 Font

Although the shape of the elements (i.e., pixels) that make up a character do not seem to matter, alphanumeric characters that approximate the Standard Highway Gothic font are most desirable, and any nonserif font using at least a 5 by 7 matrix (as shown in the acceptable example below) is acceptable. Any attempt to double stroke a font using a 5 by 7 matrix (as shown in the unacceptable example below) should be avoided. The legibility of the unacceptable font is very poor and is not appropriate on highways.

Acceptable:

Unacceptable:



2.3.8.2 Letter Height

A letter height of at least 45 cm (18 in.) is necessary on high-speed roads. This height should provide an exposure time between 6 and 10 s for drivers traveling at 105 km/h (65 mph), depending on the driver's visual ability. On lower-speed roads, a letter height of 30.5 cm (10 in.) should provide a similar amount of exposure time. (See Tech Note 20.)

2.3.8.3 Height-to-Width Ratio

To optimize legibility, the width of a letter should be between 70 and 100 percent of its height.

2.3.8.4 Stroke-Width-to-Height Ratio

With positive contrast letters (i.e., light letters against a dark background), the ratio of stroke width to letter height should be between 0.10 and 0.18, with 0.13 being optimal. Negative contrast signs (i.e., dark letters against a light background) may use wider stroke width, but are not recommended for night construction (see discussion of contrast orientation below).

2.3.8.5 Matrix Size and Lower Case

Any matrix that is 5 by 7 or greater will optimize the legibility of capital letters. Lower case letters cannot be presented with a 5 by 7 font. Because place names have greater recognition when shown in lower case, a matrix larger than 5 by 7 would be preferable when place names are to be displayed.

2.3.9 Message Components

Message components represent sign characteristics that affect the legibility of the sign copy (i.e., actual symbols or text) without regard to the internal characteristics of the characters. Message variables include the spacing between the letters, words, and lines of text. Copy and the border are message variables that do not directly affect legibility. Both of these variables can affect conspicuity, and copy may affect familiarity and, therefore, the distance at which the message is read.

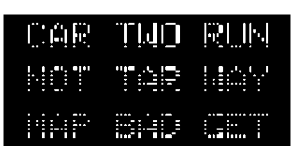
2.3.9.1 Interletter Spacing

Providing adequate spacing is a cost-effective way of improving legibility and maximizing the exposure time of the CMS message. The spacing between letters should be 125 percent of the standard spacing of the highway font, as shown below.

This much spacing will provide about 10-percent greater legibility than standard highway spacing will provide. Spacing as narrow as a letter stroke width, as shown below, should be avoided.

2.3.9.2 Interword Spacing

The spacing between words should be equal to the letter height, as shown in both examples below.



2.3.9.3 Interline Spacing

The spacing between lines may be as little as 20 percent of the letter height if only two lines of text are displayed. If three lines of text are displayed, interline spacing should be increased up to 75 percent of letter height, as shown in the first example in Section 2.3.9.2.

2.3.10 Photometric Variables

The critical photometric variables that describe CMSs are color, luminance, contrast of letters against the background, and direction of contrast (i.e., dark letters on a light background or light letters on a dark background). Contrast and contrast orientation primarily affect legibility, whereas luminance primarily affects conspicuity.

2.3.10.1 Contrast Orientation

CMSs that provide positive contrast (i.e., bright legend on dark background) are recommended for night construction work zones because they provide about 20 percent more legibility than negative-contrast CMSs do. CMSs that provide for only dark letters against a bright background should be avoided for night construction.

2.3.10.2 Contrast

The contrast of legend to background should be no less than 5 and no greater than 50. (See Tech Note 21.)

2.3.10.3 Luminance

At night, the luminance of text on a positive-contrast CMS should be maintained between 30 and 150 cd/m^2.

2.3.10.4 Color

The color of the elements that make up a CMS message does not affect legibility if luminance and contrast are maintained. Color coding is used in highway signing and may affect conspicuity. Therefore, there may be some advantage for CMSs that use a yellow or orange text against an unlighted dark background.

2.4 ARROW PANELS

Traditionally, an arrow panel has been thought of as a highly conspicuous sign with a matrix of lights that are capable of flashing or sequential displays of arrows or chevrons intended to provide warning and directional information to assist in controlling traffic through or around a temporary traffic control zone. The 2000 edition of the MUTCD refers to arrow displays with a matrix of elements instead of a matrix of lights. The intent is to broaden the definition to include new technologies and to recognize that even a CMS can simulate an arrow display. As with all advance warning signs, the use of an arrow panel is most important at night, when more drivers are less alert. On high-speed roads, using an arrow panel is essential.

Diesel-powered arrow panels represent a clear example of a high-target-value traffic control device capable of getting attention under the most demanding circumstances of visual noise, as well as adverse sun and traffic conditions. Although the use of solar panels has lowered the target value of these devices by virtue of reduced brightness, it is safe to assume that under night work conditions almost any arrow panel will have high target value. Arrow displays on CMSs are not as effective because of their reduced brightness. Therefore, these guidelines recommend the use of arrow panels only.

The guidelines for the design and deployment of arrow panels are discussed in the following sections.

2.4.1 Location Lane Closure on Roads with Multiple Through Lanes

The arrow panel should be located to maximize the distance at which it is recognized. For stationary lane closures, the arrow panel should be placed on the shoulder at the beginning of the taper (see Figure 17) or, if there is insufficient space on the shoulder, in the closed lane behind the channelizing devices but as close to the beginning of the taper as possible. (See Tech Note 22.)

Figure 17. Preferred arrow panel location on the shoulder at the start of the taper.

2.4.1.1 Restricted Sight Distance

If hills, curves, or other obstructions reduce the available recognition distance, the sight distance should be increased by moving the taper upstream and extending the lane closure. If the panel must be moved upstream, it should be located on the shoulder, not the roadway. If there is no space on the shoulder at that point, the taper should be brought upstream as well and the lane closure extended. (See Tech Note 23.)

A minimum sight distance of 460 m (1,500 ft) is essential for high-speed roads and 300 m (1,000 ft) for low-speed roads. These minimum requirements are based on studies of DSD. Wherever possible, it is recommended that greater sight distances be provided. (See Tech Note 24.)

2.4.1.2 Multiple-Lane Closures

If arrow panels are used when multiple lanes are closed in tandem, the additional arrow panels should be located in the closed lane at the start of the next merge taper, as shown in TA-37 of the MUTCD.

2.4.1.3 Avoid Work on Shoulder or Two-Lane Roads

An arrow panel in the arrow mode should never be used on two-lane highways because the panels can cause unwanted lane changing and result in confusion and collisions, even when flaggers are present. Advance warning signs and CMSs may be used to warn of roadside work without the danger of unnecessary lane changing. Although a caution mode is available for this purpose, it is best not to use arrow panels for shoulder or roadside work activities when there is no need for a lane change. This guideline is even more critical at night when many visual cues are missing, the location of the shoulder may not be visible, and driver uncertainty is increased. (See Tech Note 25.)

2.4.2 Mode

The arrow panel mode refers to the type of display used for a lane closure (including the flashing arrow, sequential chevron, or moving stem or head) or for caution (including the horizontal bar or four-corner display).

2.4.2.1 Left- or Right-Lane Closure

The flashing arrow is recommended, and the sequential arrow or chevron is least preferred. (See Tech Note 26.)

2.4.2.2 When to Avoid Caution Display

Although not recommended for shoulder work at night, the four-corner mode is recommended whenever a caution display is needed, except when there is extreme curvature and the arrow panel must be viewed at an angle. In these situations, the visibility of the four-corner display will be limited and other signing or warning lights should be in operation. The bar mode should be avoided, as it may suggest a lane closure. (See Tech Note 27.)

2.4.3 Visual Performance

The guidelines for maintaining visual performance are intended to meet the following goals:

- To ensure that the arrow panel is legible at the distances required by the MUTCD when viewed on axis with sufficient sight distance,
- To ensure that the arrow panel is recognized at the minimum required sight distance when viewed off axis, and
- To reduce nighttime intensity levels to avoid discomfort and other disabling effects of glare on driver vision.

2.4.3.1 High-Speed, High-Volume Stationary Projects

A Type C arrow panel should be used with lamps bright enough for recognition at 1,600 m (5,280 ft or 1 mi) when viewed on axis. When viewed on a curve (off axis), the arrow panel should be recognized at a minimum of 460 m (1,500 ft). (See Tech Note 24.)

2.4.3.2 Intermediate Speed Roads

A Type B or larger arrow panel should be used with lamps bright enough for recognition at 1,200 m (3,960 ft or 0.75 mi) when viewed on axis. When viewed on a curve (off axis), the arrow panel should be recognizable at a minimum of 300 m (1,000 ft). (See Tech Note 24.)

2.4.3.3 Low-Speed Urban Streets

A Type A arrow panel should be recognized at 800 m (2,640 ft or 0.5 mi) when viewed on axis.

2.4.4 Size

The MUTCD indicates that Type A panels, which should be recognized at 0.80 km (0.5 mi), are suitable for low-speed urban streets; Type B panels, which should be recognized at 1.2 km (0.75 mi), are suitable for intermediate-speed roadways and mobile operations on high-speed roadways; and Type C panels, which should be recognized at 1 mi, are intended for high-speed, high-volume projects.

Type C panels should be preferred at night, whether for fixed operations or on a vehicle, especially on freeways or other high-speed, high-volume roads. Again, the enhanced visibility of the larger size helps to compensate for the added risks of night work. However, given the greater conspicuity of these devices at night and the more stringent requirements for advance notice, warning, and channelization described for night use elsewhere in this document, Type B arrow panels may be used on lower-speed roads or when a Type C panel cannot be accommodated on a vehicle.

2.4.5 Photometrics

While some arrow panels do not have sufficient brightness to meet these visual performance requirements during daylight, most arrow panels will have adequate brightness at night, particularly when viewed on axis. The performance of some arrow panels off axis is marginal at night. If such an arrow panel must be used, extreme care must be taken in aiming the device.

2.4.5.1 Minimum Brightness

For use on high-speed roads after dark, lamps should measure at least 150 candela (cd) on axis and 30 cd at ±13 deg horizontal and ±3 deg vertical viewing angles. The corresponding values on low-speed roads are 90 cd on axis and 18 cd off axis. Highway agency specifications for higher-intensity levels should be followed if they exist. (See Tech Note 28.)

2.4.5.2 Maximum Brightness

Disability glare reduces the likelihood that objects will be seen, and discomfort glare is annoying and may result in drivers not looking at the area where the arrow panel is placed. Because of transient adaptation effects, disability glare may persist past the location of the arrow panel if the area beyond the arrow panel is unlit. Because of the mounting height of arrow panels, glare may be a more significant problem for truck drivers. To reduce disability and discomfort glare at night, luminous intensity should be reduced to a maximum of 5,500 cd per panel or 550 cd per lamp for arrow displays and 370 cd for chevron displays. This limit may represent no reduction at all for many solar lamps and more than a 50-percent reduction for diesel lamps. (See Tech Note 28.)

2.4.5.3 Dimming

The electronic controls should keep the intensity of the lamps at the nighttime requirement levels whenever the ambient light is at or below 215 lux. If the controls provided allow for continuous adjustment of lamp output with respect to ambient light level, then the lamp intensity may be linearly increased from the nighttime levels at 215 lux to the daytime levels at 35,000 lux. If continuous adjustment is not provided, then the electronic controls should keep the lamp intensity at the daytime requirement levels whenever the ambient light level is greater than 215 lux.

If a solar arrow panel is to be used, it is essential that the solar panel be exposed to the sun during daylight or that the batteries be recharged using a generator. The lamp, voltage and visibility checks listed below are essential to be certain that the arrow panel is functioning properly.

2.4.6 Maintenance

2.4.6.1 Lamp Checks

The following is a list of checks that ought to be completed for each lamp. If a lamp fails any one of these tests, it should be considered "not functioning." (See Tech Note 29.)

- Lamps must meet any agency certification requirements that may exist.
- Each lamp must be the same as every other lamp on the panel.
- Each lamp must be functional and must not appear weak compared with the other lamps on the arrow panel.
- The lens of the lamp must not have any obscuring material on its face or condensation inside its housing. Any dirt should be removed.
- The lamp should be seated properly in its socket. Use the indications on the lamp, such as the manufacturer name or even the word "TOP," to determine proper orientation.

To be acceptable, arrow panels to be used in the flashing arrow mode ought to have no more than one lamp "not functioning" in the stem and all lamps functioning in the head. In the chevron mode, not more than one lamp may be "not functioning" in any chevron segment. In caution mode, a minimum of four lamps ought to be functioning properly. If the arrow panel contains more "not functioning" lamps than allowed, then steps must be taken to correct the "not functioning" lamps (*17*).

2.4.6.2 Voltage Checks

An arrow panel operates at a minimum of two different voltages: a daytime voltage and a nighttime voltage. These voltages are determined by the type of lamp used in the arrow panel. The particular voltage levels a lamp requires to produce the required intensity can be found either in the certification of the lamp or in the lamp manufacturer's literature. The voltage of interest is not the supply voltage of the batteries, but the voltage that is actually delivered to the lamps. If the required voltage is not known, perform the visibility verification discussed below.

If the arrow panel makes no direct provision for measuring voltage, such as a separate voltmeter, then a handheld voltmeter should be used. The meter should be capable of measuring pulse-width modulated signals. A location that is easily accessible should be chosen, such as at the terminals of a lamp or at the location where the lamp power cables connect to the controller. After the voltage requirements have been determined, the following checks should be made:

- The nighttime dimming control should be operational. When the ambient illumination falls below the specified level, the arrow panel should operate at the nighttime voltage level. Visual testing can be used to verify that the lamps are dimmed when the photocell is covered, which should put the arrow panel into nighttime mode.
- The measured voltage at the nighttime setting should be within the range specified for the type of lamps used in the arrow panel. If the arrow panel makes no provisions for directly testing the nighttime voltage, covering the photocell should put the arrow panel in its nighttime mode, and the voltage level can be measured in the same way as the daytime voltage.

CAUTION: If the arrow panel does not meet the minimum requirements for brightness when placed in the nighttime mode, the unit should be replaced or the nighttime setting should be bypassed. If bypassing the nighttime setting results in the maximum requirement being exceeded, the panel should be aimed away from traffic to reduce glare. If the arrow panel were active over a 24-h period, the panel would have to be re-aimed to provide adequate visibility during daylight. Units that cannot meet the criteria should be replaced with units that will. (See Section 2.4.4 and Tech Note 30.)

2.4.7 Aiming and Setup of Arrow Panel

Equally important to having a properly maintained arrow panel is its placement and aiming. The arrow panel should be aimed toward the traffic it is attempting to inform of the lane closure. The goal is to make certain that the maximum light intensity is directed toward the oncoming traffic. This goal becomes especially critical in the areas of both horizontal and vertical curves. When placing an arrow panel, one should strive to direct the aiming of the arrow panel at a point at least as far away as the DSD (see Table 2) prior to the lane closure. Aiming should be done using the aiming device on the panel support structure. If the arrow panel does not have an aiming device, an inexpensive small-caliber rifle scope may be used for this purpose. Once properly setup, the orientation of the

TABLE 2 Recommended decision sight distance and stopping sight distance

Traffic Speed	DSD (feet)	SSD (feet)
> 45 mph	1500	600
<45 mph	1000	300

DSD = decision sight distance
SSD = stopping sight distance

arrow panel support structure should be marked so that routine maintenance checks can verify the arrow panel placement.

2.4.8 Visibility Verification

Visibility verification needs to be done in the field and must represent the same conditions with which the driver will see the arrow panel. Two methods are offered: (1) a method that requires only a subjective visibility rating and (2) a method that estimates light intensity using a relatively inexpensive luminance meter. Of primary concern is the angle at which the arrow panel is viewed and its effect on visibility.

2.4.8.1 Subjective Evaluation

After the arrow panel operation has been verified, a subjective evaluation drive should be conducted to verify that the arrow panel display is visible throughout the visibility distance of the site. The visibility distance is the distance interval between the arrow panel and the observer in which the arrow panel display should be clearly recognized. The upper end of the interval is the required DSD for the road speed condition, while the lower end is the minimum SSD, based on the road speed condition.

This procedure will determine whether an arrow panel has been properly set up and aimed. The procedure will also verify that the arrow panel has sufficient beam width for placement and geometry in which it is used. In choosing the time of day to perform this evaluation, field personnel should be aware that sun conditions affect visibility. Therefore, it is essential that the inspection take place after dark when the nighttime voltage has been set.

The procedure for a drive-through inspection is simple. The inspector approaches the arrow panel from a distance that is twice the required DSD for the site and travels toward the arrow panel until the direction of the displayed arrow or chevron is clearly visible. If the arrow panel display does not become clearly visible at a distance that exceeds the required DSD, then the arrow panel fails the drive-through inspection. If the panel display is clearly visible at the required DSD, the inspector should continue to drive toward the panel, making certain that the panel display remains clearly visible until the minimum SSD is reached. The recommended DSD and SSD are shown in Table 2.

The most difficult part of the drive-through inspection is knowing when a panel is clearly visible. A rating scale may be used to help with this evaluation. (See Tech Note 31.)

There are two reasons why the panel display may not be clearly visible at the DSD. First, the arrow panel itself may not be visible because there is no line of sight to the panel. The absence of a line of sight may be caused by the presence of trees, buildings, or other obstructions and the existence of horizontal curvature. Refer to Section 2.4.1.1 for discussion of restricted sight distance.

If there is an adequate line of sight but the direction of the arrow panel display mode is not clearly visible, then either the beam width is inadequate or the panel was not properly aimed or set up. If the particular site is not typical for some reason, such as extreme geometry, the arrow panel should be aimed to optimize its visibility range and the drive-through inspection should be repeated.

If, after aiming, the arrow panel display is still not clearly visible throughout the required distance interval from DSD to SSD, then either the lane closure should be moved upstream or, if a narrow beam panel is being used, a panel with higher intensity or beam width should be sought.

The drive-through inspection should be repeated each night. If ever the panel fails this inspection, the panel should be checked to determine the cause of the visibility loss. Individual lamps should be examined to determine whether lamp burnout has occurred. The panel should be checked for recent damage or the batteries recharged, if required. If all of the lamps appear to be operational and there is no apparent reason for the loss in visibility, the panel should be replaced and returned to the yard for a check of its voltage levels, charging system, and, possibly, lamp replacement.

2.4.8.2 Photometric Evaluation

A photometric measure provides a more objective test of the arrow panel brightness. A procedure is available to estimate the intensity of the arrow panel display using an inexpensive luminance meter. This procedure enables one to estimate the intensity from any observer position and may, therefore, be used to verify that the arrow panel has adequate angularity measured in terms of intensity aimed at the farthest sight distance to maximize conspicuity. (See Tech Note 32.)

2.5 FLAGGING OPERATIONS

The use of flaggers at night should be avoided whenever possible. However, flagging operations may be necessary to supplement other traffic control procedures at night. Flagger operations are inherently more dangerous during darkness and must be conducted with extreme care if they are to be safe for drivers and flaggers. Flagging is discussed in Section 6E, “Flagger Control,” of the MUTCD. Additional guidelines for safe nighttime flagging operations are presented here.

Training is discussed in Sections 2.8.3, 2.8.4, and 2.8.5. The discussion includes general information on flagger training. Note, however, that because of the increased danger of night flagging operation, task-specific flagger training is recommended. Such training should furthermore be conducted off-site under simulated conditions, and the operation should be carefully monitored during the first few hours of operation for each flagger crew. Finally, a debriefing should be done after the initial shifts of each crew to identify any problems that may be occurring. Following the debriefings, all identified problems should be discussed with all crews and any necessary procedural changes should be implemented as soon as possible.

A nighttime flagging operation is shown in NWTA-6 in Appendix A.

2.5.1 Use of Flaggers

Because of lower visibility and reduced driver performance typically encountered in nighttime operations, the use of flaggers at night should be limited only to those situations where other methods cannot provide adequate traffic control. Situations where flaggers may be needed include alternating one-way flow, truck and equipment entrances and exits, and intersection control. These situations are discussed below. Flaggers may also be needed for stop and yield situations on ramps, as discussed in Section 1.4.3.

2.5.1.1 Alternating One-Way Flow

Sections 6C.10 through 6C.15 of the MUTCD provide for one-lane, two-way traffic control. The methods described are flagger control, flag transfer, pilot car, temporary traffic signal, and stop or yield control. Because roads where night operations are normally conducted tend to have relatively high volumes, temporary traffic signals and stop and yield control are normally not appropriate for night work. The guidelines and considerations for choosing among the flagger control, flag transfer, and pilot car are given in the MUTCD and are not any different for night operations.

2.5.1.2 Truck Equipment at Entrances and Exits

Flaggers may be necessary to assist haul trucks and other equipment in entering and exiting the work zone. Flaggers may also be necessary at entrances to the work space or at road closure points to prevent inadvertent or deliberate intrusions by the public. In extreme cases, uniformed guards or police officers may be required in lieu of flaggers at closure points to prevent deliberate intrusions. See Sections 2.5.5 and 3.5.

2.5.1.3 Intersection Control

When work must occur within an intersection, especially for very brief periods, it may be impractical to set up temporary traffic patterns through the intersection using channelizing devices. In such instances, flaggers may be effective in controlling traffic through the intersection. When available, police officers may be used to assist or replace flaggers at intersections, especially if traffic volumes are high. Because several streams of traffic must be accommodated simultaneously, flagging operations at intersections are inherently more difficult. It is therefore essential to use a sufficient number of flaggers to (1) provide positive control for each of the traffic approaches and (2) ensure positive coordination between flaggers.

When existing traffic signals are present in an intersection, it is preferable for the flagging operation to coordinate with the signal operation whenever possible. When that is not possible, it is necessary to deactivate the signal, either by turning it off or turning it to a flashing caution mode. Regardless of the signal mode selection, it is essential that the signal and the flaggers do not present conflicting commands to approaching drivers, since this would result in uncertainty as to which command to obey. This requirement is especially critical at night, when visibility is reduced and drivers may be less alert.

2.5.1.4 Temporary Traffic Stoppage

Work operations may require temporary traffic stoppage to adjust the traffic pattern, move equipment, or perform critical operations such as setting structural steel. In these situations, flaggers and perhaps police are necessary to stop and hold traffic until the operation is completed. The assistance of police vehicles or work vehicles is normally needed to affect the initial stoppage or road closure (see Section 3.3.5).

2.5.1.5 Flaggers as Spotters

When work operations occur immediately adjacent to open travel lanes without positive traffic barriers, and especially when the lateral buffer space is narrow, flaggers may be placed immediately upstream of the work crew. Spotters can provide an advance warning in the event of vehicles intruding into the work space or other erratic or threatening vehicles approaching the work space. The spotter can also provide a warning if workers unintentionally step out of the protected work space. In addition, flaggers can direct traffic to shift away from the work space as it passes the work crew. This function is especially important when lateral clearance past the work space is limited. Flaggers used as spotters should be provided with a handheld audible alarm so that a warning can be provided to the work crew if necessary. To be effective, the alarm device must be readily available to the flagger for instant use if needed. Small aerosol-powered devices can be clipped to the flagger's belt or to the staff of the stop-slow paddle to make the devices immediately available in an emergency.

2.5.1.6 Speed Control

Experience has shown that flaggers can produce small speed reductions by drivers, especially when specific flagging techniques are used. When used as spotters at restricted work sites, or where operations such as concrete curing require speed control, flaggers may be used to elicit the speed reduction. The signaling procedures in the MUTCD include a signal to slow. Other potentially useful methods used by flaggers to control speed have not been evaluated widely enough to be included as a guideline, nor have they been evaluated at night. (See Tech Note 33.)

2.5.2 Illumination, Visibility, and Temporary Lighting

The reduced visibility inherent at nighttime work sites makes flagging riskier for both flaggers and drivers. It is therefore essential to make both the flagging station and the flagger as visible as possible at night.

Except for very short-term or emergency operations, it is highly desirable to provide temporary illumination at nighttime flagging operations. Guidelines for temporary lighting are provided in Section 2.9.

The objective of lighting flagger stations is to make the flagger stand out from the surroundings. In unlighted areas, a portable luminaire at the flagger station accomplishes this objective. When permanent roadway lighting or temporary work site lighting is present, an additional temporary luminaire at the flagger station helps to make the flagger stand out from the surroundings. To be effective, it is essential for the flagger to be illuminated from above rather than from the front or rear. This position reduces glare both for approaching drivers and for the flagger.

For short-term or emergency operations when a temporary luminaire cannot be provided, the flagger station should be positioned, to the extent possible, to take advantage of existing or work site luminaires.

2.5.3 Location of Flagger Sites

Section 6E.05 of the MUTCD provides guidelines for the location of flagger stations and the position of flaggers at the flagger station. Reduced visibility and impaired driver performance at night make it essential to consider the following guidelines.

2.5.3.1 Location of Flagger Station

The flagger station must be selected to provide good advance sight distance. At a minimum, DSD should be available upstream from any queue that may develop when traffic is stopped. The flagger station should also be selected to provide adequate buffer space prior to the work space. See Table 6E-1 of the MUTCD for suggested speed-related lengths.

In addition to sight distance and buffer space, the flagger station should be selected to isolate the flagger from the work operation, other workers, and equipment. This isolation helps drivers to more easily detect the flagger as they approach. Equally important, the isolation makes it easier for the flagger to see approaching traffic and to avoid any vehicles that fail to stop or that swerve toward the flagger.

2.5.3.2 Flagger Position

The MUTCD recommends that flaggers stand on the shoulder or closed lane adjacent to the open lane as the traffic approaches, moving into the open lane only after traffic has stopped and only if necessary to be seen by other traffic. Especially at night, it is critically important that a flagger is not positioned in the path of an approaching vehicle or between two traffic streams, so that the flagger has the best possible chance to avoid the vehicle. In the event that an impaired driver fails to respond or drifts out of the lane, the flagger has the best possible chance to avoid the vehicle. Under no circumstances should a flagger be positioned where the escape path is blocked by parked vehicles, equipment, or other features.

2.5.4 Flagger Equipment, Procedures, and Apparel

Guidelines for equipment, procedures, and apparel are provided in Chapter 6E of the MUTCD. The following guidance is provided to enhance nighttime flagging operations.

2.5.4.1 Equipment

The stop-slow paddle is the standard hand signaling device and should be used for all flagging operations except emergencies. Signal flags may be used for emergencies until paddles can be obtained. Both paddles and flags used at night must be reflectorized and meet all of the requirements of the MUTCD. (See Tech Note 34.)

An improved paddle incorporating flashing lights in the handle or face of the sign has been shown to improve driver response and is now approved for use. This device may offer advantages in situations where drivers are not expecting to encounter a flagger, especially if the traffic volumes are low and approach speed is relatively high. However, this device is relatively new and has not gained extensive field experience. (See Tech Note 35.)

Another supplement to the conventional stop-slow paddle is a reusable temporary stop bar combined with an oversized paddle. This device is useful in helping drivers decide when and where to stop relative to the flagger location. However, the device has not yet been widely evaluated. (See Tech Note 36.)

2.5.4.2 Flagger Procedures

Standard signaling procedures are provided in the MUTCD. To ensure that drivers understand the signals, it is essential that flaggers for night operations are adequately trained and supervised to consistently display the proper signals. Flagger training must also include the special considerations for night work. Proper coordination of flaggers for alternating one-way flow and intersections must be arranged prior to the start of the operation and be fully understood by all flaggers and supervisors. Flaggers must also understand and consistently adhere to procedures in terms of flagger position. Finally, site-specific procedures are needed to assist flaggers in determining when to stop an approaching vehicle.

2.5.4.3 Flagger Apparel

The MUTCD provides a range of choices for flagger apparel. At night, reflective markings on the flagger vest or outer garment are essential to make the flagger as visible as possible to approaching traffic. Brightly colored garments in fluorescent colors, with reflective stripes, enhance the visibility of workers at night (*30*).

To the extent practical, flagger apparel should be as highly visible as possible, and consideration may be given to providing special apparel such as brightly colored garments and coveralls. Sufficient area of retroreflective markings must be applied to the vest or outer garment to enhance visibility. Although no specific guidelines for total area or pattern are available, it is essential for the flagger to be clearly visible at a distance of 305 m (1,000 ft) under headlight illumination. The pattern of reflective striping must be visible under the entire range of body motions.

Although there is no clear-cut consensus that any particular color is inherently superior in terms of worker or flagger visibility, it is generally accepted that a uniform, distinctive appearance for flaggers is desirable. At a minimum, good quality vests in one of the bright colors described in the MUTCD are to be worn by all flaggers. Strong yellow-green (SYG) vests with horizontal and vertical orange retroreflective stripes worn over white overalls may offer the best protection for day and night use when seen against varying colors of background and equipment. (See Tech Note 37.)

Distinctive apparel that uniquely identifies the flagger from other workers is of added advantage at night. To ensure good visibility, vests must fit properly and cover the entire upper torso of the flagger. Vests must be kept closed in the front and back and must be clean and in good condition. Full jackets and trousers in bright colors and equipped with reflective striping may further enhance flagger visibility. However, a vest worn over any special shirt or jacket may still be desirable, in that it can uniquely identify the wearer as a flagger.

Further, union work rules and job assignment considerations may make it difficult to provide special apparel for flaggers. Regardless of the design, colors, and so forth, flagger apparel must, at a minimum, meet all requirements of the relevant regulatory agency, including those of MUTCD, the Occupational Safety and Health Administration (OSHA), and the highway agency.

2.5.4.4 Advance Warning Signs

In addition to other advance warning signs, the flagger warning sign must be displayed in advance of flagger stations whenever the flagger is present. The various signing configurations that include the flagger warning sign are shown in TA-10, -13, and -14 of the MUTCD. To maintain driver respect for this sign, however, it should be removed when the flagger is not present. This removal is recommended even for brief interruptions of more than a few minutes. A supplementary distance plaque providing distance to the flagger may also be provided, as shown in TA-10 of the MUTCD. This provision is especially important if there is restricted sight distance on the approach to the flagger. However, if at all possible, the flagger station should be moved to improve visibility rather than relying on a supplemental distance plaque.

To avoid clutter and potential confusion, signs in advance of flagger operations should be coordinated with other signs on the project. For example, the ROAD WORK sign in these figures should be eliminated if advance warning signs were provided earlier. Additional guidelines for advance signing are provided in Section 2.2.

In addition to the advance flagger sign, a BE PREPARED TO STOP warning sign may be displayed, especially on expressways and other locations where drivers do not expect to stop.

A high-level warning device (i.e., flag tree) may also be helpful in attracting driver attention if displayed in a flood-lighted area. If used, this device must be far enough ahead that it does not restrict visibility of the flagger for drivers or restrict the visibility of vehicles for the flagger.

2.5.5 Control of Work Vehicles

Construction vehicles and equipment—especially haul vehicles—entering, exiting, or crossing travel lanes often present a safety concern at night. Flaggers are often used to control such movements. To ensure the safest possible operation, it is essential to plan such operations in advance and to train flaggers to conduct these operations with complete regard for safety. Work crews are typically intent on maximizing production, which normally means giving priority to the movement of construction traffic. Stopping moving traffic always entails risk, and the risk is increased at night; therefore, consideration should be given to modifying the normal priority for night operations.

To reduce the risk of rear-end accidents, flaggers should not stop moving traffic to permit truck movements unless absolutely necessary. If adequate gaps are often available in the traffic stream, work vehicles should be held until an acceptable gap is available. When the traffic stream must be stopped to permit construction vehicles to proceed, flaggers must be trained to recognize when to initiate the stop. The cues associated with the decision not to stop traffic are vehicles moving at higher speeds, heavy vehicles, and vehicles with other vehicles following closely behind. If any such situation prevails, public vehicles should be allowed to proceed if at all possible.

In some situations, it may be necessary for heavily loaded construction vehicles to cross the travel lanes. When these vehicles must approach at a significant speed or on a downgrade, it may be necessary to stop the traffic in the travel lanes to permit the work vehicles to proceed safely. Consideration should be given to replacing flaggers with temporary signals or uniformed guards for such situations if feasible.

Regardless of the method used to control construction traffic, it is essential that all of the drivers and operators on the project are adequately trained such that they are familiar with the procedures and know what is required of them, as described in Section 3.1.2.

2.5.6 Temporary Traffic Signals

Temporary traffic signal control offers an excellent alternative to flagger control in that it reduces the safety risk for flaggers. It may also generate better driver obedience, especially if police patrols are active on the project. Because nighttime operations must typically be installed and removed nightly, any temporary signal operation must be designed to facilitate rapid deployment and removal. When alternating one-way flow is in place for only a short time, or the location of the section must change often, flaggers offer more flexibility than temporary signals. For these situations, a well-designed flagging operation may provide a better choice than temporary signals. (See Tech Note 38.)

2.6 OTHER SAFETY DEVICES

In addition to the various traffic control devices discussed in Sections 2.1 though 2.4, a number of safety features may apply in temporary traffic control zones for night construction operations. Because they must normally be installed and removed on a nightly basis, devices used in nighttime traffic control zones must be readily portable, or at least easy to install and remove nightly. However, in some cases, certain safety devices may be left in place for an extended period to protect roadway or construction features that are present throughout the construction operations. Such features include roadside excavations, exposed traffic barrier ends, and openings in bridge decks.

Like channelizing devices and signs, other safety features used in work zones should minimize harm if impacted. Refer to Section 2.1.5 for (1) a discussion of current requirements for impact performance for work zone traffic control devices and (2) references for devices meeting *NCHRP Report 350* (*8*) criteria.

The sections that follow (1) describe a number of safety devices that may be applicable for nighttime operations and (2) present guidelines for their use.

2.6.1 Crash Cushions

Crash cushions prevent errant vehicles from impacting fixed-object hazards by gradually decelerating a vehicle to a safe stop for a head-on impact or redirecting the vehicle away from the hazard for side impacts. Crash cushions are intended for use at locations where fixed objects cannot be removed, relocated, or made breakaway and cannot be shielded by a longitudinal barrier.

2.6.1.1 Crash Cushions or Impact Attenuators

Two general types of crash cushions are available. One type functions by absorbing the kinetic energy of the impacting vehicle by crushable or plastically deformable materials or by the use of hydraulic energy absorbers placed in front of an obstacle. The second type involves the transfer of the momentum of the moving vehicle to an expendable mass—usually sand—placed in the vehicle's path. However, this type rarely provides effective protection for site impacts.

2.6.1.2 Operational Crash Cushions

The 1996 AASHTO *Roadside Design Guide* describes characteristics of operational crash cushions (*5*). The technology involving these devices is improving rapidly, and new and improved crash cushions are introduced on a regular basis. Agencies involved in the design and operation of temporary traffic control zones should maintain contacts with manufacturers of crash cushions to ensure that information on the most recent devices is readily available and that all manufacturers' guidelines are followed when in use.

2.6.1.3 Applications of Crash Cushions

Typical applications of crash cushions in work zones include roadway or construction features created by the work activities that may constitute a hazard for motorists. Even though the nighttime traffic control zone is present for only part of each day, certain features adjacent to the roadway may be present around the clock. Temporary longitudinal traffic barriers, especially portable concrete barriers, are frequently installed adjacent to the travel lanes, often with only a small lateral offset. Crash cushions may be a good choice to protect the exposed ends of these longitudinal barriers when they cannot otherwise be shielded from traffic. Crash cushions may also be good choices to protect lateral excavations or open bridge decks when longitudinal barrier cannot be fitted to the location.

2.6.1.4 Performance Levels

Crash cushions are available for a range of performance levels. When the decision is made to employ a crash cushion, the device selected should be capable of protecting vehicle occupants for the impact conditions reasonably predictable for that roadway. *NCHRP Report 350* provides three test levels for crash cushions, equivalent to impact speeds of 50, 70, and 100 km/h (30, 45, and 60 mph) (*8*).

2.6.1.5 Device Characteristics

The characteristics of crash cushions vary widely. Characteristics of interest include size, initial and repair cost, portability and installation requirements, damage repair requirements, and performance level. Portability is a critical factor for devices that must be installed and removed nightly. Size—both width and length—may factor in work sites with limited available space. For sites prone to frequent impacts, simplicity and low cost of repairs may outweigh a higher initial cost. Conversely, for sites where impacts are expected to be rare, low initial cost normally outweighs ease and economy of repair.

Regardless of the other factors considered, the crash cushion selected must provide adequate protection for the anticipated impact conditions. The performance level for the device and its physical configuration must be adequate to physically protect errant vehicles from contacting the hazard or secondary hazards if the vehicle penetrates the end of the crash cushion—known as gating—or is redirected in a side impact.

2.6.1.6 Portability

Few crash cushions are portable to the extent that they can be deployed or removed within a few minutes. However, a number of devices are available that can be installed on a temporary basis with a minimum of site preparation. Such devices may offer a good choice to protect temporary barrier ends and similar work zone features.

A system to rapidly deploy or remove sand-barrel crash cushions using pallets winched on and off a tilt-bed trailer was developed under the SHRP program (*31*). Although prototypes were built, only limited experience has been gained with this system to date. The intent of this system is to permit the rapid placement and removal of crash cushions, even on a daily basis if necessary. Because sand barrels require no site preparation other than a smooth surface, they are ideal for construction sites that change frequently.

An excellent choice where true portability is required is truck-mounted crash cushions, also known as truck-mounted attenuators (TMAs). Because these devices are attached to a truck, they can be moved as often as necessary, permitting them to keep up with moving work crews. These devices are available with performance levels up to 100-km/h (60-mph) impacts. More details on shadow vehicles and truck-mounted crash cushions are provided in Section 2.6.7.

2.6.2 Portable Traffic Barriers

Because traffic control setups for night work must typically be installed and removed on a nightly basis, the use of portable traffic barriers is often more complicated than for situations where the barrier can be left in place for an extended period. However, portable concrete barriers may have applications in certain situations.

2.6.2.1 Portable Concrete Barrier

A number of portable concrete barrier designs are described in the AASHTO *Roadside Design Guide*. Those described are capable of meeting a range of performance levels up to Test Level 3, as defined by *NCHRP Report 350* (*5, 8*). However, the time and traffic exposure necessary to complete the installation and removal on a nightly basis often outweigh any advantages associated with use of portable concrete barrier, except in cases where it can be installed and left in place for an extended period. Portable concrete barrier may enhance work zone safety when it is used to protect work spaces adjacent to travel lanes. When workers are present immediately adjacent to travel lanes, portable concrete barrier may be especially beneficial to protect the workers from vehicle intrusions.

A typical application for night work involves setting the barrier along the edge of the travel lanes for the duration of the work at that location while leaving all of the travel lanes open. During the night work shift, one or more of the travel lanes is then closed to provide contractor access for haul trucks and other work vehicles alongside the barrier. Although those vehicles are only separated from the travel lanes by channelizing devices, the workers and most of the work operation are protected by the barrier. The barrier also provides protection for traffic from any hazards within the work space during nonwork hours. Such an application is shown in NTWA-4A and -4B in Appendix A.

Special attention to barrier installation details is essential to ensure protection for the work space and to protect traffic from impacts on the barrier ends. Recommended practices for portable concrete barrier installation are provided in the AASHTO *Roadside Design Guide* (*5*).

2.6.2.2 Portable Plastic Barriers

Lightweight portable plastic barriers that have been approved by FHWA are available for various test levels of *NCHRP Report 350*. These barriers offer some advantage compared with concrete barrier in terms of setup and take-down time and effort because they can be placed manually without the need for equipment (see Figure 18). Their nightly use may thus be feasible, especially for crossovers of short length, where the amount of barrier needed is small (*8*).

The primary concern regarding these lightweight barriers is the relatively large lateral deflection during impact. Even when filled with water as ballast, deflections of several feet may occur, depending on impact speed and angle. During cold weather, water spilled on the pavement during filling or emptying of the barriers, or spilled during a crash, may present a serious hazard if it freezes on the pavement. Use of water ballast during cold weather should, therefore, be restricted to locations where water cannot be spilled on the travel lanes. A decision to use these barriers should be based on consideration of the time required for installation and removal, probable impact conditions, available width separating opposing traffic, and probable weather conditions.

2.6.2.3 Movable Concrete Barrier

The proprietary "quick change" portable barrier system consists of a chain of short segments of safety-shaped concrete barrier that can be shifted laterally by a transporter machine (see Figure 19). This barrier system offers a potential solution for lane closures and crossovers with two-way traffic that must be installed and removed nightly and where

Figure 18. Portable plastic barrier, which requires no heavy equipment for placement.

Figure 19. Proprietary portable barrier system, which can be shifted laterally by machine.

traffic and work site conditions are such that a positive barrier is desirable to protect traffic and workers.

Because the initial installation and subsequent removal of the barrier segments requires an extensive effort, use of this system is normally limited to applications where the barrier will be at the same location for an extended construction period. The high cost of this barrier and transporter also make its use impractical for brief construction periods. However, for longer periods, especially where traffic volumes and speeds are high, the positive protection provided against crossover accidents and work zone intrusions often outweighs this cost.

In a typical application, the movable barrier is set up in advance of the start of night operations on the shoulder. To start the nightly deployment of the barrier, the travel lane or lanes are first closed using a standard lane closure. This closure would begin upstream of the start of the barrier, providing an adequate buffer space. It is not necessary to close the lane throughout the entire crossover section because the lateral transfer of the barrier proceeds with traffic in the closed lane. Lateral transfer of the barrier continues to the downstream closure. Once the barrier is in place, the remaining features of the closure or crossover are then put in place.

The resulting traffic pattern provides positive protection for the opposing traffic streams or work space with minimum exposure and delay associated with deployment of the barrier. At the end of the night shift, the procedure is simply reversed to restore the highway to normal flow. The only significant impact on traffic during nonwork hours is the storage of the barrier on the median shoulder. Typically, the transfer vehicle is stored at either end of the barrier in the median or on the shoulder, and standard portable barrier can be provided if necessary to protect against impacts by errant vehicles.

2.6.2.4 Other Barrier Systems

An application of movable concrete barrier is shown in NTWA-5 in Appendix A. The AASHTO *Roadside Design Guide* describes other traffic barrier systems intended for rapid installation and removal in work zones (*5*). W-beam on barrels and timber barrier curb and rail have both been crash-tested and shown to perform acceptably for moderate impact conditions. These systems may be considered for use in night work zones where a barrier can be installed and left in place for an extended period and where traffic speeds do not exceed 65–70 km/h (40–45 mph). These systems may offer an advantage compared with concrete barrier in terms of lower cost and lighter weight when installed on a bridge structure.

2.6.3 Temporary Signals

The MUTCD allows the use of temporary traffic signals for special applications at temporary traffic control zones (see Figure 20). These signals include a temporary haul road or equipment crossing and work zones with alternating one-way flow, such as bridge construction. The MUTCD states that all traffic signal and control equipment should meet the standards and specifications prescribed in Part 4. It further specifies that one-way traffic flow requires an all-red interval of sufficient duration for traffic to clear the one-way zone at the posted speed limit. Furthermore, the signals must be either hard-wired or controlled by radio signals to avoid display of conflicting signals.

Research on temporary fixed-time portable signals in lieu of flaggers showed that a substantial savings in flagger labor costs, with only a minimal increase in motorist delay costs, could be achieved by using a portable fixed-time signal system. The research also suggested that the potential for vehicle accidents within the work zone may be higher with portable traffic signals because of occasional driver noncompliance with these signals. The tradeoff between a possible increase in vehicular accidents and the reduction in flagger accidents is something that must be considered in choosing between the two methods. (See Tech Note 39.)

In addition to portable signals, conventional traffic-actuated signals installed for the duration of the work may be advantageous when the signals are needed on a nightly basis. Examples include intersections on detours where higher traffic volumes must be accommodated at night and sites with alternating one-way traffic.

Some recent research provides a suggested methodology to optimize the section length and timing of alternating one-way signal control installations. (See Tech Note 40.)

2.6.4 Rumble Strips

Rumble strips are transverse strips of rough-textured pavement used to alert drivers to an upcoming change in the roadway or traffic pattern by imparting a vibratory and audible warning to the driver (see Section 6F.78 of the MUTCD and Figure 21). Although portable rumble strips are available, they are practical for low speeds only because they are easily dislodged by higher-speed traffic. Rumble strips installed into or adhered to the pavement can provide good durability and can be used where they will be in place over an extended period. However, nonportable rumble strips are generally not practical where they must be installed and removed nightly. Possible applications include median crossovers or other temporary pavement where it is desirable to alert drivers to the changed conditions at night. Rumble strips may also be installed in the normal travel lanes to alert drivers prior to nighttime traffic pattern changes, as long as they are not considered objectionable during nonwork hours.

Figure 20. Temporary traffic signals.

Figure 21. Temporary rumble strips formed from removable pavement masking tape.

2.6.4.1 Effectiveness of Rumble Strips

Although rumble strips do not necessarily produce a reduction in the speed of traffic, they can be effective in alerting inattentive drivers who fail to notice visual information. This effect may be especially helpful where drivers have been mesmerized by traveling long distances on an unrestricted highway and then suddenly encounter a work zone. Alerting these drivers to changes in the roadway character may reduce the accident potential (*32*). The installation of rumble strips may improve traffic flow in the event that additional warning signs and a CMS do not reduce late merges and congestion. (See Tech Note 41.)

One condition under which temporary rumble strips may not be effective in improving driver recognition of work zone traffic control measures is where there is little activity in the work zone (*33*).

2.6.4.2 Installation Procedures

Long-term rumble strips may be installed using several methods. Where the pavement will be overlaid or removed after completion of the work, recessed strips may be installed by sawcutting or milling grooves into the pavement surface. Raised rumble strips may be provided by adhering a thin strip of asphalt concrete to the pavement surface. To achieve long-lasting adhesion, the pavement must first be cleaned and a tack coat applied. Raised strips can also be installed by building up layers of pavement marking tape to the desired thickness. Either removable or permanent tapes can be used, depending on the required durability and ease of removal.

2.6.4.3 Rumble Strip Patterns

Patterns must be balanced to provide adequate warning to drivers without being so severe that they startle drivers or upset motorcycles. Sets of six parallel strips spaced about 10 ft apart are acceptable for high-speed roadways, with closer spacings for slower speeds. Multiple sets of strips spaced several hundred feet apart can be used to provide repeated warnings. Widths of 10–15 cm (4–6 in.) and depths or heights of approximately 1 cm (0.5 in.) have been widely used and normally provide adequate warning without being too severe or endangering motorcycles. However, trial installations may be helpful in determining the preferred depth or height for a given application.

2.6.4.4 Restrictions on Use

Even strips with very shallow depths or heights may affect control of bicycles, especially in night situations where the cyclist cannot see them in advance. Therefore, rumble strips should normally not be installed where bicycle traffic is expected, especially at night. However, if dedicated bicycle lanes are provided, rumble strips installed only in the vehicle lanes may be acceptable (*5*).

2.6.5 Screens

Glare screens mounted on temporary traffic barriers help to reduce driver distraction from nighttime work operations (see Figure 22). Screens also reduce headlight glare from oncoming traffic. Application of screens is described in Section 6F.79 of the MUTCD and is also discussed in the AASHTO *Roadside Design Guide* (*5*). Screens may be especially helpful at night because a lighted work space may attract drivers' attention to an even greater extent than in daylight.

2.6.5.1 Screen Design

The design of screens is discussed in the AASHTO *Roadside Design Guide* (*5*). Screens should have an adequate height to achieve the desired level of view restriction. Screens are often attached to the top of longitudinal traffic barriers, especially concrete barriers. There are numerous commercially available products for this purpose. Freestanding screens may also be designed to provide portability where attachment to a barrier is not possible. Regardless of the design, it is essential that the screen is sturdy and durable so it is not dislodged, creating a traffic hazard. Screen designs must also be capable of performing in a safe, predictable manner if impacted. The use of horizontal members, such as pipe or timber, to support the screen should be avoided because of the risk of vehicle penetration if impacted.

2.6.5.2 Limitations on Use

Screens should not be installed where they restrict the driver's view of the roadway ahead, such as on the inside of

Figure 22. Screens mounted on temporary traffic barrier.

short-radius curves. Screens may also be undesirable where it is important that police officers be able to observe the entire roadway.

2.6.6 Opposing Traffic Lane Divider

The opposing traffic lane divider, described in Section 6F.64 of the MUTCD, is a delineation device used to separate opposing traffic on a two-lane, two-way operation. This device is suitable for use in nighttime operations because it provides a clear separation of opposing lanes and it can be quickly installed and removed. Portable versions are available with weighted bases that are intended to keep the device in place and resist movement or overturning by traffic-induced wind forces. Versions are also available that can be attached to the pavement, but they are generally not appropriate when the device must be installed and removed nightly.

Recommendations for spacing are not provided in the MUTCD. Considering the often reduced alertness level of drivers at night, the spacing should be close enough to clearly delineate the opposing lanes and to discourage drivers from cutting between devices to pass other vehicles. A spacing of 60 m (200 ft) may be satisfactory for most situations. However, if there is concern that drivers may attempt to cross the centerline, the spacing should be reduced. An even more effective treatment may be achieved by maintaining the 60-m (200-ft) spacing and adding tubular markers between devices. Where pavement markings conflict with the temporary traffic pattern, very close spacings, as little as 3 m (10 ft), may be necessary.

2.6.7 Shadow Vehicles and Truck-Mounted Attenuators

Trucks or trailers may be used to protect workers or work operations from errant vehicles that enter the work space. While the vehicle provides protection for workers ahead of it, collision with the rear of a truck or trailer often results in severe consequences for the occupants of the impacting vehicle. TMAs should thus be installed on the rear of the vehicle to protect occupants of the impacting vehicle. However, if a work vehicle must be present, keep workers ahead of it if possible. Additional information is provided in Section 6F.76(2) of the MUTCD and in the AASHTO *Roadside Design Guide*.

2.6.7.1 Applications for Shadow Vehicles

Because they are completely mobile, shadow vehicles are a good choice to protect workers and work operations at any location where vehicles may intrude into the work space. They can also be used to protect vehicle occupants from construction features such as deep excavations, open bridge decks, and other fixed hazards. The added risks associated with night work make these devices well suited for a variety of situations when it is impractical or impossible to install barrier or a fixed crash cushion. However, shadow vehicles only protect vehicles approaching from the rear and cannot provide longitudinal protection for an extended work space.

These devices are best suited for situations when workers or a hazard are confined to a limited area. When an operation is spread out over more than a short distance, the risk of intrusions along the length of the work space increases, and the shadow vehicle cannot provide protection over the extended length. In such situations, additional protection may be achieved by spacing more than one vehicle throughout the work space.

2.6.7.2 Impact Protection

TMAs should be evaluated according to *NCHRP Report 350* criteria, which require testing with both a small sedan and a full-size pickup (*8*). Commercially available devices have been developed to test Levels 2 and 3 at 70 km/h and 100 km/hr (45 mph and 60 mph). Depending on the model selected, protection for occupants of the impact vehicle can be provided for speeds typically encountered in most work zones.

Excellent protection is provided for the workers when the impact vehicle is a passenger car, because the shadow vehicle is pushed ahead only a short distance. However, if impacted by trucks or other large vehicles, protection for the occupants is not ensured, and the shadow vehicle may be pushed ahead a considerable distance. Reported experience with shadow vehicles equipped with attenuators shows that they are very effective in protecting the work space. For impacting vehicles within the range of weight and impact speed for which the attenuator was designed, excellent protection is also provided to occupants of the impacting vehicle (*34*).

2.6.7.3 Vehicle Characteristics

Shadow vehicles equipped with TMAs protect workers from vehicles that may intrude into the work space. The TMA protects the occupants of the intruding vehicle (see Figure 23). TMAs are typically tested using shadow vehicles in the range of 18,000–20,000 lb. Use of heavier vehicles reduces roll-ahead, especially if impacted by a larger vehicle. The small sedan tests are performed with the shadow vehicle placed against a rigid barrier to eliminate roll-ahead. Use of a heavier shadow vehicle, thus, will not affect occupant protection for small-car impacts. However, the use of lighter shadow vehicles may result in increased roll-ahead when impacted by larger vehicles and should be avoided unless speeds are low and there are few trucks or other large vehicles in the traffic stream.

Trailers configured similar to the rear of a truck and ballasted to the appropriate weight may be used to support the TMA. Where frequent movement of the trailer during the

Figure 23. Shadow vehicle with truck-mounted attenuator.

work shift is not required, use of a trailer avoids the need to assign a driver for the entire shift. It also eliminates the risk for the support vehicle driver in the event of a severe impact by a high-speed or large vehicle.

When stationary, the support vehicle's brakes should be locked and the transmission placed in the lowest gear to reduce roll-ahead if impacted. Slightly turning the wheels away from the work space and adjacent travel lanes may further reduce roll-ahead risk. For operations that move ahead frequently or at a steady pace, the shadow vehicle should be kept in a low gear and the brakes should be locked whenever the vehicle stops.

2.6.7.4 Vehicle Lighting

In addition to the TMA, shadow vehicles should be equipped with warning lights and reflective material as described in Section 2.7. If the shadow vehicle is used to form a lane closure, it should also be equipped with an arrow panel. Arrow panel operation should be in strict accordance with the guidelines presented in Section 2.4.

2.6.7.5 Position of Vehicle

Shadow vehicles must be properly placed to ensure that they are not pushed forward into the work space if impacted. At the same time, positioning the vehicle farther back than necessary increases the risk of an errant vehicle intruding ahead of the vehicle. Because longitudinal buffer space is intended to be free of all hazards, the shadow vehicle should be positioned beyond the downstream end beyond the buffer space or farther into the work space, depending on the location of the workers or hazard to be protected.

The optimum position of the vehicle usually involves a tradeoff between roll-ahead and risk of intrusions ahead of the vehicle. The optimum position must be determined based on the speed and size of the vehicles in the traffic stream, the characteristics of the work operation, and the weight of the protective vehicle. Recommended vehicle positions are provided in *Transportation Research Record 1304* (*35*).

2.6.8 Arrestor Nets

Arrestor nets are designed to safely stop an impacting vehicle in a head-on impact by snaring the front of the vehicle in a net attached to energy-absorbing reels of steel tape (see Figure 24). The proprietary "Dragnet" arrestor nets are described in detail in the AASHTO *Roadside Design Guide*. This device is capable of decelerating full-size automobiles and similar-sized vehicles from 60 mph or faster, depending on the components used, and does so with minimum risk to the vehicle occupants.

Although anchorages are required to absorb the impact energy, a variety of temporary anchorages have been developed that make it possible to quickly install or remove the arrestor net at most sites. Arrestor nets can be installed or removed on a nightly basis and provide nearly complete protection against vehicle intrusions—at little risk to vehicle occupants. This device is thus a good choice for installation at ramp and full-roadway closures where the risk of intrusions is high or where an intrusion would result in severe consequences. (See Tech Note 42.)

2.6.8.1 Impact Performance

Depending on the energy-absorbing units installed and the width of the net itself, stopping distance from 50 mph is typically limited to approximately 70 ft for large cars at an average deceleration of less than 2 *g*. However, these parameters can easily be adjusted to meet specific site conditions, including designs to stop large trucks. Specific design alternatives are available from the distributor.

2.6.8.2 Typical Applications

Arrestor nets may be considered for use when all traffic must be precluded from a closed roadway or entrance ramp. They are especially appropriate when intruding vehicles can

Figure 24. Arrestor net.

travel for some distance on the closed roadway before encountering the work space.

2.6.8.3 Site Geometry

Adequate stopping distance that is free of all objects and vehicles must be provided behind the nets. Required stopping distance can be determined using formulas provided by the distributor for specific net and energy absorber configurations. In addition to the net and stopping distance behind it, adequate space must be available for traffic control devices in front of the net. In addition, it is often necessary to permit construction traffic to enter the closed roadway, which requires that an acceptable temporary roadway circumventing the net be provided. This roadway should be adequate for the construction traffic expected, including wet weather access, while discouraging errant drivers from entering the closed roadway.

2.6.8.4 Traffic Control Devices

Appropriate traffic control devices, as described in Section 1.1, are essential to alert drivers to the closure before they encounter the arrestor net. At a minimum, ROAD-CLOSED signs, Type III barricades, and flashing warning lights should be provided to effectively close the roadway or ramp prior to the net. Where space permits, adequate buffer space should be provided such that vehicles that proceed through the barricades are provided room to stop before impacting the net. It may be desirable to place the arrestor net some distance beyond the primary closure. In such cases, it is essential to provide a second set of barricades with flashing lights immediately in front of the net to alert construction traffic and any drivers that circumvent the primary closure.

2.6.8.5 Watch Guard

Where there is a concern that drivers will deliberately try to enter the closed roadway by driving around the net, stationing a watch guard or police officer at the closure point should be considered. The vehicle should be equipped with appropriate warning lights and positioned where it is visible to approaching traffic, but where it is not at risk of being struck.

2.6.8.6 Where to Avoid Positioning Watch Guard

Under no circumstances should the watch guard's vehicle be positioned behind the net where an impacting vehicle may deflect the system and strike the vehicle. The watch guard should be equipped with a radio to alert the work crew of any vehicle intrusions.

2.6.9 Intrusion Alarms

A variety of commercially available alarm systems to detect vehicle intrusions into a buffer space or the work activity area are available. Models that provide audible or visual warnings, or both, are available. Because night operations often involve work crews separated from traffic only by channelizing devices and because of the higher incidence of impaired drivers at night, use of these alarm systems provides added protection for workers.

The selection of an intrusion alarm system for night operations depends on the type of operation. If the system must be removed during daylight hours, only systems that are reasonably portable will be feasible. Currently available alarm systems include both mechanical systems (e.g., road tubes) and electrical systems (e.g., ultrasonic or infrared beam sensors). Other systems use a worker to detect intrusions and activate a warning signal. Along with portability, the layout of the site is another factor that will dictate the type of system that can be used. System sensors must be configured such that work vehicles can enter and exit the site without activating an alarm. Also, the site must permit the location of sensors such that all workers will have sufficient time to take evasive action if an intrusion occurs.

The type of alarm used to warn workers of an intrusion depends on the work situation. Generally, an audible alarm is best so that the workers will get the warning signal regardless of what they are doing. However, on sites with high ambient noise levels, it may be necessary to supplement the audible alarm with a visual alarm, such as strobe lights. Another factor to be considered is the incidence of false alarms due to activation of the alarm by ambient signals emanating from construction equipment, from communications equipment, or, if in an urban environment, from local activity. Also, some electrical systems that use a signal reflected off of channelizing devices can issue a false alarm if the channelizing device is slightly displaced because of vehicle-generated winds.

At this time, both portability and reliability are probably most adequately met by using a worker observer to detect intrusions and activate an alarm. However, because few intrusions are likely to occur and the observer task can therefore become extremely boring, causing inattention, worker observer shifts should be relatively short. (See Tech Note 43.)

An alternative to a dedicated observer that can be considered is using a flagger or the driver of a shadow vehicle to activate the intrusion alarm. Using such personnel will obviously depend on whether they have an adequate view of the site.

2.7 VEHICLE PROTECTION

Construction vehicles and equipment are frequently involved in traffic accidents in and adjacent to temporary traffic control zones (*34*). Accidents involving work vehicles and equipment may increase because of the special concerns associated with night work. Reduced visibility, impaired and unfamiliar drivers, and higher speeds may combine to result in both higher accident rates and increased severity. This section provides guidelines to make work vehicles adequately visible and identifiable at night. Drivers must be able to not only see work vehicles, but also identify work vehicles as such in order to prepare for, and avoid hitting, work vehicles that slow, stop, or turn unexpectedly. This section also provides suggested procedures to reduce the risk of crashes between these vehicles and equipment and the traveling public.

2.7.1 Warning Lights

Warning lights are effective in terms of enhancing the visibility of work vehicles and equipment. Even when equipped with conventional highway lighting equipment, the addition of warning lights makes work vehicles and equipment more readily visible and identifiable as being associated with the work.

Past studies have shown that the effectiveness of vehicle warning lights varies with the lighting configuration and the type of work operation (*36*). However, the practicalities of construction operations normally dictate that a single lighting configuration is selected for a given vehicle or piece of equipment. Other than turning lights on and off, it is generally not practical to vary the configuration from operation to operation.

2.7.1.1 Avoid Strobe

Individual rotating or flashing incandescent lights are preferable to strobe lights or flashing light bars. Strobe lights provide the advantages of low initial cost, low power draw, good durability, and excellent long-distance visibility; however, they do not perform well in terms of conveying distance information and closure rates to other drivers. Because approaching drivers need to sense distance and closure rate of a work vehicle in order to initiate appropriate response to the work vehicle, strobe lights are not recommended (*36*).

A wide selection of light bars, incorporating a variety of flashing and rotating incandescent lights, combined with strobe lights are commercially available and are commonly used on emergency and law enforcement vehicles. Although these light bars provide excellent visibility, they are probably less effective than simple rotating or flashing beacons in terms of distance and closure rate information. Combined with their higher initial cost and higher power draw, they are thought to be less appropriate for night construction use than rotating or flashing beacons. However, for police vehicles used in night work, these light bars clearly identify the police vehicle and provide a worthwhile function. Likewise, for tow trucks or other special-function vehicles already equipped with light bars, they provide clear identification and should continue to be used without adding the conventional rotating or flashing lights used on other work vehicles and equipment.

2.7.1.2 Flashing or Rotating Beacons

Flashing beacons and rotating beacons, which provide the appearance of flashing, provide better distance and closure information and, thus, are recommended for night use on all work vehicles and equipment, except as otherwise noted below. Mounting these lights in pairs, one on each side of the vehicle, further enhances driver judgment of distance. Furthermore, using two lights ensures continued visibility if one light is blocked or fails.

2.7.1.3 Brightness

In addition to type, number, and position, warning lights must be adequately bright to ensure good visibility. NYSDOT nighttime specifications require that warning lights must be visible for a minimum of 300 m (1,000 ft) in all directions in daylight. This level of brightness is thought to provide good visibility at night and can be provided by a wide range of commercially available warning lights (*17*).

2.7.1.4 Color

Although various colors are available, amber is widely recognized as associated with highway service vehicles and with the need for caution. Standardization on yellow further reduces the chance of confusing the work vehicles with emergency and police vehicles or other types of service vehicles that may be present in the traffic stream, but not associated with the work.

2.7.1.5 Installation

Warning lights should be attached on the vehicle or equipment in a position that provides 360-deg visibility if possible. Warning lights mounted on the front of a haul truck provide excellent visibility to motorists approaching from all directions (see Figure 25). If configuration of the equipment prohibits 360-deg visibility, then two pairs of lights should be added, with one pair visible in each direction. It is also essential that the mounting position does not result in the warning light creating glare for the driver or operator. On rollers and other open equipment, it may be necessary to mount the lights on a mast to place them well above the operator's line of sight.

2.7.2 Reflectorized Markings

Rotating or flashing lights on equipment and vehicles are effective in making the equipment and vehicles visible at night. However, these lights may not define the size of the vehicle or equipment. Furthermore, if the lights fail or are not

Figure 25. Warning lights mounted on the front of haul truck.

Figure 26. Reflectorized sign on the rear of haul truck.

in operation, visibility is severely limited. To define shape and size, and to ensure visibility if the lights are not operating, reflective tape should be added to the rear of dump trucks and other large trucks and to the front, rear, and sides of rollers and other equipment.

A band of 5-cm (2-in.)-wide, red and white reflective tape defining the outline of the vehicle or equipment greatly enhances visibility and defines the width of the vehicle for approaching drivers. When the configuration of the equipment limits the area available to apply tape, a minimum of 100 in.^{2} of material should be provided whenever possible in a pattern that at least defines width (*37*).

Reflective tape on haul vehicles and equipment becomes dirty and may deteriorate rapidly. This tape must be cleaned and replaced as needed to maintain visibility.

2.7.3 Identifying Signs and Markings

In spite of the flashing or rotating beacons, drivers may sometimes mistakenly attempt to follow work vehicles as the work vehicles exit travel lanes to pull into the closed portion of the roadway. This risk can be reduced by adding reflectorized signs to the rear of haul trucks and similar work vehicles that must frequently exit the traffic stream (see Figure 26). A standard message such as WORK VEHICLE—DO NOT FOLLOW displayed on the rear of such vehicles is recommended. NYSDOT requires a 0.6 m by 1.2 m (2 ft by 4 ft) size for this application, which should provide adequate legibility for following drivers while permitting easy mounting on most vehicles. The standard black-on-orange color provides further identification with the work activities. It is essential that these signs be cleaned frequently and replaced as needed to maintain their legibility on the rear of dump trucks. These signs should be covered or removed when not needed to maintain driver credibility for signs that are needed.

2.7.4 Inspector and Supervisor Vehicles

Although the addition of two rotating or flashing amber beacons to all trucks and equipment is practical and should be required for night work, the addition may be impractical for passenger vehicles and personally owned light trucks operated by inspectors and supervisory staff within the project limits. However, these vehicles still must be visible, and motorists must be able to clearly identify the vehicles as being associated with the work. Workers must also be able to clearly and readily identify vehicles that are authorized within the closed portions of a roadway and, thus, do not present a risk to workers and other traffic. The addition of a single fixed or portable rotating amber beacon to the roof of such vehicles provides good visibility and is practical to implement. Magnetic bases make these lights easy to deploy and remove as needed without damaging the vehicle's finish. Regardless of the type of light selected, it should meet the same brightness requirements as for larger trucks—that is, 300-m (1,000-ft) daytime visibility.

2.7.5 Light Usage

Warning lights should be in operation whenever needed, but turned off when not needed to reduce the potential for driver confusion and to maintain the credibility of the lights when needed. In addition to the rotating or flashing beacons, the four-way emergency flashers should be activated on vehicles when appropriate to provide additional warning and closure rate information to other drivers or to make parked vehicles visible when in an exposed location.

To minimize distraction and driver confusion, warning lights and four-way flashers on all work vehicles, including passenger cars and light trucks used by project staff, should be turned off whenever the vehicle is moving at normal speeds in the traffic stream for substantial distances. Likewise, warning lights should be turned off when the vehicle is parked out of the traffic stream in a position where it is protected from traffic and other work vehicles.

Prior to slowing down in the traffic stream or exiting or entering the traffic stream, it is essential for the warning lights to be turned on to enhance visibility and to provide a warning to other drivers. To ensure that the driver of the work vehicle does not forget to turn the warning lights on when needed, especially if unexpected stops or turns occur, it is generally preferable to leave the warning lights in operation when operating for short distances in the traffic stream within the active area of the project.

Required warning lights should be displayed at all times when operating on closed roadways to alert workers and other construction traffic and to denote vehicles that are authorized on the closed roadway. Likewise, work vehicles parked or momentarily stopped on the pavement or shoulders of closed roadways should display either warning lights or four-way flashers so that the vehicles can be seen by other construction traffic.

2.7.6 Direction of Vehicle Movements

To avoid confusing traffic, work vehicles in closed lanes or shoulders should travel in the same direction as traffic whenever possible. Exceptions must be made for asphalt rollers and other equipment that must move in both directions. When vehicles must move against traffic, such as for picking up lane closures, the vehicle should normally back up at a controlled speed to avoid confusing traffic and to avoid the need to turn around adjacent to traffic. However, when temporary lighting allows work vehicles to operate without headlights and when adequate turnaround space is available without intruding into traffic, it may be permissible to drive upstream in the closed lane without causing confusion or a risk to ongoing traffic.

2.7.7 Protecting Slow-Moving Equipment

Construction equipment does not perform well when operated in the traffic stream because it does not accelerate, decelerate, or turn quickly. In addition, it is often wider than typical highway vehicles, and its large weight and size often makes it especially hazardous if impacted. Even when equipped with warning lights, construction equipment may be less visible to drivers than normal vehicles are, and drivers may fail to recognize the equipment as slow-moving equipment. Whenever possible, construction equipment should not be moved in open travel lanes or on shoulders adjacent to travel lanes.

Occasionally, however, it may be necessary to move certain types of equipment from work areas to staging and storage areas. When such moves become necessary, it is essential to take appropriate precautions to minimize risks to other traffic. Whenever possible, such moves should be made when traffic is lightest and during daylight hours. The length of such moves should be held to an absolute minimum. This limit may require establishing temporary storage areas along the length of a project rather than returning equipment to a central yard on a nightly basis.

Occasionally, one must move construction equipment in open lanes, or on the shoulder adjacent to open lanes, and at speeds well below normal traffic speeds. In such cases, the equipment should be equipped with a pair of rotating or flashing lights.

Added protection should be provided by following the equipment with a chase vehicle equipped with one or more rotating beacons and four-way flashers. Normally, the chase vehicle will consist of a pickup or other light truck. The chase vehicle provides added visibility, is more maneuverable if it must evade an errant vehicle, and can provide added protection at turning points and other locations where the equipment must slow or stop momentarily. The chase vehicle should vary its distance behind the equipment. Normally, it will follow closely enough that vehicles cannot cut in between the chase vehicle and equipment. However, on hill crests or other locations with restricted sight distance, it may need to lag farther behind.

2.7.8 Vehicle and Equipment Parking and Storage

Vehicles and equipment parked on shoulders, in closed lanes, or adjacent to the roadway may represent a potential hazard to traffic and to other work vehicles. This possibility exists both on open and closed roadways during work hours and on open roadways during nonwork hours, both day and night. Steps can be taken to reduce this potential hazard.

First, designated parking should be provided for workers' personal vehicles in a safe location. Not only must the location ensure that the parked vehicles are not a hazard to traffic and work vehicles, but workers must also be able to safely reach the work area after parking. In urban work locations with limited space on the roadway, it may be necessary to provide parking off-site and transport workers to the work area. Providing temporary lighting for the parking area provides security for both workers and the parked vehicles and reduces the risk of vehicle-pedestrian accidents in the parking area.

Inspectors and supervisors must often use personal vehicles to move about the work area throughout the work shift. In such cases, it is essential that these workers park their vehicles at locations that minimize the risk to other work vehicles and traffic. Once work vehicles are (1) parked safely off the roadway or in areas designated for worker parking and (2) lit or clearly identified such that they are visible to other work vehicles and traffic, all vehicle lights should be turned off to reduce distraction for other drivers.

In addition to workers' vehicles, equipment and large trucks must often be stored within the highway limits during nonworking hours. This equipment may represent a significant roadside hazard if parked where it can be struck by errant vehicles. This risk must be minimized by parking all vehicles and equipment behind existing traffic barriers, well beyond the roadside clear zone, or in other areas not accessible to errant vehicles that depart the roadway. In some cases, it may also be important to consider security during nonwork hours. Theft or vandalism and risk of injury to trespassers may all be concerns in some locations.

2.8 WORKER PROTECTION

Highway construction and maintenance work are recognized as high-risk activities for workers, and those risks are generally greater at night. In order to protect workers from the risks inherent in night work activities, it is essential for specific measures to be included in the design and operation of the project. This section provides guidelines for enhancing worker visibility at night and for training workers to work safely in the night environment.

Workers need to be aware of the risks inherent in night work, as well as the site-specific procedures to avoid those risks. Contractors should be encouraged to develop their own safety programs that include training. OSHA regulations require training for construction workers for all types of projects. These guidelines provide a general overview of methods and content of work site safety training and mention specific issues relative to worker safety on night construction projects.

2.8.1 High-Visibility Apparel

Although the need to provide enhanced visibility and conspicuity for flaggers under night conditions is obvious, the need is equally important for other workers, particularly for personnel who may be working in (or frequently entering) areas of the work site that are hazardous because of the possibility of intrusion by public traffic or because construction vehicles may be traveling through. Ensuring adequate visibility of exposed workers may be more difficult than ensuring adequate visibility for flagger personnel. This increased difficulty is because flaggers will always be in an upright position and facing traffic, whereas other workers may be in any position: standing, stooping, facing away from traffic, and so forth. Thus, the area of the body and head that must be emphasized is not predictable. From the standpoint of detection by drivers of both public vehicles and on-site work vehicles, workers must be recognizable as workers over the entire range of body motions and positions. This necessity implies a greater need for “whole-body” visibility, including hard hats, than would be the case for flaggers alone.

Whereas the goal with respect to flaggers is to provide retroreflective patterns or colors that clearly differentiate flaggers from other workers so that flaggers are adequately detected by drivers when illuminated by headlamps, workers in general may need to be visible from any direction and without the aid of retroreflection. If flagger personnel are to be used as spotters to warn workers of intruding vehicles or crossing or entering work vehicles, it is necessary that the worker reflectorization be adequate for detection by the spotter. Although most work vehicles whose operators need to see other workers will have headlighting, such lighting is not ensured and the angle at which these vehicles approach workers is unpredictable. Therefore, it is prudent to have workers clearly visible under diffuse, as well as retroreflective, conditions. This visibility is best accomplished by having workers wear light-colored clothing in addition to their retroreflective vests and hats. One state has reported requiring all workers to wear white overalls together with striped retroreflective vests. (See Tech Note 44.)

Another factor that must be considered is the visibility of workers against a background of nonmoving equipment, vehicles, or both. In this case, the reflective patterns and colors of delineation used on the equipment must be taken into consideration relative to the visibility of workers against the likely background. This necessity clearly argues against clothing of a solid color and suggests an advantage to alternating colors in stripes. (See Tech Note 45.)

If worker clothing might be worn during daylight, and particularly if workers may be exposed during dawn or twilight conditions, visibility may be significantly enhanced with the use of fluorescent colors. (See Tech Note 46.)

Other than the facts that, in general, light-colored materials provide greater amounts of reflection than darker colors do, and fluorescent colors reflect more light under some daylight conditions, there are no clear guidelines as to the amount, color, or pattern of reflective markings on clothing. The only guidance that can be given is that enhancement of visibility via both retroreflective and diffuse reflective apparel is desirable for workers who are more likely to be exposed to work vehicle or public traffic, particularly if they must be detectable against complex backgrounds or under lower levels of site lighting.

2.8.2 Work Site Safety Training

Informal on-site training, “tailgate safety programs,” or “toolbox safety training” are important to address safety issues both for workers and for inspection staff. In order to have maximum effectiveness, work site safety programs should focus on concerns directly related to project activities and should occur on a regular basis. Regularly scheduled training frequently occurs as often as once per week, and, in extreme cases, each work shift may begin with a very brief reminder of safety concerns for each crew as it convenes at the work site. Safety training programs may take a few minutes away from normal production; however, if well planned and organized, these programs provide a significant payback in terms of avoiding lost productivity associated with accident costs.

In addition to regularly scheduled training sessions, special training sessions may be appropriate from time to time.

Prior to the start of work on a new task or activity, it is frequently helpful to hold a session to address safety procedures and concerns for the new operation.

A detailed drawing of each step in the procedures or a trial practice in a parking lot may be helpful. In addition, special sessions may be called to address incidents or accidents that occur on the project. By discussing the cause of an incident with workers and reviewing applicable safety procedures or changes in procedures, the probability of recurrence can be reduced.

Occasionally, apprenticeship or other on-the-job training programs are in place on a project. However, specific work skills, such as flagger training, are normally attained by workers prior to employment or through skill-specific training provided to address individual work assignments. Job-site safety training, however, is normally intended to familiarize workers with safety procedures specific to their job assignment and to maintain a constant attitude of safety awareness. Because safety procedures are site-specific and require constant reminders to achieve a high level of compliance, this aspect of training must occur on a regular basis at the work site.

2.8.3 Training Topics

Workers should be instructed to be alert at all times to traffic, especially to construction traffic on closed roadways where workers may be lulled into a false sense of security. It is essential that they not place themselves in a vulnerable position where they cannot see or be seen by traffic or construction equipment. Drivers and equipment operators need to be trained to be especially alert for workers on foot at night.

Some sites may require specific procedures for workers to gain access to the work site. These procedures may involve designated parking locations and specific walkways and crossing points to safely access the work site. The procedures must be conveyed to workers and reviewed periodically, especially if compliance becomes lax.

Backing accidents are a serious worker safety concern at night when workers behind equipment and vehicles may be nearly invisible. Even on well-lit sites, shadows may restrict visibility at times, making workers on foot difficult to see. The need for specific operational procedures is discussed in Section 3.1, and those procedures must be conveyed to workers through on-site training.

Normally, a review of safety apparel requirements is also included. Workers need to know specific requirements for vests, hard hats, other safety apparel, and general work clothing requirements as they apply to the work site or to specific work tasks.

Avoidance of overhead utilities is a risk on many sites and becomes more critical at night (see Section 3.1.6). Specific site hazards (such as drivers forgetting to lower dump bodies before bridges and sign structures) and procedures to avoid them should be covered in on-site training.

Finally, work site policies for compliance with safety rules need to be conveyed and reviewed periodically. All workers must clearly understand that the added risks inherent in night work make 100-percent compliance essential. Failure to comply entails unacceptable risks for individual workers and for the overall safety of the project. Violation of work rules through deliberate oversight, forgetfulness, or carelessness must entail clearly defined penalties.

2.8.4 Training Methods

Because on-site training is most often delivered in the field by project supervisors, it is frequently conducted on an informal basis. Much of the training is provided to small groups of workers involved in a specific operation by the floor leader or general supervisor. To be effective, training materials must be provided to the session coordinator in advance. The material should be brief, concise, and in simple terms that are understandable by the workers. Commercially available training programs provide a large selection of topics for use at individual sessions. Some firms, however, have found that materials prepared or selected at the company or project level are more specific to project needs and, thus, are more effective.

Regardless of the source of materials, someone at the project, preferably the site safety officer, must arrange for training topics to be provided to session leaders on a regular basis. Because the needs of the individual work crews vary, it is often necessary to provide different topics to various crews.

Although many of the sessions are conducted for individual crews by the crew leader or supervisor, larger meetings for multiple crews or all project staff may be appropriate from time to time. These meetings provide an opportunity for individuals, such as the project superintendent or company manager, to address all workers. Other sources of trainers are also available, including insurance company representatives, union leaders, industry association representatives, and OSHA or other safety agency officials. Occasionally inviting outside presenters to address workers on-site offers an opportunity to address specialized topics by someone with recognized expertise and to generate worker support for safety.

2.8.5 Training Administration

Record keeping is essential to ensure effectiveness of the program. Project records should be maintained on the topics scheduled and materials covered. Workers attending should sign in, with the attendance sheets maintained in the project records.

In addition to safety training for workers (which is normally the responsibility of the contractor), there must be safety training for inspection staff and other representatives of the owner agency, who are also exposed to risks associated with night work. Although this program is often separate from the contractor's program, there are benefits in providing coordination between the two. Inspection staff should periodically attend contractor sessions to ensure that the contractor is making a reasonable effort to train inspection staff and other representatives of the owner agency. From time to time, special sessions may be conducted that can benefit all project staff, including inspectors. Attendance at such sessions helps to develop an overall project awareness and dedication to safety.

2.9 LIGHTING REQUIREMENTS

Previous research has shown lighting to be one of the most important factors in nighttime construction. Safety in the work zone, quality of work, and morale of workers are all directly related to work zone lighting. The requirements for lighting are determined by the visibility requirements of the workers and motorists using the area. Factors that must be considered in defining lighting requirements were summarized in the final report for NCHRP Project 5-13 (*38*). Stated briefly, for any given observer with a defined visual ability, the smaller that the object to be seen is and the less contrast the object has with its background, the more light is needed for adequate visibility. Also, the presence of glare degrades visibility while bright ambient conditions improve visibility.

Lighting requirements are most easily defined in terms of illuminance, which is the amount of light falling on a surface. Illuminance is measured in either footcandles or lux. Illuminance may be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the surface area. (See Tech Note 47.)

The system advanced by Ellis et al. was to categorize the majority of highway and bridge maintenance tasks and to assign a minimum level of illuminance to each category (*38*). Given this knowledge concerning how much light is needed in different locations of the work area, a lighting design can be identified that provides the required photometrics.

Appropriate lighting fixtures must be selected, and the appropriate location, arrangement, and spacing must be determined to achieve the required illuminance levels. This information should be included in the lighting plan discussed in Section 3.4. Inspection methods that may be used to determine whether the installed system meets the photometric requirements of the design and plan are discussed in Section 3.2.

This section addresses the amount of lighting that is needed in specific work areas and for different work tasks. It also provides a general discussion of methods that may be used to achieve these levels and the limits and methods required to provide adequate control of glare.

Anyone responsible for developing a lighting plan for night construction work should be knowledgeable in photometrics and vision and should consult the final report for NCHRP Project 5-13 (*38*) and the IES Lighting Handbook (*40*) from which these guidelines were developed.

2.9.1 Classification of Illumination Requirements by Task

Lighting should be adequate to provide the minimum level of illuminance required in different work areas and for different tasks. Each area, task, or both must therefore be categorized as to what level of lighting is required:

- **Level 1.** This level of illuminance is recommended for the general illumination of all work operations by contractor's personnel in areas of general construction operations, including layout and measurements ahead of the actual work, excavation, cleaning and sweeping, landscaping, planting, and seeding. Work areas, such as stockpiles, are illuminated to Level I to enhance safety and improve work efficiency (see Figure 27). This level of illuminance is primarily important in areas where crew movement may take place and is limited to tasks requiring low accuracy, involving slow-moving equipment, and having large objects to be seen. Level I illuminance should also be provided at the area of lane or road closures continuously throughout the period of closure, including the setup and removal of the closures. (See Tech Note 48.)

  This level of illuminance should also be provided during the setup of lane closures or road closures installed in conjunction with nighttime construction operation and should be maintained until the closure is removed. Such lighting should be used at the actual points of closure, including the lane closure tapers. Level I illumination is required in the taper, since work crews will be in this area during setup and takedown and the potential always exists that a worker will drift into this area for some unplanned reason. Leaving the area without minimum illumination creates an unsafe situation, as workers need to see obstacles when they move into this area. Also, the taper is where there is the greatest uncertainty about path, and driver expectancies will often be violated. Level I illumination will provide some additional protection against impaired drivers, allowing them to see workers

Figure 27. Remote area illuminated to Level I.

and avoid this area during setup and takedown. Lighting need not be required throughout the entire lane closure, except as required at active work sections (*41*).

Whether or not the taper should be lit at times other than setup and takedown depends, in part on the lighting characteristics of the sections adjacent to the taper. The concern here is the possible creation of a transient adaptation effect. That is, as a driver traverses a brighter section of roadway, the eye adapts to that illumination level. Upon going into a darker area, it takes the eye a short period of time to adapt to the lower level of illumination. During the adaptation period, the visibility of objects is reduced. Because, as mentioned, the taper is a transitional area for the driver, any situations that produce reduced visibility should be avoided (*42*).

- **Level II.** This level of illuminance is recommended for areas on or around construction equipment. This level of minimum illuminance is necessary both for safety in operating equipment and for attaining an acceptable level of accuracy. Asphalt paving, milling, and concrete placement and removal are examples.
- **Level III.** This level of illuminance is suggested for tasks requiring a higher level of visual performance or for tasks with a higher level of difficulty. Pavement or structural crack and pothole filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical or mechanical equipment, and other tasks involving fine details or intricate parts and equipment require Level III illuminance.

2.9.2 Illumination Criteria

Luminaires should be of sufficient wattage and quantity to provide an average maintained illuminance equal to or greater than the following:

- Level I: 59 lux (5 footcandles),
- Level II: 108 lux (10 footcandles), and
- Level III: 215 lux (20 footcandles).

Although most tasks require maintenance of horizontal illumination, some tasks (such as bridge painting, concrete and steel repairs on bridges, and work on overhead signs and sign structures) require that vertical illuminance be maintained.

Horizontal illumination refers to measurements made with the photocell parallel to the road surface. For purposes of roadway lighting, the photocell is placed on the pavement. Vertical illumination refers to measurements made with the photocell perpendicular to the road surface. Vertical measurements require that the direction and the height above ground be specified. See Tech Note 47.

2.9.3 Paving and Milling Operations

For paving and milling operations, including bridge decks, New York State requires Level II illuminance 15 m (50 ft) ahead of and 30 m (100 ft) behind the paving or milling machine. Although these distances have been found appropriate by New York, other distance boundaries may be acceptable (*41*).

In addition, New York State recommends Level I illuminance for a minimum of 120 m (400 ft) ahead of and 245 m (800 ft) behind the paving or milling machine, or for the entire area of concrete placement or pavement work if less than this distance. This area is extended as necessary to incorporate all vehicle and equipment operations associated with the paving operation. The only exception to the requirement for Level I illuminance throughout the area of construction operations is that finish rollers will work beyond the area of Level I illuminance using floodlights mounted on the roller. This exception is necessary because, given the length of time pavement may take to cool, the finish roller may drop farther than 245 m (800 ft) behind the paver (*41*).

In the night paving project in Figure 28, portable light towers throughout the work area provide Level I illumination. Floodlights on the paver and rollers supplement the towers to provide Level II illumination at the paving operation.

The New Jersey DOT has developed specifications to mount luminaires on paving equipment to achieve Level I and II illumination. The DOT reports good results with equipment-mounted lighting to meet these levels (*43*).

2.9.4 Uniformity

The uniformity of illuminance, defined as the ratio of the average illuminance to the minimum illuminance over the work area, should not exceed 10:1, with 5:1 being more desirable (*38*, *41*).

2.9.5 Glare

The eye reacts in two distinct ways to the presence of glare. One reaction is described as discomfort glare. This reaction is

Figure 28. Level I and II illuminance at a nighttime paving project.

measured subjectively and has no direct effect on vision. Discomfort glare may, however, result in fatigue that may have a deleterious effect on vision. The other reaction of the eye to glare is referred to as disabling glare. Disabling glare results from light scatter within the eye that effectively reduces contrast and, therefore, visibility of objects. Disabling glare is measured in terms of veiling luminance in units of candela per square meter. Because the sensation of glare is related to the adaptation of the eye, the Illuminating Engineering Society (IES) has set the criteria for glare in terms of the ratio of veiling luminance to pavement luminance under the assumption that pavement luminance controls the level of driver adaptation. The IES recommends that veiling luminance be no greater than a third of average pavement luminance. Therefore, in well-lit areas where the level of pavement luminance is high, a higher level of glare becomes tolerable (*40, 44*).

2.9.5.1 Principles for Controlling Glare

The most direct way to minimize glare is to locate the luminaire so that the axis of maximum candlepower is located away from the most critical line of sight of motorists. Critical lines of sight would include looking at the road ahead, reading signs, and observing directions from flaggers. Three factors affect the angle between a luminaire's beam angle and the normal lines of sight, and all three factors interact with each other. These factors are the distance between the viewer and the luminaire, the height of the luminaire relative to the observer distance, and the direction in which the luminaire is aimed. As mounting height is increased, the angle drawn from the light source to any point on the road surface within the work area decreases. The greatest candlepower from the luminaire is thus directed to the work zone, and reduced candlepower is directed to the travel lanes (*38*).

2.9.5.2 Methods to Minimize Glare

At a minimum, the following requirements must be met to avoid objectionable glare on roadways open to traffic in either direction:

- Tower-mounted luminaires should generally be aimed either parallel or perpendicular to the roadway.
- All luminaires should be aimed such that the center of the beam axis is no greater than 60 deg above the vertical (straight down).
- None of the luminaires should provide a luminous intensity greater than 20,000 candela at an angle of 72 deg above the vertical (straight down).

Luminaires vary in beam patterns. By selecting a cutoff luminaire, a greater proportion of candlepower may be directed to the work area and glare reduced. (See Tech Note 49.)

Several agencies have reported using a tethered balloon with a 4,000-watt halogen light source to get both portability and the luminaire height needed to control glare. This technology is capable of reaching Level II illumination within a 20-m (65-ft) radius (see Figure 29). Information may be obtained at www.airstar-light.com.

In some cases, it may be impossible to control glare with the physical installation of the luminaire itself. For example, it may be impossible to get sufficient mounting height given restrictions on where poles may be located.

Glare aimed at oncoming traffic with shadows and nonuniform illumination within the work space may result if portable light towers are not fully extended, with the luminaires aimed at least 30 deg below horizontal (see Figure 30).

Even when the lighting design is very successful in controlling glare, there may be a few locations where glare may still need to be controlled. In these cases, it may be possible to mount shields, visors, or louvers on the luminaire itself or to use glare avoidance screens or barrier walls to protect workers and motorists from glare. One agency reported using glare screens of 70-percent shaded cloth or plywood.

Figure 29. Light balloons attached to pavers and other equipment.

Figure 30. Glare aimed at oncoming traffic.

2.9.6 Configuration of Lighting System

Existing street and highway lighting may not eliminate the need for additional lighting of the work zone. Before the lighting system can be designed and a layout created, the user must choose among lighting systems based on temporary, portable, or mobile equipment. The choice among these systems is a function of cost, efficiency, power requirements, and ability to satisfy minimum requirements while controlling glare. Consideration should be given to the amount of illumination provided by existing fixed lighting in determining the wattage, quantity, or both of lights to be provided. Whenever existing fixed lighting is contributing to the work zone lighting, this contribution must be included in the lighting plan.

2.9.6.1 Temporary Systems

Temporary systems are used to light an entire work zone area. They use existing or temporary poles to mount luminaires. Temporary systems allow luminaires to be uniformly spaced at relatively high mounting heights that result in a uniform lighting with low glare. This type of system may be cost-effective when it is to supplement an existing fixed lighting system, when the work activity will last a significant period, or both.

2.9.6.2 Portable Systems

Portable systems integrate the luminaire, power supply, and pole into one fixture that can easily be moved from one location to another. Portable systems may consist of either ground-mounted or trailer-mounted light towers. Portable trailer-mounted light towers can be easily transported throughout the project (see Figure 31), as well as easily raised into position at the work site (see Figure 32). Light towers may also be affixed to paving machines, finishing machines, and milling machines. Although easy to operate and maintain, these systems often provide more light than needed, which reduces their cost-effectiveness. Spacing and positioning of these devices typically results in very nonuniform illumination, which, together with the low mounting height, often results in a severe glare hazard.

If these systems are the primary means of illumination, they are required to provide Level I illuminance throughout the work area. They must then be supplemented as necessary by equipment-based systems to provide Level II and III illuminance where it is needed.

2.9.7 Mobile Equipment-Based Systems

Mobile equipment-mounted systems generally do not conform to any criteria that may be used to calculate expected illuminance levels. As such, they should not be relied upon for the primary lighting for areas or tasks requiring Level II or III lighting. All construction equipment—including rollers,

Figure 31. Portable trailer-mounted light tower being transported throughout the project.

backhoes, loaders, and other equipment—operating in work areas not illuminated to a minimum of Level I illuminance must be equipped with floodlights that provide a minimum of 1 fc (10.8 lux). Construction equipment that operates solely in areas illuminated by tower lighting that meets the minimum lighting requirements do not require floodlights (*41*).

When being driven beyond a lighted work area, slow-moving equipment, such as pavers and milling machines, require a minimum of 1 fc (10.8 lux) for a distance up to 5 m (15 ft) in the direction of travel. Fast-moving equipment—such as backhoes, loaders, motor graders, or rollers—requires this level of illuminance for up to 20 m (65 ft) in the direction of travel. These requirements do not replace the minimum illuminance requirement for each specific task (*38*).

2.9.7.1 Supplemental Lighting

Equipment-mounted systems may also be advantageous to increase the level of lighting from Level I to Level II or III (see Figure 33). Illumination immediately in front of and behind a paver is often improved by this type of lighting. Also, a supplemental luminaire may be mounted on a vehicle and moved from joint to joint in pavement repair operations to increase illumination to Level II or III.

2.9.7.2 Mounting

Suitable brackets and hardware must be provided to mount lighting fixtures and generators on machines and equipment. Mountings should be designed so that light fixtures can be aimed and positioned as necessary to reduce glare and provide

Figure 32. Portable trailer-mounted light tower raised into position at the work site.

Figure 33. Supplemental flood lights mounted on equipment.

the required illuminance. Mounting brackets and fixtures should not interfere with the equipment operator or any overhead structures and must provide for secure connection of the fixtures with minimum vibration.

2.9.7.3 Headlights

Whether or not floodlights are provided, all construction equipment must be equipped with conventional vehicle headlights to permit safe movement in nonilluminated areas. Headlights should not be permitted as the sole means of illumination while working.

2.9.7.4 Advantages

Equipment-mounted lighting may offer a number of advantages when compared with area floodlighting (*38*). These advantages include the following:

- There can be high-intensity illumination on the work plane.
- The positioning of lights between operator and task eliminates shade.
- The operator can adjust light to direct high-intensity illumination where needed.
- The rate of nighttime work can approach the daytime rate.
- The equipment can be operated independently of general illumination.
- The possibility of general shutdown of work due to failure of lighting and power-generating equipment is minimized.
- The need for equipment such as floodlighting trailers and generators is minimized, thus eliminating time and labor spent in transporting and erecting such equipment.

2.9.8 Lighting Equipment

Guidelines for the selection of lighting equipment to meet the photometric requirements of a project are discussed in the final report of NCHRP Project 5-13 (*38*) and are not covered in detail here. Lighting equipment includes the luminaire; the lamps that it houses; and the poles, mast arms, wiring, and other hardware necessary for installation. Knowledge of the fundamental characteristics of lighting equipment and the photometric characteristics that result is essential for success in designing any lighting system. Prior to designing any system, representatives of equipment manufacturers should be contacted to obtain the most recent information concerning current products and their photometric output (*38*).

2.9.8.1 Fuel

The fuel tank capacity and the availability of fuel on-site must be sufficient to permit uninterrupted operation of all portable generators used to furnish adequate AC power to operate all required lighting equipment throughout the complete night shift.

2.9.8.2 Electrical

Adequate switches must be provided to control the various lights. All wiring must be weatherproof and installed according to local, state, federal, and OSHA requirements. All power sources must be equipped with a ground-fault circuit interrupter to prevent electrical shock.

2.9.9 Photometrics

Photometric characteristics are largely determined by the luminaire. Some type of cutoff luminaire is highly recommended to shield the light source above some minimum vertical angle and, therefore, reduce glare, although there may be situations where it is not essential. A brief discussion of photometrics and measurement methods is given in Tech Note 50.

2.9.10 Lighting Design Process

A procedure for developing a lighting plan for night construction is illustrated using the project represented in Figure NWTA-7 in Appendix A.

2.9.10.1 Example Problem

The work area is a four-lane highway with 12-ft (3.6-m) lanes, 6-ft (1.8-m) shoulders, and no median. The construction consists of joint removal and replacement in a 1,000-ft (305-m) section of concrete pavement on the two northbound lanes (shown by the shaded region in NWTA-7). The operation will consist of several sequential steps that will progress simultaneously from joint to joint, including (1) sawcutting the area to be removed, (2) removing existing material, (3) preparing subbase and concrete surfaces, (4) placing and finishing new concrete, and (5) sawcutting and sealing new joint. Guardrail has been installed on the outside of the shoulders because of the steep embankments on both sides of the roadway, which would not be suitable for installing temporary lighting. Therefore, the placement of the light towers is restricted to the shoulders or the travel lanes within the work area.

2.9.10.2 Example Solution

In most cases, especially if the contractor has done night construction before, the design process will consist of tailoring lighting equipment that the contractor owns or has rented to the new work area. This tailoring includes adjusting the height, spacing, tilt, and fixture locations to meet the illumination and glare requirements discussed in Sections 2.9.1 and 2.9.5. For this example, it is assumed that the contractor already owns portable light towers that can adjust from 12 ft to 30 ft in height with 1,000-watt, metal-halide lamps (MH1000) and a National Electrical Manufacturers Association (NEMA) 6 beam spread. A set of IsoFootcandle diagrams for different height and aiming combinations of the MH1000 are also available to the contractor. These diagrams, which exist for different lamp types, beam spreads, heights, and tilt, can usually be obtained from the lamp manufacturer (see Figure 34).

The following steps illustrate the procedure used to determine the number of light towers required, their location, the number of lamps per tower, and their height and aiming.

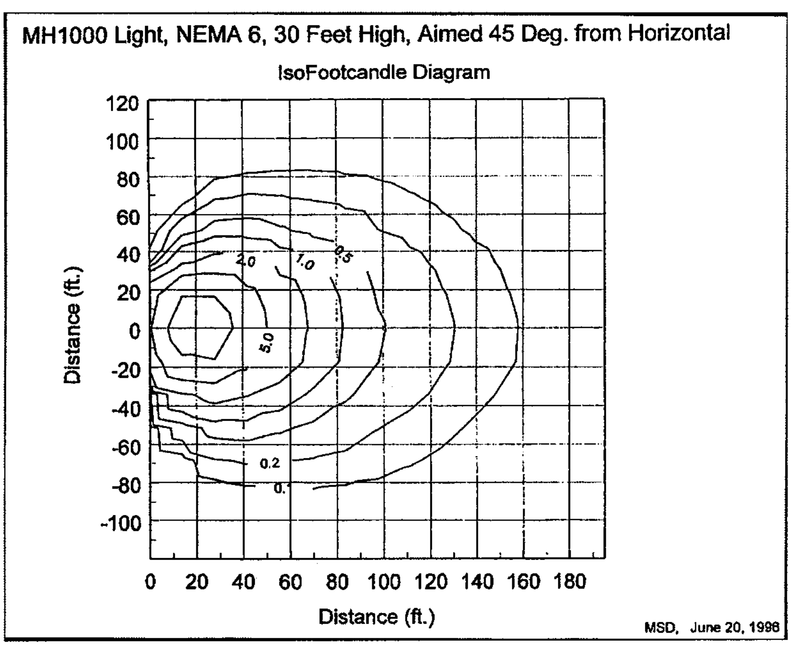


Figure 34. IsoFootcandle diagram.

2.9.10.3 Identify the Recommended Lighting Levels

Joint removal and replacement is an activity that requires a visual task of small sizes. According to Tech Note Table 3, at least 20 fc should be provided at the joint locations during concrete placement, finishing, and cutting of the new joints. The remainder of the 1,000-ft section should be lighted with 5 fc for worker movement and general safety. Road closures and tapers should also be illuminated with 5 fc for worker safety during setup and takedown and for aiding drivers who may be uncertain of which path to take.

2.9.10.4 Assess the Work Zone and Surrounding Area and Select Possible Tower Locations

As the problem states, guardrail has been installed outside of each shoulder because of the steep banks on both sides of the roadway. With this restraint, along with the suggestion in Section 2.9.5 to aim the lights either parallel or perpendicular to the direction of motorist travel, there are three plausible locations for the towers: (1) on the right shoulder aimed perpendicular, parallel, or both to the travel lanes; (2) on the left shoulder aimed perpendicular to the travel lanes; or (3) within the two closed lanes on the upper and lower boundary of the 1,000-ft concrete section and aimed parallel to the direction of travel.

Light towers on the left shoulder would have to project over a large distance because they are located far away from the work area. Towers within the lanes aimed parallel to the motorist travel not only would have to project over a large distance, but also may get in the way of workers and equipment. Therefore, the most desirable location would appear to be the right shoulder. If lights on the right shoulder alone do not meet the illumination requirements, the other locations may need to be used. Towers on the right shoulder should also be sufficient for lighting the road closures and tapers.

2.9.10.5 Determine the Mounting Height and Aiming Points

Most portable light towers have an adjustable mounting height ranging from about 12 ft to 30 ft and lights that can be aimed at any angle (ranging from 0 deg to 90 deg from the horizontal). The IsoFootcandle diagrams discussed earlier should be used to choose the right combination of height and tilt. The diagrams show two common patterns: (1) for a given lamp size and tilt, the horizontal illumination will increase as the mounting height decreases and (2) for a given lamp size and height, the maximum horizontal illumination observed increases as the angle from the horizontal increases.

Because the light towers will be on the right shoulder—aimed perpendicular, parallel, or both to the travel lanes—a height and aiming combination should be chosen that will provide at least 5 fc in the area up to 24 ft from the base of the tower (this provision ensures that 5 fc of illumination will cover both lanes of the work area). For the road closure and taper, a height-aiming combination is needed that will also provide at least 5 fc at the proper spots.

A review of numerous IsoFootcandle diagrams for the MH1000 indicates that a 30-ft height with one lamp aimed 45 deg from horizontal will provide 5 fc out to 50 ft from the base of the tower in the direction that the center of the beam is pointed (see Figure 35). For practical purposes, multiple lamps are usually mounted on each tower and are aimed in different directions. This placement allows an increased tower spacing while still providing the proper illumination. For example, if three MH1000 lamps are mounted on a tower, each aimed 45 deg from horizontal with one pointed perpendicular and two pointed parallel in opposing directions, the IsoFootcandle diagrams can be overlaid to show that the tower will have a 50-ft radius of at least 5 fc and a 60-ft radius of at least 2.5 fc (see Figure 35).

2.9.10.6 Choose Tower Locations on the Basis of Spacing and Check Design for Glare

To locate the individual tower locations, the final IsoFootcandle diagram of the three MH1000 lamps in Figure 35 was overlaid onto the work area (see Figure 36). It was determined that a 110-ft spacing between towers would provide the 5 fc at all spots required for worker movement and general safety. A portable system with two MH1000 lamps, mounted 30 ft high, pointed perpendicular to the travel lanes and aimed 60 deg below the horizontal, should move along with the work crew and be placed on the right shoulder at each joint to provide the required 20 fc for the joint replacement task. Alternatively, a balloon luminaire (shown in Figure 29) could be used to provide the additional lighting at the joints. Also, as Figures 35 and 36 confirm, one tower, placed on the right shoulder directly across from a road closure and taper, with three MH1000 lamps mounted at 30 ft and aimed the

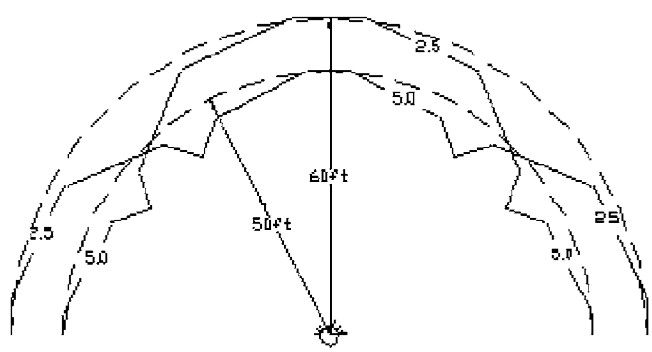


Figure 35. Overlaying IsoFootcandle diagrams for three MH1000 lamps to obtain a 50-ft radius of 5 fc and a 60-ft radius of 2.5 fc.

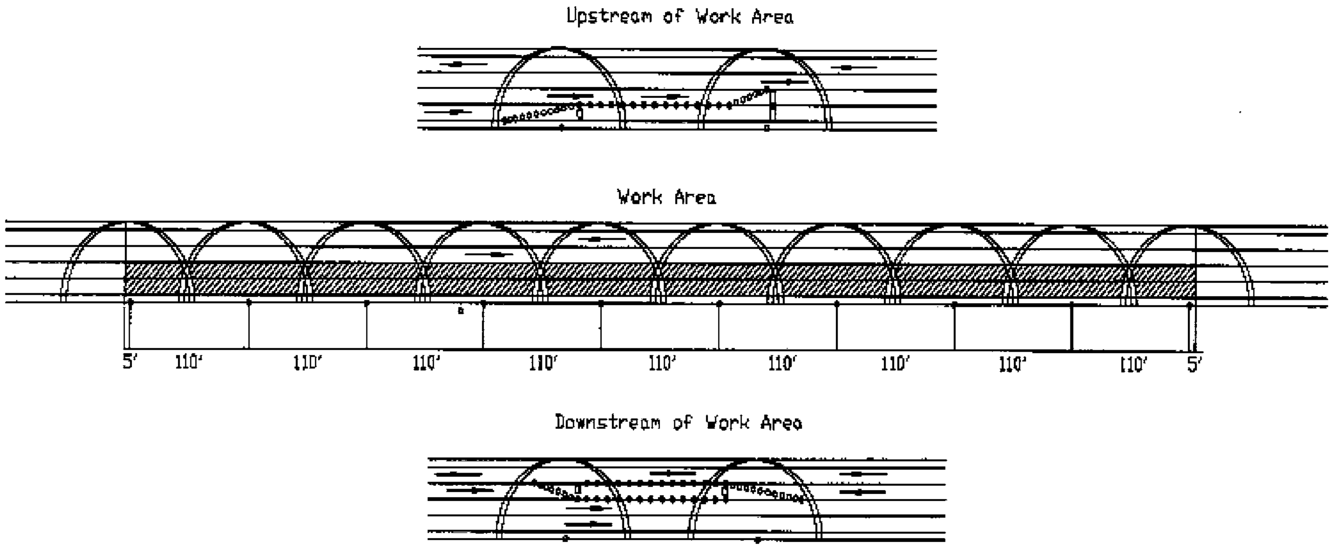


Figure 36. Final tower locations for the work area and the upstream and downstream lane tapers and closures.

same as in the work area, should provide the recommended 5 fc at these locations. Therefore, the lighting plan consists of 14 towers (nine stationary and one portable within the work area, one at each lane closure and one at each lane shift).

The final step of the design procedure is to check the lighting design against the requirements listed in Sections 2.9.1 and 2.9.5 to avoid objectionable glare to drivers. These requirements are reviewed below with regards to the lighting design example:

- Tower-mounted luminaires should be aimed either parallel or perpendicular to the roadway. All of the mounted lights should be aimed either perpendicular or parallel to the travel lanes.
- All luminaires should be aimed such that the center of the beam axis is no greater than 60 deg from vertical. The center of the beam axis should be aimed either 45 deg or 30 deg from vertical for all towers in the lighting plan.
- None of the luminaires should provide a luminous intensity greater than 20,000 cd at an angle of 72 deg above the vertical. Because the center-of-beam axes are only 45 deg and 30 deg from vertical, meeting this requirement should not be a problem.

CHAPTER 3

IMPLEMENTATION AND OPERATION OF NIGHTTIME TRAFFIC CONTROL

3.1 OPERATIONAL PLAN

Night construction and maintenance activities are frequently more complex and more difficult to manage than normal daytime operations are. Factors affecting night work are discussed in “Assessment Procedures,” Section 1D of *NCHRP Report 475* (*2*). To ensure the safety and operational success of night road work operations, detailed advance planning to address those factors is essential, whether the work is to be performed by a contractor under the supervision of a highway agency or the work is to be performed by the highway agency’s own maintenance forces. This section discusses planning for the actual conduct of night road work operations. Although the procedures involved in preparing and reviewing the plan will differ considerably between operations conducted by contractors and operations conducted by agency maintenance staff, the basic elements of the plans need to be similar in most respects.

To ensure that adequate planning is done to address all of the factors potentially involved, some agencies require contractors to submit a written plan prior to the start of work, and work cannot begin until the plan has been reviewed by agency staff. For all except very simple projects, this procedure is strongly recommended for night construction to be performed by contract. Although the complexity of the plan can be simplified somewhat if the work is to be performed by agency staff, a written operational plan must still be developed to ensure that all of the involved factors have been considered and that adequate resources and procedures will be in place to address them.

If prepared by the contractor, the plan should be submitted sufficiently in advance of the planned start of night road work to permit agency review and revision if necessary. Although a shorter review period may be necessary for emergency or urgent projects, a requirement for at least 30 days advance submission is reasonable for normal projects. However, agencies will need to adjust the submission date to suit the needs of individual projects and the internal procedures of the agency. Even when the work is to be performed by agency staff, an adequate planning and review period should be provided to ensure that an acceptable plan is developed.

The plan should detail all aspects of the traffic control setup: lighting plans; the functions, responsibilities, and identities of the traffic control supervisor and crew; and other details as necessary. The plan should also include a contingency plan identifying foreseeable problems and emergencies that may arise and the approach that will be used to address them. To accommodate actual conditions on the project, the plan should be revised and updated by the contractor, as necessary, during the progress of the work.

When the work is to be performed by contract, the specifications should identify specific requirements for the contractor to include in the development of an operational plan. The agency may also need to develop certain portions of the operational plan and include them as contract provisions. The sections that follow discuss specific elements of the operational plan. Although many of these elements apply to most projects, they are not universal. To reduce costs and needless complexities, the contract plans and specifications should be subjected to a final review to ensure that all essential elements have been included and that nonapplicable elements have been excluded.

3.1.1 Work Crew Staffing Plan

A critical element of the operational plan is planning for adequate staffing to perform the work under nighttime conditions. Especially important is assurance that adequate levels of staffing can be obtained for night shifts. Although staffing for work tasks may be similar to daytime operations, added staff may be needed to address the more complex traffic control operations and lighting operations.

3.1.1.1 Traffic Control Crew

A full-time traffic control supervisor—with adequate training, experience, and authority to implement and maintain all traffic control operations—should be assigned for nighttime operations. The traffic control supervisor should be assisted by a full-time traffic control crew equipped with a suitable vehicle or vehicles and a mobile communications system consisting of radios or cellular phones. The duties and responsibilities of the traffic control supervisor should be included in the plan of nighttime operations. During setup and removal of traffic control devices, the traffic control supervisor and crew should be assisted by additional workers as necessary.

To ensure that qualified staff will be available to conduct the traffic control operations, this staffing should be specifically addressed in the plan. For projects involving extensive traffic control operations, a qualified traffic control supervisor is essential. The qualifications should be specified in the operational plan. Suitable qualifications may consist of a combination of experience and training, such as certification through nationally recognized work zone training programs. The makeup of the traffic control crew should also be addressed in the plan. For projects with extensive traffic operations, it may be necessary to assign a full-time traffic control crew consisting of the supervisor plus any additional staff required to meet the demands of the particular project. In addition to setting up, removing, and maintaining the traffic control devices throughout the night, staff will also be needed to set up, operate, and maintain the lighting equipment.

3.1.1.2 Flaggers

Flagging operations are always a critical traffic control task, made even more difficult at night. If the TCP includes flagging operations, the operational plan should address training, qualifications, and equipment of flaggers. It may also be worthwhile to require specific levels of flagger training or certification to ensure high competence.

3.1.2 Worker Training

Because night work places added demands on workers and exposes them to greater risks than daytime work does, additional training may be needed to ensure that workers are prepared to meet the added demands of working at night. All workers on night projects need to be made aware of the special risks inherent in night work, along with the safeguards and procedures to be followed on the project to compensate for these risks. To ensure that training needs associated with night work are identified and addressed, the operational plan should include a discussion of training as it relates to the specific project. Worker training is discussed at length in Section 2.8.

One agency requires workers to fill out a death-related information form when hired and to have it updated every six months. Information includes who is to be told of the death, who should do the telling, and where the body should be taken. The form, which reminds workers of the hazards of night work and the seriousness of their safety responsibilities, is kept on site in case a worker dies.

Another agency treats night work operations as a mission. During a “tailgate session” at the beginning of each night’s operation, the goals of the mission are stressed, with emphasis on safety and the warning that, if careless, workers may not come back.

3.1.3 Project Site Patrol

The proper maintenance of traffic control devices is most critical at night. Devices are more likely to be subject to damage and disruption by impaired drivers. In addition, project staff conducting daytime reviews may have difficulty noticing devices that have had their reflectivity damaged. Factors such as these reinforce the need for project staff to frequently patrol the entire project at night to ensure that all devices and safety features are in good order, making adjustments and changes as needed. Plans for addressing this function should be included in the operational plan. For projects with complex TCPs, the agency should consider requiring a constant site patrol by the contractor or, if the work is performed by the agency’s maintenance staff, providing a crew to perform this function.

3.1.4 Material Availability

Access to concrete and asphalt products and other construction materials used on the project may be more difficult to obtain at night, especially at sites away from large metropolitan areas. Specific arrangements to obtain materials need to be addressed in the operational plan. This concern affects not only construction materials, but also other supplies, such as fuel for equipment, repair parts, and other supplies necessary to support the operation. Availability of specialized construction equipment, such as cranes, and repairs to all equipment may also be more difficult at night. The operational plan should thus specify how construction equipment will be obtained and repaired during night hours if material availability is a factor in completing the work.

3.1.5 Setup and Takedown Procedures

Section 3.3.5 discusses procedures for the setup and takedown of traffic control devices requiring nightly changes. It is important for these procedures to be specified in the operational plan in specific terms for the project. Ensuring that the traffic control measures are safely and efficiently installed and removed is essential. It is equally important to ensure that adequate staff and time are allowed to complete removal of the setup at the end of the night operations. Slow removal of lane closures or other temporary traffic patterns may have an extremely disruptive effect as traffic volumes increase into the morning peak.

Equipment breakdowns, material delivery disruption, traffic interruptions, and other unplanned or unexpected events occur from time to time during construction and maintenance operations. During daytime, these events may result in loss of productivity and traffic delays. At night, three things are different. First, lighting is more critical for effective and safe traffic control and being able to do the work. If the lights go out, traffic may experience difficulty, and the work will slow or stop. Second, it is often more difficult to obtain repairs at night, so a simple breakdown creates a greater problem. Third, night traffic patterns must normally be cleared before the onset of morning rush hour. If a breakdown results in delays, the result may be a massive traffic delay. These special night problems may affect the ability to complete an operation and restore the normal traffic pattern at the end of the night work period.

3.1.6 Overhead Power Lines

Contact with overhead power lines constitutes a potential hazard during any construction operation. During night operations, reduced visibility and worker fatigue combine to make this hazard more acute than during normal operations. It is not necessary to physically contact electrical transmission lines to expose workers to electrical shock, because high-voltage electrical currents can arc several feet to metal construction equipment or other conductors. Increased humidity frequently encountered during night hours may increase the tendency for arcing to occur.

Operations especially likely to entail risks of power line contacts include (1) paving and other operations using dump trucks; (2) excavation using backhoes or other equipment with raised booms; and (3) any operations using cranes, pile drivers, or similar equipment. Whenever possible, power lines should be rerouted away from the work space or deenergized during work hours to remove the risk of electrical contact. When these options are not possible, one or more of the following procedures should be followed:

- Use alternative work methods that do not entail the use of cranes and dump trucks. For example, forklifts may be substituted for cranes for some material handling operations, and trailers with augers can be substituted for dump trucks to haul paving materials.
- Maintain specific clearance distances from live power lines as required in OSHA Regulations 29 CFR 1926, Subparts N (Cranes) and O (Other Equipment). Clearances between lines and equipment are a minimum of 3 m (10 ft) and increase with line voltages above 50 kV.
- Assign dedicated spotters to warn drivers and operators of encroachments into safety zones around overhead lines.
- Perform vertical utility clearance checks prior to the start of work and as work progresses. Mark the location of overhead power lines on the ground to draw attention to them. (See Tech Note 51.)
- Make use of available devices to prevent and limit the effects of contact with an energized line. Such devices include
  - Nonconductive, handheld controls on vehicles with truck-mounted cranes and other boom-mounted equipment;
  - Boom-insulating equipment;
  - Magnetic and electric field detection devices on booms to warn operators of encroachment on an energized line;
  - Nonconductive slings and rigging; and
  - Isolated hook-block assemblies.
- Prohibit the storage of materials and equipment in the vicinity of overhead power lines.
- Establish and strictly enforce a rule prohibiting dump trucks from moving with the box raised unless under the direct control of a spotter.

The portable sign in Figure 37, equipped with warning light, alerts workers to an overhead power line during night operations.

3.1.7 Emergencies and Contingencies

To ensure that unplanned events such as those described above do not result in severe disruptions or unacceptable risks to workers and traffic, it is important to identify potential emergencies and disruptions in the operation plan and to develop contingency plans to mitigate their impact. Typical events that may have to be addressed include breakdown of critical equipment, such as a paver or batch plant; failure of lighting equipment; breakdown of vehicles in restricted travel lanes; unexpectedly high traffic volumes; and traffic accidents. Specific means to respond to these various situations should be included in the plan.

3.1.7.1 System Repairs

The operational plan should provide for stocking spare parts for equipment on or near the project and maintaining spare lighting equipment. It is also important to ensure that replacement parts are available for all traffic control items and other safety features that are critical at night. These parts

Figure 37. Portable sign with warning light.

would include signs, barricades, parts for CMSs, arrow panels, crash cushions, TMAs, portable barriers, barricades, and arrestor nets. For example, replacement parts for arrestor nets should be readily available on the project to expedite repairs if an impact occurs. Impacts on the system result in damage to the energy-absorbing units, and replacement is required to place the net back into service. Similarly, spare signs, lamps, batteries, and so forth may be needed to maintain other traffic control items.

3.1.7.2 Response to Emergencies

When vehicle breakdowns or minor accidents severely impede traffic, it may be appropriate to provide for tow trucks or motorist assistance vehicles at the project. Maintaining a supply of emergency flares on the project should also be considered for use in slowing and controlling traffic in emergency situations where the normal traffic controls cannot be quickly adjusted to meet an unplanned situation. However, the flares must be stored and used in areas that are not a fire hazard.

3.1.7.3 Meeting the Schedule

In spite of emergencies or unexpected contingencies, it is usually critical that the work be completed and that the facility be reopened to traffic by the contract-specified time that reflects the expected morning rush hour. Therefore, there can be very little tolerance for late openings. Owner agencies have limited choices:

- They can specify an early completion time in hopes that even if the contractor fails to meet the specified time, there is enough leeway to avoid congestion.
- They can give the contractor the latest completion time and then assess liquidated damages equal to the expected public damages for late opening.
- They can impose other nonmonetary disincentives.

Shorter work windows, disincentives, and liquidated damages are poor alternatives to prompt reopening. Therefore, to avoid these negatives, critical milestones or intermediate production goals with completion times need to be identified as a part of the work plan. These completion times must reflect the operational restrictions discussed in Section 3.3 and the time required for setup or curing of seals and road surfaces. These milestones then become the bridge between the operational plan and the contingency plan. If production lags or emergencies occur and these milestones are not being met, early corrective actions need to be taken that will ensure timely reopening.

3.2 OWNER AGENCY INSPECTION AND OVERSIGHT

In addition to technical issues associated with traffic control and performance of the construction activities during night hours, nighttime construction also entails specific concerns relative to inspection and oversight of the work by the owner agency. These concerns include issues related to providing adequate inspection staff at night, maintaining contact with agency support staff, and addressing other administrative concerns that either are unique to night work or become heightened when working at night.

The following sections identify a number of these concerns and provide guidelines for addressing them.

3.2.1 Inspection Staffing Plan

Just as for daytime construction, obtaining quality work at night requires adequate inspection of the contractors' operation by the owner agency or its representative. Consideration of the following points will help to ensure that adequate inspection is available.

3.2.1.1 Determine Inspection Needs

Night construction may result in different inspection staffing requirements than normal daytime work for several reasons. In some cases, project operations may be split between daytime and nighttime operations, thus requiring some degree of duplication of staff between day and night. While traditional staffing patterns may be equally applicable at night, it is essential to evaluate the specific work tasks that will be underway and estimate inspection staff needs based on that evaluation. If daytime activities are also underway, total staff requirements may be greater than for a comparable daytime-only project. However, the duration of the night-related staff assignment will typically be shorter.

3.2.1.2 Consider Staff Availability

Obtaining qualified inspection staff willing and available to work at night may be difficult. Unless a sizable pay differential is offered for night work, most workers prefer to work days to coincide with normal family and social patterns. To ensure that adequate staff will be available when night work begins, advance planning is essential.

To the extent possible, night staff should be recruited on a voluntary basis. Offering a shift differential will typically encourage workers to work at night. It is essential to examine agency and union work rules relative to changes in work shifts, overtime and pay differentials, worker assignments, and other related issues. Identifying such issues well in advance is important to avoid last-minute staffing problems.

In addition to providing adequate staff for the planned level of activity, it is important to identify additional staff who will be available for night reassignment on short notice. These staff members will be needed to address contingencies such as illnesses, vacations, and reassignment requests by inspectors who do not adjust to night work.

3.2.1.3 Project Supervisory Staff

Depending on the nature of the project work, it may be necessary to provide an agency project supervisor (project engineer or resident engineer) both at night as well as during the day. The nature of the specific tasks should be carefully examined to determine when the project engineer will work and how to provide supervision when the project engineer is not on duty. Although it may be acceptable for the project engineer to be present on the project only occasionally during the shift normally not worked, frequent shift changes may lead to fatigue, loss of effectiveness and, in extreme cases, even health problems.

If significant work is underway during more than one shift, a qualified chief inspector or assistant project engineer should be designated for the shift not worked by the project engineer. Methods will be needed to maintain contact between the two shifts. These include overlapping between shifts so the day and night supervisors can have some contact, maintaining an on-call system for the project engineer when not on duty, using pagers and telephone as needed, leaving messages from day to night and night to day, and so forth.

3.2.1.4 Traffic Control Inspector

A key inspection task for night construction involves the traffic control operation. A qualified and experienced inspector totally familiar with traffic control operations should be assigned to this task. Depending on the complexity of the construction and traffic control operations, this assignment may be handled by the project engineer or another senior inspector. However, on complex projects, this should be a full-time assignment, requiring an inspector dedicated to the inspection of traffic control and related items.

3.2.2 Administrative and Technical Oversight and Supervision

In addition to project inspection staff, access to other owner agency staff is essential for field staff assigned to the night work. Technical staff who may be needed to provide support to the project staff include individuals with expertise in materials, soils, structures, design, traffic engineering, and other technical specialties. In addition, administrative support staff such as budget and finance, legal, personnel, and others may need to be contacted by field staff. Finally, upper-level construction management staff not assigned to field positions need to maintain contact with and provide supervision to the field staff.

Most agency staff assigned to the district or central offices work normal daytime shifts and must normally remain on those hours to be accessible for routine functions and other projects not working at night. At the same time, it is essential for such staff to be accessible to staff on the night project, especially when problems that need resolution occur during the night shift. In addition, routine supervision and technical oversight must be provided.

Advance planning is essential to ensure that adequate support and supervision will be available, both on a continuing basis and for response to problems and emergencies that occur. This planning may entail assigning a portion of the support staff to work adjusted hours, possibly on a rotating schedule. In some cases, it may be necessary to assign some staff to on-call status such that appropriate response can be provided to address project needs during night hours. This step may entail providing pagers to staff who are on call during night hours.

Regardless of the procedure selected, it is essential to provide field staff assigned to night work with a current roster of support and management staff, including after-hours phone numbers and pager numbers.

3.2.3 Trial Run of Night Procedures

Night work often entails, on a nightly basis, extensive mobilization of traffic control devices, construction equipment, and workers, followed by demobilization at the end of the shift. Frequently, both the traffic control and the construction operations are very complex, and the two operations must be staged in the proper sequence to maximize efficiency and safety. Because of the large hourly cost for workers and equipment and the need to order materials in advance, contractors typically exert pressure to begin work as soon as possible to reduce costs, minimize material waste, and achieve maximum productivity during the hours available. In some cases, this may result in a conflict between proper deployment of the TCP and start of the construction operations.

3.2.3.1 Scheduling a Dry Run

To avoid this potential conflict, it is often desirable to conduct a dry run of the traffic control setup prior to the actual start of the construction activity. By scheduling the dry run the night before work actually begins, the contractor is not faced with workers and equipment standing idle while needed adjustments are made in the traffic control or lighting plan. Scheduling a dry run provides an ample opportunity to adjust temporary lighting and placement of the traffic control devices. It also provides an opportunity to determine the time required to deploy and remove the traffic control setup. Based on this time requirement, the actual work operation, including arrival of materials, can be scheduled to fit within the time slot actually allowed for roadway occupancy.

3.2.3.2 Initial Adjustments

A dry run also provides an opportunity to obtain and add lighting fixtures, to obtain required illumination levels, and to make adjustments, if needed, to reduce glare. Based on the traffic response to the traffic control setup, it may also be necessary to adjust various elements, such as taper length and location, channelizing device spacing, or other traffic control devices. It is preferable to complete such adjustments before workers and equipment are present on the roadway.

3.2.3.3. Contract Requirements

To avoid misunderstandings with the contractor, requirements for the dry run should be spelled out in the contract documents and discussed with the contractor during development of the operational plan. For projects entailing minimal traffic control setups, especially if traffic is light, a formal dry run may not be required. However, it is still essential to carefully inspect the setup and temporary lighting equipment the first night of operation to ensure that it meets all contract requirements and adequately addresses traffic needs. If needed, any adjustments should be made prior to the start of work.

3.2.4 Inspection and Maintenance of Lighting

The development of a lighting plan and the installation of the lighting system are discussed in Section 3.4. Inspection and maintenance of the lighting system are essential to ensure that the lighting requirements are met, that glare is not a problem for drivers or workers, and that lighting intensity and uniformity are adequate to ensure that the work can be completed in a proper manner and meet the contract specifications.

Lighting inspection should include (1) instrument measurements to determine illumination levels and uniformity, (2) subjective observation of the lighting setup to evaluate glare potential for drivers and workers, and (3) a physical check of the lighting equipment to ensure that it complies with the specification requirements included in the contractor's lighting plan.

Proper operation and maintenance of the lighting system is equally important to good design. The contractor must provide sufficient fuel, spare lamps, generators, and qualified personnel to ensure that all required lights will operate continuously during nighttime operation. In the event of any failure of the lighting system, the operation should be discontinued until the required level of illumination is restored.

3.2.4.1 Scheduled Maintenance

Scheduled maintenance is the most effective way to deal with problems of equipment aging and exposure to dirt and the effects of weather. This maintenance may entail cleaning of lamps and luminaires and a check of critical components in both power systems and lighting equipment on a scheduled basis. Group relamping is one procedure that has been shown to be highly effective in maintaining performance and reducing costs. Scheduled maintenance should be addressed in the lighting plan.

3.2.4.2 Emergency Maintenance

Demand or emergency maintenance is typically dictated by problems reported, such as flickering lamps, outages, unusual color, blown fuses, etc. Procedures for dealing with these problems are typically addressed by manufacturers' troubleshooting literature. Otherwise, a qualified electrician may be needed. Emergency maintenance should be addressed in the lighting plan.

3.2.4.3 Subjective Evaluation

Beyond scheduled and emergency maintenance, there must be some means of identifying problems associated with glare and inadequate illumination before an emergency occurs. Two types of inspections are recommended. Both of these inspections should be completed on the first night before work begins and also at regular intervals throughout the job. One inspection, to be performed nightly, is a subjective evaluation of the lighting from the perspective of the worker and the driver. This inspection should isolate any problems with glare that may arise, as well as any areas that may seem to have inadequate light. Most demand or emergency conditions would be spotted at the same time. The site drive-through to check for glare from the driver's perspective can be accomplished along with the visual inspection of all traffic control devices.

3.2.4.4 Lighting Measurements

A second inspection is needed to obtain measurements of horizontal illumination. A uniform pattern of measurements should be made every 6–10 ft throughout the work area. The lighting plan should be annotated to show the approximate location where readings are to be taken, along with the minimum acceptable value in footcandles or lux. Readings obtained on the first night should be analyzed for problems and recorded as a baseline against which future measurements may be compared. Readings obtained the first night that do not conform to the design specifications should be investigated, and the lighting plan should be modified to bring these readings up to specification. An investigation should also be initiated whenever subsequent readings fall significantly below the baseline readings. This investigation may indicate that lamps need to be replaced, that there is a power supply problem, or that perhaps some equipment has been moved or reoriented. (See Tech Note 52.)

3.2.5 Accident Monitoring

Compiling and analyzing data from accidents that occur during night work provide important insights with regard to adjustments of TCPs. When compiled on an agencywide or even wider basis, accident data are extremely helpful in evaluating the effectiveness of traffic control guidelines and procedures and in making decisions concerning when to use night work.

3.2.5.1 Accident Data

A critical shortcoming of traditional accident reporting procedures is that they often fail to relate accidents to the details of the road geometry or the temporary traffic controls. In addition, several months may be required for the police reports to filter back to the highway agency. In 1998, the FHWA initiated a study to compile work zone accident data, and this study will hopefully provide important information concerning accident experience on nighttime projects.

3.2.5.2 Accident Reporting

Because both contractor personnel and owner agency inspection staff are present during night work, project staff are almost always on the scene and aware of traffic accidents directly involving the temporary traffic pattern. In addition, police officers are frequently assigned to the night work. This combined presence generally makes it possible to compile basic information concerning traffic accidents within the project during work hours at the time they occur. Combined with followup inquiries to the investigating police agency when necessary, it is usually possible to obtain timely reports on these accidents.

3.2.5.3 Accident Analysis

When accident reports are obtained, analysis must be performed by qualified staff to determine whether the temporary traffic controls or work operations may have contributed to the accident or its severity. If indicated, changes should be considered in the traffic controls or in the work procedures. Accidents, by their very nature, are rare events, and single or limited numbers of accidents that occur on a single project often do not establish a trend or identify areas of concern. However, when accident data are compiled for a number of projects, especially over more than one year, a sufficiently large database may result in the identification of key areas of concern. This identification might suggest changes in the individual traffic control devices, setup of the devices, or overall procedures.

Accident data compiled over an extended period can also be used to refine the basic decision-making process for night work. Even when project-level data are compiled and analyzed on the project, it is essential to compile data for all projects at a centralized location for agencywide analysis and followup.

3.2.6 Community Complaints and Concerns Regarding Night Work

It should be expected that night work will generate comments and concerns from the community concerning night work activities. The likelihood of community input increases in urban areas, especially when commercial and residential areas are involved. It is important to recognize in advance that night work will generate community comment and that adequate mechanisms should be in place to allow input and to provide timely response.

Methods of addressing a wide range of problems that communities have with nighttime construction is the focus of *NCHRP Synthesis of Highway Practice 218* (*45*). Although most of this document relates to problems with noise, it also addresses additional problems with lighting, dust, and vibration.

3.2.6.1 Community Outreach

Community input can best be addressed in the planning stages of the project by involving community groups in the process and providing good communication on what the community impacts will be. Once work starts, it is important to provide a mechanism for ongoing community input. Although some complaints and concerns may be addressed directly to the project staff, concerns will more likely be voiced to the agency district, the central office, or local public officials. Publicizing phone numbers and addresses in the local media and to local officials will help members of the community to channel concerns to the proper destination.

3.2.6.2 Response Procedures

Mechanisms for addressing community input should be established in advance. Many simple concerns can be addressed by minor adjustments made at the project level. For example, minor adjustments to temporary lighting may be effective in reducing complaints concerning glare. Other issues will require decisions above the project level. For example, concerns over traffic detour patterns through local neighborhoods may require redesign of the detour routes and could entail extensive effort by the design staff.

3.2.6.3 Noise Variance

The most common residential complaints concerning nighttime roadwork relate to noise levels. When a local jurisdiction has passed a noise ordinance, a noise variance will have to be obtained before night work may begin. Obtaining this variance may take several months, so that planning is essential.

3.2.6.4 Noise Control

Substituting a solar arrow panel for a diesel-powered unit may easily satisfy a noise complaint in a residential neighborhood without compromising traffic safety. Intermittent noises, such as vehicle backing alarms, are sometimes a bigger concern than constant loud noise. One agency has received OSHA approval to use a spotter during backing operations and to disconnect the warning alarm for night operations. Strobe lights should not be substituted for backup alarms because of confusion with other warning lights typically found in the work area. (See Tech Note 53.) The subject of noise control is extensively addressed in *NCHRP Synthesis of Highway Practice 218* (*45*).

3.2.6.5 Being Responsive

Regardless of the nature of the input, it is essential that timely acknowledgment be provided to all complaints and expressions of concern. This acknowledgment should not imply that a complaint will be addressed at once. In fact, it is important that commitments are not made when they will be impossible to keep. In some cases, a followup call may be necessary to obtain sufficient information so that the complaint can be analyzed. In many cases, analysis will take some time to reach a decision. Ultimately, however, communication regarding the outcome of the complaint should be provided to the person or agency making the initial expression of concern.

Obviously, it will not be possible to provide a favorable response to all community requests. However, it is essential to maintain a positive public image concerning night work and to respond to all concerns in a manner that is responsive to the complainant. When the concern can reasonably be addressed, it should be. When addressing the concern is not practical or feasible, a reasonable explanation of the agency's position should be provided. Community acceptance of night work operations is essential to the success of this strategy, and timely, responsive replies to community expressions of concern are essential in this regard.

3.3 OPERATIONAL PROCEDURES

Even well-designed TCPs may require constant monitoring and adjustment to match actual conditions in the field and to respond to changes in traffic patterns and work operations. Even when changes in traffic patterns and work procedures do not occur, nighttime traffic control configurations must typically be deployed and removed on a nightly basis. This setup and removal creates substantial changes in traffic patterns at the time of the changeovers and often represents the highest risk period of the entire work shift.

Well-thought-out and clearly defined procedures are essential to set up and remove the nightly TCP and to ensure that other needed changes are identified and implemented. In addition, the design of the initial plan must respond to the characteristics of the traffic flow through the project and the needs and concerns of the community where the project is located.

This section provides guidelines for the operation and adjustment of TCPs for night work and discusses a number of basic considerations essential to making the plan fit the needs of the individual project.

3.3.1 Determine Operational Restrictions

Reasonable operational restrictions may reduce traffic conflicts and risks, while having only minimal impact on construction operations. Any such restrictions should be determined during design and stated in the contract documents.

During the planning and design phases of the project, traffic patterns should be spelled out in detail. This information should include hourly and daily traffic volumes on the project and potential detour and diversion routes, as well as identification of special events and traffic generators that may affect traffic through the project. Given this information, operational restrictions for the project should be determined and included in the contract documents. Clearly stating such restrictions and requirements in advance is essential for bidders to prepare an intelligent bid and will reduce disputes between the contractor and owner once the work begins.

3.3.1.1 Work Hour and Day Restrictions

Permissible hours of work operation and traffic control operations should be determined on the basis of traffic patterns and associated factors and should be so stated in the contract. The allowable hours for lane closures and road closures should be stipulated.

Consideration should be given in advance as to which nights the work zone will be active. Friday and Saturday nights are often at higher risk for driving under the influence (DUI)–related incidents and may have higher late-night volumes. Sunday through Thursday may thus be a better choice for a 5-night operation, although Sunday night may require a wage premium. In special cases where a facility serves substantial nighttime work or commuter traffic, weekends may be a better choice for full-road closures to minimize inconvenience to such traffic.

Regardless of the days or hours permitted for work, to the extent that traffic and site conditions allow, the contractor should take advantage of daylight hours before and after the shift begins for the setup and removal of traffic controls and other preparatory and cleanup work.

3.3.1.2 Length of Closure

The actual length of lane closures should be restricted to the minimum necessary to accomplish the work efficiently and safely. Long lane closures without work activity present may compromise safety by encouraging deliberate encroachment by impatient drivers. In addition, long closures are counter to good public relations and add to traffic delays and congestion. However, a single long closure is preferred over several short closures located close to each other. The objective is to keep the closure (1) as short as possible, (2) commensurate with a reasonably efficient construction operation, and (3) consistent in traffic pattern through the project. In most cases, the appropriate length of closure can best be determined by the project engineer and the contractor, although in some cases the plan designer can develop estimates for fixed operations. A maximum length of a lane closure should be stated in the contract documents.

Any restrictions or special requirements on paving or other operations, such as restricting the length of paving passes in a single lane, should also be stated in the contract.

3.3.1.3 Equipment and Material Storage Restrictions

When a pedestrian pathway is required on a work site, the choice of storage locations for equipment, materials, and debris should be evaluated not only from the standpoint of availability, but also from the standpoint of pedestrian safety. The initial locations and subsequent changes necessitated by the work progress should be specified in the contract following pedestrian safety evaluations (*9*).

3.3.1.4 Other Special Restrictions

Any restrictions on work operations that may cause noise or lighting complaints or violate local ordinances should be stipulated in the contract. To the extent possible, such operations should be scheduled during hours that will minimize inconvenience for local residents and businesses.

3.3.2 Inspection and Supervision

Sections 3.1 and 3.2 discussed contractor and owner agency staffing requirements to provide work site supervision and inspection. This subsection discusses specific procedures that are essential to ensuring continual high-quality traffic control during night work. At night, accident risks are higher, visibility is restricted, TCPs are more complex, and drivers may not perform as predictably as during daytime operations. All of these factors necessitate additional attention on traffic control supervision and inspection at night. During nighttime operations, the traffic control supervisor and crew should constantly patrol the work area to ensure that conditions on the site are adequate for public safety and convenience at all times, to ensure worker safety from intrusions into the work site, and to ensure that the contract provisions for maintenance and protection of traffic are adhered to.

3.3.2.1 Contractor Oversight

Under typical construction contracts, the contractor is assigned primary responsibility for operation of the temporary TCP. In addition to setting up and removing the traffic control devices, the contractor must continually adjust and maintain the entire setup to ensure that it operates effectively throughout the work shift. Any problems that develop must be identified and addressed quickly to avoid traffic congestion or increased accident risk.

For projects involving significant traffic control operations, the contractor should be required to assign a full-time traffic control crew to this task. Additional staff may be required during setup and removal. While the plan is in operation, the traffic control crew should be required to continuously patrol the project, making adjustments and corrections as necessary.

The crew should be provided with a suitable vehicle equipped with warning lights and a sufficient quantity of spare traffic control devices. Adequate staff should be assigned to the crew to address reasonably foreseeable circumstances, with additional staff available from the work force to address special incidents or emergencies. It is especially important that the supervisor of this crew be qualified by virtue of training and experience to supervise setup, operation, and removal of the TCP and equipment involved. In addition to correcting damaged, malfunctioning, or misplaced devices, the crew should be prepared to identify and correct operational problems, such as long queues extending past the advance warning signs, backups into intersections, glare from temporary lighting, vehicle breakdowns, and other situations that require immediate correction.

Requirements for the traffic control crew should be varied to meet the actual demands of the project. On simple projects with only minimal traffic control setups, especially when active travel lanes are not affected, it may not be necessary to assign the crew to full-time project patrol. However, a qualified individual should be available for immediate response if needed. On very large and complex projects, it may be necessary to assign more than one crew.

3.3.2.2 Spare Parts and Equipment

As part of the contractor's oversight, it is essential to ensure that spare parts and equipment are readily available at the job site and can be quickly deployed to replace equipment or traffic control devices that have failed or that are damaged by accidents. At a minimum, spares should be readily available for lighting equipment, arrow panels, CMSs, and any other equipment that are essential to the TCP.

Conventional traffic control devices, such as extra signs and channelizing devices, may be needed to replace damaged devices. In some cases, extra channelizing devices may be necessary to extend lane closures or to reduce device spacing if traffic does not respond appropriately to the initial setup.

3.3.2.3 Owner Inspection

During night operations, the inspection staff should be in regular communication with the contractor's project management and traffic control supervisor. The inspection staff should check the traffic control setup at the beginning of the shift, at regular intervals throughout the night, and at the end of the shift to make sure the roadway is restored to normal operations and that all devices and equipment are safely stored.

While the contractor's traffic supervisor and crew should be responsible for checking and maintaining the TCP on a constant basis, the inspection staff should inspect the operation for compliance with the contract requirements and provide direction to the contractor when situations arise that require unplanned adjustment to the TCP.

Operations that have cure or setup time requirements should be inspected by the inspection staff prior to allowing the contractor to reopen the facility. Improperly cured seals or surfaces could present a hazard to traffic.

3.3.3 Approval of Traffic Control Changes

An important aspect of work zone traffic control is ensuring that necessary adjustment and changes are identified and implemented when appropriate. Routine operational adjustments and changes should be planned in advance, with the contractor authorized to make such adjustments when appropriate. Unexpected changes and adjustments, when minor in nature, should be reviewed and authorized by representatives of the owner at the project site, with documentation in the project records. If the need for more significant changes in the TCP is identified, owner representatives at the project level should provide a recommendation and request review and approval by appropriate design or traffic staff. Although owner agencies typically have internal procedures to address such changes, the procedures must be known to the project staff. For night work, timely responses to change requests must be provided.

3.3.4 Communications System

During the course of nighttime operations, it is essential that the inspection staff, contractor's traffic crew, police patrols, and contractor's supervisory staff can communicate clearly and effectively from any location on the project. Although the inspection staff, contractor, and police agency all normally have communication equipment, effective communications will be provided only if the systems permit direct communications between the various parties.

For radio communication to be effective, all project staff must operate on the same system and frequency. Therefore, a dedicated frequency should be assigned to the project to guard against interference that may preclude timely communication at critical points. Realize, however, that a state agency may not have the ability or the desire to provide contractors with access to their internal radio communications network. In such a case, cellular telephones are an equally useful alternative means of communication.

Cellular telephones are widely available at reasonable cost and offer reliable communication between all parties. They also offer ancillary benefits, such as the ability to call 911 or program a CMS through a modem. However, to be effective, a projectwide phone list must be provided to all project staff and upper-level supervisory staff. Further, it is necessary to ensure, prior to the actual start of the project, that cellular phones provide adequately clear voice links from all portions of the site where they may be needed. As such, location and communication tests should be conducted.

3.3.5 Setup and Takedown

The period during setup and removal of the TCP often involves the greatest risk for the traveling public and, especially, for workers. During this period, full traffic controls are not in place. Thus, the traffic pattern is in transition and may not be obvious to drivers. Also, workers and equipment are often located very close to moving traffic. To minimize the risks associated with setup and takedown, careful planning and advance preparation is essential. If police are available, this period is often the most advantageous for their use. Finally, advance training and ongoing supervision of the work crews are essential to accomplish the setup and takedown quickly and efficiently (i.e., with minimum disruption in traffic and exposure of workers to traffic). Guidelines in the following sections are offered to facilitate setups and takedowns in a safe, efficient manner.

3.3.5.1 Advance Preparation

Depending on the type of TCP involved, the setup and subsequent removal of devices may entail a complex operation involving a significant number of workers, equipment, and devices. Detailed written plans should be prepared in advance for all but the most simple setups to ensure that all required steps are addressed and that everyone knows the correct sequence of steps involved. During these operations, additional workers are often required so that signs, channelizing devices, and other devices can be quickly set up and removed.

When site conditions permit, required devices should be placed outside the shoulders prior to the setup. During takedown, devices can first be moved from the travel lanes to the outside of the shoulders for later pickup.

Prior to starting either operation, all crews and equipment must be at the assigned locations, and communications must be established between various elements of the work crew.

3.3.5.2 Sequence of Operations

The sequence of the steps for setup and removal is critical to ensure that traffic and workers are provided the greatest level of protection as the operation progresses. The following sequence is generally appropriate for setups:

1. Activate CMSs to notify drivers of detours, diversions, and other traffic changes.
2. Place or uncover detour route signs and activate other temporary traffic controls within detours.
3. Place or uncover advance warning signs for detours, closures, and other temporary traffic patterns.
4. Place all portable lighting units at all closure points and other critical points prior to establishing closures. Lights should be adjusted as they are placed to eliminate glare.
5. Implement on-ramp closures for sections of roadways to be closed or restricted by placing barricades and other devices at closure points.
6. If off-ramps are to be closed, place advance signing, and effect closure by placing channelizing devices, barricades, and signs. A police patrol car, a well-lit work vehicle, or both should be used to temporarily block the ramp while the closure is placed.
7. Place arrow panels on the shoulder or other areas where they will not interfere with traffic and beyond the clear zone if they are not to be used during daylight. During nonwork hours, light towers and other equipment are safely stored in the median beyond the roadside clear zone (see Figure 38).
8. Complete shift, diversion, or lane closure by placing channelizing devices.

Figure 38. Equipment safely stored in median beyond the roadside clear zone.

3.3.5.3 Creating Closure

A critical stage in any setup is the momentary stoppage or diversion of traffic while the new traffic pattern is set in place. This step normally requires police vehicles or well-lit and marked work vehicles to temporarily slow, stop, or divert traffic while the channelizing devices are set in place. For full or partial closures starting at intersections or on-ramps, the police or work vehicle can block traffic while the barricades or other devices are set. An arrow panel on the back of a work vehicle can be very helpful. At night, the driver of this vehicle must keep the vehicle close to the devices already set up; otherwise, because of reduced visibility, vehicles may get back in the closed lane after passing the arrow panel.

For lane closures or shifts on freeways or other high-speed roadways, police or work vehicles can be used to form a rolling roadblock, providing sufficient time for crews to set channelizing devices in place. An example of this operation is shown in NWTA-1B in Appendix A. If two or more lanes are closed, or if the entire roadway is closed with traffic diverted onto the off-ramp or temporary roadway, it may be possible to make the closure in multiple stages, with the rolling roadblock making more than one pass. When this technique is used, the rolling block must be started far enough upstream to provide the needed time to make the closure. Traffic should preferably continue to move at a reduced speed rather than coming to a complete stop. However, if essential, a brief stop can be used to permit completion of the setup. The more quickly the setup can be completed, and the less the disruption to traffic, the less the risk of congestion, queuing, and rear-end or other accidents.

3.3.5.4 Setting Channelizing Devices

The setting of channelizing devices presents a substantial risk to workers and the public. Devices should be set in a manner that reduces exposure of workers to intruding vehicles and to the risk of falling from work vehicles. Under no circumstances should workers be allowed to ride on the tailgate or open body of work trucks. This behavior places workers at extreme risk of serious injury from intruding vehicles, as well as from falling from the vehicle and being run over. These risks are even greater at night. Workers setting devices from vehicles should be protected by work cages, restraint systems, or other devices or methods that prevent falls from the vehicle.

Normally, devices should be set moving downstream with traffic, starting with the taper. When the number of devices to be set is small, it may be preferable for workers on foot to set the devices. In this case, traffic must be momentarily stopped or diverted to reduce the risk of intrusions.

On high-speed, high-volume roadways, the use of shadow vehicles equipped with a portable attenuator is especially important to protect workers and the public during setup.

3.3.5.5. Takedown

Removing temporary setups generally proceeds in the reverse order of the setup. However, it is normally not necessary to create a brief traffic delay or stoppage while the operation takes place. The channelizing devices are normally removed working in an upstream direction, so the workers are protected until the final moments of the operation.

Drivers may be confused when work vehicles operate against traffic in the closed lane, especially with headlights on. Furthermore, a problem is created when the device pickup is completed and the work vehicle must turn around in an unprotected location. When temporary or permanent roadway lighting makes it possible for the work vehicle to operate without headlights and when the pickup operation ends at a median crossover, ramp, intersection, or other location where the work vehicles can safely exit or turn around, the pickup vehicle can be operated in a forward direction against traffic using the closed lane or the shoulder. This procedure has the headlights off, but the warning lights still in operation, as described in Section 2.7.5. This procedure not only speeds up the operation, but it is often safer for workers.

3.3.5.6 Inspection

Following both setup and removal, the traffic control supervisor must drive through all affected portions of the project to ensure that all devices are properly in place (for setup) or that normal operations are fully restored (for removal). Inspectors should spot check to confirm satisfactory completion of the operation.

3.3.6 Operational Adjustment and Shifts

As the work progresses, it is frequently necessary to make operational adjustments and shifts in the temporary TCP. Examples include changing traffic from lane to lane as paving progresses (see NWTA-1C in Appendix A), lengthening setups as the work progresses, and opening and closing ramps to accommodate progress in the work operations. Generally, it is possible to plan these changes in advance, and preparations can be in place to make the changes quickly and safely using the same guidelines as for setups and closures. Additional detailed guidelines were provided in Sections 1.2 through 1.4 for a number of specific traffic control setups, including lane and shoulder closures, diversions and shifts, and ramp closures. (See Tech Note 54.)

3.3.7 Traffic Control Device Adjustments

Continuous checking of traffic control devices by the traffic control crew is essential throughout the night to ensure that all devices remain in serviceable condition and at the proper location and position. Devices that are damaged or dislodged must be adjusted quickly to maintain smooth traffic flow and safe operation. A supply of replacement devices should be available to replace damaged devices as necessary.

In addition to damaged or dislodged devices, different devices may at times be needed to address unexpected traffic conditions or responses. For example, additional channelizing devices may become necessary if vehicles attempt to cut between devices. Additional warning signs placed farther upstream should be added if backups become longer than anticipated. Additional directional signing may be necessary if detour traffic appears to be missing turns or is otherwise behaving erratically.

One situation that may be difficult to correct, but which merits consideration for inspection activities, is confusion or distraction that may be produced by work vehicle warning lights (e.g., revolving lights, emergency flashers, or strobe lights). The interaction of work vehicle lights with other lights or with retroreflective patterns associated with traffic control devices could create a visual environment that is confusing or distracting to drivers and, therefore, becomes a hazard. Hazardous visual situations are related to site-specific geometrics and the types of traffic control devices. As such, variations will be numerous, and general guidelines for treating such a problem cannot be given. Furthermore, the situation may be extremely short-lived and, therefore, may not create a hazard. However, when modifications of work vehicle activity are expected, when the geometrics of the site are changed because of movement of the work zone activity area, or both, an assessment of possible confusion or distraction problems is merited.

3.3.8 Monitoring Flow, Access, and Safety

Nighttime TCPs should be designed and operated to ensure safe, smooth flow of traffic with a minimum of delays and congestion. To ensure that these objectives are achieved, it is essential for project staff to monitor traffic flow and for work operations to identify disruptions in traffic flow, safety concerns, or problems associated with contractor access to the work site.

In addition to actual crashes, many driver behaviors indicate inadequate capacity or driver confusion. Workers assigned to monitor traffic flow should be alert to sudden or abrupt slowdowns, queuing, erratic driver behavior, use of shoulders, or backing vehicles.

Work site access should be monitored to ensure that workers, equipment, and materials can gain access to work spaces safely and efficiently. Abrupt disruptions to traffic caused by the movement of personnel or work vehicles is a concern in terms of both safety and traffic flow. Good work site access is also essential to ensure that materials arrive at the work space in a continuous flow with no interruptions and with minimum time in transit.

By monitoring each of these aspects of the traffic control operation, one can identify the need for adjustments and make the adjustments quickly before significant problems arise. In addition to observations by project supervisors and inspectors, comments and complaints from motorists and workers should be carefully considered.

3.3.9 Adjustments to Work Hours and Days

Selection of days and hours to be worked should be made prior to the start of work on the basis of projected traffic volumes and patterns, special events, and requirements of the work operations. Once work operations begin, it is important to monitor traffic flow to determine whether adjustments in work hours or days are necessary. In some cases, traffic volumes may differ considerably from design predictions.

3.3.9.1 Hourly Volume

If traffic volumes are lower than predicted at either end of the work shift, it may be acceptable to lengthen the work shift with little or no additional impact on traffic. Lengthening the shift generally improves productivity, reduces costs, and speeds completion of the project. Likewise, similar benefits may be achieved by lengthening the work week if traffic conditions permit.

Although more liberal work schedules are sometimes possible, heavier-than-expected traffic or unanticipated events may necessitate reducing access to the roadway to fewer hours or days than planned. If congestion is unexpectedly high at either end of the shift, delaying setup or requiring an earlier takedown may become necessary.

3.3.9.2 Special Events and Seasonality

In some cases, benefits may be achieved by changing the days worked. Traffic flows on Friday, Saturday, and Sunday nights may be especially unpredictable and may change from season to season. Project staff must be alert to such shifts in nightly traffic patterns and consider changing nights worked if necessary. In areas with high tourist traffic, seasonality factors may require changes in both work hours and work days as the project progresses.

3.3.10 Adjustments to Closures and Detours

Project traffic control supervisors should be alert to the need for changes in road and ramp closures and detour routes and signing. Changes may be necessitated on the basis of operational deficiencies, complaints and comments from motorists and residents, or accident experience. It is essential for the contractor's traffic control supervisor and traffic control inspectors to drive detour routes periodically to observe actual operation.

3.3.10.1 Device Adjustments

Adjustments to closures and detours may include minor improvements to traffic control devices, such as additional signs and channelizing devices. Supplemental devices and other methods used when a detour or closure is first implemented may help motorists become familiar with the change. Examples include posting additional CMSs a few days before and after the change is implemented and placing a police officer with a patrol car at closure points for the first few nights.

3.3.10.2 Detour Signing

Abrupt stopping, backing, or turning around at closures or intersections on detour routes indicates that detour signs are not sufficiently clear or visible and calls for adjustments as appropriate.

3.3.10.3 Congestion

Traffic congestion along detour routes may be alleviated by adjustments in permanent controls along the route. Typical examples include adjusting traffic signal timing or prohibiting certain movements while the detour is in effect.

3.3.10.4 Accidents

Traffic accidents along detour routes at night should be examined to determine whether signing or other roadway improvements may be needed. Changes as simple as trimming vegetation at an intersection may reduce accident potential. If problem intersections are identified, it may be necessary to station a police officer at the intersection while the detour is active or at least during periods of high traffic flow.

3.3.10.5 Rerouting Detours

Because considerable advance preparation is often required to establish a detour route, revising a route is normally not a desirable option. However, when more basic adjustments do not alleviate operational or safety problems, or if serious complaints persist, it may become necessary to consider rerouting all or part of a detour. If this consideration becomes a reality, it is essential to involve design and traffic engineering staff as soon as possible and to quickly, but thoroughly, explore all viable options.

If the decision is made to revise the detour or closure pattern, clear notification must be provided to motorists to avoid added confusion. Normally, this notification would entail conventional traffic signs, CMSs, and media alerts. All detour signing must be properly changed over, including complete removal of the previous route signs, by the time the change takes effect.

3.3.11 Speed Control

Although designing a work zone that allows drivers to maintain normal speed is desirable, imposing a speed reduction is often necessary. Several situations may contribute to speed-related problems in work zones:

- Motorists exceed the posted speed limit on the approach to the work zone and fail to slow sufficiently on entering the work zone.
- The posted speed limit on the approach is higher than the posted speed in the work area. A typical example is a work area in a residential or commercial area, following a section of highway with an unrestricted speed limit. In such cases, traffic may fail to slow down as drivers enter the reduced-speed zone.
- Physical and operational restrictions in the work zone require travel speeds that are lower than those in effect prior to construction.

3.3.11.1 When to Use Speed Control

The work zone conditions that justify the use of reduced speeds are highly variable, and, therefore, a comprehensive listing of conditions is not possible. However, the conditions listed below are examples of those that may, depending on traffic conditions and other project considerations, indicate the need for a reduced speed limit:

- Workers or equipment in open travel lanes or in closed lanes, shoulders, or medians immediately adjacent to the open travel lanes and unprotected by a positive barrier;
- Construction vehicles or equipment entering or crossing the travel lanes on a frequent basis in a manner that may interrupt traffic flow and require stopping and slowing;
- Alternate one-way traffic controlled by flaggers or a signal;
- Closure of one or more travel lanes, resulting in restricted flow in the lanes remaining open;
- Narrowed lanes or diversion of travel lanes to a new path, requiring a speed reduction for safe traversal of the lanes or diversion;
- Sight distance restrictions that do not provide adequate DSD at the posted speed limit (the sight distance deficiencies may be produced by physical restrictions or interruptions caused by construction activity); and
- Any situation where restrictions imposed by the construction activity make it impossible for a normally alert and prudent driver to safely traverse the work area at the normally posted speed limit, but where advisory speeds alone are not expected to result in adequate compliance.

3.3.11.2 Determining Work Zone Speed Limits

Blanket speed reductions for all work zones are not recommended. Speed reductions should be based upon consideration of engineering factors specific to the work site and should be applied only during the hours needed and in the specific section of the work zone where an analysis suggests speed reduction is needed. A procedure for determining the amount of speed reduction appropriate for a work zone was developed in *NCHRP Research Results Digest 192* (*46*). (See Tech Note 55.)

3.3.11.3 Methods of Speed Control

The methods of active speed control for night operations are generally the same as methods used during the day: law enforcement, CMSs, rumble strips, flashing beacons, lane width reduction, flagging, or some combination of these methods. Various methods that have been shown to be effective under certain circumstances are described below. The comparative effectiveness of these methods has not been tested at night. Given that these methods will vary in the level of visibility that each will have at night, their relative visibility should be considered when choosing a method for controlling night speed reductions.

3.3.11.4 Enforcement

One of the most effective methods of speed control in work zones is the strict enforcement of posted speed limits by police agencies. To enforce reduced speed limits, it is first necessary to ensure that speed limits are legally established and posted. (See Tech Note 56.) The establishment and posting of speeds lower than the normal limits should be based on traffic engineering considerations and actual work zone parameters.

Planning enforcement methods that use police requires a high degree of administrative coordination and cooperation involving police departments, highway officials, and construction officials. It is recommended that state and local agencies (1) make special contractual provisions for implementation of law enforcement treatments and (2) include such treatments in the TCP. Otherwise, the involvement of police agencies may not be sufficiently consistent for the potential effectiveness of the methods to be realized. Administrative and contractual provisions related to speed enforcement are discussed in Section 3.5.3.

3.3.11.5 Active Enforcement

Under most conditions, active police enforcement of speed limits can be expected to achieve significant speed reductions and, whenever possible, should be employed when lower-than-standard speeds are required in a work zone. The greatest effectiveness can be expected when enforcement is carried out in a highly visible manner and when drivers traveling through the project see that active enforcement is underway. Effectiveness may be enhanced further by obtaining prominent media coverage of the enforcement activities, by doubling the fines for speeding in work zones, or both. The use of a "doubled fine" strategy requires that drivers be made aware of the double fine via signing (see Figure 39).

Figure 39. Sign alerting motorists to doubled fines for work zone speeding violations.

A marked police car with cruiser lights, active radar, and the use of a uniformed police officer to control traffic can produce a reasonably effective speed reduction when a lane closure results in two or more lanes remaining open. (See Tech Note 57.)

3.3.11.6 Credibility of Enforcement

In very congested projects, police enforcement is often complicated by the inability of the police officer to pursue and stop violators. For effective enforcement, police must be able to quickly enter the moving traffic stream, pursue the target vehicle, and make the stop in a safe location. An enforcement area should be provided whenever possible. When traffic is confined to a single lane, or if narrow roadways limit safe stopping locations, especially for long distances, police may be severely limited in their ability to issue citations except in cases of extreme violations.

3.3.11.7 Passive Enforcement, or Unmonitored Police Cars

Although simply stationing patrol cars along the project may have some initial enforcement effect, it is questionable whether a significant lasting effect can be achieved unless drivers perceive an actual risk of citation. For that reason, unmonitored patrol vehicles or patrol vehicles stationed in locations without obvious access to the roadway will probably result in limited effectiveness unless there is a high percentage of nonrepeat traffic.

3.3.11.8 Statutory Speed Limits

Posting reduced statutory speed limits in work areas may reduce speed somewhat. To maintain credibility and enhance driver compliance, it is essential to restrict speed limit reductions to active work areas, with normal speed limits restored whenever possible. The addition of black-on-orange WORK ZONE panels to REDUCED SPEED AHEAD (R2-5a) signs may further add credibility to these reductions. Likewise, the addition of flashing lights and WHEN FLASHING panels to REDUCE SPEED AHEAD signs has been shown to enhance effectiveness, particularly if speed reductions are only required when workers are present. Another means of increasing the effectiveness of speed control measures is the use of a variable message sign with messages such as TROOPER ON SITE and SPEED LIMITS ENFORCED. A typical alternative to the flashing lights is the addition of small strobe lights. (See Tech Note 58.)

3.3.11.9 Advisory Speed Panels

The addition of advisory speed panels to work zone warning signs may also help in conveying to drivers appropriate speeds through specific portions of the project. Because most drivers select speed on the basis of their perception of the roadway and traffic situation, advisory panels may be especially helpful where drivers do not have a clear forward view of the roadway, such as at curves, diversions, or locations where sight distance is reduced by construction features and activities. Effectiveness of these signs depends highly on their credibility as judged by motorists. Therefore, they must be posted only where they are actually justified by roadway conditions, and the posted speed or advisory must be realistic.

3.3.11.10 Flaggers

Flagging should not normally be considered as a speed reduction technique for nighttime construction because flaggers are less visible and the risk to their safety is greater at night. However, if it is necessary to provide flaggers for other purposes, they may also be used to encourage drivers to slow down. The flagger should display the SLOW signal in an exaggerated manner, followed by pointing to a nearby speed limit sign (*47, 48*). If flagging operations are used at night, the flagger position must be well lit and retroreflective materials must be incorporated into the clothing being worn. Full body garments, as described in Section 2.8, are recommended so that whole body movement is detectable by drivers. It has been found that a properly trained flagger, adjacent to a speed limit sign, can reduce average speeds by 8–16 km/h (5–10 mph). Flagging methods are effective in construction areas where one lane remains open to traffic.

3.3.11.11 Real-Time Speed Displays

Various devices incorporating radar speed measurement with variable message signs or other speed displays are commercially available. These devices display either the speed of approaching vehicles or a warning message using a CMS. Either display is more effective in reducing speed as compared with passive MUTCD signing only. The message YOU ARE SPEEDING SLOW DOWN is the most effective when variable message signs are used. A speed-monitoring display that uses radar to measure the speeds of approaching vehicles and shows these speeds to traffic on a digital display panel may also be effective. This display is intended to slow traffic by making drivers aware of how fast they are traveling. (See Tech Note 59.)

3.3.11.12 Radar

It is expected that the radar associated with a variable message display will also cause some drivers using radar detectors to slow down. Because radar detectors are activated in vehicles using these devices, some speed reduction effects may be achieved simply from radar alone. Because drivers using radar detectors likely comprise a group that is more prone to speeding, the net safety benefit may be more than would otherwise be anticipated. (See Tech Note 60.)

3.3.11.13 When to Avoid Reduction of Lane Width

Lane widths should not be reduced to control speed at night, particularly when temporary lane and edge lines are not being used. The safety effects of this method have not been assessed under any conditions. (See Tech Note 61.)

3.3.12 Revision to Basic Traffic Control Strategy

Previous sections discussed the need to constantly monitor individual components of the TCP, making adjustments and revisions as necessary. This need also applies to the overall traffic control strategy for the project. Careful planning and design normally ensure that a TCP will operate effectively, although minor adjustments may be needed. On rare occasions, it may become apparent after the plan is implemented that overall operation is not satisfactory. As for individual elements, problems may be associated with unacceptable levels of delay and congestion, safety concerns, accidents, inadequate work site access for the contractor, undue interference with the work activities, or persistent strong complaints from the community.

If adjustments and revisions to elements of the plan, made with the assistance of traffic and design staff, cannot satisfactorily resolve these problems, it may occasionally become necessary to consider a major change in the TCP. Such a change may include (1) closing the facility and implementing a detour or (2) eliminating an objectionable detour and returning traffic to a portion of the roadway under construction. In extreme cases, it may become necessary to cancel night work and return to conventional daytime work, using other traffic management strategies to address the project traffic control objectives.

When the need for a basic change in the traffic control strategy becomes apparent, it is essential to quickly and thoroughly explore all viable options. Hopefully, it will be possible to develop a revised plan and transition to it while work progresses. However, in extreme cases, it may be necessary to temporarily shut down construction operations, or at least the night work, until the new plan can be designed and implemented.

3.4 WORK ZONE LIGHTING SYSTEM

The planning and design of work zone lighting systems is primarily concerned with the selection and placement of equipment that will provide the minimum illumination necessary for a variety of nighttime work activities. Minimum illumination requirements and basic design considerations were presented in Section 2.9. Consideration must also be given to the control of glare as it affects passing motorists.

Every project should have a lighting plan that addresses the items shown in Section 3.4.1.

It is the contractor's responsibility to select appropriate lighting fixtures and to determine the appropriate location, arrangement, and spacing to achieve the required illuminance levels. The contractor will also need to check the photometric charts for the proposed luminaires to ensure that there will not be any major problems with regard to glare.

An example of lighting plan details is shown in Section 2.9 and NWTA-7 in Appendix A.

3.4.1 Content of Lighting Plan

Prior to the start of nighttime operations, a lighting plan should be submitted and approved. This plan should provide, in detail, the following information for each piece of lighting equipment:

- The location of all lights necessary for every aspect of work to be done at night;
- A description of light towers and other lights to be used, including type of luminaire and manufacturer's number;
- Mounting details for lights on equipment, including how the lights are to be attached, oriented, and aimed;
- Technical details on all lighting fixtures to be used, including power ratings and photometric charts;
- The typical spacing, lateral placement, and luminaire height for all lights;
- A description of all electrical power sources;
- Details on hoods, louvers, shields, or other equipment to be used to control glare, including mounting details and locations where the equipment is to be used; and
- Lighting calculations confirming that the proposed plan meets the illumination requirements.

3.4.2 Installation

The contractor must have all necessary lighting equipment installed before work is to begin, including any fixed lighting and supplemental lighting on mobile machines and equipment. The contractor should then locate, aim, and adjust the lighting fixtures to provide the required level of illuminance and uniformity in the work area without creating objectionable glare.

3.4.3 Photometric Measurements

Prior to the first night of operation, the project engineer must check the adequacy of the installed lighting using a photometer that measures illumination in lux or footcandles. A summary of these measurements should be noted in the inspection records to provide a basis for comparing measurements made at subsequent intervals.

A uniform pattern of readings spaced approximately every 3 m (10 ft) throughout a representative test area should be taken. A test area might include several luminaires or one luminaire from each of several areas. Although it is unnecessary to measure the same location whenever measurements are taken, the spacing of measurements should be consistent and uniform whenever readings are made. Each reading should be above the required lighting level for that area. A comparison of the average of the readings with the lowest reading obtained should be no greater than 10:1 and preferably near 5:1. If the required illuminance and uniformity levels are not met, the contractor must make the necessary adjustments to the lighting plan before work continues.

3.4.4 Glare Control

All lighting must be designed, installed, and operated to avoid glare that interferes with traffic on the roadway or that causes annoyance or discomfort for residences adjoining the roadway. The project engineer must therefore check for glare that may impair drivers passing through the project. The project engineer should be the sole judge of when glare exceeds acceptable levels, either for traffic or for adjoining residences. If severe glare is noted for any travel path, the luminaires must be adjusted, or shields, visors, or louvers must be added as necessary to reduce objectionable levels of glare.

3.5 POLICE SERVICES

The need for and the extent of police services should be considered in the planning stage of all projects for which work activities are to be scheduled during night hours. Furthermore, specific types of police services and their scheduled occurrence should be part of the project TCP. The plan, with regard to police services, should reflect the nature and extent of the cooperation that can be expected from local, state, or both police agencies. To the extent that such expectations do not appear to meet the needs of the project, consideration must be given to the use of "dedicated," as opposed to "cooperative," enforcement aid. Visible police enforcement is highly desirable on nighttime construction operations to encourage driver adherence to traffic regulations and to manage incidents such as accidents, breakdowns, and major congestion.

3.5.1 Criteria for Police Services

Suggested criteria to determine the need for police services include the following situations:

- Construction activities closely adjacent to traffic without positive protection,

- Restrictions to traffic flow based on geometry (e.g., no shoulder, reduced shoulder width, reduced lane width, or reduced number of travel lanes),
- Locations where incidents are expected to produce substantial congestion and delays on the facility,
- Special operations that require traffic control or shifts of the traffic pattern,
- Locations where traffic conditions and accident history indicate that substantial problems may be encountered during construction, and
- Projects with heightened public concern regarding the impacts of the TCP.

To the extent that these situations are expected to occur in combination with high-speed, high-volume traffic flow, the accurate assessment of the need for police assistance becomes a critical planning task.

3.5.2 Police Functions

Depending on the type of project being designed, the functions identified below should be considered as candidates for police assistance. The frequency with which situations requiring such tasks are expected to occur will, along with the criteria noted previously, determine the level of police staffing necessary. Examples of the types of police functions that may be required are as follows:

- Keeping travel lanes free of illegally parked or stalled vehicles on detour routes and major traffic arteries by arranging for their removal from the travel lanes;
- Controlling illegal turning movements that might restrict capacity at intersections;
- Directing traffic in congested situations;
- Providing advance warning of heavy congested or stopped traffic in advance of problem area, such as a lane closure;
- Assisting in traffic control for special construction events, such as bridge steel erection, changes in traffic patterns, and blasting;
- Observing and reporting traffic problems on state highways or detour routes to the appropriate engineering staff;
- Enforcing speed and any other restrictions in or near the work zone area;
- Aiding in traffic control during the daily setup and takedown activities for operations that are conducted only during nighttime hours; and
- Preventing intrusions into closed lanes, exits, and so forth.

3.5.3 Administrative Arrangements

After the police assistance needs are established, the means of obtaining the services must be evaluated. At least four administrative arrangements can be used to obtain police services:

- Cooperative services for which the police agency is not paid, but agrees to participate at some predefined level;
- Dedicated services for which the police agency is paid under a formal agreement with the state or local agency;
- Dedicated services for which the police agency is paid under a formal agreement with the contractor, the cost of which is bid as a contract item; or
- Some combination of the above options, whereby certain specific services are dedicated and others are obtained on a cooperative basis.

Regardless of the method used to arrange police services, all police agencies providing highway patrols in the vicinity of the project should be notified about the night operations and the associated potential impact of the TCP prior to the start of the work. This notification will permit the police agencies to plan for any traffic impact on their routine activities and, where necessary, to concentrate traffic enforcement activities on detours and other roadways that might be affected by the project. These agencies should be encouraged to concentrate their routine patrol activities on detours, diversions, and other roadways affected by the project.

3.5.3.1 Cooperative Enforcement

Under a cooperative enforcement procedure, the highway agency solicits the cooperation of the local police agency with jurisdiction for the highway in question. Officers and patrol cars are then assigned to the project for specific periods and operations to the extent that the officers and patrol cars are available. Typically, the officers assigned are from staff normally on duty at that time, and they are assigned to the project when they are not needed at other locations or assignments. Depending on the availability of officers and the project needs, police patrols may be present on only a part-time basis or for short periods when the need is greatest.

The principal advantage of the above arrangement is that the highway agency generally does not pay for the cost of providing the patrols. In return, the police agency retains greater flexibility in reassigning the officers to higher-priority tasks on short notice as the need arises. Although a limited level of police presence can be provided on some projects under this arrangement, the procedure does not ensure a specific level of police enforcement. Depending on the resources of the police agency, the level of enforcement may be suitable in some cases. A good working relationship between agencies is essential to ensure success. However, for activities such as setup, takedown, and other specific scheduled construction events, cooperative arrangements are not advised because there is no guarantee that police services will be available, and the hazard to workers and the driving public may be unacceptably high without the service. Another disadvantage of the cooperative arrangement is that police may not be available to direct traffic in congested situations produced by work activities, accidents, and so forth.

3.5.3.2 Dedicated Enforcement by Direct Highway Agency Agreement

A direct highway agency agreement may be enacted between the highway and police agencies prior to the start of work to cover assignment of officers and reimbursement of costs. It is preferable to enact a blanket agreement covering the basic arrangement, with individual projects added by task order to the basic agreement. Once the basic agreement is in place, the addition of individual projects can normally proceed quickly. Although the highway agency pays for the costs of the police patrols, it may be possible to charge those costs to capital construction funds as a direct project cost. Although this arrangement provides less flexibility than cooperative enforcement does, this arrangement is better able to ensure that the desired level of enforcement will be available when needed. It also provides a greater measure of control to the highway agency in the use of the police resources on the particular project.

3.5.3.3 Dedicated Enforcement Funded through the Construction Contract

Dedicated enforcement may also be funded through the construction contract. Police patrols are arranged between the contractor and the police agency. The contractor reimburses the police agency directly and submits the costs as a reimbursable expense under the project, normally with a markup for profit and overhead. This arrangement may offer the greatest flexibility in terms of obtaining police services quickly, especially when the need arises unexpectedly. However, the degree of highway agency control may be reduced, and the total cost to the highway agency is the highest of the three arrangements.

3.5.3.4 Combined Dedicated and Cooperative Enforcement

When dedicated enforcement is arranged for a project, its use is typically limited to specific tasks and operations where extensive police presence is needed at specific times. Routine enforcement can frequently be provided through cooperative arrangements, even though dedicated enforcement is provided for certain phases of the project. Incorporating both types of arrangements within a project ensures that the needed enforcement is available for specific operations, while routine enforcement is provided throughout the project at little or no additional cost to the highway agency. A good working relationship between the highway and police agencies is essential to obtain a good balance between cooperative and dedicated enforcement, especially when both are used within the same project.

3.5.3.5 Selection of Administrative Arrangement

As noted previously, the need for police services should be considered in the planning phase of any project and should be a feature included in the TCP. If the criteria listed in Section 3.5.1 are met and if it is decided that police presence is required, the degree of required police cooperation must then be assessed against the expectations for cooperation. If past experience has shown that the level of cooperation or the reliability of police presence is not expected to meet the project needs, a formal contract with state or local police for “dedicated” (as opposed to “cooperative”) services may be required. This requirement is one reason why it is necessary to make police service–related decisions during the planning process. The negotiation of a contract mutually agreeable to the police unit and the agency is likely to involve the use of the legal division of the agency, therefore requiring a long lead time. The biggest problem with planning the use of police services without negotiating a formal contract with the participating police agency is that the state or local agency may have little or no control over its presence or location. When dedicated police services are used on a project, the actual level of police presence and the police location on the project can be under the control of the resident engineer. (See Tech Note 62.)

3.5.4 Operational Requirements

A number of possible operational requirements are described below. Specific operational requirements such as these should be developed during planning and should be communicated in writing to the police service units involved or should form the basis of any formal agreement to be negotiated:

- When a lane closure or full road closure is being set up on high-speed highways, police should be stationed upstream with flashing lights operating.
- After a lane closure has been implemented and work is underway, patrol cars should normally be stationed upstream of the work area, with flashing lights in operation.
- Patrol cars can be used to temporarily stop traffic or to create a rolling roadblock to provide a contractor full access to the roadway to set up lane and road closures and to shift from one side of the road to the other.
- To maintain credibility of enforcement efforts, a second patrol car should occasionally be stationed downstream

from the work area to issue citations for speeding or other violations through the project.

- Patrol cars should operate their radar to activate radar detectors on vehicles approaching the work zone.
- Patrol cars should assist with clearing accidents or incidents such as vehicle breakdowns.
- Patrol cars should assist with controlling traffic at problem locations, such as ramp closures and other potential intrusion locations.

3.5.5 Enforcement Activities

One important function aided by police presence on a work site is that of controlling speed in the approach to and in the work area. There is general consensus that the various law enforcement strategies are effective in controlling speed. For a number of reasons, this safety benefit is important at night. First, speeds are frequently higher at night because the volumes are lower. Second, drivers impaired by drugs, alcohol, and fatigue are more likely at night. Given the impairments, the generally reduced visibility, and the higher speeds, the increased danger to both the drivers and the workers is obvious.

However, on many projects where night operations are chosen, volumes may remain relatively high for at least part of the night, with varying levels of congestion. In these situations, speed enforcement is not a primary function until later at night because speeds tend to be self-regulating to a large extent. In such cases, the most important police functions are preventing deliberate intrusions (into closed lanes, exits, and so forth) and preventing other attempts to circumvent the temporary traffic controls. Also important are police activities, such as traffic control during short-term traffic interruptions for setups, takedowns, setting steel, and so forth. Under higher-volume conditions, police are needed to clear accidents and remove blockages from other types of incidents, such as vehicle breakdowns.

3.5.6 Staffing Levels and Locations

The level of police staffing to be assigned to the project should be determined to meet the specific needs of the project by joint agreement of the highway and police agencies. If the primary function is to calm traffic flow and encourage drivers to respect traffic regulations, a single patrol car and officer may be effective, especially on small projects. Assigning police on a rotating basis may provide almost the same benefit as full-time patrols, and at lower cost. However, the schedule should be staggered such that drivers cannot predict with relative certainty when the police will be present. In addition, the frequency of police presence must be sufficient to maintain driver expectation of encountering a police unit.

On projects extending considerable distances, or those affecting traffic flow in both directions, the use of additional units may be advantageous. When the police patrols must perform specific functions, such as short-term traffic stoppages or traffic diversions to place a lane closure or road closure, then the number of police units must be based on a plan for that specific operation to ensure adequate control of the traffic flow. Significant speed enforcement efforts typically require a minimum of two units or more, depending on expected traffic volumes and number of potential violations.

Keeping the number of police units to the minimum necessary to ensure safe, orderly traffic flow reduces costs and frees up police units for other enforcement activities. Depending on the needs of the project, it may be advantageous to vary the number of police units present over the course of the night. Typically, two or more units are used to assist in the traffic control setup and to provide enforcement early in the evening when volumes are highest. Later at night, some of the units can be released, with one unit remaining throughout the night. In some cases, police union provisions or police agency procedures may affect the required number of officers present, especially during late-night shifts.

The location of the police units on the project depends on the specific functions being performed and on the site characteristics. Patrol cars should normally be positioned in advance, or near the beginning, of the project to gain driver compliance as they approach the activity area. The patrol unit must be visible to approaching traffic and to maintain the appearance that pursuit can be undertaken in the case of violations. A patrol car parked behind concrete barrier with no access to the travel lanes is generally not viewed as a threat to potential violators. The police unit must also be positioned safely. Because drivers may encounter unexpected situations requiring evasive maneuvers, the patrol cars should not be located in buffer spaces. Likewise, parking patrol cars on the shoulder very close to the travel lanes should be avoided if possible. If significant speed enforcement is planned, it will be necessary to identify locations where the radar vehicle can set up and where the stops can be made safely without undue interference with traffic.

3.6 PUBLIC AWARENESS ACTIVITIES

The public must be made aware of impending night construction activities and be provided with an opportunity to be involved in the planning stage. The public must also be kept aware of progress during any night construction project. When planning night construction, input should preferably be obtained prior to any detailed design work (see *NCHRP Report 475*). Public meetings, news media, or both can be used to explain the reasons for night scheduling and to obtain comments and suggestions from the community. In addition, a phone number and address should be provided to the public to gather comments and suggestions from the public.

In the weeks preceding the actual start date of the construction, the public must be informed of what is going to happen, when it will occur, and how it is likely to affect the public (see Figure 40). The public should also know about the things

Figure 40. Leaflet used by Caltrans to inform the public about what, why, and when night work will occur.

it might do to mitigate or avoid the anticipated impacts. After the start of the work, the public should be kept abreast of progress, changes, and actual conditions on a day-by-day or week-by-week basis. If such "updating" information is not provided via news media sources, the public should at least be provided with names and numbers of individuals who can be called to get such information. Communication with the public will normally be done through the public news media, by direct contacts with night trip generators and public agencies, and by posting specific information adjacent to the project using a CMS. A website is also a very convenient way to communicate with a large segment of the public.

3.6.1 Work Zone Public Awareness Campaign

Public awareness activities are extremely important for night operations in that, in addition to the normal concern of informing the public about the schedule, alternate routing, and so forth, several concerns become significant at night only. These concerns typically are the concerns of the community with regard to noise and lighting that would normally be tolerable during daylight hours. The closer the work activity is to operating business and residential areas, the greater is the concern with night operations. Therefore, the issue that must be dealt with is not only public awareness, but also public relations aimed at mitigating the real or perceived negative effects of night work on the public.

Construction noise that may be acceptable in daylight hours may be unacceptable at night. Also, work zone lighting and associated glare may not be acceptable if the site is in a residential area. Although the sources of glare and of noise (such as vehicle backing alarms, pile driving, and pavement breaking) cannot be alleviated, negative public reaction can perhaps be mitigated if the public is fully informed about and prepared for the activity and is helped to understand why the activity is necessary.

Another element of a public awareness campaign should involve identification of the anticipated traffic impacts and the schedules associated with the impacts. Traffic-related information should include road closures, changes in travel patterns, increased travel on detour and diversion routes, user security on secondary routes, and access to businesses, entertainment facilities, and so forth. This type of information must also be updated as a project progresses.

3.6.2 Information Requirements and Media Contacts

Specific information should be developed to describe the location and nature of the night work activity, including the expected impact on traffic patterns (e.g., x-minute delays can be expected). Any viable suggestions for alternative travel patterns and routing should be provided. Additionally, the specific work schedule (in hours and days) and the overall duration of the work should be specified. If the project involves a night-only schedule, the public must know that daylight travel will be normal. The information provided must be correct, as credibility can be affected if a message is inaccurate.

The information may be provided to the local media (e.g., newspaper, television, and radio) in the form of press releases in advance of the start of night work. Frequently, local radio stations will include information about planned and active closures in their regularly scheduled traffic-monitoring broadcasts.

In addition to the information described previously, a press release should identify contact persons in the agency, and an Internet address if one is maintained, for questions and followup. To relieve agency personnel of some of the administrative load associated with maintaining public awareness, contracts sometimes require the purchase of public service announcements.

3.6.3 Involvement with Local Officials and Business and Industry Contacts

The types of information identified previously should be provided directly to local officials and selected business and industry contacts. This provision should include automobile clubs and any major night traffic generators, such as shopping centers and major entertainment or sports facilities. It is particularly important to directly provide the information to any industrial plants that have night shift operations and whose workers are likely to use the work zone during the hours of work activity. To avoid total reliance on the media, it is desirable to design information releases that can be distributed to and posted in such plants.

If possible, meeting with local officials and selective business and industry leaders prior to initiation of a project (i.e., in the planning stages) is desirable to obtain input as to problems foreseen or suggestions related to timing or nightly schedules. Although implementing suggestions or avoiding all of the problems identified may be impossible, mitigating some of the anticipated negative effects via modifications to the operational plan may be possible.

Information must also be provided to local police agencies and emergency service agencies (e.g., fire department and ambulance services) far enough in advance of the construction or maintenance activity that appropriate changes in emergency response procedures can be planned.

When feasible, the agency should establish a working relationship and contact with local news outlets so that schedule changes and progress updates can be provided on a regular basis. Direct contact with emergency service agencies should be made to inform local news outlets about schedule changes. Methods currently used to accomplish these goals include

- Media taps into traffic command centers for road closure and other construction-related information,
- A website that is updated regularly for lane closures and other information, and
- A toll-free telephone line (specifying road or traffic information) that can be accessed by anyone.

To maximize the number of people informed, use a combination of communication methods.

3.6.4 Project Signing Recommendations

In addition to using news media, websites, and toll-free telephone lines, advance notice of night operations should also be posted adjacent to the planned work site, particularly on roadway sections that normally carry significant commuter traffic and other local traffic at night. Project signing can provide advance notification with static signs or CMSs. Large black-on-orange static signs can be used to list work locations and dates and to suggest alternative routes. To be legible at operating speeds, the messages on these signs must be restricted to no more than three lines of text, with no more than a few words per line. When it is necessary to provide longer messages, the information must be displayed on multiple signs spaced at least 150 m (500 ft) apart, with no other signs between them. It is important for these signs to be located where good sight distance is available and where they will not interfere with other signs. On roadways with three or more lanes, these signs should be posted on both the left and right side of the roadway.

CMSs should be used to supplement fixed signs for a few days before work begins by displaying specific information on the nature of the work and the schedule. An example of an appropriate two-part message is “Night Paving: 10 PM–6 AM/Starts Aug. 15.”

NIGHT PAVING
10 PM - 6 AM

NIGHT PAVING
STARTS AUG. 15

When the work is actually underway, messages on the CMSs should be revised to provide information specific to that operation. An example of an appropriate message would be the following:

NIGHT PAVING AHEAD
LEFT 2 LANES CLOSED

During nonworking hours and days off, the message would revert to the following:

NIGHT PAVING
10 PM - 6 AM

Additional information on CMSs is provided in Section 2.3.

3.6.5 Highway Advisory Radio

Highway Advisory Radio (HAR) is another useful means to inform drivers. Specific details on night work operations should be broadcast on HAR when equipment is available. Signs advising drivers of the availability of HAR should be posted in advance of the project. To enhance the credibility of HAR, only concise, up-to-date information providing specific travel instructions should actually be provided. Use of HAR to broadcast general information or safety slogans may cause drivers to question the HAR’s value. Likewise, signs alerting drivers to the availability of HAR must be displayed only when HAR is in operation. To maintain system credibility, these signs must be removed or covered when HAR is not operational.

3.6.6 Internet Website

Most DOTs and many communities already have websites, and DOTs already use these websites to list construction activity. With more than a third of the public having access to the Internet, a website is a valuable method for communication with the public. In addition to giving information about what will be done and why it must be done at night, the website can provide timely information about closures and delays, as well as phone numbers and HAR availability to obtain further information. The website is also a useful medium for the public to raise questions and to make its suggestions of how to reduce the negative impact of the night work.

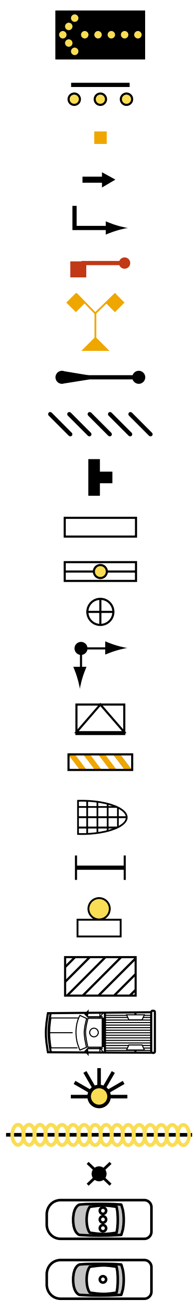
3.6.7 Monitoring Work Schedules

Someone must be assigned to monitor the work schedules so that information regarding delays, changes in the areas scheduled for work activity, and so forth can be given to the individual responsible for contacting the media sources. The assignment of a specific individual to this activity will help ensure that relevant information is provided to the public in a timely manner. Although this assignment is also a requirement for daylight operations, it is more important for night operations because drivers do not expect night activities. To ensure that the messages are appropriate to ongoing activity, the same person should be assigned to review the messages to be conveyed via any CMSs used.

APPENDIX A

TYPICAL APPLICATIONS FOR NIGHT WORK

This appendix contains seven sets of typical application drawings showing examples of traffic control setups for night work. These drawings are similar in format and appearance to typical application drawings provided in Section 6H of the Manual on Uniform Traffic Control Devices (MUTCD). The same symbols used for traffic control devices in the MUTCD are used here, although some additional symbols are added:



Arrow panel
Arrow panel support or trailer
Channelizing device
Direction of traffic
Direction of temporary traffic detour
flagger
High-level warning device (flag tree)
Luminaire
Pavement markings that should be removed for a long-term project
Sign (shown facing left)
Temporary barrier
Temporary barrier with warning lights
Surveyor
Traffic or pedestrian signal
Truck-mounted attenuator
Type III barricade
Crash cushion
Changeable message sign or support trailer
Warning lights
Work space
Work vehicle
Portable light tower -- rays indicate direction of aim
Arrestor net
Intrusion alarm
Police cruiser
Watch guard vehicle

It is important to point out that the drawings provided in this appendix are intended to supplement the drawings in the MUTCD—they do not supersede those drawings. These night work typical applications illustrate the information provided throughout this report and provide examples of how MUTCD applications can be enhanced to address the added concerns associated with night work. Some of these drawings also provide information on traffic control setup, adjustment, and removal procedures. In addition, a sample of a temporary lighting plan for night work is shown. These drawings are intended to illustrate the information provided in the report and to provide examples of how traffic control plans for night work may be developed. However, they specifically do not establish a standard or constitute recommended practice.

Like the typical applications in the MUTCD, these drawings are supplemented by notes. While the notes in the MUTCD provide standards and guidance as well as options and support (information), the notes in this appendix are intended to provide support (information) and discuss options. However, they do not provide standards or specific guidance. That remains the function of the MUTCD.

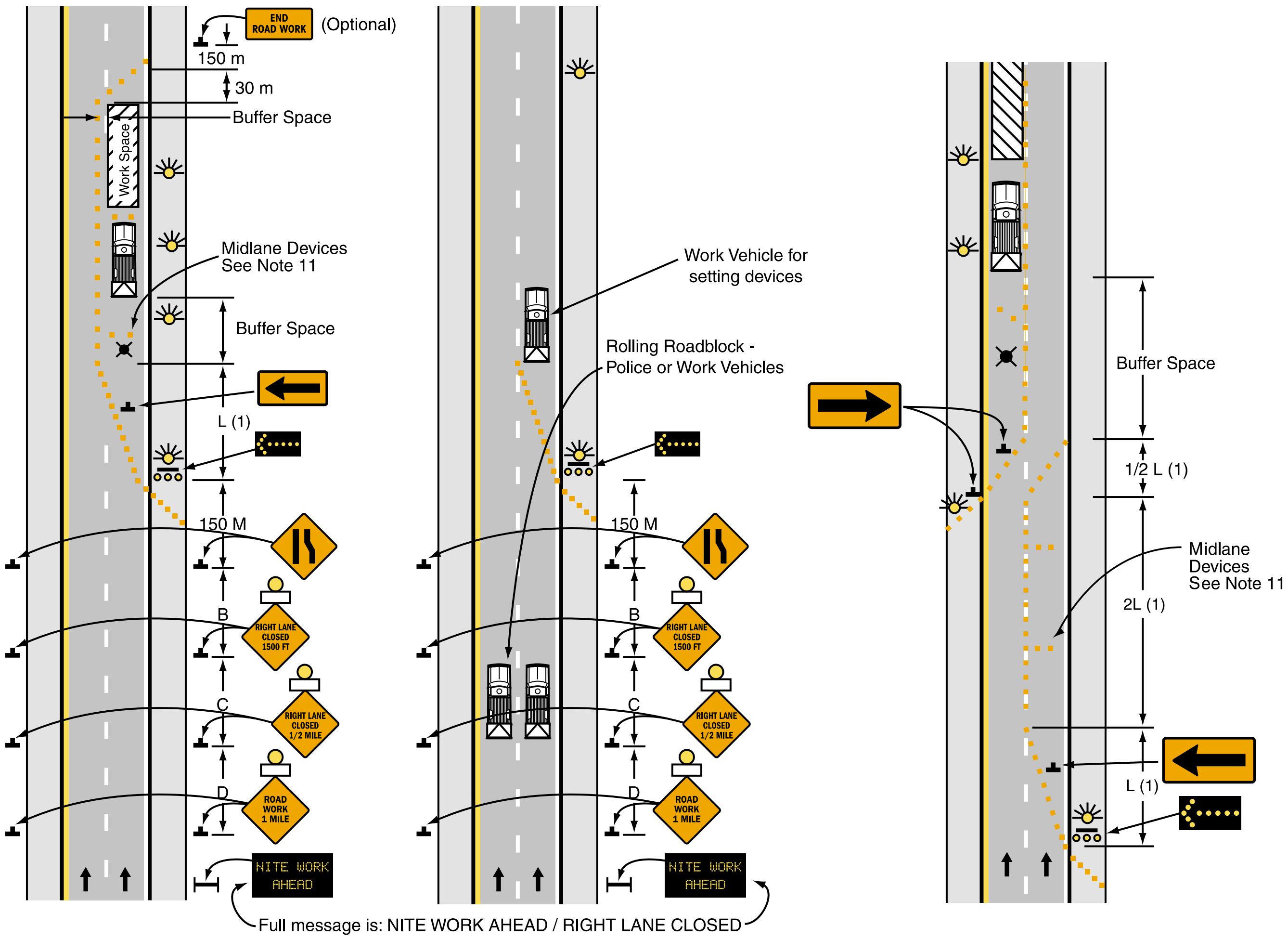
The following night work typical application (NWTA) drawings are provided:

- NWTA-1—Lane closure on divided highway for night work;
- NWTA-2—Freeway closure for night work with traffic diversion to service road;
- NWTA-3—On-ramp closures for night work;
- NWTA-4—Freeway shoulder closure using temporary concrete barrier with lane closure for night work;
- NWTA-5—Freeway median crossover for night work using moveable concrete barrier;
- NWTA-6—Night work on two-lane, two-way roadway using flaggers to control alternating one-way traffic; and
- NWTA-7—Night work lane closure with lighting plan details.

NWTA-1—LANE CLOSURE ON DIVIDED HIGHWAY FOR NIGHT WORK

See Figure NWTA-1. Refer to MUTCD TA-33 for additional information.

1. Advance warning distances shown are appropriate for 55-mph highways. Distances may be adjusted for other speeds or for special situations—see Section 1.2.8 of this report.



NWTA-1A. Right Lane Closure **NWTA-1B. Lane Closure Setup** **NWTA-1C Lane Closure Changeover**

(1) See Note 5 for taper length.
(2) See Notes 6 & 7 for channelizing device details.
(3) Refer to Section 1.2.8 of the report and MUTCD Tables 6C-1 and 6H-3 for spacing of advance warning signs.

Figure NWTA-1. Lane closure on divided highway for night work.

2. A BE PREPARED TO STOP sign (W20-7) may be added if traffic is slowing excessively or stopping at the merge area—see Section 1.2.8.
3. A portable or permanent CMS may be used to provide advance project information or driver guidance specific to the night operation. For information on use and message content, see Section 2.3.
4. Taper starting point should be located to provide good sight distance, be separated from other conflict points, and be located where roadside recovery area is available, see Section 1.2.1.
5. Recommended taper length—see Section 1.2, Tech Note 1, and 1.2.
6. Channelizing devices are drums, 300 mm by 600 mm vertical panels, or Type II barricades (and 900-mm cones only in the tangent sections)—see Section 2.1.1.
7. Channelizing device spacing in meters equals 0.3 times the speed limit in miles per hour, with a maximum of 12 m. Spacing is halved at ramps, intersections, and other conflict points—see Sections 1.2.6 and 2.1.2.
8. Longitudinal and lateral buffer spaces—see Section 1.2.3.
9. Where lateral buffer space is not available, a flagger or spotter may be used to protect workers close to the travel lane—see Sections 1.2.3 and 2.5.
10. Where positive separation between the traffic space and work space is desirable, temporary barrier may be added—see Sections 1.2.4 and 2.6.2.
11. Midlane devices are provided at 225-m maximum spacing to reduce risk of intrusions when work operations permit and to mark pavement excavations. Type

III or II barricades, drums, or 300 mm by 600 mm vertical panels are suitable—see Section 1.2.6.
12. Type A warning lights are installed on the first two channelizing devices on the taper—see Section 1.2.6.
13. Type B warning lights may be added to enhance the conspicuity of advance warning signs—see Section 2.2.10.
14. Type C arrow panel operating in the left arrow or chevron mode is placed on the shoulder at the start of the taper if space permits or farther downstream in the taper if necessary—see Sections 1.2.7 and 2.4.
15. DO NOT PASS signs (R4-1) may be added throughout the closure at 0.8-km spacing where long lane closures and spotty work activities may result in impatient drivers attempting to pass—see Section 1.2.8.
16. When each lane must be alternately closed over the work shift, see 1.2.9 for information on which lane to close first.
17. A shadow vehicle with a truck-mounted attenuator (TMA) is positioned upstream of workers or equipment when work operations are concentrated at specific locations—see Section 2.6.7.
18. An intrusion alarm may be located in the longitudinal buffer space or at other locations upstream of the work operation when construction traffic will not trigger false alarms—see Section 2.6.9.
19. For lighting and protection details for work vehicles and workers, see Sections 2.7 and 2.8.
20. For information on temporary lighting, see Section 2.9. NWTA-7 shows a sample temporary lighting plan setup.
21. Setup and removal sequences—see Section 3.3.5.
    - Activate changeable message sign (CMS) with operation-specific message.
    - Advance warning signs are placed or uncovered. Workers are protected by work or police vehicles on the shoulder. Workers should not cross active traffic lanes to place signs.
    - Arrow panel is placed and activated on the shoulder, and the light tower is placed downstream from the arrow panel.
    - Channelizing devices are set in the taper working from a work vehicle with TMA. Police or work vehicles with TMA may be used to form a rolling roadblock when traffic conditions are severe.
    - Channelizing devices are set in tangent section working from work vehicle, protected by TMA or police cruiser, and midlane devices are placed.
    - Remaining signs and devices are placed using work vehicle with TMA to protect workers. Light towers are placed in the work space.
    - Removal sequence proceeds in reverse order.
22. Lane changeover sequence—see Sections 1.2.9 and 3.3.6.
    - Channelizing devices in shift area are placed on the shoulder prior to start of the changeover.
    - Police cruiser or protection vehicle with TMA delays traffic in open lane.
    - Workers relocate devices to form shift taper along each side of the travel lane while traffic is delayed. Refer to Section 1.2.6 for recommended lateral clearance between channelizing devices in the shift taper.
    - Large arrow (W1-6) is placed at the start of the taper.
    - Portable light tower is set up at the start of the shift taper.
    - Traffic is allowed to proceed.
    - Removal sequence proceeds in reverse order.

NWTA-2—FREEWAY CLOSURE FOR NIGHT WORK WITH TRAFFIC DIVERSION TO SERVICE ROAD

See Figure NWTA-2. Refer to MUTCD TA-37 for additional guidance on freeway lane closures.

1. Refer to NWTA-1 for additional details on advance signing, taper details, and channelizing device type and spacing.
2. Where space permits, a distance of 2*L* is desirable between tapers to smooth flow, with a minimum of 0.5*L*—see Section 1.2.9.3.
3. An arrestor net is shown for intrusion protection. Other options may be appropriate, and a watch guard or police cruiser may be used with or without the arrestor net—see Section 1.1.6.
4. Stopping distance beyond the arrestor net is based on design parameters for the specific installation—see Section 2.6.8.
5. Type A warning lights are used on the first two devices in each taper and on Type III barricades across the closed roadway—see Sections 1.1.5, 1.2.6, and 2.1.6.
6. A Type C arrow panel operating in the right arrow or chevron mode is placed on the shoulder at the start of the left-lane taper if space permits, or farther downstream in the taper if necessary. Another Type C arrow panel is placed in the center-lane taper corresponding to the placement location for the left-lane taper. No arrow panel is used for the right-lane shift—see Sections 1.2.7 and 2.4.
7. Channelizing devices for the right-lane shift taper are Type III barricades placed in a continuous array—see Sections 1.1.3, 1.2.6, and 2.1.2.
8. Width of travel lane at diversion from the main line is based on geometry and expected vehicles, with a desirable maximum of 4.5 m to prevent passing—see Section 1.1.3.
9. Detour route signs are provided on the service road from the closure to the return to the main line—see

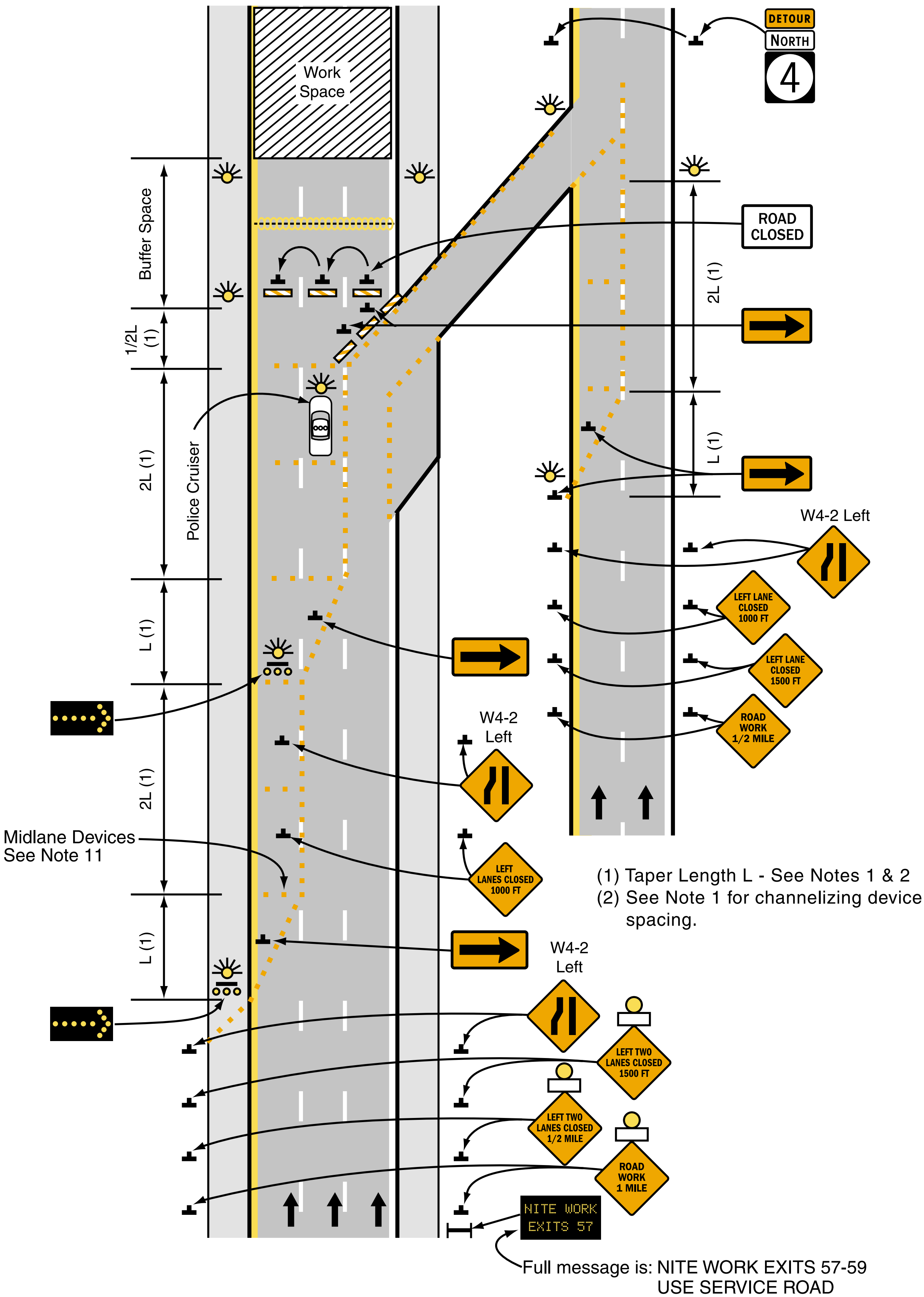


Figure NWTA-2. Freeway closure for night work with traffic diversion to service road.

Section 1.1.2. MUTCD TA-9 shows typical detour route signing.

10. Advance warning distances shown are appropriate for 55-mph highways. Distances may be adjusted for other speeds or for special situations—see Sections 1.1.1 and 1.2.8.
11. A BE PREPARED TO STOP sign (W20-7) may be added if traffic is slowing excessively or stopping at the merge area—see Section 1.2.8.
12. A portable or permanent CMS may be used to provide advance project information or driver guidance specific to the operation. For guidance on use and message content, see Sections 1.1.8 and 2.3.
13. For lighting and protection details for work vehicles and workers, see Sections 2.7 and 2.8.
14. For information on temporary lighting, see Section 2.9. NWTA-7 provides a sample temporary lighting plan setup.
15. NWTA-1 provides details on setup and removal sequences. Detour signs on the service road must be placed or uncovered prior to diverting traffic from the main line and removed or covered when the main line is reopened. In addition, the service road left-lane closure is placed prior to diverting traffic from the main line.

NWTA-3—ON-RAMP CLOSURES FOR NIGHT WORK

See Figure NWTA-3. Refer to MUTCD TA-8 for additional information on road closures and detours.

NWTA-3A—On-ramp closure from service road:

1. A continuous array of Type III barricades is used to close the entrance to the ramp from the service road—see Section 1.1.3.
2. A second row of Type III barricades is placed perpendicular to the ramp downstream from the service road.
3. An advance posting distance of 150 m is adequate for the RAMP CLOSED AHEAD sign for speeds of 45 mph or less, with additional distance provided for higher speeds—see Section 1.1.1.
4. Two Type A warning lights are mounted at the top of the first Type III barricade adjacent to the service road. Type A warning lights are spaced at approximately 1.2–1.5 m on the barricades perpendicular to the ramp—see Sections 1.1.5 and 2.1.6.
5. In NWTA-3A, an arrestor net is used for intrusion protection. A police cruiser or watch guard may be used with or without the arrestor. NWTA-3B shows an alternate treatment using Type III barricades. For other treatments, see Section 1.1.6.
6. Stopping distance beyond the arrestor net is based on design parameters for the specific installation—see Section 2.6.8.
7. Construction traffic may be allowed to enter if a path is available around the barricades and arrestor net. The work entrance must not encourage deliberate or inadvertent intrusions.
8. RAMP CLOSED signs are placed behind the Type III barricades along the service road, oriented perpendicular to the service road, and above the second row of barricades, oriented perpendicular to the ramp.

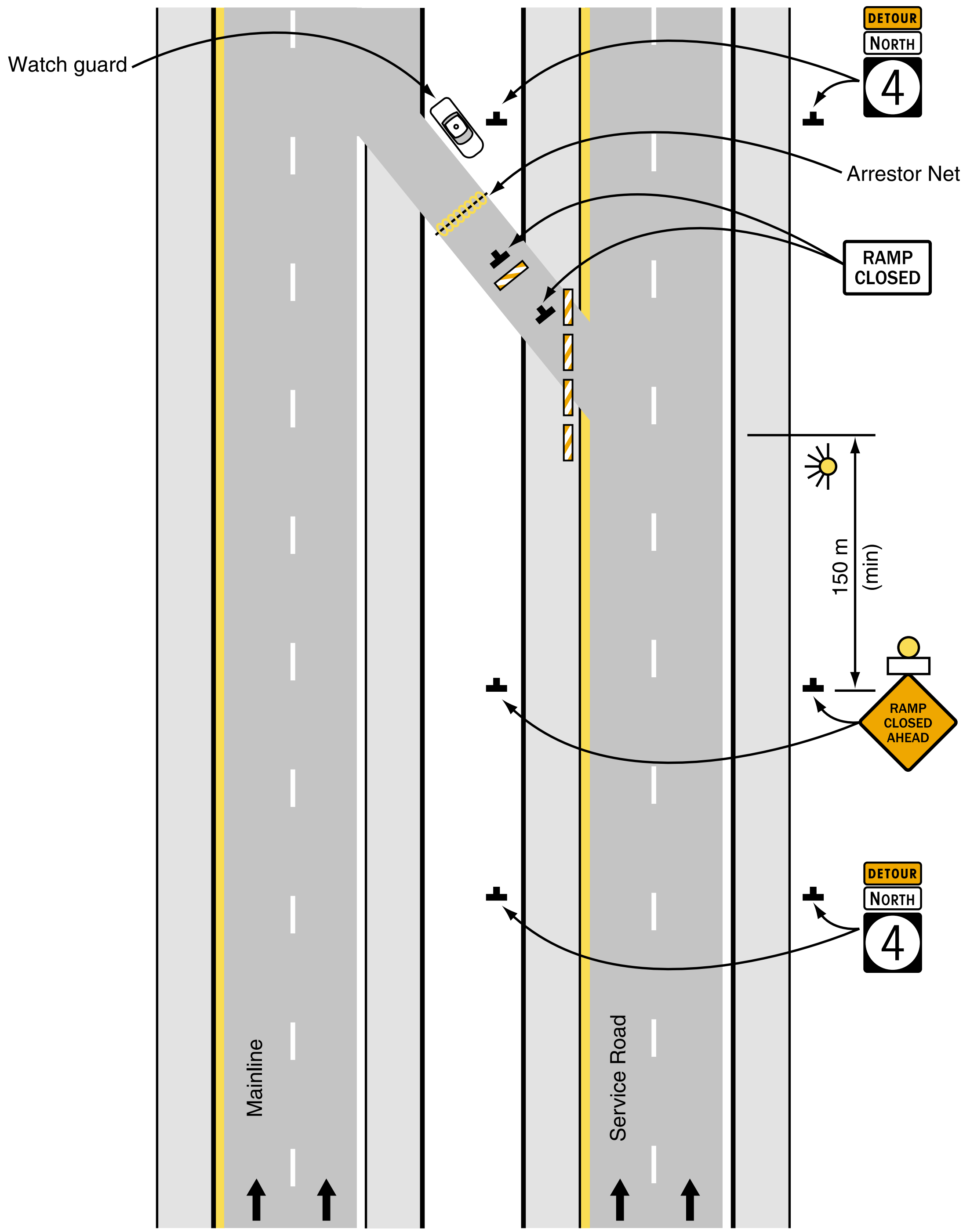
NWTA-3B—On-ramp closure from cross street:

1. An advance posting distance of 150 m for the DETOUR AHEAD sign (W20-2) on each approach is adequate for speeds of 45 mph or less, with additional distance provided for higher speeds—see Section 1.1.1.
2. Type III barricades are placed continuously across the on-ramp to prevent entrance—see Section 1.1.3. Type III barricades are also placed across the westbound (WB) off-ramp to prevent wrong-way intrusions.
3. Type A warning lights are spaced at 1.2–1.5 m on both sets of barricades—see Sections 1.1.5 and 2.1.6.
4. The detour signing shown is based on the assumption that the WB expressway traffic is detoured onto the eastbound (EB) expressway to an alternate route at an exit farther east. Other detour routes should be signed appropriately—see Section 1.1.2.
5. In NWTA-3B, multiple rows of barricades are used for intrusion protection. A police cruiser or watch guard may be used with or without the barricades. NWTA-3A shows an alternate treatment using an arrestor net. For other treatments, see Section 1.1.6.
6. Regulatory RAMP CLOSED signs are placed above and behind the barricades on both the on- and off-ramps.
7. Two DETOUR ARROW signs (M4-10) are placed on the face of the barricades on the on-ramp.
8. Where exit lanes or turn bays are provided for the on-ramp, channelizing devices will be needed to close them as well.
9. If traffic speed and/or ramp volumes are high, or other conditions indicate the need for it, a RAMP CLOSED AHEAD (W20-3) sign may be added upstream of the DETOUR AHEAD sign.

NWTA-4—FREEWAY SHOULDER CLOSURE USING TEMPORARY CONCRETE BARRIER WITH LANE CLOSURE FOR NIGHT WORK

See Figure NWTA-4. Refer to MUTCD TA-5 and MUTCD TA-33 for additional information on shoulder and lane closures.

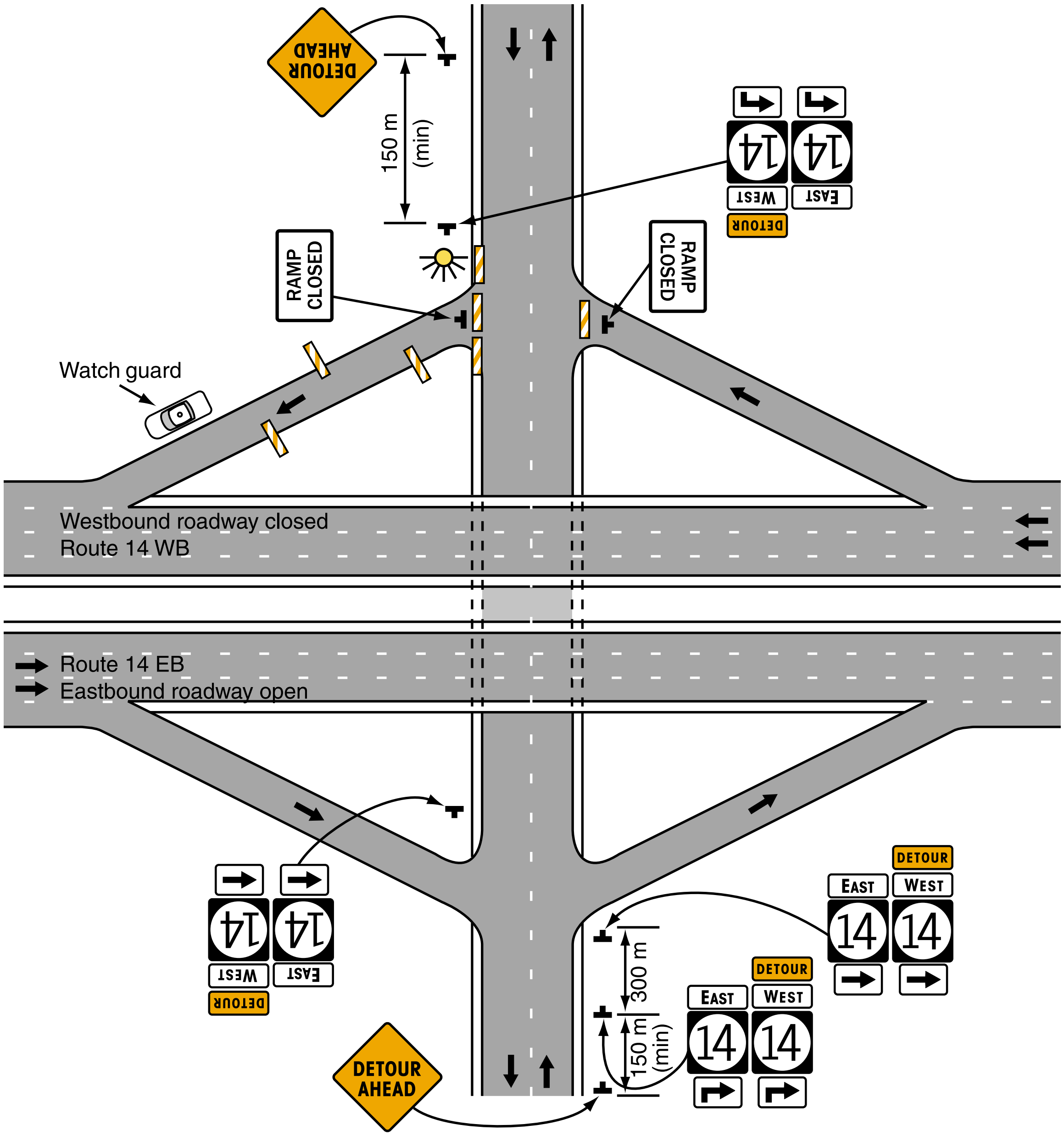
1. Temporary concrete barrier (TCB) is used when long-term activities on the shoulder require positive protection—examples include deep excavations or temporary bridge supports—see Sections 1.2.4 and 2.6.2.



NWTA-3A. On-Ramp Closure from Service Road

Figure NWTA-3. On-ramp closures for night work.

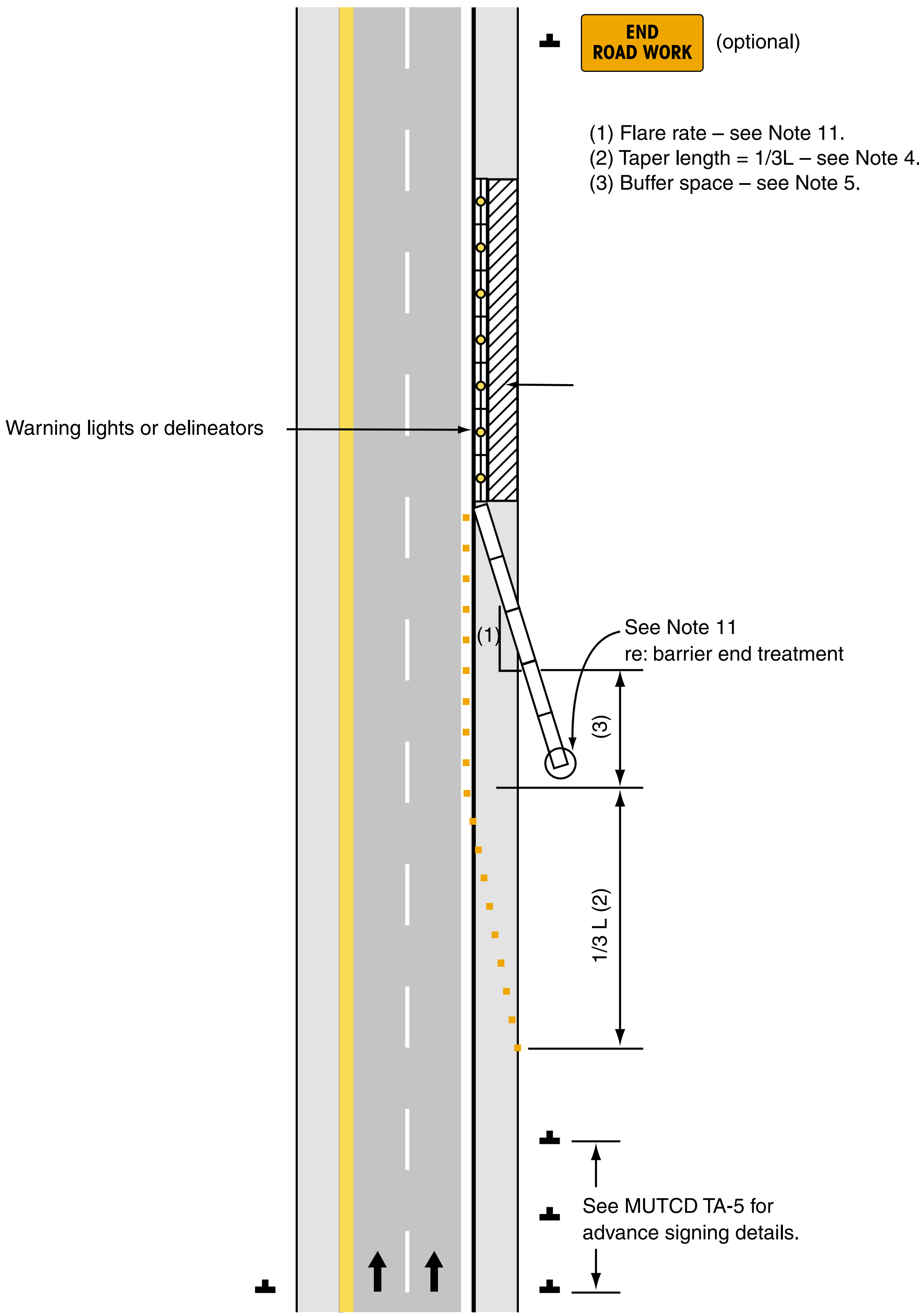
2. NWTA-4A shows shoulder closure details for periods when the lane closure is not in place.
3. Information on channelizing device type and spacing is provided in NWTA-1. For additional information, see Sections 2.1.1 and 2.1.2.
4. Shoulder taper length is (1/3) *L*—see Section 1.2.9.3.
5. Buffer space is shown between the downstream end of the taper and the TCB. For information on buffer space, see Section 1.2.3.
6. A shadow vehicle with TMA is shown in the closed lane to protect workers and the public—see Section 2.6.7.



NWTA-3B. On-Ramp Closure from Cross Street

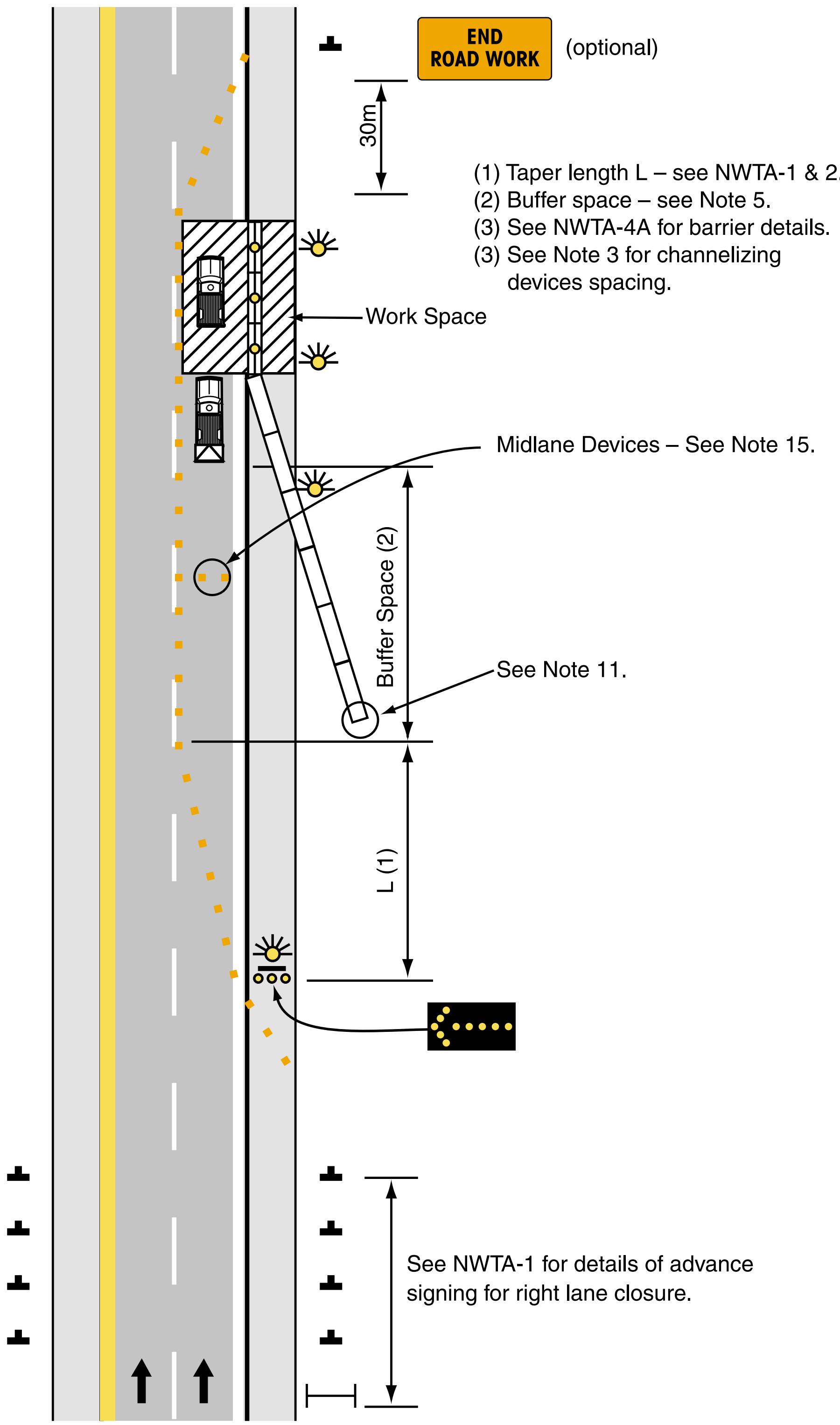
Figure NWTA-3. Continued

7. Several options are available for work vehicles to enter the closed lane, depending on site and traffic characteristics:
   - Work vehicle enters on shoulder between shadow vehicle and TCB.
   - Work vehicle backs into position from downstream end of closed lane.
   - Work vehicle enters closed lane from the open travel lane, but only if traffic conditions permit. A worker may need to relocate one or two channelizing devices temporarily to permit the work vehicle to enter.
   - Details for work vehicle access should be addressed in the contractor's operational plan—see Section 3.1.
8. NWTA-1 shows details of lane closure setup and removal sequences, which are appropriate for NWTA-4B. In addition to those steps, the advance warning signs for NWTA-4A must be covered or removed when the lane closure signs are placed, and restored when the lane closure is removed. One option is to place the lane



NWTA-4A. Shoulder-Closure - Non-Work Hours

Figure NWTA-4. Freeway shoulder closure using temporary concrete barrier with lane closure for night work.



NWTA-4B. Right-Lane Closed for Night Operations

Figure NWTA-4. Continued

closure signs over the shoulder closure signs if the locations of the signs coincide.

9. An alternative to the setup shown is to use moveable concrete barrier. It would be positioned along the edge of the shoulder during nonwork hours and shifted to close the lane during work hours—see Section 2.6.2. This alternative provides positive protection for the entire work operation, although cost and initial setup and final removal times may increase.
10. If moveable barrier is used, the lane closure is installed by first setting up the lane closure advance signing and channelizing devices following the procedure in NWTA-1. Then the barrier is shifted into position. Removal proceeds in the reverse order.
11. For information on barrier flare rates and end treatments, see Section 1.2.4.
12. For lighting and protection details for work vehicles and workers, see Sections 2.7 and 2.8.
13. For information on temporary lighting, see Section 2.9. NWTA-7 shows a sample temporary lighting plan setup.
14. Only the northbound (NB) roadway is shown. Traffic control may also be needed for the southbound (SB) roadway if traffic operations are affected.
15. Two midlane devices are shown in the buffer space—their use depends on the length of the buffer space—see Section 1.2.6.

NWTA-5—FREEWAY MEDIAN CROSSOVER FOR NIGHT WORK USING MOVEABLE CONCRETE BARRIER

See Figure NWTA-5. Refer to MUTCD TA-39 and TA-45 for additional information.

1. Use of moveable barrier may be appropriate when traffic speed and volume during night work hours indicate the need for positive separation between opposing traffic streams—see Sections 1.2.4 and 2.6.2.
2. NWTA-1 shows details on advance signing for lane closures.
3. Channelizing devices are drums, 300 mm by 600 mm vertical panels, or Type II barricades (and 900-mm cones only in the tangent sections)—see Sections 2.1.1 and 2.1.2.
4. Channelizing device spacing in meters equals 0.3 times the speed limit in miles per hour, with a maximum of 12 m. Spacing is halved at ramps, intersections, and other conflict points—see Section 1.2.6.
5. A portable or permanent CMS may be used to provide advance project information or driver guidance specific to the night operation. For information on use and message content, see Section 2.3.
6. Where space permits, a distance of 2*L* is desirable between the NB lane closure taper and the crossover shift taper to smooth flow, with a minimum of 0.5*L*—see Section 1.2.2.
7. Information on design of the crossover geometry is provided in MUTCD TA-39.
8. Appropriate points for work vehicles to enter the work space should be identified in the contractor's operational plan—see Section 3.1. Entrance from the shoulder prior to the right lane closure or from the downstream end of the work space, is preferred. Work vehicles entering from the tapers, single lane, or crossover are discouraged to minimize the risk of interference with traffic flow.
9. NWTA-5 includes multiple rows of Type III barricades and a watch guard to discourage traffic intrusions beyond the roadway closure. Alternate means to discourage intrusions include arrestor nets (shown in NWTA-2) and police patrols—see Section 1.1.6.
10. Depending on the alignment and total length of the crossovers, use of either curve W1-2 or reverse curve W1-4 signs may be appropriate to alert drivers to the alignment changes.
11. The setup and removal sequence for this NWTA is as follows:
    - Install SB left-lane closure—see NWTA-1 for setup sequence.
    - Shift barrier into position downstream from the left-lane closure using the barrier transfer machine. Additional protection is not needed during the barrier shift—see Sections 2.6.2 and 2.6.3.
    - Working from the closed SB left lane and median, place channelizing devices and signs throughout the length of the crossover.
    - Install NB right-lane closure—see NWTA-1 for setup sequence.
    - Use a rolling roadblock of work vehicles or police cruisers to delay traffic briefly while placing channelizing devices for the NB shift taper into the crossover.
    - Complete placement of roadway closure barricades, signs, and intrusion safeguards in the closed NB roadway.
    - Removal proceeds in reverse order.

NWTA-6—NIGHT WORK ON TWO-LANE TWO-WAY ROADWAY USING FLAGGERS TO CONTROL ALTERNATING ONE-WAY TRAFFIC

See Figure NWTA-6. Refer to MUTCD TA-10 for additional information.

1. Advance warning distances shown are appropriate for 55-mph highways. Distances may be adjusted for other speeds or for special situations—see Section 1.2.8.
2. SB warning signs are normally the same as shown for NB, but may be adjusted if conditions are different.

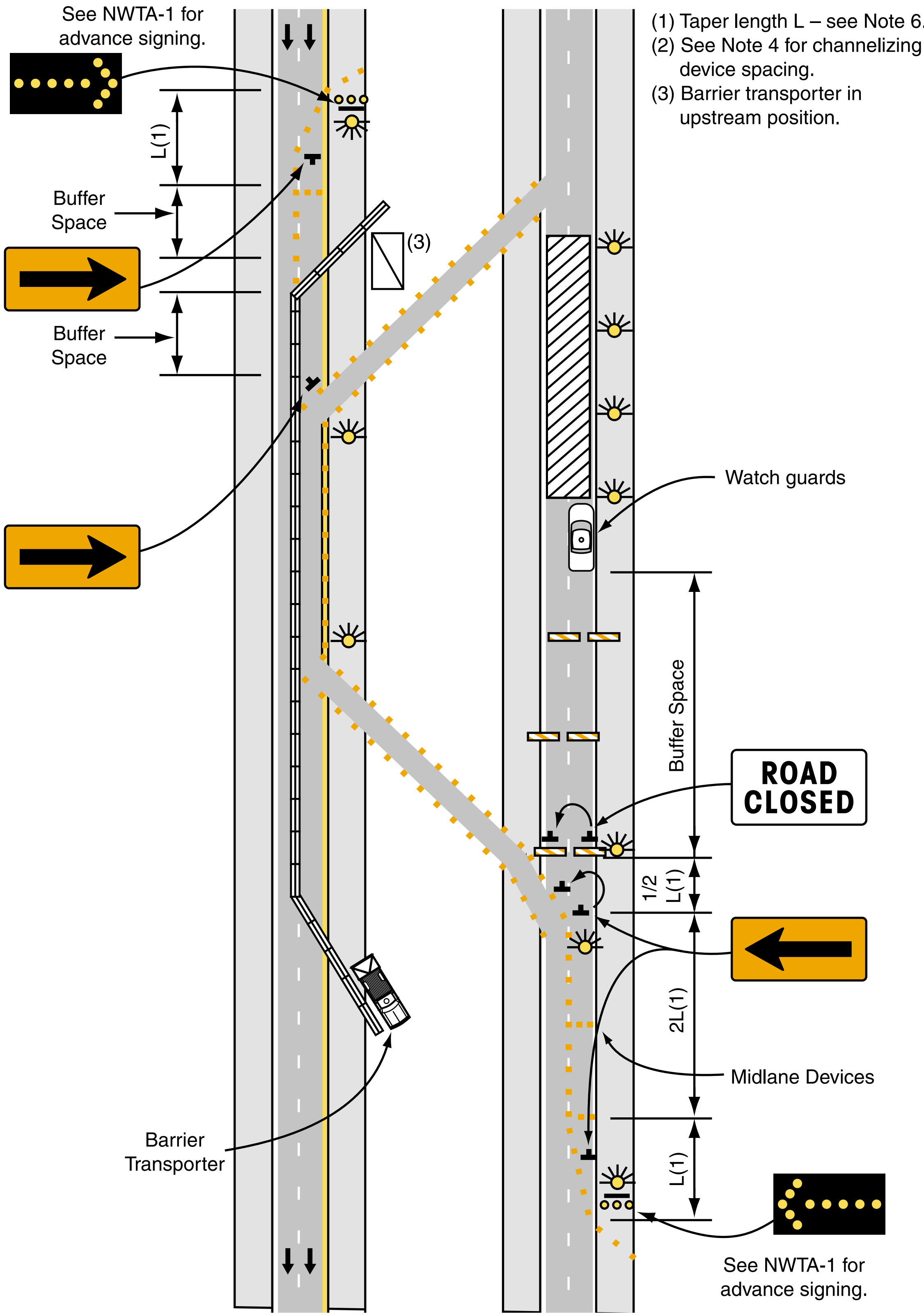


Figure NWTA-5. Freeway median crossover for night work using moveable concrete barrier.

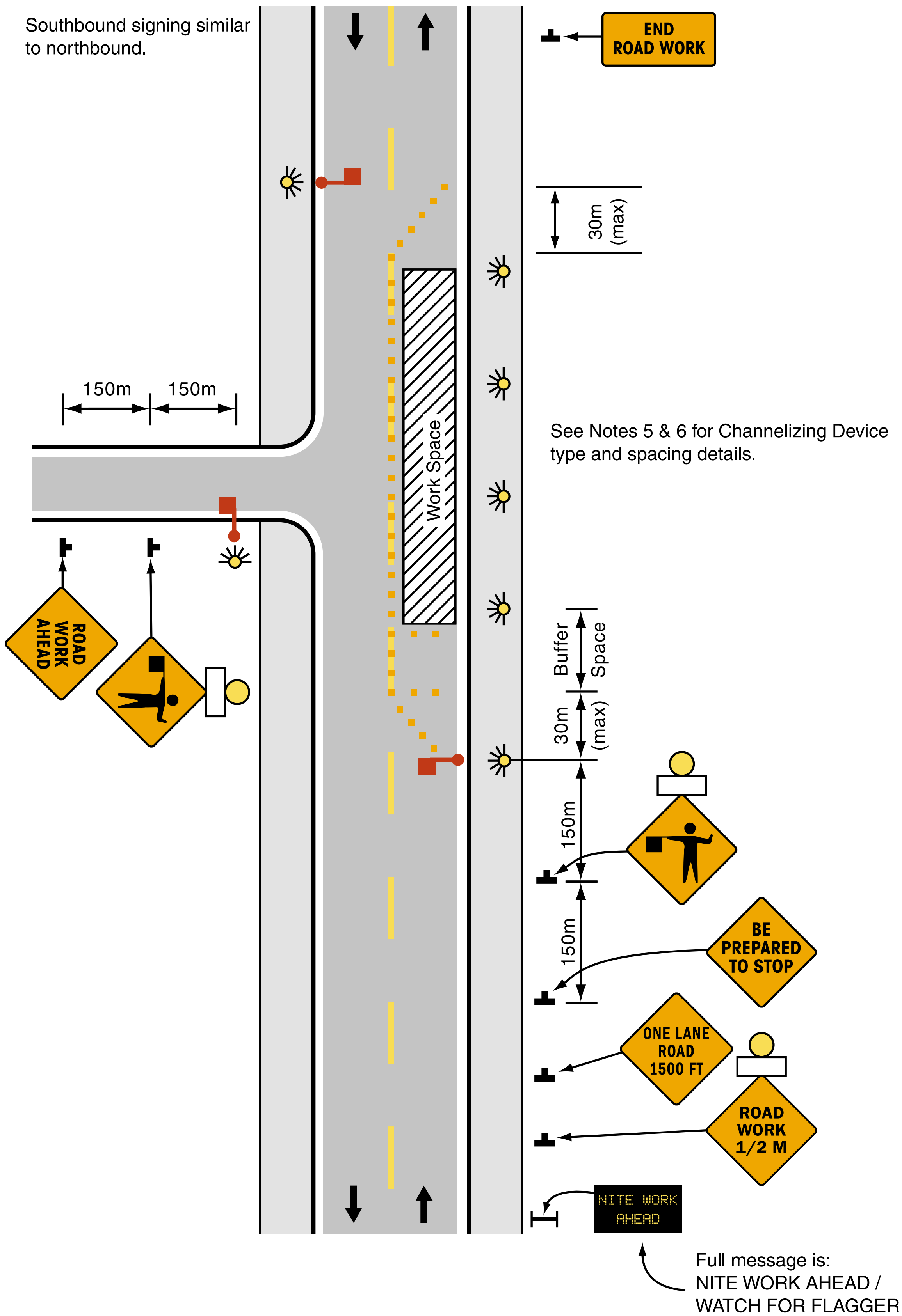


Figure NWTA-6. Night work on two-lane, two-way roadway using flaggers to control alternating one-way traffic.

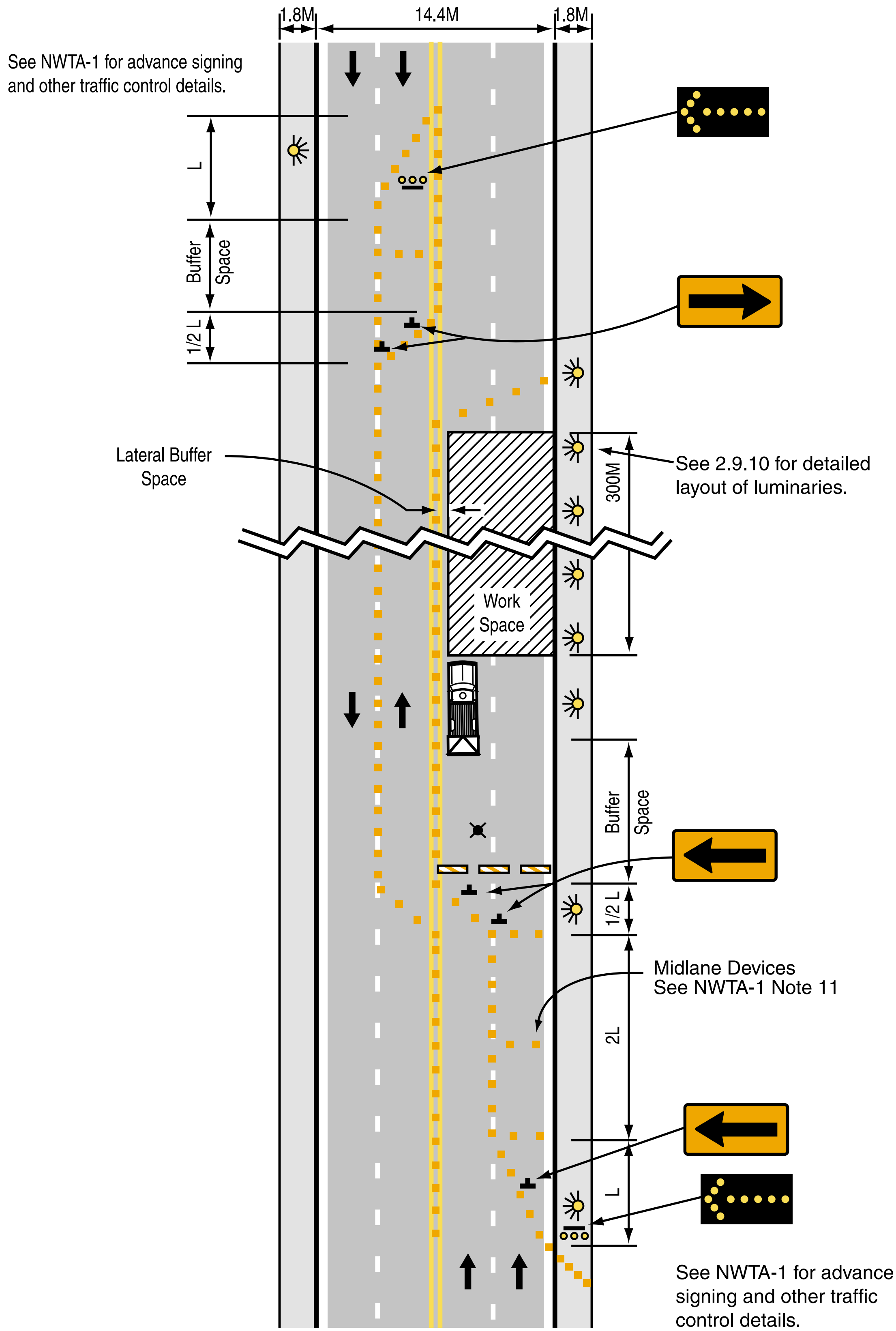


Figure NWTA-7. Night work lane closure with lighting plan details.

3. A portable or permanent CMS may be used to provide advance project information or driver guidance specific to the night operation. For information on use and message content, see Section 2.3.
4. Portable light towers are used to illuminate the flagger stations and work space—see Sections 2.9 and 2.5.2.
5. Channelizing devices are drums, 300 mm by 600 mm vertical panels, or Type II barricades, and 900-mm cones only in the tangent sections—see Section 2.1.1.
6. Channelizing device spacing in meters equals 0.3 times the speed limit in miles per hour, with a maximum of 12 m. Spacing is halved at ramps, intersections, and other conflict points—see Section 1.2.6.
7. Flagger stations are located to provide good sight distance approaching the flagger and to provide buffer space before the work space. In addition, flaggers are isolated from other workers and equipment—see Section 2.5.3.
8. Reflectorized stop-slow paddles are used for flagging. Flashing lights may be added to the staff—see Section 2.5.4.
9. For information on flagging procedures, training, and apparel, see Sections 2.5 and 3.1.1.
10. Traffic control consisting of a flagger or other positive means is needed at all intersections and driveways within the one-way section.
11. Positive coordination between flaggers is essential. At a minimum, radio communication is needed. Use of a pilot vehicle also provides speed control and reduces the risk of work space intrusions. Pilot vehicles are especially appropriate for long one-way sections.
12. When approach speeds and volumes are high, a BE PREPARED TO STOP sign (W20-7) may be added upstream of the flagger sign (W20-7).
13. When flagging operations are conducted at the same location for extended periods, use of temporary traffic signals may offer cost and safety advantages—see Section 2.5.6. MUTCD TA-12 provides additional information on temporary signal installations.
14. Type A or Type B warning lights are used on the flagger signs to increase conspicuity.
15. Flagger, ONE LANE ROAD, and BE PREPARED TO STOP signs are removed when the roadway is returned to normal two-way operations. However, the ROAD WORK and other appropriate signs remain in place if needed to warn drivers of other conditions associated with the work.

NWTA-7—NIGHT WORK LANE CLOSURE WITH LIGHTING PLAN DETAILS

See Figure NWTA-7. Refer to MUTCD TA-32 for additional information on lane closures.

1. Refer to NWTA-1 and NWTA-2 for details on advance signing and other traffic control devices used for night lane closures.
2. Details on channelizing device type and spacing are provided in NWTA-1 and NWTA-2. Nine-hundred-millimeter cones spaced at a maximum of 6 m may be used to separate opposing traffic if roadway width is limited.
3. Placement and spacing of portable light towers is based on specific luminaire properties shown in Figures 34–36. For other luminaire properties, placement and spacing must be changed to ensure that illuminance, uniformity, and glare criteria are satisfied—see Section 2.9.
4. Information on longitudinal and lateral buffer spaces is provided in NWTA-1.

TECHNICAL NOTES

1. Tech Note Table 1 providing criteria for taper lengths was taken from the MUTCD Table 6C-2.
2. A study of the effects of taper length on traffic operations in work zones suggested the formula $L = WS^2/60$, which results in a shorter taper length without greater traffic conflicts or an increase in erratic maneuvers from the standard taper length formula of $L = WS$. Particularly at urban sites, the advantage of the shorter taper length is less interference with driveways and intersections. MUTCD use of shorter taper lengths at slower speeds appears to reflect these findings (*49*).
3. Texas DOT has tried and evaluated both of these methods. When the use of a shoulder lane is possible, the traffic control device (TCD) sequence included (1) an advance sign informing the driver how far ahead the use of the shoulder was permitted, (2) a sign identifying the beginning of permitted shoulder use (along with a short cone taper to mark the start of the shoulder use section), (3) a sign specifying that shoulder use is permitted and that caution should be used (located throughout the shoulder use section), and (4) a sign identifying the end of permitted shoulder use (along with a short cone taper to mark the end of the shoulder use section). There is no standard advance signing for a traffic split. However, Texas DOT has used an innovative lane blocked sign and a symbolic traffic split sign successfully (*47, 50*).
4. The Illuminating Engineering Society (IES) recommends 2–10 lux, depending on the level of pedestrian activity. Because of the potential level of danger and the novelty of the temporary situation, the highest light level is recommended (*40*).
5. An FHWA-sponsored study containing observations of more than 7,000 pedestrian crossings found that mean walking speeds range from approximately 3.94 ft/s to 4.79 ft/s. The 15th-percentile walking speed for younger pedestrians (i.e., pedestrians under 65 years of age) was 3.97 ft/s, and the 15th-percentile walking speed for older pedestrians (i.e., pedestrians over 65 years of age) was 3.08 ft/s. For design purposes, values of 4.0 ft/s for younger pedestrians and 3.0 ft/s for older pedestrians can be assumed (*10*).
6. New York State permits the use of cones in tangent sections and the alternate use with barrels, as suggested in this report (*6*).
7. An FHWA research study showed that the use of brighter materials could offset the effects of smaller size of retroreflective traffic signs (*57*). During daylight, the small spatial area of the tubular device limits its visibility to relatively short distances. At night, the small reflective area may act as a point light source (i.e., a light source whose detection is not affected by the size of the target). Although the research has not been done, one can hypothesize that the more reflective the material used on a tubular marker, the farther away the marker will be detected and the less its limited target size will affect its utility as a channelizing device. The marker's small size, however, will still limit its usefulness as a barrier to restrict intrusions.
8. Field testing has indicated that opposing lane traffic dividers show much promise (*51*). Note that the device tested is now in mass production in certain areas.
9. On the basis of extensive experience with night work, the NYSDOT continues to specify engineer-grade reflective sheeting on channelizing devices. However, some other agencies require brighter grades of sheeting. For example, Iowa requires Type III or IV sheeting on channelizing devices.
10. In addition to having the obvious disadvantage of shorter recognition distance, dimmer materials increase the scanning behavior of drivers toward lane or edge lines, therefore possibly detracting from detection of other critical work zone features or signing information (*52*). An additional consideration in choosing the brightness of the pavement markings is the needs of older drivers. Older drivers require brighter materials to visually perform at the level of younger drivers (*53*).
11. Although no research directly relates to the question of sign spacing, a generally accepted model allows for reasonable guidelines. Two recent reports suggest a decision sight distance (DSD) requirement of 5.5 s for establishing the minimum required legibility distance (MRLD) on which letter height and sign location should be based (*54, 55*). This time requirement translates into a distance of 440 ft for vehicles traveling at 85 km/h (55 mph). A minimum spacing of 150 m (500 ft) will therefore provide drivers with sufficient time to read one sign before encountering another. The MRLD for speeds of 55 km/h (35 mph) is 85 m (275 ft) so that the spacing on low-speed roads might be decreased to 90 m (300 ft).
12. Roadside-mounted traffic signs should be oriented slightly away from perpendicular to reduce specular glare. A nominal value for this deflection is –4 deg. As this angle (i.e., the entrance angle) gets large, the retroreflectivity of most materials is dramatically reduced. The retroreflectivity of Type III, encapsulated, glass-bead, high-intensity sheeting is reduced by 40 percent when the entrance angle is changed from –4 deg to 30 deg. The retroreflectivity of Type IV, unmetallized, microprismatic, high-intensity sheeting is reduced by 67 percent when the entrance angle is changed from –4 deg to 30 deg. This angular change is in a plane perpendicular to the road edge. A similar reduction in retroreflectivity should be expected when tilting a sign away from perpendicular to the road edge while keeping the sign essentially perpendicular to the ground (*16*).
13. At night, drivers with the poorest vision may read a traffic sign at a distance of only 10 m (30 ft) per inch of letter height, while drivers with superior vision will read a traffic sign at better than 15 m (50 ft) per inch of letter height. Daytime performance is at least 10 percent better. However, drivers with poor vision are less likely to drive at night, and those that do may approach a work zone more slowly than other drivers do. With a 6-in., Series D letter, one can expect 60–90 m (200–300 ft) of legibility. With a 20-cm (8-in.) letter, one can expect 75–120 m (250–400 ft) of legibility. At 90 km/h (55 mph), 60 m (200 ft) provides 2.5 s to read a sign, which is sufficient time to read 2–5 words of sign message. Performance with Series C letters may be somewhat less. Research has shown that the letter series should not be decreased in order to increase the letter height. Also, increasing the stroke-width-to-height ratio, as with a Series E letter, may control the irradiation effects of high-intensity material. Brighter materials will not increase these distances very much. Brightness has its greatest effect on conspicuity, not legibility (*56, 57*).

TECH NOTE TABLE 1 Criteria for taper lengths (from MUTCD Table 6C-2)

Type of Taper	Taper Length
Upstream tapers	
Merging taper	at least L*
Shifting taper	at least $0.5L$
Shoulder taper	at least $0.33L$
One lane, two-way traffic taper	30 m (100 ft) maximum
Downstream taper	30 m (100 ft) per lane

* Note:

For speed limits of 60 km/h (40 mph) or less,

L (in meters) = $WS^2/155$ and
L (in feet) = $WS^2/60$

Where

W = width of offset and
S = posted speed, or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed.

For speed limits of 70 km/h (45 mph) or greater,

L (in meters) = $WS/1.6$ and
L (in feet) = WS

14. Iowa requires Diamond Grade™ fluorescent sheeting on signs, and Florida requires Diamond Grade sheeting on signs.
15. The recommendation for high-intensity material is consistent with the minimum retroreflectivity values being considered by FHWA. The minimum values for black-on-orange signs—which vary by type of legend, size of sign, and type of material—are shown in Tech Note Table 2. These values are currently being revised by the FHWA to account for recent changes in headlamp technology and sign materials. Although the revised values may be somewhat higher, the general discussion that follows will still be applicable.

    The R_A for bold legends is lower than the R_A required for text, the R_A for large signs is lower than for small signs, and the R_A for high-performance materials is greater than for low-performance materials. While the minimum values of R_A vary for different material, the luminance that results at larger observation angles will be almost the same because of differences in the optics of each type of material (*27*).

    The ASTM minimum specification of R_A for Type 1 Engineering Grade orange sheeting is 25 at 0.2 alpha, –4 beta, which suggests that this material may be used with standard size signs and all signs with bold symbols. In practice, the material typically has an R_A at least 20 percent greater when new. However most construction signs use text and not bold symbols and new Type 1 sheeting will not meet the requirements for 75 cm (30-inch) signs while providing no more than 50-percent excess reflectivity for 120 cm (48-inch) signs. Signs with Type 3 or greater reflectivity are needed to provide minimum brightness on small signs and a sufficient margin of safety with standard signs in complex backgrounds and high-speed situations. Type 3 materials are recommended since they permit greater degradation before needing replacement while providing for greater conspicuity when new (*16, 27*).

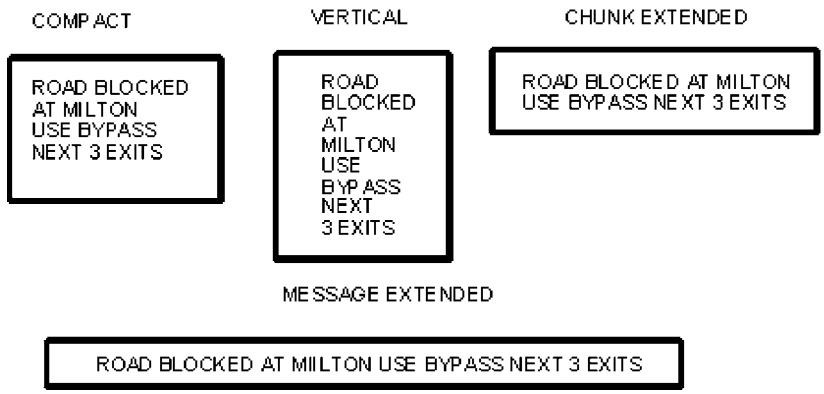
    Rollup signs are made from Type VI material, which has an ASTM specification for retroreflectivity of 70 cd/lux/m^2 at 0.2 alpha, –4 beta. This retroreflectivity is significantly less than that for Type III material (100 cd/lux/m^2). A recent evaluation of the weathering of this material suggests that rollup signs may fail to meet ASTM specifications with less than 24 months of exposure (*58*). The retroreflectivity of rollup signs limit their use at night to low-speed, low-volume roads. Also, the low-mounting heights of rollup signs make rollup signs inappropriate at night, except for two-lane roads.
16. Several reports suggest that a nominal value for the decision sight distance for traffic signs requiring a lane change or speed reduction maneuver is 5.5 s. At 90 km/h (55 mph), this value translates into a legibility requirement of 135 m (445 ft). Signs that do not require a maneuver, such as most construction warning signs, require only a 2–3-s exposure (*54, 55*).
17. Dudek (*59*) identified four discrete formats shown in Tech Note Figure 1. The compact and chunk extended are the two formats

TECH NOTE TABLE 2 Minimum retroreflectivity guidelines for black-on-yellow and black-on-orange warning signs

Legend	Material Type	Sign Size >=48-in	36-in	<=30-in
Bold Symbol	All Materials	15	20	25
Fine Symbol & Word	I	20	30	45
	II	25	40	60
	III	30	50	80
	IV & VII	40	70	120

Notes:

1. cd/1ux/m^2 is measured at an entrance angle of –4 deg and an observation angle of 0.2 deg.
2. 1 in. = 25.4 mm.



Tech Note Figure 1. Four discrete formats for displays (from Dudek [59]).

recommended for discrete displays. Either the compact or chunk extended are acceptable for night work zones. Knoblauch et al. (*60*) developed messages for the vertical format based upon the limitation that the CMS would permit a maximum of eight characters per line.

18. The minimum required legibility distance (MRLD) is determined by a variety of factors, including workload, message load, message length, familiarity, decision complexity, and display format.

    Workload increases as the complexity of the driving task increases because of extremes in geometrics, heavier traffic volumes, increases in the percentage of trucks, traffic conflicts, and visual complexity of the environment. Increased workload means drivers must attend to the information that they feel is most important to them. Therefore, as workload increases, drivers have less time to read sign messages. Long messages and high workload require that the driver glance at the sign more than one time to process all of the information. Multiple glances make the required reading exposure time longer than would be required to read the same information in a single glance.

    Message load refers to the information content of the message. It is recommended that no more than three units of information be displayed in one sign sequence. A fourth unit may be displayed if it is minor and does not need to be recalled in order to take appropriate action.

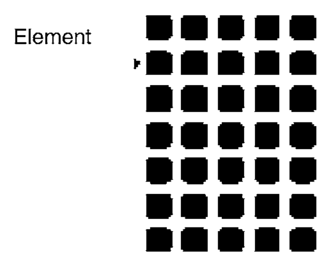
    Message length refers to the number of words in a message. One unit of information may consist of one to three words. It is suggested that a sign message should be limited to eight words, excluding prepositions (about four to eight characters per word).

    Familiarity of drivers with the type of information displayed and/or the content of the message (e.g., a specific road or place name) results in a reduction of reading time.

    Decision complexity and expectancy of the required action may require additional time and distance (anywhere from 0.5 to 2.5 s) for a driver to make a decision (e.g., to exit or not exit).

    Display format refers to whether the entire message is displayed discretely (at once), in sequential displays, or as a run-on message. Only discrete and sequential displays are considered acceptable alternatives for high-speed work zones.

19. **Character Components.** The parts of a CMS that affect its visibility fall into two major classes: character components and message components. Character components can, in turn, be divided into element or "pixel" variables and character variables. A CMS element is the smallest individually addressable unit that can be used to create a character (as shown in the 5 by 7 character matrix below). For example, the elements in a flip disc are the fluorescent discs, and the elements of an LED CMS are the bundles or groups of LEDs. The character variables, while not structurally independent of the element variables, represent what the driver sees (e.g., the character font).



    The design of the element variables—including size, shape, spacing, and luminance—can be flexible as long as the character components discussed in Section 2.3.8 are within the recommended ranges.

20. **Letter Height**. Minimum letter height should be 460 mm (18 in.) for CMSs on roadways with 90-km/h (55-mph) or greater speed limits. Properly illuminated 300-mm (12-in.) letters would be acceptable for most younger drivers under these conditions; however, this size would fail to accommodate the majority of drivers over 60 years of age. Based on 200 m (650 ft) of legibility distance for 460-mm (18-in.) signs on an 90-km/h road, 300-mm letters could be used effectively on 55-km/h (35-mph) or slower roadways, as these traffic speeds increase the message-reading time available to the driver.

    Increases in letter height over 460 mm will not result in proportional increases in legibility distance. For example, observers should not be expected to read 915-mm (36-in.) letters twice as far away as 460-mm (18-in.) letters. The operational recommendation is to increase the letter height by 1.5 times the proportional height. If, for example, you wanted the observers to read the signs at twice the distance that your 460-mm (18-in.) letters produced, you would need to increase the letter height to 1,140 mm (45 in.); if you wanted to increase the distance by half, you would need to use 815-mm (32-in.) letter heights.

21. **Contrast.** CMS contrast reduction is typically caused by glare reflecting off of the sign face (called veiling luminance) or insufficient brightness of the active elements. Veiling luminance is the result of sun angle or the sign's own lighting system. An appropriate black matte finish applied to the background portion of a CMS helps; however, the main reason for the loss of contrast is the reflection of light off the plexiglass sheeting used to protect the sign face. CMSs with new protective sheeting typically produce appropriate contrast levels; problems occur mainly when the sheeting is allowed to become dirty or scratched. Regular cleaning, as well as replacement when surfaces become excessively scratched, is highly recommended. Usually, the protective sheeting can be cleaned with a mild nonabrasive detergent, warm water, and a soft cloth; however, the manufacturer's recommendations should be consulted.

    The formula for determining the luminance contrast of a CMS is

$$\frac{L_t - L_b}{L_b}$$

    where

    L_t = luminance of a character module with all the elements "on" and
    L_b = luminance of the character module with all elements "off."

    A photometric procedure for measuring the luminance and contrast of a CMS is provided by Garvey and Mace (*61*).
22. As part of their work, Graham et al. looked at the placement issue from two dimensions: shoulder versus lane, and beginning versus downstream taper positions. Using experimental evidence and other research reports, they found that the board is most effectively placed directly in the lane that is being closed, because "various literature sources indicate that arrow board connotes lane closure." However, Graham et al. also report that results from their arrow board field studies indicated that placing the arrow board on the shoulder near the start of the taper produced a more effective lane-changing pattern than did placing the arrow board in the closed lane in the middle of the taper. In the two tests where the arrow board was placed on the shoulder upstream from the start of the taper, the results indicated that this placement may be even more effective than the placement at the start of the taper (*62*). The efficacy of locating the arrow panel at the beginning of a taper on the shoulder rather than placing it in the closed lane farther downstream was confirmed by Pain (*63*).
23. Because the MUTCD does not provide an operational definition for "recognition distance," the recommended placement can vary depending on state requirements, road curvature, or the common sense of the road crew setting up the work zone. The guideline is based on an FHWA pamphlet (undated) entitled *Advance Warning (Flashing) Arrow Panels: Positive Guidance*, which addresses issues of curvature (*64*).
24. The MUTCD specifies that a Type C arrow panel should be legible at 1 mi, but the MUTCD does not say anything about the lighting condition, the angle at which the arrow panel is viewed, or the age or visual ability of the observer. The 1-mi criterion would easily be met if the observer were a 17-year-old with 20/17 vision, viewing the arrow panel on axis, without windshield attenuation or interference from the sun. However, if the observer were a 65 year old, viewing the arrow panel under less than ideal conditions, the likelihood of the 1-mi legibility criterion being met is low. The guidelines in *NCHRP Research Results Digest 259* (*39*) ensure that, for high-speed roadways, the arrow panel will be legible at 1 mi when viewed on axis and at a minimum distance of 460 m (1,500 ft) when viewed off axis. The minimum distance was based on DSD theory that suggests that at 90 km/h (55 mph), a distance of 300 m (1,000 ft) is sufficient for the clear recognition of an arrow panel for 99 percent of drivers (*4*). DSD is defined as "the distance at which a driver can detect a signal . . . recognize it . . . select appropriate speed and path, and perform the required action safely and efficiently" (*65*). The 460-m (1,500-ft) minimum is based on the assumption that many drivers will be driving at a speed greater than 90 km/h (55 mph). The recommended minimum for low-speed roadways, based on the same kind of analysis, is 300 m (1,000 ft).
25. Laboratory studies have indicated that flashing arrows and sequential chevrons are quickly recognized by drivers and that these displays mean lane closure or lane change (*66*). These findings support earlier recommendations that the use of the flashing arrow panel was inappropriate for shoulder work or caution messages (*67*).
26. Flashing or "blinking" arrows and sequential chevrons have been found to outdistance sequential arrows, and there is no clear superiority of flashing arrows over the sequential chevrons (*67*). When several operational modes were presented to 63 Midwestern drivers and to 46 Eastern drivers, both groups clearly preferred the flashing arrow and sequential chevron over the sequential arrow (*62*). For the Midwestern drivers, there was no clear preference between the flashing arrow and sequential chevron. However, Eastern drivers did show a clear preference for the flashing arrow over the sequential chevron. This difference in preference could indicate a regional bias. The authors hypothesized that the sequential chevron is used more frequently in the Midwest and report that Virginia "no longer uses the sequential chevron mode." Mace and Finkle found the flashing arrow to result in the shortest reaction time compared with all other modes and no regional differences among respondents (*39*). The flashing arrow, because it has fewer lamps, is also more energy efficient. Conversely, these lamps can be made to have a higher intensity and, therefore, greater visibility. Collectively, these studies suggest that the flashing arrow should be the preferred display mode. If local practice strongly favors a chevron mode, there is no evidence that this preference would create a safety problem.
27. Mace and Finkle observed that when the bar, four-corner, and flashing arrow were tested together, the reaction time to the four-corner display was faster than the bar (*39*). Mace and Finkle also observed that when viewed off axis, one or two lamps in the four-corner display may appear less bright or not be visible at all, making the display difficult to identify. Adjusting the orientation of the arrow panel on a curve can improve visibility at some locations, but the arrow panel will not maintain this visibility over much distance on the curve. Also, there has not been any research supporting the fact that drivers know what any caution display means; therefore, caution displays are not recommended for shoulder work.

Noel et al. visited eight states and found that arrow panel caution modes were used for shoulder work (*68*). Three of the states used the four-corner flashing mode, while Pennsylvania and Virginia specified use of the flashing-bar mode. Noel et al. noted "concern on the part of some researchers and highway agencies that the caution flashing bar may be interpreted as a malfunctioning flashing arrow, resulting in unnecessary lane changes. Consequently, some agencies prefer the four-corner flashing mode for caution displays."

28. The lamps used in the arrow panel are vital to the panel's visibility. It is recommended that each lamp be independently tested and certified. Testing could be done by the state or an outside laboratory, and a report should be available to identify the lamp beam width and the daytime and nighttime operating voltages.

    The requirements for nighttime arrow panel operation are similar to those for daytime, with the addition of a limit on the maximum intensity allowed. The additional requirement is to limit the amount of glare the arrow panel produces. The maximum intensity requirement must be met at the lamp "hot spot," which may or may not be on axis with the optical center of the lamp. Nighttime glare studies found that the maximum tolerable total intensity, combined from all arrow panel lamps, was 5,500 cd. This total leads to 370 cd per lamp for a chevron display and 570 cd per lamp for an arrow display. Limiting the maximum intensity to 370 cd per lamp ensures that both discomfort and disability glare will be controlled for either type of display (*39*).

    The requirements for minimum on-axis and off-axis intensities at night are based on previous research with nighttime requirements for traffic signals (*69*). Freedman et al. found that a nighttime level that was 30 percent of the daytime level did not reduce visibility of the signal. Applying this requirement to the daytime arrow panel intensity gives a nighttime minimum intensity level of 150 cd on axis and 30 cd off axis for high-speed roads and 90 cd on axis and 18 cd off axis for low-speed roads.

29. The procedures to ensure proper visibility of an arrow panel were taken from *NCHRP Research Results Digest 259* (*39*). These procedures include the recommended lamp checks, voltage checks, setup and aiming procedures, and procedures to verify arrow panel visibility.

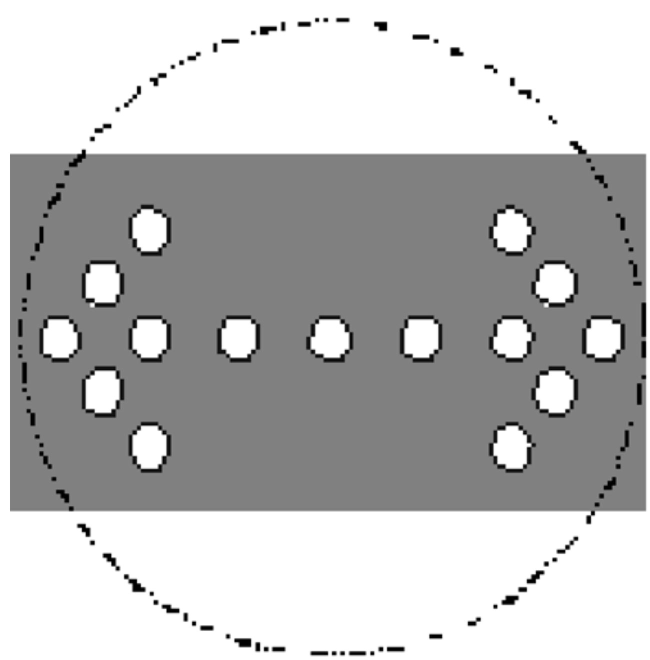
30. If the failure to meet minimum requirements at night is the result of a defect, the unit should be replaced or repaired as soon as possible. However, some arrow panels, when new and operating as designed in their nighttime mode, may not meet the minimum requirements suggested by *NCHRP Research Results Digest 259* (*39*). If operated in the daytime mode, they will likely exceed the maximum requirement to control glare at night. If the criteria of *NCHRP Research Results Digest 259* are to be followed, units not meeting those criteria should be replaced as soon as possible with a unit that does.

31. **Subjective evaluation of arrow panel.** The most difficult part of subjectively evaluating the clarity of an arrow panel is knowing when a panel is clearly visible. For this purpose, the following rating scale will be of help. There should be no difficulty in identifying arrow panels that are perfect, poor, or very poor. It is obvious when you have no idea or are guessing about what is on the panel or if the panel could not be any better. The difference between "clear" and "fair" is less obvious, but experience will help in making this distinction. If there is some doubt about whether the arrow panel is "clear" or "fair," be sure to do the test under adverse sun conditions. If you can definitely tell the direction of the arrow under these conditions, the arrow panel visibility is acceptable. See Tech Note Figure 2.

32. **Photometric evaluation of arrow panel.** Because the visibility of an arrow panel is most reliably assessed by photometric performance, the purpose of this tech note is to describe a procedure for the photometric measurement of arrow panels in the field. The procedure involves measuring the luminance of the entire arrow panel with a luminance meter. Because arrow panels are rectangular and the aperture of most photometers is circular, a portion of the arrow panel's background will enter into the measurement (see Tech Note Figure 3). *Therefore, the accuracy of photometric levels is improved if the measurements are made at night to ensure a uniform background for the photometer's aperture*. Because luminance meters have fixed apertures, the selection of a measuring distance will be restricted by the length of the arrow and by the diameter of the photometer's aperture. Although the measurements may be made at any distance (preferably one where the arrow panel fits within the aperture) at any location (even a parking lot), there is some advantage to making the measurements at the SSD or DSD with the arrow panel placed on-site as it will be used. The advantage of field measurement at either the SSD or DSD is that the lamp

Perfect	____5____	Could Not Be Better
Clear	____4____	It Was Obvious
Fair	____3____	Could Just Make It Out
Poor	____2____	Had To Guess
Very Poor	____1____	Had No Idea

Tech Note Figure 2. Arrow panel visibility scale.



Tech Note Figure 3. Aperture.

intensity may be estimated in the precise geometry where it will be viewed.

The luminance measurement obtained using a photometer is converted into an intensity-per-lamp value by dividing the measured luminance by the area contained in the aperture and dividing the result by the number of lamps in the measurement. Lamp intensity expressed in candelas (cd) is the appropriate unit of measurement, as it is the standardized method used to describe the characteristic distribution of light emitted from lamps.

The procedure for photometric evaluation of an arrow panel is as follows (for further information, see *NCHRP Research Results Digest 259*):

i. If measurements are to be made at SSD or DSD, a luminance meter with at least a 1-deg aperture is required. Meters with smaller apertures are unable to view the entire arrow panel at all the required DSD and SSD locations. In fact, a 1-deg aperture fails to view the entire arrow panel at distances closer than 120 m (400 ft). If the aperture is too small to make the measurements at SSD or DSD, the intensity may be estimated from measurements made at other distances, and the needed angularity may be simulated by moving the luminance meter to a location that approximates the viewing angle at these other distances.

ii. When ambient lighting is a factor, such as during daytime measurements or any time stray light sources enter the background, a second luminance measurement must be made. This measurement must be taken with the arrow panel off. This "off" measurement is then subtracted from the "on" measurement, and the resultant luminance is used to derive the intensity in Equation 1 of Tech Note Figure 4.

iii. With the meter attached to a tripod for stability and located at the sight distance to be tested and at an angle that is either on axis or off axis conforming to the driver's line of sight, measure the luminance of the arrow panel with the lamps on and again with the lamps off. When taking the "on" measurement, set the meter to measure the peak reading. This setting overcomes the flashing nature of the arrow panel. Although it is preferable to position the arrow panel so that there are no extraneous light sources within the aperture, if there must be extraneous light sources, make certain they stay in the aperture for both "on" and "off" measurements. If the measurements are made in daylight, the "off" measurements must be made close in time to the "on" measurement so that the ambient lighting conditions do not change. This timing is easiest on a cloudy overcast day.

iv. Either estimate the lamp intensity using the calculation procedure described (see Tech Note Figure 4) or check the measurement against the following standards: The minimum luminance needed to provide the minimum 30 cd per lamp for arrow recognition on high-speed roads at night is 38 cd/m^2 at 185 m (600 ft) and 6 cd/m^2 at 460 m (1,500 ft). For low-speed roads, the minimum luminance to provide 18 cd per lamp is 90 cd/m^2 at 90 m (300 ft) and 9 cd/m^2 at 300 m (1,000 ft). Similar values for chevron displays are 56 and 9 cd/m^2 for high-speed roads and 135 and 14 cd/m^2 for low-speed roads.

To calculate the total intensity of an object from the luminance measured for objects much smaller than the aperture of the luminance meter, the following equation for luminance can be used:

$$I = L * A \quad (1)$$

where: I = total intensity (cd)
L = measured luminance (cd/m^2)
A = area encompassed by the aperture at the measurement distance (m^2)

The area encompassed by the aperture is found using the following equation:

$$A = [\tan(APsize) * D]^2 * \pi \quad (2)$$

where: APsize = aperture size (radians)
D = distance between target and luminance meter (m)

Note: If the target is larger than the aperture, then the area (A) is no longer the area enclosed by the aperture, but becomes the area of the target.

Tech Note Figure 4. Calculations.

In the case of an arrow panel, the total intensity is the summed contribution of several lamps. To derive the intensity of an individual lamp, the total intensity of the arrow panel is divided by the number of lamps used to create the stimulus. This calculation assumes that each lamp contributes an equal portion of intensity, which is false. There is variation in the amount of light coming from each lamp. This variation results from the fact that some lamps are more off axis than others are and that lamps may be slightly different colors. An explanation of the theory and testing of this procedure can be found in a paper by Finkle (*70*).

33. If other methods of speed reduction are not available, a properly trained flagger standing adjacent to a speed limit sign can reduce average speeds at freeway work zones by 8–16 km/h (5–10 mph). For speed reduction purposes, the flagger should get the attention of the approaching motorists using the "alert and slow" signal such as the one recommended in the Texas MUTCD. The flagger then points to a nearby speed sign and motions drivers to slow down to the posted speed. In a similar fashion, a flagger can encourage motorists to read and respond to work zone warning signs such as lane closure and shoulder use signing (*47*). Of course, if flaggers must be used, the guidelines presented in this section are essential to provide proper protection of the flagger.

34. In a study of 13 different work zone flagger signals, all of the less understood signals were shown to involve the use of the red flag (*71*).

35. The flashing stop-slow paddle looks like a standard flagger paddle that has been modified with the addition of flagger-activated light(s) mounted on the paddle face. The lights, which can be seen at distances up to 640 m (2,100 ft), flash alternately until automatically or manually deactivated. The fact that the light activation is under the control of the flagger permits the flagger to choose when to attempt to slow oncoming traffic. The safety benefits of the device are smoother slowing and a reduction in

the likelihood of rear-end accidents due to sudden slowing. The device can also reduce the likelihood of a high-speed vehicle encroaching into the work space. Also, it is a powerful warning device, and if a motorist seems to be ignoring the flagger's instruction, the flagger can press a button to activate the battery-powered flashing lights, which are bright enough to get the attention of daydreaming drivers. This feature can be particularly useful in limited sight distance situations to get the driver's attention immediately when he or she comes into view (*51*).

36. As an alternative to the normal stop-slow paddle, the Texas Transportation Institute recently evaluated a reusable, temporary stop bar and a freestanding, oversized stop-slow sign paddle at lane closures on two-lane, two-way highways where flaggers were used to alternate one-way traffic. Operational data on distances from the flagger at which vehicles stopped, speeds through the work zone, and approach speeds were analyzed. The data showed that the temporary stop bar and oversized paddle were useful in helping drivers decide when and where to stop in front of the flagger. However, the stop bar and sign paddle had no significant effect on reducing approach speeds or speeds through the work zone. The flaggers who actually used the supplemental devices commented that the oversized stop-slow paddle helped drivers respond to their commands better and that the temporary stop bar helped identify a point at which drivers were to stop (*72*).
37. Minnesota DOT has conducted an evaluation of fluorescent yellow garments with horizontal and vertical orange retroreflective stripes. The garments included pants in addition to vests, shirts, and jackets. The two-piece garments were judged to emphasize the human element within a work zone and provide greater visibility at a distance, particularly during nighttime construction. Although the evaluations were informal, the opinions of both workers and the driving public were obtained. Further, the use of fluorescent yellow (with orange stripes) is expected to differentiate the workers from orange vehicles, signs, and so forth, and the addition of pants to the outfits, which provides additional "movement" cues to drivers, can logically be expected to increase detectability and identification of workers (*30*). The Pennsylvania DOT reports a potential problem with the visibility of strong yellow-green (SYG) vests in daylight. The California DOT recommends all-white overalls along with a retroreflective vest for all road workers.
38. Portable traffic signal systems are now being marketed by several manufacturers. These systems have the potential for replacing flaggers in many work zones that require alternating one-way traffic control. However, because these systems are relatively new, information is needed about their effect on traffic operations and safety at work zone locations. The Texas Transportation Institute, in cooperation with TXDOT, recently conducted studies of a fixed-time portable signal system at three work zone lane closures on two-lane, two-way highways. At each site, data were collected on traffic volumes, driver noncompliance with the signals, and vehicle-stopped delay. The data showed that a substantial savings in flagger labor costs could be achieved by using a portable fixed-time signal system with only a minimal increase in motorist delay costs. Conservative estimates of the savings at the study sites ranged from $9 to $14 per hour. The studies also suggested that the potential for vehicle accidents within the work zone may be higher with portable traffic signals because of occasional driver noncompliance with these signals. The tradeoff between this possible increase in vehicular accidents and the reduction in flagger accidents could not be estimated from this research. The portable signals appear to be sufficiently promising that testing on additional sites and night testing is merited (*73*).
39. Portable fixed-time signals for one-lane, two-way operations were evaluated on only three sites and only during daylight operation. Additional evaluations should be done on a wider range of site characteristics. Also, compliance with the signals should be evaluated under night conditions. Under daylight conditions, fixed-time portable signals were found to be a reasonable alternative to flaggers at work zones requiring alternating one-way traffic through a work zone. The study suggests that significant savings in flagger labor costs can be realized with what appears to be a minimum of additional delay costs to motorists (*73*).
40. A new methodology that yields an optimal timing policy for the pair of traffic signals has been developed; this development was necessary because the control of the one-lane, two-way situation is quite different from that of an ordinary intersection. The information required to derive the timing is available in nomogram form. Strategies to determine the optimal length of the closure section, where there is a tradeoff between the cost of traffic delay and the setup cost, are also available (*74*).
41. On high-speed, high-volume, four-lane roads, supplemental warning signs indicating a lane closure ahead, located at 5, 4, 3, and 2 mi ahead, result in smoother flow of traffic through lane closures. When one-way hourly volumes on such roadways exceed 1,000 (i.e., when ADT exceeds 20,000), adding a CMS to the supplemental signs also provides smoother flow. If the combination of devices described above do not reduce late merges and there is excessive congestion, application of rumble strips to the pavement has been found to enhance flow during daylight (*75*).
42. The NYSDOT has reported positive experience with arrestor nets in terms of preventing intrusions with little harm to vehicle occupants. This agency has developed guidelines for the design and application of arrestor nets both for permanent and for work zone applications (*34, 76*).
43. Discussions of the various types of intrusion alarm systems, along with the advantages and disadvantages of the various types of system, are provided in the references shown below. One reference cited generally describes the results of 39 field and maintenance yard evaluations of various systems, along with the results of a survey conducted by NYSDOT. A second reference describes the various types of intrusion alarm systems available, along with some of the advantages and disadvantages of the various designs (*77, 78*).
44. Reflection is the process by which light rays strike a material and bounce back in a different direction. The three most basic types of reflection are diffuse, specular (mirror), and retroreflection. Diffuse reflection occurs when light is scattered relatively equally in all directions. Flat paints and other materials with matte finishes reflect light at all angles and exhibit very little directional control. Surfaces that are microscopically rough and light in color reflect more light. Because light is scattered in so many directions, visibility in any one direction is reduced. Specular reflection occurs when light strikes a surface that is microscopically smooth and reflects at an angle that is equal, but opposite, to the angle of the incoming light. Light is returned

directly to the source only when it is exactly perpendicular to the surface. Retroreflective materials return light directly to the source, whatever the direction of incoming light. Because most of the light is returned in one direction only, retroreflective materials appear much brighter, but only to an observer located near the light source.

45. Minnesota DOT has conducted an informal evaluation of various types of clothing. Although the evaluations were informal, the opinions of both workers and the driving public were obtained. The study suggested that the use of fluorescent yellow (with orange stripes) can be expected to differentiate the workers from orange vehicles, signs, and so forth and that the addition of pants to the outfits, which provide additional "movement" cues to drivers, can logically be expected to increase detectability and identification of workers (*30*).
46. A study was conducted to determine the most conspicuous color of safety clothing for daytime use in work zones. Eleven colors of safety vests were evaluated, including eight fluorescent colors (green, yellow-green, yellow, yellow-orange, red-orange, a combination of red-orange with yellow green, red mesh over a white background, and pink). Nonfluorescent yellow and orange and semifluorescent yellow completed the test color set. The procedure involved a vehicle equipped with a binocular tachistoscopic device mounted on the passenger side. As the test vehicle approached a work zone, the passenger subject was given a 300-millisecond view of the work zone and simulated worker wearing a particular color safety vest every 30 m (100 ft). The dependent measure was detection distance (i.e., the distance from the target at which the subject correctly identified the existence of a safety vest and the approximate color).

    The tests were conducted on a closed facility and involved four types of work zones, which were signed and delineated in accordance with Part VI of the 1993 revision of the MUTCD. The following results were obtained: Fluorescent red-orange was found to have the highest mean detection distance and was significantly different from every other color except the red mesh, yellow-green, and the red-orange/yellow-green combination. Each of these colors was recommended for use in safety garments, with the exception of the red mesh, since the mesh material may not perform well if worn over darker clothing.

    Limitations of the study include a relatively small sample size and the absence of an older driver subsample. (However, as the authors point out, the statistics are stable because of the large number of observations by each subject.) The other deficiency noted is the fact that no work vehicles or other equipment was included on the sites, and so the colors viewed against various backgrounds (e.g., a yellow-green vest against a yellow truck background) may turn out to have different detection distance than those measured. From the standpoint of the current study, a primary limitation is the absence of results obtained under the various lighting conditions appropriate to night operations. Such data should be obtained to form a basis for recommendations for clothing under such conditions (*79*).
47. Illumination is defined as the density of the luminous flux incident on a surface. Lux (lx) is the international system unit for illumination. A lux is the illumination on a surface 1 m^2 in area on which there is a uniformly distributed flux of 1 lumen. A footcandle is the unit of illumination on a surface 1 ft^2 in area on which there is a uniformly distributed flux of 1 lumen. Lux may be converted to footcandles by multiplying lux by 0.0929. Footcandles may be converted to lux by multiplying footcandles by 10.76. Illumination, which describes light falling on an area, is to be distinguished from luminance, which describes light reflected off of a surface.
48. The levels of illuminance needed for different types of activities and tasks are shown in Tech Note Tables 3 and 4 as identified by Ellis et al. (*38*).
49. The IES provides the following general descriptions for four types of candle power distributions (*44*):
    - **Full cutoff**: A luminaire light distribution where no candela occur at or above an angle of 90 deg above nadir (horizontal). Additionally, the candela per 1,000 lamp lumens does not numerically exceed 100 (10 percent) at a vertical angle of 80 deg above nadir. This distribution applies to any lateral angle around the luminaire.
    - **Cutoff**: A luminaire light distribution where the candela per 1,000 lamp lumens does not numerically exceed 25 (2.5 percent) at or above an angle of 90 deg above nadir (horizontal), and 100 (10 percent) at or above a vertical angle 80 deg above nadir. This distribution applies to any lateral angle around the luminaire.
    - **Semicutoff**: A luminaire light distribution where the candela per 1,000 lamp lumens does not numerically exceed 50 (5 percent) at or above an angle of 90 deg above nadir (horizontal), and 200 (20 percent) at or above a vertical angle 80 deg above nadir. This distribution applies to any lateral angle around the luminaire.
    - **Noncutoff**: A luminaire light distribution where there are no candela limitations.

    Although cutoff luminaires have the advantage of reducing glare, they also require closer spacing to achieve overlapping light patterns.
50. The IES has established a standard format for presenting photometric data describing the geometric distribution of light from a luminaire. These data are presented in candela, a metric value that is independent of the distance and orientation of the luminaire to a surface. The intensity of light in candela may be converted to the illuminance criteria in lux by applying both the inverse square law and the cosine law. The inverse square law states that the illuminance, E, at a point on a surface varies directly with the luminous intensity, I, of the source and inversely with the square of the distance, d, between the source and the point. When the point on the surface is not normal to the direction of incident light, the cosine law states that the illuminance on any surface varies as the cosine of the angle of incidence. The angle of incidence, θ, is the angle between the normal and the direction of the incident light. The inverse square law and cosine law together combine as follows:

    $$E = I/d^2 (\cos \theta)$$

    The reader is referred to the IES Lighting Handbook and to manufacturers' data for help in making this conversion. Some lighting manufacturers have software available that can assist in determining the illumination that will result from any proposed lighting design (*40*).
51. Under a safety grant from FHWA, the Laborer's Health and Safety Fund of North America developed a number of safety devices and procedures to protect workers from work site hazards. Two versions of a Powerline Awareness Marker (PAM) were

TECH NOTE TABLE 3 Recommended minimum illuminance levels and categories for nighttime highway maintenance and construction

Level of Illuminance	Illuminance in Footcandles (lux)	Area of Illumination	Type of Activity	Example of Areas and Activities to be Illuminated
I	5(54)	general illumination throughout spaces	performance of visual task of large sizes; or medium contrast; or low desired accuracy; or for general safety requirements	a) Excavation b) Sweeping and cleanup c) Movement area in the workzone d) Movement between two
II	10 (108)	general illumination of tasks and around equipment	performance of visual task of medium sizes; or low to medium contrast; or medium desired accuracy; or for safety on and around equipment	a) Paving b) Milling c) Concrete work d) Around paver, miller and other construction equipment
III	20 (216)	illumination of task	performance of visual task of small sizes; or low contrast; or desired high accuracy and fine finish	a) Crack filling b) Pothole filling c) Signalization or similar work requiring extreme caution and attention

included in that effort. One consists of a square yellow plastic column 90 cm (35 in.) high with hazard warnings printed on the sides of the column. Its shape, color, and size distinguish it from traffic control devices typically encountered in highway work zones. The second device consists of a neon-green sleeve with printed hazard warnings. This sleeve fits over a standard 70-cm (30-in.) traffic cone. Small strobe lights are available for both devices for use at night and in other low-light conditions (*80*).

52. New York State requires a uniform pattern of readings spaced approximately every 3 m (10 ft) throughout a representative test area (*41*). The procedure recommended by the Illuminating Engineering Society of North America (IESNA) requires two transverse points per lane at a maximum of 5 m (16.5 ft) between longitudinal points (see IESNA's *Guide for Photometric Measurement of Roadway Lighting Designs*, LM-50-99, 1999).
53. A proposal was made in California to allow the use of strobe lights during the hours of darkness as an alternative to the backup alarm. This proposal was presented by the staff of the board responsible for adopting OSHA orders because of the significant number of requests it had received for variances. At a public hearing, this proposal was opposed by the Laborers and Operating Engineers Unions, the Associated General Contractors (AGC), and two traffic control trade associations. The rationale for defeating the proposal was that the proposed allowance would be unsafe because of other warning lights typically found in a highway work zone.
54. Many agencies have internal procedures in place for the review and approval of ongoing changes to TCPs. An Iowa DOT procedure (*81*) that also includes staff guidance for numerous other aspects of work zone traffic control operation provides an example of how one agency addresses changes.
55. If the TCP is designed so that the work activities are removed from the roadway by 3 m (10 ft) or more, a speed reduction may be unnecessary. Otherwise, a speed reduction may be necessary depending on specific engineering factors at the site. The procedure developed in NCHRP Project 3-41 indicates that speed limit reductions greater than 15 km/h (10 mph) are not recommended unless the design speed of a geometric element is more than 15 km/h (10 mph) greater than the normal speed. The research was based upon daytime conditions so that generalization to night work should be done with care (*46*).
56. Additional material related to the means of legally establishing speed limits, and material on maintenance of speed limit credibility, is given in the New York State document from which much of the information in the first several paragraphs were taken (*82*).
57. The recommendation for conspicuous active enforcement is based upon field data from projects requiring speed reduction from the regulatory 90 km/h (55 mph) to an advisory 70 km/h (45 mph). All speed control treatments were evaluated under ideal conditions, with Level of Service A on sites where speed enforcement was normally high. If lower levels of service or reduced enforcement activity had prevailed, results might have been different (*48*).
58. The effectiveness of a radar unit attached to a CMS was studied by Fontaine and Garber (*83*). If the radar detected a vehicle traveling above a preset speed threshold, the CMS displayed the message YOU ARE SPEEDING SLOW DOWN. It was found that speeders reduced their speeds by a significant amount from the beginning of the work zone to the middle and end of the work zone. No significant differences existed in the speed reductions between vehicle types. Analysis of variance also revealed that average speeds were reduced and fewer vehicles were speeding by any amount or by 8 km/h (5 mph) or more for all traffic in the middle of the work zone when a CMS was in

TECH NOTE TABLE 4 Recommended target illumination levels for typical highway tasks

Task	Description of Construction and Maintenance Tasks	Suggested Illumination		
		Category	footcandles	lux
1	Excavation - regular, lateral ditch, channel	I	5	54
2	Embankment, Fill and Compaction	I	5	54
3	Barrier Walls, Traffic Separators	II	10	108
4	Milling, Removal of Pavement	II	10	108
5	Resurfacing	II	10	108
6	Concrete Pavement	II	10	108
7	Subgrade Stabilization and Construction	I	5	54
8	Base Course Construction	II	10	108
9	Surface Treatment	II	10	108
10	Waterproofing and Sealing	II	10	108
11	Sidewalks	II	10	108
12	Sweeping and Cleaning	I	5	54
13	Guardrails, Fencing	II	10	108
14	Painting Stripes, Pavement Markers	II	10	108
15	Landscape, Grassing and Sodding	I	5	54
16	Highway Signs	II	10	108
17	Traffic Signals	III	20	216
18	Highway Lighting Systems	III	20	216
19	Bridge Decks	II	10	108
20	Drainage Structures, Culverts, Storm Sewers	II	10	108
21	Other Concrete Structures	II	10	108
22	Maintenance of Earthwork Embankment	I	5	54
23	Reworking Shoulders	I	5	54
24	Repair of Concrete Pavement	II	10	108
25	Crack Filling	III	20	216
26	Pot Hole Filling	II	10	108
27	Resetting Guardrail, Fencing	II	10	108

operation. A CMS with radar appears to be an effective alternative form of speed control. Similar results were obtained by Garber and Patel (*84*). In both studies, there was no night data collection. The description of the methodology does not permit an assessment as to the possibility of novelty effects.

59. The effectiveness of the speed-monitoring device was evaluated at a work zone on an interstate highway in South Dakota. The speed-monitoring display reduced mean speeds and excessive speeds on the approach to the work zone. Mean speeds were reduced by 6–8 km/h (4–5 mph), and the percentages of vehicle exceeding the advisory speed limit of 70 km/h (45 mph) were reduced by 20–40 percentage points. These speed reductions are greater than those reported for the use of radar alone. Note that all data for the study were obtained under daylight and clear, dry conditions. Also, the extent of the reductions may have been limited by the design of the sign assembly and its close proximity to other work zone traffic control devices on the approach to the work zone. As the authors suggest, the optimum design and location of the speed-monitoring displays should receive further study. Finally, the device should be tested on additional sites before any large-scale implementation (*85*).

60. A regulatory 72 km/h (45 mph) speed limit sign, augmented with two small strobe lights and two orange plates, was tested at a rural interstate construction zone. The results of the evaluation of the sign with strobe indicated that the average speed of cars was reduced by 3–11 km/h (1.9–7.1 mph) and that the average speed of trucks was reduced by 2–10 km/h (1.3–6.0 mph) when the strobe lights were flashing. In general, the speed reduction effects were more pronounced on the cars than on the trucks and at a location past the work space than before it. The speed reductions at the location past the work space were 2–3 times more than the speed reductions at the location before the work space. Cars reduced their speeds, on the average, by 3–8 km/h (1.9–4.9 mph) before and by 9–11 km/h (5.9–7.1 mph) after the work space. Similarly, the speed reduction for trucks was 2–5 km/h (1.3–2.9 mph) before and 5–10 km/h (3.3–6.0 mph) after the work space (*86*).
61. In addition to the safety issue, the lane width reduction was found to have a relatively minor effect. For example, in an evaluation conducted in Texas, it was found that a 3-m (9.5-ft) lane produced an average speed reduction of only 6–8 km/h (4–5 mph) (*47*).
62. At least two states, New York (*87*) and Wisconsin (*88*), have established procedures for including police services in construction projects, and the material in this section reflects some of those procedures. Administrative and legal considerations associated with police services are discussed in this section in a generic sense. However, these considerations vary extensively from state to state and may not be relevant everywhere. Procedures for obtaining police services must thus be based on the legal and administrative considerations applicable to the individual agency involved (*6*).

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation