Design of Construction Work Zones on High-Speed Highways
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Design of Construction Work Zones on High-Speed Highways

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Research sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board’s recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The authors acknowledge and appreciate the contributions of state DOT personnel who provided valuable input through responses to a survey. Additionally, the Pennsylvania DOT and Texas DOT provided a special contribution by enabling the research team to collect work zone speed data on active construction projects.
This report presents the findings of a research project to develop guidance for designing geometric features of construction work zones on high-speed highways. The report will be of particular interest to practitioners responsible for the design of construction work zones.

Work zones require drivers to increase their attention in order to discern situations requiring special care. These special situations include the temporary geometrics that occur on the high-speed facilities that carry much of the nation’s traffic. The consequences of errors made at high rates of speed are generally severe. U.S. DOT data show that most fatal work zone crashes for all vehicles and large trucks occurred on roads with speed limits of 55 mph or greater.

Both the American Association of State Highway and Transportation Officials (AASHTO), through its Strategic Highway Safety Plan, and the Federal Highway Administration (FHWA) consider improvement of work zone safety and mobility a high priority. More than 40,000 people are injured each year as a result of motor vehicle crashes in work zones. Recent data for work zone crashes show over 1,000 fatalities each year between 2002 and 2005.

The AASHTO Policy on Geometric Design of Highways and Streets (Green Book) provides design criteria for permanent highway and street facilities. It does not provide detailed guidance for design of high-speed highway construction work zones, for topics such as temporary geometrics (e.g., ramps, crossovers, diversions, and superelevation rates). Also, the Manual on Uniform Traffic Control Devices (MUTCD) includes a chapter on temporary traffic controls, but there is no direct link with the Green Book or guidance on many of the geometric decisions associated with work zones.

Some state DOTs have comprehensive work zone design guidance; however, no comparable national guideline has been published. Better information and design guidelines are needed to assist designers in making decisions about the safest and most effective work zone design and traffic control treatments.

Under NCHRP Project 3-69, “Design of Construction Work Zones on High-Speed Highways,” researchers at the Pennsylvania State University developed guidance for the design of geometric features, including horizontal and vertical alignment, cross-sectional features, and temporary concrete barrier placement. The research team also developed a work zone speed prediction model that estimates free-flow vehicle speeds through two types of construction work zones on four-lane freeways: single-lane closure and median crossovers.

The research team reviewed the literature and ongoing research related to work zone design and safety. A survey of state DOTs was also conducted. Survey responses and a review of state DOT websites provided substantial information on current DOT work zone design
policies and guidelines. The survey also identified priority topics associated with the design of construction work zones, and these priorities guided the research effort. Seventy-five percent of the states responding to the survey ranked improved guidance on traffic barriers and design as the “most important/critical” need. The roadside design and barrier placement guidance includes a discussion of the clear zone concept and its applicability to construction work zones, the identification of work zone hazards that may require treatment or shielding, and the use of benefit-cost analysis for roadside safety treatment decisions.

The subject of speed is inextricably connected to work zones. There is a widely held perception that speed is one of the most significant factors in road crashes. The work zone speed prediction model enables designers to develop a speed profile to detect inconsistencies in construction work zone designs.
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Supplemental Materials
This publication is intended for consideration by state departments of transportation (DOTs) in developing policies and procedures related to work zone safety and mobility. It is also intended for use by transportation agency and consultant personnel involved in the planning, design, and review of construction work zones on high-speed highways. This publication is not a standard.

No document alone can guide a user to the most appropriate design choice for every application. Experience and relevant knowledge are also necessary in rendering work zone design decisions. The guidance provided in many areas reflects consideration of engineering principles, research findings related to work zones and permanent roads, and agency work zone practice. For many design factors, there are no published research findings to indicate the safety or operational consequences of a particular choice. Furthermore, specific practice and criteria used by different agencies sometimes vary substantially. As such, the recommended design approach and values do not necessarily reflect a complete understanding of all work zone factors or a consensus of DOT policies. Therefore, agencies are encouraged to place substantial weight on processes and criteria that have been implemented in an operational environment and carefully evaluated.
CHAPTER 1

Introduction

1.1 Background

After decades of rapid highway system expansion, construction of additional capacity has diminished. Increasingly, capital program resources are being directed to the enhancement and preservation of existing facilities. However, growth in highway travel continues unabated. Exhibit 1-1 illustrates the recent asymmetric growth of travel and basic capacity in the United States.

Many segments of highway infrastructure constructed during the system expansion era are approaching or have exceeded their useful lives. As a result, construction activity on existing facilities is increasing at a time when the facilities are of increasing importance to economic efficiency and social activity. Transportation agencies are challenged with continuous management of highways, assuring their adequate performance in the near term and far into the future. To meet long-term expectations, highway infrastructure renewal and enhancement are needed. The construction work zones required to improve infrastructure are a source of potential disruption that often impede mobility and are widely perceived as locations of elevated crash risk. Management and design strategies can substantially reduce the negative consequences caused by construction work zones.

This publication is intended to directly guide work zone design decisions associated with construction on high-speed highways. High-speed highways are those with free-flow speeds of 80 km/h [50 mph] or more. The guidance was not developed for maintenance and utility work zones or for work zones on low- and intermediate-speed roads and streets.

Historically, plans for highway construction work zones have emphasized temporary traffic control (TTC), which is intended to facilitate travel through a construction work zone by the use of devices that inform, advise, and regulate motorists. Guidance for the development of TTC plans is provided by FHWA’s Manual on Uniform Traffic Control Devices (MUTCD), which is the national standard for traffic control. While the importance of TTC grows as traffic exposure and public expectations increase, there are additional aspects of construction work zones for which guidance is needed that are not covered by the MUTCD or other publications. In general, this guidance is related to the geometric characteristics and physical infrastructure of roadways within construction work zones on high-speed highways. Consequently, this publication is intended for use in conjunction with the MUTCD, not as a substitute.

This report will be the first of its type: guidance for designing the geometric features of construction work zones, with intended national application. However, other nationally disseminated publications address aspects of roadway and roadside design in work zones. A Policy on Geometric Design of Highways and Streets (Green Book) (1) and the Roadside Design Guide (2), both of which are published by American Association of State Highway and Transportation Officials (AASHTO), also provide limited guidance on the design of work zones. The information in this report is intended to enhance that found in the Green Book. Most of the information in Chapter 9 of the 2002 Roadside Design Guide—“Traffic Barriers, Traffic Control Devices and Other Safety Features for Work Zones”—relates to the installation details and structural characteristics of particular barrier systems. However, limited roadside design and barrier placement guidance are also provided (Section 9.1). The information provided in Chapters 4 and 5 of this report is intended as an enhancement of the information in Chapter 9 of the Roadside Design Guide. Exhibit 1-2 identifies the intended general relationship between this report and the other publications.

This report provides an approach for the selection of an appropriate construction work zone type. Guidance for the design of geometric features, including horizontal and vertical alignment, cross-sectional features, and barrier placement is included. Guidance for a variety of ancillary features (e.g., drainage systems, lighting, and surface type) is also provided.
### Exhibit 1-1. Changes in U.S. travel and capacity.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Year</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1980</td>
<td>2000</td>
</tr>
<tr>
<td>Million Vehicle-Kilometers Traveled</td>
<td>2,458,945</td>
<td>4,427,183</td>
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<tr>
<td>Lane-Km</td>
<td>12,754,700</td>
<td>13,239,663</td>
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<tr>
<td>Million Vehicle-Miles Traveled</td>
<td>1,527,295</td>
<td>2,749,803</td>
</tr>
<tr>
<td>U.S. Customary Lane-Miles</td>
<td>7,922,174</td>
<td>8,223,393</td>
</tr>
</tbody>
</table>


### 1.2 Terminology

Construction and work zone terms are not used consistently across agencies and disciplines (planning, design, enforcement, construction, etc.). To facilitate communication, terms used in this publication are defined here.

- **50th-percentile speed**: the median speed of the observed traffic at a particular point or segment.
- **85th-percentile speed**: the speed at or below which 85 percent of all observed traffic is traveling at a particular point or segment.
- **Advisory speed**: the speed displayed on an advisory speed plaque and determined on the basis of an engineering analysis.
- **Alternating one-way operation**: a construction work zone mitigation strategy used on two-way roadways wherein opposing directions of travel take turns using a single travel lane. Flaggers, with or without pilot vehicles; STOP signs; or signals are normally used to coordinate the two directions of traffic. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as one-lane, two-way operation.

### Annual average daily traffic (AADT): the total volume of traffic passing a point or segment of a highway in both directions for 1 year divided by the number of days in the year.

### Anticipated free-flow speed: the speed at which vehicles are expected to travel when roadway conditions (e.g., geometry and traffic control devices), and not other vehicles, control speed.

### Average daily traffic (ADT): the total volume of traffic passing a point or segment of a highway in both directions for a period of time (in whole days), greater than 1 day and less than 1 year, divided by the number of days.

### Construction work zone: an area occupied for three or more days for the purpose of constructing, reconstructing, rehabilitating, or performing preventive maintenance. A construction work zone extends from the first TTC device to the last TTC device.

### Crossover: a construction work zone type for which adjacent traffic lanes that normally carry traffic in the same direction are converted to two-way traffic operation. Also see median crossover for a particular type of crossover.

### Design consistency: the provision of geometric features and design elements that meet driver expectancies.

### Design controls: factors outside the designer’s discretion that may affect the design process and designed solution. Examples include traffic volumes, vehicle size and weight, atmospheric conditions, driver, and other human characteristics.

### Design criteria: characteristics by which the sufficiency of a design feature may be assessed.

### Design features: geometric and dimensional characteristics of the roadway and roadside, including horizontal and vertical alignment and cross-sectional elements.

### Design hourly volume (DHV): a two-way hourly volume determined for use in design, representing traffic expected to use a highway.
Detour: a construction work zone mitigation strategy wherein traffic in one or both directions is rerouted onto an existing highway to avoid a construction work zone. Detoured vehicles may travel on permanent roads only or on a combination of permanent and temporary roads. This strategy compensates for the removal of permanent travel lanes from service.

Direction design hourly volume (DDHV): an hourly volume determined for use in design, representing traffic expected to use one direction of travel on a highway.

Diversion: a construction work zone mitigation strategy wherein traffic in one or both directions on a designated route is carried by a temporary roadway around a work area and reconnected with the permanent infrastructure of the designated route. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as a shoofly or runaround.

Emergency turnouts: segments of wider-than-typical shoulder. May be provided as disabled vehicle refuge at regular intervals or where conditions permit on roadways (perhaps temporary) where it is not practical to provide a continuous full-width shoulder. May also be referred to as intermittent shoulders.

Entrance/exit ramp configurations: geometric attributes of expressway ramps within a construction work zone.

Freeway: an expressway with full access control and no at grade intersections.

Full road closure: a construction work zone mitigation strategy wherein traffic operations are removed or suspended in either one or two directions on a segment of roadway or ramp.

Half-width construction: a construction strategy wherein half of a symmetrical (or nearly so) roadway is reconstructed (or refurbished) as a phase without encroachment on the other half. For divided highways, a one-way roadway is reconstructed as a phase.

High-speed highway: a road or highway on which traffic operates with an 85th-percentile free-flow speed of 80 km/h [50 mph] or greater.

Intermittent closure: a construction work zone mitigation strategy wherein all traffic in one or both directions is stopped for a relatively short period to allow for construction operations.

Lane closure: a construction work zone mitigation strategy wherein one or more travel lanes and any adjacent shoulders are closed to traffic. As defined here, this term is not limited to closing one lane of a multilane highway. Lane closures are inherent to median crossovers.

Lane constriction: a construction work zone mitigation strategy wherein the width of one or more travel lanes is reduced. The number of travel lanes may be retained (possibly through median or shoulder use) or reduced.

Lane construction: a construction work zone mitigation strategy wherein a travel lane is reconstructed (or refurbished) without encroaching into other travel lanes.

Median crossover: a construction work zone mitigation strategy used on expressways (including freeways) to establish two-way traffic on a normally divided facility. In this strategy:

- The number of lanes in both directions is reduced;
- At both ends, traffic in one direction is routed across the median to the opposite-direction roadway on a temporary roadway constructed for that purpose; and
- Two-way traffic is maintained on one roadway while the opposite direction roadway is closed.

This strategy involves the inherent use of median crossovers, and this strategy may be employed in combination with use of shoulder.

One-lane, two-way operation: see alternating one-way operation.

Operating speed: the 85th-percentile of the distribution of vehicle speeds observed operating under free-flow conditions.

Part-width construction: a construction strategy wherein roadway elements (travel lane, shoulder, etc.) are reconstructed while traffic is maintained on adjacent elements.

Percent trucks (%T): of the average daily traffic at a particular point or segment, the percentage that is trucks.

Portable concrete safety-shape barrier: see temporary concrete barrier.

Posted speed: see regulatory speed.

Regulatory speed: the legally established and designated speed limit. With further modification, the term includes (1) the regulatory speed of a roadway as a driver approaches a work zone, (2) the regulatory speed for a road prior to its inclusion in a work zone, and (3) the regulatory speed within a work zone.

Runaround: see diversion.

Shoofly: see diversion.

Shoulder closure: a construction work zone mitigation strategy wherein a shoulder is closed to traffic.

Temporary concrete barrier (TCB): a temporary concrete longitudinal traffic barrier. Same as portable concrete safety-shape barrier.

Temporary roadway: a roadway constructed to carry highway traffic exclusively during construction. Temporary roadways are used in conjunction with diversion and median crossover work zone strategies and may be used with a detour work zone mitigation strategy.

Temporary traffic control (TTC): a construction work zone mitigation strategy wherein devices and measures are used to facilitate road users through work zones.

Transportation management plan (TMP): a strategy to manage the work zone impacts of a project. Each TMP will include a TTC plan. For some projects, the TMP will also include...
additional elements addressing transportation operations and public information.

Two-way traffic on a normally divided facility (TWTNDF): a construction work zone type in which traffic in one direction of a normally divided facility is transferred to two-way operation on one roadway. A median crossover is the infrastructure used to implement this work zone type. The terms are sometimes used interchangeably. Use of shoulder may also be used to support this work zone type.

Use of shoulder: a construction work zone mitigation strategy involving the use of a right-side or median shoulder as all or part of a temporary traffic lane. This strategy compensates for the removal of permanent travel lanes from service. Employing this strategy may require constructing or upgrading shoulder pavement structures to adequately support traffic loads.

Work zone design speed: a selected speed used to determine specific work zone geometric design features.
The design of construction work zones involves many of the same factors that pertain to permanent roads, and much of the knowledge used for highway design is also relevant to design of construction work zones on high-speed highways. Yet there are substantive differences between permanent roads and roads in construction work zones that should be reflected in the respective design processes.

Separate design guidance for permanent roads and roadways in construction work zones is appropriate for two major reasons. First, construction work zones have short service lives. Exposure is directly related to service life and is a key consideration in any design decision involving safety. Service life also affects the cost-effectiveness of investments (i.e., costs related to infrastructure and impacts). Second, the design of work zones is far more restricted than the design of permanent roads. The feasibility of work zone alignment and cross-sectional alternatives is often limited by the necessity to tie in existing facilities and to avoid costs and impacts associated with short-term arrangements.

This chapter covers subjects that serve as background to the development of design guidance and to individual design decisions. The chapter is organized in a manner somewhat similar to guidance provided for permanent roads and reflects many of the same considerations and conventions involved in designing permanent roadways.

2.1 Design Controls

Design controls are factors that lie outside the designer’s discretion but may affect the design process and the designed solution. Factors can be grouped as outlined below.

2.1.1 Human

Vehicle operators and pedestrians have an expected range of capability and performance with respect to visual acuity, cognition, attentiveness, dexterity, and coordination. Nearly all human and driver characteristics have safety overtones when they affect performance within an operating environment that includes high-mass, high-speed vehicles. The number of licensed drivers in the United States is approaching 200 million, and individual drivers will react to the same conditions differently. Accommodating such a large and diverse set of performance levels and expectations is a major consideration in developing nearly all design criteria.

2.1.2 Material

The engineering and physical properties (e.g., friction, resistance to deformation, and retroreflectivity) of roadway components and appurtenances affect some design criteria.

2.1.3 Vehicles

Vehicle characteristics and performance capabilities affect design criteria. Vehicle factors that directly or indirectly influence design criteria include dimensions, height of operator’s seat, weight-to-power ratio, acceleration and deceleration (i.e., braking) capability, body roll angles, and cornering and turning stability. In construction work zones, geometry is often constrained. Several key decisions (e.g., minimum lane width and maximum grades) are strongly influenced by traffic volume and composition (i.e., type of vehicles).

2.1.4 Setting

Highways are woven into communities and natural settings. The characteristics of a project location are referred to as the setting, and they affect design criteria and specific design choices. Examples of setting include area type (e.g., rural or urban), terrain, density and type of adjacent land use, natural and human-made environmental features, and community characteristics.
2.1.5 Traffic

The magnitude and intensity of vehicle usage imposed on a specific facility are generally beyond the control of the design process. These factors (measured by ADT, DHV, and %T) have a substantial influence on design criteria and design choices. Transportation management plans for some projects include activities that will reduce the construction work zone traffic demand and may exclude specific vehicle categories from the traffic stream.

2.1.6 Facility Type

Construction work zones are designed and exist within the context of one or more existing transportation facilities. Traffic routinely using the facilities and traffic approaching the work zone may have expectations based on previous experience with a facility type. These expectations might involve the number and width of lanes, the shoulder width and type, appropriate speeds, the location of decision points, and access arrangements.

2.1.7 Scope of Construction

There may be some latitude in scope (e.g., pavement overlay and reconstruction), but a project’s basic purpose generally lies beyond the designer’s discretion and has substantial influence on the time and space required for construction. The time and space requirements, in turn, affect work zone design.

2.2 Design Principles

Through research and practice, a set of principles have been developed to guide design decisions. The principles address various aspects of the complex and interdependent vehicle-highway-human system. As an evolving body of knowledge, design principles have been used to develop explicit and narrowly tailored criteria (e.g., travel lane width) and as holistic guidance (e.g., combination of alignment elements) for permanent roads.

Principles exist in a context of objectives and constraints. Although difficult to quantify, all roads, individually and collectively, involve benefits and costs. Highways are constructed and maintained because they provide social benefits that exceed their cost. The principal objectives and direct benefits of highways are mobility and land access. Different highways, roads, and streets provide these functions in different proportions. The differences in emphasis are the basis for the functional classification system. Mobility is critical to an advanced and efficient economy, and it addresses a fundamental human and social desire. By creating access, land can be used for agricultural, commercial, industrial, recreational, and residential purposes. Both the mobility and land access functions are essential to community and personal vitality. Temporary reductions in these basic highway functions are sometimes required in conjunction with construction and reconstruction. A design objective specifically related to work zones is to minimize any reduction in the mobility and access functions.

Highways and mobility are not cost free. In addition to public expenditures for planning, designing, constructing, and reconstructing facilities, there are nonfinancial costs associated with the construction and operation of highways. Direct and indirect impacts are imposed on the natural (i.e., air, land, and water) and human environment. Some of these impacts are incurred at the time and location of construction, while other impacts develop over time and reach far beyond the immediate highway location. These negative consequences, some of which are also attached to construction work zones, are regarded as social costs. Some costs can be reasonably quantified, but others have to be considered on a qualitative basis. Through careful consideration of design alternatives and their respective probable impacts, designers and decision makers attempt to minimize negative impacts during the design development process.

The feasible range of design alternatives is often constrained by cost and setting (e.g., right-of-way and environmental features), including factors identified as controls. Designs for highways in construction work zones are often more restricted than designs for permanent roadways, since work zones must also accommodate construction operations and be closely aligned with the permanent road. The principles used to develop design criteria and to make choices at the project level are discussed below.

2.2.1 Safety

All movement and travel involves some level of risk. Regrettably, property damage, injuries, and death occur in conjunction with highway travel. Negative safety consequences are social costs. A primary objective of design policies and processes, including those used for construction work zones, is to minimize the frequency and severity of crashes. To effectively address safety in construction work zones, design guidance should reflect the growing body of highway safety knowledge. Increasingly, highway safety is treated as an objective and quantitative subject that requires the use of explicit terminology and measures.

However, the term “safe” is subjective and qualitative; in the context of highway travel, it does not have a specific meaning. If a safe highway is one that will never be the site of a crash, then safe highways exist only as conceptual abstractions. In fact, the discrete terms “safe” and “unsafe” are not meaningful in characterizing the likelihood or results of crashes.

Highway safety is a relative characteristic that is best described using quantitative measures. Crashes can occur on
any highway open to traffic; however, the probability of crash occurrence varies. “Substantive safety” is defined as “the expected crash frequency and severity” (3). Substantive safety is distinguished from “nominal safety,” which is “examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures” (3). Highways with low expected crash frequencies and severity (i.e., with a high level of substantive safety) are a desirable outcome of the design process. The objective of design is to provide maximum benefits at minimum cost on an aggregate basis. Therefore, substantive safety is a principal, but not sole, consideration in developing design guidance for permanent roads and roads in construction work zones.

Substantive safety is a function of exposure. Exposure is the degree to which a highway element is subject to potential crash occurrence and is often measured via traffic volume. Since permanent roads exist for an indefinite period of time, analysis can be performed using a recurring increment of time for all relevant factors (e.g., number of crashes, traffic, and infrastructure costs). ADT is a suitable indicator of exposure for permanent roads, since the estimated rate will be fairly constant for a long period of time, probably indefinitely. Its use is conducive to the development of benefit-cost analysis on an annualized basis. However, work zones exist for a finite period of time, and it is appropriate to think of exposure in different terms. A specific condition may exist for a period ranging from hours to years, but not indefinitely. For construction work zones, exposure can be characterized by accounting for both rate (e.g., ADT) and duration. Conditions that may not be acceptable indefinitely (i.e., as part of a permanent roadway) may be acceptable for a low level of exposure (i.e., for a short duration and low traffic volume). Exposure is explicitly considered in quantitative safety analysis and should also be factored into the development of design policy and individual design decisions.

This design guidance is based on the pursuit of substantive safety, along with other considerations previously discussed. However, it should not be interpreted as outlining the boundaries for “safe” construction work zones. Designs that do not conform to this guidance should not be regarded as unsafe. That term has no practical meaning. Further, no general guidance can provide explicit direction for each and every design decision.

2.2.2 Design Consistency

Drivers continually interpret and respond to the roadway environment. Repeated exposure to, as well as successful experience with, certain roadway configurations creates driver expectancies. These expectancies instill an inclination by drivers to respond to common situations in predictable ways that have been successful in the past. Design consistency calls for the production of designs that reinforce (rather than violate) prevailing expectancies. Design consistency is the use of design elements that meet driver expectancies and that avoid unexpected geometric conditions and features. Work zone designs should conform to the reasonable expectations of drivers based on their previous experience. Information sources, including the roadway and associated traffic control devices, should provide positive guidance and be presented consistent with the principle of primacy. Design consistency is also related to speed management.

2.2.3 Primacy

Primacy refers to how drivers prioritize information they receive from various sources (e.g., traffic control devices, geometry, traffic, and terrain). Construction work zones often present drivers with higher information loads than permanent roads. Under the principle of primacy, safety-critical and other important information should be clearly, conspicuously, and prominently presented to drivers.

2.2.4 Speed Management

There is a widely held perception that speed is one of the most significant factors in road crashes. This perception is especially strong with regard to work zones. Speed reduction measures are a prominent topic in work zone practice and published research. Perceived speed-safety linkages stem, in part, from the relationship between vehicle speed and operator capability. Crash severity is related to the change in speed upon impact. Crash severity increases with speed and substantially so for speeds exceeding 100 km/h [60 mph]. The relationship of vehicle speed to crash probability is less clear. For permanent roadways, there is evidence indicating that crash probability is related to speed deviation above and below the mean speed. Crash rates are lowest for vehicles traveling near the mean speed. The objective of speed management is to elicit appropriate speed selection by drivers.

Many factors can influence the speed at which a motorist drives, including driver age, gender, attitude, and perceived risks of law enforcement or crash. Therefore, different drivers will choose different speeds for the same conditions. Speed choice is also influenced by factors such as weather, road and vehicle characteristics, speed zoning, speed adaptation, and impairment (4). The speed management practices discussed below are intended to influence mean speeds and speed variance and are considered appropriate for application to work zones.

2.2.4.1 Establish Reasonable Target Speeds

Target speed is the desirable free-flow operating speed. No single value can represent all vehicle speeds, since different
drivers will choose to operate at different speeds under the same conditions. The 85th-percentile speed is commonly used to characterize operating speed at a location or segment. In this guidance, target speed is the desirable 85th-percentile free-flow speed within a construction work zone.

The general characteristics of certain highways and drivers’ previous experience with specific facilities create expectations, including those related to appropriate speed. Target speeds that meet or nearly meet experience-based expectations are desirable. The MUTCD suggests that TTC plans “be designed so that vehicles can reasonably safely travel through the TTC zone with a speed limit reduction of no more than 16 km/h [10 mph].” A speed prediction model developed during this project (NCHRP Project 3-69) may be used to estimate speeds for two common freeway work zone types: median crossovers and travel lane closure adjacent to active lane. Development of the model is summarized in NCHRP Web-Only Document 105, Section 4.2, which is available online at www.trb.org/news/blurb_detail.asp?id=7362. The model and user’s manual are provided online at the same URL.

For a variety of reasons, experience-based speed expectations are not always reasonable targets speeds. Operating speeds at particular locations must sometimes be reduced substantially below approach speeds. On high-speed facilities, this is undesirable yet unavoidable. Work zone design features are a potential cause of speed reduction and may preclude a target speed directly related to experience-based speed expectancies. This situation is addressed in the next section.

### 2.2.4.2 Employ Measures to Attain Significant Speed Reductions

The requirements for construction operations and other factors (e.g., right-of-way restrictions and existing features) may not allow a work zone design resulting in speeds comparable to those on the approaches or that prevailed on the same segment prior to establishing the work zone. Although the MUTCD suggests designing TTC plans that provide for reasonably safe travel with a speed limit reduction of no more than 16 km/h [10 mph], the potential need for greater speed reductions required by restrictive features is also recognized. In such a case, the work zone target speed is based on the restrictive features. A target speed selected in this manner may not be consistent with driver expectancy.

When a restrictive feature implies a speed limit reduction greater than 16 km/h [10 mph], driver notification should be provided through consistent, credible, and complementary information sources. Although static (i.e., advisory and regulatory) signage is a fundamental and important source of information, it should not be presumed as independently sufficient. The array of design, enforcement, legal, and technology strategies should be considered. Specific candidate speed management measures include automated enforcement (if applicable), dedicated enforcement patrols, drone radar, portable changeable message signs, rumble strips, speed trailers, warning devices, and variable speed limits. The selection of speed management measures should also consider the magnitude of speed reduction, exposure (i.e., traffic volume and duration of condition), and experience with comparable situations. Work zone speed management and control strategies are the subject of ongoing development and evaluation. Current information is available through a variety of websites, including the National Work Zone Safety Information Clearinghouse and sites hosted by organizations such as AASHTO and the FHWA.

#### 2.2.5 Work Zone Design Speed

The Green Book and many other design policies employ a design speed approach for the design of permanent roads. With this convention, criteria for some design elements (e.g., sight distance, minimum radii, maximum grade, some cross-sectional dimensions, and superelevation) are directly related to design speed, whereas criteria for other roadway design elements (e.g., some cross-sectional elements and vertical clearance) are not related to design speed. Many, but not all, state transportation agencies use a speed parameter to guide some work zone design decisions. Agencies may use a speed parameter primarily for selected features (e.g., horizontal curvature) and/or for selected work zones types (e.g., median crossover). This report employs the work zone design speed that is defined (in Chapter 1) as “a selected speed used to determine specific work zone geometric design features.” A value equal to or slightly greater than the target speed (discussed in Section 2.2.4) is appropriate. In this report, work zone design speed is applicable to radius of curvature and superelevation. When the work zone design speed is less than 60 km/h [40 mph], it is also used to determine appropriate sight distance. Work zone design speed may also be used in computing minimum length of sag vertical curves. Other speed parameters (e.g., speed limit and anticipated 85th-percentile speed) are also referenced in some design guidelines.

The establishment of a target speed and work zone design speed, design of TTC, and potential selection of speed management measures are related. Speed-related decisions within specific domains (i.e., design, regulatory, and speed management) should be consistent with an overall strategy. Exhibit 2-1 illustrates a process for work zone speed-related decisions.

#### 2.2.6 Sight Distance

Drivers acquire most of the information they use to control and navigate their vehicles visually. Therefore, facilitating...
Decision, Intersection, Passing, and Stopping.

Each of these sight distance types may be applicable to work zones, although providing for passing opportunities in work zones is not a priority.

Work zone designs that provide extensive visibility of their existence and features are desirable. Decision sight distance is defined as the distance needed by a driver to (a) detect an unexpected or difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered, (b) recognize the condition or its potential threat, (c) select an appropriate path, and (d) initiate and complete the maneuver safely and efficiently (5). Although extended sight distances throughout work zones are desirable, the underlying need for decision sight distance (because of an unexpected or difficult-to-perceive information source or condition) should be avoided in designing construction work zones. TTC and other driver information strategies should be used in conjunction with extended sight distance to mitigate work zone conditions that are atypical or involve complex driver decisions.

The Green Book provides an approach for determining the minimum sight distance value for permanent roads. Current sight distance criteria for work zones vary among DOTs; some agencies have stopping sight distance criteria and others do not. For DOTs that have work zone stopping sight distance criteria, the typical approach is to use the value associated with the permanent road design criteria and the work zone speed parameter. Typically, Green Book values are used.

Several research studies have investigated a possible relationship between available sight distance and crash rates on permanent roads. These studies were reviewed (6) as a group, and no discernable effect of limited sight distance on crash frequencies or rates was found. However, one of the studies (7) reported that crash frequencies on crest vertical curves with sight distances less than 90 m [300 ft] were more than 50 percent higher than those on crest vertical curves with very long sight distances. No studies investigating the effects of sight distance on work zone safety have been published.

In conclusion, extended sight distance approaching and within work zones is desirable from an operations perspective. Safety considerations also point to the need for some minimum sight distance. For work zone design speeds less than 60 km/h [40 mph], the stopping sight distance values tabulated in the Green Book and corresponding to work zone design speed are recommended. For work zone design speeds of 60 km/h [40 mph] and greater, the Green Book design-speed-corresponding values do not necessarily represent the minimums that can be accepted, and a minimum sight distance of 90 m [300 ft] is recommended using a driver eye height of 1,080 mm [3.5 ft] and an object height of 600 mm [2.0 ft].

### 2.2.7 Forgiving Roadside

Vehicles leave the traveled way for a variety of reasons. Regardless of the reason for the departure, a roadside environment free of fixed objects with stable, relatively flat slopes enhances the opportunity for reducing accident severity (2). Although a vehicle may depart from any roadway, the roadway itself can influence the probability of a departure; roadside characteristics affect the probable consequences of the departure. The forgiving roadside and risk exposure principles...
are the basis for traffic barrier placement and roadside design guidance. Specific guidance related to the forgiving roadside principle is provided in Chapter 5, “Roadside Design and Barrier Placement.”

### 2.2.8 Roadway Surface and Cross Section

Driving surface characteristics, especially roughness and friction, have an influence on motorist comfort and tire-road interaction. As discussed earlier in Section 2.2.1, traffic exposure should be considered in any assessment of how design decisions will affect safety. Several transportation agency work zone policies provide for the use of unpaved surfaces on temporary roadways in construction work zones. In most cases, the guidance establishes exposure as the principal consideration, referring to short durations, low volume, or a combination of duration and volume as factors under which unpaved traveled way surfaces may be used. Some agencies provide quantitative guidance, and others provide qualitative guidance.

Exhibit 2-2 is an adaptation of one agency’s guidance. It is objective, easy to apply, and considered reasonable, but it should not be rigidly applied. For example, these guidelines may not be appropriate for locations where heavy precipitation is routine.

No relevant research is available on the safety effects of unpaved traveled way surfaces in work zones. However, many design criteria for high-speed facilities are specifically related to paved driving surfaces. Additionally, unpaved driving surfaces are difficult to maintain. Therefore, some form of speed control may be appropriate when gravel or aggregate driving surfaces are employed. Prevailing environmental conditions and maintenance requirements should also be considered in selecting temporary traveled way surface types and their ongoing maintenance requirements should also be considered in selecting temporary traveled way surface types and their ongoing maintenance requirements.

Temporary roadway cross slopes should generally follow the guidance applicable to permanent roadways, including consideration of surface type, number of lanes, and environmental exposure factors (e.g., rainfall or ice). For paved traveled way surfaces, 1.5 to 2.5 percent is appropriate. For aggregate and treated surfaces, cross slopes should generally be in the range of 0.5 to 1.0 percent higher than percentages used for paved surfaces.

Temporary roadway shoulder widths vary by volume and type (i.e., crossover and diversion) and are often not paved. Shoulder cross slopes may be difficult to control because of width and material type. Generally, shoulder slopes should be greater than the slopes of the adjacent traveled way, particularly if the shoulder is unpaved. Shoulder slopes of up to 8 percent are appropriate.

For superelevated temporary roadways, the maximum rollover (i.e., the algebraic difference of roadway and high-side shoulder slope) should be limited to approximately 8 percent.

### 2.3 Alignment Principles

Although there are similarities in the design of permanent road alignments and alignments through work zones, there are also substantial differences. A key difference is that of service life, permanent versus temporary. Costs, impacts, and right-of-way acquisition are more difficult to justify when the corresponding usefulness is short lived. Roads designed in conjunction with construction work zones are typically more constrained by setting than permanent roads. Yet temporary roads must connect to existing roads and provide sufficient space for construction operations. Consequently, there is a strong and appropriate motivation to use and integrate permanent infrastructure elements (e.g., embankments, pavements, structures, and appurtenances) into construction work zone roadway alignments. Constructing and removing temporary infrastructure is warranted when doing so is necessary to provide the desired levels of access, mobility, and safety.

The degree to which a work zone roadway requires temporary infrastructure and imparts impacts is influenced by the horizontal and vertical alignment. The service a roadway provides is also influenced by its horizontal and vertical alignment. The design of construction work zones, including alignments, is an exercise of balancing cost, impacts, and service provided over a finite period of time.

The following information addresses horizontal and vertical alignment design of temporary roadways in construction work zones. Two general approaches to establishing a relationship between horizontal curvature and superelevation are presented, and guidance on the use of both approaches is provided.

#### 2.3.1 Curvature-Superelevation Relationship

Horizontally curved permanent roadways are routinely designed and analyzed using the following basic curve formula.

In metric units:

\[
0.01e + f = \frac{V^2}{127R} \tag{2-1a}
\]
Where
\[ e = \text{rate of superelevation, percent;} \]
\[ f = \text{side friction (demand factor);} \]
\[ V = \text{vehicle speed, km/h; and} \]
\[ R = \text{radius of curve, m.} \]

In U.S. customary units:

\[ 0.01e + f = \frac{V^2}{15R} \]  \hfill (2-1b)

Where
\[ e = \text{rate of superelevation, percent;} \]
\[ f = \text{side friction (demand factor);} \]
\[ V = \text{vehicle speed, mph; and} \]
\[ R = \text{radius of curve, ft.} \]

This approach treats a vehicle as a point mass. The simplifying assumptions and derivation of the formula are discussed in many texts and research publications and are omitted here.

2.3.2 Superelevation Distribution

For a specific radius and speed (actual or design), the value of the right side of Equation 2-1 can be calculated explicitly. The equation can be satisfied by an infinite number of \( e + f \) combinations on the left side. Both \( e \) and \( f \) have practical limits (i.e., maximum values) and the Green Book provides guidance on selecting limiting values. The individual limits of \( e \) and \( f \) impose a limit on the absolute magnitude of the left side of the equation. For speed-radius combinations that require less than a maximum \( e \) and \( f \), a method of distributing these values across their ranges is used. The Green Book identifies five distribution methods. Methods 2 and 5 are the most commonly used distributions. Exhibit 2-3 illustrates how \( e \) and \( f \) vary with curvature (expressed as the inverse of radius) for Methods 2 and 5. Information on other distribution methods can be obtained from the Green Book.

The Green Book, which is used primarily for the design of permanent roadways, recommends Method 5 for the distribution of \( e \) and \( f \) on rural highways, urban freeways, and high-speed urban streets. The Green Book recommends Method 2 for the design of horizontal curves on low-speed urban streets. Both methods are used for designing temporary roadways in construction work zones on high-speed highways. Typically, a state DOT uses one method or the other exclusively for work zone temporary roadway designs. Several points are worth noting:

- The Green Book–designated limiting friction values are related to driver comfort: “A key consideration in selecting the maximum side friction factors for use in design is the

Exhibit 2-3. Method 2 and 5 distributions.
level of centripetal or lateral acceleration that is sufficient to cause drivers to experience a feeling of discomfort and to react instinctively to avoid higher speed.”

- The selection of a distribution method (e.g., Method 2 or Method 5) has no effect on the maximum values of $e$ and $f$. Although the design rate of superelevation for a specific curve will be different depending on the selected distribution method, no method (if properly applied) will result in limiting values of $e$ or $f$ being exceeded.

- The use of any distribution method will yield the same maximum curvature (i.e., minimum radius) for a specific speed and limiting values of $e$ and $f$.

Maximum superelevation rates are typically selected as a matter of policy rather than for specific projects. Absent other considerations, the $e_{\text{max}}$ used for permanent roadways is appropriate for construction work zones.

Superelevating roadway curves necessitates superelevation transitions, which bring alignment and other (e.g., drainage) complications. For these reasons, it is common design practice to provide curves that are sufficiently flat to not require the introduction of superelevation. Since Method 2 relies more on friction (and less on superelevation) than Method 5, its use for establishing superelevation rates on work zone roadway curves has been adopted by some state DOTs. Guidance for designing horizontal curves using Method 2 and Method 5 distributions is provided.

The next two sections provide information and references for the use of Methods 2 and 5. More discussion and design guidance (Exhibit 2-4) are provided for Method 2 than for Method 5. This is not an indication that Method 2 is the preferred or superior approach. Additional information on Method 2 is provided because it is not widely used for designing permanent high-speed roads and many design guides do not include tabulated design values.

2.3.2.1 Design Superelevation Rates Based on Method 2 Distribution

Method 2 distribution is often used to avoid the need for superelevation. Exhibit 2-4 indicates the minimum radii that should be provided for a specified superelevation rate and work zone design speed based on Method 2 distribution.

Along with the values that result from Equation 2-1, there are several other guidelines that apply. Roadway cross slopes should be at least 1.5 percent. Consequently, no minimum radius values are shown for superelevation rates between $-1.5$ and 1.5 percent.

Negative superelevation is the condition where a driving surface is sloped away from the center of a horizontal curve. For example, a roadway curving to the left with a slope of 2 percent from left to right has a superelevation rate of $-2$ percent. The example below clarifies how Exhibit 2-4 is used, specifically regarding negative superelevation.

In metric units:

Given:
Temporary work zone roadway
Normal cross slope = 2 percent (left to right)
Work zone design speed = 90 km/h

Determine:
Minimum radius for normal cross slope

From Exhibit 2-4
Minimum radius ($e = -2.0$ percent) = $R = 580$ m

In U.S. customary units:

Given:
Temporary work zone roadway
Normal cross slope = 2 percent (left to right)
Work zone design speed = 55 mph

Determine:
Minimum radius for normal cross slope

From Exhibit 2-4
Minimum radius ($e = -2.0$ percent) = $R = 1,833$ ft

It is possible to have negative superelevation rates with magnitudes greater than 2.5 percent (i.e., values less than $-2.5$ percent). For this condition (e.g., $-3.5$ percent superelevation), Equation 2-1 should be used to determine the minimum radius corresponding to the superelevation and work zone design speed. The friction value ($f$) selected for use in the equation should be the “Maximum $f$” tabulated in Green Book Exhibit 3-15 and corresponding to the design speed.

2.3.2.2 Design Superelevation Rates Based on Method 5 Distribution

The Green Book, which is used primarily for designing permanent roads, recommends Method 5 distribution for rural highways, urban freeways, and high-speed urban streets. Many agencies also use Method 5 for construction work zone temporary roads. For Method 5, the use of $e_{\text{max}} = 4$ percent is recommended only in urban areas and with design speeds of 100 km/h [60 mph] and less. To apply Method 5, Green Book Exhibits 3-25 through 3-29 may be used to determine the minimum radius for a superelevation rate and work zone design speed.
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Exhibit 2-4. Minimum radii for superelevation rates and work zone design speed based on Method 2 superelevation distribution.
### U.S. Customary

#### Exhibit 2-4. (Continued)

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Exhibit 2-4. (Continued)
2.3.3 Other Horizontal Alignment Considerations

A variety of techniques are used by agencies to attain superelevation along an alignment for various types of permanent roads. The superelevation transition techniques used for high-speed permanent roads should be applied to roadways within construction work zones on high-speed highways.

In addition to cross slope and superelevation, sight distance is a consideration in designing horizontal alignments. Cross-sectional and other features common to construction projects (e.g., barriers, material stock piles, and equipment) may limit sight distance on the inside of horizontal curves. Refer to Section 2.2.6 for sight distance guidance.

2.3.4 Vertical Alignment Considerations

Generally, the same maximum grade criteria applicable to the highway under construction should be applied to work zone roads. However, marginally exceeding these criteria is often justified in consideration of all factors. Grades below the maximum are desirable. When designing work zone temporary roadways, the potential effect of grades on operations and capacity should be considered. When speeds are substantially reduced in advance of a temporary roadway (e.g., in conjunction with a reduction in the number of lanes), the work zone capacity may be controlled by heavy vehicles attempting to accelerate on grade. Capacity, in turn, influences queue formation.

The minimum length of vertical curves for permanent roads is typically established on the basis of sight distance considerations. Sight distance information and considerations relative to safety and operating speed are outlined in Section 2.2.6. When minimum sight distance design criteria are adopted for work zones, minimum vertical curve length criteria on that basis are appropriate. The most common basis for agency work zone sight distance design criteria is the Green Book stopping sight distance values. For this case, minimum crest and sag vertical curve lengths are determined from Green Book Exhibits 3-71 and 3-74, respectively.

Some agencies have adopted a policy of determining the minimum sag vertical curve length on the basis of comfort. For this case, minimum lengths are determined from a Green Book formula, which is adapted here as Equation 2-3.

In metric units:

\[ L = \frac{AV^2}{395} \]  

(2-3a)

Where

- \( L \) = length of sag vertical curve, m;
- \( A \) = algebraic difference in grades, percent; and
- \( V \) = work zone design speed, km/h.

In U.S. customary units:

\[ L = \frac{AV^2}{46.5} \]  

(2-3b)

Where

- \( L \) = length of sag vertical curve, ft;
- \( A \) = algebraic difference in grades, percent; and
- \( V \) = work zone design speed, mph.
Agency policies and procedures directly and indirectly impact work zone design. Directly, agency policies and guidance are sources of information that guide decisions. Indirectly, these same policies define the conditions that designers of subsequent projects will face. For example, suppose the design policy for a particular road indicates that a minimum of 22 feet of pavement is needed, so the designer provides 22 feet of pavement. Fifteen years later, the road has to be resurfaced. To maintain traffic, it would be nice if there were a 32-foot-wide road so that traffic could pass around the paving operation. Thus, the guidance on 22 feet of pavement essentially led to one decision and created the conditions encountered for the work zone designer.

Work zone design decisions should be integrated into project development. Alternative work zone types, along with their impacts, mitigation, and costs should be evaluated at the same time as, and in conjunction with, other design factors. The level of detail to which work zone issues are evaluated should be proportional to the potential work zone consequences. Some project categories (e.g., resurfacing and deck repair) pose a limited number of design alternatives and perhaps even fewer feasible work zone alternatives. However, substantial impacts can occur in connection with routine projects, and the impacts may extend far beyond the limits of the work zone. Impacts may take the form of traffic congestion, interruption of commercial and industrial activity, cost overruns, decreased constructability, adverse safety experience, disturbance of local travel patterns (including non-motorized modes), and citizen complaints.

### 3.1 Project-Level Work Zone Strategies

All projects require a strategy or set of strategies that will accommodate needed construction operations while maintaining acceptable transportation service. These strategies are outlined in transportation management plans (TMPs), which are prepared for specific projects. When potential impacts are substantial, a comprehensive, integrated and proactive work zone management and design effort is needed. Impacts may be mitigated through strategies such as traffic demand reduction measures, public involvement and information, provision of permanent facilities with wider cross sections to accommodate temporary traffic use during construction, innovative construction techniques, incident management, and advanced traveler information systems. In all cases, a strategy is needed to carry traffic through or around the facility under construction through a system of infrastructure and temporary traffic control (TTC). This section identifies common work zone strategies and factors that should be considered in the selection process.

The following strategies have been widely and successfully employed for construction work zones on high-speed highways:

- Alternating one-way operation,
- Detour,
- Diversion,
- Full road closure,
- Intermittent closure,
- Lane closure,
- Lane constriction,
- Median crossover, and
- Use of shoulder.

These strategies are not necessarily separate, individual choices. In fact, several of them do not provide a complete and workable solution. Use of a full road closure requires one or more additional strategies (e.g., detour or diversion). Some of the strategies are identified as mitigation strategies, meaning that they can be used to offset negative consequences (e.g., reduced capacity and access limitations) for one or more other strategies.

The basic characteristics of individual work zone design strategies result in general advantages and disadvantages, as summarized in Exhibit 3-1 and outlined in successive sections.
3.1.1 Alternating One-Way Operation

Alternating one-way operation: a construction work zone mitigation strategy used on two-way roadways wherein opposing directions of travel take turns using a single travel lane. Flaggers, with or without pilot vehicles; STOP signs; or signals are normally used to coordinate the two directions of traffic. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as one-lane, two-way operation.

There are several variations of this strategy related to the type of control employed (e.g., STOP sign, temporary signal control, or pilot car), as outlined in the MUTCD. Design and TTC provisions are also required to facilitate transition from high-speed approaches to stop conditions for the spectrum of operational conditions (e.g., day-night and weather). The agency cost and nontransportation impacts of this strategy are generally low.

This strategy has a significant impact on capacity. As the length of the one-way segment increases, capacity is reduced. Also, construction operations take place in close proximity to traffic operations. Application of this strategy is generally limited to low-volume, two-lane, two-way roads.

3.1.2 Detour

Detour: a construction work zone mitigation strategy wherein traffic in one or both directions is rerouted onto an existing highway to avoid a construction work zone. Detoured vehicles may travel on permanent roads only or on a combination of permanent and temporary roads. This strategy compensates for the removal of permanent travel lanes from service.

When traffic is directed from a facility under construction to an alternative traffic route, construction operations can be prosecuted with little restraint. This can improve construction efficiency (i.e., reduce cost) and quality. Agency costs to implement detours may involve only TTC or temporary infrastructure.

Generally, a detour is applicable to all approaching traffic, but some detours reroute a portion of the traffic from the affected facility and accommodate all other traffic through the work zone. Selective detours may apply to vehicles that carry certain
categories of cargo or exceed specified dimensions or gross vehicle weights. In these cases, special attention to TTC is needed.

Detouring traffic imposes additional capacity and load demands on an alternative route and may result in congestion and infrastructure deterioration on the detour (i.e., alternate route). Detours should be carefully evaluated to ensure that they are capable of accommodating the volume and types (configuration, size, and weight) of detoured vehicles. Mitigation may include temporary changes to traffic control (e.g., signal timing and signs) and remedial pavement and bridge work. When detours are being considered, the access normally provided to various land uses (e.g., residents and businesses) by the closed facility should also be considered. The added length of trips using the detour is a cost to motorists and should be evaluated.

Ownership or owner agreement is usually needed to use a facility as a detour. If the agency detouring traffic from a facility does not own the roadway onto which traffic is detoured, coordination with the other agency is needed. In some jurisdictions, interagency agreements are needed and may provide for improvements to the detour route in preparation for the detour or as redress for damage induced by the detour traffic.

### 3.1.3 Diversion

**Diversion:** a construction work zone mitigation strategy wherein traffic in one or both directions on a designated route is carried by a temporary roadway around a work area and reconnected with the permanent infrastructure of the designated route. This strategy compensates for the removal of permanent travel lanes from service and is sometimes referred to as a shoofly or runaround.

This strategy provides substantial separation of construction from traffic, although generally not as much as detours. Diversions are often used for bridge projects, including bridge replacements, but are also used for other types of work. When used in conjunction with bridge projects, a temporary bridge or culvert may also be needed.

Unless a detour is also established to carry a portion of the traffic, the diversion will accommodate the entire approach volume, including large and oversized vehicles. Selection of a work zone design speed, as outlined in Section 2.2.5, is recommended. The capacity of the diversion should generally be close to or equal to that of the approach roadway to avoid substantial delay, queue formation, or trip-length extension. The geometry of the diversion and associated TTC should consider traffic characteristics on the approach roadway. Construction of temporary roads can be costly. Major variables affecting cost include the length and design features (e.g., barriers, earthwork, hydraulic structures, and surface/pavement). The design and cost of these elements vary based on traffic volume and duration of use.

Diversions involve construction of new, temporary roads. Therefore, some of the institutional processes associated with road construction may apply to provision of a diversion. The need to acquire property interests (e.g., right-of-way or easements), impose impacts on protected resources (e.g., historic sites), or acquire permits generally affect project schedules and should be considered.

Detailed design guidance for this strategy is provided in Section 4.1.

### 3.1.4 Full Road Closure

**Full road closure:** a construction work zone mitigation strategy wherein traffic operations are removed or suspended in either one or two directions on a segment of roadway or ramp.

When roadway traffic is completely eliminated, construction efficiency and the resultant quality of permanent features (i.e., bridge and pavements) are maximized, while the time required for completion is minimized. Contract provisions (i.e., liquidated damages) should reflect the degree of disruption that this strategy involves.

The cost of the full road closure itself is very low; however, this work zone strategy does not provide for maintenance of traffic. Therefore, one or more supplemental strategies are needed, with detours being the most common. The supplemental strategies may have impacts, as outlined in this report, and should be considered. Full road closures have been used successfully on low-, medium- and high-volume facilities. When full road closures are used with high-volume facilities, alternative strategies (e.g., detours) usually cannot fully compensate for the capacity reduction. TMPs are needed, including an aggressive public information component.

### 3.1.5 Intermittent Closure

**Intermittent closure:** a construction work zone mitigation strategy wherein all traffic in one or both directions is stopped for a relatively short period to allow for construction operations.

This work zone strategy alone is generally not adequate for an entire construction project. It is often employed during specific operations (e.g., setting bridge beams, conducting blast detonation, and moving equipment) for which project personnel can select the beginning point and reasonably predict the duration. In nonemergency cases, intermittent closure should be used only if the duration of closure and period of traffic impact will be short (less than 20 minutes).

### 3.1.6 Lane Closure

**Lane closure:** a construction work zone mitigation strategy wherein one or more travel lanes and any adjacent shoulders are closed to traffic. As defined here, this term is not limited to closing one lane of a multilane highway. Lane closures are inherent to median crossovers.

Reducing existing capacity increases the probability of queue formation and delays. Depending on traffic density, the
ability of drivers to individually select their speeds is reduced or lost. Traffic impacts (e.g., speeds, queue formation, and delay) should be assessed, and lane-closure length, roadway grades, traffic volumes, and percent trucks should be considered. The agency cost to implement this work zone strategy varies depending on the supporting infrastructure employed. Many common TTC devices (e.g., drums, signs, and arrow panels) can be transported using medium-duty vehicles. When lane closures are used for invasive construction operations (e.g., pavement reconstruction), temporary concrete barriers are often used and can substantially increase the cost of implementation. When barriers are omitted, this work zone strategy can be installed and removed over short periods (i.e., hours). Because of its flexibility, this work zone strategy can be used on high-volume facilities during periods when traffic impacts are deemed acceptable (e.g., weekends, mid-day, and nighttime).

This work zone type is often used in conjunction with lane construction involving operations adjacent to an active traffic lane. This creates the possibility of conflict among construction equipment operations (e.g., compaction, demolition, deliveries, and material placements), workers, and roadway traffic. In addition to safety concerns, the proximity may interfere with construction quality objectives.

### 3.1.7 Lane Constriction

Lane constriction: a construction work zone mitigation strategy wherein the width of one or more travel lanes is reduced. The number of travel lanes may be retained (possibly through median or shoulder use) or reduced.

The use of this work zone strategy is often associated with traffic in close proximity to construction operations. This also creates the possibility of conflict among construction equipment operations, workers, and roadway traffic. In addition to raising safety concerns, the proximity may interfere with construction quality.

This work zone strategy is employed when maintaining traffic with less-than-desirable travel lane widths is preferable to other candidate alternatives. At some level of expenditure and impact, constricted lanes can almost always be avoided. The decision to use this strategy is made in consideration of the magnitude of the constriction (i.e., actual traveled way width), the service conditions (e.g., duration, length, and traffic), and the cost associated with avoiding the constriction. In making these decisions, agencies often draw on their considerable accumulated experience.

This work zone strategy can directly impact the ability of the facility to accommodate large vehicles. In some cases, agency coordination involving permits for oversized vehicles is needed.

Detailed design guidance for this strategy is provided in Section 4.2.

### 3.1.8 Median Crossover

Median crossover: a construction work zone mitigation strategy used on expressways (including freeways) to establish two-way traffic on a normally divided facility. In this strategy:

- The number of lanes in both directions is reduced;
- At both ends, traffic in one direction is routed across the median to the opposite-direction roadway on a temporary roadway constructed for that purpose; and
- Two-way traffic is maintained on one roadway while the opposite direction roadway is closed.

Substantial separation of construction from traffic is provided by this work zone strategy. Generally, this strategy allows construction of an entire one-way roadway (e.g., travel lanes, shoulders, structures, and appurtenances) with little conflict between roadway traffic and equipment, workers, or onsite material movement. The work is generally more expedient and results in higher construction quality than would be produced with a lane-construction approach. This work zone type is typically employed with full (i.e., pavements or bridges) or extensive reconstruction.

Median crossovers involve a reduction in the number of travel lanes and capacity. Depending on traffic density, the ability for drivers to individually select their speeds is lost or reduced. Traffic impacts (e.g., speeds, queue formation, and delay) should be assessed, and overall median crossover length, roadway grades, traffic volumes, and percent trucks should be considered. The overall median crossover length is defined by the distance between the temporary crossover roadways. Locating termini (and thus establishing the overall median crossover length) requires system and site considerations. Decisions to close or maintain existing access points (i.e., interchanges and intersections for expressways) may influence the crossover locations. Additionally, substantial grade differences between one-way roadways or within median topography can influence the feasibility and cost of a temporary crossover roadway. Even under favorable conditions, temporary crossover roadways are a significant cost consideration.

Detailed design guidance for this strategy is provided in Section 4.3.

### 3.1.9 Use of Shoulder

Use of shoulder: a construction work zone mitigation strategy involving the use of a right-side or median shoulder as all or part of a temporary traffic lane. This strategy compensates for the removal of permanent travel lanes from service. Employing this strategy may require constructing or upgrading shoulder pavement structures to adequately support traffic loads.

This strategy uses existing roadway width to compensate for the capacity lost by closing a permanent travel lane and is viable on many facility types (e.g., divided multilane, undi-
provided multilane, and two-lane). Many shoulders are narrower than the closed travel lane. Additionally, many shoulders do not have the same pavement structure as the adjacent travel lanes. Depending on the traffic service requirements (e.g., duration, traffic volumes and types, and speed), considerable work and expense may be required to provide a suitable surface or pavement structure. Full-width shoulders with the same pavement structure as the adjoining travel lane can generally be used as a travel lane at low agency cost. Some bridges have narrower shoulders than the approach roadways, which may determine or limit the feasibility of this strategy.

Invariably, when a shoulder is used to carry traffic, the roadside hazards on that side will be closer to traffic. The existence, proximity, and nature of roadside features (e.g., bridge piers) should be considered in assessing this strategy.

Detailed design guidance for this strategy is provided in Section 4.4.

### 3.2 Contracting Strategies and Considerations

Traditionally, highway construction was undertaken during daylight hours by contractors procured through the conventional contract model. Under the conventional contract model, the transportation agency prepares a set of contract documents (i.e., plans and specifications), which describe the responsibilities and duties of the parties. Bids are solicited, and a contract is awarded to the responsible bidder submitting the lowest responsive bid. Under the conventional approach, the contract documents include an agency-prepared work zone design. Most agencies allow the contractor to propose an alternative work zone design, which will be adopted if approved by the agency. The conventional contract model remains the dominant approach to contracting, but a number of contracting strategies are being employed to reduce the impacts of construction on traffic. These strategies include alternative procurement techniques and contract provisions requiring that construction be performed during off-peak traffic periods (including at night). This section addresses three contract issues that are closely related to work zones: (1) alternative contracting techniques (including A+B bidding, design-build contracting, incentive-disincentive provisions, and lane rental), (2) night construction, and (3) evaluation of work zone designs proposed by contractors.

### 3.2.1 Alternative Contracting Techniques

Avoiding and reducing work zone impacts are an impetus for alternative contracting techniques and for specifying that work be undertaken at night (although no alternative contracting technique is necessarily associated with the specification of night work). Other reasons for using alternative contracting techniques are to centralize accountability (in one organization rather than several), improve quality, and reduce project delivery time. The alternative contracting processes with the closest relationship to work zone design are

- A+B bidding,
- Design-build contracting,
- Incentive-disincentive provisions, and
- Lane rental.

These contracting techniques are not work zone strategies, per se, but are sometimes regarded as a means to reduce work zone impacts. In general, the transportation agency uses competitive market-based incentives to attain its objectives. Each of these techniques and night work will be discussed separately.

Contracts are legal documents. Agencies are governed by a body of law, including procurement statutes. Therefore, project personnel should be aware of potential limitations and requirements as contracts are awarded and administered. Special Experimental Project No. 14 (SEP-14—Innovative Contracting) is an ongoing FHWA activity to encourage and evaluate promising contracting processes. Approval is needed under this program before any contracting technique that deviates from federal competitive bidding provisions can be used. Some of the techniques have already been classified as operational (e.g., A+B bidding and lane rental), and of the contracting techniques listed above, only design-build contracting requires SEP-14 approval.

Some agencies have combined two strategies in a single contract. For example, lane rental could be combined with A+B bidding or incentive-disincentive provisions. The strategies should be consistent with each other and with agency goals. For example, a lane rental fee structure designed to discourage peak-hour traffic interference may not have its intended effect if the contract also includes an early completion incentive provision that is large enough to economically justify occupying lanes during peak-hour periods.

Coordination with agency construction contracting offices to obtain current information is recommended prior to applying any of the four listed contracting techniques.

The role and responsibilities of contractors varies substantially with contracting type. This variation is intended. Contracting strategies and some of the associated opportunities and implications are described below.

#### 3.2.1.1 A+B Bidding

A+B bidding is also known as cost-plus-time bidding, and each “bid” is computed using Equation 3-1.

In metric units and U.S. customary units:

\[
\text{Bid} = A + B x
\] (3-1)
Where

\[ A = \text{the dollar amount to perform all work identified in the contract, as submitted by the bidder}; \]
\[ B = \text{the total number of calendar days required to complete the project, as estimated by the bidder}; \]
\[ x = \text{Road user cost per day as designated by the agency}. \]

Equation 3-1 is used to determine the lowest bid. Contractor payments are based on the schedule of bid items (\( A \) portion of bid).

Additionally, for each day in excess of \( B \) used by the contractor to actually complete the work, an assessment is made for road user costs. Frequently, there is a reciprocal incentive provision when the actual number of days to complete construction is less than the number of days bid (\( B \)).

Typically, the agency’s cost-plus-time contract documents include a work zone design in the same or similar manner as if the contract were a conventional one. Contractors, as bidders and in contract performance, have a strong business incentive to minimize the number of days needed to complete the specified work. Therefore, the contract documents must clearly indicate contractor duties and limitations with regard to traffic control and work zone design. This strategy is generally applied to projects with a high potential for mobility and/or safety impacts, generally on high-volume facilities that do not have reasonable detour routes.

### 3.2.1.2 Design-Build Contracting

Under this contracting method, an agency-owner procures a single contract providing for both design and construction. This avoids questions of responsibility and coordination between a contract designer and contract constructor. It has been employed on a wide variety of project scales, including the reconstruction of I-15 in Salt Lake City, Utah.

Benefits attributed to design-build contracting include time savings, contractor innovation, and administration efficiencies.

Design-build practices are emerging and varied due to the merging of these traditionally separate functions. In many jurisdictions, design service and construction contract procurements are governed by distinct laws and traditions. Federal and state laws may be relevant to contracts that include both categories of service.

FHWA recommends that this technique be used only for projects that fit the design-build process, including adequate scope definition by the agency prior to requesting proposals. A design-build project should have a strong creative design component. Relatively simple projects, such as roadway resurfacing or minor roadway widening, do not provide significant design components and are not the ideal type of projects for design-build (8).

Under design-build contracting, work zone design is generally the responsibility of the contractor. In some cases, the agency may provide a schematic or conceptual plan, and in other cases, the development of the entire TMP may be assigned to the design-build contractor. The agency should always specify its high-level requirements and acceptable criteria and processes. Examples of high-level requirements may include: minimum number of lanes by day and time (e.g., holidays and peak periods), access requirements and allowances (e.g., to abutters and interchange ramps), noise restrictions, and public information programs. Criteria and process requirements include definition of applicable TTC and design criteria.

### 3.2.1.3 Incentive-Disincentive Provisions

Incentive-disincentive contract provisions provide for specified financial consequences to contractors based on actual completion of identified work (considered critical by the agency owner) relative to scheduled completion. The schedule (calendar days or completion date) for critical work items is established by the owner agency and identified in the bid documents. A daily incentive-disincentive amount is also established by the owner agency in the procurement documents. Additional contractor payment (i.e., incentive payment) is made for each day that the identified critical work is completed ahead of schedule, and contractor payment is reduced for each day that the contractor overrun the scheduled completion.

Incentive-disincentive provisions are intended primarily to minimize work zone impacts on critical projects. The determination of incentive-disincentive daily amounts includes consideration of traffic safety, road user delay, and maintenance of traffic costs (9).

As it relates to work zone design and traffic control, the use of an incentive-disincentive provision is somewhat similar to A+B (cost-plus-time) bidding. The contract documents must clearly indicate contractor duties and limitations with regard to traffic control and work zone design.

### 3.2.1.4 Lane Rental

Lane rental involves assessing the contractor a preestablished fee to occupy a travel lane or shoulder as part of the contract. Rental rates are established by the agency in the procurement documents and are typically stated in dollars per travel lane or shoulder per time period (e.g., day, hour, or faction of hour), with peak periods carrying higher rates. The anticipated times or durations of occupation are not stated in the agency procurement or bid. The contract is awarded to the low bidder on the basis of pay items.

During execution of the contract, rental fees are computed by the agency based on the agency’s rental rates and actual times that the contractor occupies travel lanes and shoulders. The rental fees reduce the net amount paid to the contractor and provide a financial incentive to minimize the duration of contractor occupations and hasten return of the facility to service.
The lane rental approach allows some flexibility in the distribution of work zone design assignments between agency and contractor. The conventional approach of providing a work zone design with the contract documents is workable and common. When a TTC and/or construction phasing plan are provided, the competitive and innovative forces are focused on minimizing the time that travel lanes are occupied while completing the identified work. Alternatively, an agency may identify the high-level requirements and lane rental fee schedule. This more open approach allows the contractor greater flexibility and more areas of potential innovation. This approach has been used for several freeway paving projects.

3.2.2 Night Construction

Conducting construction operations and implementing the associated capacity-reducing measures during periods of reduced demand is a method of bringing available capacity more closely into balance with demand. Night traffic volumes are generally lower than daylight volumes. Consequently, agency interest in night work as a means of reducing impacts is growing. Generally, there are no or few legal and contracting limits on an agency’s authority to specify day and time restrictions. However, schedule restrictions (i.e., days, dates, or times when activities are not permitted) or requirements (i.e., days, dates, or times when activities must be performed) carry many potential consequences. Although some research has been conducted into the consequences of night construction and more is being conducted, a rigorous evaluation of all its implications has not been undertaken. Exhibit 3-2 summarizes commonly perceived advantages and disadvantages of night work.

When commercial land uses abut facilities being constructed (or reconstructed), access by customers and suppliers may be impaired. Restoring access and capacity during nonwork periods (i.e., business day and time) reduces impacts. This consideration is more important in commercial areas, where speeds tend to be lower than on high-speed highways.

There are many costs involved in highway construction, including those related to safety, user delay, and possible economic disruption. Agency costs are those paid by the transportation agency to employees, contracting constructors, and engineers. These direct costs tend to be higher for night construction because of additional devices, wage differential, and producer costs. Additionally, agencies and personnel experienced in administering night construction often refer to elevated risk factors (e.g., higher speeds, impaired drivers, and reduced visibility). Prevailing commercial, personal, family, and social patterns are the very reasons that traffic volumes are reduced at night; therefore, working at night may be very disruptive to a person’s quality of life. This may affect the ability of the transportation agency and contractor to attract qualified personnel. Also, construction often creates sound, and the noise levels that may be tolerable and conform to ordinances during day hours may not be at night. Also, nearly all construction operations (e.g., materials placement and compaction) are vision dependent. Although lighting systems can mitigate for the absence of sunlight, there remains a concern that some work is compromised by limited visibility.

Specifying night work is a contracting strategy that is increasingly attractive to many agencies. However, a careful evaluation of potential ramifications should be conducted before selecting this alternative. Paving high-volume facilities is a common project type for this strategy.

3.2.3 Evaluation of Work Zone Designs Proposed by Contractors

As outlined in Sections 3.2 and 3.2.1.2, there are situations under which contractors develop work zone designs and submit them for agency approval or concurrence. There should be a basis for the review. Exhibit 3-3 is a general framework for conducting a comparative evaluation between an agency-prepared design and a proposed alternative. Some of the factors are quantifiable, and others have to be assessed qualitatively. An agency could elaborate on this general approach by adding additional factors and assigning weights to factors.

3.3 Identifying and Evaluating Alternative Work Zone Strategies

The identification of candidate strategies begins after the project scope is defined and other preliminary information (e.g., typical sections, traffic volumes, right-of-way, and context) is available. Based on experience and guidance, such as the guidance in Exhibits 3-4 and 3-5, a set of preliminary alternatives is identified. Exhibits 3-4 and 3-5 identify candidate work zone strategies for combinations of six generic facility types and two generic construction methods. Lane construction refers to an operation where a single lane (i.e., travel or auxiliary) is constructed or reconstructed while an adjacent lane carries traffic. Resurfacing, pavement reconstruction, and

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lower traffic volumes and lower traffic impacts</td>
<td>• Higher agency cost</td>
</tr>
<tr>
<td>• Lower impacts to commercial activity</td>
<td>• Higher safety risks</td>
</tr>
<tr>
<td></td>
<td>• Disrupts normal social patterns of work force</td>
</tr>
<tr>
<td></td>
<td>• Noise</td>
</tr>
<tr>
<td></td>
<td>• Possible compromise in construction quality</td>
</tr>
</tbody>
</table>

Exhibit 3-2. Perceived advantages and disadvantages of night construction.
some types of bridge work are routinely accomplished using lane construction. Half-width construction refers to constructing or reconstructing one-half of the typical template as a single phase. Reconstruction of some bridges on divided highways is an example of this category.

The following guidance applies to Exhibits 3-4 and 3-5:

- **Lane construction feasible** means that the basic roadway construction activity (e.g., resurfacing or reconstruction) can be accomplished in basic lane-by-lane phases. During each phase, a single permanent travel lane or shoulder is occupied for construction, and the other cross-sectional elements (roadway and roadside) are available for traffic management and control.

- **Half-width construction feasible** means that the roadway construction activity (e.g., resurfacing or reconstruction) can be accomplished in two basic phases. During each phase, half of the permanent roadway cross section is occupied for construction, and the other half of the cross section and roadides are available for traffic management and control.

- From a traffic control standpoint, **lane construction** is considered to be a subset of **half-width construction**. Generally, any traffic control strategy that is feasible for half-width construction is also feasible for lane construction, although the strategy may not be desirable because of the wider range of choices available for lane construction. However, in some cases, half-width construction may be feasible when lane construction is not. Some bridge deck replacements are in this category.

- The numerical rankings in the matrix cells represent the general ranking and feasibility of various zone design strategies for various construction work requirements and facility types. The lower-numbered strategies are generally more preferred and feasible than higher-numbered strategies, although no general characterization is true for all cases. The selection of an appropriate strategy always requires project-specific information. The exhibits recommend strategies for consideration. The numerical rankings do not imply that lower-numbered strategies are superior, but rather suggest that lower-numbered strategies be considered before final selection of a higher-numbered alternative. As an example, before selecting the #3 strategy, the #1 and #2 strategies should be considered. Further, in using these exhibits, the designer is not restricted to considering only strategies that are ranked, nor must the designer consider all of the strategies that are ranked.

Exhibit 3-3. Framework for evaluating alternative work zone design.
Alternating, one-way operation (mitigation)  2s  2s  2s  6s  5s
Crossover (mitigation)  3s, 4s  3s, 4s  3s  2s
Detour (mitigation)  2s  3s, 5s  2s  5s, 6s  5s, 6s  2s  4s, 7s  3s, 6s
Diversion (mitigation)  3s  4s, 6s  3s  3s, 4s, 7s  3s, 4s, 7s  3s  5s, 8s  4s, 7s
Full road closure  2, 3  5, 6  2, 3  5, 6  2, 3  7, 8  6, 7
Intermittent closure  1  1  1  1  1  1  1  1
Lane closure  2, 3, 4  2, 3, 4, 5  2, 3, 4, 5  2, 3, 4, 5, 6  2, 3, 4, 5
Lane constriction (mitigation)  4s  4s
Use of should (rms) (mitigation)  3s  3s, 4s  2s, 3s  2s, 3s
Two-lane road, no shoulders
Lane construction feasible? Yes
Half-width construction feasible? No

Two-lane road, narrow shoulders
Lane construction feasible? Yes
Half-width construction feasible? No

Two-lane road, full shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Multilane undivided road, no shoulders
Lane construction feasible? Yes
Use of shoulders (mitigation)  3s  4s  5s  6s  7s  8s  9s
Lane construction feasible? Yes
Half-width construction feasible? No

Multilane undivided road, shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Multilane divided road, shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Alternating, one-way operation (mitigation)  8s  7s
Crossover (mitigation)  2s  4s, 6s  3s, 5s  2s  8s, 10s  2s, 5s  6s
Detour (mitigation)  2s  3s, 7s  4s, 6s  3s  8s, 11s  3s, 9s  6s
Diversion (mitigation)  3s  5s, 7s  6s, 8s  2s  5s  7s
Full road closure  2, 3, 4, 5, 6, 7
Intermittent closure  1  1  1  1  1  1
Lane closure  3s  4s, 6s  4s
Lane construction  4s, 6s  4s  3s
Reversible lane (mitigation)  3s  5s  5s
Use of shoulders (mitigation)  3s, 4s, 5s, 6s, 7s  3s, 4s, 5s  2s, 3s  3s, 4s, 5s
Two-lane road, no shoulders
Lane construction feasible? Yes
Half-width construction feasible? No

Two-lane road, narrow shoulders
Lane construction feasible? Yes
Half-width construction feasible? No

Two-lane road, full shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Multilane undivided road, no shoulders
Lane construction feasible? Yes
Half-width construction feasible? No

Multilane undivided road, shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Multilane divided road, shoulders
Lane construction feasible? Yes
Half-width construction feasible? Yes

Notes: Numbers indicate general ranking and feasibility, with lower numbers being generally more preferred and feasible than higher numbers. An “s” next to a number indicates a supporting element of the strategy(ies) with the same number (e.g., one or more “3s” strategies support “3”). A complete strategy includes all of the primary and supporting elements with the same number in a particular column. Multiple numbers in the same cell indicate different rankings for a strategy (as either a base or support) used in a different combination with others.

Exhibit 3-4. Preliminary work zone strategy screening, two-lane roads.

Exhibit 3-5. Preliminary work zone strategy screening, multilane roads.
way and worker safety, and traffic engineering provide a valuable perspective. Evaluation of work zone strategies should consider the factors in the following sections.

### 3.3.1 Access

All roads are accessible, but not to the same degree. The functional classification system is based on the proportional distribution of access and mobility functions. Exhibit 3-6 depicts the relative functionality of various facility types. Potential work zone impacts are directly related to the functionality of a highway in its permanent state (i.e., prior to construction work zone). Temporary denial or impedance of access to commercial, industrial, recreational, and residential property can be very disruptive. Additionally, freeway interchanges are sometimes closed or substantially altered during construction. In designing the work zone, the access function should be inventoried and well understood.

Access to highways is provided through the following mechanisms:

- Abutting land use (i.e., driveways and private roads),
- At-grade intersections,
- Interchange ramps, and
- Temporary occupancy (i.e., work zones).

Each of these mechanisms is a work zone design variable, meaning that the design process can affect the status quo. However, designers rarely exercise unconstrained flexibility on any aspect. Although excluding all other access to a highway work zone may result in the greatest construction efficiency, that option is rarely available (and is generally used in the interest of rapid completion). Normally, existing access mechanisms are sustained as part of work zone design, but often at a diminished level.

### 3.3.2 Basic Traffic Functionality and Operation

Construction necessarily alters the preproject roadway configuration. The ramifications of the alterations are sometimes overlooked until project implementation. Tabulating the following information for each alternative will show the probable effects on basic traffic and highway operations:

- Bridge deck width available compared with approach road;
- Freeway entrance ramps closed;
- Freeway entry ramp acceleration lane length reductions;
- Freeway exit ramps closed;
- Freeway exit ramp deceleration lane length reductions;
- Horizontal clearance to bridge piers, above-ground lighting hardware, signs, and other roadside appurtenances;
- Impact on existing drainage systems;
- Location and control of affected intersections;
- Number of lanes per direction;
- Railroad crossings affected;
- Roadway lighting affected;
- Travel lane widths for each affected road; and
- Vertical clearance (based on temporary roads and including construction appurtenances).

Physical alteration and occupation by construction operations can affect traffic operations in many ways. Example impacts include increasing the response time of emergency services and rendering facilities unsuitable for oversized vehicles. The identification of undesirable features may be used to mitigate the condition or, if the condition is unmitigated, to serve as an evaluation factor.

### 3.3.3 Capacity and Queues

Construction work zones often reduce the capacity of a facility below its preproject capacity level and below the capacity level of the approach roadways. Capacity is related to the number of travel lanes and free-flow speeds; thus, construction-related factors that reduce either will reduce capacity. Although the number of travel lanes is a substantive control on capacity, many additional factors can also influence traffic flow and capacity, including access, lane width, lateral clearance, and activities that result in speed reduction (i.e., enforcement and construction-related activities).

When demand exceeds capacity, two undesirable consequences follow: delay and queue formation. Delay results in user costs. Queues are considered a safety risk.
number of measures have been developed to warn drivers approaching queues (e.g., a moving vehicle with strobes and technology-based measures), avoidance is preferable. Some agencies have developed policies limiting the projected queue length for work zone strategies involving a reduction in the number of travel lanes. Various techniques have been employed to estimate work zone capacity and traffic impacts. The QuickZone software was developed by FHWA (12) to assess various project strategies and phases within strategies. QuickZone can estimate the length of total mainline queue, the total mainline delay in vehicle hours, the total passenger car costs, the total travel time in minutes, and the detour delay costs. Some agencies have conducted analyses of their highway networks and predetermined facility segments for which work zone capacity reductions are prohibited or permitted within defined time frames (i.e., time and day).

### 3.3.4 Constructability

The ability to “bid and build” proposed work is a fundamental necessity of every project. When the feasibility of constructing as-designed work comes into question, then delays, disruption, and additional costs often follow. To prevent this situation and in consideration of increasing project complexity, a growing number of state DOTs routinely conduct constructability reviews. In some cases, the reviews are conducted entirely with internal agency staff; however, more often external people or organizations are engaged. A body of guidance based on research and experience is available to guide these reviews. AASHTO’s *Constructability Review Best Practices Guide (13)* outlines processes and procedures used by several state DOTs, including consideration of work zones (e.g., maintenance and protection of traffic and detours), for conducting these reviews.

Rudimentary evaluation factors include the following:

- Traffic movement through the work zone during all construction phases and the geometric constraints of temporary construction features (e.g. shoring and bracing);
- Separation of through (i.e., nonconstruction) traffic from construction operations, workers, and construction traffic (equipment and vehicles) and stationary construction roadside hazards; and
- Access by construction forces to storage areas (equipment and materials) and to all necessary operations.

Whether a documented constructability review or a less structured constructability review is conducted, design plans and work zone strategies should be reviewed by personnel experienced in construction operations to evaluate the feasibility and possible cost implications of the design.

### 3.3.5 Cost

Work zone strategies have both agency and user cost consequences. Agency costs associated with maintenance and protection of traffic are always estimated for the selected strategy. Typically, the costs of TTC items are explicitly associated with maintenance and protection of traffic. Bidders submit prices as an element of their cost proposal, and this bid history is typically used to estimate the cost. However, the actual agency cost of a work zone type can be considerably different from the cost of TTC. Work zone strategies often influence the general method and efficiency of construction operations and the bid prices for major cost items (e.g., earthwork, pavement, and structures). Such differences may not be recognized by design teams. This point emphasizes the benefit of a multidisciplinary approach to work zone strategy evaluation and selection. The safety risk specifically associated with queue formation has not been quantified, but is widely considered to exist. As a result, many agencies endeavor to prevent or mitigate for queue formation. Quantitative estimates of user cost associated with delay are possible. Time-distributed traffic demand (i.e., volume by time of day and day of week) is needed. The values that an agency uses for delay in its life cycle cost analysis policy may be appropriate for a user cost estimate.

### 3.3.6 Human Environment and Other Modes

The category of “human environment and other modes” covers a myriad of factors that may arise at the intersection of construction operations and transportation facilities and that may not be specifically identified under another category. Disruption of pedestrian and social patterns, noise, natural resource impacts, and displacements are matters of public concern, and the impacts often vary with work zone strategy.

The potential effects of work zones on disabled populations, transit users, intermodal connections, and nonmotorized travel should be evaluated.

### 3.3.7 Summary

The strategy that is most responsive to the evaluation factors, on an overall basis, is selected. Only rarely is the same strategy optimal for all factors. Usually, the various strategies will exhibit offsetting considerations (e.g., cost or disruption of commerce) that cannot easily be converted to a common measure. In such cases, agency policy, preferences, and discretion prevail.

At the conclusion of the identification and evaluation phase, a work zone strategy and supporting strategies should be selected. The level of information assembled and the evaluation process should be sufficiently detailed to ensure feasibility of the selected strategies.
Chapter 3 identifies common work zone strategies. Several of these, including alternating one-way operation, full road closure, intermittent closure, and lane closure, are normally implemented exclusively or primarily through temporary traffic control (TTC). Exhibit 4-1 identifies work zone strategies for which the MUTCD Part 6 provides direct and illustrated guidance (in the form of typical applications). The MUTCD in its entirety, with specific emphasis on the Part 6 “General and Fundamental Principles” chapters, should be relied upon. As stated in Chapter 1, this report is intended for use in conjunction with the MUTCD, not as a substitute.

Implementation of a detour may or may not require temporary roadway infrastructure. When temporary roadways are needed, the guidance provided for diversions (see Section 4.1) is generally applicable. Other work zone types generally involve the design of roadways, including geometric design and the provision of supporting appurtenances. This chapter addresses the work zone roadway design elements of specific work zone strategies, including temporary roadway infrastructure and existing roadways that are geometrically altered within work zones.

4.1 Diversions

Diversions, sometimes referred to as runarounds or shoo-fly, are a specific type of temporary roadway. This strategy offsets the effect of removing the permanent roadway from service. When the number of diversion travel lanes is the same as the affected roadway and speeds are comparable, the mitigation is nearly complete. General considerations and common applications are identified in Section 3.1.3. Diversions can carry one-way or two-way roadways. Two-lane, two-way diversions, such as the one illustrated in Exhibit 4-2, are the most common type.

The diversion design must reflect the service requirements and site constraints. Diversions are often used in conjunction with bridge construction and may involve grade separation or hydraulic structures (temporary bridges, culverts, etc.), which strongly influence the overall geometric design. Selection of the work zone design speed for the diversion should follow the Section 2.2 guidance.

Sight distance guidance is provided in Section 2.2.6. Diversions commonly consist of a series of horizontal and vertical curves. Lateral sight obstructions and crest vertical curves should be reviewed.

Diversions are most common on two-lane roads, and the TTC for that condition is the subject of a Typical Application in the MUTCD. Diversions are sometimes used on other facilities types, as well. Appropriate TTC should be based on general direction and guidance in the MUTCD and with reference to the Typical Application for a two-lane road diversion.

4.1.1 Horizontal Alignment and Superelevation

The cost and impacts of a diversion may be directly related to the length of the alignment between tie-in points on the permanent roadway. This suggests that the best curve radii to use are the smallest curve radii that satisfy all design considerations (e.g., work zone design speed, safety, and project-specific features). A common diversion design (see Exhibit 4-2) includes pairs of opposing-direction horizontal curves. For reasons indicated in Section 2.3.2, it is common design practice to provide curves that are sufficiently flat to not require superelevation. Where superelevation is needed, the agency-adopted policy of superelevation distribution (as discussed in Section 2.3.2) should be applied and the alignment-superelevation criteria met. Where superelevation is provided, the alignment should provide for adequate transitions. In the case of superelevated reverse curves, a tangent between the curves is needed. Normal crown and superelevated cross sections are depicted in Exhibits 4-3 and 4-4, respectively.

4.1.2 Vertical Alignment

Section 2.3.4 is applicable to diversions.
4.1.4 Roadside Design and Barrier Placement

For a discussion of the principles guiding roadside design and safety for construction work zones, see Chapter 5. For a specific discussion of barrier use for a temporary bridge that is part of a diversion on a two-lane, two-way highway, refer to Section 5.5.4.

4.2 Lane Constriction

General considerations are outlined in Section 3.1.7. It is desirable to maintain the approach roadway travel lane width through construction work zones. However, “lane constriction” implies a width reduction, and desirable dimensions are generally not attainable. Therefore, this strategy inherently involves providing a design feature that is less than desirable. Research indicates that reducing lane widths through work zones may increase crash rates. Relationships between the magnitude of the reduction and the corresponding safety effect were not reported.

It is common practice to reference “travel lane width” as the key lane constriction decision variable. However, operations in one travel lane are influenced by operations in adjacent lanes. Additionally, adjoining travel lanes occasionally have different widths. Therefore, it may be more appropriate for design guidance to address traveled way width. For example, a 3.0-m [10-ft]-wide travel lane adjacent to a 3.6-m [12-ft] travel lane is generally more desirable than a 3.0-m [10-ft]-wide travel lane adjacent to a travel lane of the same width.

A number of factors should be considered in determining the minimum acceptable traveled way width, including the presence and proximity of roadside features. As indicated by the Roadside Design Guide (see Section 5.6.1 of this report),

<table>
<thead>
<tr>
<th>Work zone strategy</th>
<th>MUTCD guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freeway</td>
</tr>
<tr>
<td>Alternating one-way operation</td>
<td>NA</td>
</tr>
<tr>
<td>At-grade intersections</td>
<td>NA</td>
</tr>
<tr>
<td>Detour</td>
<td></td>
</tr>
<tr>
<td>Diversion</td>
<td></td>
</tr>
<tr>
<td>Full road closure</td>
<td>(1)</td>
</tr>
<tr>
<td>Interchange ramp</td>
<td>√</td>
</tr>
<tr>
<td>Intermittent closure</td>
<td>√</td>
</tr>
<tr>
<td>Lane closure</td>
<td>√</td>
</tr>
<tr>
<td>Lane constriction</td>
<td></td>
</tr>
<tr>
<td>Median crossover</td>
<td>√</td>
</tr>
<tr>
<td>Use of shoulder</td>
<td>√</td>
</tr>
</tbody>
</table>

√ Explicitly addressed by MUTCD Part 6.
NA Not applicable.
1 Full road closure requires a detour.
2 MUTCD typical application provided for one category of lane constriction (Shoulder Work with Minor Encroachment) pertains to minor roads with low speeds.
3 Covered in conjunction with Lane Shift.

Exhibit 4-1. Coverage of MUTCD Part 6 TTC guidance for various work zone strategies.

Exhibit 4-2. Example plan of diversion.

Exhibit 4-3. Diversion typical section with normal crown.

Exhibit 4-4. Diversion typical section with normal crown.
vehicle speeds and position (i.e., lateral vehicle location) may be affected by roadside features. Section 9.2.1.1.2 of the *Roadside Design Guide* indicates that the minimum desirable offset from the edge of the travel lane to the temporary concrete barrier (TCB) is 0.6 m [2 ft]. While the 0.6-m [2-ft] offset is desirable, a number of agencies use lower minimum values.

Traveled way widths that result in 3.6-m [12-ft]–wide travel lanes and provide offsets to constraining features (e.g., barriers) are desirable. However, lane constrictions are less-than-ideal conditions that must sometimes be provided as a matter of practicality. Factors that are sometimes considered in determining acceptable traveled way lane width include:

- Traffic volumes,
- Heavy-vehicle (i.e., truck) volumes,
- Lateral constraint,
- Speed,
- Horizontal curvature,
- Duration of lane constriction,
- One-way or two-way roadway (i.e., if all other factors are equal, the minimum traveled way width for an undivided two-way roadway should be greater than for the one-way roadway), and
- Number of lanes.

Traveled ways that result in travel lane widths of 3.3 m [11 ft] are fairly common in work zones; those that result in travel lanes less than 3.0 m [10 ft] are generally not used for construction work zones on high-speed roads.

Exhibit 4-6 and the accompanying notes are an example framework that uses a number of factors to determine minimum traveled way width. For traveled ways with constraint, the distances indicated are measured to the face of the constraining features (i.e., the offset is included in the tabulated dimension).

Lateral constraint may also restrict sight distance, which should be reviewed in light of Section 2.2.6.

Lane constrictions are often used in conjunction with lane shifts, lane closures, and shoulder closures. Guidance on TTC for each of these is provided in the MUTCD. With the use of a constricted lane, the use of a W5-1 (Road Narrows) sign should be considered in coordination with other applicable TTC devices.

### 4.2.1 Barrier Placement and Traffic Separation

For a discussion of the principles guiding roadside design and safety for construction work zones, see Chapter 5 of this report. For a specific discussion of barrier use for lane and shoulder closures with minor encroachments onto the remaining travel lanes, refer to Sections 5.5.1 through 5.5.3. In these conditions, a design decision that must be made is how to distribute the remaining paved roadway for temporary lanes and shoulders. A number of combinations can often exist. For the tools used to develop barrier placement guidance, different combinations of lane and shoulder widths did not affect the resulting guidance in the referenced subsections.

### 4.3 Median Crossover

A *median crossover*, as defined in this document, is the infrastructure used to support the *two-way traffic on a normally divided facility*. In practice, the two terms are often used interchangeably. General considerations and common applications are identified in Section 3.1.8. The core requirement in establishing the length and limits of a median crossover is to remove traffic from the portions of the infrastructure that are to be reconstructed. Although a specific absolute maximum length cannot be established and agency practice in this area varies, crossover lengths should be limited. Crossovers impose more constraint on drivers than the approach roadway. There is usually only one one-way lane, which limits driver lane and speed choice. Additionally, cross-sectional arrangements often involve operation near barriers and provide reduced refuge opportunity for disabled vehicles. These factors increase driver anxiety and may require heightened vigilance. In recognition of these considerations, crossovers longer than 15 km [10 mi] are used infrequently, and some agencies prefer lengths of 8 km [5 mi] and less. The temporary roadways should be sited to avoid unnecessary proximity to bridge structures; substantial grade differences between one-way roadways; complex, sensitive, or formidable geologic features (e.g., rock outcrops or wetlands); and other attributes that require extensive roadbed

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**Exhibit 4-4. Diversion typical section with superelevation.**

**Exhibit 4-5. Recommended two-lane diversion travel way and roadway widths.**

```
<table>
<thead>
<tr>
<th>Current ADT (veh/day)</th>
<th>Metric</th>
<th>U.S. Customary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traveled way width (m)</td>
<td>Roadway width (m)</td>
</tr>
<tr>
<td>&lt; 1,000</td>
<td>6.6</td>
<td>7.8</td>
</tr>
<tr>
<td>1,000–3,000</td>
<td>6.6</td>
<td>9.0</td>
</tr>
<tr>
<td>&gt; 3,000</td>
<td>7.2</td>
<td>10.8</td>
</tr>
</tbody>
</table>
```
preparation. Interchange ramps are another potential location control.

Selection of the work zone design speed for the median crossover should follow the guidance in Section 2.2. Horizontal curves and grades, particularly those on the temporary median roadways, should be designed in recognition of their potential effect on speed. Sight distance guidance is provided in Section 2.2.6. Median crossovers often include a series of horizontal and vertical curves in combination with a TCB. The effect of crest vertical curves and lateral sight obstructions should be reviewed.

Exhibit 4-7 schematically depicts a median crossover. The distance from the downstream end of the lane-closure taper to the beginning of the curve (“d” in Exhibit 4-7) varies by agency from one-half to twice the lane-closure taper length. Higher values (i.e., longer distances) are desirable to provide separation between locations of driver decisions and associated maneuvering.

Median crossovers are the subject of Typical Applications in the MUTCD, which should be referenced in establishing TTC.

4.3.1 Temporary Roadways Connecting the Permanent Roadways

Median crossovers are a common work zone type (and therefore familiar to drivers) in some regions and not in others. Additionally, the temporary roadways used to connect normally divided highways represent a departure from the default path, the permanent alignment through travel lanes. Hence, driver familiarity and expectancies are not uniform. From the driver’s perspective, these temporary roadways are a non-discretionary exit ramp from a mainline alignment. Although the movement is required for drivers, the combined and complementary use of geometry and TTC is needed to provide positive guidance for a distinctive departure from the perma-
nent road alignment. The geometry should provide extended sight distance, a well-aligned and -delineated path, and a forgiving cross section.

TCBs in conjunction with other TTC (channelizing devices, pavement markings, etc.) are frequently used to delineate travel paths and to separate opposing directions of travel in the areas where the permanent roadway carrying two-way traffic and temporary connecting roadway converge and diverge (in Exhibit 4-7, locations A and B). The option of providing a TCB to separate traffic throughout the length of two-way roadway is discussed in Section 4.3.3. In cases where a TCB is used at the convergence and/or divergence points and terminated within the limits of the two-way roadway, a crashworthy end treatment is required.

4.3.1.1 Horizontal Alignment and Superelevation

The agency-adopted policy of superelevation distribution (as discussed in Section 2.3.2) should be applied and the alignment-superelevation criteria met. When practicable, the horizontal alignment should be flat enough to avoid the need for superelevation. This goal is often attainable outside urban areas.

4.3.1.2 Vertical Alignment

Section 2.3.4 is applicable to temporary roadways connecting the permanent roadways of a normally divided highway. The discussion on the potential effect of grades on heavy-vehicle performance and capacity is especially relevant to crossovers.

4.3.1.3 Cross Section and Surface

In some cases, median crossovers provide more than one travel lane in the same direction. However, the most common case is a single travel lane per direction. For that case, a number of alternative roadway cross-sectional configurations may be used, including

- Crowned in center, with equal-width shoulders;
- Crowned at center of traveled way, with wide right shoulders;
- Uniform traveled way cross slope, with equal-width shoulders; and
- Uniform traveled way cross slope, with wide right shoulders.

The appropriate selection depends on several factors. Some agencies leave crossovers in place for future use, rather than remove them at the conclusion of a project. Under a subsequent project, the same temporary roadway might carry traffic in the opposite direction (e.g., eastbound in one case and westbound in another). For this situation, both shoulders are a left and right shoulder at various points in their service lives. Additionally, curves may or may not be superelevated, depending on policy and specific design features (e.g., radius and work zone design speed).

The factors discussed above affect cross-sectional design, and agencies have developed a variety of cross-sectional design
practices. Travel lane widths for a single lane range from 3.6 to 4.8 m [12 to 16 ft], with 4.8 m [16 ft] being more common and recommended. The high overall- and truck-traffic volumes and speeds normally associated with freeways and temporary road curvature favor a wide cross section, including the traveled way. Equal-width shoulders are more common than the alternative and are appropriate when the same temporary roadway will be used for opposite-direction traffic at different times. Shoulders range in width from 0.6 to 2.1 m [2 to 7 ft]. For temporary roadways that will carry traffic only in one direction, consideration should be given to a wide right shoulder to reinforce the customary role and driver expectancy of the right shoulder as the location for emergency stopping and refuge. Additionally, emergency stops on the right side reduce potential conflicts with temporary barriers that are often located on the left side in the areas where temporary crossovers converge with and diverge from the one-way roadway carrying two-way traffic.

For multilane temporary roadways serving as median crossovers on high-speed highways, the travel lane should be at least 3.6 m [12 ft] wide. Shoulders 1.5 to 2.4 m [5 to 8 ft] wide on both sides are desirable.

Cross-sectional arrangements different from those stated above are appropriate when supported by agency experience.

A traveled way cross slope transition may be needed between the permanent one-way roadway and the temporary roadway. The direction and magnitude of temporary roadway superelevation are principal considerations.

The median crossover, temporary roadway pavement structure should reflect the difficulty of performing surface maintenance and repairs within a complex operational environment. Except for very low volumes and short durations, which are rarely the case with divided highways, a full-depth pavement structure is appropriate for the traveled way. Shoulders may be stabilized aggregate, paved, or paved part-width.

4.3.2 One-Way Roadway Used for Two-Way Traffic

One-way roadways are not specifically designed to carry two-way traffic. Yet this strategy has proven to be highly effective and is commonly employed in many regions. Using a one-way roadway for two-way traffic requires reapportioning the cross section and other adjustments.

A common freeway one-way roadway is shown in Exhibit 4-8. In locations where a TCB is placed, the permanent traveled way width available for use is 6.6 m [22 ft]. A common arrangement is shown in Exhibit 4-9. This asymmetrical configuration provides a much wider shoulder on the outside than the median side. Additionally, the useful traveled way width is reduced by the barrier width footprint and its shy effect. The arrangement shown in Exhibit 4-10 is sometimes used to allocate the roadway width (i.e., traveled way and shoulders) more evenly. When all or part of a shoulder is temporarily used as a travel lane, certain complications follow. Shoulder pavement structures may not be capable of supporting heavy and sustained traffic. Shoulder slopes may not be compatible with high-speed travel because of superelevation requirements on horizontal curves. For these reasons, when a two-lane, one-way roadway is used for two-way traffic, the separation (TCB or channelizing device) is usually centered on the line between the two permanent travel lanes. Separation by vertical panels is depicted in Exhibit 4-11. Although the separation device may result in a shy effect, experience with these conditions indicates that operations are acceptable.

The median shoulder in Exhibits 4-9 and 4-11 does not provide for a paved shoulder width comparable to permanent freeway conditions. Vehicle malfunctions and crashes are possible within work zones. This particular work zone inherently reduces capacity by a reduction in the number of travel lanes (i.e., two instead of four); therefore, further impediments are unwanted. Emergency turnouts (i.e., intermittent shoulders) are responsive to these conditions and are discussed in Section 6.3.

Many freeway shoulders have rumble strips. Depending on their location in relation to temporarily designated travel lanes, the rumble strips may interfere with two-way operations on the one-way roadway. This condition is further discussed in Section 6.9.

When a one-way roadway is used for two-way operation, the probability of an errant vehicle striking certain median hazards may increase substantially. For example, what is normally the departure end of a bridge becomes the approach end. Median roadside hazards should be evaluated. Guidance for common situations is provided in Sections 4.3.3, 5.5.5, and 5.5.6.

Exhibit 4-8. Typical section of freeway to be used for median crossover.
4.3.3 Barrier Placement and Traffic Separation

For a discussion of the principles guiding roadside design and safety for construction work zones, see Chapter 5. For a specific discussion on temporary barrier use for two-lane, two-way traffic on a normally divided facility, refer to Sections 5.5.5 and 5.5.6.

4.4 Use of Shoulder

General considerations are outlined in Section 3.1.9. As indicated in that section, there are numerous variations of this strategy for different facility types and work requirements. A common freeway example is shown in Exhibit 4-12.

This use of shoulder involves limited design decisions and is implemented primarily through TTC. The transitional path of traffic from the permanent travel lane approaching the work zone to the shoulder (as a temporary travel lane) is delineated by shifting traffic. Adoption of a work zone design speed may be appropriate for the evaluation of superelevation (see Section 4.4.1) and sight distance. Because the shoulders will be part of a permanent high-speed roadway, no horizontal or vertical alignment decisions are generally needed. Temporary work zone features can affect sight distance, and the design should be developed and evaluated from that perspective, as discussed in Section 2.2.6.

The use of shoulder in conjunction with a lane shift is the subject of Typical Applications in the MUTCD, which should be referenced in establishing TTC.

4.4.1 Cross Section and Surface

The adequacy of the existing shoulder pavement for use as a travel lane may be assessed in terms of cross slope, structure, and surface characteristics. In some cases, pavement rehabilitation or reconstruction may be needed.
If the shoulder being used to carry traffic is on a horizontal curve, the magnitude and direction of its cross slope should be compared with the superelevation requirement. The agency’s work zone policy for superelevation, using the Method 2 or 5 distributions outlined in Section 2.3.2, should be applied. If the actual curve radius is equal to or greater than the tabulated minimum radius for the work zone design speed and existing cross slope (accounting for direction and magnitude), the evaluation is complete. As sometimes occurs, the travel lane adjacent to a shoulder will be adequately superelevated but the shoulder will not.

Several measures have been employed when the shoulder cross slope does not meet the applicable work zone design criteria. The most comprehensive measure is to extend the cross slope of the adjacent travel lane to the shoulder through pavement reconstruction or surfacing. Other potential mitigation measures include speed advisories and speed-dampening measures (e.g., lane rumble strips). Detouring trucks and buses or prohibiting these vehicles from the shoulder that is temporarily in use for traffic and restricting them to the adjacent lane is an option used in some jurisdictions. An enabling regulation and the corresponding administrative procedures are needed.

Some shoulders have the same pavement structure as the adjoining travel lane; others do not. Travel lanes are subject to more intense service loads than shoulders. These factors, the age of the existing pavement, and the expected temporary pavement service requirements (e.g., traffic volumes, composition, and duration of use) should be considered in evaluating the potential use of existing shoulder pavements as travel lanes. The decision to reconstruct, rehabilitate, or retain an existing pavement structure should reflect the difficulty of performing surface maintenance and repairs within a complex operational environment. Providing a highly durable pavement structure should be considered.

Roadway design is based on the assumed availability of certain minimum friction between vehicle tires and the roadway surface. A shoulder being considered for use as a travel lane should meet or exceed the assumed values. Motorist surveys have revealed that rough-riding surfaces and work zones are independently two of the most dissatisfying aspects of highway travel. From a customer satisfaction standpoint, it is undesirable that these be combined in a single experience.

Before using an existing shoulder as a travel lane without modification, it should be considered adequate in each category: cross slope, structure, and surface conditions (i.e., friction and smoothness).

Many shoulders have rumble strips that may be within the wheel-path band. A situation where drivers are preoccupied with steering to avoid contact with rumble strips may induce unwanted distraction and tendencies. If this condition is anticipated, temporary rumble strip eradication and subsequent restoration should be considered. The feasibility and cost of these treatments (eradication and restoration) depend on the rumble strip configuration and shoulder pavement structure.

**4.4.2 Barrier Placement and Traffic Separation**

When a shoulder is used as a travel lane, the probability of an errant vehicle striking certain existing, permanent roadside hazards may increase. However, for most common construction work zone conditions, providing roadside barriers that shield existing hazards is not cost-effective. The previous statement refers to permanent (preproject) features and does not refer to construction-related work zone roadside hazards. Further, even permanent features with very high levels of exposure justify individual assessment.

**4.5 Interchange Ramps**

Access provisions are a significant factor for any construction involving interchanges. Maintaining existing access points and associated traffic movements reduces the negative impacts of interrupting established traffic patterns. However, avoidance of these impacts should be weighed against the feasibility of providing adequate infrastructure for traffic to enter and exit the mainline facility. The decision on interchange access during construction progresses in the following manner: temporary connections are provided when adequate arrangements
are feasible, and access points are closed when adequate arrangements are not feasible. The determination of adequacy is often related to speed change (i.e., acceleration or deceleration), lane length, and the associated traffic control.

A temporary single-lane interchange ramp should have a travel lane of approximately 4.5 m [15 ft], with a 1.8-m [6-ft] right shoulder and minimum 0.6-m [2-ft] left shoulder. However, different cross-sectional arrangements are appropriate when supported by agency experience and in consideration of project-specific factors (e.g., traffic volume, mix, and duration of service).

The MUTCD provides considerable guidance and illustrated examples of TTC provisions and schematic geometry for accommodating interchange ramps within work zones. The MUTCD does not provide specific geometric criteria for speed change lanes. These elements are discussed in Sections 4.5.1 and 4.5.2.

**4.5.1 Entrance Ramps**

Maintaining service on existing entrance ramps is often feasible, regardless of work zone strategy (e.g., median crossovers, lane closure, or use of shoulder). Exhibit 4-13 illustrates a temporary entrance ramp for a median crossover.

The feasibility of maintaining an entrance during construction often hinges on providing an adequate combination of roadway geometry and traffic control to facilitate merging. Acceleration lanes enable entering traffic to increase speed while simultaneously selecting a gap in through-lane traffic. The basic principles and considerations associated with permanent entrance ramps pertain to temporary arrangements. Therefore, acceleration lanes in work zones that meet the design criteria for permanent facilities are desirable. However, attaining these lane lengths is often not practical. State DOTs have generally not published explicit minimum acceptable criteria. However, several “rules of thumb” are in use and provided here. One suggestion is to provide at least 90 m [300 ft] of acceleration lane. A second suggestion is to provide at least 70 percent of the permanent roadway criteria length. Traffic volumes (mainline and entrance ramp) and sight distance are sometimes considered in determining the minimally acceptable acceleration lane length for a specific location.

Traffic control measures may be employed to mitigate less-than-desirable acceleration lane lengths. STOP, YIELD, and other signs are often used to mitigate less-than-desirable acceleration lane lengths and conditions. A variety of practices are employed by agencies in establishing appropriate traffic control for interchange entrance ramps. Exhibit 4-14 summarizes the process used by the Maryland State Highway Administration (Standard MD 104.01.31) to install a YIELD sign on entrance ramps merging with expressways/freeways.

When the combination of traffic, geometric, and traffic control factors indicate an adequate entrance is not feasible, the entrance ramp should be closed. Advance coordination with the affected community, public information, and implementation of TTC measures are needed.

*Exhibit 4-13. Temporary interchange entrance ramp for median crossover.*
Exhibit 4-14. Sample method of determining signing for entrance ramps (Standard MD 104.01.31, used by the Maryland State Highway Administration).
4.5.2 Exit Ramps

Maintaining service on existing exit ramps is usually feasible for all work zone types. An adequate combination of roadway geometry and traffic control is needed to facilitate diverging from the mainline, negotiating the ramp, and meeting the operational requirements at the intersecting roadway (stop, yield, and turn). Deceleration lanes enable exiting traffic to reduce speed after departing the mainline through lane and prior to encountering features that require lower speeds or stopping. The basic principles and considerations associated with permanent exit ramps pertain to temporary arrangements. Therefore, deceleration lanes in work zones that meet the design criteria for permanent facilities are desirable. It is desirable for exiting traffic to depart the through lanes at mainline speed and not reduce speed while occupying the mainline through lane. When this is not practical, the geometry of the ramp should be reviewed to determine if the ramp’s length, horizontal alignment, and grade allow for gradual deceleration before reaching speed-critical features.

Exhibit 4-15 illustrates a temporary interchange exit ramp for a median crossover. This example has a parallel deceleration lane. This arrangement has some operational benefit, since a segment dedicated to deceleration is clearly visible to drivers on the freeway approaching the decision point and may reduce a tendency toward decelerating in the through travel lane. When using this arrangement, a 60-m [200-ft] taper length is adequate, and length of the parallel portion should be in the 60- to 90-m [200- to 300-ft] range. Although the parallel arrangement depicted has the noted benefits, tapered configurations (i.e., no lane parallel and adjacent to the through travel lane) are also used.

4.6 At-Grade Intersections

The general approaches to designing construction work zones that encompass at-grade intersections on high-speed highways can be grouped into the categories described below.

In each case, coordination with the affected community and development of appropriate TTC measures are keys to successful performance. Flaggers are often useful in providing positive guidance in a potentially complex and dynamic setting.

4.6.1 Intersection Closure

The feasibility of intersection closure depends on the availability of a reasonable detour. If a detour is feasible, access to the main road is temporarily terminated. If coordinated with affected parties (local officials, residents, and businesses), then short-duration closures that interrupt access to a limited number of land uses are sometimes possible. When intersections are closed, the facility and associated work zone function as a continuation of the approach segments.

4.6.2 Intersection Relocation

Intersection relocation should be considered when there is no suitable detour and when extensive work will take place

Exhibit 4-15. Temporary interchange exit ramp for a median crossover.
within the intersection. An example is shown in Exhibit 4-16. The feasibility of this option is tied to having or acquiring property interests (e.g., easement or right-of-way) for the temporary facility. This option is rarely practical unless undeveloped land exists in one or more quadrants.

4.6.3 Maintain Movements with TTC

Maintaining movements with TTC is the most commonly used option when other options are less desirable or not feasible.

Intersections are inherently points of conflict. Even in cases where intersections are closed or relocated, drivers face choices and uncertainty. Therefore, positive guidance should be applied to the high-speed facilities approaching and going through intersections within work zones. Additionally, at the intersection proper, the design features and TTC devices should be developed with consideration given to use of temporary channelizing features that

- Separate conflicts,
- Control the angle of conflict,
- Regulate traffic and indicate proper usage,
- Provide preferential treatment of predominant turning movements, and
- Protect stored and turning vehicles.

These options are not always needed or practical in the context of a construction work zone. However, their applicability should be considered.

Additional traffic control measures—including changes in intersection control type, warnings, portable changeable message signs, and pavement markings and restrictions—are often used at intersections within construction work zones.
5.1 Introduction to Roadside Safety in Construction Work Zones

Adoption of the roadside safety principles and procedures outlined in the Roadside Design Guide has significantly enhanced highway safety. Foremost of the Roadside Design Guide principles is the forgiving roadside concept, which holds that “Regardless of the reason for a vehicle leaving the roadway, a roadside environment free of fixed objects with stable, flattened slopes enhances the opportunity for reducing crash severity.”

A critical step in translating the forgiving roadside concept to practical guidance was the establishment of a clear zone, a traversable and unobstructed roadside area. When the clear zone was introduced in AASHTO’s 1974 Highway Design and Operational Practices Related to Highway Safety (Yellow Book), the dimension of the desired clear zone, 9 m [30 ft], was based on studies that indicated that 80 percent of the vehicles leaving the roadway could recover within this distance. A single value was perceived to be impractical and not necessarily appropriate for facilities with widely differing volumes, speeds, and roadside slopes. In response, AASHTO’s 1977 Guide for Selecting, Locating and Designing Traffic Barriers introduced a variable clear zone width based on design speed, volume, and roadside slopes, with adjustments based on the horizontal alignment. The current edition of the Roadside Design Guide retains this approach.

If objects are located on the roadside, and especially within the desired clear zone, a series of alternative actions should be considered to reduce the risk to errant vehicles. The order of preference for addressing roadside obstacles follows:

1. Remove the obstacle;
2. Redesign the obstacle so it can be safely traversed;
3. Relocate the obstacle to a point where it is less likely to be struck;
4. Reduce impact severity by using an appropriate breakaway device;
5. Shield the obstacle with a longitudinal barrier designed for redirection, or use a crash cushion;
6. Delineate the obstacle if the above options are not appropriate.

Options 4 and 5 introduce the concept of crashworthiness. Where conditions require the presence of an obstacle or barrier near the traveled way, the obstacle or barrier should be designed to perform appropriately (i.e., with minimized probable motorist harm) if struck. Signs, signals, luminaire supports, and utility poles should use breakaway supports. Guidance for these objects is contained in AASHTO’s Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals; A Policy on the Accommodation of Utilities within Highway Right-of-Way; and A Policy on the Accommodation of Utilities within Freeway Right-of-Way. Roadside barriers and end treatments are deemed crashworthy by passing the crash test criteria of NCHRP Report 350: Recommended Procedures for Safety Performance Evaluation of Highway Features (14).

Roadside safety concepts (i.e., forgiving roadside, clear zone, prioritized treatment of hazards, and crashworthiness) apply to construction work zones on high-speed highways and permanent roadways. While the principles governing roadside design are generally the same, the work zone environment and permanent road environment are very different. Equipment, materials, and workers are inherent to construction work zones but are not normally present for permanent roadway conditions. Depending on the setting, several of the prioritized roadside hazard treatments (e.g., removal or relocation) may not be a practical option.

The assessment of roadside risk involves two factors, the probability of an errant vehicle encountering a roadside feature and the probable harm that will result from an encounter. The amount of traffic on the roadway is a key indicator of the probability of an encounter. Unlike permanent roadway...
conditions, which may exist for an indefinite time period, the duration of a construction work zone is definite. The shorter the duration of an observation period, the less likely it would be for 1, 2, or \( n \) vehicles to strike a roadside feature. Therefore, undesirable conditions that would warrant intervention on a permanent roadway may not justify an investment for a safety treatment in a construction work zone. These considerations were important in the development of the following roadside safety and barrier placement guidance.

### 5.2 Clear Zones

The clear zone approach has been used in roadside safety and design since the 1960s. The clear zone is a traversable and unobstructed roadside area extending from the edge of the traveled way. The use of clear zones as a design convention has been widely accepted, partly because of its perceived simplicity. In general, the idea is to provide a hazard-free roadside border that is desirably at least as wide as the design clear zone. If attaining this condition is not practical, alternative mitigation actions are evaluated. Given the relative ease of application, some state DOTs have developed desirable clear zone dimensions for construction work zones. As discussed, work zones exist for a finite period and therefore will experience lower total levels of vehicle exposure than a permanent roadway segment with the same daily traffic volume. On this basis, some agencies have developed desirable work zone clear zone dimensions that are less than those applied to permanent roadways. Dimensions representative of current DOT guidance regarding work zone clear zones are shown in Exhibit 5-1.

The state guidance on which Exhibit 5-1 is based includes a statement for use of these dimensions (15): “The potentially hazardous conditions typically found within work zones warrant the use of considerable judgment when applying these clear zone distances.”

<table>
<thead>
<tr>
<th>Approach posted speed limit</th>
<th>ADT (veh/day)</th>
<th>Front slopes</th>
<th>Back slopes</th>
<th>Work zone clear zone distances (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Under 750</td>
<td>1:6 or flatter</td>
<td>1:5 to 1:4</td>
<td>1:3</td>
</tr>
<tr>
<td>35 mph or less</td>
<td>1.5–2.0</td>
<td>1.5–2.0</td>
<td>1.5–2.0</td>
<td>1.5–2.0</td>
</tr>
<tr>
<td>750–1,500</td>
<td>2.0–2.5</td>
<td>2.5–3.0</td>
<td>2.0–2.5</td>
<td>2.5–3.0</td>
</tr>
<tr>
<td>1,500–6,000</td>
<td>2.5–3.0</td>
<td>3.0</td>
<td>2.5–3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Over 6,000</td>
<td>3.0</td>
<td>3.0–3.5</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>35–50 mph</td>
<td>Under 750</td>
<td>2.0–2.5</td>
<td>2.5–3.0</td>
<td>2.0–2.5</td>
</tr>
<tr>
<td>750–1,500</td>
<td>3.0</td>
<td>3.0–4.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>1,500–6,000</td>
<td>3.0–3.5</td>
<td>4.0–5.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Over 6,000</td>
<td>4.0</td>
<td>4.5–5.5</td>
<td>4.0</td>
<td>4.5–5.5</td>
</tr>
<tr>
<td>55 mph</td>
<td>Under 750</td>
<td>2.5–3.0</td>
<td>3.0–3.5</td>
<td>2.5–3.0</td>
</tr>
<tr>
<td>750–1,500</td>
<td>3.0–3.5</td>
<td>4.0–4.5</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>1,500–6,000</td>
<td>4.0</td>
<td>4.5–5.5</td>
<td>4.0</td>
<td>4.5–5.5</td>
</tr>
<tr>
<td>Over 6,000</td>
<td>4.0–4.5</td>
<td>5.0–6.0*</td>
<td>4.0–4.5</td>
<td>5.0–6.0*</td>
</tr>
<tr>
<td>60 mph</td>
<td>Under 750</td>
<td>3.0–3.5</td>
<td>4.0–4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>750–1,500</td>
<td>4.0–4.5</td>
<td>5.0–6.0*</td>
<td>4.0–4.5</td>
<td>5.0–6.0*</td>
</tr>
<tr>
<td>1,500–6,000</td>
<td>5.0–6.0*</td>
<td>7.0–8.5*</td>
<td>5.0–6.0*</td>
<td>7.0–8.5*</td>
</tr>
<tr>
<td>Over 6,000</td>
<td>5.0–6.5*</td>
<td>7.0–8.5*</td>
<td>5.0–6.5*</td>
<td>7.0–8.5*</td>
</tr>
<tr>
<td>65 mph</td>
<td>Under 750</td>
<td>3.5–4.0</td>
<td>4.0–5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>750–1,500</td>
<td>4.5–5.0</td>
<td>5.5–7.0*</td>
<td>4.5–5.0</td>
<td>5.5–7.0*</td>
</tr>
<tr>
<td>1,500–6,000</td>
<td>5.5–6.0*</td>
<td>6.5–8.0*</td>
<td>5.0–4.0</td>
<td>6.5–8.0*</td>
</tr>
<tr>
<td>Over 6,000</td>
<td>5.5–6.5*</td>
<td>7.0–8.5*</td>
<td>5.0–4.0</td>
<td>7.0–8.5*</td>
</tr>
</tbody>
</table>

* Clear zones may be limited to 5.5 m for practicality.
** Use guidance for permanent roadways.

Notes:
- All distances are measured from edge of traveled way.
- For clear zones, the ADT will be the total ADT on two-way roadways and the one-way ADT on one-way roadways. Traffic volumes will be expected traffic volumes through the work zone.
- The values for back slopes apply only to a section where the toe of the back slope is adjacent to the shoulder. For roadside ditches, use permanent roadway guidance.
- The approach posted speed is the approach posted speed prior to the work zone.

Exhibit 5-1. Example of work zone clear zone distances (15).
(continued on next page)
The Roadside Design Guide provides similar language regarding the use of clear zone dimensions for permanent roadways:

A basic understanding of the clear zone concept is critical to its proper application. The numbers obtained . . . imply a degree of accuracy that does not exist. . . . In some cases, it is reasonable to leave a fixed object within the clear zone; in other instances, an object beyond the clear zone distance may require removal or shielding.

In summary, the clear zone convention alone cannot be used to make all roadside design decisions, and the clear border that is provided along any specific roadway segment must consider numerous factors, including the applicable design clear zone dimension. When a potentially hazardous roadside obstruction or nontraversable slope is located on the roadside, an analysis should be conducted that assesses the risk of vehicle collisions with the obstruction, estimates the severity of collisions with the obstruction, and determines the cost-effectiveness of one of the six prioritized treatments of the hazard. This process, as it relates to construction work zones, is discussed in Sections 5.3 through 5.5.

### 5.3 Identification and Treatment of Construction Work Zone Hazards

There are limited data available on the frequency that various work zone objects are struck by errant vehicles and the corresponding severity of those crashes. Therefore, experience and judgment are used to identify hazardous features. In addition to considering the potential severity for an encroaching vehicle driver and occupant, in construction work zones, the designer must also consider the severity of crashes involving workers. The probability of a fatality for a pedestrian being struck by a vehicle traveling at 60 km/h [40 mph] is approximately 85 percent (16). Besides workers, other roadside hazards are of concern.
hazards that may be present in construction work zone road-sides include

• Construction equipment and materials;
• Edge drop-offs;
• Severe roadside slopes;
• Existing permanent guardrail/concrete barriers;
• Exposed ends of temporary concrete barriers;
• Bridge piers;
• Bridge rail or parapet ends;
• Structure foundations;
• Excavations and rock cuts;
• A gap in the median between dual bridges; and
• Untreated guardrail ends in two-lane, two-way operations.

This list is not exhaustive, and designer experience and judgment should be used to identify other potential hazards introduced by construction activities, work zone plan, and traffic control. In assessing potential work zone hazards, it is important to keep in mind that traffic may be rerouted via diversion or median crossover. Such a change may alter the relationship (i.e., separation) between traffic and fixed features and different traffic streams (i.e., opposing traffic).

5.4 Roadside Safety and Economics

Once an obstruction or potential hazard in the work zone roadside has been identified, the question then becomes selecting the most appropriate treatment (if any) to mitigate the obstruction or hazard. Transportation agencies operate with finite resources, and roadside safety decisions should be both practical and cost-effective.

Benefit-cost analysis is “a method by which the estimated benefits to be derived from a specific course of action are compared to the costs of implementing that action” (2). The benefits usually refer to the reduced crash or societal costs as a result of decreases in the number and/or severity of crashes. The costs of implementing the action are the direct costs to the highway agency for initial installation, maintenance, and repair. If the ratio of the benefits to costs, determined by Equation 5-1 below, exceeds 1, then the benefits derived will be worth the investment over the analysis period. The benefit-cost ratio can be used to compare several different actions against each other and against the no-action option.

\[
\text{B/C Ratio}_{ij} = \frac{\text{CC}_i - \text{CC}_j}{\text{DC}_j - \text{DC}_i}
\]  

(5-1)

Where

\[
\text{B/C Ratio}_{ij} = \text{incremental benefit-cost ratio of alternative } j\text{ to alternative } i;
\]

\[
\text{CC}_i, \text{CC}_j = \text{crash or societal costs resulting from crashes under alternatives } i\text{ and } j\text{ (annualized over the analysis period)}; \text{ and}
\]

\[
\text{DC}_j, \text{DC}_i = \text{direct costs for alternatives } j\text{ and } i\text{ (annualized over the analysis period)}.
\]

Having a benefit-cost ratio greater than 1 does not alone justify the implementation of a particular alternative. Conversely, a ratio less than 1 does not imply that no action should be taken. However, observing the ratios provides designers or other decision makers with quantitative information to help in making the best investment for safety and mobility needs. To perform a benefit-cost analysis based on safety, several tools must be available for the analyst:

• A method to predict crash frequencies under all proposed options,
• A method to predict crash severities under all proposed options,
• Crash cost estimates by severity,
• Repair cost estimates by crash type,
• Installation and maintenance costs for specified safety treatments, and
• A discount rate over the analysis period.

If the appropriate information is attainable, benefit-cost analysis is a preferred method. Similar analysis has been used to revisit the median barrier warrants in the Roadside Design Guide (17). In addition, a computerized cost-effectiveness analysis procedure that is capable of evaluating alternative roadside safety treatments at spot locations over sections of roadway or is applicable to development of warrants and guidelines for safety features with different performance levels is available. The Roadside Safety Analysis Program (RSAP) was developed under NCHRP Project 22-9 (18). RSAP is intended for use in evaluating roadside safety options associated with permanent roadways. However, with adaptation of the analysis periods, an encroachment model, and roadside features to construction activities, RSAP can also be used to analyze construction work zone scenarios (see NCHRP Web-Only Document 105, Section 4.1.5.2, which is available online at www.trb.org/news/blurb_detail.asp?id=7362). This was done in order to develop the temporary barrier guidelines presented in Section 5.5.

5.5 Barrier Placement Guidance for Construction Work Zones

As discussed in Section 5.1, because of the presence of construction activities and the roadside hazards inherent within, it is often not practical to remove, redesign, or relocate potential work zone roadside hazards. Therefore, designers are
often faced with decisions regarding which hazards to shield and which device (e.g., barrier type or crash cushion) is most appropriate. State DOT work zone guidance documents devote considerable attention to these subjects. Factors and situations that are normally considered in making this decision include:

- Duration of construction activity,
- Traffic volumes,
- Nature of hazard,
- Length and depth of drop-offs,
- Work zone design speed,
- Highway functional class,
- Length of hazard,
- Proximity of traffic to construction workers and equipment,
- Adverse geometrics,
- Two-way traffic on one roadway of a divided highway,
- Transition areas at crossovers, and
- Lane closures or lane transitions.

RSAP was used to develop a benefit-cost analysis for a set of generic scenarios representing commonly occurring instances where a designer must choose whether to provide a temporary barrier to separate traffic from the work area and/or other hazards. The scenarios were based on the MUTCD Part 6H Typical Applications, as well as practitioner input. The following sections provide a short description, a graphic representation of a work zone plan and cross sections, and the benefit-cost design aid resulting from the RSAP runs for each scenario.

The design aids illustrate benefit-cost regions resulting from simulated crash analyses of the general scenarios presented. Some assumptions were made regarding crash severities, costs, and encroachment rates (see NCHRP Web-Only Document 105 Section 4.1.5.2, available online at www.trb.org/news/blurb_detail.asp?id=7362). Given these assumptions and the assumptions inherent in RSAP, the probabilistic nature of motor vehicle crashes, and the range of conditions for work zones of specific types, the results should not be used in place of more current (or site-specific) data. The following boundaries were selected for the benefit-cost regions:

- \((B/C \text{ ratio} > 1.25)\),
- \((0.75 < B/C \text{ ratio} \leq 1.25)\),
- \((0.5 < B/C \text{ ratio} \leq 0.75)\), and
- \((B/C \text{ ratio} \leq 0.5)\).

RSAP is based on a probabilistic approach to roadside safety. Further, numerous assumptions have been made in the development of RSAP and its application to work zone scenarios (e.g., construction costs and work zone configurations). Consequently, the results of RSAP (including benefit-cost ratios) should be regarded as estimates of what would occur over many repetitions of the same conditions. Real-world scenarios would rarely conform to the exact conditions modeled. Therefore, the results shown should not be regarded as precise or always-accurate indications of the cost-effectiveness of a specific barrier placement.

The benefits computed by RSAP are the reduced safety costs resulting from the placement of TCBs. There may be other benefits associated with work zone TCB installations, such as control of aggressive driving and more orderly contractor operations. These benefits and others that may result from TCB placement are not quantified in the RSAP-based analysis, nor are they reflected in the graphic design aids in this chapter. These potential added benefits may also be considered in barrier placement decisions.

### 5.5.1 Outside Lane and Shoulder Closure for Part-Width Construction on a Four-Lane Divided Highway

The scenario of a part-width construction that requires an outside lane and shoulder closure on a four-lane divided highway is depicted in MUTCD Figure 6H-33. Possible vehicle encroachments from the opposite traveled way (i.e., cross-median encroachments) are not considered. This reconstruction project scenario assumes 0.3-m [1-ft] pavement edge drop-off at the joint between travel lanes, a worker area, and one piece of heavy construction equipment. The segment analyzed is approximately 4.2 km [2.6 mi] long. For the no-barrier work zone alternative, the right edge of the travel lane was 0.9 m [3 ft] away from the pavement edge drop-off. For the barrier alternative, the edge of the barrier was placed 0.3 m [1 ft] from the pavement drop-off and was 0.6 m [2 ft] wide. Therefore, traffic on the inside lane used part of the median shoulder as a travel lane.

Exhibits 5-2 and 5-3 illustrate a plan and cross sections, respectively, for the right lane closure. The scenario was run with average daily traffic (ADT) values ranging from 10,000 to 43,500 veh/day; durations of 2 months, 4 months, and 6 months; and speed limits ranging from 50 to 120 km/h [35 to 70 mph]. The results are illustrated in Exhibit 5-4.

The benefit-cost ratios for the scenarios outlined in Sections 5.5.1, 5.5.2, and 5.5.3 are slightly different. However, from a practical standpoint, the figures illustrating the benefit-cost regions would look the same. Therefore, Exhibit 5-4 is used for all three scenarios.

### 5.5.2 Outside Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

An outside shoulder closure with minor encroachment into the traveled way on a four-lane divided highway is depicted in
Exhibit 5-2. Plan for outside lane and shoulder closure for part-width construction on a four-lane divided highway.
MUTCD Figure 6H-6. Possible types of work for this set-up are shoulder/roadside work or roadway widening (i.e., expansion from a four-lane to a six-lane highway). The scenario is different from the one in Section 5.5.1 in that the traffic is distributed over two travel lanes instead of one and the volumes observed are slightly higher.

Possible vehicle encroachments from the opposite traveled way (i.e., cross-median encroachments) are not considered. There is an assumed 0.3-m [1-ft] pavement edge drop-off at the joint between the outside travel lane and shoulder, a worker area, and two pieces of heavy construction equipment. The segment analyzed is approximately 4.0 km [2.5 mi] long. For the no-barrier work zone alternative, the right edge of the right travel lane was 0.9 m [3 ft] away from the pavement edge drop-off. For the barrier alternative, the edge of the barrier was placed 0.3 m [1 ft] from the pavement drop-off and was 0.6 m [2 ft] wide. Therefore, to maintain two 3.6-m [12-ft] travel lanes, there was a slight lane shift, and traffic on the inside lane used part of the median shoulder as a travel lane.

Exhibits 5-5 and 5-6 illustrate a plan and cross sections, respectively, for the outside shoulder closure. The scenario was run with ADT values ranging from 10,000 to 80,000 veh/day; durations of 2 months, 4 months, and 6 months; and speed limits ranging from 50 to 120 km/h [35 to 70 mph]. The results are illustrated in Exhibit 5-4.

5.5.3 Median Shoulder Closure on a Four-Lane Divided Highway with Minor Encroachment

For a four-lane divided highway requiring closure of the median shoulder with minor encroachment into the traveled way, possible types of work are shoulder/median work or roadway widening (i.e., expansion from a four-lane to a six-lane highway). This scenario is different from those in Sections 5.5.1 and 5.5.2 in that the traffic is distributed over two travel lanes instead of one and the work is adjacent to the inside (i.e., left) travel lane, which usually carries a smaller percentage of the total traffic.

Possible vehicle encroachments from the opposite traveled way (i.e., cross-median encroachments) are not considered. There is an assumed 0.3-m [1-ft] pavement edge drop-off at the joint between the inside travel lane and median shoulder, a worker area, and two pieces of heavy construction equipment. The segment analyzed is approximately 4.0 km [2.5 mi] long. For the no-barrier work zone alternative, the left edge of the inside travel lane was 0.9 m [3 ft] away from the pavement edge drop-off. For the barrier alternative, the edge of the barrier was placed 0.3 m [1 ft] from the pavement drop-off and was 0.6 m [2 ft] wide. Therefore, to maintain two 3.6-m [12-ft] travel lanes, there was a slight lane shift and traffic on the outside lane used part of the outside shoulder as a travel lane.
Exhibit 5-4. Barrier guidelines for (1) outside lane and shoulder closure for part-width construction, (2) outside shoulder closure with minor encroachment, or (3) median shoulder closure with minor encroachment on a four-lane divided highway.
Exhibit 5-5. Plan for outside shoulder closure on a four-lane divided highway with minor encroachment.

Exhibit 5-6. Cross sections for outside shoulder closure on a four-lane divided highway with minor encroachment.
Exhibits 5-7 and 5-8 illustrate a plan and cross sections, respectively, for the median shoulder closure. The scenario was run with ADT values ranging from 10,000 to 80,000 veh/day; durations of 2 months, 4 months, and 6 months; and speed limits ranging from 50 to 120 km/h [35 to 70 mph]. The results are illustrated in Exhibit 5-4.

5.5.4 Bridge Reconstruction with a Temporary Diversion/Runaround on a Two-Lane, Two-Way Highway

A bridge reconstruction project on a two-lane highway involves the construction of a two-lane diversion, or runaround, with a temporary bridge to accommodate traffic during the bridge reconstruction. It is assumed that the bridge crosses a drop-off that is 90 m [300 ft] wide and 8.0 m [26 ft] deep. Other roadside hazards include construction equipment and workers. Travel in both directions is considered.

The base condition assumes that a concrete barrier will be installed on the temporary bridge and will therefore introduce four barrier blunt ends to traffic exposure (see MUTCD Figure 6H-7). For the base condition, no additional barrier is installed to shield the blunt ends or worker and equipment areas, or to stop encroachments that may reach the drop-off. In Alternative 1, a guardrail starting at each blunt end...
end runs 15 m [50 ft] parallel to the roadway and then tapers for 43 m [140 ft] at a rate of 15:1. The multiple purposes of the guardrail are to (1) shield the barrier blunt end by providing a guardrail-concrete barrier transition (see the Roadside Design Guide Section 7.8), (2) shield the equipment and worker areas, and (3) stop an encroaching vehicle from possibly reaching the 8.0-m [26-ft] drop-off. For Alternative 2, the same length of guardrail is provided, but only on the upstream barrier blunt ends for each direction of travel. Exhibits 5-9 and 5-10 illustrate a plan and cross sections, respectively, of the bridge reconstruction with a temporary diversion.

Because of the encroachment curve for two-lane undivided highways in RSAP, an ADT of 5,000 veh/day was used for all analyses, with different durations (ranging from 1 month to 12 months) used to obtain the range of exposure. For a more detailed explanation, see NCHRP Web-Only Document 105, Section 4.1.5.2, which is available online at www.trb.org/news/blurb_detail.asp?id=7362. Speed limits ranged from 50 to 90 km/h [35 to 55 mph]. The results are illustrated in Exhibits 5-11 and 5-12.

5.5.5 Separation of Two-Lane, Two-Way Traffic on a Normally Divided Facility

When a one-way roadway on a normally divided facility is used to accommodate two-way operation, a median crossover is the infrastructure used. This scenario involves a substantial decrease in the separation of opposing traffic on higher-volume facilities, and an important design decision is whether to provide a temporary concrete barrier between the opposing directions of travel. Section 6G.15 of the MUTCD states:

> When two-lane, two-way traffic control must be maintained on one roadway of a normally divided highway, opposing vehicular traffic shall be separated with either temporary traffic barriers (concrete safety-shape or approved alternate) or with channelizing devices throughout the length of the two-way operation. The use of markings and complementary signing, by themselves, shall not be used.

A discussion of this strategy, along with an example plan and cross sections, can be found in Section 4.3 of this report. State practice varies. Some states always provide a temporary barrier between opposing directions of travel. Other states provide a barrier depending on the length of the two-lane, two-way segment. Important factors in the decision should include anticipated operating speed, volume, and the presence of restrictive cross-sectional conditions. Ross and Sicking (19) developed a roadside analysis program similar to RSAP for construction work zones. Unlike RSAP, Ross and Sicking’s program had the ability to model encroachments and head-on collisions for two-lane, two-way traffic on normally divided facilities. The guidelines from their analysis are shown in Exhibit 5-13. Regions to the right of the three line types represent benefit-cost ratios greater than or equal to 1.0.
5.5.6 Protection of a Normally Downstream Barrier End for Two-Lane, Two-Way Traffic on a Normally Divided Facility

For two-lane, two-way traffic on a normally divided facility, blunt barrier ends on bridges that are normally downstream to traffic become upstream blunt ends for traffic that has been rerouted onto the opposite roadway by a median crossover. When the opposing traffic is separated by a temporary concrete barrier, only one blunt end is exposed to traffic. Exhibits 5-14 and 5-15 illustrate a plan and cross sections, respectively, for this condition. RSAP was used to analyze the decision to shield this blunt end with a guardrail. The guardrail starts at the blunt end, runs 15.25 m [50 ft] parallel to the roadway, and then tapers for 42.70 m [140 ft] at a rate of 15:1. The purposes of the guardrail are (1) to protect the barrier blunt end by providing a guardrail-concrete barrier transition (see the Roadside Design Guide, Section 7.8) and (2) to stop an encroaching vehicle from possibly reaching the 7.9-m [26-ft] drop-off. For speed limits between 50 and 120 km/h [35 and 70 mph] (inclusive), the benefit-cost ratio exceeds 1.0 for exposure greater than $1.0 \times 10^6$ vehicle-days and exceeds 1.25 for exposure greater than $1.5 \times 10^6$ vehicle-days.

When the opposing traffic stream is not separated by a temporary concrete barrier, two blunt ends are exposed to traffic. Exhibits 5-16 and 5-17 illustrate a plan and cross sections, respectively, for this condition. Similar to the previous analysis, RSAP was used to analyze the decision to shield one (the nearest to traffic) or both blunt ends with guardrail. For the decision to shield one blunt end (the nearest to traffic), the results are similar to the condition discussed above: for speed limits between 50 and 120 km/h [35 and 70 mph] (inclusive), the benefit-cost ratio exceeds 1.0 for exposure greater than $1.0 \times 10^6$ vehicle-days and exceeds 1.25 for exposure greater than $1.5 \times 10^6$ vehicle-days. For the decision to shield both barrier ends at speed limits between 50 and
Exhibit 5-13. Barrier guidelines for separation of two-lane, two-way traffic on a normally divided facility.

Exhibit 5-14. Plan for protection of a normally downstream barrier end for two-lane, two-way traffic on a normally divided facility (with a temporary barrier separating opposing traffic).
120 km/h [35 and 70 mph] (inclusive), the benefit-cost ratio exceeds 1.0 for exposure greater than $1.0 \times 10^6$ vehicle-days and exceeds 1.25 for exposure greater than $2.0 \times 10^6$ vehicle-days.

Information contained in the *Roadside Design Guide* is not repeated or summarized here, because the *Roadside Design Guide* is updated periodically. Reliance should be placed on the current edition in its complete form.

### 5.6 Other Considerations

Various other considerations are associated with traffic barriers and roadside safety features in construction work zones. Some of the following sections reference parts of the *Roadside Design Guide*, mainly Chapter 9, which, as stated in the first paragraph of the *Roadside Design Guide* Chapter 9, “describes the safety, functional, and structural aspects of traffic barriers; traffic control devices; and safety features used in work zones; and provides guidance on their application.”

#### 5.6.1 Traffic Barriers

Section 5.5 of this report provides estimated benefit-cost ratios for the use of temporary concrete barriers. This type of barrier is the option most commonly used by state transportation agencies in construction work zones. Several other temporary traffic barrier designs are available that may be appropriate for work zone applications. Section 9.2 of the *Roadside Design Guide* discusses types of temporary concrete barrier systems as well as other types of barriers.
Exhibit 5-16. Plan for protection of a normally downstream barrier end for two-lane, two-way traffic on a normally divided facility (without a temporary barrier separating opposing traffic).
5.6.2 Length of Need

A sufficient distance of full-strength barrier upstream of the hazard will reduce the possibility that a vehicle will run behind the barrier and impact the hazard. For a discussion of length of need, see Section 5.6 of the Roadside Design Guide.

5.6.3 Flare Rates

Flare rates for temporary concrete barriers should be selected to provide the most cost-beneficial safety treatments possible. Section 9.2 of the Roadside Design Guide discusses flare rates ranging from 4:1 to 8:1 for temporary concrete barriers. These rates were developed for restricted work zones (20). Observed state practice is to use flare rates closer to those for permanent concrete barriers from Table 5.7 of the Roadside Design Guide.

5.6.4 End Treatments

Desirable end treatments for a temporary barrier are discussed in Section 9.2 of the Roadside Design Guide.

5.6.5 Crash Cushions

Crash cushions are protective systems that prevent errant vehicles from impacting obstacles by either smoothly decelerating the vehicle to a stop or redirecting it away from the obstacle. Two types of crash cushions used in work zones are stationary and mobile. For a discussion of each type, see Section 9.3 of the Roadside Design Guide.

Exhibit 5-17. Cross sections for protection of a normally downstream barrier end for two-lane, two-way traffic on a normally divided facility (without a temporary barrier separating opposing traffic).
This chapter covers a variety of work zone topics other than geometric design. Some of the sections cross-reference other publications, particularly the MUTCD and the Roadside Design Guide. Information in those two publications is not repeated or summarized here, because both publications are updated periodically and reliance should be placed on the current editions in their complete form. For subjects covered by the MUTCD or the Roadside Design Guide, limited supplemental information is selectively provided in this publication. The supplemental information does not supersede any information in either of the cited publications.

6.1 Drainage

Drainage for construction work zones has several purposes, including rapid evacuation of moisture from the driving surface, prevention of pavement structure saturation, prevention of damage to properties, and maintenance of the hydrologic systems traversed by the roadway. Provision of construction-phase erosion and sediment control, bank protection, and storm water management are important elements of work zone design. However, the associated design techniques and provisions vary substantially by geographic location, and jurisdictional requirements (e.g., permits) and are not covered in this report.

6.1.1 Basics

A well-drained driving surface, during and after construction, is needed for continued and safe operations during adverse weather conditions. The measures used to provide for drainage of permanent roadways also apply to construction work zones; however, the relatively short life span of temporary roadways in construction work zones is cause for some modification.

The Rational Equation (also known as the Rational Formula) is used in generally the same manner and with the same limitations as it is for permanent drainage structures. One difference relates to the selection of a design event (i.e., design storm), and there are differences among agency practices. Several state DOTs use the same criteria for temporary drainage structures as they would for similar structures in a permanent roadway (e.g., 25-year event for cross drain); many other agencies use different recurrence intervals for permanent and temporary installations. The AASHTO Model Drainage Manual (21) suggests using a 2-year design frequency for temporary drainage facilities (e.g., channels, culverts, and bridges) if the temporary roadway is required for a year or less, and a 5-year frequency if the roadway is required for more than a year. However, these recommendations may not be consistent with relevant jurisdictional regulations and permitting requirements. Longer recurrence intervals (e.g., 10 years) may be used for temporary bridges than for other temporary hydraulic structures.

6.1.2 Considerations Unique to Work Zones

Often, the placement of devices and infrastructure for each phase of a construction work zone is not detailed to the same level of specificity as for permanent roads. At any given point in the construction of a roadway, the driving surface and adjacent area may be a quilt-like combination of preproject, new permanent, and temporary pavements. Drainage systems are needed to accommodate each phase. The placement of inlets and connecting pipes is a principal means of capturing surface flow from roadway and roadside surfaces. The patterns, locations, and types of temporary inlets may differ from those of permanent roads. Inlets may be needed within and between travel lanes. Some agencies use longitudinal, slotted inlets, such as the one illustrated in Exhibit 6-1, for complex work zone conditions that would not exist within permanent roads. Slotted drains have several advantages that make them particularly useful in work zone application. Slotted inlets can accommodate heavy vehicular traffic in addition to bicycles. Also important, they can intercept sheet drainage and do not
require a defined depression to capture surface flow. The installation of slotted drains is relatively simple and fast. Some applications of slotted drains also pose some unique maintenance requirements, such as more frequent removal of accumulated debris.

Designers should be mindful that many roadway features (e.g., shoulders, swales, and medians) are part of highway drainage conveyance systems. Several work zone types inherently alter the design of the existing drainage system. For example, when the outside shoulder of a highway is used as a traveled lane, the potential for surface water encroachment into the temporary travel lane is elevated. The following work zone drainage issues are common:

- Temporary infrastructure (e.g., temporary concrete barrier, temporary curbs, and sandbags) may affect roadway drainage patterns, including spread into traveled lanes.
- Existing culverts may require extension to accommodate temporary roadways.
- Positive drainage for emergency turnouts (see Section 6.3) should be provided.
- When a highway with two or more lanes sloped in the same direction is milled, surface water can be trapped, as indicated in Exhibit 6-2.

The analysis and design techniques provided in state DOT drainage manuals and supplementary information sources provide the tools needed for providing work zone drainage.

Anticipation of construction phase conditions and adaptation to dynamic construction and weather conditions are central to successful execution.

### 6.2 Temporary Bridges

Temporary bridges are sometimes needed as part of temporary roadways. The functional design (i.e., structural capacity, cross section, and clearances) is generally determined by the agency. The agency may perform the detailed design or include this function as part of the construction contract. In the latter case, the functional requirements and criteria are specified in the contract along with the design criteria and other requirements. Typically, temporary bridges designed though construction contracts require approval of the transportation agency prior to their construction.

Guidance related to the hydraulic design of temporary bridges over watercourses is provided in Section 6.1.1.

### 6.3 Emergency Turnouts

Cross-sectional width is often reapportioned in work zones, resulting in the reduction or elimination of shoulders and travel lanes. Since shoulders are the traditional refuge for disabled vehicles, operators of disabled vehicles may be faced with unfamiliar conditions and a set of poor choices. The provision of emergency turnouts or intermittent shoulders mitigates cross-sectional reductions.

Agency use of emergency turnouts is mixed. Some agencies do not use them, while others do so for projects where they are considered necessary and feasible. Factors considered in determining necessity are facility type, traffic volume, vehicle mix, and length of road without a shoulder (e.g., less than 0.8 km [0.5 mi] is acceptable).

When provided, sight distance is an important consideration in emergency turnout location selection and design. Extended sight distance aids driver performance in resolving potential conflicts between traffic in the through lanes and traffic that is entering or exiting an emergency turnout. Sight distance approaching the emergency turnout facilitates a smooth departure of traffic entering the emergency turnout. Traffic departing the emergency turnout and merging into a travel lane also benefits from extended sight distance. With extended sight distance, drivers operating in the travel lanes may be able to increase gaps for entering vehicles by changing lanes or speed.

Locating emergency turnouts on flat, tangent sections of the roadway to maximize available sight distance is desirable but not always feasible. When emergency turnouts must be located near crest vertical curves, locating them in advance of the curve will maximize available sight distance for approaching traffic.

When emergency turnouts are provided, typical spacing ranges from 0.8 to 1.6 km [0.5 to 1 mi]. Terrain and other

*Exhibit 6-1. Longitudinal, slotted inlet.*

*Exhibit 6-2. Water trapped by milling.*
context considerations (e.g., structures and slopes) often determine feasible locations and spacing. Emergency turnouts should be located on the right side of the travel lanes. Left-side pullout areas violate driver expectancy and should be avoided. An example emergency turnout configuration is shown in Exhibit 6-3.

Advance construction guide signing improves the use and safety of emergency turnouts. By knowing the distance to a refuge, drivers experiencing emergencies can make informed decisions on the approach and exiting maneuvers. Signing also provides other drivers with notice of potential exiting and merging traffic. Signing should indicate the distance to the emergency turnout.

6.4 Enforcement Pullout Areas

Visible work zone law enforcement presence encourages motorist compliance with warning and regulatory signs and overall safe driver behavior. However, effective enforcement is hindered by the absence of paved shoulders or other locations where officers can safely position themselves and/or pull violators over. Including provisions for temporary enforcement pullout areas in the construction and traffic control plans may be beneficial.

6.4.1 Evaluating the Need for Enforcement Pullout Areas

One or more enforcement pullout areas may be appropriate when the following conditions exist:

- Significant enforcement is needed to achieve compliance with reduced regulatory speeds or other safety-related work zone traffic regulations, and
- There is no left or right shoulder for a distance of more than 5 km [3 mi].

Enforcement pullout areas should be a supporting feature of an enforcement plan; the enforcement areas alone will yield no compliance benefits. Assurances are needed from the jurisdictional enforcement agencies that if enforcement pullout areas are provided, they will be used.

6.4.2 Enforcement Pullout Area Design

To be both safe and effective, enforcement pullout areas should be

- Wide enough to allow the performance of enforcement activities,
- Long enough to afford safe entry to and exit from the normal traffic stream, and
- Spaced so as to be effectively used by both motorists and enforcement vehicles.

Guidance in these three areas is provided below, and an example design is provided in Exhibit 6-4.

Enforcement pullout areas should be wide enough to allow an officer to stand next to a vehicle to issue a citation. Experiences with enforcement areas for high-occupancy vehicle (HOV) lanes on high-speed roadways indicate that a minimum
of 3.6 m [12 ft] in width is required and that 4.3- to 4.6-m [14- to 15-ft] widths are desirable. A minimum width of 3.6 m [12 ft] for work zone enforcement pullouts is recommended.

Pullout areas should be long enough to provide space for the violator and the enforcement vehicle, as well as long enough to provide the opportunity for departing vehicles to accelerate slightly prior to reentering the traffic stream. Based on limited field data from enforcement activities, existing roadway design criteria for vehicle accelerations, experiences with HOV lane enforcement areas, and the preferences of law enforcement personnel, an enforcement pullout length of at least 0.4 km [0.25 mi] is recommended for high-speed roadways. Enforcement pullout areas should be located on the right side of the travel lanes. Left-side pullout areas violate driver expectancy and should be avoided.

Spacing of enforcement pullout areas should reflect a balance between enforcement and construction considerations. Excessive separation of enforcement pullouts reduces the opportunities for enforcement personnel to take action near the point of observed infractions. Conversely, closely spaced enforcement pullout areas may significantly disrupt the effectiveness and efficiency of construction operations. A spacing of approximately 5 km [3 mi] is a reasonable compromise between enforcement and contractor needs.

Sight distance considerations for enforcement pullout areas are similar to those associated with emergency turnouts (see Section 6.3).

6.4.3 Other Implementation Considerations

Enforcement pullout areas are not the only means of facilitating work zone enforcement. Project sequencing and use of other infrastructure (e.g., rest areas and weigh stations) can also be used to implement enforcement efforts. For example, a long project can be divided into segments that are 5 km [3 mi] long or shorter, and a special contract provision can be added specifying that emergency shoulders in adjacent segments must not be eliminated at the same time during the project.

One of the primary concerns of enforcement personnel in work zones is driver unpredictability once enforcement vehicle warning lights are activated to pull the driver over. The lack of a clear choice as to where to go and/or where the next opportunity to pull over is located can lead to potentially unsafe driving decisions and behaviors (e.g., slowing down excessively or even stopping in the travel lanes, or focusing attention on the enforcement vehicle behind rather than on traffic conditions ahead).

Advance construction guide signing to notify motorists of the presence of an enforcement pullout area ahead (and the distance to that area) can be helpful in reducing driver indecision and unsafe behaviors. Signing should be placed at a location to allow drivers adequate time to decide to use the enforcement pullout area and make appropriate driving adjustments.

6.5 Screens

The MUTCD Part 6 identifies and describes screens and provides guidance on their use. The Roadside Design Guide Chapter 9 also provides guidance, and both publications should be referenced.

6.5.1 Glare Screens

Glare screens are the most common category of screens and are installed between opposing-direction travel lanes to prevent high-mounted headlights from impairing the night vision of oncoming motorists and to prevent motorist distraction. Factors that are considered in providing for glare screens include traffic volume and composition (i.e., percent trucks), horizontal and vertical curvature, ambient light sources, and lateral separation between the opposing-direction travel lanes.

Glare screen types in use include vertical extension of temporary concrete barrier, commercially available paddles mounted atop temporary concrete barrier, and chain link fence with woven fabric.

6.5.2 Construction Activity Visual Barriers

Screens installed on the outside of the traveled way are less common in construction work zones. However, much of the construction activity in work zones may be an attractive distraction to motorists and interfere with their ability to successfully perform driving functions (e.g., speed, headway, and path maintenance). Visual barriers are devices that shield construction activity from driver visibility. Use of these devices, sometimes referred to as “gawk screening,” is not widespread.

6.6 Portable Changeable Message Signs

The MUTCD Part 6 and Roadside Design Guide Chapter 9 provide guidance on the use of portable changeable message signs.

6.7 Arrow Panels

The MUTCD Part 6 and Roadside Design Guide Chapter 9 provide guidance on the use of arrow panels, which are also known as flashing arrow boards and flashing arrow signs.

6.8 Lighting

Lighting for construction work zones includes units that are part of temporary traffic control devices (e.g., beacons, warning lights, and steady burn lights). Work zone guidance and specifications are included in the MUTCD Part 6.
Flood lighting and conventional highway lighting are sometimes provided in construction work zones. The provision of floodlights to illuminate nighttime construction activity (e.g., paving operations and flaggers) may be specified by the agency or identified as a contractor responsibility. Factors that must be considered in this decision are the vision and comfort of drivers and the ability of the workers to perform different types of tasks. Guidelines for illumination criteria are identified in *NCHRP Report 498* (22). Examples that use these guidelines and that illustrate important procedures and considerations of temporary lighting for the purpose of night work can be found in *NCHRP Report 476* (23).

Conventional highway lighting that is present in pre-work zone conditions should normally be maintained during construction projects. If individual lighting units are removed from service during construction, temporary units should be considered.

The provision of temporary highway lighting generally considers the same warrants and criteria used for permanent lighting to address issues such as high night-to-day crash ratios, high traffic volumes, high traffic speeds, substantial queuing, complex maneuver areas, restrictive roadway geometry, and high pedestrian volumes. Warrants for highway lighting have been developed for permanent roadways, but because of the complexity of the warrants, they have not been put into widespread use. Experience and judgment have historically been relied upon to determine whether the resulting safety benefits justify the cost of lighting.

The most commonly used lighting design criteria have been based on a set magnitude and uniformity of illuminance, a measure of the amount of light falling on a surface, and on luminance, a measure of the amount of light reflecting from the surface. Guidelines for these criteria have been published by AASHTO and the Illuminating Engineering Society of North America (IESNA).

### 6.9 Rumble Strips

The MUTCD Part 6 provides guidance on the use of rumble strips.

Several temporary transverse rumble strip configurations are in use. One configuration is sawed or milled into existing asphalt pavement. Another configuration is raised above existing (i.e., preproject) travel lane pavements. Within this configuration, individual strips may consist of basic pavement material (e.g., asphalt) or manufactured materials (e.g., removable neoprene or multiple layers of traffic tape) fastened to the road surface. The depth (i.e., thickness) of typical installations is approximately 0.64 cm [0.25 in.]. Several clusters of temporary rumble strips are generally placed in advance of a segment or feature where reduced speed or elevated driver awareness is desirable. A number of patterns have been evaluated. A common cluster configuration consists of six individual rumble strips, each separated by distances ranging from 0.5 to 3.0 m [1.5 to 10.0 ft]. Within a cluster, spacing between individual strips may be uniform or irregular (24).

Research on the effectiveness of transverse rumble strips on reducing work zone speeds is inconclusive (25).

Several work zone strategies (e.g., median crossover or use of shoulder) reallocate the roadway cross section, which changes the relationship between wheel paths and the existing edge or shoulder rumble strips. Depending on the pavement material, type of rumble strips, location of wheel paths relative to rumble strips, and duration of temporary reallocation, the rumble strips may be modified, such as by paving over portions of the rumble strips.
References

Supplemental Materials

The following materials are available for free online at www.trb.org/news/blurb_detail.asp?id=7362:

- The research team’s final report for this project (a PDF listed as NCHRP Web-Only Document 105)
- The work zone speed prediction model (an Excel file)
- A user’s manual (a PDF)
<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>AAAE</td>
<td>American Association of Airport Executives</td>
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<tr>
<td>AASHTO</td>
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<tr>
<td>ACI–NA</td>
<td>Airports Council International–North America</td>
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<td>ACRP</td>
<td>Airport Cooperative Research Program</td>
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<td>ADA</td>
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<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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