PART 5

Traffic and Safety

Archived December 31, 2012

NOTE: **Revisions to these chapters occurring after January 1, 2012 are not included in this document, but have been included in the 2013 *Indiana Design Manual*. Users should consult Design Memoranda issued during 2012 for details related to revisions to this manual between January 1, 2012 and January 1, 2013.**

CHAPTER 502

Traffic Design

Design Memorandum	Revision Date	Publication Date*	Sections Affected
12-11	June 2012	Jan. 2013	75-4.07
12-13	June 2012	Jan. 2013	77-5.09, Figure 77-5DD
12-14	June 2012	Jan. 2013	77-6.03, Figure 77-6A

*Revisions will appear in the next published edition of the *Indiana Design Manual*.

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CHAPTER SEVENTY-FIVE

HIGHWAY SIGNS

The majority of the information required for the selection, design, and placement of highway signs is shown in the *Manual on Uniform Traffic Control Devices (MUTCD)* and the INDOT *Standard Drawings*. The intent of this chapter is not to reiterate the information presented in these sources, but rather to supplement these references and, where deemed necessary, to provide the user with additional guidance.

75-1.0 MUTCD CONTEXT

Throughout the *MUTCD*, the words *shall*, *should*, and *may* are used to describe the appropriate application for various traffic-control devices. The *MUTCD* defines these terms as follows:

1. Shall. A mandatory condition. Where certain requirements in the design or application of the device are described with this stipulation, it is mandatory where an installation is made that such requirements be met.

2. Should. An advisory condition. Where this stipulation is used, it is considered to be advisable usage, recommended but not mandatory.

3. May. A permissive condition. No requirement for design or application is intended.

The *MUTCD* shall prevail on each public highway or street in which Federal funds will be or were used.

The *MUTCD* shall prevail on the National Highway System regardless of the funding source.

75-2.0 GENERAL CRITERIA

A sign should only be used where it is warranted by the *MUTCD* criteria, accident history, or field studies. A sign should provide information on special regulations, for hazards which are not self-evident, or for highway routes, directions, destinations, or points of interest. Each traffic-control device should be in accordance with the basic requirements as follows.

1. It should be capable of fulfilling an important need.

2. It should command attention.
3. It should convey a clear, simple meaning.
4. It should command respect of road users.
5. It should be located to give adequate time for response.
6. It must be sanctioned by law if it controls or regulates traffic.

75-2.01 References

The following is the recommended list of publications for selecting, designing, manufacturing, or installing highway signs.

1. *Manual on Uniform Traffic Control Devices*, FHWA;

2. *Traffic Control Devices Handbook*, FHWA;

3. *Standard Highway Signs*, FHWA;

4. *INDOT Standard Highway Signs*;

5. *Standard Alphabets for Highway Signs and Pavement Markings*, FHWA;

6. *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, AASHTO;

7. INDOT *Standard Specifications*;

8. *Traffic Engineering Handbook*, Institute of Transportation Engineers;

9. Chapter Forty-nine of this *Manual*; and

10. *Manual of Steel Construction*, American Institute of Steel Construction.

The INDOT publications may be obtained by contacting the Traffic Control Systems Division. For other publications, the indicated source should be contacted.

75-2.02 Reflectorization

All signs should be reflectorized. The INDOT *Standard Specifications and Standard Drawings* provide the reflectorization criteria for signs. Illumination will be required only as described in

Section 75-2.03. The reflective-sheeting type should not be shown on the plans, and is not included in the pay-item names. For a local facility, reflectorization of signs will be based on the city or county's preference. For additional information on reflective materials, the publications that can be reviewed are as follows:

1. *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide*, FHWA/DF-88/001, November 1987.

2. NCHRP Report 346, *Implementation Strategies for Sign Retroreflectivity Standards*, TRB, April 1992.

3. ASTM Designation: D4956 *Standard Specification for Retroreflectivity Sheeting for Traffic Control*, latest version.

75-2.03 Illumination

Most signs are designed to be illuminated by vehicular headlights and the sign message reflected back to the driver. Therefore, external sign lighting and related appurtenances such as a sign walkway will not be required for an overhead-sign or box-truss structure, and should not be shown on the plans.

However, conduit should be specified to be installed in the foundations. A structure handhole should be specified to be placed toward the base of the sign support. A grounding system should be specified.

Sign-structure mounting height should be specified as described in Section 75-2.03, if a lighting-support assembly or walkway must be retrofitted.

Lighting may be provided for the sign preceding a truck weigh station which indicates that the station is open or closed. This is accomplished with an internally-lighted sign.

75-2.04 Sign Placement

The *MUTCD* and the INDOT *Standard Drawings* provide criteria for the placement of a sign next to or over the roadway. These sources also provide criteria for the maximum and minimum allowable sign heights.

A warning sign is to be placed in advance of the condition to which it calls attention. A regulatory sign is placed where its mandate or prohibition applies or begins. A guide sign is placed at a variable location to inform drivers of their route of travel, destination, or point of interest.

The uniform position of each sign, although desirable, is not always practical to achieve because the alignment and design of the road often dictates the most advantageous position for the sign. For determining the sign location, the designer should review the guidelines as follows.

1. A sign should be placed on the driver's right side. A sign may sometimes be placed on a channelizing island or overhead or, where there are short sharp curves to the right, it may be placed on the driver's left side directly in front of the driver.

2. A dual-mounted sign may be considered for additional emphasis where it is anticipated that a single sign may not provide adequate warning, such as at an intersection just beyond a sharp horizontal curve or at a location where a driver may be required to make an unexpected maneuver.

3. Sign placement and the roadway geometric design should be coordinated as early as practical during the project planning and design stages. If a roadway design does not permit adequate placement of the required signs, the geometric design may need to be revised accordingly. An improper geometric design cannot always be corrected by signing.

4. Where lane control is desired, a sign should be placed directly over its affected lane.

5. Each sign should be located to optimize nighttime visibility.

6. Adherence to the criteria provided in the *MUTCD* and INDOT *Standard Drawings* is not always practical. Actual sign placement may be adjusted to meet field conditions. The placement problem areas that should be avoided are as follows:

   a. at a short dip in the roadway;

   b. beyond the crest of a vertical curve;

   c. where a sign may be obscured by parked cars;

   d. where a sign would create an obstruction for pedestrians or bicyclists;

   e. where a sign would interfere with a driver's visibility to hazardous locations or objects;

f. where sign visibility would be impaired due to existing overhead illumination;

g. where a sign is vulnerable to roadside splatter or to being covered with snow by plowing operations; or

h. too close to trees or other foliage that could cover the sign face now or in the future.

7. A sign's location can sometimes be shifted longitudinally without compromising its intended purpose. This may improve its visibility, avoid blocking other signs, enhance safety, or enhance traffic operations (e.g., by providing more distance between signs in a series).

8. Each sign should be erected individually on separate posts or mountings. However, it may be appropriate to group signs (e.g., route-marker assemblies) with consideration for wind loading and breakaway characteristics.

9. The INDOT *Standard Drawings* provide criteria for the lateral clearance of roadway signing. The designer should also review Section 75-2.05.

10. Each wide-flange post installation should include a perforated fuse plate as well as a perforated hinge plate. A note on the plan sheet and wide-flange sign summary sheet should also be included, so that the contractor will install the structure accordingly.

75-2.05 Roadside Safety

Chapter Forty-nine describes the Department's criteria for clear zones, roadside barriers, impact attenuators, and other roadside safety issues. These are also applicable to roadside signs. The designer should also consider the following.

1. Ground-Mounted-Sign Support. The support for each ground-mounted sign should be made breakaway or yielding, including that outside the clear zone. Posts should be of the square cross section type shown on the INDOT *Standard Drawings*. However, for a local agency project, channel posts may be used if desired by the local agency. A new sign support behind guardrail should have adequate clearance to the back of the guardrail post to provide for the guardrail's dynamic deflection (see Section 49-4.0).

2. Overhead-Sign Support. The support for each overhead sign should be non-breakaway. Each overhead-sign structure inside the clear zone must be protected with guardrail or, where applicable, with an impact attenuator. In a median, an overhead-sign support should be protected as follows.

a. If the distance between the sign support and the edge of the travel lane or auxiliary lane is 25 ft or less, an impact attenuator should be used.

b. If the distance between the sign support and the edge of the travel lane or auxiliary lane is greater than 25 ft, a gravel barrel array should be used.

See Section 49-6.0 for additional information on the design and layout of impact attenuators.

3. Ground-Mounted Panel Sign. A sign of over 48 ft^2 in area on slipbase breakaway supports should not be placed where the opportunity exists for it to be struck at a point that is more than 9 in. above the normal point of vehicular bumper impact. Normal bumper height is 1'-6". To avoid being struck at an improper height, a sign should be placed as follows.

   a. Fill Slopes Flatter than 4:1. A sign should be located a minimum of 30 ft from the edge of the travel lane to the nearest edge of the sign.

   b. Fill Slopes 4:1 or Steeper. The nearest sign edge should be located 6 ft from the edge of shoulder or 12 ft from the edge of the travel lane, whichever is greater.

4. Roadside Appurtenance. A large breakaway sign support should not be located in or near the flow line of a ditch. If such a support is placed on a backslope, it should be offset at least 3 ft from the toe of the backslope of the ditch.

5. Exit Gore Sign. An exit gore sign should be placed in each gore area of a freeway as shown on Figure 75-2C, Sign Gore Treatment.

75-2.06 Overhead Panel Sign

The following provides guidelines to consider in whether to place an overhead or ground-mounted panel sign.

1. Lane Control. An overhead sign should be considered where the message is applicable to a specific lane. If the sign is placed over the lane, lane use can be made significantly more effective, especially where additional guidance is required for a driver who is unfamiliar with the area.

2. Visibility. An overhead sign should be considered where traffic or roadway conditions are such that an overhead mounting is necessary for adequate visibility (e.g., vertical or horizontal curve, closely spaced interchanges, three or more through lanes in one direction).

3. Divergent Roadways. An overhead sign should be considered at, or just in advance of, a divergence from a heavily traveled roadway (e.g., at a ramp exit where the roadway becomes wider and a sign on the right side is usually not in the line of sight for the driver).

4. Exit. An overhead panel sign should be considered where left-hand or multi-lane exit ramps are in place.

5. Interchange. An overhead panel sign should be considered at a complex interchange where there may be driver confusion, where there are closely-spaced interchanges, Interstate-to-Interstate interchanges, or where there are lane drops on the exit ramp or mainline within the interchange.

6. Trucks. An overhead sign should be used where there are significant numbers of large trucks which may block a passenger-car driver's visibility to a ground-mounted sign.

7. Limited Right of Way. An overhead panel sign should be considered where there is limited space for a sign on the roadside (e.g., where right of way is narrow).

8. Roadside Development. An overhead sign should be considered where roadside development seriously detracts from the effectiveness of a roadside sign (e.g., a brightly-lighted area).

9. Uniformity. An overhead sign may be used to be consistent with other signs on a given section of highway.

Each new overhead sign installation will require a minimum vertical clearance of 17’-6” above the roadway and shoulders but not greater than 18’-0”. This includes an additional 6 in. clearance for a future overlay. An existing overhead sign may have a vertical clearance of 17’-0”.

Where sign lighting is used, an overhead sign should not be placed on a bridge overpass. A non-lighted sign may be placed on an overcrossing structure provided that the vertical clearance of the sign exceeds the vertical clearance of the overcrossing structure by at least 6 in.

75-2.07 Sign Priority

Providing motorists with too much information may cause improper driving and impair safety. Therefore, some sign information should be removed, replaced, or relocated. Where sign-information overload may be a problem, the following lists the recommended priority for sign types.

1. regulatory (e.g., speed limit, stop, turn prohibition);

2. warning (e.g., curve, crossroad, narrow bridge);
3. guidance (e.g., destination, routing);
4. emergency services (e.g., hospital, telephone);
5. motorist services (e.g., fuel, food, camping);
6. public-transportation (e.g., park and ride, bus stop);
7. traffic-generators (e.g., museum, stadium, historic building); and
8. general information (e.g., county line, city limit).

Within the various sign groups, the sign bearing the most important message should supersede the others.

75-2.08 Computer Software

There are many computer software programs available that may be used in the design of highway signing including sign layouts, legends, quantities, structural supports, etc. The designer should be aware that not all software packages are applicable to Indiana. Therefore, the user should first contact the Traffic Control Systems Division to determine which programs and versions are acceptable for use for a project. The following is a brief summary of the programs currently acceptable to the Department.

1. SignCAD 2000. This program helps the designer determine the appropriate panel size for each guide sign along a freeway. The program was developed by Berg and Effrem, Inc.

2. GuidSIGN. This program provides the designer with standardized guide-sign layouts, text fonts, letter spacing, and sign sizes. The program was developed by Transoft Solutions.

Addresses or contacts for the software companies listed above may be obtained from the Traffic Control Systems Production Management Division.

75-2.09 Symbology

Where the *MUTCD* permits the use of either words or symbols on the sign, the preferred practice is to use only the symbol message.

75-2.10 Structural Design

The INDOT *Sign Design Guide* provides the Department's criteria for foundation design, sign structure design, I-beam post selection, etc. Copies of this publication can be obtained from the Traffic Control Systems Division.

75-2.11 Applications

All placement and usage of signs should follow the criteria described in the *MUTCD* and INDOT *Standard Drawings*. The use of an experimental traffic control device is acceptable provided that its approval is in accordance with the criteria shown in the *MUTCD*. Figure 75-2D, Sign Types, provides guidelines for general usage of each sign type. The following sections on regulatory, warning, and guide signs provide additional guidance or supplementary information for specific signs. For all signs, including those in the following sections, the references in Section 75-2.01 should be reviewed to determine the appropriate sign application.

75-3.0 REGULATORY SIGNS

75-3.01 Official Action

An Official Action will be required if there is a proposed change in the regulatory nature of a sign or situation affecting a facility. For example, an Official Action is required if changes are made to the intersection control, parking restrictions, no-passing zones, traffic signals, or certain work-site speed zones (e.g., installing a stop sign at an existing uncontrolled intersection). For a Department-maintained facility, the designer must obtain an approval for the proposed change from the appropriate district traffic engineer prior to implementation of the change. For a local facility, approval must be obtained from the appropriate jurisdiction prior to implementation.

75-3.02 "Stop" or "Yield" Sign

75-3.02(01) General

A "Stop" sign should be installed at each at-grade, non-signalized local road or street which intersects a Department-maintained highway. A "Yield" sign may be used if the intersection is operating in a merge condition (e.g., channelized intersection with a turning roadway) or at an entrance ramp to an access-controlled facility.

For a local facility, the warrants provided in the *MUTCD* should be followed. For additional information, the following publications may be reviewed to determine the need for a "Stop" or "Yield" sign.

1. *Stop, Yield, and No Control at Intersections*, Report No. FHWA/RD-81/084, FHWA, June 1981; or

2. NCHRP 320, *Guidelines for Converting Stop to Yield Control at Intersections*, TRB, October 1989.

75-3.02(02) Multiway Stop Control

The *MUTCD* describes the warrants for where a multiway "Stop" sign installation may be considered. However, it should not be used unless the traffic volume for each approach leg of the intersection is approximately equal. A traffic signal is the preferred traffic-control device for an intersection with heavy traffic volume.

A multiway stop control is frequently used in a residential area. The following lists guidelines for the installation of a multiway stop control in a residential area.

1. <u>Collector Streets</u>. At the intersection of two collector streets that are primary to the area.

2. <u>Four-Way Intersection</u>. Where there is a 60-40 percent (or closer) volume split for the intersection.

3. <u>Three-Way Intersection</u>. Where there is a 75-25 percent (or closer) volume split for the intersection.

4. <u>Accidents</u>. Where there are three or more accidents in one year's time.

75-3.02(03) Stop Sign at Railroad Crossing

A "Stop" sign may be placed at each roadway approach to a railroad crossing where two or more trains cross per day and is without automatic traffic-control devices. For a crossing with passive protection, a "Stop" sign may be placed after a need has been established by a traffic-engineering study. The study should consider such factors as volume and character of highway and train traffic, adequacy of stopping sight distance, crossing accident history, and need for active control devices. Where a "Stop" sign is installed, a "Stop Ahead" advance warning sign should also be installed.

<u>75-3.03 Speed Limit Sign</u>

The district traffic engineer is responsible for determining the speed limits on each Department-maintained facility. Each request for a speed-limit determination must be transmitted to the appropriate district office. For a local facility, each local jurisdiction is responsible for determining the appropriate speed limits within its boundaries. This typically occurs after a speed study has been conducted. When determining a speed limit, the considerations are as follows:

1. the 85th-percentile speed;
2. the design speed used during project design;
3. the road-surface characteristics, shoulder condition, grade, alignment, and sight distance;
4. functional classification and type of area;
5. type and density of roadside development;
6. the accident experience during the previous 12 months;
7. parking practices and pedestrian activity; and
8. the maximum or minimum speed permitted by State law.

The *MUTCD* indicates the elements that should be reviewed in an engineering study. The ITE *Manual of Traffic Engineering Studies* provides guidance on how to conduct a speed study. Each public road's speed is controlled by means of a regulatory speed limit, either through a "Speed Limit" sign or a speed limit established by State law. Section 40-3.02(03) lists the maximum and minimum legal speed limits for a rural or urban area and for a State or local facility.

75-3.04 "No U-Turn" Sign

On a freeway, the "No U Turn" sign should be placed at each median crossover. This sign should be placed at the far side of the median crossover for oncoming traffic.

75-3.05 Lane-Use Control Signs at Intersection

An overhead lane-use control sign should be placed at a major urban intersection where left- and right-turn lanes are provided or where there is the possibility of confusion at the intersection.

75-3.06 "Right Turn Only" Sign

Where an exclusive right-turn-only lane is provided, the use of an overhead sign should be considered where background clutter may be a problem. If background clutter is not a problem, a ground-mounted sign may be as visible and may be more cost effective.

75-3.07 Two-Way Left Turn Only (TWLTO) Signs

An overhead lane-control sign should be provided at the beginning and end of a two-way left-turn-only lane. In an urban area, one should also be placed at approximately every 1000 ft along the lane. In a suburban or built-up rural area, the intermediate TWLTO sign spacing may be increased to 1200 ft. For the beginning and end, the supplementary "Begin" and "End" plates should also be included.

A TWLTO sign should also be used on the back side of a "Left Turn Only" sign where a two-way left-turn-only lane is transitioned into a one-way left-turn lane. The supplementary "Begin" and "End" plates are not included for this situation. Section 76-2.05(02) illustrates the pavement markings used for this transition.

The preferred practice is to install the signs as ground-mounted. Signs should be placed on an overhead structure only if the district traffic engineer deems necessary.

75-3.08 "No Passing Zone" Sign

The beginning of a no-passing zone is marked with a "No Passing Zone" sign on the driver's left side of the roadway. The end of the zone is indicated with a sign post installed on the driver's right side of the roadway with three white delineators attached. A "No Passing Zone" sign is not required for a zone marked due to presence of a railroad crossing, nor at a zone marked due to presence of an intersection or in an urbanized area.

75-3.09 Parking Signs

The generic "No Parking" sign should be used where practical on a Department-maintained facility. Where necessary, signs with other messages regarding parking restrictions or permissions may be used as shown in the *MUTCD*.

75-3.10 "No Turn On Red" Sign

A right turn at a red light after a stop is permitted at each intersection leg unless the leg is signed to prohibit it. Where two one-way streets intersect, a left turn at a red light after a stop is permitted at each applicable intersection leg unless the leg is signed to prohibit it. After conducting an engineering study as defined in the *MUTCD*, the designer will submit a recommendation on the need for eliminating turn-on-red movements to the district traffic engineer or to the appropriate local jurisdiction. The district traffic engineer or local jurisdiction will have final approval for each turn-on-red restriction. Once the decision has been made to eliminate the turning movement, the proper "No Turn On Red" sign should be placed as specified in the *MUTCD*.

75-4.0 WARNING SIGNS

A warning sign is used where it is deemed necessary to warn a driver of an existing or potentially hazardous condition on or adjacent to a highway or street. Each warning sign must be located in advance of the condition to which it applies. The use of warning signs should be kept to a minimum. Overuse of warning signs at an obvious hazardous location tends to cause non-compliance for all signs. The following provides additional guidance for the placement of warning signs.

75-4.01 Placement of Advance Warning Sign

Figure 75-4A, Suggested Minimum Distances for Placement of Advance Warning Signs, provides the suggested minimum distances for preliminary placement of advance warning signs. The final location for each warning sign will be determined during the field check in conjunction with INDOT or local agency personnel. The distances in Figure 75-4A are based on the conditions which are defined by the *MUTCD* as follows.

1. Condition A. A high driver-judgment condition which requires the driver to use extra time in making and executing a decision because of a complex driving situation.
2. Condition B. A condition in which the driver will likely be required to stop.
3. Condition C. A condition in which the driver will likely be required to decelerate to a specific speed.

If these distances cannot be achieved, other measures should be considered to attract the motorist's attention to the sign. These additional measures will be determined as required for each site.

For those warning signs typically used by the Department, Figure 75-4B indicates which of the three Conditions will most likely apply. The following examples illustrate how to use Figures 75-4A and 75-4B, Conditions for Placement of Advance Warning Sign.

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Example 75-4.1

Given: Stop-controlled intersection

Posted speed limit on stop-controlled leg is 50 mph

Problem: Where to place a "Stop Ahead" sign

Solution: From Figure 75-4B it is determined that the "Stop Ahead" sign is a Condition B category (i.e., the driver must stop). From Figure 75-4A, the set-back distance from the "Stop" sign should be 375 ft.

If the sign cannot be adequately placed at a set-back distance of approximately 375 ft, then other measures may be required to provide additional emphasis to the warning sign.

<u>Example 75-4.2</u>

Given: A 45-mph horizontal curve
Posted speed limit 55 mph

Problem: Where to place an Advance Curve symbol sign

Solution: From Figure 75-4B it is determined that the Advance Curve symbol sign is a Condition C category (i.e., the driver must slow down from 55 mph to 45mph). From Figure 75-4A, the minimum set-back distance from the horizontal curve's PC is shown to be 180 ft.

An Advisory Speed "45 MPH" plate indicating that the maximum recommended speed for negotiation of the curve is 45 mph should also be used.

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75-4.02 Advance Turn or Advance Curve Symbol Sign

The *MUTCD* describes several horizontal-alignment signs, but it does not fully identify where to use these signs. The decision on using an advance turn or curve symbol sign is dependent upon many factors including posted speed, alignment, accident history, etc. It would be impractical and uneconomical to place an advance warning sign at every horizontal curve. Before using an advance turn or curve sign, the designer should consider the following:

1. <u>Speed Determination</u>. In determining whether or not to place an alignment warning sign and advisory speed plate, the designer first must determine the appropriate speed for negotiating

the curve. If the curve radius and superelevation rate are known (e.g., from construction plans), then the appropriate negotiation speed can be calculated (see Section 43-2.0). If the radius of the curve is unknown, then a field study is warranted. This type of study is done using a ball-bank indicator.

The ball-bank indicator test involves driving a test vehicle around a curve at various speeds and reading a curved level to determine an appropriate negotiation speed for the curve. Figure 75-4C, Ball-Bank Indicator Readings, lists the various maximum recommended negotiation speeds for a curve based on several ball-bank readings. Test runs should be conducted in both directions.

2. Highway Alignment. The designer should review the overall highway alignment to determine if advance curve signs are warranted. An unexpected curve after a long tangent section is a likely candidate for placement of an advance curve sign. Conversely, curves on a winding highway may not warrant the use of an advance curve sign because the driver will be expecting the curve. An advance curve sign should always be provided where the vertical alignment obstructs the driver's vision of the horizontal curvature.

3. Posted Speed. Relative to the posted speed, the designer should consider the following:

   a. A highway with a posted or statutory speed limit of lower than 30 mph will not warrant an advance warning sign.

   b. An advance curve sign should be considered if the maximum recommended negotiation speed of the curve is found to be more than 12 mph below the posted speed limit.

4. Accident History. The accident history should be reviewed to determine if there is a disproportionate number of run-off-the-road accidents that can be attributed to the horizontal curve. A high-accident location will most likely warrant an advance curve sign, an Advisory Speed plate, or Chevron symbol signs.

5. Driver Familiarity. A highway serving local needs (e.g., collector or local road) will rarely warrant advance curve signs because the typical driver will be aware of the restrictive alignment. However, on an arterial or a recreational road, the typical driver may be less familiar with the highway, so it may require additional warnings.

6. Area Classification. An urban area will not warrant the use of advance curve signs because speeds tend to be lower and there is greater driver familiarity and awareness.

7. Public Reaction. Local residents have some indication of how drivers are reacting to a horizontal curve. If there are no complaints relative to near misses or accidents, the curve will probably not warrant the need for signing. Frequent complaints usually warrant further investigation.

8. Advance Turn Versus Advance Curve Symbol Sign. If it is determined that an advance alignment warning sign is warranted, the *MUTCD* recommends that an Advance Turn symbol sign be used if the curve's maximum recommended negotiation speed is 30 mph or lower. An Advance Curve symbol sign should be used if the curve's maximum recommended negotiation speed is higher than 30 mph.

9. Advisory Speed Plate. If an Advance Turn symbol sign is to be placed, an Advisory Speed plate should also be placed showing the maximum recommended speed. For an Advance Curve symbol sign, an Advisory Speed plate should be placed if the recommended negotiation speed of the curve is more than 12 mph lower than the posted speed limit. An Advisory Speed plate is not required where the curve-negotiation speed is equal to or higher than the posted or statutory speed limit.

10. Combination Curve. A combination curve consists of two or more successive curves. They may be connected with or without a short tangent section, and they may be in the same or in opposite directions. If either of the curves requires an Advance Curve or Advance Turn symbol sign, a Reverse Curve symbol sign should be used instead. For three or more successive curves, the Winding Road symbol sign should be used. If an Advisory Speed plate is necessary, the lowest recommended negotiation speed for all of the curves should be shown on the plate.

75-4.03 Chevron Symbol Sign

A Chevron symbol sign should be used where there is a history of run-off-the-road accidents in conjunction with a horizontal curve. The Department's practice is to install at least three Chevron symbol signs. The *MUTCD* provides the criteria for placement of such signs.

75-4.04 Signal Ahead Symbol Sign

The need for the Signal Ahead symbol sign will be determined for each signalized intersection based on the accident history and sight-distance restrictions. Typical locations for a Signal Ahead symbol sign include an isolated signalized intersection or in advance of the first intersection in a series of signalized intersections. They are not used in an urban area with multiple signalized intersections.

75-4.05 Advisory Exit Speed Sign

An Advisory Exit Speed sign should be placed at each exit-ramp gore where the ramp design speed is lower than the mainline design speed. The "Exit ____ MPH" sign may be used on the ramp. If the ramp connects two freeways or expressways, the "Ramp ____ MPH" sign should be used.

75-4.06 Advance Street or Road Name Sign

An Advance Street or Road Name sign may be provided before each major street crossing. On a Department-maintained facility, a sign is usually not provided for a minor street crossing. This supplementary sign is used in conjunction with the Cross Road, Side Road, or Signal Ahead symbol sign.

75-5.0 GUIDE SIGNS

The *MUTCD* provides the criteria for the placement and design of guide signs. In addition, the following provides supplemental information relative to guide signs.

75-5.01 Distance Sign

A Distance sign can display two or three destination points and the distances to these destinations. Destination points should be arranged on the Distance sign as follows:

1. Top Line. The top line should include the name of the next meaningful community, number of the next intersecting route, or name of the next intersecting highway, and distance in miles to it, on which the traveler's route passes.

2. Middle Line. The middle line, if used, should include the name of a community, number of an intersecting route, or name of an intersecting highway, and distance in miles to it, that is beyond the destination listed in the top line and is of general interest to the traveler. Figure 75-5A provides a list of the regional control cities for use on distance signs along the Interstate system. Regional control cities are the intermediate cities between the major control cities that are located within the State's boundaries.

3. Bottom Line. The bottom line should include the name of the next national control city and the distance in miles to it. Figure 75-5B provides a list of the major control cities for use on

distance signs along the Interstate system. National control cities are those cities which have national significance for the through traveler.

75-5.02 Logo Signing

A Logo sign is a specific-informational panel that has a separately-attached sign consisting of a single or multicolored symbolic design unique to a product, business, or service facility. It is used to identify traveler services that are available on a crossroad at or near an interchange or an intersection. Information on INDOT's logo signing policy can be found in the State statutes or by contacting the Highway Operations Division. These signs are placed and maintained through a contract with INDOT. However, Logo signs are a part of the INDOT signing system. They may be relocated or temporarily removed as deemed necessary by the contractor. The *MUTCD* should be consulted in the design, layout, and placement of each Logo sign.

75-5.03 Supplemental Guide Signs

Figure 75-5C describes the Department's general guidelines for determining the eligibility of traffic generators (cities, attractions, other major traffic generators) to place a permanent tourist-oriented directional sign or other supplemental information guide sign along a Department-maintained highway. If the designer is requested to install new such signage, he or she should contact the Highway Operations Division or the district traffic engineer for more information on the Department's supplemental-guide-signage policy.

75-5.04 Guide Signs for Interchange Crossroads

The design and layout criteria for Advance Exits and Directional signs on a freeway are clearly defined and shown in the *MUTCD*. Figures 75-5D through 75-5Q illustrate INDOT's preferred practice for the placement of Directional signs along the crossroad approaching an interchange. Figure 75-5D lists the guidelines for which sign layout plans shown in Figures 75-5E through 75-5Q should be used for the various interchanges and crossroad types. The figures and the titles are listed below.

75-5D	Typical Crossroad Signing at Freeway Interchange
75-5E	Diamond Interchange Signing (Freeway Under Divided Highway)
75-5F	Diamond Interchange Signing (Freeway Over Divided Highway)
75-5G	Diamond Interchange Signing (Freeway Under Undivided Highway)
75-5H	Diamond Interchange Signing (Freeway Over Undivided Highway)
75-5 I	Full Cloverleaf Interchange Signing (Freeway Under Divided Highway)

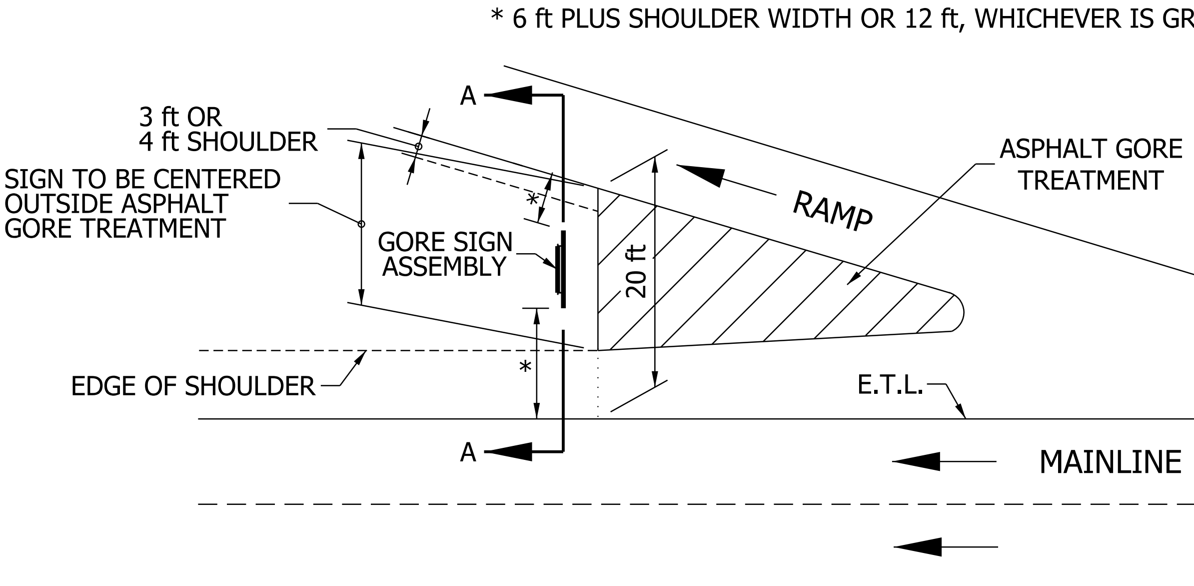
75-5J	Full Cloverleaf Interchange Signing (Freeway Over Divided Highway)
75-5K	Full Cloverleaf Interchange Signing (Freeway Under Undivided Highway)
75-5L	Full Cloverleaf Interchange Signing (Freeway Over Undivided Highway)
75-5M	Partial Cloverleaf Interchange Signing (Freeway Under Divided Highway)
75-5N	Partial Cloverleaf Interchange Signing (Freeway Over Divided Highway)
75-5 O	Partial Cloverleaf Interchange Signing (Freeway Under Undivided Highway)
75-5P	Partial Cloverleaf Interchange Signing (Freeway Over Undivided Highway)
75-5Q	Trumpet Interchange Signing System (One Road Terminates)

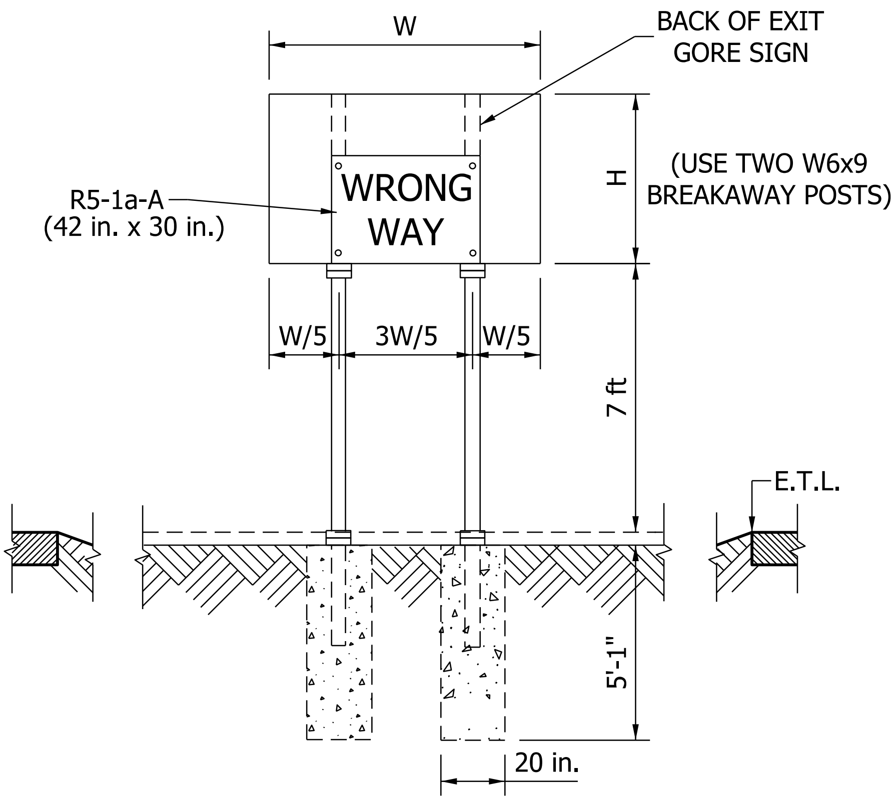
See the INDOT *Standard Drawings* for ground-mounted panel-sign wide-flange posts quantities, length, and size determination.

75-5.05 Street Name Sign

A Street Name sign is very helpful to the motorist and should be legible for a sufficient distance in advance of the cross street to permit the motorist to perceive and react in time to make the desired maneuver in a safe manner. In order to provide adequate sign visibility, sign letter heights should be as follows:

1. Ground-Mounted Sign.
   a. Posted speed limit ≥ 30 mph.
      (1) Upper-case letters: Series C or D, 6 in. height
      (2) Lower-case letters: Series C or D, 4½ in. height
   b. Posted speed limit ≤ 25 mph: Upper-case letters only, Series C or D, 4 in. height.
2. Overhead Sign.
   a. Upper-case letters: Series EM, 8 in. height.
   b. Lower-case letters: Series EM, 6 in. height.





SECTION A-A

SIGN GORE TREATMENT

Figure 75-2C

Sign Type	Intended Use	Typical Uses
Regulatory	To inform motorist of traffic law or regulation which applies at definite location or specific time.	4 Intersection control 4 Designating legal right-of-way 4 Speed limit 4 Turning movement control 4 Pedestrian control 4 Exclusion or prohibition 4 Parking control and limits 4 Regulations for maintenance or construction area
Warning	To warn motorist of unusual or potentially hazardous condition(s) on or adjacent to a street or highway.	4 Horizontal alignment 4 School area 4 Crossing or entrance to street, highway, or freeway 4 Intersection 4 Road construction or maintenance
Guide	To provide simple and specific information to aid motorist in reaching his or her destination.	4 Route markings 4 Destination 4 Information 4 General services 4 Parks and recreational signing

SIGN TYPES

Figure 75-2D

Posted or 85th percentile speed (mph)	Condition A: High Judgment needed[1, 2] (ft)	General Warning Signs[1, 3]								
		Condition B: Stop Condition (ft)	Condition C: Deceleration to indicated advisory speed or desired speed (mph) at condition (ft)							
			15	20	25	30	35	40	45	50
20	150	Note 4	Note 4	--	--	--	--	--	--	--
25	250	75	30	Note 4	--	--	--	--	--	--
30	325	150	100	75	Note 4	--	--	--	--	--
35	425	200	175	150	100	50	--	--	--	--
40	500	300	250	225	200	150	75	--	--	--
45	550	350	300	300	250	200	125	75	--	--
50	600	375	350	350	275	225	150	100	75	--
55	700	450	425	400	350	300	250	175	150	100
60	800	550	500	500	450	400	350	275	250	200
65	875	625	600	575	550	500	450	375	350	95

Notes:

1. *Distance shown is for a level roadway. Distance is based on placement of a 36 in. x 36 in. sign. If a 48 in. x 48 in. sign is placed, the legibility distance may be increased to 200 ft. This would permit reducing the above distance by 65 ft.*

2. *Distance is based on 10-second perception/reaction time and 125 ft sign legibility distance. In an urban area, a supplementary plate underneath the warning sign should be used specifying the distance to the condition if there is an intersection between the sign and the condition which might confuse the motorist.*

3. *Distance provides for 125 ft sign legibility distance, 3 s in gear and comfortable braking distance as indicated in the AASHTO* A Policy on Geometric Design of Highways and Streets.

4. *No suggested minimum distance provided. At this speed, sign location depends on physical conditions at site.*

5. *The suggested minimum distance is for preliminary placement of an advance warning sign. The final location will be determined during the field check in conjunction with INDOT or local agency personnel.*

SUGGESTED MINIMUM DISTANCES FOR PLACEMENT OF ADVANCE WARNING SIGNS

Figure 75-4A

CONDITION A	CONDITION B	CONDITION C
W4-1 (L)	W2-1	W1-1 (L)
W4-1 (R)	W2-2 (L)	W1-1 (R)
W4-2 (L)	W2-2 (R)	W1-2 (L)
W4-2 (R)	W2-4	W1-2 (R)
W4-3 (L)	W2-5	W1-3 (L)
W4-3 (R)	W3-1	W1-3 (R)
W5-3	W3-3a	W1-4 (L)
W9-1 (L)	W8-6	W1-4 (R)
W9-1 (R)	W8-6A	W1-5 (L)
W9-2 (L)	W8-6S	W1-5 (R)
W9-2 (R)	W10-1	W5-1
W9-13 (L)	W11-1	W5-2
W9-13 (R)	W11A-2	W6-3
W12-2	W11-3	W6-3A
W6-1	W11-4	W7-1
W6-1a	W11-5	W7-1a
W6-2	W11-6	W8-1
W6-2a	W11-8	W8-2
	W11-9	W8-5
		W13-1
		W13-2
		W13-3

Note: *This list only applies to those warning signs typically used by the Department. See Section 75-4.01 for definitions of each Condition when determining conditions for other warning signs.*

CONDITIONS FOR PLACEMENT OF ADVANCE WARNING SIGNS

Figure 75-4B

VEHICULAR SPEED	BALL-BANK READING	MAXIMUM RECOMMENDED SPEED OF CURVE
20 mph or lower	14º or greater	Speed at which the 14º reading occurs
25 or 30 mph	12º	Speed at which the 12º reading occurs
40 mph or higher	10º	Speed at which the 10º reading occurs

BALL-BANK INDICATOR READINGS

Figure 75-4C

ROUTE	REGIONAL CONTROL CITIES
64	Evansville
65	Gary, Columbus, Lafayette
69	Anderson, Angola
70	Terre Haute, Richmond
74	Crawfordsville, Shelbyville
80	(none)
94	Michigan City, Gary

REGIONAL CONTROL CITIES FOR INTERSTATE ROUTES

Figure 75-5A

ROUTE	NATIONAL CONTROL CITIES
64	St. Louis, Louisville
65	Louisville, Indianapolis, Chicago
69	Indianapolis, Fort Wayne, Lansing
70	St. Louis, Indianapolis, Dayton, Columbus
74	Peoria, Indianapolis, Cincinnati
80	Chicago
94	Chicago, Detroit

NATIONAL CONTROL CITIES FOR INTERSTATE ROUTES

Figure 75-5B

<table>
<tr><th>TYPE OF GENERATOR</th><th colspan="3">SPECIFIC CRITERIA
Distance From Interchange (mi)</th><th>SIGN COLORS</th></tr>
<tr><td>Airports and Colleges</td><td>MAJOR METRO AREA 100,000 OR OVER</td><td>URBAN AREA UNDER 100,000</td><td>RURAL</td><td></td></tr>
<tr><td>Airport:
City or county owned with regularly scheduled airline service</td><td>5</td><td>5</td><td>5</td><td>White on Green</td></tr>
<tr><td>College or University:
Fully accredited by Indiana State Regents for Higher Education (Full-time with 700 student enrollment)</td><td>5</td><td>5</td><td>25</td><td>White on Green</td></tr>
<tr><td>Vocational-Technical School:
Fully accredited by Indiana State Dept. of Vo.-Tech. Education (Full--time with 700 student enrollment)</td><td>5</td><td>5</td><td>5</td><td>White on Green</td></tr>
<tr><td rowspan="2">Military Base</td><td colspan="3">MINIMUM 5000 EMPLOYEES AND PERM-ANENTLY ASSIGNED MILITARY PERSONNEL</td><td></td></tr>
<tr><td colspan="3">5</td><td>White on Green</td></tr>
<tr><td>Tourist Attractions</td><td colspan="3">ANNUAL ATTENDANCE</td><td></td></tr>
<tr><td rowspan="5">Amusement Park
Arena
Auditorium
Convention Hall
Fairground
Major Recreational Area
Monument
Museum
Park
Stadium
State or National Park
Zoo</td><td>50,000</td><td>50,000</td><td>50,000</td><td rowspan="5">White on Brown</td></tr>
<tr><td colspan="3">MINIMUM NUMBER OF SEATS (If Applicable)</td></tr>
<tr><td>6,000</td><td>6,000</td><td>6,000</td></tr>
<tr><td>5</td><td>5</td><td>5</td></tr>
<tr><td colspan="3">Distance may be increased one-half mi for each 15,000 people over the annual attendance listed up to maximum of 25 mi.</td></tr>
<tr><td rowspan="2">Hospital</td><td colspan="3">MINIMUM NUMBER OF BEDS</td><td rowspan="2"></td></tr>
<tr><td>400</td><td>100</td><td>100</td></tr>
<tr><td>Must have at least one resident physician on duty 24 h per day; 7 days per wk</td><td>3</td><td>5</td><td>5</td><td>White on Blue</td></tr>
<tr><td rowspan="2">Central Business District</td><td colspan="3">POPULATION (City of 300,000 or More)</td><td></td></tr>
<tr><td colspan="3">5</td><td>White on Green</td></tr>
<tr><td rowspan="2">Other Incorporated City</td><td colspan="3">POPULATION (City of 3,000 or More)</td><td></td></tr>
<tr><td colspan="3">5</td><td>White on Green</td></tr>
<tr><td rowspan="2">Toll Highway</td><td colspan="3">LOCATION: DIRECT ACCESS FROM STATE HIGHWAY SYSTEM</td><td></td></tr>
<tr><td colspan="3">Toll facility name or marker may be included as part of the major guide sign, where applicable.</td><td>White on Green</td></tr>
</table>

GUIDELINES FOR SIGNING TRAFFIC GENERATORS ON A FREEWAY

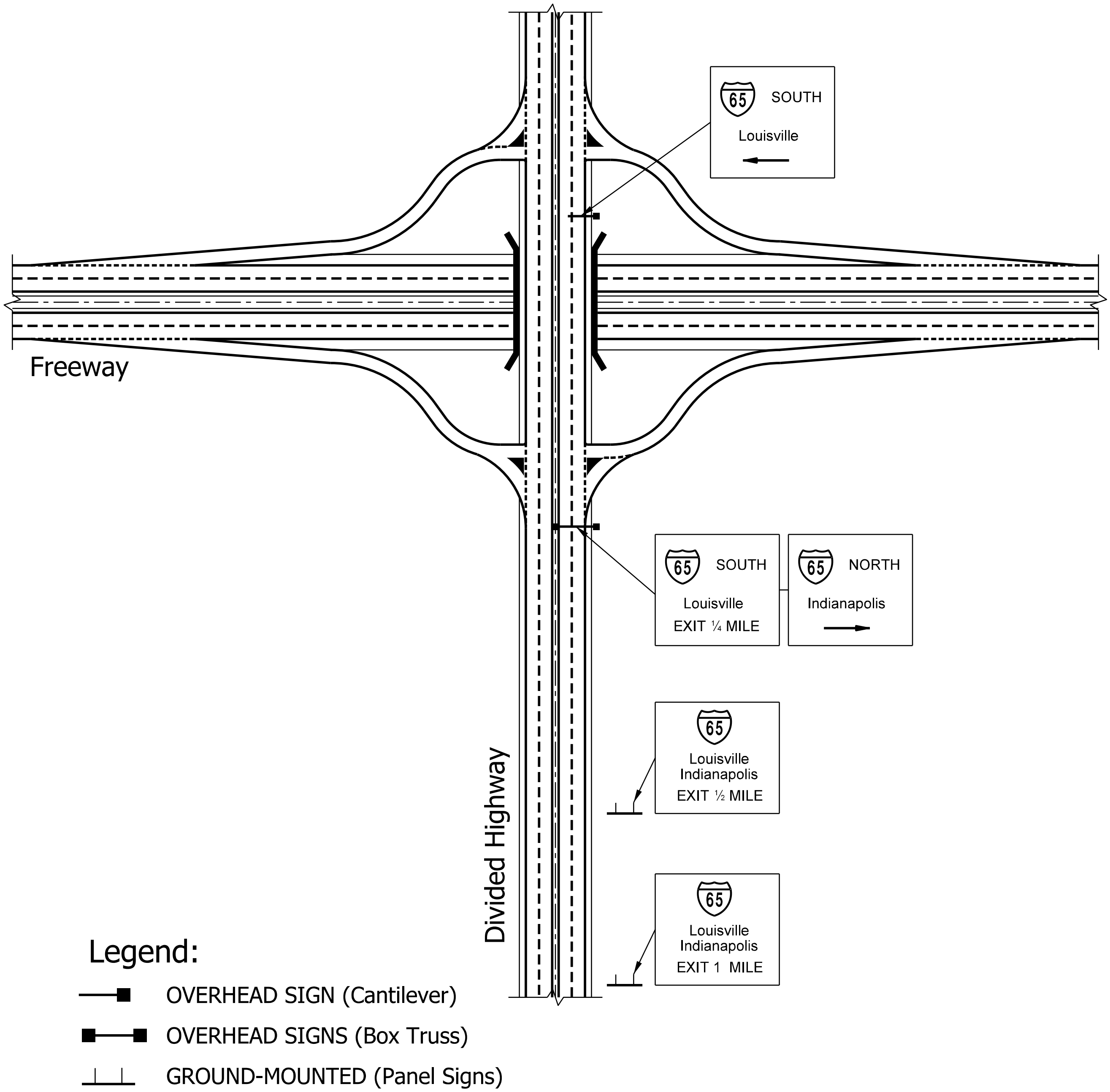
Figure 75-5C

HIGHWAY FACILITY	INTERCHANGE TYPE			
	DIAMOND	PARTIAL CLOVERLEAF	TRUMPET	FULL CLOVERLEAF
Divided highway with partial control of access within limits of signing	Figure 75-5E Figure 75-5F	Figure 75-5M Figure 75-5N	Figure 75-5Q	Figure 75-5 I Figure 75-5J
Multi-lane approach with no control of access within limits of signing	Figure 75-5G Figure 75-5H	Figure 75-5 O Figure 75-5P	Figure 75-5Q	Figure 75-5K Figure 75-5L
One-lane approach (Two-lane highway)	Figure 75-5G Figure 75-5H	Figure 75-5 O Figure 75-5P	Figure 75-5Q	Not Applicable

Note: Sign spacing shown in Figures 75-5E through 75-5Q may be varied to fit local geometric, land use, or traffic conditions.

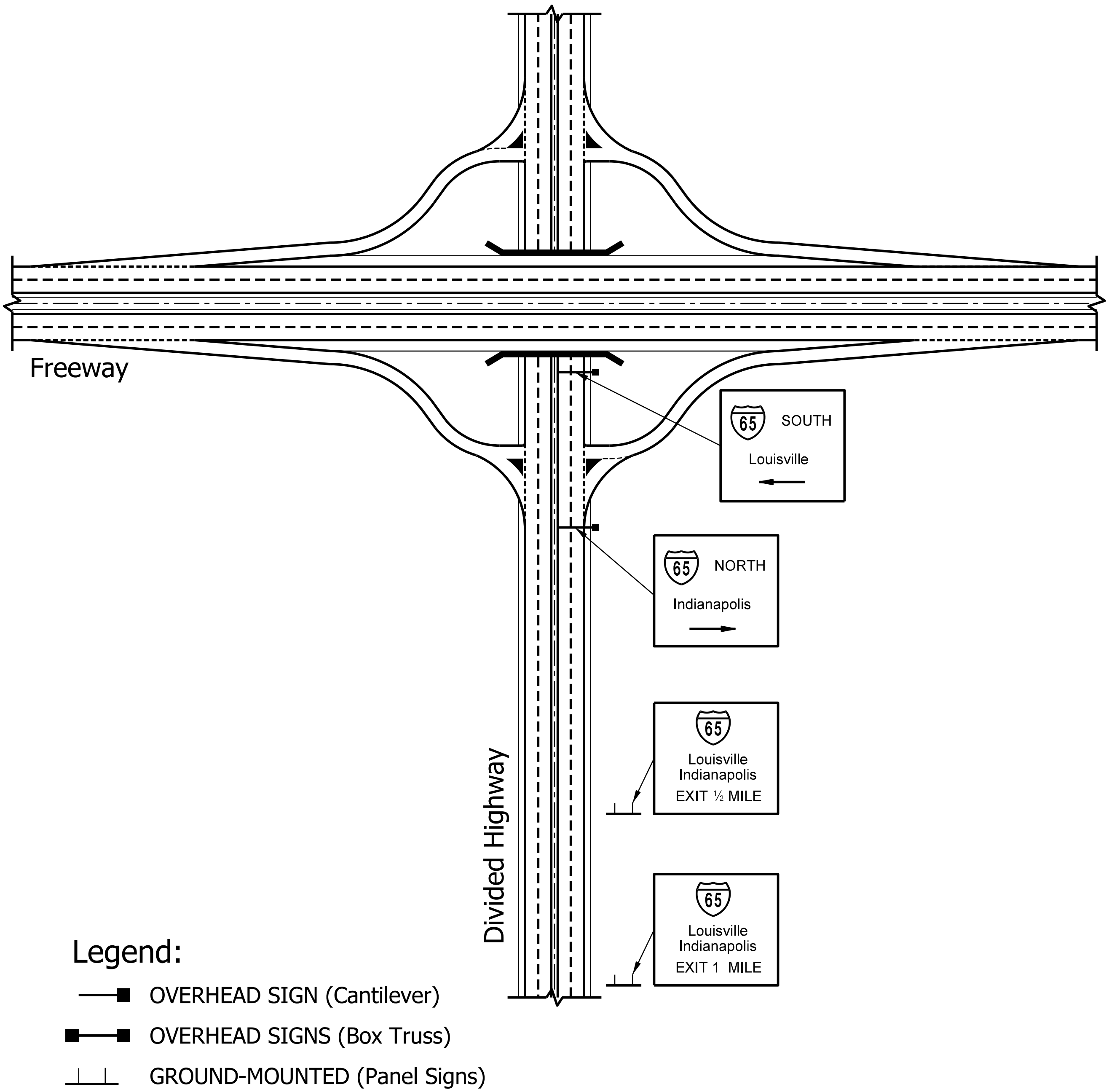
FIGURE REFERENCES FOR TYPICAL CROSSROAD SIGNING AT FREEWAY INTERCHANGE

Figure 75-5D



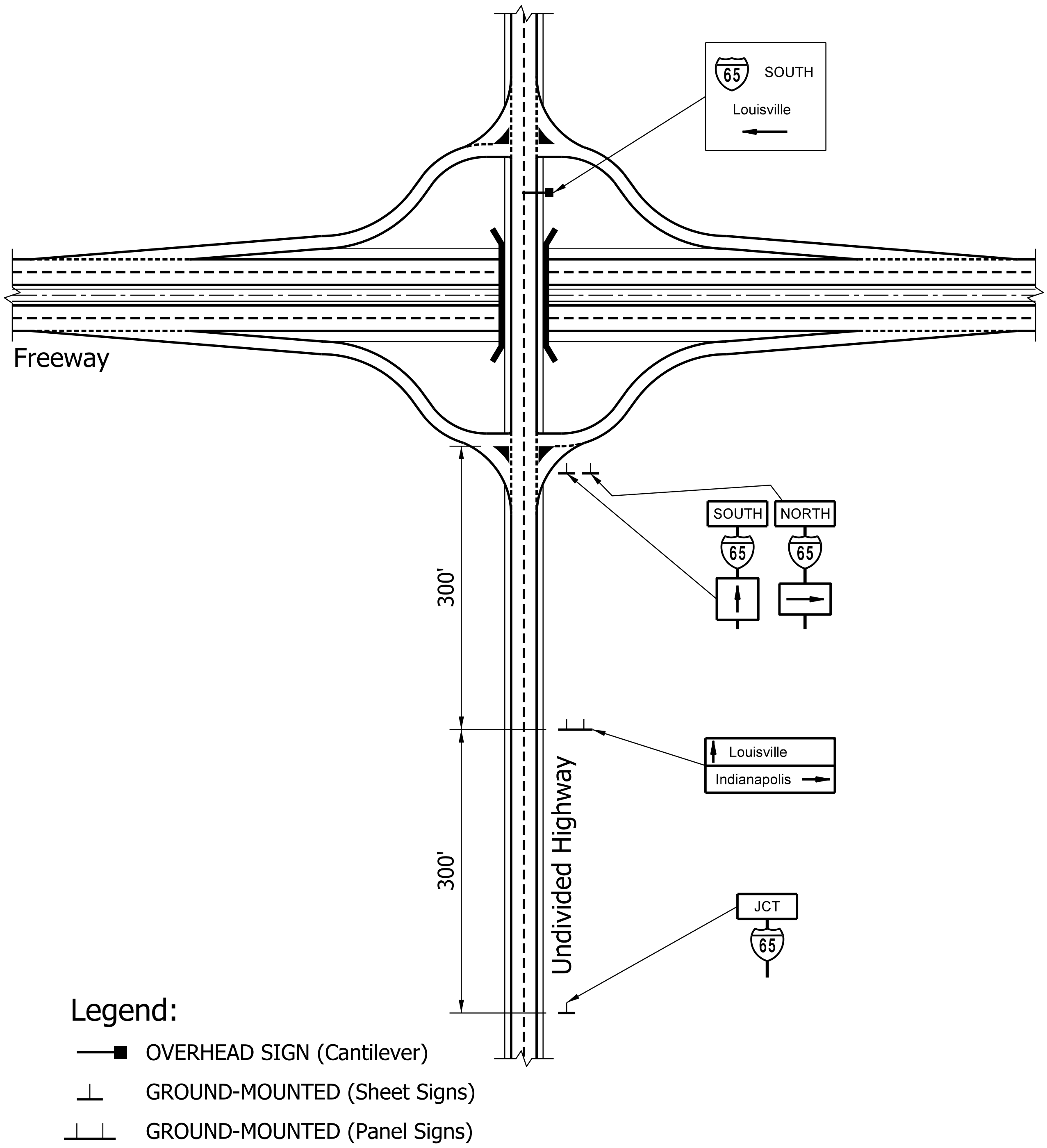
DIAMOND INTERCHANGE SIGNING
(Freeway Under Divided Highway)

Figure 75-5E



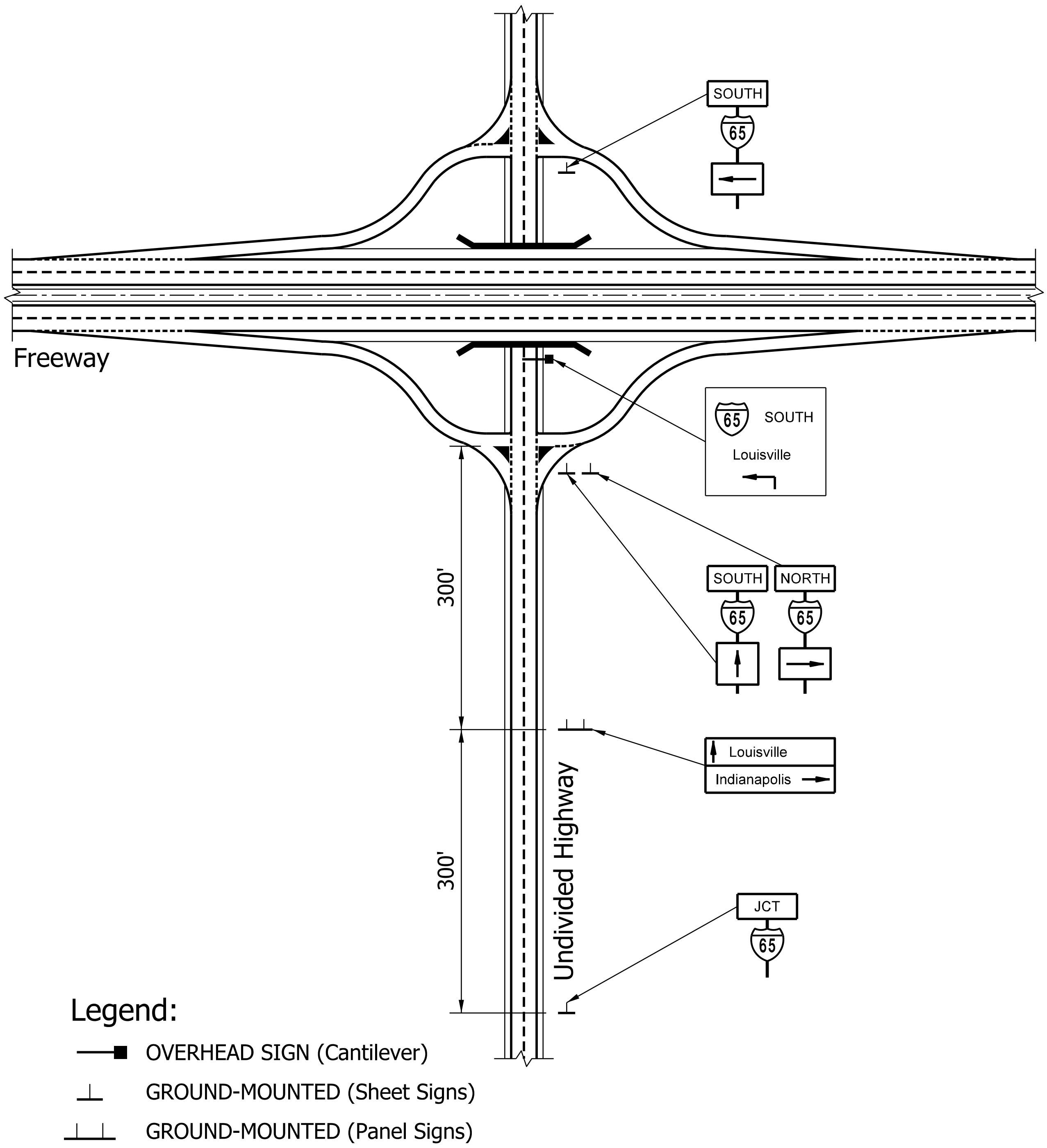
DIAMOND INTERCHANGE SIGNING
(Freeway over Divided Highway)

Figure 75-5F



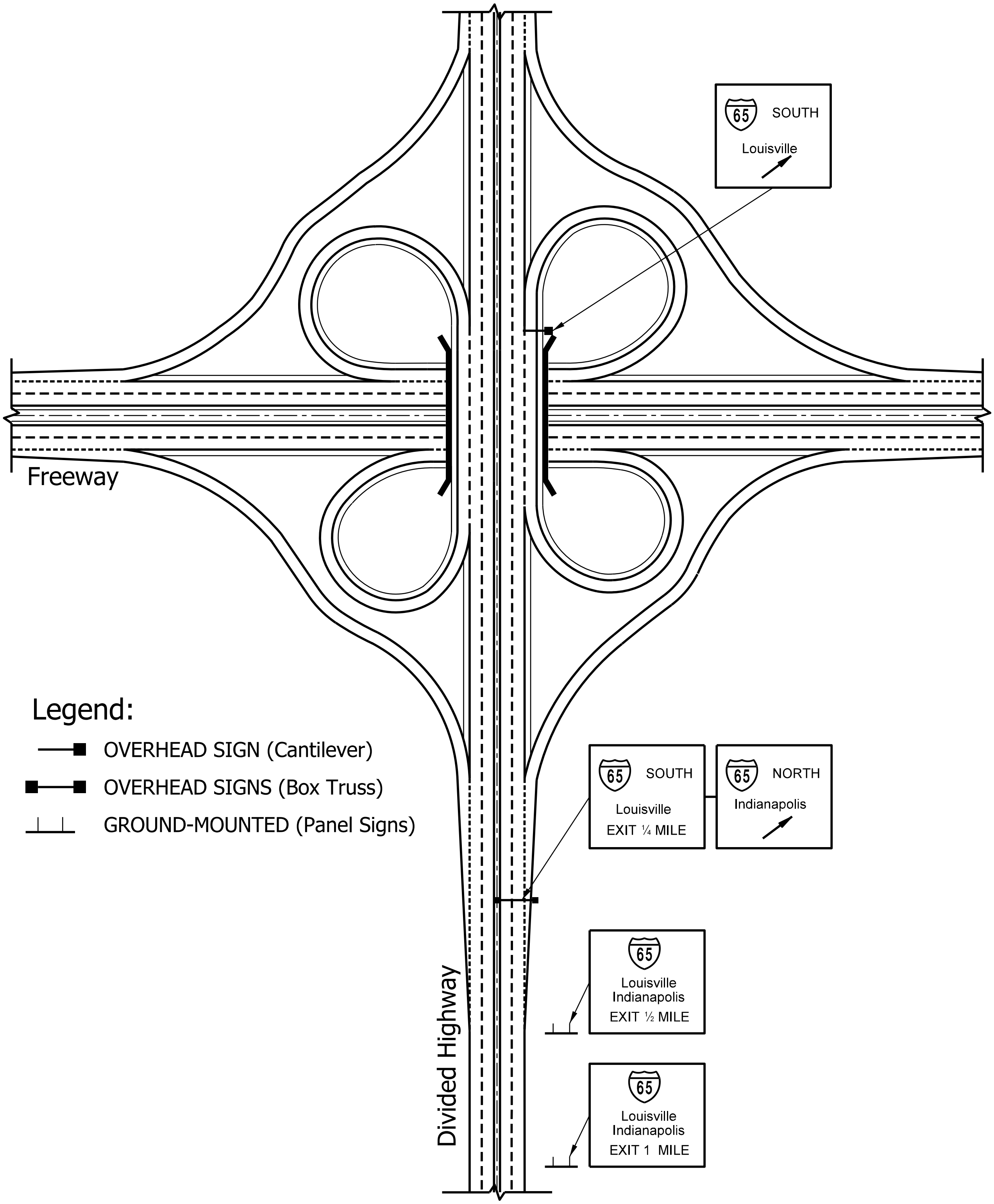
DIAMOND INTERCHANGE SIGNING
(Freeway under Undivided Highway)

Figure 75-5G



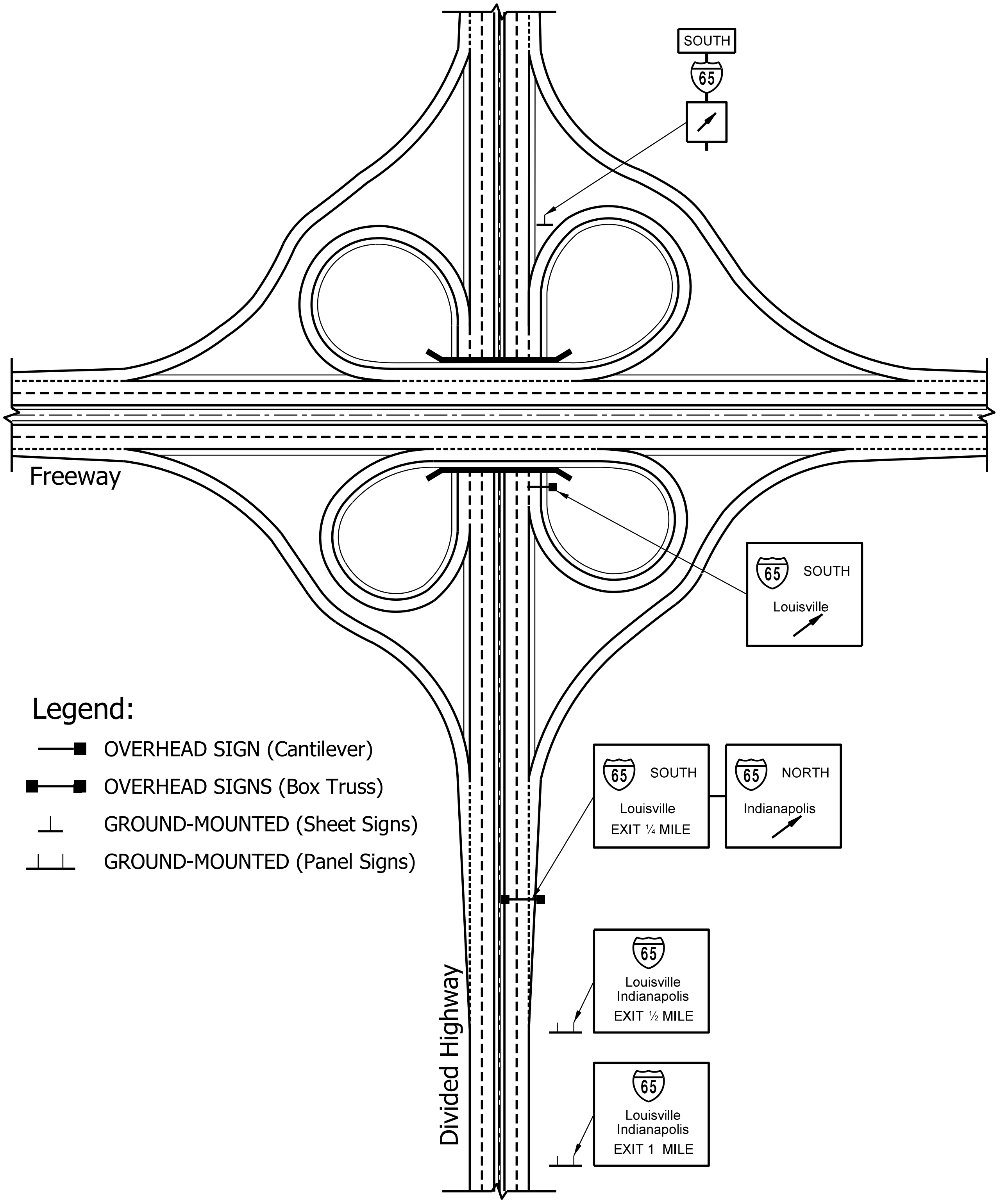
DIAMOND INTERCHANGE SIGNING
(Freeway over Undivided Highway)

Figure 75-5H



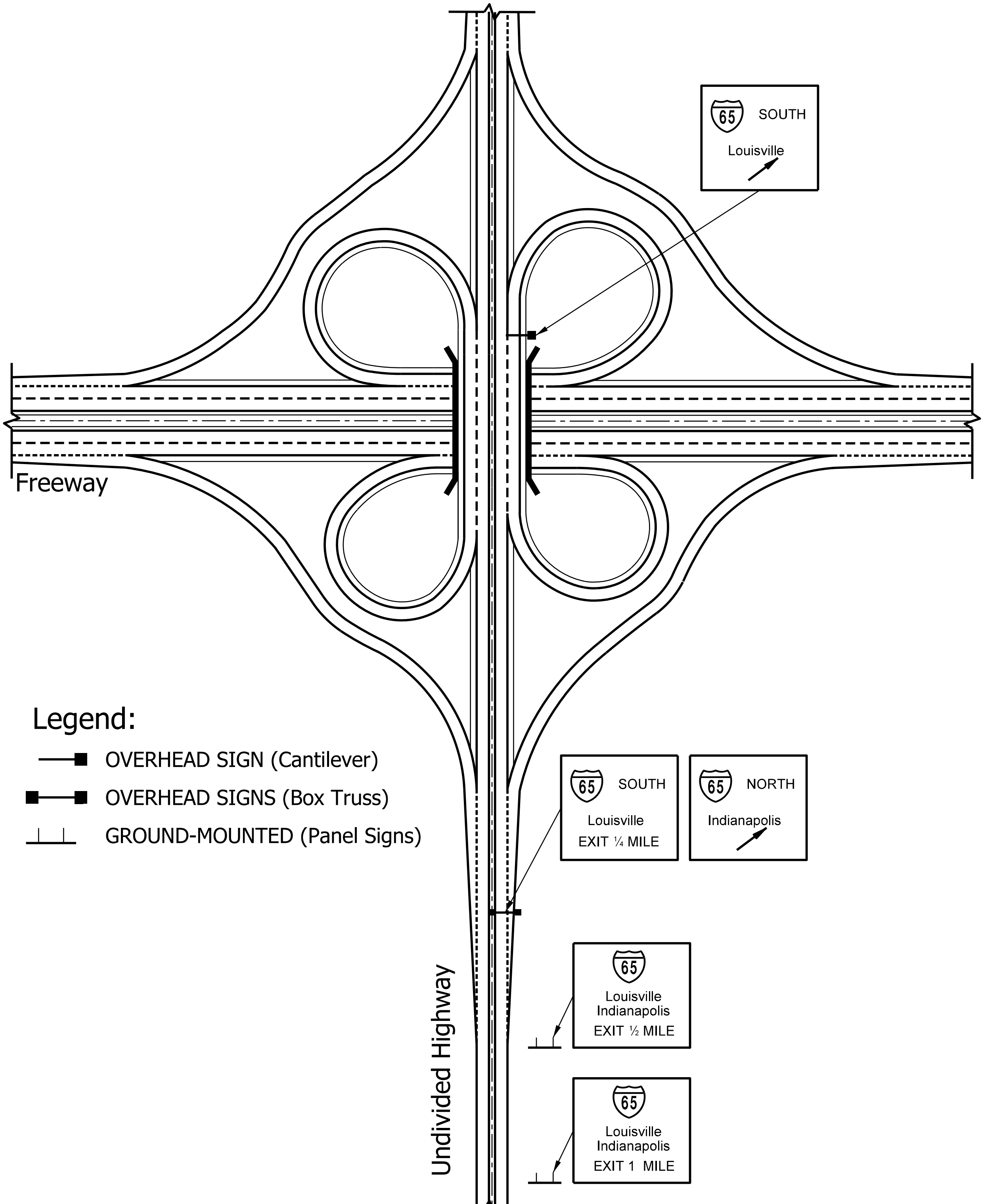
FULL CLOVERLEAF INTERCHANGE SIGNING
(Freeway under Divided Highway)

Figure 75-5 I



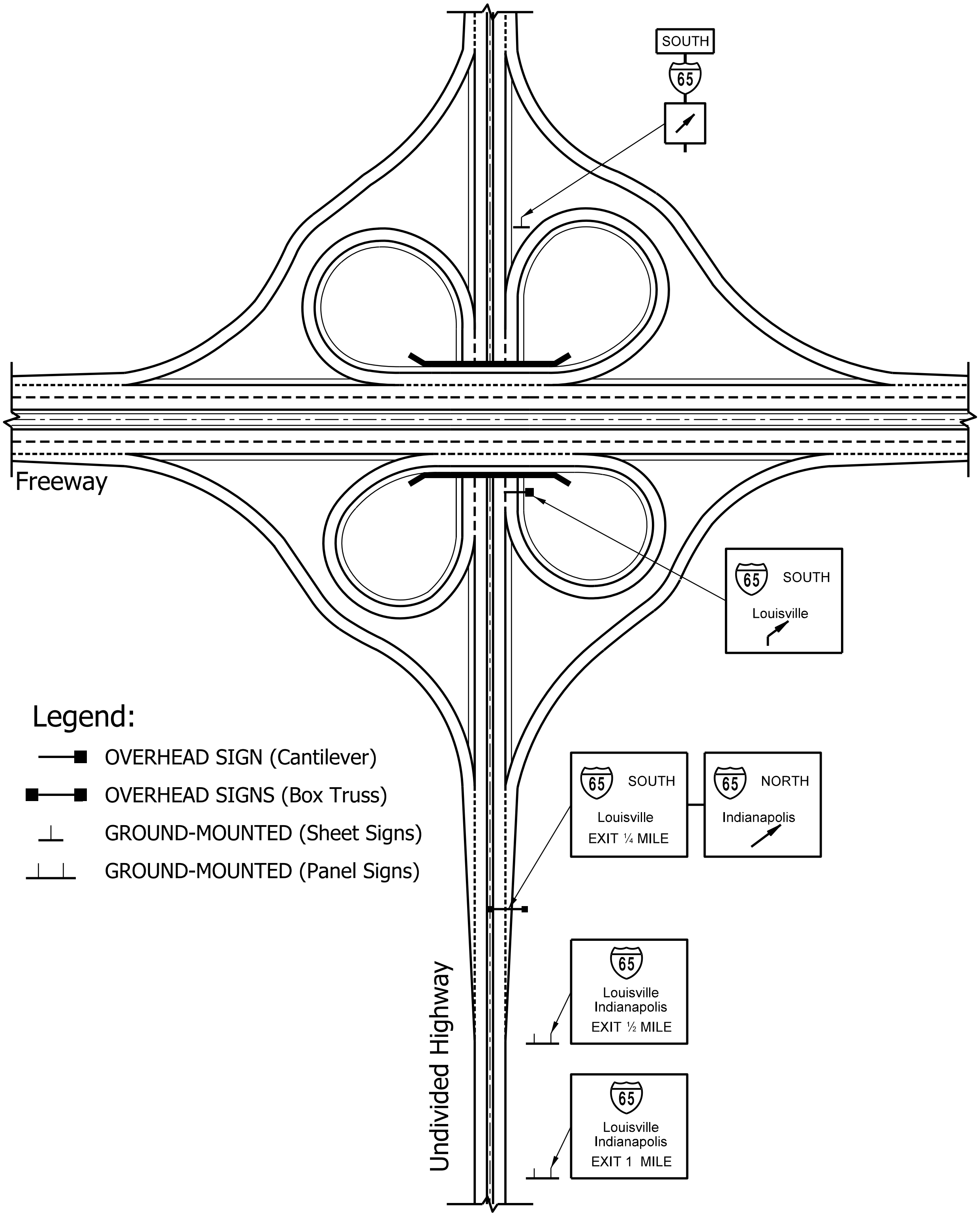
FULL CLOVERLEAF INTERCHANGE SIGNING
(Freeway over Divided Highway)

Figure 75-5J



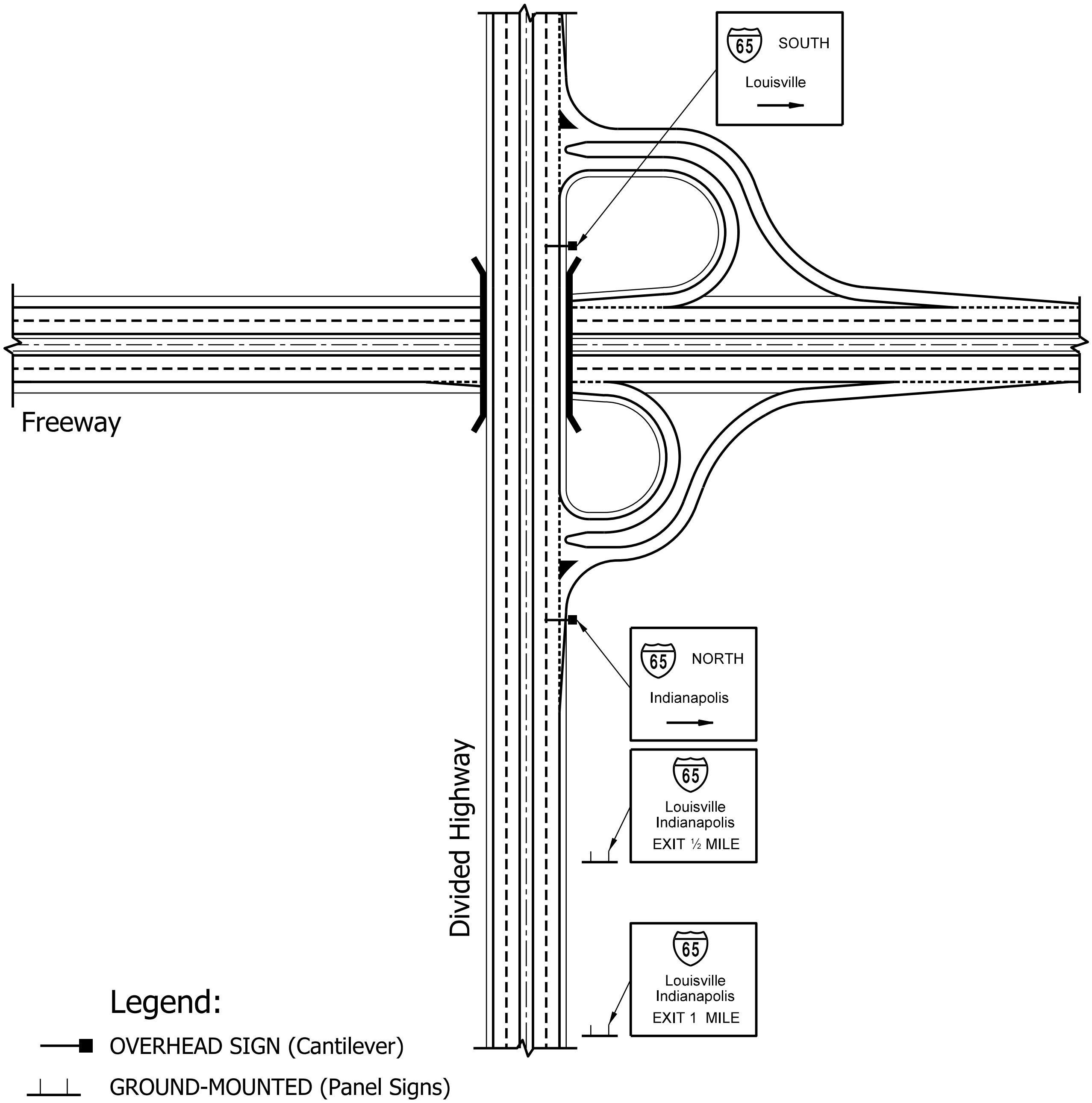
FULL CLOVERLEAF INTERCHANGE SIGNING
(Freeway under Undivided Highway)

Figure 75-5K



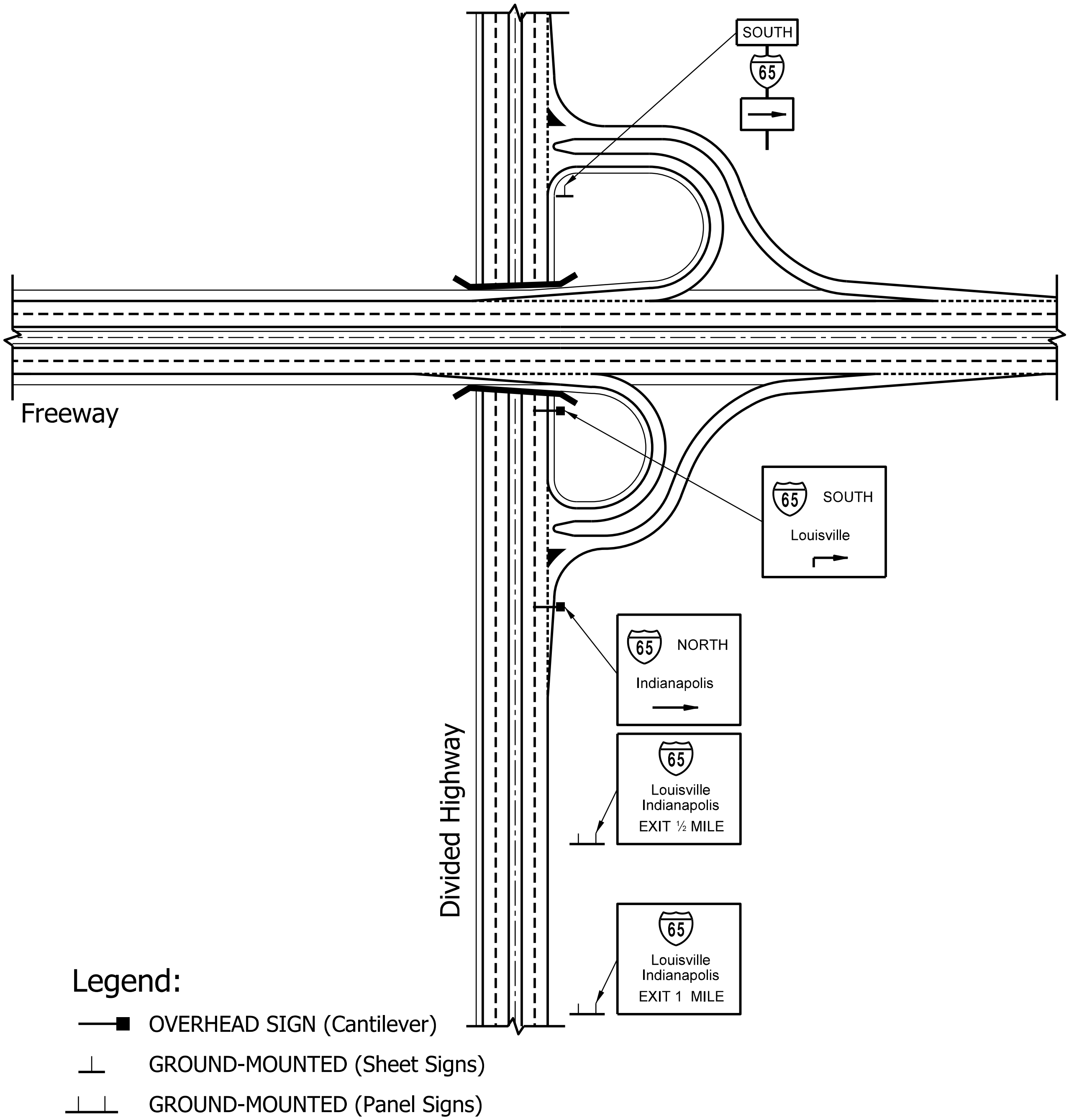
FULL CLOVERLEAF INTERCHANGE SIGNING
(Freeway over Undivided Highway)

Figure 75-5L



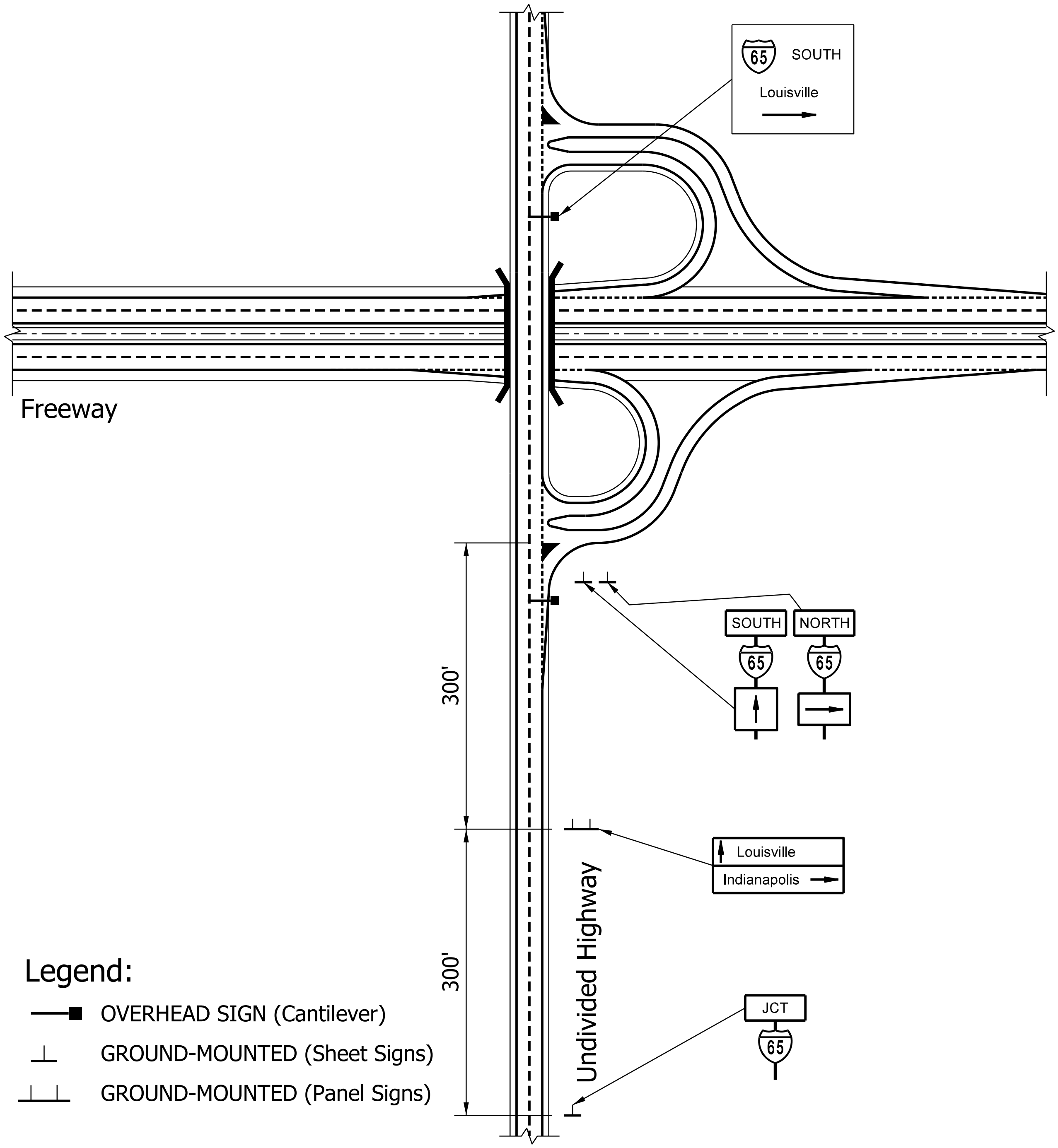
PARTIAL CLOVERLEAF INTERCHANGE SIGNING
(Freeway under Divided Highway)

Figure 75-5M



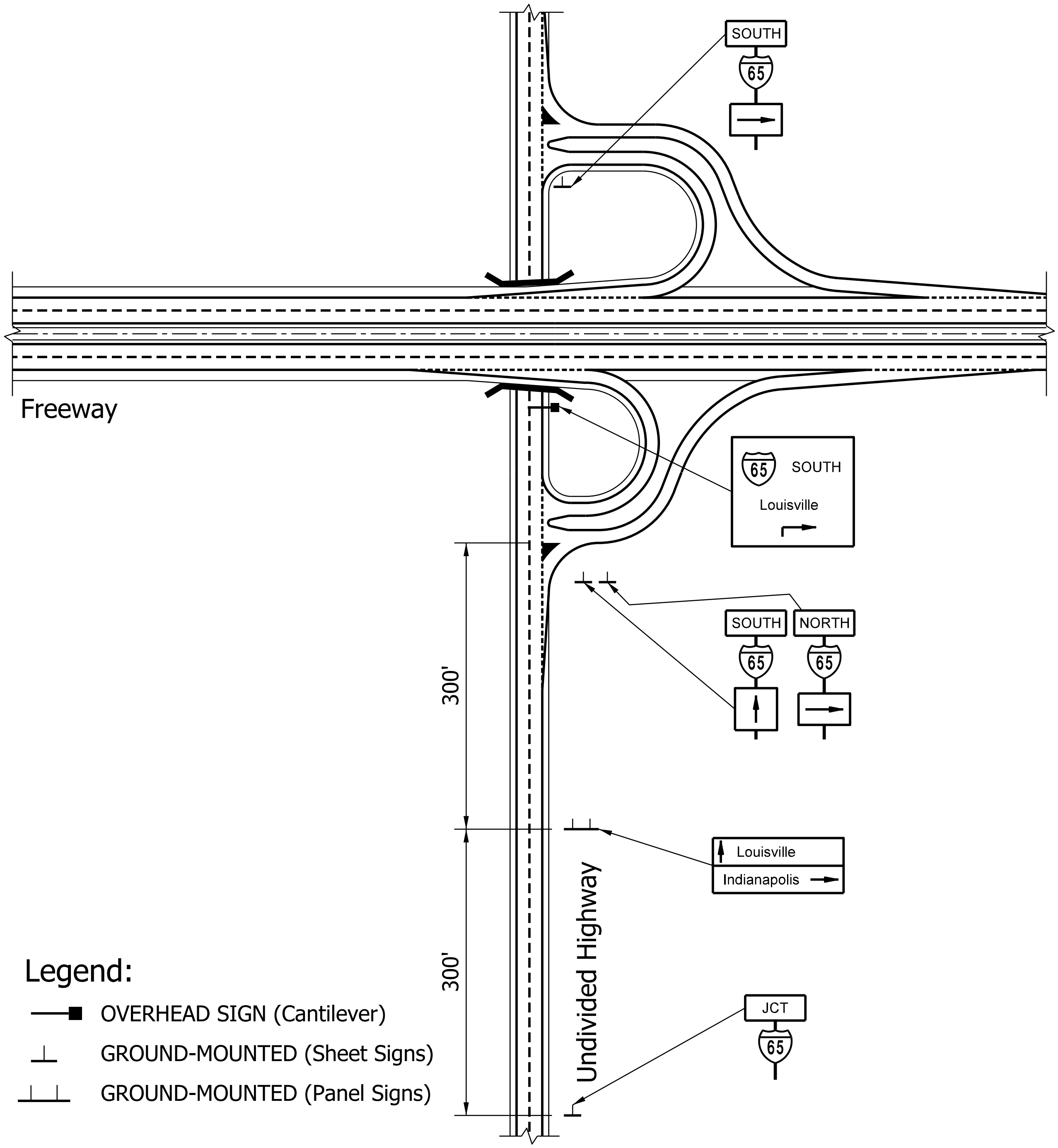
PARTIAL CLOVERLEAF INTERCHANGE SIGNING
(Freeway over Divided Highway)

Figure 75-5N



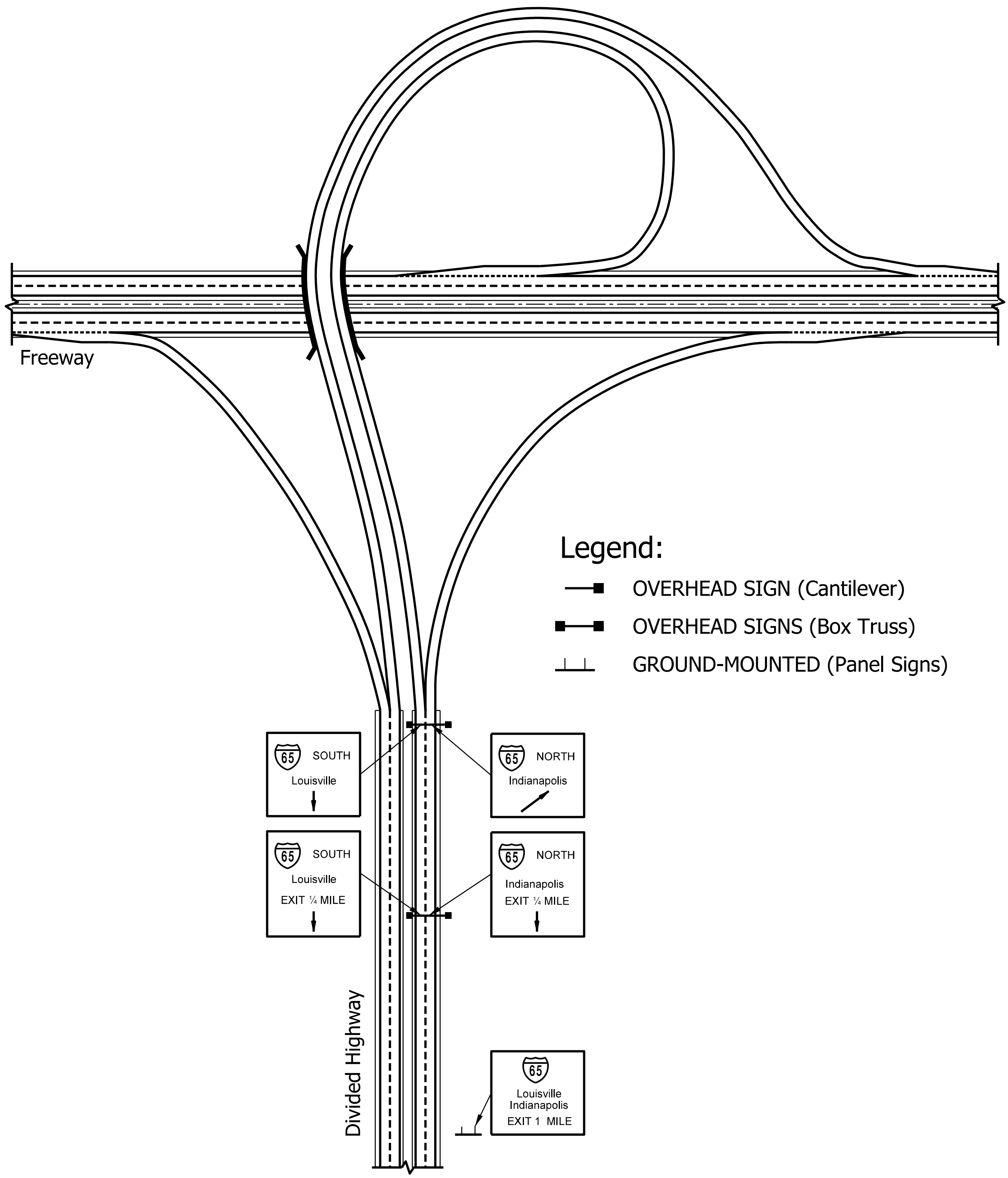
PARTIAL CLOVERLEAF INTERCHANGE SIGNING
(Freeway under Undivided Highway)

Figure 75-5 O



PARTIAL CLOVERLEAF INTERCHANGE SIGNING
(Freeway over Undivided Highway)

Figure 75-5P



TRUMPET INTERCHANGE SIGNING SYSTEM
(One Road Terminates)

Figure 75-5Q

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Title**

CHAPTER SEVENTY-SIX

PAVEMENT MARKINGS

76-1.0 GENERAL

Markings must be uniform in design, position and application. As with all other traffic control devices, it is imperative that markings be uniform so that they may be recognized and understood instantly. The proper use of pavement markings will reduce accidents on most facilities. New and improved markings have been demonstrated to significantly reduce nighttime and wet-pavement accidents.

This Chapter provides the Department's criteria for the application of permanent pavement markings. Chapter Eighty-three provides criteria for the use of temporary pavement markings through a construction zone.

76-1.01 MUTCD Context

Throughout the *Manual on Uniform Traffic Control Devices (MUTCD)*, the words *shall*, *should*, and *may* are used to indicate the appropriate application of traffic control devices. Section 75-1.0 defines the Department's application for these qualifying words, which also apply to pavement markings.

76-1.02 Line Types

Figure 76-1A, Types of Pavement Lines, identifies typical pavement stripes and their application. Section 76-2.0 provides additional information on the applications of these pavement markings.

76-1.03 References

For additional information on pavement markings, the designer is referred to the publications as follows:

1. *Manual on Uniform Traffic Control Devices*, FHWA;

2. *Traffic Control Devices Handbook*, FHWA;

3. *Traffic Engineering Handbook*, ITE; or

4. NCHRP Synthesis 138, *Pavement Markings: Materials and Application for Extended Service Life.*

76-1.04 Official Action

Where a new or revised pavement marking alters the regulation of an existing condition, an Official Action is required. For a State-maintained highway, the designer must coordinate and obtain an approval for the proposed change from the appropriate district traffic engineer before implementation of the proposed change. For a locally-maintained facility, approval must be obtained from the appropriate jurisdiction before implementation. Adding a new no-passing zone or revising the length of an existing no-passing zone will require an Official Action. Because pavement markings, in general, supplement signs, an Official Action will only be required for changing the sign and will not be required for changing the pavement markings.

76-2.0 APPLICATIONS

The following provides guidelines for the application of pavement markings. The MUTCD provides additional guidance and illustrations for the placement of pavement markings.

76-2.01 Travelway Markings

76-2.01(01) Center Line

Each INDOT-maintained highway requires a center line. Based on the highway type, the following will apply.

1. On an undivided rural highway or city street of 4 or more lanes where there are a minimum of two lanes of moving traffic in each direction at all times, the center line consists of two 4-in.-width solid-yellow lines, separated by a space of approximately 8 in.

2. On a 2-way, 2-lane highway or street, the center line should be a yellow broken line; a double line consisting of a yellow broken line and a solid yellow line; or double solid yellow line. The line type depends upon the allowable passing condition at each specific site.

3. The center line is not continued through intersections with public roads but is continued across driveways.

5. At a signalized intersection, a 50-ft-length center line should be provided on the minor facility if it has no markings.

The center line marking is placed 4 in. on either side of the longitudinal joint of the roadway. This will minimize the need for repainting after a joint-sealing operation.

For a non-INDOT highway, a center line is recommended at each of the following locations.

1. Roadway Width. In a rural area, a center line should be provided on a 2-lane roadway which has a surface width of 16 ft or more with the prevailing speed higher than 30 mph.

2. Divided Highway. A center lines should be provided if the highway has four or more lanes.

3. Urban Area. In a residential or business district, a center line should be provided on each through highway or on other highways where there is a significant traffic volume.

4. Low-Volume Road. On a paved low-volume road, a center line should be provided where the AADT is at least 300.

5. Horizontal Curve. If not provided elsewhere, a center line marking should be provided on a horizontal curve with a radius of 2300 ft or less. The marking should begin about 1000 ft in advance of the PC, continue through the curve and end about 1000 ft beyond the PT.

7. Bridge. If not provided elsewhere, a center line marking should be provided at a narrow bridge where the approaching roadway's width is 18 ft or greater, including paved shoulders, or where the bridge width is less than the approaching roadway's width. The marking should begin about 1000 ft in advance of the restricted bridge, continue across the bridge and end about 1000 ft beyond the bridge.

8. Field Conditions. A center line marking should be provided as necessary to meet field conditions or where engineering studies indicate a need.

76-2.01(02) Lane Lines

Lane lines are used to separate lanes of traffic traveling in the same direction. The facility may be one roadway of a divided highway, or a one-way street. For a non-freeway facility, the lane line is a 4-in.-with, broken white, reflectorized line. A lane line on a freeway is a 5-in.-with, broken white, reflectorized line. A solid white line may be used if lane switching is to be discouraged (e.g., approach to a signalized intersection). A lane line should be offset 4 in. from the longitudinal construction joint to facilitate future maintenance operations. A lane line is not continued through intersections with public roads but is continued across driveways.

76-2.01(03) Edge Lines

Edge lines are to be used on each INDOT-maintained highway. For a non-INDOT paved highway, the use of edge lines should be considered as follows:

1. along each facility of 4 or more lanes;
2. along a roadway having a paved surface width of 20 ft or greater;
3. across a bridge with a width of 18 ft or greater;
4. where run-off the road accidents are disproportionately high; or
5. where engineering judgment indicates a need.

The left-hand edge line is a median line and is discussed in Section 76-2.01(04). The right-hand edge line is a 4-in.-width, solid white, reflectorized line. The following provides guidelines for the placement of edge lines on an INDOT or a non-INDOT facility.

1. Intersection or Driveway. Gaps must be provided at each public-road intersection but are not provided at driveways.

2. Interchange. For edge lines at an interchange, see Section 76-2.04.

3. Paved Shoulder or Curb Offset. Edge lines should be placed approximately 4 in. from the longitudinal construction joint to eliminate the need for repainting after joint-sealing operations. For a roadway with curbs and no curb offsets, the curb itself may be painted with reflectorized solid white paint, or a 4-in.-width, solid white line may be applied to the pavement adjacent to the curb.

4. Unpaved Shoulders. For a roadway with unpaved shoulders, the edge line should be placed approximately 4 in. from the pavement edge. See Figure 76-2A, Location of Edge Lines with Unpaved Shoulders. However, the edge line should be placed 1 ft from the edge of pavement if one of the conditions exists as follows:

    a. if placing the edge line approximately 4 in. from the pavement edge would result in a lane width greater than 12 ft; or

    b. the width from the center line to the pavement edge is a minimum of 11 ft and the road section is without at least a 2-ft stabilized (compacted aggregate or asphalt) shoulder, or a minimum 4-ft usable earth shoulder.

If the above criteria results in lane widths greater than 13 ft, consideration should be given to revising the placement of the center line and edge line so that only a 12-ft lane is provided.

5. Uniformity. An edge line should be located to provide a constant lane width, as practical, throughout the roadway section. The widest lane practical, up to 12 ft, should be provided.

6. Bridge. Edge lines should be continued straight across a structure if the lane widths across the bridge are as wide as or wider than the lane widths approaching the bridge. Where the lane width on the structure is less than the approaching lane width, the edge line alignment should to be tapered to meet the narrower roadway width across the bridge. Section 76-2.01(06) provides the taper lengths. The INDOT *Standard Drawings* provide additional information on the placement of traffic-control devices, including edge lines across a bridge structure.

76-2.01(04) Median Lines

Median lines are required on each divided highway of 4 lanes or more. Gaps are to be provided at each at-grade intersection or median crossover. The following provides the median line applications based on the median-curb type.

1. No Curbs. Provide a 4-in.-width, solid yellow, reflectorized median line at the left edge of the travelway.

2. Curb Offsets. For a facility with curbs and curb offsets, provide a 4-in.-width, solid yellow, reflectorized median line at the left edge of the travel lane. The median marking should be placed a minimum of 4 in. on either side of the longitudinal joint between the roadway and the curb and gutter.

3. No Curb Offsets. For a facility with curbs but no curb offsets, the curb itself may be painted with solid yellow, reflectorized paint, or a 4-in.-width, solid yellow line may be applied to the pavement adjacent to the curb.

76-2.01(05) Channelizing Line

A channelizing line may be a solid white or solid yellow reflectorized line. It may vary in width from 4 in. to 24 in. depending on field conditions and the emphasis required. Yellow channelizing markings are used between opposing traffic. White channelizing markings are used for separating traffic traveling in the same direction. Section 76-2.03 provides information on channelizing lines at an intersection. Section 76-2.04 provides information on channelizing lines at an interchange.

Channelizing lines may also be used to indicate a flush median or to emphasize a continuous mounded corrugated median. Channelizing lines are not used unless the median is at least 4 ft or wider.

76-2.01(06) Lane Transition

Where a lane reduction is required, pavement markings are used to guide the motorist through the transition area. Figure 76-2B provides the minimum taper rates and lengths that should be used for a lane reduction. Figure 76-2C, Taper Length Criteria (Application), illustrates the application of the various taper types. These transition lengths are also appropriate for the pavement markings.

For a downstream taper (e.g., the beginning taper for a left- or right-turn lane, freeway exit), as defined in the *MUTCD*, the minimum taper should be 100 ft.

Figure 76-2D, Transition Markings (4-Lane Undivided to 2-Lane Undivided), Figure 76-2E, Transition Markings (4-Lane Divided to 2-Lane Undivided - Right), and Figure 76-2F, Transition Markings (4-Lane Divided to 2-Lane Undivided - Left), illustrate the typical pavement marking patterns used for transitioning from 4 to 2 lanes.

76-2.01(07) Truck-Climbing Lane

Section 44-2.0 provides the Department's criteria for truck-climbing lane warrants and design. Figure 76-2G illustrates the pavement markings that should be used with a truck-climbing lane.

76-2.02 No-Passing Zone

76-2.02(01) Warrants

The following are the Department's warrants for a no-passing zone.

1. Horizontal or Vertical Curve. Where center lines are installed, no-passing zones will be established at each vertical or horizontal curve or elsewhere on a 2- or 3-lane highway where an engineering study indicates passing must be prohibited due to inadequate sight distance or other special conditions. Figure 76-2H provides the minimum distances that

should be used for determining no-passing-zone markings placement. These values provide sufficient distance for the passing vehicle to abort the passing maneuver. These values should not be confused with the minimum passing sight distances provided in Section 42-3.0, which are used for geometric design purposes and are based on the assumption that the passing vehicle will be able to complete the passing maneuver.

2. Roadway Obstacle. Passing should not be allowed prior to or around an obstacle which is located next to or within the roadway (e.g., bridge pier). The pattern of the no-passing zone in the immediate vicinity of such an obstruction will be reviewed and determined by the district traffic engineer for an INDOT highway or the local authority for a non-INDOT facility.

3. Transitions from 4 to 2 Lanes. Figure 76-2D, Transition Markings (4-Lane Undivided to 2-Lane Undivided), Figure 76-2E, Transition Markings (4-Lane Divided to 2-Lane Undivided - Right), and Figure 76-2F, Transition Markings (4-Lane Divided to 2-Lane Undivided - Left), illustrate the typical placement of no-passing zone markings in the transition area.

4. Bridge. The following no-passing zone determinations will apply at a bridge.

    a. For a bridge width that is narrower than the full approach-roadway width or for a 1-lane bridge, passing will not be allowed on the bridge. Figure 76-2 I provides minimum lengths for implementing the no-passing criteria in advance of the structure.

    b. For a bridge width which matches the full approach-roadway width or for narrow bridges where the full approach-lane widths are carried across the bridge, the need for no-passing markings will be determined based on the criteria in Item 1.

5. Intersection or Railroad Crossing. Passing is not allowed prior to or through a major intersection or railroad crossing. Figure 76-2 I provides the minimum lengths for implementing the no-passing criteria in advance of a major intersection or railroad crossing.

6. Gap. Figure 76-2J provides the minimum distances for passing between successive no-passing zones. If these distances cannot be attained, the no-passing zones should be connected. If the distance from the end of a preceding zone and the no-passing zone for the intersection is less than the minimum allowable gap shown in Figure 76-2J, Minimum Passing Zone Gaps, the no-passing line should be continued to the intersection.

7. Traffic Volume. A no-passing zone may be established where opposing traffic volumes are such that it would be impractical or unsafe to allow passing maneuvers (e.g., urban

area). This determination will be determined for each project.

8. Boundaries. A review of the no-passing zones should be conducted for a sufficient distance prior to and beyond the marking area to ensure that the area will be properly marked (e.g., eliminating less-than-minimum gaps).

76-2.02(02) Design Criteria

The following are the Department's design criteria for determining the location of a no-passing zone.

1. Design Speed. If known, the highest of the posted speed, the 85th percentile speed, or the design speed should be used to establish the no-passing zone. If the posted speed limit is used, the speed used in determining the distances in Figures 76-2H and 76-2 I should be approximately 5 mph higher than the posted speed. For example, if the posted speed limit is 55 mph, use the appropriate sight distance for 60 mph.

2. Passing Distance. Figures 76-2H and 76-2 I provide the various distances used to mark no-passing zones. The beginning of a no-passing zone is that point at which the distance first becomes less than that specified in Figures 76-2H and 76-2 I. The end of the zone is that point at which the distance again becomes greater than the minimum specified in Figures 76-2H and 76-2 I.

3. Minimum Length. The minimum length for a no-passing zone is 500 ft. If the no-passing zone length, as determined above, is less than 500 ft, additional no-passing markings must be added to the beginning of the no-passing zone until the 500-ft minimum criteria is attained.

4. Eye and Object Height. For determining no-passing zone location, the distance is measured from a 3.5-ft height of eye to a 3.5-ft height of object.

76-2.02(03) Pavement Markings

A no-passing zone line is a 4 in.-width, solid yellow, reflectorized line. It is separated from a broken yellow center line with an 8-in. gap.

** *PRACTICE POINTER* **

The no-passing pavement markings should be extended to the end

of the no-passing zone, regardless if the zone extends beyond the project limits.

Section 75-3.07 provides Department practices for supplementing no-passing lines with "No Passing Zone" signs and delineators.

76-2.02(04) No-Passing-Zone Record

A no-passing-zone record is required for Official Action purposes on an INDOT roadway and is recommended for a non-INDOT roadway. This also assists in the remarking of each no-passing zone due to worn out markings or after resurfacing. Developing the record involves taking field measurements and recording the location of the beginning and ending points of each no-passing line. In developing the written no-passing-zone record, the following should be noted for INDOT highways.

1. <u>Beginning and Ending Points</u>. The record should begin and end at each county line or at the extreme points of the road within the county. For an even-numbered route, the record should begin at the west county line or at the westerly beginning point of the route within the county. The record should proceed easterly and terminate at the east county line or at the easterly termination point of the route within the county. For an odd-numbered route, the record should begin at the south county line or at the southerly beginning point of the route within the county. The record should proceed northerly and terminate at the north county line or at the northerly termination point of the route within the county.

2. <u>Measurements</u>. The beginning reading is at zero and measurements will be made in feet. The measuring device should be calibrated to measure within 10 ft per mile. For a survey route of longer than 10 mi, the record should be stopped at an intersection and reset to zero to eliminate any accumulated errors resulting from distance measuring. All of the elements noted in Item 3 below should be referenced in feet from the beginning of the record.

3. <u>Elements to be Recorded</u>. The recorder should note the following elements in the no-passing-zone record.

    a. The center line of each intersecting city street, county road, or State highway should be measured and recorded. The name or number of the street or road should also be recorded. The name or number of each facility which is not signed in the field should be obtained from local official agency maps or records. Federal-aid route numbers should not be recorded.

b. The recorder should locate and identify each permanent-type landmark, including railroad crossing, narrow or 1-lane bridge, obstruction, or city or town limits (as identified by a sign designating such limits).

c. Each major bridge not included above should be noted in the record under the Special Reference notation. This will allow the name of a stream or river to be identified in the record.

d. All reference markers from the roadway reference system should be noted.

A record for a non-INDOT facility may be prepared similarly to that for an INDOT highway.

76-2.03 Intersection Markings

Figure 76-2K provides an example of the markings used at intersections. The following provides additional information on intersection pavement markings.

76-2.03(01) Stop Line

For a State facility, the stop line is a 24-in.-width, a solid white, reflectorized line. The stop line should extend across each approach lane, usually to the center line. It should be placed 4 ft in advance of the nearest crosswalk line and should be perpendicular to the center line. The stop line will be parallel with the crosswalk lines. In the absence of a marked crosswalk, the stop line should be placed at the desired stopping point and perpendicular to the line of travel. The stop line should not be placed more than 30 ft or less than 4 ft from the nearest edge of the crossing travel lane or point of potential conflict (e.g., crosswalk, turn lane, turning vehicle path).

The location of the stop line may be adjusted to fit field conditions. For example, where turning trucks are known to encroach into the opposing lane, the stop line should be placed beyond the point of potential conflict. On a facility of 4 or more lanes that intersects the cross road at an angle, it may be appropriate to stagger the stop line for each lane. This may be especially important at a signalized intersection where clearance times may be substantial.

76-2.03(02) Crosswalk Line

Crosswalk lines are solid white, reflectorized lines of not less than 6 in. width. They are used to mark both edges of the crosswalk. The distance between lines is determined by the width of the sidewalks to be connected. However, they should not be spaced less than 6 ft apart. The crosswalk must encompass all curb ramps. For information on curb ramps and the crosswalk width, see Section 51-1.08. The *MUTCD* provides additional information on other crosswalk types.

76-2.03(03) Channelized Island

Figure 76-2L illustrates the typical pavement markings used to delineate a raised, corrugated, triangular island. Figure 76-2M illustrates the typical pavement markings used to delineate a raised corrugated and a painted, flush elongated island.

76-2.03(04) Multiple Turn Lanes

For multiple turn lanes (e.g., dual left-turn lanes), a series of single dotted lines may be used to guide the turning traffic through the intersection considering the turning path of the design vehicle. These lines are the extension of the lane lines and, therefore, are the same color as the lane line.

76-2.03(05) Word or Symbol Marking

A word or symbol marking on the pavement may be used to guide, warn, or regulate traffic. It should be limited to not more than a total of three lines of information. It must be white in color. For additional information on the design and layout of word or symbol markings, see the INDOT *Standard Drawings* or the FHWA *Standard Alphabets for Highway Signs and Pavement Markings*, which are used in conjunction with the *MUTCD*.

An arrow symbol may be used to convey either guidance or a mandatory message. However, where a movement that would otherwise be legal is prohibited, the arrow marking must be accompanied by the pavement-marking word “Only.” Signs should be considered in addition to the markings where determined necessary by a field investigation. Signs or markings may be repeated in advance of mandatory turn lanes when necessary to prevent entrapment and to help the motorist select the appropriate lane before reaching the end of the line of waiting vehicles.

Pavement-marking words are 8 ft height, except where the traffic speed is very low. If the message consists of more than one word, it should be read up (i.e., the first word should be nearest to the approaching driver). At an intersection, the marking is placed approximately 20 ft from the point where traffic stops. The space between words of a single message should be approximately four times the height of the characters for a low-speed road, and up to ten times the height of the characters for a high-speed road. Typical layouts are shown in Figure 76-2N, Traffic-Control Word or Symbol Markings.

<u>76-2.04 Interchange Markings</u>

The following provides the Department’s practice for installing pavement markings at an interchange.

1. <u>Exit Ramp</u>. Figures 76-2 O and 76-2P provide the typical pavement markings used for a parallel or tapered exit ramp, respectively.

2. <u>Entrance Ramp</u>. Figures 76-2Q and 76-2R provide the typical pavement markings used for a parallel or tapered entrance ramp, respectively.

3. <u>Gore Markings</u>. Figure 76-2S illustrates the supplemental gore markings. For an Interstate route or other facility with a design speed of 50 mph or higher, the gore markings should consist of 24-in.-width stripes at 40-ft spacing. For a facility with a design speed of 45 mph or lower, the gore markings should consist of 12-in. width stripes at 20-ft spacing.

4. <u>Ramp or Cross Road Junction</u>. Figure 76-2T illustrates the placement of supplemental exit-ramp markings that may be used where wrong-way movements may occur. The design of these markings should be as shown on the INDOT *Standard Drawings* or the FHWA *Standard Alphabets for Highway Signs and Pavement Markings*.

<u>76-2.05 Miscellaneous Markings</u>

76-2.05(01) Railroad Crossing

In a rural area, the minimum distance from the railroad-crossing marking to the stop line should be the stopping sight distance. In an urban area, this distance will vary depending on the signal location and city-blocks spacing. The minimum distance should be the same as for a rural area. However, this distance is often not practical due to the need to maintain the markings within the same city block or between the nearest track and the adjacent traffic signal. This spacing should not be less than 50 ft. The INDOT *Standard Drawings* provide additional details for the location of railroad-crossing markings.

On a highway of 4 lanes or more, the transverse lines should be extended across all approach lanes. The individual railroad-crossing symbols should be provided in each lane.

For a 2-way left-turn lane, the center lane should be discontinued across the railroad crossing and marked as a flush median or as a 1-way left-turn lane.

76-2.05(02) Two-Way Left-Turn Lane (TWLTL)

A TWLTL is a center lane reserved for the exclusive use of left-turning vehicles in either direction. The center lane is marked to delineate the bi-directional, left-turn movement. Section 46-5.0 provides the design requirements for a TWLTL. Figure 76-2U illustrates the typical marking pattern for a TWLTL. The pavement word and symbol marking groups should, at a minimum, be at least 400 ft apart. In a rural area, the marking groups should not exceed 1200 ft. At a signalized or other major intersection, the TWLTL should be transitioned to an exclusive left-turn lane. Figure 76-2V illustrates the pavement markings used for this transition. See Section 75-3.05 for information on the appropriate signing for use in conjunction with a TWLTL.

76-2.05(03) School Crossing

Pavement markings for a school crossing should only be used with the appropriate signing, so therefore should not be used without the signing. The need for school-crossing signing and markings will be determined as required in conjunction with the local school officials. INDOT's practice is to replace the school-crossing markings if they are removed or covered during a project. The INDOT *Standard Dr*awings and the *MUTCD* provide additional guidance for the placement of school-crossing markings.

76-2.05(04) Bicycle Facility

The color and type of lines used for a bicycle facility will be the same color and type as determined for automobiles (e.g., yellow broken line for a 2-way bicycle facility). Broken lines for a bicycle facility should have a 1 to 3 ratio (e.g., 3-ft line with a 9-ft gap). A solid white line should be used to separate pedestrians and bicycles if they share a common facility. The preferential lane symbol as defined in the *MUTCD* must be provided where bicycles and motor vehicles share the same facility and a separate bike lane is provided. Figure 76-2W, Bicycle Markings (Intersection), illustrates the AASHTO *Guide for the Development of Bicycle Facilities* recommendations on how to mark an intersection with vehicles turning right across a bike lane. The *MUTCD* and the AASHTO *Guide* provide additional guidance for marking bicycle facilities.

76-2.05(05) Parking Markings

On-street parking markings placement will be determined based on local requirements. If local requirements are unavailable, the designer should reference the *MUTCD* for details. Section 51-4.0 provides information on the design and layout of parking stalls for off-street parking. Solid white lines, of 4 in. to 6 in. width, are used for marking parking stalls. Section 51-1.0 provides the criteria for laying out a handicapped-parking stall. The pavement markings will be white or blue.

76-3.0 PAVEMENT-MARKING MATERIALS

76-3.01 Material Types

The pavement marking materials used by INDOT are described below.

1. Paint. Quick-drying paints are applied as a 4-in. or wider white or yellow stripe. Glass beads are dropped onto the wet paint which then bond to the paint surface when it dries. The use of glass beads greatly enhances the reflectivity of the paint stripe. Per unit cost, paint-applied markings are significantly cheaper than another method. One of the major disadvantages of paint is that it can be quickly worn away on a high-traffic-volume roadway, and, therefore, often needs to be reapplied more than once a year.

2. Thermoplastic. Thermoplastic markings are made from hydrocarbon or alkyd resins, pigment, and filler. The materials are heated to a high temperature and are applied in thicknesses of 0.1 in. to 0.2 in. The material is applied to the surface and, while it is still hot, glass beads are dropped onto the mixture. Once the material cools, the glass beads are then bonded to the surface. Thermoplastic markings must be applied to a clean, dry asphalt pavement. A primer may be required to ensure satisfactory performance. Thermoplastic markings are significantly more expensive than paint, but often can last 5 or more years if applied properly. Thermoplastic is the preferred marking for a high-traffic-volume roadway due to its long life.

3. Epoxy Paint. Epoxy markings are made from a two-component epoxy resin, pigment, extenders, and fillers. The two epoxy resin components are mixed together just prior to being applied to the roadway surface. The two epoxy components produce a chemical reaction which binds them together. Materials using this type of chemical reaction are called thermoset materials. Epoxy markings are applied in thicknesses of 0.1 in. to 0.2 in. and can also be applied to a wet pavement. Glass beads are dropped onto the mixture. However, they may be applied by several different means depending on the epoxy material types used.

4. Preformed Plastic. Preformed plastic markings are premade in a factory from vinyl, pigment, and fillers and can come in strips, words, or symbols. Glass beads are embedded into the surface of the markings at the factory. Application of the marking involves removing a protective strip, laying the marking in place, and applying pressure with a roller. Temporary tape is commonly used in a construction zone because the tape

can be easily removed. However, a common problem with some temporary preformed plastics is that they tend to break up easily and must be routinely checked for adequacy.

5. Raised Pavement Marker. A raised pavement marker (RPM) is a cube-cornered acrylic lens, tempered-glass lens, or glass-bead lens, mounted in either a plastic or iron base. It is placed with an adhesive to either the pavement surface or into a precut groove. For a temporary application, it may be placed in a plastic base and applied directly to the pavement with an adhesive. RPMs are designed to reflect the appropriate striping color (e.g., white, yellow, red) and are used as a supplement to other markings and as position guidance devices. To enhance the service life, the marker is recessed to allow a snow plow to pass over it without damage.

6. Experimental Markings. With the continued advancement of technology in pavement markings, there will always be new materials or methods available in the placement of pavement markings. The designer is encouraged to pursue the use of these new materials or procedures. However, the use of an experimental pavement marking material on a State-maintained facility must be first approved by the Highway Operations Division.

76-3.02 Applications

Figure 76-3A provides the recommended applications for the pavement-marking materials used by the Department. The following provides additional guidance on the application of the materials. For the purpose of the following discussion, transverse markings include, but are not limited to, those for a crosswalk, railroad crossing, stop line, or pavement words or symbols.

76-3.02(01) Paint

Paint should be used where it can provide satisfactory, year-round visibility and where the additional cost of durable pavement markings cannot be justified. Paint should be used as follows:

1. where the average daily traffic is less than 1000 vehicles per lane;

2. where the remaining surface life of the pavement is less than three years, or where the pavement is scheduled for resurfacing within three years; or

3. for marking non-mountable islands and raised curbs.

76-3.02(02) Thermoplastic

Hydrocarbon and alkyd thermoplastic markings may be used on asphalt pavement under the following conditions.

1. Travelway Lines. Thermoplastic markings may be used for the center line or lane lines at a location that is not proposed or scheduled for resurfacing within the next four years. Where used for edge lines, the standard pattern is 25 ft of line with a 1-ft break for drainage.

2. Transverse Markings. Thermoplastic markings may be used for a location that is not proposed or scheduled for resurfacing within the next three years and where the average daily traffic is in excess of 1000 vehicles per lane.

3. Painting Cycles. Thermoplastic markings may be used on a road that requires two or more applications of paint lines per year, or on a road which requires one application of paint lines per year and the average daily traffic exceeds 3500 vehicles per lane.

4. Decision Point. Thermoplastic markings may be used where there is a need for more positive lane identification because of alignment, transitions, or channelization.

76-3.02(03) Epoxy Paint

Epoxy markings may be used for the center line, lane lines, or edge lines. They are not used for transverse markings or for marking a non-mountable island or raised curb because of problems that can develop with the intermittent application. Epoxy markings may be used as follows:

1. at a location where the average daily traffic is in excess of 1000 vehicles per lane, and the location is not proposed or scheduled for resurfacing within the next three years; or

2. at a location that is not proposed or scheduled for resurfacing within the next two years, and requires two or more applications of paint lines per year, or requires one application of paint lines per year and the average daily traffic exceeds 3500 vehicles per lane.

76-3.02(04) Preformed Plastic

The criteria for epoxy markings provided in Section 76-3.02(03) is also applicable for a permanent application of preformed plastic markings. However, they should only be used as follows:

1. there is highway illumination;
2. they can be supplemented by RPMs; or
3. they are permitted, by special provisions, on a bridge-deck overlay project.

Temporary preformed plastic markings are commonly used in a construction zone. Temporary preformed plastic markings should not be used for a permanent application.

76-3.02(05) Raised Pavement Markers (RPMs)

Snowplowable RPMs provide a supplemental method of delineation and are a positive position guidance device. They should not be used as a replacement for standard pavement markings or conventional roadside delineation. The INDOT *Standard Drawings* provide details on the placement and color locations for RPMs. In addition, the following placement considerations should be reviewed.

1. Location. Site selection should be based primarily on the need for additional alignment delineation specifically in an area of frequently inclement weather (e.g., fog, smoke, rain) and in an area of low roadway illumination. RPMs placement should be considered where vehicles are leaving the roadway, an area showing excessive wear of existing pavement markings, an area with excessive skid marks, interchange ramp, etc.

2. Pavement Life. RPMs should not be placed at a location that is scheduled for resurfacing or reconstruction within the next four years.

3. Illumination. RPMs may not be required at a location that is illuminated.

4. Traffic Volume. RPMs should be considered where ADT exceeds 2500 for a 2-lane roadway, or 6000 for a 4-lane roadway. On a lower-volume road, an engineering investigation should be conducted to determine whether RPMs are appropriate to supplement the standard traffic-control devices.

5. Spacing. The spacing for RPMs on a tangent section is 80 ft. Spacing for center line RPMs used in conjunction with a no-passing zone may be reduced to 40 ft. Six RPMs at 40-ft spacing (640 ft) may be used in advance of and following a delineated no-passing zone. Consideration should be given to connecting two locations or zones of RPMs where the distance between them is less than 3000 ft. See the INDOT *Standard Drawings* for additional details for spacing at other locations.

6. Special Locations. RPMs should not be used exclusively with edge lines or gore markings. RPMs may be used at a pavement transition, 1-way or narrow bridge, special channelization area, or where there is strong justification for installation of the devices.

7. <u>Blue Retroreflectors</u>. An RPM with blue retroreflectors should be specified where a fire hydrant is located within the roadway's right of way. Such an RPM should be specified only for a roadway where RPMs with yellow or white retroreflectors are to be installed.

The RPM should be placed at an approximately right angle to the fire-hydrant location. It should be a two-way marker visible in both directions of travel. It should be placed in addition to RPMs with yellow or white retroreflectors.

For a two-lane, two-way roadway, the RPM should be placed within the transverse limits of the center-line marking.

For a 3-lane roadway with a bidirectional left-turn lane, the RPM should be placed within the transverse limits of the yellow markings on the hydrant side of the bidirectional left-turn lane.

For a roadway of 4 lanes or more, the RPM should be placed within the transverse limits of the lane-line marking nearest the fire hydrant, but should not be placed within the transverse limits of the pavement-edge line.

Local-public-agency (LPA) standards, if such exist, should be applied to a road under LPA jurisdiction. The district traffic engineer should be contacted to determine if an LPA's standards, if such exist, should apply on a Department-maintained route within the LPA's jurisdiction.

The locations of RPMs with blue retroreflectors should be shown on the plans. Quantities for such RPMs should therefore be incorporated into the quantities for other RPMs.

76-3.02(06) Surface Conditions

Most pavement markings can be placed on either an asphalt or concrete pavement. Pavement markings on an asphalt surface tend to last longer than those on a concrete surface. Hot-applied thermoplastic pavement-marking materials should not be placed on a concrete surface.

76-4.0 OBJECT MARKERS AND DELINEATORS

<u>76-4.01 Object Markers</u>

76-4.01(01) Types

An object marker is used to mark an obstruction which is within or adjacent to the roadway. Where deemed necessary, one or more of the following object markers should be used.

1. Type 1. A type 1 object marker consists of an 18-in. or larger diamond-shaped panel with one of the arrangements as follows.

   a. Reflectors with Yellow Background. This marker consists of 9 yellow, 3-in. diameter reflectors arranged symmetrically on a yellow diamond-shaped panel.

   b. Reflectors with Black Background. This marker consists of 9 yellow, 3-in. diameter reflectors arranged symmetrically on a black diamond-shaped panel.

   c. Reflectorized Sheeting. This marker is a yellow diamond-shaped panel with reflective sheeting and no reflectors.

2. Type 2. A type 2 object marker can be either a 6-in. x 12-in. reflectorized, yellow rectangular panel, or a 6-in. x 12-in. white rectangular panel with three, yellow 3-in. diameter reflectors. Either type can be arranged vertically or horizontally. A type 2 marker may be made larger to meet special conditions.

3. Type 3. A type 3 object marker consists of a 12-in. x 36-in. rectangular panel with alternating black and reflectorized yellow stripes sloping downward at an angle of 45 deg toward the side of the obstruction on which traffic is to pass. For an object on the right-hand side, the stripes should begin at the upper right side of the panel and slope downward to the lower left side. For an object on the left-hand side, the stripes should begin at the upper left side and slope downward to the lower right side.

4. End-of-Road Marker. An end-of-road marker is similar to a type 1 marker except that the reflectors and background colors are red instead of yellow. This marker is used at the end of a roadway where there is no alternative vehicular path.

76-4.01(02) Application

The following provides guidelines for the application of an object marker.

1. Mounting Height. For marking an object which is 8 ft or less from the roadway, the bottom of the marker should be approximately 4 ft above the surface of the nearest travel lane. For an object which is greater than 8 ft from the roadway, the bottom of the marker may be 4 ft above the ground. Adjustments may be made to the mounting height to meet

field conditions.

2. Object in the Roadway. An obstruction within the roadway should be marked with either a type 1 or a type 3 object marker. An obstacle with large surfaces (e.g., bridge pier) may be painted with reflectorized paint in a pattern similar to the Type 3 object marker. Appropriate signing may be used instead of the object marker to direct traffic to one or both sides of the obstruction.

3. Object Adjacent to the Roadway. A type 2 or type 3 object marker may be used where an object is relatively close to the roadway (e.g., bridge pier, bridge abutment, culvert headwall, shoulder drop-off, gore, small island). The inside edge of the marker should be in line with the inner edge of the obstruction.

76-4.02 Delineators

Delineators are light retro-reflecting devices mounted along the roadside, which are used to guide the motorist, particularly where the alignment might be confusing, or at a pavement-width transition. Delineators are defined according to the number of reflecting devices on the post. For example, a type D2 delineator consists of two yellow or white delineators on a post. The delineator itself can be either a 3-in. diameter reflective element or a rectangle unit that substitutes for two circular units.

76-4.02(01) Application

The following are the guidelines for the application of delineators.

1. Color. The delineator color should match the color of the edge line. For example, if the edge line is white, the delineator will be white. For the median side of a divided highway, the delineator, if used, must be yellow. Red delineators may be used on the reverse side of a delineator post to alert a motorist who may be traveling the wrong way on a one-way roadway (e.g., ramp).

2. Freeway. Single delineators should be provided on the outside-shoulder side of a freeway or on at least one side of each interchange ramp. Yellow single delineators may also be provided on the left side of the ramp.

3. Interchange. Single delineators should be provided along the outside of each curve on an interchange ramp. Double or vertically-elongated delineators should be installed at 100-ft intervals along each acceleration or deceleration lane.

4. Detour. Delineators should be provided along a temporary roadway (e.g., crossover, temporary runaround) to guide the motorist through the construction zone. See the INDOT *Standard Drawings* for additional details.

5. Median Crossover. For a median crossover, a double yellow delineator should be placed on the median side of the through roadway and on the far side of the crossover.

6. Transition. Delineators should be used to guide the motorist through a lane-narrowing transition or lane merge. Figure 76-2D, Transition Markings (4-Lane Undivided to 2-Lane Undivided), Figure 76-2F, Transition Markings (4-Lane Divided to 2-Lane Undivided - Left), Figure 76-2G, Truck-Climbing Lane Markings, and the *INDOT Standard Drawings* provide illustrations on where to place delineators within these transition areas. Where continuous delineation is provided on one or both sides of the highway, the delineation should be continued through the transition area and a closer spacing may be warranted.

7. Lighting. Where lighting is provided, the need to use delineators in the area will be determined as required for each project.

8. Guardrail. Barrier delineators are required on each run of median barrier, temporary concrete barrier, or concrete railing or metal beam guardrail.

9. Island. Delineators may be used to outline a raised island. A solid yellow reflectorized panel should be used where the island channelizes traffic to the right. Where traffic may pass on either side of the island, a solid white reflectorized panel should be used. A continuous median island is not delineated unless deemed necessary.

10. No-Passing Zone. The end of the no-passing zone is indicated on the right side of the roadway with three, horizontally aligned, white delineators.

11. Raised Pavement Markers. Delineators may be removed along a roadway where raised pavement markers are used for a substantial distance.

76-4.02(02) Delineator Placement and Spacing

The INDOT *Standard Drawings* provide criteria for the placement of delineators next to a roadway with curbs or a roadway with no curbs. They also illustrate the placement of delineators next to a roadway approaching a narrow bridge. In addition to the INDOT *Standard Drawings*, the designer should consider the following.

1. Height. The top of the delineator should be placed so that the top of the reflecting head is approximately 4 ft above the surface of the nearest travel lane.

2. Placement. Delineators should be placed at a constant distance from the roadway edge unless guardrail or another obstruction intrudes into the space between the pavement edge and the extension of the line of delineators. Delineators should not be placed less than 2 ft or more than 8 ft from the outside edge of the shoulder.

3. Spacing. For a tangent section, delineators should be spaced from 200 ft to 500 ft apart. On a freeway or other divided facility, the delineator spacing should be 400 ft. Where normal uniform spacing is interrupted by a driveway, cross road, etc., the delineator should be moved to either side provided the distance does not exceed one-quarter of the normal spacing. If this criterion is exceeded, the delineator should be deleted.

   For a horizontal curve, the delineator spacing should be adjusted so that several delineators will always be visible to the driver. Figure 76-4A provides the recommended maximum spacing for delineators around a horizontal curve.

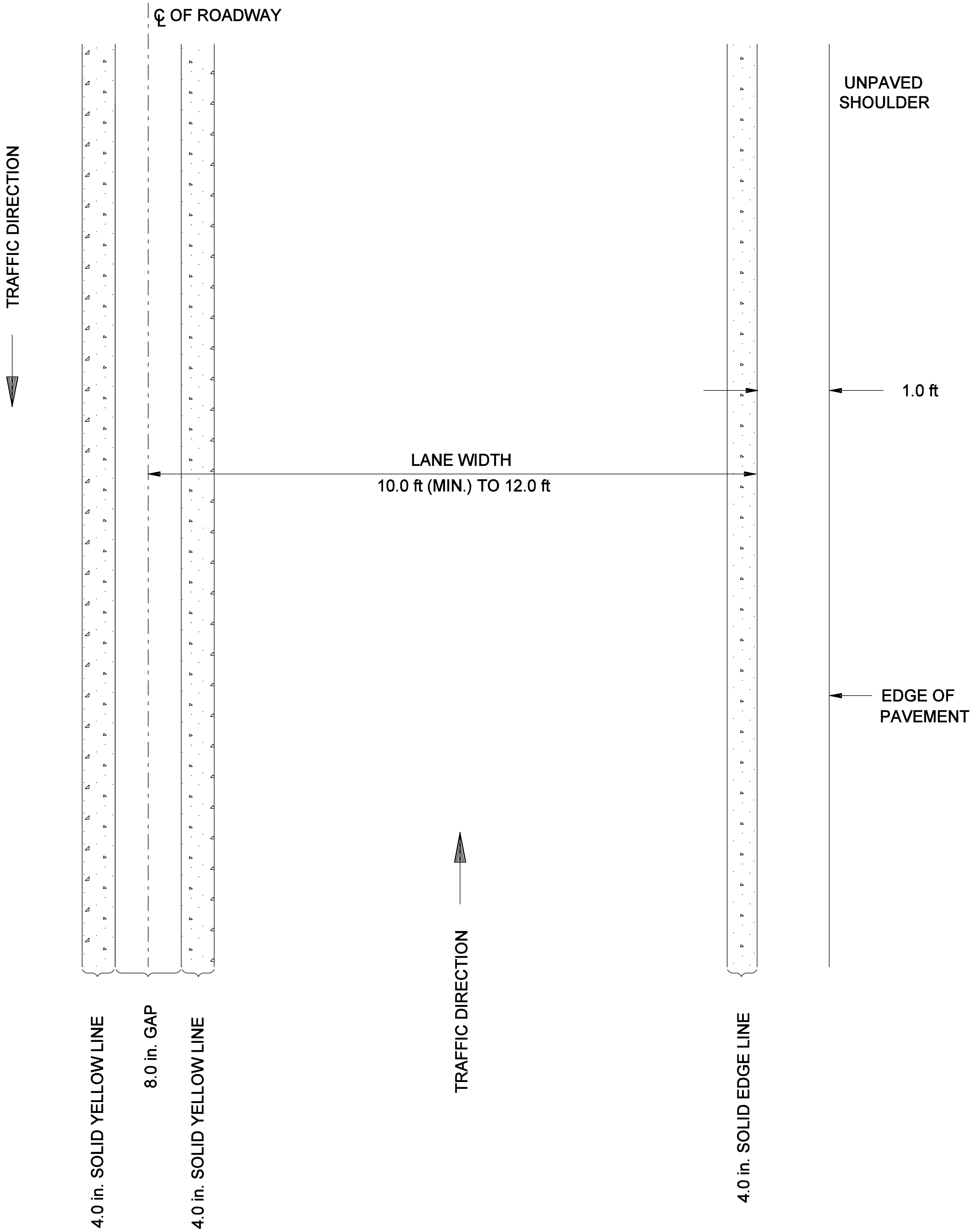
DESCRIPTION	COLOR	WIDTH (in.)	APPLICATION
Single Broken Line	White	4	Separation of lanes on which travel is in the same direction, with crossing from one lane to the other permitted (e.g., lane lines on multilane roadways). The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10-ft segment followed by a 30-ft gap for a total cycle length of 40 ft.
		5	Separation of freeway lanes on which travel is in the same direction, with crossing from one lane to the other permitted. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10-ft segment followed by a 30-ft gap for a total cycle length of 40 ft.
	Yellow	4	Separation of lanes on which travel is in opposite directions, and where overtaking with care is permitted (e.g., centerline on 2-lane, 2-way roadways). The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10-ft segment followed by a 30-ft gap for a total cycle length of 40 ft.
Single Solid Line	White	4	Separation of lanes, or of a lane and shoulder, where lane changing is discouraged (e.g., lane lines at intersection approaches, right-edge stripes).
		6	Lane lines separating a motor vehicle lane from a bike lane.
		8	Delineation of locations where crossing is strongly discouraged (e.g., separation of turn lanes from through lanes, gore areas at ramp terminals, paved turnouts, edge lines at lane drops, painted island edges).
	Yellow	4	Delineation of left-edge lines on divided highways, 1-way roads and ramps.
Double Solid Lines	White	4-8-4*	Separation of lanes on which travel is in same direction, with crossing from one side to the other prohibited (e.g., channelization in advance of obstructions which may be passed on either side).
	Yellow	4-8-4*	Separation of lanes on which travel is in opposite directions, where overtaking is prohibited in both directions. Left-turn maneuvers across this marking are permitted. Also used in advance of obstructions which may be passed only on the right side.
Solid Line Plus Broken Line	Yellow	4-8-4*	Separation of lanes on which travel is in opposite directions, where overtaking is permitted with care for traffic adjacent to the broken line, but prohibited for traffic adjacent to solid line. Used on 2-way roadways with 2 or 3 lanes. Also used to delineate edges of a two-way left-turn lane — solid lines on the outside, broken lines on the inside.
Double Broken Line	Yellow	4-8-4*	Delineates the edges of reversible lanes. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 10-ft segment followed by 30-ft gap for a total cycle length of 40 ft.

DESCRIPTION	COLOR	WIDTH (in.)	APPLICATION
Single Dotted Line	Either	4	Extension of lane lines through intersections. Color same as that of line being extended. Also used to extend right-edge line of freeway shoulder lanes through off-ramp diverging areas in problem locations. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 2-ft segment followed by 8-ft gap for a total cycle length of 10 ft.
	White	8	Separation of through lane and auxiliary lane or dropped lane. The broken or dashed line is formed by a pattern of segments and gaps. The typical pattern is a 2-ft segment followed by 8-ft gap for a total cycle length of 10 ft.
Transverse Lines	White	6 (min)	Crosswalk edge lines (minimum 6-ft apart).
		24	Limit lines or stop lines.
Diagonal Lines	White	12	Crosshatch markings for 1-way traffic, placed at an angle of 45°, at 6-m apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds less than 45 mph.
		24	Crosshatch markings for 1-way traffic, placed at an angle of 45°, at 40 ft apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds of 70 km/h or greater.
	Yellow	12	Crosshatch markings for 2-way traffic, placed at an angle of 45°, at 20 ft apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds less than 45 mph.
		24	Crosshatch markings for 2-way traffic, placed at an angle of 45°, at 40 ft apart, on shoulders or channelization islands to add emphasis to these roadway features for design speeds of 45 mph or greater.

**100-200-100 indicates typical width in mm of the lines and the 200-mm unpainted gap between them*

Types of Pavement Lines

Figure 76-1A



LOCATION OF EDGE LINES
(Unpaved Shoulders)

Figure 76-2A

Design Speed (mph)	Merging-Taper Rate
20	10:1
25	10:1
30	15:1
35	20:1
40	30:1
45	45:1
50	50:1
55	55:1
60	60:1
65	65:1
70	70:1

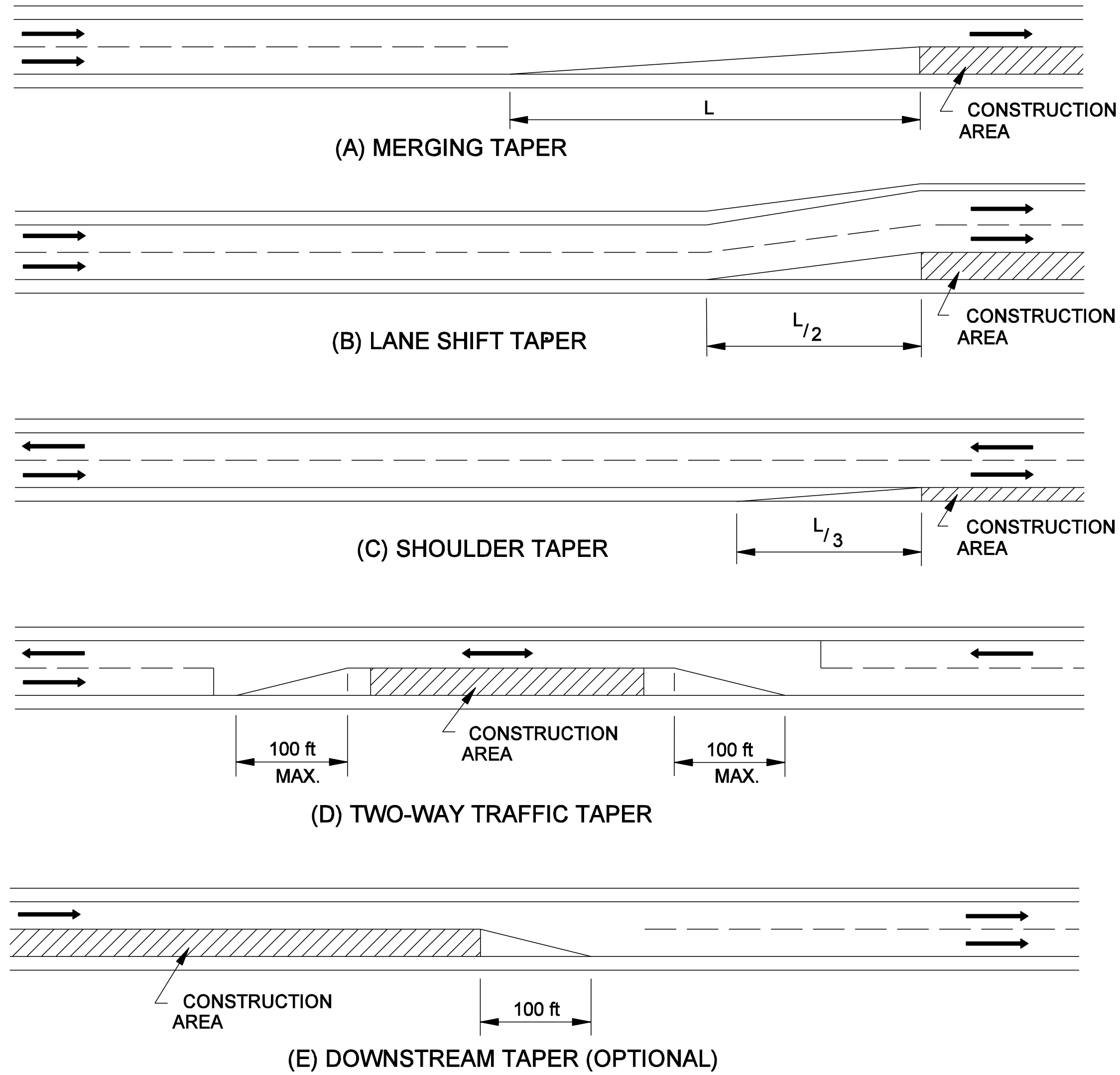
Taper Type		Minimum Taper Length
Upstream	Merging Taper (Lane Drop)	*L*
	Lane-Shift Taper	½ *L*
	Shoulder Taper	1/3 *L*
	Two-Way-Traffic Taper	100 ft
Downstream		50 ft / lane [2]

Notes:

1. *Taper Length*, L = *Merging-Taper Rate x Offset Distance*
2. *The desirable length is 100 ft / lane.*
3. *Figure 76-2C illustrates the various types of tapers.*

LONGITUDINAL TAPER RATE AND LENGTH

Figure 76-2B

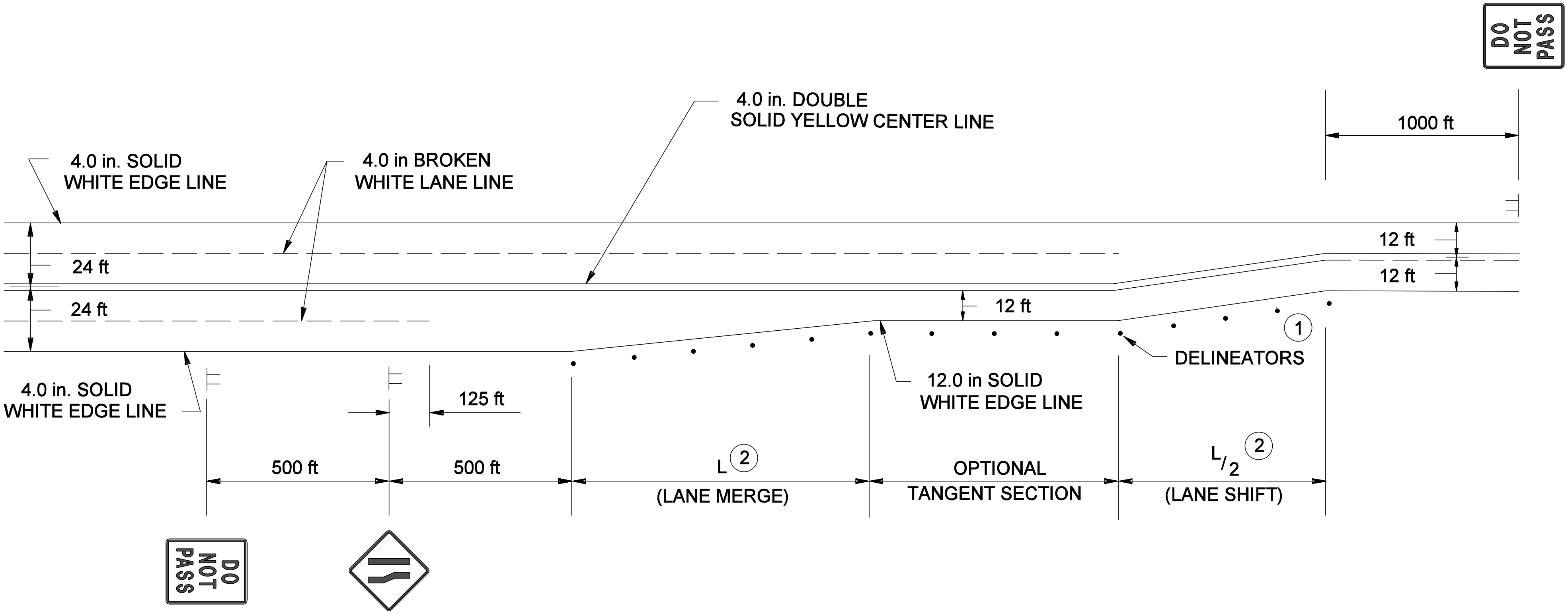


Notes:

1. *Length "L" determined from 76-2B.*
2. *Figures may apply to situations other than construction zones.*

TAPER LENGTH CRITERIA
(Application)

Figure 76-2C



(1) SEE SECTION 76-4.0 FOR DELINEATOR SPACING.

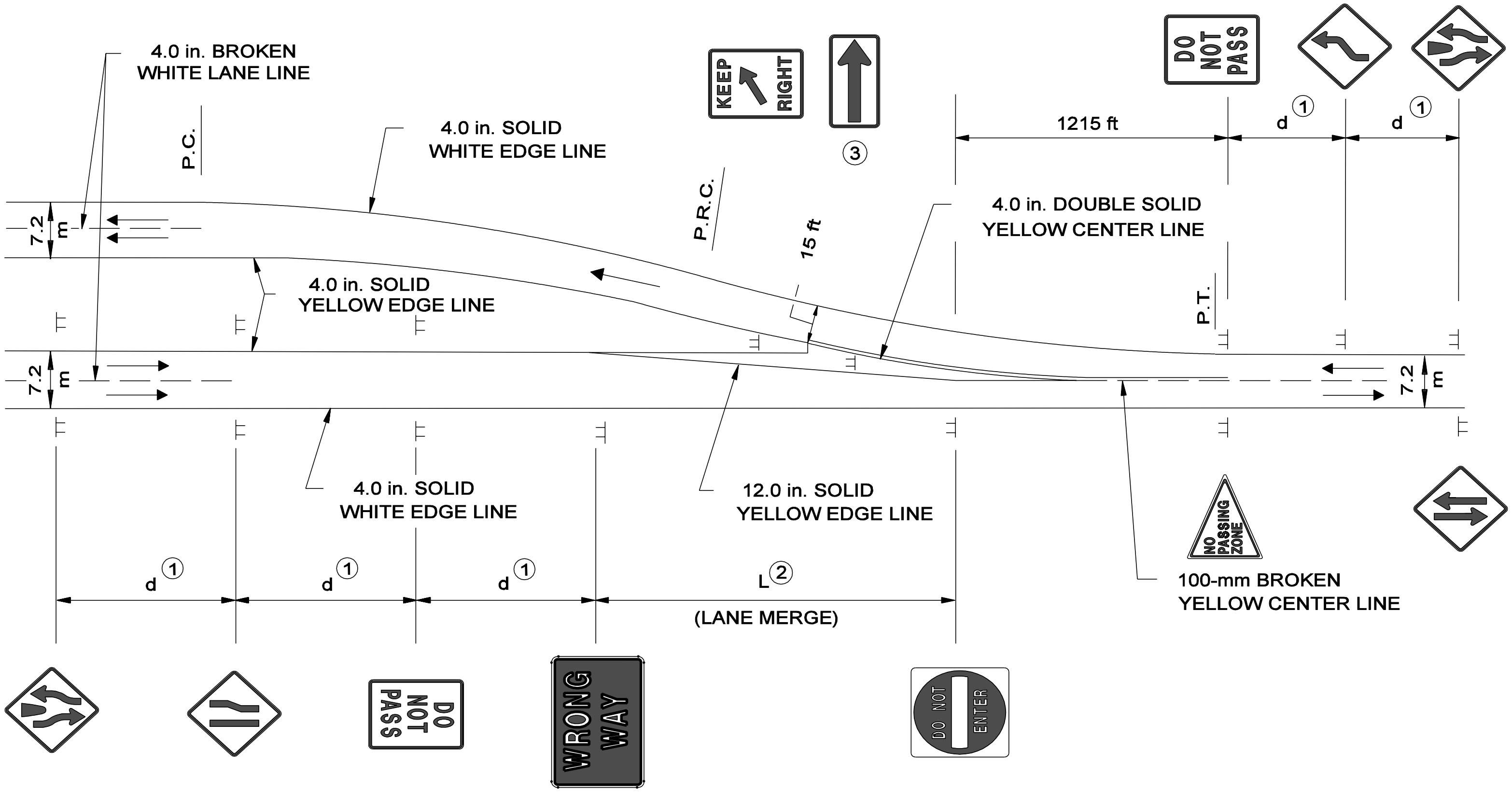
(2) SEE FIGURE 76-2B FOR TAPER LENGTH.

Notes:

1. *RPM's are desirable along all edge and center lines within the transition area.*
2. *Adjustments to the signing and pavement marking locations may be required to meet field conditions.*

TRANSITION MARKINGS
(4-Lane Undivided to 2-Lane Undivided)

Figure 76-2D



1 d = ADVANCE WARNING DISTANCE, SEE FIGURE 75-4A.

2 SEE FIGURE 76-2C FOR TAPER LENGTHS.

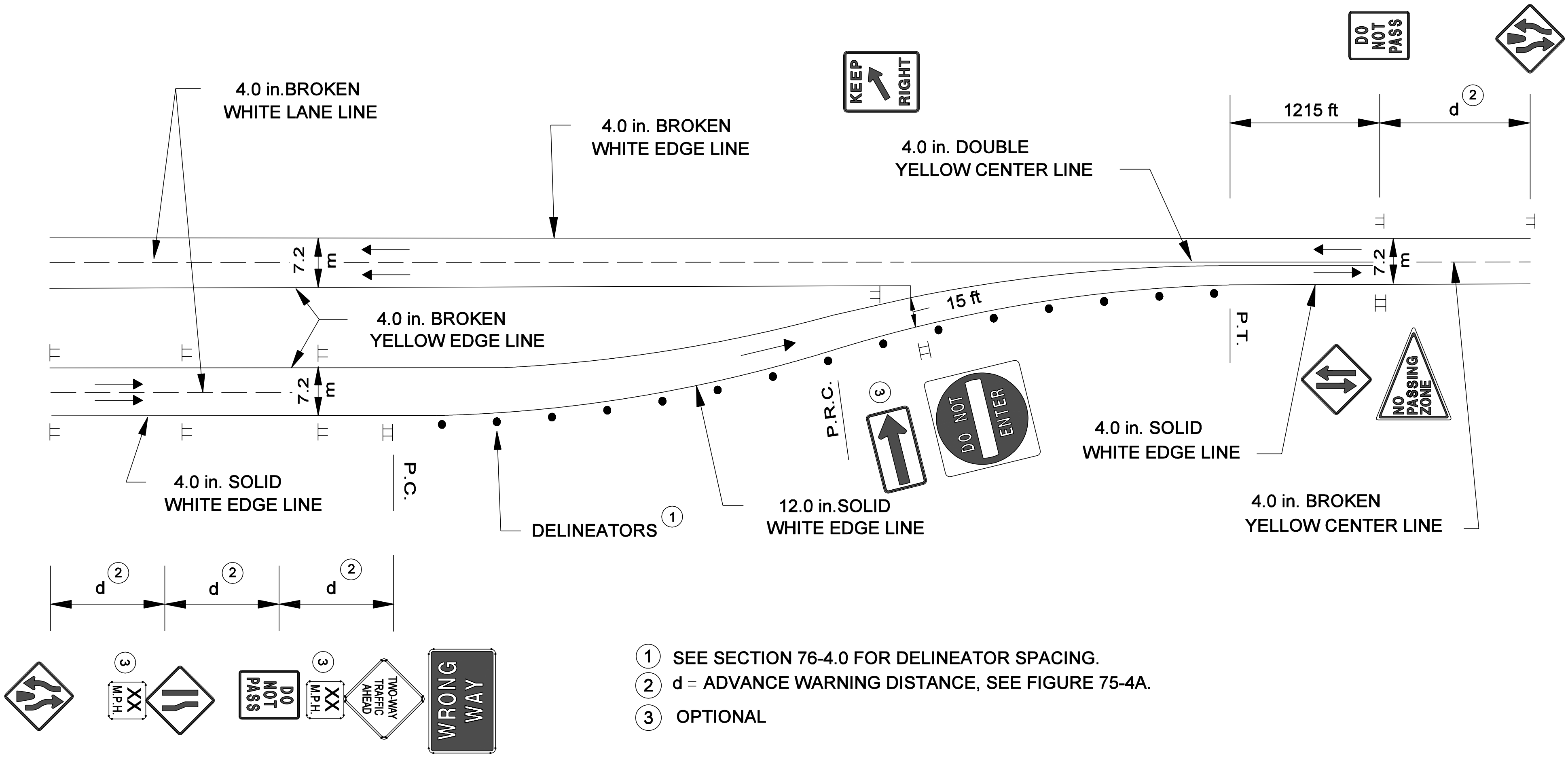
3 OPTIONAL

Notes:

1. *RPM's are desirable along all edge and center lines within the transition area.*
2. *Adjustments to the signing and pavement marking locations may be required to meet field conditions.*
3. *This transition design should only be used for existing conditions.*

TRANSITION MARKINGS
(4-Lane Undivided to 2-Lane Undivided --- Right)

Figure 76-2E

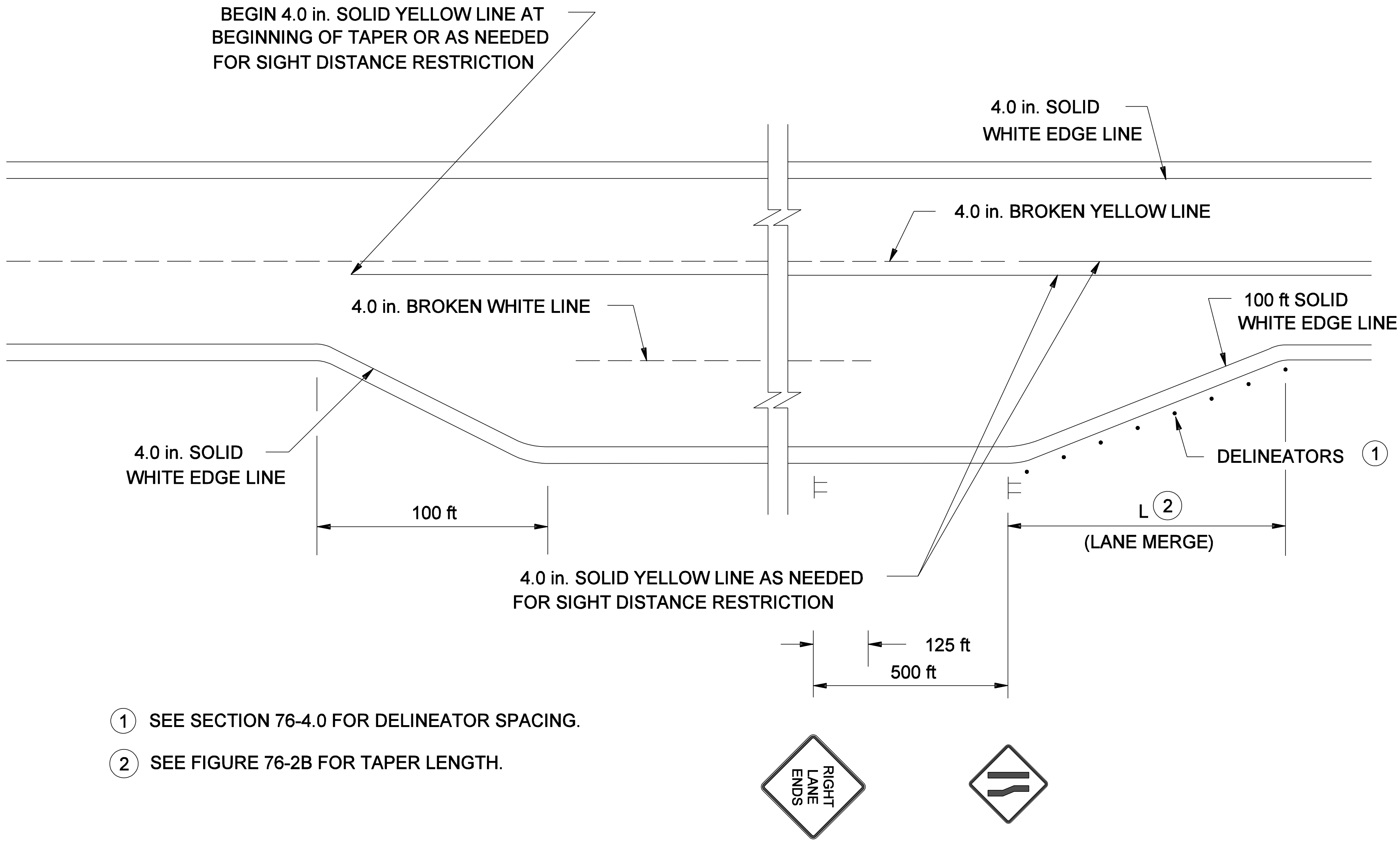


Notes:

1. *RPM's are desirable along all edge and center lines within the transition area.*
2. *Adjustments to the signing and pavement marking locations may be required to meet field conditions.*

TRANSITION MARKINGS
(4-Lane Undivided to 2-Lane Undivided --- Left)

Figure 76-2F



TRUCK-CLIMBING LANE MARKINGS

Figure 76-2G

Speed (mph)	Minimum Distance (ft)			
	Passing Sight Distance [1]	Stopping Sight Distance [2]	Aborted Passing Maneuvers [3]	
			APM-A	APM-B
25	900	155	290	295
30	1090	200	430	365
35	1280	250	560	430
40	1470	305	675	495
45	1625	360	745	530
50	1835	425	805	560
55	1985	495	920	625
60	2135	570	1050	675
65	2285	645	1185	740
70	2480	730	1320	810

1. AASHTO Passing Sight Distance; see Section 42-3.01.
2. AASHTO Stopping Sight Distance; see Section 42-1.02.
3. Report No. FHWA RD-81-093, *No-Passing-Zone Treatments for Special Geometrics and Traffic-Operational Situations.*

Notes:

APM-A *is the distance for a vehicle which is aborting a pass, slows down, gets behind the slower vehicle, then both vehicles come to a stop. Both vehicles decelerate but at different rates. This is measured from where the pass-aborting vehicle begins to slow down to where it stops.*

APM-B *is the distance for a vehicle which is aborting a pass, slows down, then gets behind the slower vehicle. The slower vehicle maintains a constant speed, and the passing vehicle decelerates to the speed of the slower vehicle. This is measured from where the pass-aborting vehicle begins to slow down to where it reaches the slower vehicle's speed.*

NO-PASSING-ZONE DISTANCES

Figure 76-2H

FEATURE	MINIMUM CRITERIA (1)	MARK NO-PASSING ZONE THROUGH FEATURE
Horizontal or Vertical Curve	MUTCD	Yes
Major Intersection	SSD	No
Minor Intersection	0	n/a
Obstruction (center-of-roadway or median underpass pier, etc.)	(2)	Yes
Railroad Crossing (Rural)	SSD + 75 ft	Yes
Railroad Crossing (Urban)	Variable	Yes
One-Lane Bridge	APM-A	No
Narrow Bridge	APM-B	Yes
Stop Intersection (where required)	SSD	No

(1) *See Figure 76-2H for minimum length*

(2) *See MUTCD Section 3B-13 for additional information*

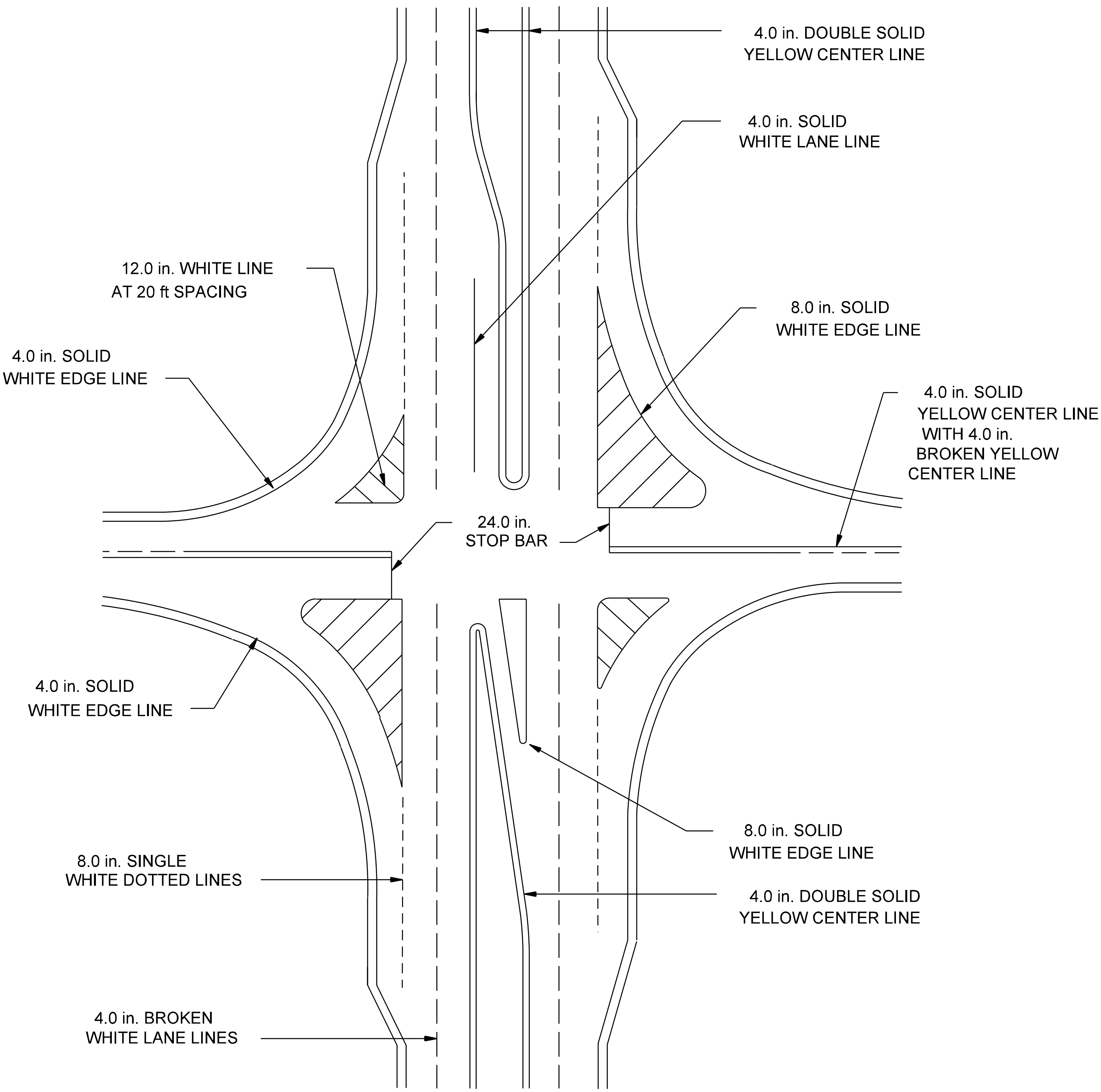
NO-PASSING-ZONE DISTANCE APPLICATIONS

Figure 76-2 I

Design Speed (mph)	Minimum Allowable Gap (ft)
30	400
35	475
40	550
45	575
50	600
55	725
60	850
65	1000

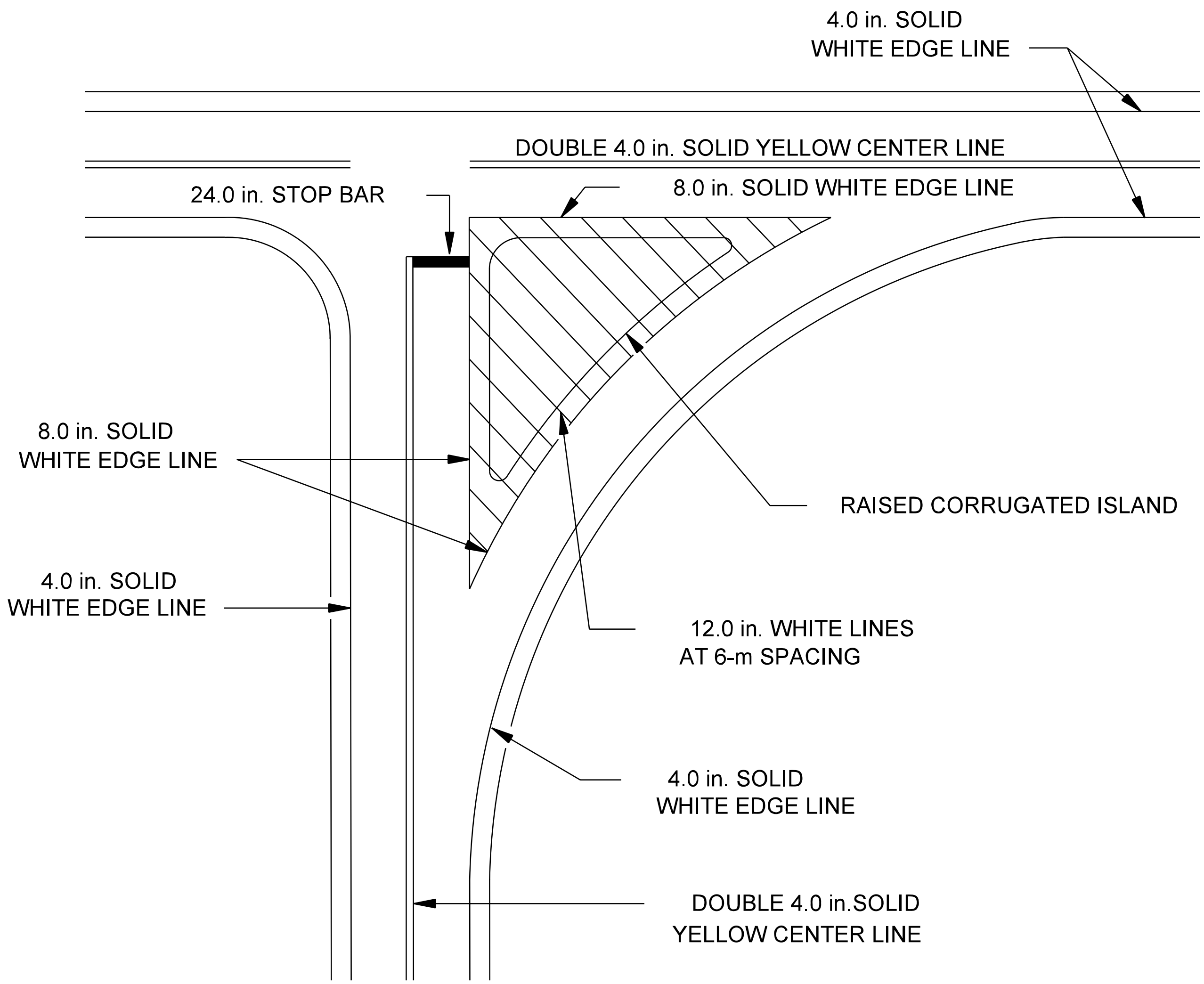
MINIMUM PASSING-ZONE GAP

Figure 76-2J



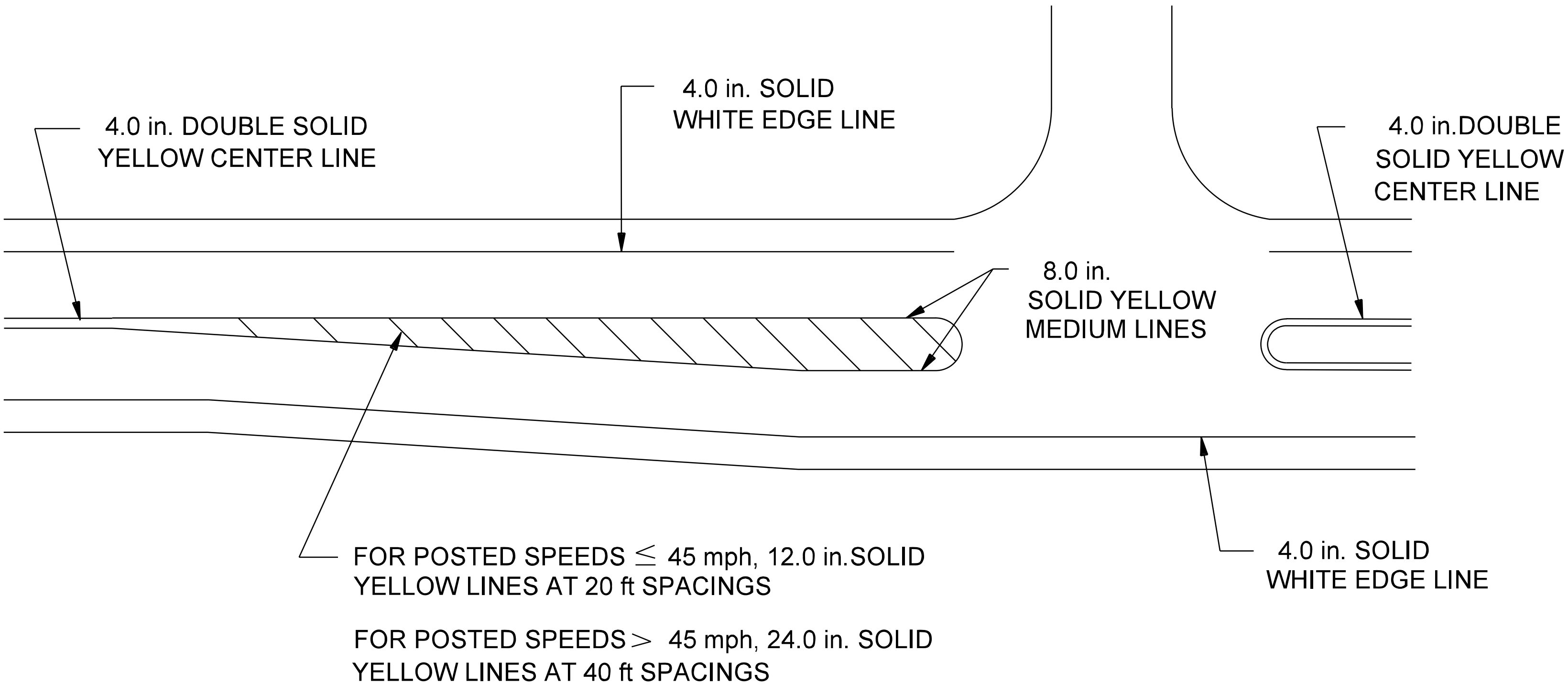
SAMPLE INTERSECTION MARKINGS

Figure 76-2K



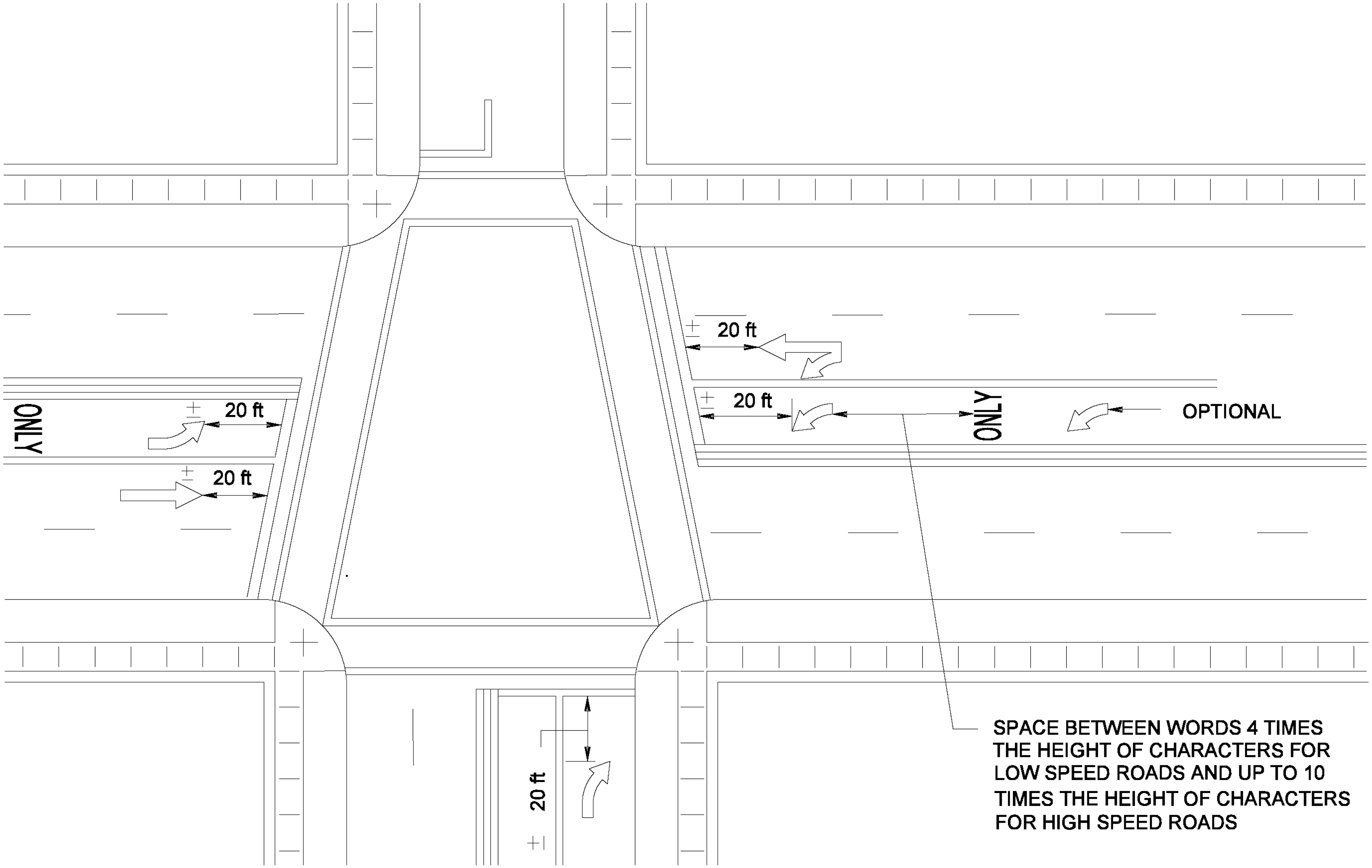
CHANNELIZED ISLAND MARKINGS
(Triangular Island)

Figure 76-2L



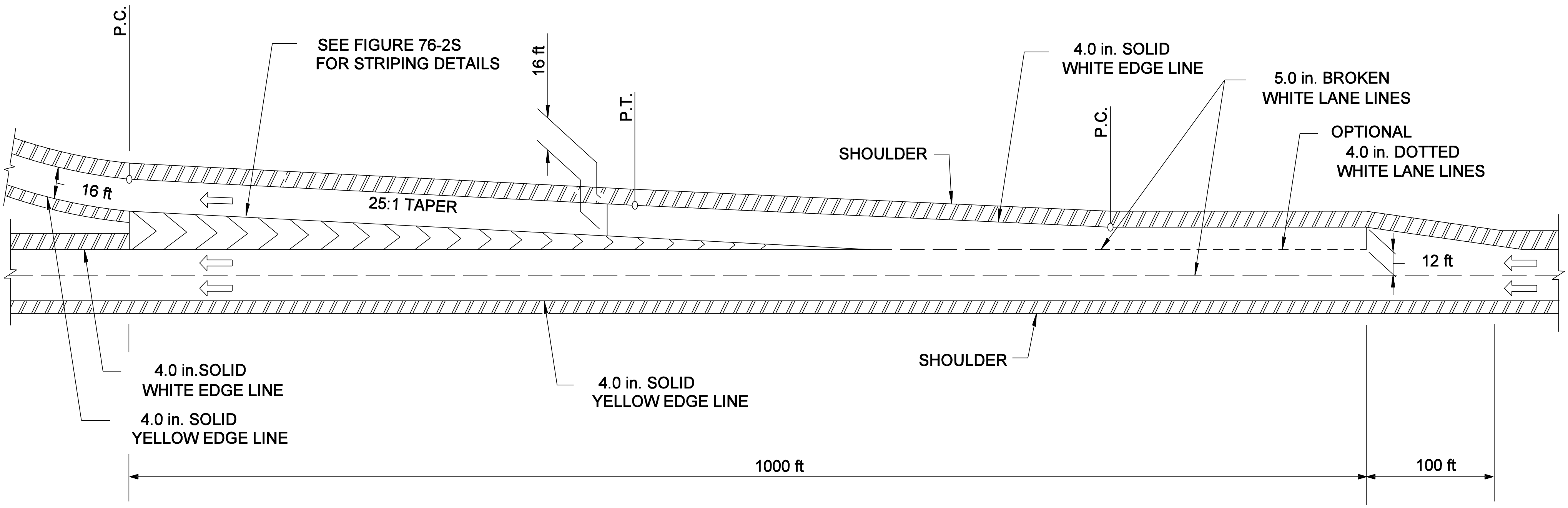
CHANNELIZED ISLAND MARKINGS
(Flush or Raised Corrugated Elongated Islands)

Figure 76-2M



TRAFFIC CONTROL WORD/SYMBOL MARKINGS

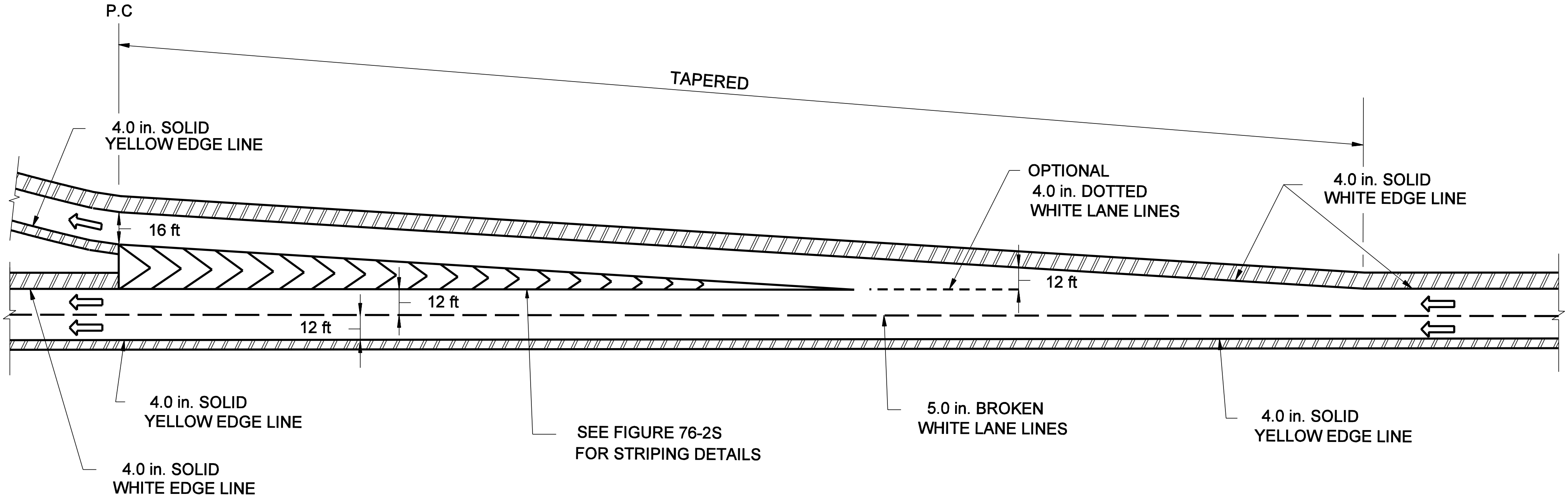
Figure 76-2N



Note: See INDOT Standard Drawings for RPM Locations.

PARALLEL EXIT RAMP MARKINGS

Figure 76-2O

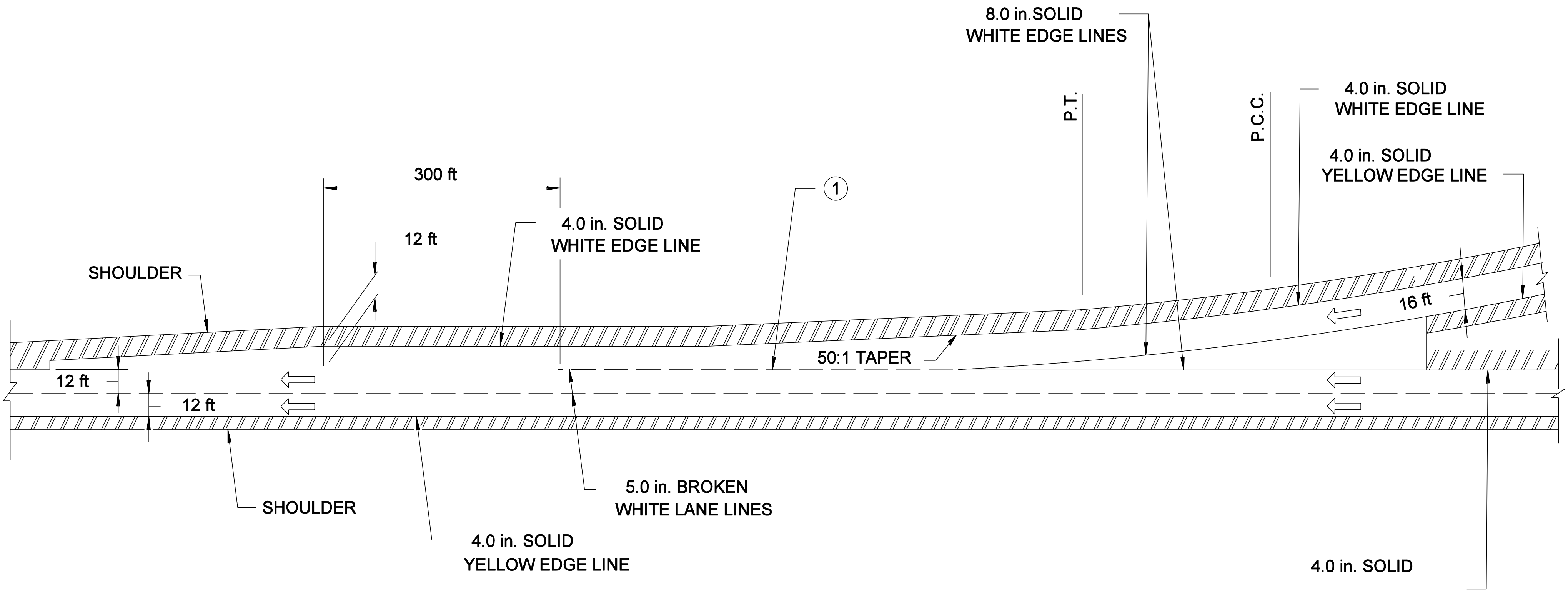


Notes:

1. *See INDOT Standard Drawings for PM Locations.*
2. *This figure applies to existing tapered exit ramps.*

TAPERED EXIT RAMP MARKINGS

Figure 76-2P

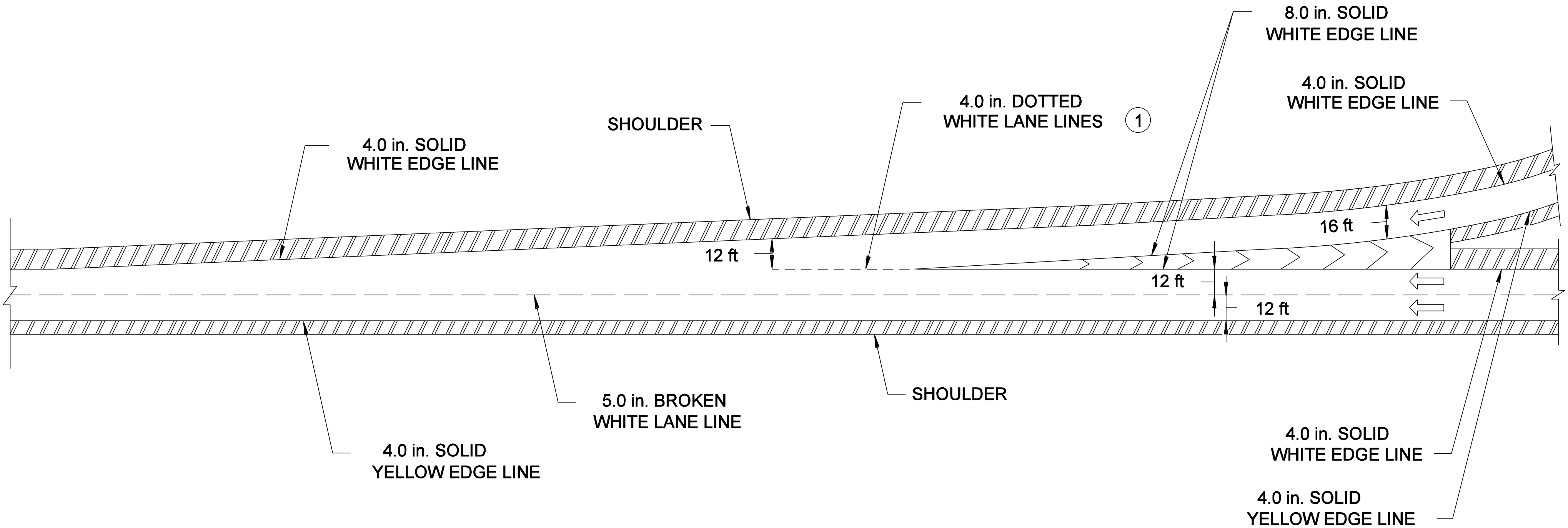


(1) USE 8.0 in. SOLID WHITE EDGE LINES FOR WEIGH STATION OR FOR ENTRANCE RAMPS WITH TRUCK VOLUMES GREATER THAN 15 %.

Notes: See INDOT Standard Drawings for RPM Locations.

PARALLEL ENTRANCE RAMP MARKINGS

Figure 76-2Q



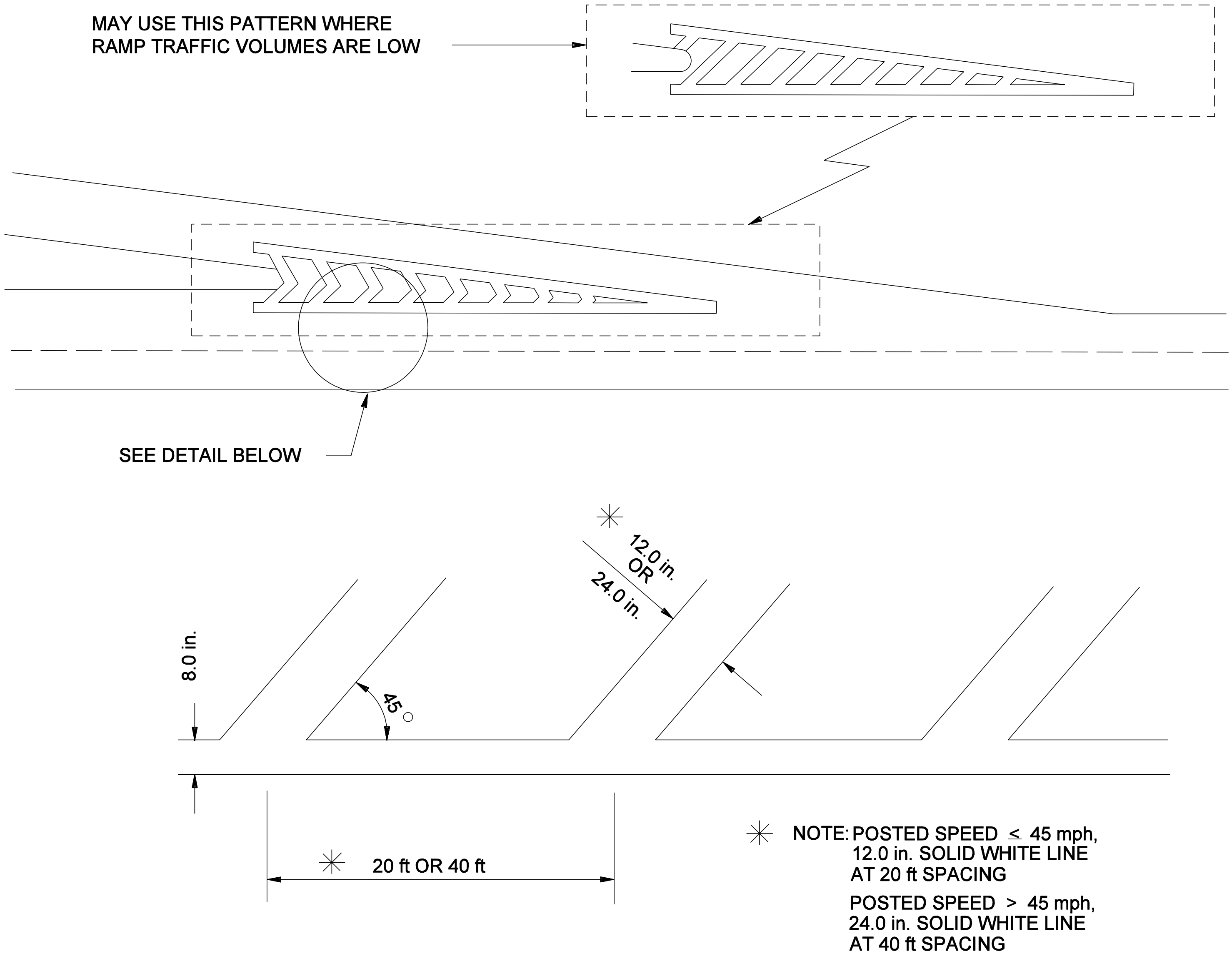
1 USE 8.0 in.SOLID WHITE EDGE LINES FOR WEIGH STATION RAMPS OR FOR ENTRANCE RAMPS WITH TRUCK VOLUMES GREATER THAN 15 %.

Notes:

1. *See INDOT Standard Drawings for RPM Locations.*
2. *This figure only applies to existing tapered entrance ramps.*

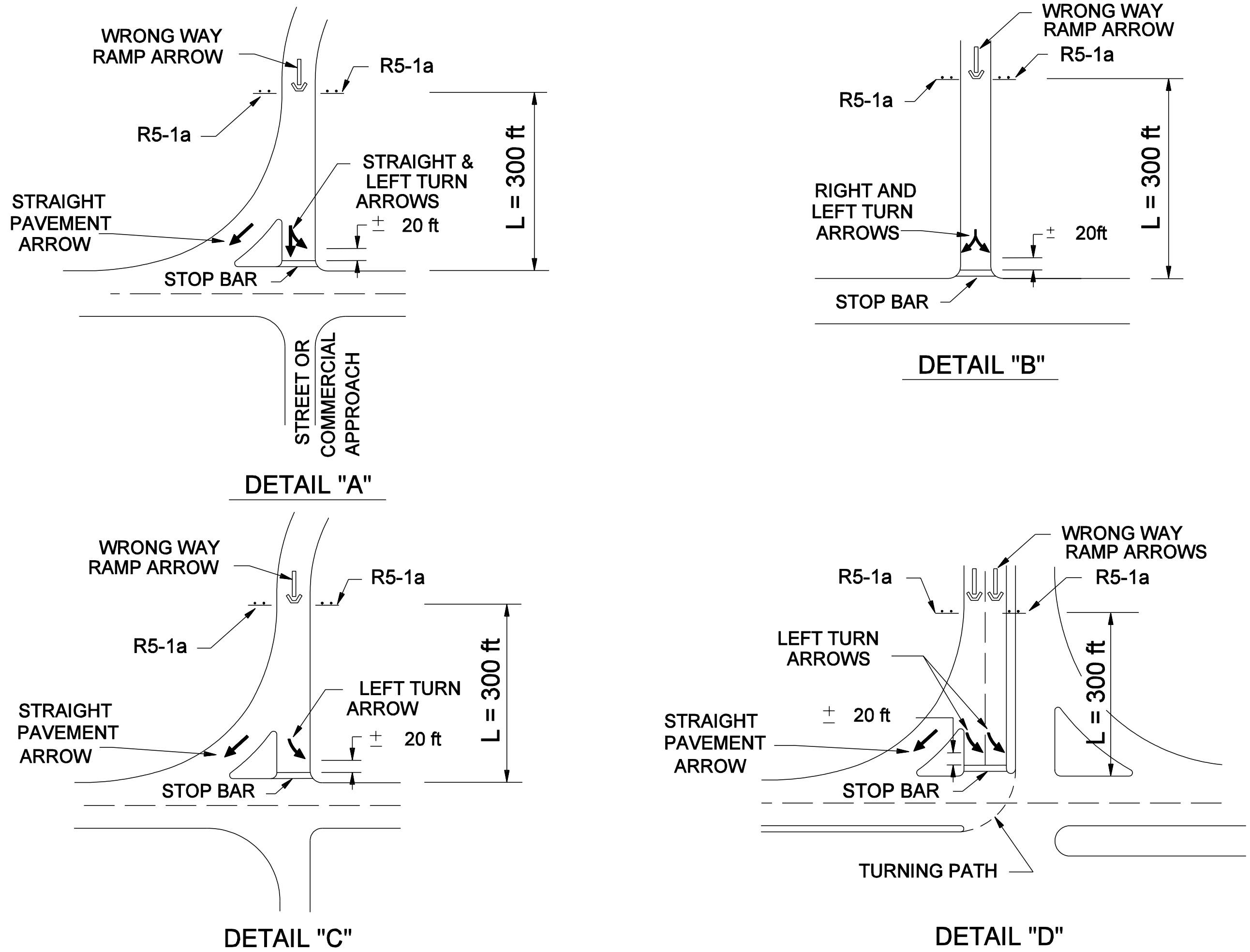
TAPERED ENTRANCE RAMP MARKINGS

Figure 76-2R



EXIT GORE MARKINGS

Figure 76-2S

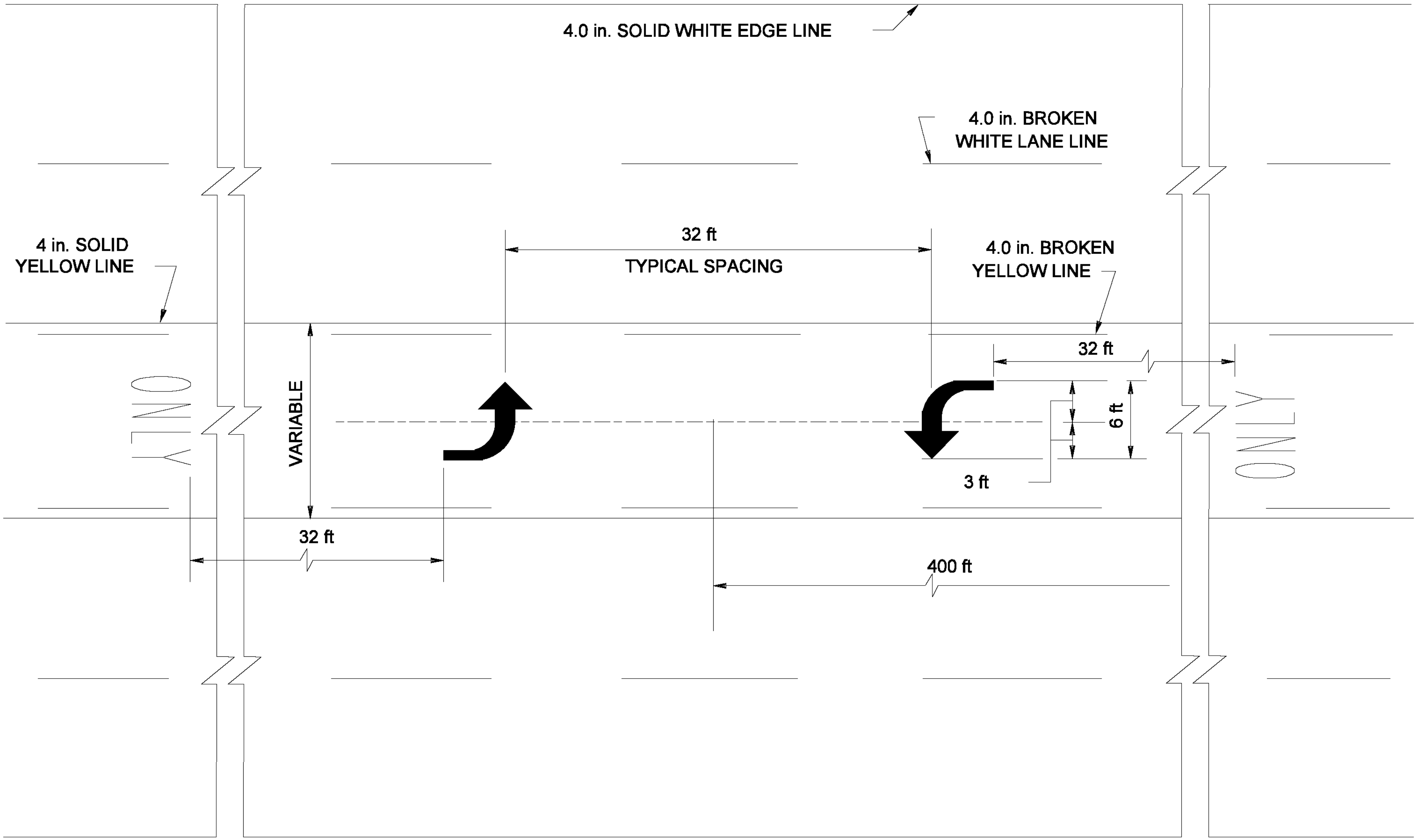


Notes:

1. *See INDOT Standard Drawings for RPM Locations.*
2. *R5-!a is a "WRONG WAY " sign.*

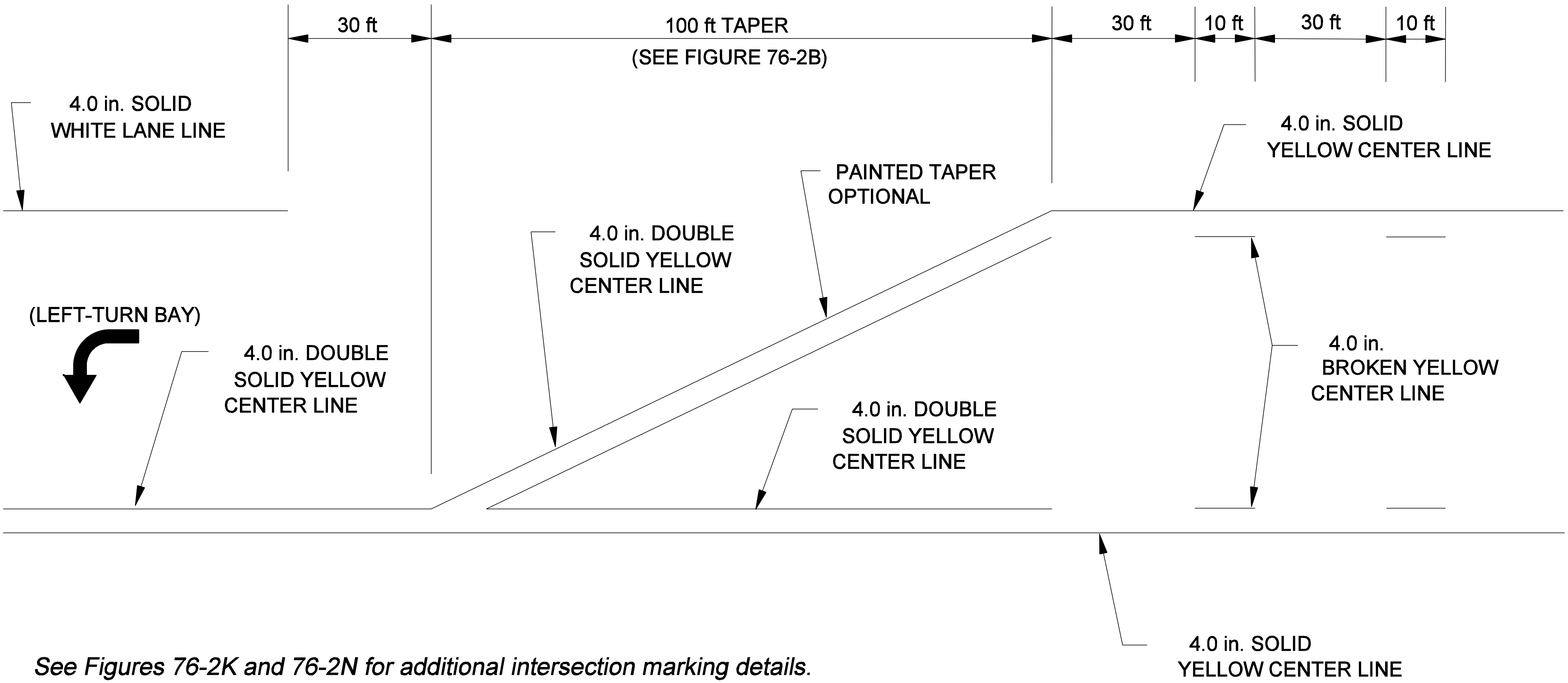
WRONG-WAY MARKINGS

Figure 76-2T



TWO-WAY LEFT-TURN LANE MARKINGS

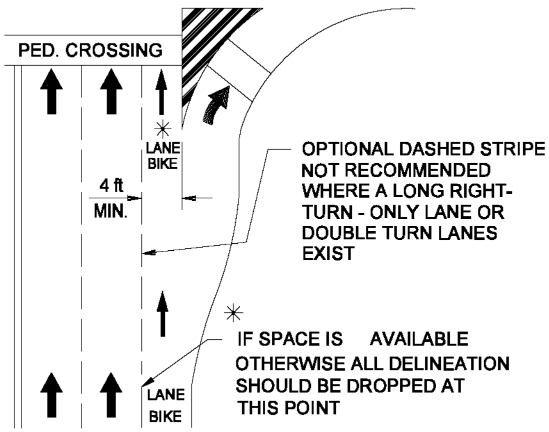
Figure 76-2U



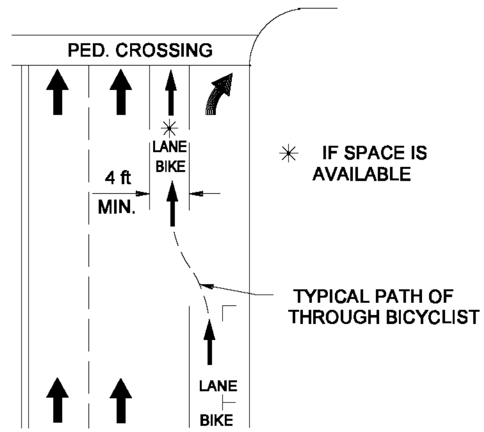
See Figures 76-2K and 76-2N for additional intersection marking details.

TWO-WAY LEFT-TURN LANE TRANSITION MARKINGS
(TWLTL to Exclusive Left-Turn Lane)

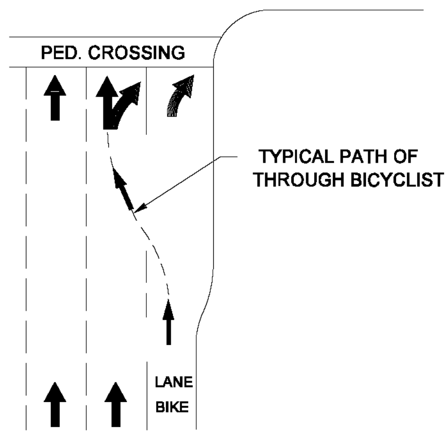
Figure 76-2V



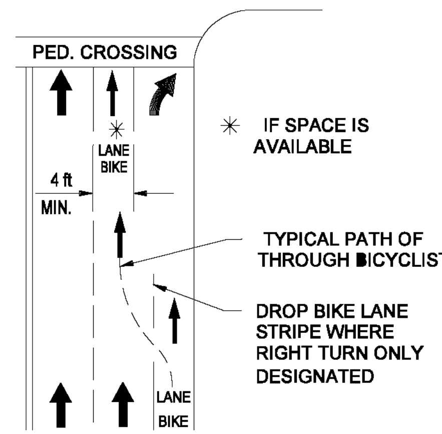
RIGHT-TURN-ONLY LANE



PARKING LANE BECOMES
RIGHT-TURN-ONLY LANE



OPTIONAL DOUBLE
RIGHT-TURN-ONLY LANE



RIGHT LANE BECOMES
RIGHT-TURN-ONLY LANE

BICYCLE MARKINGS
(Intersections)

Figure 76-2W

Application [1]	Paint	Thermo-plastic	Multi-Component	Preformed Plastic	Ext.-Warranty Preformed Plastic	Raised Pavement Markers
	Material Type					
ADT per lane	< 1000	> 1000	> 1000	> 1000	> 6000	> 2500, 2-lane > 6000, 4-lane
Pavement Surface Life	< 3 Years	≥ 3 Years	≥ 3 Years	≥ 3 Years	≥ 4 Years	≥ 4 Years
Edge Lines	X	X	X	X		X
Center Line	X	X	X	X		X
Transverse Markings	X	X		X		
Concrete Pavement	X		X	X	X [2]	X
Asphalt Pavement	X	X		X	X [2]	X

Notes:

[1] *Other applications or restrictions may apply; see Section 76-3.02 for additional information.*

[2] *Broken lines only.*

RECOMMENDED PAVEMENT-MARKING APPLICATIONS

Figure 76-3A

CURVE RADIUS (ft)	SPACING ON CURVE (ft)
100	20
150	30
200	40
300	50
400	55
500	65
600	70
700	75
800	80
900	85
1000	90

Note: *Spacing for a specific radius not shown may be interpolated from the table and rounded to the nearer 5 ft. The minimum spacing should not be less than 20 ft nor greater than 300 ft. The spacing of the first delineator approaching a curve should be placed at 2S, the second 3S, and the third 6S, but the distance should not exceed 300 ft. S refers to the delineator spacing for a specific radius computed from the formula* $S = 3.4\sqrt{R - 50}$.

SUGGESTED MAXIMUM SPACING FOR DELINEATORS ON A HORIZONTAL CURVE

Figure 76-4A

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER SEVENTY-SEVEN

TRAFFIC SIGNALS

77-1.0 GENERAL

The design of traffic signals is one of the most dynamic fields of traffic engineering. Although this Chapter will address most traffic-signal-design issues, it is impractical to provide a complete traffic-signal-design guide. For detailed design information, the references listed in Section 77-1.02 should be reviewed. The intent of this Chapter is to provide the user with an overview of the traffic-signal-design issues and to provide INDOT's applicable positions, policies, and procedures.

77-1.01 MUTCD Context

Throughout the *Manual on Uniform Traffic Control Devices (MUTCD)*, the words *shall*, *should*, and *may* are used to describe the appropriate application for traffic-control devices. Section 75-1.0 provides the Department's position on these qualifying words.

77-1.02 References

For additional information on traffic-signal design, see the publications as follows:

Equipment and Material Standards of the Institute of Transportation Engineers, ITE;
Highway Capacity Manual, Transportation Research Board (TRB);
ITE Journal (published monthly), ITE;
Manual of Traffic Signal Design, ITE;
Manual on Uniform Traffic Control Devices, FHWA;
Manual on Uniform Traffic Control Devices, Indiana;
manufacturers' literature;
National, State and local electrical codes;
Standard Drawings, INDOT;
Standard Specifications, INDOT;
Traffic Control Devices Handbook, FHWA;
Traffic Control Systems, National Electrical Manufacturers Association (NEMA);
Traffic Detector Handbook, FHWA;

Traffic Engineering Handbook, ITE; and
Traffic Signal Installation and Maintenance Manual, ITE.

77-1.03 Official Action

Where a new traffic signal is installed or an existing traffic signal is removed, an Official Action is required. For a State-controlled highway, the designer must obtain an approval for the proposed change from the Highway Management Deputy Commissioner. The request for an Official Action should be sent to the appropriate district traffic engineer before implementation of the proposed change. If the district traffic engineer concurs with the request to install or remove a traffic signal, an Official Action will be drafted and sent to the district Deputy Commissioner for approval of the new traffic signal or existing traffic signal removal. For a locally-controlled facility, approval must be obtained from the appropriate jurisdiction before starting design. An Official Action may also be required where other regulatory-controlled items are revised in association with a traffic signal, e.g., “No Turn On Red” sign.

77-1.04 Project and Plan Development

Chapter Two provides the Department’s procedures for preparing a typical traffic-signal project. Chapter Two also indicates the responsible unit for each activity. Part II provides the Department’s criteria for developing a set of plans, which are also applicable to a traffic-signal project. Part II also includes information on scale sizes, drafting requirements, plan-sheet requirements, quantities, specifications, etc.

77-1.05 Definitions

The following are definitions for the more commonly used terms in traffic-signal design.

1. <u>Controller Assembly</u>. A complete electrical device mounted in a cabinet for controlling the operation of a highway traffic signal.

2. <u>Cycle</u>. For a pretimed controller, it is the period of time used to display a complete sequence of signal indications. For an actuated controller, a complete cycle is dependent on the presence of calls on all phases.

3. <u>Cycle Length</u>. The time required for one complete sequence of signal indications.

4. <u>Delay</u>. A measure of the time that has elapsed between the stimulus and the response.

a. Traffic Delay. The time lost while traffic is impeded by some element over which the motorist has no control.

b. Fixed Delay. The delay caused by traffic controls.

c. Operational Delay. The delay caused by interference between components of traffic.

5. Demand. The need for service, i.e., the number of vehicles desiring to use a given segment of roadway during a specified unit of time.

6. Detection. The process used to identify the presence or passage of a vehicle at a specific point, or to identify the presence of one or more vehicles in a specific area.

7. Detector. A device for indicating the presence or passage of vehicles or pedestrians, e.g., loop detector, microloop detector, push button.

8. Indecision Zone. A range of distances from the intersection where a driver can react unpredictably to a yellow signal indication, i.e., deciding to stop or to continue through the intersection.

9. Interconnected. The situation in which traffic signals, signs, or computers are designed to work in coordination with each other.

10. Interval. The part of a signal cycle during which signal indications do not change.

11. Interval Sequence. The order of appearance of signal indications during successive intervals of a signal cycle.

12. Interval Timing. The passage of time that occurs during an interval.

13. LED. A light-emitting diode used to illuminate signal indications. It is the only illumination device that complies with the U.S. Energy Policy Act of 2005.

14. Loop Amplifier. A device capable of sensing a change in the inductance of a loop detector.

15. Loop Detector. A device embedded in the roadway that senses the presence of a vehicle by changes in magnetic lines of flux that are generated around the loop, thereby increasing the inductance so that a change is detected as monitored by the loop amplifier.

16. Offset. The time difference or interval in seconds between the start of the green indication at one intersection as related to the start of the green interval at another intersection or from a system time base. It may also be expressed in percent of cycle length.

17. Pattern. A unique set of timing parameters (cycle length, split, and offset) associated with each signalized intersection within a predefined group of intersections.

18. Phase. A part of the traffic-signal-cycle length allocated to a combination of traffic or pedestrian movements receiving the right of way simultaneously during one or more intervals.

19. Phase Overlap. A phase that operates concurrently with one or more other phases.

20. Phase Sequence. The order in which a controller cycles through all phases.

21. Point Detection. The detection of a vehicle as it passes a point on a roadway.

22. Preemption. Interruption or alteration of the normal signal sequence at an intersection in deference to a situation such as the passage of a train, bridge opening, or the granting of the right of way to an emergency vehicle.

23. Presence Detection. The ability of a vehicular detector to sense that a vehicle, whether moving or stopped, has appeared in its detection area.

24. Recall. An operational mode for an actuated intersection controller whereby a phase, either vehicular or pedestrian, is displayed during each cycle whether the demand exists or not.

25. Signal Coordination. The establishment of timed relationships between adjacent traffic-control signals.

26. Signal Head. An arrangement of one or more signal lenses in one direction.

27. Signal Indication. The illumination of a signal lens or equivalent device.

28. Split. A percentage of the cycle length allocated to each of the various phases in a signal sequence.

29. Yield Point. The point at which the controller permits the existing phase to be terminated

to service a conflicting phase.

77-2.0 PRELIMINARY DESIGN ACTIVITIES

The district Office of Traffic is responsible for making the determination regarding the need for a new or existing traffic signal. This determination is based on factors including traffic volumes, accident history, schools, pedestrians, local needs, driver needs, construction costs, and maintenance costs. The following provides information on the guidelines, policies, procedures, and factors used by INDOT to make these determinations.

77-2.01 Signal-Study Request

A request for a new signal can be generated by FHWA, the district Office of Traffic, other INDOT divisions, local officials, or developers or local citizens. Each request for a new traffic-signal installation should be first forwarded to the appropriate district traffic engineer. If the district traffic engineer determines that the request merits further investigation, he or she will then begin coordinating the collection of the necessary traffic data.

For an in-house request, the district traffic engineer, possibly in conjunction with others, will conduct the appropriate traffic studies to obtain accurate and up-to-date traffic data and projections. For another type of request, the latest traffic data and projections should be forwarded with the request. The data collector should refer to the *MUTCD*, which provides the warrants for traffic signals, to determine the appropriate information required. For additional information on the collection of traffic data, the ITE publication, *Manual of Traffic Engineering Studies*, should be reviewed, or the Environmental Services Division should be contacted.

If it is determined that a traffic signal is warranted, the district traffic engineer, the District Office of Design, the Division of Highway Design and Technical Support, or a consultant, will prepare the design for the proposed traffic signal. The district traffic engineer will be responsible for determining the traffic-signal timings. The local agency or consultant may sometimes be responsible for determining the traffic-signal timings.

77-2.02 Signal Warrants

Each new traffic signal should satisfy one or more of the primary warrants listed below. The *MUTCD* traffic signal warrants are as follows:

Warrant 1, Eight-Hour Vehicular Volume

Warrant 2, Four-Hour Vehicular Volume
Warrant 3, Peak-Hour Volume
Warrant 4, Pedestrian Volume
Warrant 5, School Crossing
Warrant 6, Coordinated Signal System
Warrant 7, Crash Experience
Warrant 8, Roadway Network

The *MUTCD* provides the criteria and procedures that should be used to determine if the warrant is satisfied.

77-2.03 Warrant Analysis

Though traffic volume may be sufficiently high to satisfy one or more of the warrants, the installation of a traffic signal may not always be the most prudent choice. In addition to the *MUTCD* warrants, the following information should be considered.

1. Minimums. The *MUTCD* warrants are considerations for determining the need for a traffic signal. The intent of the *MUTCD* thresholds is to establish a minimum boundary below which a traffic signal should not be installed. The satisfaction of one or more traffic-signal warrants should not in itself require the installation of a traffic control signal.

2. Benefits. The benefits of the traffic signal should outweigh its disadvantages. A traffic signal will cause delays for at least one leg of the intersection while serving the needs of another. A traffic signal should be installed only if the safety or the operations of the intersection or system are improved.

3. Crash History. A traffic signal is often installed to reduce certain types of crashes, e.g., right-angle collision, pedestrian crossing. However, the installation of a traffic signal can increase the number of rear-end collisions and can fail to reduce turning conflicts between vehicles and pedestrians. Consideration should be given as to whether a change in crash types and their severity will be an actual improvement for the intersection. Crash data for the location should be available for at least the past three years. Consideration should be given to alternative solutions to the problem of crashes, e.g., no longer permitting parking, using larger signs.

4. Geometrics. The geometric design of the intersection can affect the efficiency of the traffic signal. A traffic-signal placed at a poorly-aligned intersection may increase driver confusion and thereby reduce the overall efficiency of the intersection. If practical, the intersection should be properly aligned and have sufficient space to adequately provide

turning lanes, through lanes, etc. Chapter Forty-six provides information on the geometric design of an at-grade intersection.

5. System Analysis. The control of traffic should be conceived and implemented on a systematic system/route/intersection basis. This may sometimes result in compromises at an individual intersection in order to optimize the overall system. The presence of a traffic signal also may encourage drivers to use local unsignalized facilities so as to bypass the signal. Intersection controls should favor the major streets to move traffic through an area.

6. Location. The intersection should be considered relative to the context of the land use, density of development (e.g., urban, suburban, rural), and the potential for future development. The location of the intersection should be considered within the context of the transportation system such as isolated locations, interrelated operations, and functional classification. An isolated location is an intersection where the distance to the nearest signalized intersection or potential future signalized intersection is greater than 0.5 mi.

7. Existing Signal. For a project that includes at least one existing signal, it will rarely be required to conduct a detailed study to determine if the existing signal should be removed, retained, or upgraded. This determination will be made during the preliminary field review. If it is determined during the field review that a detailed analysis may be required, the designer should consult with the district Office of Traffic to determine if there may be a need to remove the traffic signal.

77-2.04 Responsibilities

It is the Department's policy to fund the design and installation of a traffic signal only where the intersection is on a State-maintained highway, or where a freeway exit or entrance ramp intersects with a local facility. For a State highway intersecting a private drive or road, or a public road where a high traffic volume is generated from a private source, the private entity will typically be responsible for funding the design, installation, and energy costs of the new signal.

Each traffic signal on a State highway is maintained by INDOT or through a contract agreement with others. A local municipality, through a formal contract, will rarely assume responsibility for the maintenance of a traffic signal on a State highway.

77-3.0 FLASHER OR FLASHING BEACON

77-3.01 Guidelines for Hazard-Identification Beacon

A hazard-identification beacon should only be used to supplement an appropriate warning or regulatory sign or marker. Typical applications include the following:

1. identifying an obstruction in or immediately adjacent to the roadway;
2. as a supplement to an advance warning sign, e.g., school crossing; See *MUTCD* Part 7;
3. at a mid-block pedestrian crossing;
4. at an intersection where a warning device is required; or
5. as a supplement to a regulatory signs, excluding a “Stop,” “Yield,” or “Do Not Enter” sign.

The need for a hazard-identification beacon will be determined as required for each site. The following provide additional guidance for the use of a hazard-identification beacon.

77-3.02 Speed-Limit-Sign Beacon

Where applicable, a flashing beacon with an appropriate accompanying sign may be used to indicate the time periods or conditions in which the speed limit shown is in effect.

A speed-limit-sign beacon consists of one or two circular yellow lenses, each having a minimum visible diameter of 8 in. Where two lenses are used, they should be aligned vertically at the top and bottom of the sign. If the sign is longer horizontally than vertically, the lenses may be aligned horizontally. The beacons should flash alternately. If the speed limit is for a school zone, the beacon indications may be positioned within the face of the sign.

77-3.03 Intersection-Control Beacon

This is intended for use at an intersection where traffic or physical conditions do not justify a traffic signal, but where conditions indicate a hazard potential. The installation of this device with yellow flashing for the preferential street and red flashing for the stop-condition street may be warranted where two or more of the following conditions exist.

1. <u>Crash History</u>. At an intersection with five or more reported crashes during a 12-month period that have a predominance of crash types that may be corrected by cautioning and stopping traffic.

2. <u>Sight Distance</u>. In conjunction with “Stop” signs where sight distance is limited or where other physical or traffic conditions make it especially desirable to emphasize the need for

stopping on one street and for proceeding with caution on the other.

3. Traffic Volume. Where the minimum vehicular volume entering an urban intersection from all directions averages 400 vehicles per hour for two 1-h periods of one day, and where vehicular traffic entering the intersection from the minor-street approaches averages at least 50 vehicles per hour for the same hour. For a rural area or a community with a population of 500 or less, the traffic volume is 70 percent of the urban volume, i.e., 280 vehicles per hour and 35 vehicles per hour, respectively.

4. Speed. At an intersection where excessive speed prevails. This warrant should not be considered where the 85th percentile speed is equal to or less than 40 mph.

5. School. At an intersection having at least 50 school children crossing the major approaches as pedestrians, or where 10 school buses, each transporting one or more children crossing, turning onto or turning from the major approaches per hour for any two 1-h periods of one day during regular school arrival and dismissal periods.

Where based on engineering judgment, a supplemental beacon may be used at a multi-way, stop-controlled intersection. The intersection-control beacon should be red for all approaches. An intersection-control beacon consists of one or more sections of a standard traffic-signal head, having flashing, circular yellow or circular red indications in each face. Each intersection should have at least two indications for each approach. Indications normally flash alternately, but may flash simultaneously. Supplemental indications may be required on one or more approaches to provide adequate visibility to approaching motorists.

77-3.04 "Stop" Sign Beacon

This beacon is used to draw attention to a "Stop" sign. The beacon uses one or two sections of a standard traffic-signal head with a flashing, circular red indication in each section. The lenses may be either 8 in. or 12 in. diameter. Where they are aligned horizontally they should flash simultaneously. Where they are aligned vertically they should flash alternately. The bottom of the housing for the beacon should be located 1 to 2 ft above the top of the "Stop" sign.

77-3.05 General Beacon Design

A flashing-beacon unit and its mountings should satisfy the general design specifications for traffic-control signals. These include the following.

1. Lens. Each signal-unit lens should have a visible diameter of at least 8 in. Red or

yellow lenses should satisfy the ITE *Standard for Adjustable Face Vehicle Traffic Control Signal Heads.*

2. Sight Distance. While illuminated, the beacon should be visible to all drivers it faces for a distance of 1200 ft under normal atmospheric conditions, unless otherwise physically obstructed.

3. Flashing. The flashing contacts should be equipped with filters for suppression of radio interference. Beacons should flash at a rate of at least 50 but not more than 60 flashes per minute. The illumination period of each flash should be between one-half and two-thirds of the total cycle. Where hazard identification beacons have more than one section, they may flash alternately.

4. Hours of Operation. A hazard-identification beacon should be operated only during those hours during which the hazard or regulation exists, e.g., school arrival and dismissal periods; see *MUTCD* Part 7.

5. Lamp Dimming. If a 150-W lamp is used in a 12-in. dia. flashing yellow beacon and the flashing causes excessive glare during night operation, an automatic dimming device may be necessary to reduce the brilliance during night operations.

6. Traffic Signal. A flashing yellow beacon used with an advance traffic signal warning sign may be interconnected with a traffic-signal controller.

7. Alignment. If used to supplement a warning or regulatory sign, individual flashing beacon units should be horizontally or vertically aligned. The edge of the housing should not be located closer than 1 ft outside of the nearest edge of the sign.

8. Location. The obstruction or other condition warranting the beacon will largely govern the location of the beacon with respect to the roadway. If used alone and located at the roadside, the bottom of the beacon unit should be at least 8 ft, but not more than 16 ft above the pavement. If suspended over the roadway, the beacon clearance above the pavement should be at least 17 ft, but not more than 19 ft.

77-4.0 TRAFFIC-SIGNAL EQUIPMENT

All traffic-signal equipment should satisfy the criteria set forth in the *MUTCD,* NEMA *Traffic Control Systems,* INDOT *Standard Drawings* and INDOT *Standard Specifications*. The following provides additional information regarding traffic-signal equipment. For an INDOT location, the equipment choice should be made at the preliminary field inspection with the approval of the designer and the district traffic engineer.

77-4.01 Traffic-Signal Controller

A traffic-signal controller is a microprocessor-based, menu-driven, fully-actuated device, including internal coordinator and preemption, mounted in a cabinet for controlling the sequence and phase duration of the traffic signal. Right of way is assigned by turning the green indication on or off. A controller's operation mode can be pretimed, semi-actuated, or fully-actuated. In the pretimed mode, the controller operates according to pre-determined schedules. In the semi-actuated and fully-actuated modes, the controller operates with variable vehicular and pedestrian timing and phasing intervals which are dependent upon traffic demands. If there is no demand for a phase, an actuated controller may omit that phase in the cycle. For example, if there is not a demand for left turns, the left-turn phase will not be activated. The following provides information on the modes of operation used by the Department. Section 77-5.0 describes the phasing and timing aspects of controllers. INDOT typically uses fully-actuated operation for its new traffic signals.

77-4.01(01) Pretimed Operation Mode

In the pretimed mode, the controller can be programmed to provide several different timing plans based on the time of day or day of week.

The pretimed mode is best suited where traffic volume and pattern are consistent from day-to-day, e.g., downtown area, where variations in volume are predictable and where control timing can be preset to accommodate variations throughout the day.

The primary advantage of the pretimed mode is the cost savings realized by not installing traffic-detection equipment around the intersection. The primary disadvantages of the pretimed mode are the lack of flexibility in timings, the inefficiency of traffic movements where vehicle arrivals are largely random, and the inability to automatically count traffic volume.

The pretimed mode should not be used where the posted speed limit on at least one approach is 40 mph or higher.

77-4.01(02) Semi-Actuated Operation Mode

The semi-actuated mode requires detection on one or more, but not all, approaches. Vehicular detectors or pedestrian detectors are installed only for the minor approaches, the left turns on the major approaches, and where traffic is light and sporadic. The through movements on the major approaches are kept in the green phase until a vehicle on a minor approach, or a major approach left turn, is detected. If there is a demand on a detected approach or movement, and the minimum green time for the major approach has elapsed, the right of way will then be assigned to the detected approach or movement. Controller timings are set to provide enough time to clear two vehicles. Additional time is added for each new detection up to the predetermined limit for the maximum green time. Once the detected approach demand has been satisfied, or once the maximum green time has been reached, the right of way returns to the major approaches and the cycle begins again.

The primary advantage of the semi-actuated mode is the reduced cost of installation because detection is not needed on some approaches and more-efficient operations.

The semi-actuated mode should not be used where the posted speed limit of at least one approach is 40 mph or higher due to the lack of indecision-zone protection. See Section 77-5.08 for further discussion of the indecision-zone requirements.

77-4.01(03) Fully-Actuated Operation Mode

The fully-actuated mode requires detection devices for all approaches or movements at the intersection. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears or once the preset maximum green time has elapsed. Once the minor approaches' or movements' demand has been satisfied, the right of way is typically returned to the major approaches.

The fully-actuated mode is the appropriate design choice for the conditions as follows:

1. the posted speed limit on at least one approach is 40 mph or higher;
2. an isolated location where the traffic volume on each approach is sporadic;
3. where a traffic signal is warranted for only short periods of the day; or
4. where turning movements are heavy only during specific time periods and are light the remainder of the time.

The advantages of the fully-actuated mode are as follows:

1. it can efficiently control a high traffic volume;
2. it is very efficient at an isolated intersection;
3. it can handle varying traffic demands such as a complex intersection where one or more movements are sporadic or subject to wide variations in traffic volume; and

4. it can count traffic volume for all detected movements.

The primary disadvantages of the fully-actuated mode are the additional costs associated with installing and maintaining detection equipment on all of the approaches.

77-4.01(04) Pedestrian Feature

The pedestrian feature commonly works in conjunction with the signal controller. This feature allows for the timing of the Walk and Don't Walk cycles and can be actuated by pedestrian push buttons. The use of an accessible pedestrian signal should be considered where visually-impaired pedestrians use the crosswalks at a signalized intersection.

The advantages and disadvantages of the pedestrian feature are as follows:

1. Advantages.
    a. It provides additional time for crossing pedestrians.
    b. Where there is minimal pedestrian demand, disruption to the vehicular phases can be minimized.

2. Disadvantages.
    a. Where pedestrian push buttons are required, they must be located in a convenient, accessible location.
    b. Pedestrian cycles concurrent with green time may marginally delay right-turning vehicles.
    c. They can significantly increase the required minimum green time on the minor street if the major street is substantially wider than the minor street.

77-4.01(05) Enhanced Modes of Operation

Coordination is an enhanced mode which is used to provide progression through a system of two or more signals. Coordination can be achieved with either a timed-based coordination (TBC) system or a closed-loop system. A TBC system operates on an internal time clock which is used to automatically select timing plans based upon the time of day and day of week. In a closed-loop system, the signals are interconnected using cables or other communication mechanism.

Preemption is the modification of a signal's normal operation to accommodate a special occurrence, such as the approach of an emergency vehicle, the passage of a train through a nearby grade crossing, priority passage of a transit vehicle, or the opening of a moveable bridge.

77-4.01(06) Controller-Design Concepts

As established by the National Electrical Manufacturers Association (NEMA), a controller has standard functions and input/output formats, and uses microprocessing to provide the functions. NEMA controllers are interchangeable between manufacturers, except where used in a coordinated system. If changes or upgrades to the controller are desired, the controller unit hardware is typically replaced.

INDOT uses the NEMA criteria for all of its traffic signal controllers. At a minimum, each INDOT-maintained traffic controller must satisfy the INDOT *Standard Specifications* and NEMA TS-2 criteria. Each controller is subject to approval per the requirements of the Department's *Traffic Signal Control Bench Test Procedures*. A list of all approved controller equipment is provided in the Department's approved-materials list, which can be obtained from the INDOT website.

A NEMA controller is configured to operate as a dual-ring controller unless special circumstances warrant the use of additional rings. Section 77-5.06 provides information on the selection of phases for an intersection. Figure 77-4A illustrates the appropriate phasing sequence for an 8-phase dual-ring controller. A multi-ring controller unit includes two or more rings that are arranged to time in a preferred sequence and to allow concurrent timing of all rings, subject to the restraint of a barrier. For the controller to advance beyond each barrier, a set of phases must cross the barrier line at the same time, i.e., no conflicting phases are displayed at the same time).

77-4.01(07) Associated Controller Equipment

Each controller unit will require a TS-2 power supply, Buss Interface Unit (BIU), load switches, and Malfunction Management Unit (MMU). Detection and communications devices may be added to enhance operation of the controller, depending on the intersection. All associated controller equipment must appear on the Department's approved materials list.

77-4.01(08) Malfunction Management Unit (MMU)

With solid-state equipment, there is a potential for the display of erroneous indications, e.g., green indications for conflicting movements. The MMU monitors the signal indications and, should such an error occur, the MMU switches the control of the signal indications to the flashing mode.

77-4.01(09) Controller Cabinet

A controller cabinet is an enclosure designed to house the controller unit and its associated equipment, providing for its security and environmental protection. Each controller cabinet must satisfy the INDOT *Standard Specifications*. Section 77-5.02 provides roadside-safety considerations for the placement of the cabinet. Foundation requirements for each cabinet type are shown on the INDOT *Standard Drawings.* The following discusses the cabinet types used by the Department.

1. Type G Cabinet. This is a pedestal-mounted or pole-mounted cabinet. The Department no longer uses this cabinet due to its limited size. However, this cabinet type may be used, if practical, for matching or upgrading existing local signals.

2. Type M Cabinet. This is a ground-mounted cabinet. This cabinet should be used where space limitations or sight restrictions are a factor at the intersection.

3. Type P-1 Cabinet. This is a ground-mounted cabinet. This cabinet is the preferred cabinet.

4. Type R-1 Cabinet. This is a taller version of the P-1 cabinet. It is used only where equipment needs warrant the additional space.

77-4.01(10) Preemption

Preemption-sequences details should be shown in the plans or described in the special provisions. For information on preemption equipment, the manufacturer should be contacted. The following describes situations where preemption is used.

1. Railroad Crossing. The purpose of the preemption is to clear vehicles from a railroad crossing before the arrival of a train. Where a signalized intersection is within 200 ft of a railroad grade crossing with active warning devices, preemption is required. If this distance 200 to 600 ft, a queue analysis should be performed to determine if a highway-traffic queue has the potential for extending across a nearby rail crossing. If the analysis indicates that this potential exists, consideration should be given to interconnecting the traffic signal with active warning devices at the railroad crossing. The *MUTCD* and the FHWA *Railroad-Highway Grade Crossing Handbook* describe preemption strategies and define the requirements for grade-crossing preemption.

Railroad-crossing preemption requires interconnection between the traffic-signal controller and the grade-crossing signal equipment. The preemption routine at the traffic-signal controller is initiated by the approach of a train, as detected by the railroad's controller, and starts with a transition from the current phase into the Clear Track Green interval (CTG). The CTG interval is used to clear motorists who may be stopped between the railroad-crossing stop line and the intersection. Subsequent signal displays include only those that are not in conflict with the occupied grade crossing. Once the railroad preemption call is cleared, after the train has passed, the traffic signal is returned to normal operations. For a State route, this type of preemption requires an agreement between the State and the railroad company.

Railroad-crossing preemption should be designed using either simultaneous or advance preemption sufficient to provide for Right-of-Way Transfer Time (RTT), to transition into the CTG interval. The CTG interval should be sufficient to clear the last vehicle in the queue past the Minimum Track Clear Distance (MTCD), avoid vehicle-gate interaction, and provide separation time as required.

The designer should consider best- and worst-case scenarios with regard to the signal phase state and all known preemption traps, such as the advance, second-train, failed-circuit, and vehicular-yellow preemption traps. The designer should consider pre-signals and queue-cutter signals as options where an engineering study determines that the queue extends into the track area.

Other options to consider are blank-out signs for protected/permitted left turns, optically programmable heads for pre-signals, and pavement markings and signage to prevent vehicles from stopping on the tracks if inadequate storage distance exists for the design vehicle.

2. <u>Fire Station or Fire Route</u>. The most common form of this preemption is the activation of the preemption sequence at a fixed point, e.g., a push button located within the fire station. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

   The simplest form of fire station preemption is the installation of a traffic signal at the fire-station driveway intersection with a major through street. The signal indication for the through street is green until called by an actuation in the fire station. The signal then provides a timed green indication to the driveway to allow emergency vehicles to enter the major street.

   Where the fire station is near a signalized intersection, a preemption sequence can be designed to display a movement permitting the passage of emergency equipment through the intersection.

Where emergency vehicles frequently follow the same route through more than one nearby signal, it may be desirable to provide a fire route-preemption operation. Actuation of the fire-station push button will be transmitted to all the signals along the route and, after a variable timed delay, each signal will provide a preempt movement display. This will provide a one-way green wave away from the fire station, allowing the optimal movement of emergency equipment.

3. Moving Emergency Vehicle. The preemption equipment causes the signals to advance to a preempt movement display. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

The system used on a State route for identifying the presence of the approaching emergency vehicle uses a light emitter on the emergency vehicle and a photocell receiver for each approach to the intersection. The emitter outputs an intense strobe-light flash sequence, coded to distinguish the flash from lightning or other light sources. The electronics package in the receiver identifies the coded flash and generates an output that causes the controller unit to advance through to the desired preempt sequence.

This system requires a specialized transmitting device on each vehicle for which preemption is desired. It requires that the driver activates the transmitter during the run and turns off the transmitter after arriving at the scene. This system also provides directionality of approach and a confirmation light at the signal that notifies the approaching emergency vehicle that the preemption call has been received by the equipment in the traffic-controller cabinet.

4. Transit Vehicle. Most transit-preemption systems are designed to extend an existing green indication for an approaching bus and do not cause the immediate termination of conflicting phases, as can occur for emergency-vehicle preemption. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

Two transit-vehicle preemption systems are similar to the moving-emergency-vehicle preemption system. One is a light emitter/receiver system, using the coded, flash-strobe light emitter. An infrared filter is placed over the emitter, so that the flash is invisible to the human eye, and a flash code is used to distinguish the transit preemption call from that for an emergency vehicle. The intersection receiver can be configured to provide both emergency-vehicle and transit preemption with the same equipment. The second system uses the same type of radio transmitter/receiver equipment as used for emergency-vehicle preemption.

Two other types of transit-vehicle detectors have been used and are available. One, identified as a passive detector, can identify the electrical signature of a bus traveling over an inductive loop detector. The other, identified as an active detector, requires a vehicle-mounted transponder that replies to a roadside polling detector.

5. Preemption Equipment. With a microprocessor-based controller, virtually all preemption routines are performed by the controller software. The only necessary external equipment is the preemption call-detection device.

77-4.02 Detector

77-4.02(01) Operation

The purpose of a detector is to determine the presence or the passage of a vehicle, bicyclist, or pedestrian. This presence or passage detection is sent back to the controller which adjusts the signal accordingly. INDOT uses only an inductive loop detector in its signal design. The inductive loop detector is preferred because it can be used for passage or presence detection, vehicular counts, speed determinations, and it is accurate and easy to maintain. Although the inductive loop detector is usually the system of choice, this does not prevent the designer from recommending the use of newly-developed devices in the future. If, in the designer’s opinion, a different detector should be considered, its use must be first coordinated with the district traffic engineer to determine special maintenance requirements or equipment needs.

The controller’s detection device can operate in the modes described below.

1. Passage (Pulse) Detection. A passage detector detects the passage of a vehicle moving through the detection zone and ignores the presence of a vehicle stopped within the detection zone. The detector produces a short output pulse once the vehicle enters the detection zone. The short loop design is a single 6 ft by 6 ft loop at a location upstream of the stop line.

2. Presence Detection. A presence detector is capable of detecting the presence of a standing or moving vehicle in any portion of the detection zone. A signal output is generated for as long as the detected vehicle is within the detection zone. This is subject to the eventual tuning out of the call by some types of detectors. The long loop, or long detection area, is considered to be a presence detector.

3. Locking Mode. The controller memory holds the call once a vehicle arrives during the red or yellow signal indication, or after the vehicle leaves the detection zone until the call has been satisfied by a green display.

4. <u>Non-locking Mode</u>. For this operation, the call is held only while the detector is occupied. The call is voided once the vehicle leaves the detection area. The non-locking mode is used with a presence detector.

5. <u>Delayed Detection</u>. This requires the vehicle to be located in the detection area for a certain set time before a detection is recorded. If a vehicle leaves the area before the time limit is reached, no detection is noted. This application is appropriate where a right turn on red is allowed.

6. <u>Extended-Call or Stretch Detection</u>. The detection is held by the detector after a vehicle has left the detection area. This operation is performed to hold the call until the passing vehicle has time to reach a predetermined point beyond the detection zone. With a solid-state controller, the extended-call detection is handled by the controller software.

Where the controller is part of a coordinated signal system design, extended or delayed detection should be used to ensure that the local controller will not adversely affect the timing of the system.

77-4.02(02) Inductive Loop Detector

An inductive loop detector consists of four or more turns of wire embedded in the pavement surface. As a vehicle passes over the loop, it changes the inductance of the wire. This change is recorded by an amplifier and is transmitted to the controller as a vehicular detection. NEMA criteria define the requirements for the detector unit and the INDOT approved materials list identifies the detector units approved for use.

The advantages of an inductive loop detector are as follows:

1. It can detect vehicles in both presence and passage modes.
2. It can be used for vehicular counts and speed determination.
3. It can be easily designed to satisfy various site conditions.

A disadvantage of the loop detector is that it is vulnerable to pavement-surface problems such as potholes which can cause breaks in the loops. To alleviate this problem, a sequence of loops should be used.

Along rectangular loop is 6 ft by 20 ft to 65 ft. A short octagonal or circular loop is 6 ft by 6 ft. INDOT normally uses the short loop. The long loop, as a single entity, is being supplanted by a sequence of short loops which emulate the long loop. The INDOT *Standard Drawings* illustrate loop layouts and installation details. The typical layouts shown on the INDOT *Standard Drawings* are for illustrative purposes only. Each intersection should be designed individually to satisfy local site conditions.

A sequence of loops is used at the intersection itself for presence detection of vehicles stopped at the traffic signal. A set of loops before the intersection is used to determine the passage of vehicles. The distance from the stop line to these loops is based on the posted speed limit. Section 77-5.08 provides additional information on detector location. Section 77-5.09 provides information on loops set up to count traffic.

A preformed loop is a detector loop constructed of the designated number of turns of wire contained inside a protective conduit. It is paved over with concrete or asphalt pavement. A preformed loop may be installed in a 1-, 2-, 3-, or 4-loop configuration. Wires from a preformed loop are spliced to the 2-conductor lead-in cable in a handhole or detector housing. INDOT's approved materials list identifies the preformed loops approved for use.

77-4.02(03) Other Detector Types [Rev. May 2011]

INDOT uses the inductive loop detector. However, other detector types are available, as described below.

1. Magnetic Detector. This consists of a small coil of wires located inside a protective housing embedded into the roadway surface. As vehicles pass over the device, the detector registers the change in the magnetic field surrounding the device. This signal is recorded by an amplifier and relayed back to the controller as a vehicular detection. A problem with this detector is that it can only detect the passage of a vehicle traveling at a speed of 3 mph or higher. It cannot be used to determine a stopped vehicle's presence. The advantages are that it are simple to install and is resistant to pavement-surfacing problems.

2. Magnetometer Detector. This consists of a magnetic metal core with wrapped windings, similar to a transformer. This core is sealed in a cylinder of about 1 in. diameter and 4 in. length. The detector is placed in a drilled vertical hole of about 1 ft depth into the pavement surface. This detector senses the variation between the magnetic fields caused by the passage or presence of a vehicle. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. This detector is sufficiently sensitive to use to detect bicyclists or as a counting device. A problem with the magnetometer detector is that it does not provide a sharp cutoff at the perimeter of the detection vehicle, i.e., it may detect a vehicle in an adjacent lane.

3. Microloop Detector. This is similar to a magnetometer detector, but it can work with a standard inductive-loop-detector amplifier. The microloop is installed by drilling a 3-in. diameter hole of 1.5 ft depth into the pavement structure, by securing it to the underside of a bridge deck, or inserting a 3-in. diameter conduit under the pavement to accommodate a series of microloops (non-invasive microloop system). A disadvantage of the microloop detector is that it requires some motion to activate the triggering circuitry of the detector and does not detect a stopped vehicle. This type of detector requires two detectors placed side-by-side per lane due to its limited field of detection.

4. Video-Image Detection. This consists of one to six video cameras, an automatic control unit, and a supervisor computer. The computer detects a vehicle by comparing the images from the cameras to the images stored in its memory. The detector can work in either the presence or passage mode. This detector also allows the images to be used for counting and vehicular classification. A housing is required to protect the camera from environmental elements. Early models experienced problems with the video detection during adverse weather conditions such as fog, rain, or snow. INDOT currently allows video detection only for a temporary signal.

5. Wireless Vehicle-Detection System.

   A wireless vehicle detector is similar to a magnetometer detector except that it uses a low-power radio to transmit the signal to a wireless repeater or receiver processor. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. The detector is placed in a drilled vertical hold of 0.2 ft depth in the pavement surface. The wireless repeaters and receiver processors should be mounted to the signal structures. The Ethernet cable for the receiver processors may be run across span wire on a span-and-strain-pole installation. See the INDOT *Standard Drawings*. Wireless vehicle detectors are sufficiently sensitive to detect bicyclists or for use as a counting device. A disadvantage of a wireless vehicle detector is that it should be replaced at least every 10 years, and the wireless repeater's batteries should be replaced every 2 years. See Figure 77-4B for wireless-system typical installation details, or Figure 77-4C for hybrid wireless-system typical installation details.

77-4.02(04) Decision-Making Criteria for Use of Detection System Other than Inductive Loops [Added Jan. 2011]

Such a system will require plans details. In specifying such a system, the designer should submit documentation that two of the following conditions have been satisfied.

1. An inductive loop design will not function due to a physical limitation such as right-of-way limitations, geometrics, pavement conditions, obstructed conduit paths, etc.

2. A full inductive loop design has been considered and there is a post-design lifecycle cost advantage to using a detection system other than loops. Design-time cost or labor savings will not be considered in lifecycle-cost calculations.

3. A hybrid design using loops at the stop line and wireless magnetometers for advance vehicle detection has been considered and evaluated where wireless magnetometers have been evaluated for advance vehicle detection only, and the hybrid design is the most cost effective, based on post-design lifecycle cost.

Written concurrence will also be required from the Office of Traffic Control Systems and the district traffic engineer, before wireless vehicle detection may be used at a specific location. For a local-agency project, such concurrence will be required from the local agency.

77-4.02(05) Pedestrian Detector

The most common pedestrian detector is the pedestrian push or call button. A pedestrian call button should be placed so that it is convenient to use, is reachable by the handicapped, and is not placed in the direct path for the blind. Inconvenient placement of a pedestrian detector is why pedestrians may choose to cross the intersection illegally or unsafely.

77-4.02(06) Bicycle Detector

The methods of bicycle detection are as follows.

1. <u>Pedestrian Push-Button Detector</u>. The bicyclist must stop and push the detector button for the controller to record the detection. This may require the bicyclist to leave the roadway and proceed to the sidewalk to reach the detector.

2. <u>Inductive Loop Detector</u>. This can detect the bicycle without the bicyclist’s interaction. For the greatest sensitivity of the detector, the bicycle should be guided directly over the wire. A problem with this detector is that it requires a significant amount of metal to be activated. A bicycle includes a substantial amount of non-magnetic, man-made materials to increase its strength and reduce its weight. This has substantially reduced the metal content that can be detected.

77-4.03 Signal Mounting

The Department's preferred practice is to install a traffic signal using span, catenary, and tether cables, or cantilever structures with poles on all four corners. A pedestrian signal is mounted on a pedestal or pole. A pedestal- or pole-mounted supplemental signal may be used if there is a left-turn signal head in a median or on the near side of the intersection if the intersection is significantly wide. Figures 77-4D, 77-4E, and 77-4F list the advantages and disadvantages of the post-mounted signal, cable-span signal mounting, and the cantilever signal mounting, respectively.

For spans, steel strain poles are used. Steel strain poles provide greater strength, are easier to maintain, and require less space. Wood poles require the use of down-guy cables and are limited to a temporary installation.

A cantilever structure must be designed to satisfy the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.*

Overhead highway lighting may be provided, where warranted (see Section 78-2.0), at a rural signalized intersection. Traffic-signal span-support poles or cantilever poles may be used for overhead highway lighting. Figure 77-4G provides an illustration of a combination signal-luminaire pole. INDOT does not use combination poles. Figure 77-4H provides the heads' orientation for a cable-span-mounted signal.

77-4.04 Signal Display

The traffic-signal display consists of parts including the signal head, signal face, optical unit, visors, etc. The criteria set forth in the *MUTCD* Part IV, the INDOT *Standard Specifications, and* ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* should be followed in determining appropriate signal-display arrangements and equipment. The following provides additional guidance for the selection of the signal display equipment.

1. Signal-Head Housing. This are made of polycarbonate (plastic).

2 Signal Faces. Section 77-5.01 provides INDOT's preferred signal-face arrangements for use on a State highway. The signal lenses should be placed in a vertical line rather than horizontally except where overhead obstructions may limit visibility. Where protected left turns are followed by permissive left turns, the five-section signal head is the recommended arrangement choice. The *MUTCD Part* IV provides additional information on the arrangement of signal heads.

3. Lens Size. INDOT's preferred practice is to use only 12-in. diameter lenses. INDOT specifications require the use of plastic lenses in its signal displays.

4. Signal Illumination. Only Light-Emitting Diodes (LED) should be used.

5. Visors. A visor should be used with each lens. A visor is used to direct the signal indication to the appropriate approaching traffic and to reduce sun phantom. A tunnel visor provides a complete circle around the lens. A cutaway visor is a partial visor, with the bottom cut away. A partial visor reduces water and snow accumulation and does not let birds build nests within the visor. The decision on which visor type should be used is determined on a site-by-site basis. For a Department installation, partial visors are normally used. Visors are made of the same material as the housing.

6. Louvers. Louvers are sometimes used to direct the signal indication to a specific lane. Louvers are used where several signal heads may cause confusion for the approaching driver. One example of this problem is where an intersection has its approaches at angles less than 90 deg and the signal indications can be seen from both approaches. The decision on whether to use louvers depends on site conditions and will be determined for each site.

7. Optically-Programmable Signal. Like louvers, an optically-programmable signal is designed to direct the signal indication to specific approach lanes and for specific distances. An advantage is that they can be narrowly aligned so that motorists from other approaches cannot see the indications. Applications include closely-spaced intersections or an intersection where the approaches have acute angles. An optically-programmable signal requires rigid mountings to keep the indicator properly directed. The cost is higher than for louvers but the improved visibility often makes it a better choice. The decision on whether to use an optically-programmable signal depends on site conditions and will be determined for each site.

8. Backplate. A signal indication loses some of its contrast value if viewed against a bright sky or other intensive background lighting such as advertising lighting. A backplate placed around a signal assembly enhance the signal's visibility and have been shown to provide a benefit in reducing crashes. However, a backplate adds weight to the signal head and can increase the effect of wind loading on the signal. The decision on whether to use a backplate depends on site conditions and will be determined for each site.

77-5.0 TRAFFIC-SIGNAL DESIGN

77-5.01 Design Criteria

INDOT has adopted the *MUTCD* criteria for the placement and design of a traffic or pedestrian signal. This includes, but is not limited to, signal indications, color requirements, number of lenses per signal head, number and location of signal heads, height of signal heads, location of signal supports, etc. In addition to the *MUTCD*, the INDOT *Standard Drawings*, and the references in Section 77-1.01, the following provides further information on traffic-signal design.

Once a signal is determined to be warranted, or completely modernized, the following should be considered.

1. All electric service should be metered.

2. All parking regulations should be reviewed for a distance of at least 150 ft from the stop line or back to a detector.

3. All signal-head indications should be placed within 40 to 180 ft from the stop line.

4. The necessary signal heads should be verified for the traffic movements as shown in the phase diagram.

5. All signal equipment should satisfy the lateral clearances as specified in Chapter Forty-nine for a 4R project, or Chapter Fifty-five for a 3R project.

6. The height of a steel-strain-pole support is 30 ft or 36 ft.

7. Preformed loop detection should be used where new pavement is constructed or where pavement is to be replaced.

8. All existing signal components should be field verified.

9. Position and direction of aiming for all signal heads should be in accordance with Section 77-5.01(01).

10. A detector should be provided that counts vehicles in each travel lane approaching the signalized intersection. The count loops should be identified in the loop tagging table.

11. The detection-setback-distance value shown in Figure 77-5 Z should be used.

77-5.01(01) Signal Displays

The *MUTCD* requires at least two signal indications for each through approach to an intersection or other signalized location. A single indication is permitted for control of an exclusive turn lane, provided that this single indication is in addition to the minimum two for through movements. For multiple left turn lanes, one indication per lane shall be provided.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. One signal head per approach lane has been shown to provide a benefit in reducing crashes. Situations where supplemental indications can improve visibility include the following:

1. approach in excess of two through lanes;
2. location where there may be driver uncertainty;
3. where there is a high percentage of trucks which can obscure the signal indications; or
4. where the approach alignment affects the continuous visibility of normally-positioned signal indications.

The following figures illustrate the placement for signal heads.

Figure 77-5A, offsetting intersection
Figure 77-5B, urban street with parking on the near side, no left-turn lane
Figure 77-5C, urban street with parking on the far side and a near-side left-turn lane
Figure 77-5D, left-turn lanes with permissible left turns, but no separate left-turn phase
Figure 77-5E, left-turn lanes with protected left-turn phase
Figure 77-5F, left-turn lane with both protected-phase and permissible left turns, and 5-section head. This figure also illustrates the preferred 5-section head display
Figure 77-5G, multiple-lanes approach with left-turn lanes and protected left-turn phase
Figure 77-5H, multiple-lanes approach with both left- and right-turn lanes and protected phases
Figure 77-5 I, multiple-lanes approach z-span with supplemental far-side heads
Figure 77-5J, rural one-lane approach with truck obstruction
Figure 77-5K, rural one-lane approach with obstructed sight distance, near-side signal indication, advance warning sign, and flasher.

77-5.01(02) Visibility Requirements

The minimum visibility for a traffic signal is defined as the distance from the stop line at which a signal should be continuously visible for various approach speeds. Figure 77-5L provides the *MUTCD* minimum visibility distance. If the visibility distance cannot be satisfied, an advance warning sign should be used to alert an approaching motorist of the upcoming signal.

A driver's vision is vertically limited by the top of the vehicle's windshield. This restriction requires the signal to be located far enough beyond the stop line to be seen by the driver. The *MUTCD* requires a minimum distance of 40 ft from the stop line. The lateral location of the indication should be in the driver's cone of vision. Research indicates that this cone of vision should be desirably within 5 deg on either side of the center line of the eye position (i.e., a cone of 10 deg). The *MUTCD* requires that at least one, and preferably two, signal faces be located within 20 deg on each side of the center of the approach extended (i.e., a cone of 40 deg). There may be confusion on where to measure the center of the approach lanes for a multilane approach.

Figure 77-5M, Vision Cone, illustrates INDOT's interpretation of this requirement. The right- and left-turn lanes and parking lanes are included.

The following discusses other requirements in determining the location of a signal indication.

1. Where a signal indication is meant to control a specific lane or lanes of approach, its position should make it readily visible to the drivers making the specific movement.

2. Near-side signal heads should be located as near as practical to the stop line.

3. Signal heads for one approach should be mounted not less than 10 ft apart between the centers of the heads, measured perpendicular to the direction of travel.

4. At least one, and preferably both, signal heads that control through traffic should be located not less than 40 ft nor more than 180 ft beyond the stop line.

Where the nearest signal head is more than 150 ft, but 180 ft or less, beyond the stop line, engineering judgment of the conditions, including the worst-case visibility conditions, should be used to determine if a supplemental near-side signal head should be provided. Where the nearest signal head is more than 180 ft beyond the stop line, a supplemental near-side signal head should be used.

77-5.02 Placement of Signal Equipment

There are limited options available in determining acceptable locations for the placement of signal pedestals, signal poles, pedestrian detectors, and controller cabinets. Considering roadside safety, these elements should be placed as far back from the roadway as practical. However, due to visibility requirements, limited mast-arm lengths, limited right of way, restrictive geometrics, or pedestrian requirements, traffic-signal equipment often must be placed relatively close to the travelway. The following should be considered in determining the placement of traffic-signal equipment.

1. Clear Zone. If practical, the placement of traffic-signal equipment for a new-construction or reconstruction project should satisfy the clear-zone criteria described in Section 49-2.0. For a 3R project, the equipment should be located outside of the obstruction-free zone as described in Section 55-5.02. A new-signal installation on an existing route or a signal-modernization project is considered to be a 3R project.

2. Controller Cabinet. In determining the location of the controller cabinet, the following should be considered.

   a. It should be placed in a position so that it is unlikely to be struck by an errant vehicle. It should be located outside the obstruction-free zone.

   b. It should be located where it can be easily accessed by maintenance personnel.

   c. It should be located so that a technician working in the cabinet can see the signal indications in at least one direction.

   d. It should be located where the potential for water damage is minimized.

   e. It should not obstruct intersection visibility.

   f. The power-service connect should be reasonably close to the controller cabinet.

3. Traffic-Signal Supports. These should be placed to provide the obstruction-free zone through the area where the traffic-signal supports are located. However, the following exceptions will apply.

   a. Channelizing Island. Installation of a signal support in a channelizing island should be avoided, if practical. However, if a signal support must be located in a channelizing island, a minimum clearance of 30 ft should be provided from all travel lanes including turn lanes in a rural area, or in an urban area where the posted speed limit is 50 mph or higher. In an urban area where the island is bordered by a barrier curb and the posted speed limit is 45 mph or lower, a minimum clearance of 10 ft should be provided from all travel lanes including turn lanes.

   b. Non-Curbed Facility with Posted Speed Limit of 50 mph or Higher, and ADT > 1500. Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 10 ft beyond the outside edge of the paved shoulder.

c. Non-Curbed Facility with Posted Speed Limit of 45 mph or Lower, or ADT ≤ 1500. Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 6 ft beyond the outside edge of the paved shoulder.

d. Curbed Facility. See Section 55-5.02. For a facility with curbs of less than 6 in. height, see items 3.a. and 3.b. above.

4. Location of Signal Heads Relative to Stop Line. Figure 77-5M shows this information, and the appropriate lens diameters.

5. Pedestrians. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflicts. The signal pole should not be placed such that will restrict a handicapped individual's access to a curb ramp. Pedestrian push buttons must be conveniently located. Section 51-1.0 provides criteria for handicapped accessibility.

77-5.03 Pedestrian Signal

Pedestrian-signal indications should be provided for each new or modernized traffic-signal installation in accordance with the *MUTCD.*

An INDOT pedestrian-signal installation should satisfy the INDOT *Standard Specifications*. For a local-agency facility, a pedestrian-signal installation should satisfy ITE criteria and local practice. A location where visually-impaired pedestrians are anticipated may warrant the supplemental use of an accessible pedestrian signal. The use of an accessible signal will be determined on a site-by-site basis.

77-5.04 Pavement Marking and Signing

Cantilevers and span cables often include regulatory and informational signs, e.g., left turn only, name of cross street. The effect of the weight of the sign and additional wind loading on the cantilever or the span cables should be considered. The number of signs on a traffic-signal structure should be limited. Chapter Seventy-five provides additional guidance on the placement and design of signs.

For a cable-span signal installation, a lane-use-control sign should be placed over the lane on the near-side span. A street-name sign should be placed on right side of the far-side span.

An internally-illuminated street-name sign provides increased visibility at night. INDOT does not install such a sign, but a local agency may request its installation on an INDOT-controlled traffic signal. Its installation requires a contract between INDOT and the appropriate local governmental agency.

Chapter Seventy-six provides the criteria for the application of pavement markings at an intersection. Pavement markings are used to supplement the traffic-signal indication and lane-use signs.

77-5.05 Electrical System

The electrical system consists of electrical cables or wires, connectors, conduit, handholes, etc. Electrical connections between the power supply, controller cabinet, detectors, and signal poles are carried in conduit. The following should be considered in developing the traffic-signal-wiring plan.

1. Service Connections. Service connections from the local utility lines should go directly to the service disconnect and then to the controller cabinet. The lines should be as short as practical. The service disconnect should be located as close to the controller cabinet as practical. These installations will be placed underground in separate conduits from other signal wires. Easy access to a shut-off device in the controller is required to turn the power supply off while performing system maintenance.

2. Electric Cables. All electric cables and connections must satisfy national, State, and local electrical codes, in addition to the NEMA criteria, except for the green wire, which is used for the green indication or interconnect function and not for the system ground. The number of conductor cables should be kept to a minimum, usually only 3 or 4 combinations, to reduce inventory requirements. A 7- or greater-conductor cable is used between the controller cabinet and the disconnect hangers or cantilever base. A 5-conductor cable is used between the disconnect hanger or cantilever base and 3-section signal indication. A 7-conductor cable is used between the disconnect hanger or cantilever base and 5-section signal indication. A 5-conductor cable is used between the controller cabinet and the pedestrian-signal indication. A 5-conductor cable is used between the controller cabinet and each pair of pedestrian push buttons located in the same corner of the intersection. Connections to flashers use only a 3-conductor cable. The INDOT *Standard Drawings* illustrate the correct procedures for wiring and splicing cables.

3. Cable Runs. All cable runs should be continuous between the following:

    a. controller cabinet to base of cantilever structure or pedestal;
    b. controller cabinet to disconnect hangers;
    c. controller cabinet to service disconnect;
    d. disconnect hanger to signal indications;
    e. base of cantilever structure to signal indications; and
    f. controller cabinet to detector housing.

4. Handhole. A handhole should be located adjacent to the controller cabinet, each signal pole, and each detector location. The INDOT *Standard Drawings* provide additional handhole and wiring details. The maximum spacing between handholes in the same conduit run is 250 ft.

5. Underground Conduit. Underground conduit is used to connect the controller cabinet, traffic signals, and loop detectors together. Conduits run underneath the pavement and between the handholes, using a 2-in. diameter conduit. For a run with additional cables, the conduit size may need to be increased. The NEC should be checked to determine the appropriate conduit size for the number of electric cables that can be contained within the conduit. The INDOT *Standard Drawings* provide additional placement details of underground conduit.

6. Grounding. Each metal pole, cantilever structure, controller cabinet, etc., should be grounded. The INDOT *Standard Drawings* illustrate the correct methods for grounding these devices.

7. Detector Housing. A detector housing should be a cast-aluminum box encased in concrete. A detector housing is used to splice the wires from the loops to the lead-in cable to the detector amplifier. The INDOT *Standard Drawings* provide additional information on detector housings, including wiring details.

8. Disconnect Hangers. Disconnect hangers are used for a cable-span-mounted signal to provide a junction box between the signal heads and the controller.

9. Loop Tagging. Each loop-detector cable should be tagged in the controller cabinet to indicate which loop detector wire belongs to which loop detector. Each should be labeled according to street, direction, lane, and distance from the stop line, and if the loop is a count loop.

10. Interconnect Cable. A 7-conductor signal wire is used for hard-wiring interconnected

signals. For a closed-loop system, the hard-wired connection should use a telecommunication cable consisting of either a fiberoptic cable or a 6-pair twisted cable.

77-5.06 Phasing

The designer, in consultation with the district Office of Traffic, is responsible for determining the initial phasing plan. The selected phase diagram should be shown on the plans and should include the roadway preferentiality.

77-5.06(01) Phasing Types

A signal phase is defined as the part of the traffic-signal cycle allocated to a combination of traffic movements receiving the right of way simultaneously during one or more intervals. Each cycle can have 2 or more phases. For practicality, there should not be more than 8 phases per cycle and there should desirably be fewer. An 8-phase dual-ring controller should be used with a new or modernized traffic signal. As the number of non-overlapping phases increases, the total vehicular delay at the intersection will increase due to the lost time of starting and clearing each phase. The minimum number of phases practical that will accommodate the existing and anticipated traffic demands should be used. A capacity analysis should be conducted to determine if the proposed phasing is appropriate. Phases 2 and 6 are considered to be the preferential phases. The following provides the applications for phased operations.

1. Two-Phase Operation. A 2-phase operation is appropriate with a 4-way intersection that has moderate turning movements and low-pedestrian volume. Figure 77-5N illustrates a typical 2-phase operation. A 2-phase operation is also appropriate for the intersection of two one-way streets. Disadvantages of a 2-phase operation are that left turns are in conflict with traffic from opposite directions, and that right- and left-turning traffic is in conflict with pedestrian flows.

2. Three-Phase Operation. The following describes where a 3-phase operation may be used.

    a. Major or Minor Street with Separate Phases. A 3-phase operation with separate phases on a major or minor street (split phase) may be used where there is heavy left-turning demand on the major or minor street from one or both directions and there is inadequate pavement width to provide a left-turn lane. See Figure 77-5 O, Three-Phase Operation, Separate Split Phases for Major Street, or Figure 77-5P, Three-Phase Operation, Separate Split Phases for Minor Street. This phase selection is not an efficient operation for a multilane street because it reduces capacity and increases delay.

b. Major Street with Left-Turn Lanes. A 3-phase operation should be considered where separate left-turn lanes are provided on the major street (see Figure 77-5Q). A left-turn lane will reduce the number of left-turn accidents. Left-turning traffic from both directions should be nearly equal.

c. Exclusive Pedestrian Phase. This option is used where there are a significant number of pedestrians (e.g., college, downtown business district) and where the signal normally operates in a 2-phase operation (i.e., minimum number of left-turns). Figure 77-5R illustrates a 3-phase operation with an exclusive pedestrian phase. During the exclusive pedestrian phase, pedestrians can use all crosswalks or walk diagonally across the intersection.

d. T Intersection. A 3-phase operation will be required if there is a large turning volume on the through street. The 3-phase operation allows a number of options depending on the traffic volume and geometrics of the intersection, e.g., left- and right-turn lanes. Figure 77-5S illustrates the options for single-lane approaches. Figure 77-5T illustrates the options for multiple-lane approaches.

3. <u>Four-Phase Operation</u>. A 4-phase operation may be used where left-turn lanes are provided on all four approaches and the left-turn volume for each set of opposing turns is approximately equal. However, an 8-phase controller is more efficient for this type of operation. This phase operation may be used at the intersection of multilane major routes. It is most appropriate for actuated control with detection on all approaches.

4. <u>Eight-Phase Operation.</u> An 8-phase operation provides the maximum efficiency and minimum conflicts for a high-volume intersection with many turning movements. A left-turn lane should be provided on each approach. It is most appropriate for actuated control with detection on all approaches. The 8-phase operation allows for the skipping of phases or selection of alternate phases depending upon traffic demand. Figure 77-5U illustrates an 8-phase operation, dual ring. An 8-phase operation uses the NEMA dual-ring controller.

5. <u>Other Phases</u>. For other phase operations, e.g., a 6-phase operation, one of the phase operations described above can be used by eliminating the nonapplicable phase from the sequence.

Figures 77-5N through 77-5U also illustrate the movements that should be assigned to the numbered phases. On a 4- or 8- phase operation, the through phases are assigned to the even-numbered phase-diagram locations, and the left turns are assigned to the odd-numbered phase-diagram locations. See Section 77-5.06(02) for more information on phase assignment.

The controller accommodates control of each individual phase. Each phase is programmed as a single-entry operation in which a single phase can be selected and timed alone if there is no demand for service in a non-conflicting phase. There are phases that can be timed concurrently with a dual-ring controller. For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement, but not with another phase or vice versa. For example, Phase 2 can be timed concurrently with Phase 5 or Phase 6. This concurrent timing is not an overlap because each phase times individually. An overlap is dependent on the phase or phases with which it is overlapped for time and is terminated as the phase or phases terminate.

There are computer programs available that can assist the designer to determine the appropriate phasing requirements (see Section 77-5.10). The Application Development Division can be contacted for more information on the latest software packages or versions used by INDOT.

77-5.06(02) Phase Numbering and Conventions

Phase numbers are the labels assigned to the individual movements around an intersection. For an 8-phase dual-ring controller, it is common to assign the main street's through movements as phases 2 and 6. Also, it is common to use odd numbers for left-turn signals and even numbers for through signals. The sum of phase numbers of the through movement and the adjacent left turn is equal to seven or eleven. Figure 77-5V shows typical phase-numbering schemes. Figure 77-5W shows typical phase diagrams.

For signals in a coordinated system, phases 2 and 6 are the coordinated phases.

Intersection approach directional labels and corresponding NEMA phase assignments should be shown on the plans according to standard route-numbering convention and priority routes as defined below.

1. <u>Highest-Priority Intersecting Route</u>. This should be determined based on route classification (US Route; State Route; local route, respectively). For equally-classified routes, the higher-priority route has the higher vehicular volume.

2. <u>Labeling Approaches NB, SB, EB, or WB</u>. For route-numerical designation, an odd-numbered route should be labeled NB and SB. An even-numbered route should be labeled EB and WB, for the highest-priority route (phases 2 and 6) on the intersection-design plan. All remaining minor-approach directional labels should be assigned as relative directions to the highest-priority NB or EB route. If two equally-classified routes, both even- or odd-

numbered, intersect, phase 2 should be assigned to the higher-volume NB or EB through movement. The remaining directional labels should be relatively assigned to the remaining movements.

77-5.06(03) Phase Assignments

1. 4- or 8- Phase Intersection. Phase 2 should be assigned to the highest-priority arterial NB or EB route at the intersection. The remaining even-numbered through phases should be assigned to vehicle movements clockwise around the 4-approaches intersection. Phase 4 should be immediately to the left of phase 2, followed to the left by phase 6 (opposing phase 2), and followed by phase 8 immediately left of phase 6 or right of phase 2. Odd-numbered phases should be assigned to each corresponding left-turn phase by standard NEMA convention, also increasing numerically in the clockwise direction.

   Deviation from the priority convention described above is permitted to maintain the integrity of an existing or planned coordinated system by assigning phase 2 and 6 as the coordinated phases.

2. T Intersection. A three-legged or T intersection should follow the 4- or 8- phase intersection convention, skipping those phases that are otherwise assigned to the missing vehicle movements.

3. Split-Phase Intersection. Phase assignments should follow the 4- or 8- phase intersection to the extent possible. NB and EB movements should be assigned a lower phase number than the phase number assigned to SB and WB movements, respectively.

4. Grade-Separated Intersection or Interchange. Grade-separated intersection or interchange ramps that terminate and intersect at numbered US and State arterial routes should use the through surface arterial route numerical designation to determine the NB/EB phase 2 assignment regardless of route priority. NB/WB ramp movements will be assigned to phase 8. SB/EB ramps will be assigned to phase 4.

   A ramp terminating at a local street may use either the numbered Interstate or State route as directional reference, or the nearest actual NB/EB cardinal direction of the local arterial movement in determining arterial orientation for assigning phase 2 as NB or EB. Regardless, phase 2 should be labeled NB or EB, and the remaining conventions described above should be applied.

5. TTI 4-Phase and Single-Controller Diamond Interchange. A single-controller diamond interchange should incorporate a flexible ring structure that allows TTI 4-phase, extended

3-phase, standard 3-phase, or two separate intersection modes by time-of-day selection in the controller. Phases will not strictly follow the convention described above.

77-5.06(04) Examples

1. SR 32 at SR 38 east or west side of Noblesville. SR 32 is the through movement. Phase 2 is EB SR 32.

2. SR 32 at SR 37 in Noblesville. SR 37 is the higher-volume route. Phase 2 is NB SR 37.

3. I-465 at US 31 in Hamilton County. US 31 is the odd-numbered NB route. Phase 2 is NB US 31.

4. I-465 at Allisonville Road in Indianapolis. Phase 2 is NB Allisonville Road.

5. US 30 at SR 15 in Warsaw. This is grade separated. SR 15 is the arterial route. Phase 2 is NB SR 15.

77-5.06(05) Left-Turn Phase

The most commonly added phase is for protected left-turns, for which left-turning vehicles are given a green arrow without conflicting movements. A left-turn phase can be either a leading left, where the protected left turn precedes the opposing through movements, or a lagging left, where the left-turn phase follows the opposing through movements. Opposing left turns may both be leading, lagging, or a combination of leading and lagging. The decision on whether to use either a leading-left or a lagging-left turn will be determined for each situation. The preferred practice is to use leading left turns. A combination of leading and lagging or lagging left turns can provide more-efficient operation in a coordinated signal system. Figure 77-5X provides a comparison for each left-turn phase alternative.

Not all signalized intersections will require a separate left-turn phase. The decision on whether to provide exclusive left-turn phases is dependent upon traffic volume, delays, and crash history. This will be determined on a site-by-site basis. For an intersection with exclusive left-turn lanes, the following can be used to determine the need for a left-turn phase.

1. Capacity. A left-turn phase should be considered where the demand for left turns exceeds the left-turn capacity of the approach lane. The left-turn capacity of an approach lane is 1,200 vehicles times the percent of green time minus the opposing volume, but not less than two vehicles per cycle.

2. Delay. A left-turn phase should be considered where the delay time for left-turning vehicles is excessive for 4 h during an average day. Delay is considered excessive if left-turning vehicles are delayed for more than two complete signal cycles.

3. Miscellaneous. Intersection geometrics, total volume demand, crash history, posted speeds, etc., should also be considered.

4. Non-INDOT Facility. The ITE *Manual of Traffic Signal Design* provides alternative guidelines for consideration of left-turn phasing.

   On an approach without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined on a site-by-site basis. The inclusion of a left-turn phase at an intersection without an exclusive left-turn lane will require split phasing. Where practical, opposing left-turn arrows should also be provided.

77-5.06(06) Assignment of Right of Way

The assignment of right of way, also referred to as preferentiality, at a traffic signal determines which signal indications will flash amber if the traffic signal goes to a flash condition.

None of the signal indications should flash amber. Therefore, none of the approaches should have preferentiality over the others. This condition is also referred to as all-red flash.

A local agency is permitted to assign preferentiality to one of the roads at an intersection. This will permit the preferential road's indication to flash amber while the crossroad's indication will flash red.

77-5.07 Pretimed Traffic-Signal Timing

77-5.07(01) Guidelines for Signal Timing

For a State highway, the district Office of Traffic will be responsible for timing the signal after it has been installed. For a local facility, the consultant will be responsible for determining the signal timing. However, designer must still understand the aspects of traffic-signal timing so that the appropriate equipment will be selected and an efficient design can be provided.

The following should be considered in determining pretimed-signal timing.

1. Phases. The number of phases should be kept to a minimum. Each additional phase reduces the effective green time available for the movement of traffic flows, such as increased lost time due to starting delays and clearance intervals. Adding concurrent phases may not reduce capacity.

2. Cycle Length. A short cycle length yields the best performance by providing the lowest average delay provided the capacity of the cycle to pass vehicles is not exceeded. The following should be considered relative to cycle lengths.

    a. Delay. For a 2-phase operation, a shorter cycle length of 50 to 60 s produces the shortest delays.

    b. Capacity. A cycle length of longer than 60 s will accommodate more vehicles per hour if there is a constant demand during the entire green period on each approach. Such a cycle length has higher capacity because, over a given time period, there are fewer starting delays and clearance intervals.

    c. Maximum. A maximum cycle length of 120 s should be used, irrespective of the number of phases. For a cycle of longer than 120 s, there is an insignificant increase in capacity and a rapid increase in the total delay.

3. Green Interval. The division of the cycle into green intervals will be approximately correct if made proportional to the critical lane volume for each signal phase. The critical lane volume can be determined by using the *Highway Capacity Manual*'s Planning Methodology, or the of the Highway Capacity Software's Signalized Intersections Module. The green interval should be checked against the following.

    a. Pedestrians. If pedestrians are to be accommodated, each green interval should be checked to ensure that it is not less than the pedestrian clearance time required for pedestrians to cross the respective intersection approaches plus the initial walk interval time.

    b. Minimum Lengths. Major movements relative to driver expectations should not have green intervals which are less than 15 s. An exception to this may be appropriate for special turn phases.

4. Capacity. For an intersection approach with many left turns, the capacity should be checked to determine the need for a separate left-turn lane; see Section 77-5.06(03).

5. Phase-Change Interval. Each phase-change interval (yellow plus all-red) should be designed to satisfy Section 77-5.07(02) item 2 to ensure that approaching vehicles can

either come to a stop or clear the intersection during the change interval.

6. Coordination. Traffic signals within 0.5 mi of each other should be coordinated together in a system. Section 77-6.0 further discusses signal-system coordination.

7. Field Adjustments. Each signal-timing program should be checked and adjusted in the field to satisfy the existing traffic conditions.

77-5.07(02) Cycle Determination

In determining the appropriate cycle length and interval lengths, the following should be considered.

1. Cycle Length. Cycle length should be within the range as follows:

   a. 2-Phase Operation, 50 to 80 s.
   b. 3-Phase Operation, 60 to 100 s.
   c. 4-Phase Operation, 80 to 120 s.

2. Phase-Change Interval. The yellow change interval advises the driver that the phase has expired and that he or she should stop prior to the stop line, or allows entry to the intersection if too close to stop. The phase-change interval length should be determined using Equation 77-5.1. The yellow change interval should be followed by a red-clearance interval, or all-red phase, of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released. For a more-efficient operation, start-up time for the conflicting movements may be considered in setting the length of the all-red interval.

$$Y + A.R. = t + \frac{V}{2a \pm 64.4} + \frac{W + L}{V} \qquad \text{(Equation 77-5.1)}$$

Where:
$Y + A.R.$ = Sum of the yellow and all-red intervals, s
t = perception/reaction time of driver, s, assumed to be 1 s
V = approach speed, ft/s
W = width of intersection, ft
L = length of vehicle, ft, assumed to be 20 ft
a = deceleration rate, ft/s^2, assumed to be 10 ft/s^2

The yellow change interval is in the range of 3 to 6 s. The all-red interval is in the range of 1 to 4.4 s.

3. Green Interval. To determine the cycle division, the green interval should be estimated using the proportion of the critical lane volume for each phase. The following equations illustrate how to calculate this proportion for a 2-phase system. The green interval for a signal with additional phases can be determined in a similar manner.

$$G = C - Y_a - Y_b \qquad \text{(Equation 77-5.2)}$$

$$G_a = \frac{V_a G}{V_a + V_b} \qquad \text{(Equation 77-5.3)}$$

$$G_b = \frac{V_b G}{V_a + V_b} \qquad \text{(Equation 77-5.4)}$$

Where:
G = total green time available for all phases, s
C = cycle length, s
Y_a and Y_b = yellow and all-red phase-change interval, s, on streets A and B
G_a and G_b = green interval, s, calculated for streets A and B
V_a and V_b = critical-lane volumes on streets A and B

The effect that the pedestrian clearance interval will have on the green interval should be considered where there is an exclusive pedestrian phase, or if the pedestrian phase runs concurrently with traffic at a wide intersection with a short green interval. If pedestrians walk with the green indication or a walk indication, the minimum green interval should be determined using Equation 77-5.5. The walking distance is from the edge of the near roadway to the center of the farthest travel lane.

$$G = P + \frac{D}{S} - Y \qquad \text{(Equation 77-5.5)}$$

Where:
G = minimum green time, s
P = pedestrian start-off period, 4 to 7 s
S = walking speed, 4 ft/s
D = walking distance, ft
Y = yellow interval, s

Where there are fewer than 10 pedestrians per cycle, the lower limit of 4 s is adequate as a pedestrian start-off period. A walking speed of 4 ft/s can be assumed for an adult pedestrian. Where a significant volume of elderly, handicapped, or child pedestrians is present, a reduced walking speed should be considered.

4. Recheck. After the cycle length and interval lengths have been selected, the design should be rechecked to ensure that sufficient capacity is available. Several cycle lengths should be checked to ensure that the most-efficient cycle length and interval lengths are used. If the initial design is inadequate, the designer should perform the following:

    a. select a different cycle length;
    b. select a different phasing scheme; or
    c. make geometric or operational changes to the intersection approaches, such as adding left-turn lanes.

    There are software programs available to assist in determining the most efficient design. Section 77-5.10 discusses these.

77-5.08 Actuated-Controller Setting

As with a pretimed controller, the district Office of Traffic will be responsible for timing each actuated controller on a State highway after it is installed. However, the designer should understand how the signal timing will affect the efficiency of the actuated signalized intersection. The designer should also understand how the signal timing will affect the placement of the traffic detectors.

The design of actuated control is a trade-off process where the location of vehicular detection is optimized to provide safe operation while providing controller settings that will minimize intersection delay. The compromises that should be made among these conflicting criteria become increasingly difficult to resolve as approach speeds increase. For example, for an approach speed of 40 mph or higher, the detector should be located in advance of the indecision zone. The indecision zone is the decision area, on such an approach, where the driver must decide whether to go through the intersection or stop once the yellow interval begins. Depending on the distance from the intersection and vehicular speed, the driver may be uncertain whether to stop or continue through the intersection, thus, creating the indecision problem. Figure 77-5Y further defines the indecision zone. The following discusses the design considerations for an actuated controller.

77-5.08(01) Basic-Actuated Controller

Basic-actuated control with passage detection is limited in application to an isolated intersection with fluctuating or unpredictable traffic demands and approach speeds of 35 mph or lower. Basic-actuated control includes fully-actuated and semi-actuated control equipment. INDOT does not use this type of signal control; see Section 77-5.08(02).

Because of the small area covered by the small loop detector and its location relative to the stop line, this type of detection is used only with a controller that has a locking memory feature for detector calls. The controller remembers the actuation of a detector on the yellow or red interval, or the arrival of a vehicle that did not receive enough green time to reach the intersection.

In developing the timing criteria and the detector placement for basic-actuated controllers, the following should be considered.

1. Minimum Assured Green (MAG). Although there is no timing adjustment labeled MAG on the controller, the MAG should still be calculated. The minimum green time is composed of the initial green interval plus one vehicle extension. A long minimum green time should be avoided. The minimum assured green time should be between 10 and 20 s for a major movement. The actual value selected should be based on the time it takes to clear all possible stored vehicles between the stop line and the detector. If the MAG is too short, the stored vehicles may be unable to reach the stop line before the signal changes. This time can be calculated using Equation 77-5.6.

   $$MAG = 3.7 + 2.1n \qquad \text{(Equation 77-5.6)}$$

   Where
   MAG is in s
   n = number of vehicles per lane which can be stored between the stop line and the detector

   The minimum green time selected should be able to service at least two vehicles per lane. Using Equation 77-5.6, this translates into a time of approximately 8 s. Assuming two vehicles occupy approximately 45 ft, the detector should not be placed closer than 45 ft from the stop line. Closer placement will not reduce the MAG.

   Where pedestrians must be accommodated, a pedestrian detector, e.g., push button, should be provided. Where a pedestrian call has been detected, the MAG must be sufficient enough for the pedestrian to cross the intersection. The minimum time for a pedestrian, as discussed in Section 77-5.07, is also applicable to an actuated system.

2. Vehicular Extension. The vehicular-extension setting fixes both the allowable gap and the passage of time at one value. The extension should be long enough so that a

vehicle can travel from the detector to the intersection while the signal is held in green. However, the allowable gap should be kept reasonably short to ensure quick transfer of green to the side street. Headway between vehicles in platoons average between 2 and 3 s. Therefore, the minimum vehicular extension time should be at least 3 s. For the maximum gap, studies have shown that a driver waiting on red finds that a gap of 5 s or longer is too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 s. For a quicker phase change, a shorter gap of 3 to 3.5 s should be used.

3. Initial Green. The initial green setting is the MAG minus one vehicular extension. The initial green should be limited to a maximum of 10 s.

4. Detector Placement. The detector setback distance should be set equal to the time required for a vehicle to stop before entering the intersection. The vehicular passage time is used to determine this placement, e.g., 5 s. The posted speed limit of the approach roadway should be used to determine the appropriate setback.

5. Maximum Green Interval. This is the maximum time that the green should be held for the green phase, given a detection from the side street. For a light to moderate traffic volume, the signal should gap out before reaching the maximum green time. However, for a period with higher traffic volume, the signal may rarely gap out. Therefore, a maximum green interval is set to accommodate the waiting vehicles. The maximum green interval can be determined assuming a pretimed intersection (see Section 77-5.07). It may be somewhat longer to allow for peaking.

6. Clearance Interval. The clearance interval should be determined as for a pretimed signal (see Section 77-5.07).

7. Left-Turn Lane. A left-turn lane should be treated like a side street with semi-actuated control. Short allowable gaps and minimum greens should be used. A vehicle may enter the left-turn lane beyond the detector. If this is a problem, a presence detector should be considered at the stop line; see Section 77-5.08(03).

8. Semi-Actuated Controller. For a minor street with semi-actuated control, the signal is held on green for the major street. To ensure that the mainline is not interrupted too frequently, a long minimum green interval should be used on the major street. The minor street will experience delay.

9. Intermediate Traffic. Where a vehicle can enter the roadway between the detector and intersection, e.g., driveway, side parking, or where a vehicle may be traveling so slow that it does not clear the intersection in the calculated clearance time, the signal controller

will not register its presence. A presence detector at the stop line may be required to address this situation; see Section 77-5.08(03).

77-5.08(02) Advanced-Design Actuated Controller

An advanced-design controller is used at an isolated intersection with fluctuating or unpredictable traffic demands, and approach speeds of 40 mph or higher. INDOT uses this type of controller, irrespective of the approach speed. An advanced-design actuated controller is one that has a variable initial interval. It can count waiting vehicles beyond the first one and can extend the initial interval to meet the needs of the number of vehicles actually stored between the stop line and the detector. As with basic-actuated control, the small-area detection requires that the controller have a locking memory.

The timing for an advanced-design actuated controller requires judgment. Therefore, field adjustments are often required after the initial setup. The following discusses considerations regarding the signal timing and detector placement.

1. Detector Placement. For an approach speed of 40 mph or higher, the detector should be located in advance of the indecision zone (see Figure 77-5Y). This will place the detector about 5 s of passage time from the intersection. The speed selected should be the posted speed limit of the approach roadway. Figure 77-5 Z provides the appropriate detector setback distance for each combination of passage time and approach speed. Figure 77-5 Z also provides the passage time that is appropriate for other types of detection.

2. Minimum Initial Time. Because the advanced-design actuated controller can count the number of vehicular arrivals, the minimum initial time should be long enough only to satisfy driver expectancy. The minimum initial interval is set at 8 to 15 s for a through movement, or 5 to 7 s for a left-turn movement.

3. Variable Initial Time. The variable initial time is the upper limit to which the minimum initial time can be extended. It should be long enough to clear all vehicles that have accumulated between the detector and the stop line during the red interval. The variable initial time is determined in the same manner as the minimum assured green for the basic-actuated control; see Section 77-5.08(01).

4. Number of Actuations. The number of actuations is the number of vehicles that can be accommodated during the red interval that will extend the initial green to the variable initial limit. This is a function of the number of approach lanes, average vehicle length, and lane distribution. It should be set based on the worst-possible condition, in which vehicles are stored back to the detector.

5. Passage Time. The passage time is the time required for a vehicle to pass from the detector to the stop line. This is based on the posted speed limit of the approach roadway.

6. Maximum Green Interval. The maximum green interval should be set the same as for the basic controller; see Section 77-5.08(01).

7. Allowable Gap. A density-type controller permits a gradual reduction of the allowable gap to a preset minimum gap based on cross-street traffic parameters such as time waiting, vehicles waiting, or density. Time waiting has been determined to be the most reliable and usable. As time passes after a conflicting call, the allowable gap time is gradually reduced. The appropriate minimum gap setting will depend on the number of approach lanes, the traffic volume, and the time of day. Adjustments will need to be made in the field.

8. Clearance Interval. The clearance interval should be determined in the same manner as for a pretimed signal (see Section 77-5.07).

77-5.08(03) Actuated Controller with Large Detection Area

A large-area detector is used with an actuated controller in the non-locking memory mode and with the initial interval and vehicular extension set at or near zero. This is referred to as the loop occupancy control (LOC). A large-area detector is used in the presence mode, which holds the vehicle call for as long as the vehicle remains over the loop. One advantage of a large-area detector is that it reduces the number of false calls due to right-turning-on-red vehicles. The large-area detector consists of four octagonal 6 ft by 6 ft or circular 6-ft diameter small loops, 9 ft apart connected in series; see the INDOT *Standard Drawings*. With a large-area detector, the length of the green time is determined by the time the area is occupied. However, a minimum initial time should be provided for driver expectancy. The following discusses the applications for LOC.

1. Left-Turn Lane. An LOC arrangement is appropriate for a left-turn lane where a left turn can be serviced on a permissive green or yellow clearance, or where a vehicle can enter the left-turn lane beyond the initial detector. The following should be considered in using the LOC for a left-turn.

   a. To ensure that the driver is fully committed to making the left turn, the initial loop detector may need to be installed beyond the stop line to hold the call.

b. Where motorcycles are a significant part of the vehicular fleet, the vehicular extension may need to be set to 1 s so that a motorcycle will be able to hold the call as it passes from loop to loop. An alternative is to use an extended-call detector.

2. <u>Through Lanes, Approach Speed of 35 mph or Lower</u>. The indecision zone protection is not considered a significant problem. The detection-area length and controller settings are determined based on the desired allowable gap. For example, assuming a 30-mph approach speed and 3 s desired allowable gap, the LOC area is calculated as follows:

$$\left(\frac{30\ mi}{h}\right)\left(\frac{5280\ ft}{mi}\right)(3\ s)\left(\frac{1\ h}{3600\ s}\right) = 132 \text{ ft in 3 s}$$

The vehicular length of 20 ft should be subtracted from the LOC, so that the required detector area is 112 ft. A loop layout is only 45 ft in length; therefore, for a 30-mph approach speed, the vehicular extension setting should be set at 1.5 s to provide the 3 s gap.

If the initial interval is set at zero and the vehicular extension is between 0 and 1 s then, under low-traffic-volume conditions, a green interval as short as 2 or 4 s may occur. Pedestrians or bicyclists presence should be determined. If so, the minimum green times for their crossings should be provided. Driver expectancy should also be considered. A driver for a major through movement expects a minimum green interval of 8 to 15 s.

3. <u>Through Lanes, Approach Speed of 40 mph or Higher</u>. It is not practical to extend the LOC beyond the indecision zone of 5 s of passage time back from the stop line. To address the indecision-zone problem, an extended-call detector is placed beyond the indecision zone. This detector is used in a non-locking mode. The time extension is based on the time for the vehicle to reach the LOC area. An intermediate detector may be used to better discriminate the gaps.

The concerns with using the LOC concept for this approach speed include the following.

a. The allowable gap is higher than the desired 1.5 to 3 s. The controller's ability to detect gaps in traffic is substantially impaired. As a result, moderate traffic will routinely extend the green to the maximum setting, which is undesirable.

b. An LOC design should be used only if the AADT is 8,000 to 10,000. This approach speed with a greater AADT is better served with a density controller. The intersection of a higher-speed artery with a lower-speed crossroad is better served with a density controller on the artery and LOC for the crossroad.

77-5.09 Vehicle-Counting Loop

A new or modernized traffic signal should include vehicle-counting loops. This is an inductive loop detector that, in addition to detecting the presence or passage of a vehicle, provides a count pulse once a vehicle passes over the loop. The traffic-signal controller stores the counts in a format that can be uploaded either remotely or onsite to a personal computer.

77-5.09(01) Considerations for Counting-Loop Use

The configuration of counting loops and determination of which loops are used to count vehicles at a signalized intersection are dependent on the geometry of the intersection. The considerations include the following.

1. Encroachment. A vehicle from one movement drives over a loop providing vehicle count for another movement, causing that movement to over-count. A lane with an encroachment issue should use only loop numbers 4 or 1 to count, depending on the area of encroachment.

2. Late Entrance or Early Departure. A vehicle enters or exits the side of a count loop series and does not cross every count loop in the series, causing that movement to under-count.

3. Lane Change Within the Loop System. A vehicle changing lanes within 50 ft of the stop line is unpredictable and cannot be eliminated. This is a minor issue. For a lane where this is a major issue, use loop numbers 1 or 4 to count, avoiding issues 1 and 2 above.

4. Tractor-Trailer. A tractor-trailer may be counted once or multiple times due to the difference in height of the bed and the axles. This is inconsistent between trucks and there are too many variables to eliminate this issue. For a lane where this is a major issue, using all four loops to count may minimize over-counting.

5. Shared Lane for Through and Right Movements. Figure 77-5AA shows two methods of counting through and right-turn movements if they share a lane. The minimum distance between the loops in the through lane and the loop in the radius for a right-turning vehicle should be 6 ft. Method A should be chosen if the radius is large enough that a right-turning vehicle will not cross the front loop in the lane. If a right-turning vehicle will pass partially or completely over the front loop in the lane, method B should be used.

Figures 77-5AA, 5BB, and -5CC illustrate the effects of the considerations described above, and show suggested counting-loop configurations.

77-5.09(02) Preferred Counting-Loop Configurations

One loop will provide the most accurate count but at a higher cost in hardware and detector lead-ins than for a four-loop series. Some detectors are not as accurate with one loop.

Two loops may increase accuracy for a detector that is not as accurate in counting with one loop. Counting with two loops is equal in cost to counting with one loop of a four loop series. Counting with two loops may decrease accuracy due to encroachment, late entrance, early departure, or lane changes within the count zone. Therefore, counting with two loops is subject to approval of the district Office of Traffic.

Four loops provide an accurate count installation with the lowest cost. However, this may decrease count accuracy if there are encroachments, late entrances, early departures, or lane changes within the count zone.

The preferred counting configurations, listed from most to least desired, are as follows:

1. Four loops: Loops 1, 2, 3, and 4
2. One loop: Loop 4
3. One loop: Loop 1
4. Two loops: Loops 3 and 4; requires district Office of Traffic approval
5. Two loops: Loops 1 and 2; requires district Office of Traffic approval

Only one movement can be counted per lane. As many movements as feasible should be counted at the intersection.

77-5.10 Computer Software

There are many software programs available to help assist in preparing a traffic-signal design or timing plan. New programs, as well as updates to existing programs, are continuously being developed. Before using these programs, the Traffic Control Systems Division should be contacted to determine which software packages or versions INDOT is currently using. The following programs are used for signal-timing optimization.

1. SYNCHRO and SIMTRAFFIC. SYNCHRO is a traffic-signal simulation program that develops a timing plan for either an isolated signal or an arterial signal system. It will

optimize timing for either a fixed or an actuated traffic signal. SIMTRAFFIC is a companion microscopic simulation and animation program that uses SYNCHRO files. Both programs will estimate measures of effectiveness for a timing plan.

2. PASSER II. This is Progression Analysis and Signal System Evaluation Routine II, a bandwidth-optimization program. It develops a timing plan that maximizes the through progression band along an arterial for up to 20 intersections. It works best in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER II can also be used to develop arterial phase sequencing for input into a stop-and-delay optimization model such as TRANSYT-7F.

3. TRANSYT-7F. This is Traffic Signal Network Study Tool 7F, which develops a signal-timing plan for an arterial or grid network. The objective of this program is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

4. AAP. This is Arterial Analysis Package, which allows the user to easily access PASSER II and TRANSYT-7F to perform a complete analysis and design of arterial signal timing. The package includes a user-friendly forms display program so that data can be entered interactively on a microcomputer. Through AAP, the user can generate an input file for two of the component programs to quickly evaluate an arterial signal-timing design or strategy. The package also links to the Wizard of the Helpful Intersection Control Hints (WHICH) to facilitate detailed design and analysis of the individual intersections. This program interfaces with TRANSYT-7F, PASSER II, and WHICH.

5. HCS. This is Highway-Capacity Software, which replicates the procedures described in the *Highway Capacity Manual.* It is a tool that increases productivity and accuracy, but it should only be used in conjunction with the *Highway Capacity Manual* and not as a replacement for it.

6. Passer III™-98. This is a diamond-interchange optimization software. The program can evaluate an existing or proposed signalization strategy, determine a signalization strategy which minimizes the average delay per vehicle, and calculate a signal-timing plan for interconnecting a series of interchanges on one-way frontage roads.

Most of these software programs can be purchased from McTrans Center, 512 Weil Hall, Gainesville, Florida 32611-2083, or from PC-TRANS, Kansas University Transportation Center, 2011 Learned Hall, Lawrence, Kansas 66045.

77-5.11 Maintenance Considerations

After a signal is installed, the district Office of Traffic will be responsible for the maintenance of the traffic signal. Therefore, it should be consulted early in the design process for the selected signal equipment and its location (e.g., controller, cabinet, signal heads, etc.). The selected equipment must satisfy the operator’s capability to adjust the signal and maintain it.

For a signal on a local facility, it will be the responsibility of the local municipality or county to operate and maintain the signal. The designer should review the local jurisdiction's existing traffic-signal hardware and maintenance capabilities. If practical, the designer should attempt to match the local jurisdiction’s existing hardware. This will reduce the municipality’s need for additional resources and personnel training. However, this should not limit the designer’s options, as there are consultants who can help a local government operate and maintain a traffic signal.

77-6.0 SIGNAL-SYSTEM DESIGN

As traffic volume continues to increase, installation of a coordinated signal system is an important tool to improve traffic flow. By coordinating two or more traffic signals together, the overall capacity of the highway can be significantly increased. Traffic signals which are 0.5 mi or closer should be considered for coordination. Although not a perfect solution, the use of a coordinated traffic-signal system can satisfy the traffic needs of a highway for many years. It is also a relatively inexpensive method of improving capacity, thereby reducing delay, with minimal disruption to the highway as compared to the construction of additional lanes.

77-6.01 System-Timing Parameters

The basic system-timing parameters used in a coordinated system include the following.

1. Cycle. The period of time in which a pretimed controller, or an actuated controller, with demand on all phases, displays a complete sequence of signal indications. The cycle length is common to all intersections operating together and is called the background cycle.

2. Split. The proportioning of the cycle length among the phases of the local controller.

3. Offset. The time relationship determined by the difference between a specific point in the local signal sequence, the beginning of the major-street green interval, and a system-wide

reference point.

4. Time of Day or Day of Week. This system selects a system-timing plan based on a predefined schedule. The timing-plan selection may be based not only on the time of day but also on the day of week and week of year. Some systems permit the selection of the plan based upon a specific day of the year.

5. Traffic-Responsive. A traffic-responsive system implements timing patterns based on varying traffic conditions in the street. Most traffic-responsive systems select from a number of predefined patterns. This system uses a computerized library of predefined timing patterns that are based on data collected by the system to develop the timing plan for the system.

77-6.02 System Types

The methodologies available to coordinate traffic signals take advantage of computer technology. As new signal controllers, computers, and software are developed, the design of a coordinated traffic-signal system will continue to improve. These systems should match existing systems or be coordinated with nearby systems. A traffic-signal system is designed by a consultant who specializes in this work. To maintain consistency, each traffic-signal-system design must be coordinated through the Highway Design and Technical Support Division. These systems are described below.

77-6.02(01) Interconnected Time-of-Day System

This system is applicable to either a pretimed or actuated controller, in either a grid system or along an arterial system. The configuration for this type of system includes a field-located, time-clock-based master controller generating pattern selection and synchronization commands for transmission along an interconnecting cable or via radio modem. Local intersection coordination equipment interprets these commands and implements the desired timing.

An interconnected time-of-day system can use the physical interconnection solely for the purpose of synchronizing the time clocks in the local controller. The local controller selects the desired timing from pre-programmed plans stored in the local controller.

77-6.02(02) Time-Based Coordinated Time-of-Day System

Operationally equivalent to the interconnected time-of-day system, this type of system uses accurate timekeeping techniques to maintain a common time of day at each intersection without physical interconnection. Time-base coordination is tied to the 60-Hz AC power supply, with a battery backup in case of a power failure.

Time-based coordination allows for the inexpensive implementation of a system, because the need for an interconnect cable is eliminated. However, a time-based system requires periodic checking by maintenance personnel, because the 60-Hz power-company reference is sometimes inconsistent. Power outages sometimes affect only portions of a system, resulting in drift between intersections that continue to operate on power-company lines and those that maintain time on a battery backup.

Time-based coordination often is used as a backup for a computerized signal system.

77-6.02(03) Traffic-Responsive Arterial System

This system is used with a semi-actuated controller along an arterial. The field-located system master selects predetermined cycle lengths, splits, and offsets based upon current traffic-flow measurements. These selections are transmitted along an interconnect cable or radio modem to coordination equipment at the local intersections.

Cycle lengths are selected based on traffic-volume and possibly occupancy-level thresholds on the arterial. The higher the volume, the longer the cycle length. Splits are selected based on the side-street traffic-volume demands. Offsets are selected by determining the predominant direction of flow along the arterial.

System-sampling detectors, located along the arterial, input data back to the master controller along an interconnect cable or radio modem. Most systems have the capability to implement plans on a time-of-day basis as well as through traffic-responsive techniques.

77-6.02(04) Distributed-Master, or Closed-Loop, System

This system advances the traffic-responsive arterial system one step further by adding a communications link between the field-located master controller and an office-based microcomputer. Most systems are designed to interface with a standard personal computer over dial-up telephone lines. This connection is established only if the field master is generating a report or if the operator is interrogating or monitoring the system. With proper equipment, many systems can share a single office-based microcomputer.

The system permits the maintenance of the complete controller database from the office. The controller's configuration data, phase and timing parameters, and coordination patterns can be downloaded directly from the office.

The distributed-master system provides substantial remote monitoring and timing-plan updating capabilities for only a minor increase in cost. This consists of only the expense of the personal computer and the monthly costs of a standard business telephone or cellphone line. Graphics displays are provided to assist in monitoring the system.

77-6.02(05) Central Computer, or Interval-Command System

This system can control large numbers of intersections from a central digital computer. This system requires constant communications between the central computer and each local intersection. The central computer determines the desired timing-pattern parameters, based either on time-of-day or traffic-responsive criteria, and issues commands specific to each intersection once per second. These commands manipulate the controller into coordinated operation.

The system also monitors each intersection once per second. Detector data, current-phase green, and other information is transmitted back to the computer for necessary processing. Many systems include a large wall-size map display, with indicators showing controller and detector status and other informational displays. Many systems include a color-graphics monitoring system.

A system of this type requires a large minicomputer, complete with a conditioned, environmentally-controlled computer room.

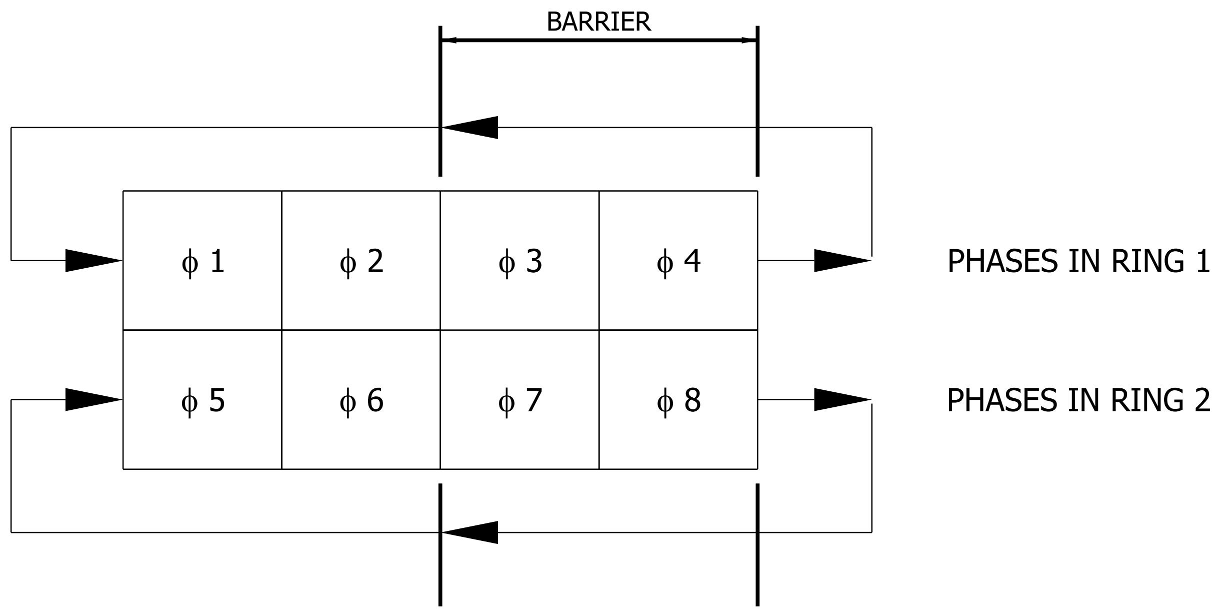
77-6.02(06) Central Database-Driven Control System

This system draws from the quality points of the distributed-master system and the central-computer system. Although communications are maintained continuously with each intersection, timing-pattern parameters are downloaded to each controller, eliminating most of the second-by-second approach. This allows a greater number of intersections to be controlled by a less-powerful computer.

The reduction in communications data required also allows an increase in monitoring data to be returned to the computer. Thus, the complex graphics displays normally found in distributed-master systems can also be implemented in a large-scale system.

77-6.03 Communications Techniques

A system other than a time-based coordinated system requires a communications medium to maintain synchronized operation between intersections. The primary options available for system interconnection are hardwired communications and through-the-air frequency. Hardwired communications can include leased telephone lines, cable-television lines, fiber optics, or direct wiring. Through-the-air interconnections can include radio, microwave, or cellular telephones. The requirements for the communications network are dependent on the needs of the system. Therefore, the decision on which interconnection method to use will be determined on a system-by-system basis.

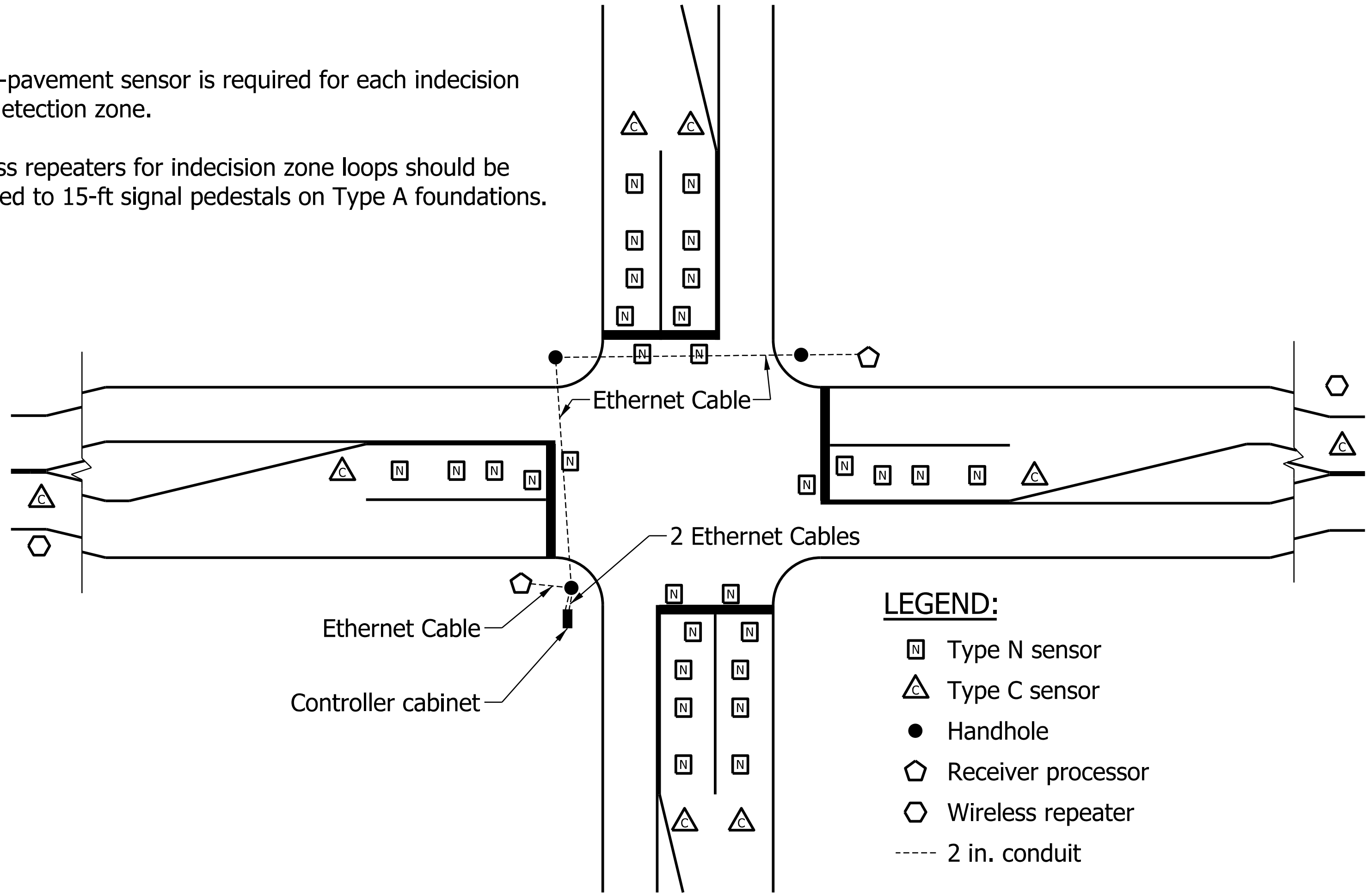


SEQUENCE OF PHASES,
8-PHASE DUAL-RING CONTROLLER UNIT

Figure 77-4A

NOTES:

1. One in-pavement sensor is required for each indecision zone detection zone.
2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.

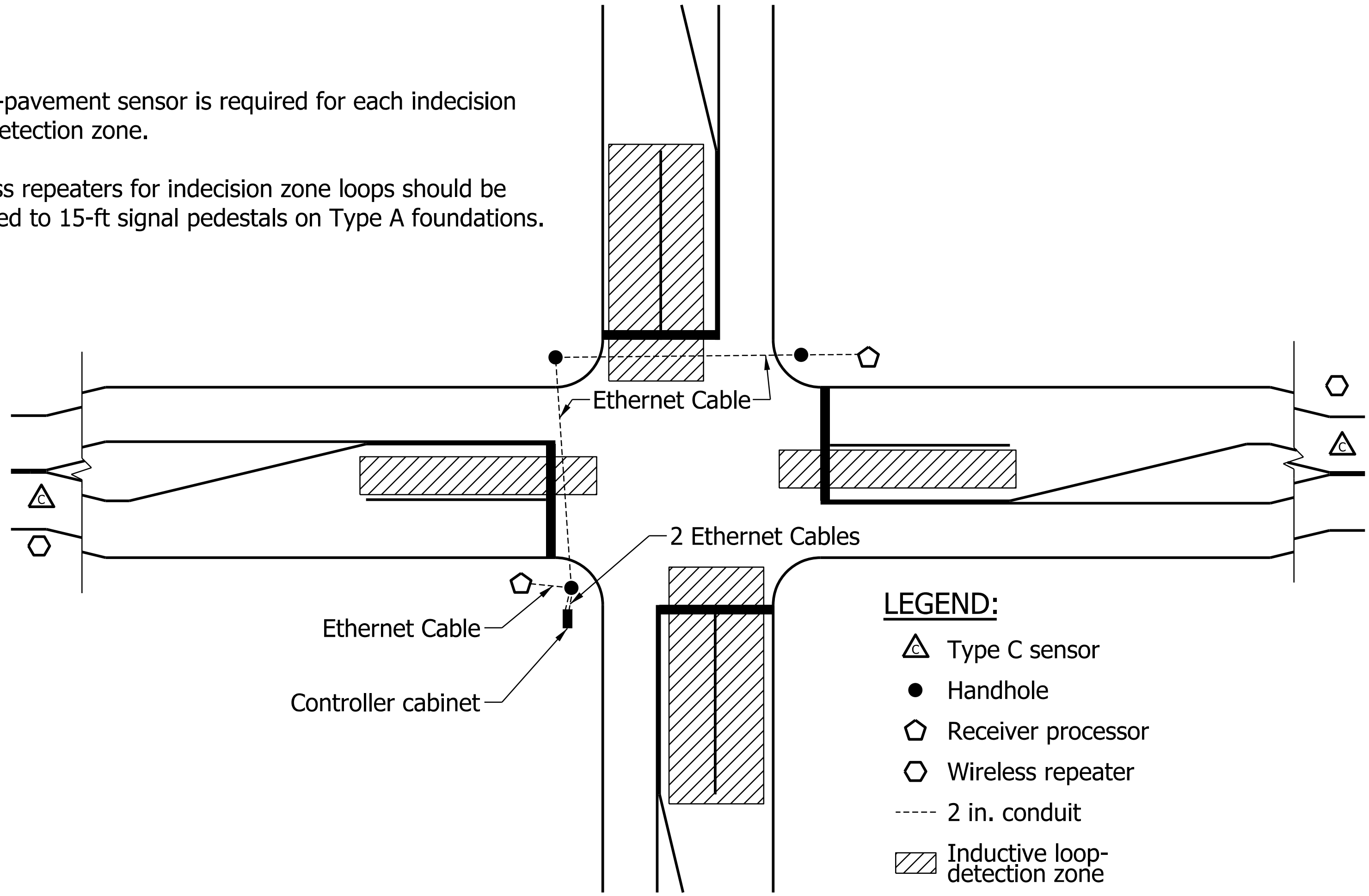


TYPICAL WIRELESS-VEHICLE-DETECTION SYSTEM

Figure 77-4B

NOTES:

1. One in-pavement sensor is required for each indecision zone detection zone.
2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.



TYPICAL HYBRID WIRELESS-VEHICLE-DETECTION SYSTEM

Figure 77-4C

Advantages
• Low installation costs. • Easy maintenance, no roadway interference. • Generally considered most aesthetically acceptable. • Generally correct locations for pedestrian signals and push buttons. • Provides adequate visibility where a wide median with left-turn lanes and phasing exist. • Unlimited roadway vertical clearance.
Disadvantages
• Requires underground wiring which can offset initial cost advantages. • Generally does not provide adequate visibility of signal indications for motorist due to lateral placement of signal indications. • May not provide mounting locations such that a display with a clear meaning is provided. • Height limitations may provide problems where approach is on a vertical curve. • Subject to vehicular impact if installed close to the roadway, particularly in a median.

POST-MOUNTED SIGNAL,
ADVANTAGES AND DISADVANTAGES

Figure 77-4D

Advantages
• Easy to install, less underground work required. • Allows excellent lateral placement of signal heads for maximum visibility. • Allows for easy future adjustments of signal heads. • Allows correct signal-placement location with respect to stop line. • Can provide convenient post locations for supplemental signal heads and pedestrian signals and push buttons. • Permits bridles to reduce distance from stop line at wide intersection (see Figure 77-4F)
Disadvantages
• Seen by some users as aesthetically unpleasing. • Requires periodic maintenance for span tightening. • Prevents passage of an overheight vehicle.

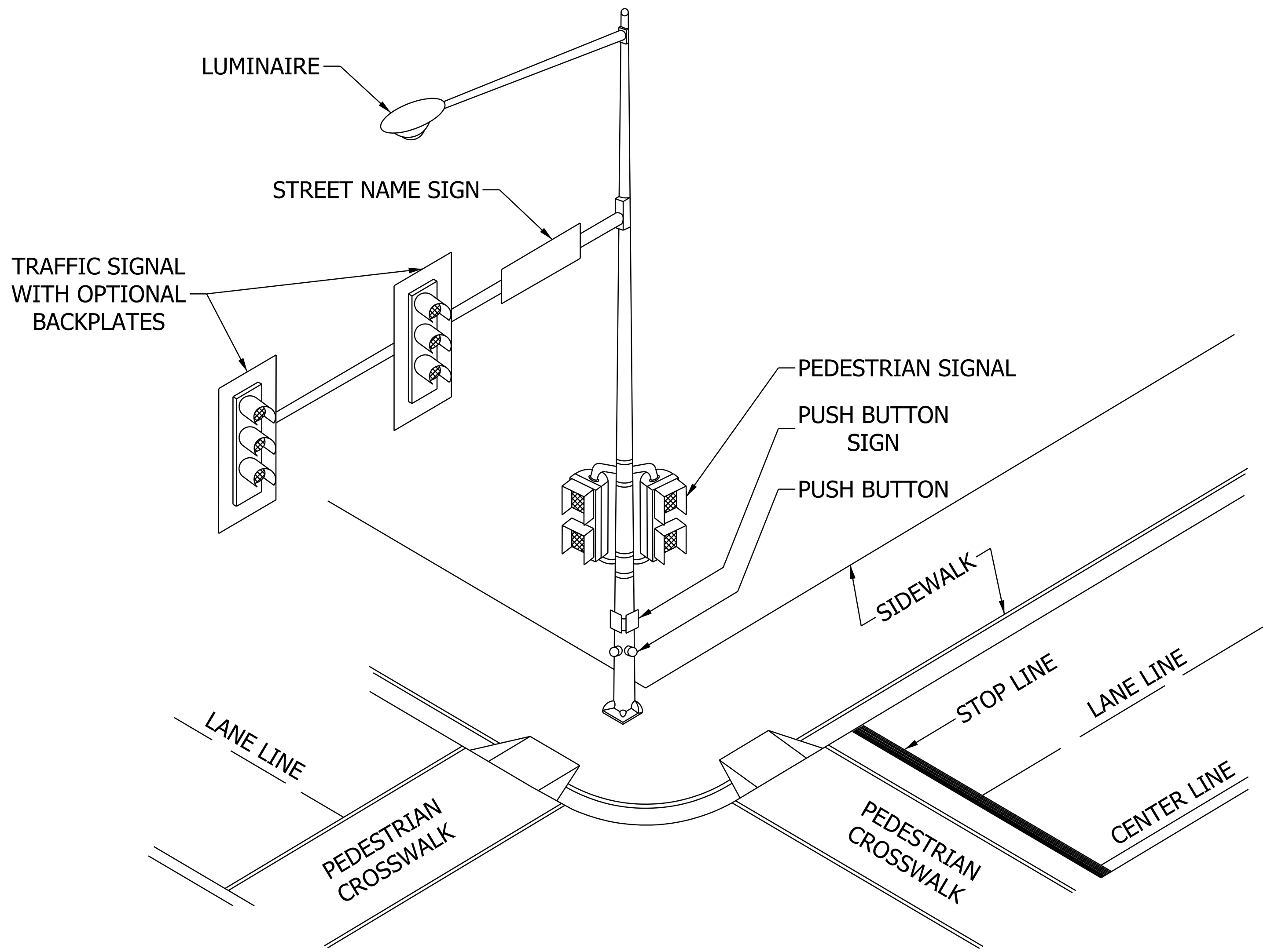
CABLE-SPAN-MOUNTED SIGNAL,
ADVANTAGES AND DISADVANTAGES

Figure 77-4E

Advantages
• Allows correct lateral placement of signal heads and placement relative to stop line for maximum visibility of signal indications. • Can provide post locations for supplementary signals or pedestrian signals and push buttons. • Accepted as an aesthetically-pleasing method for installing overhead signals in a developed area. • Rigid mountings provide the most positive control of signal movement in wind. • Allows for clearance to overhead obstructions.
Disadvantages
• Costs are generally the highest. • It may be difficult to properly place signal heads over a wide approach. • Limited flexibility for addition of new signal heads or signs on existing cantilevers.

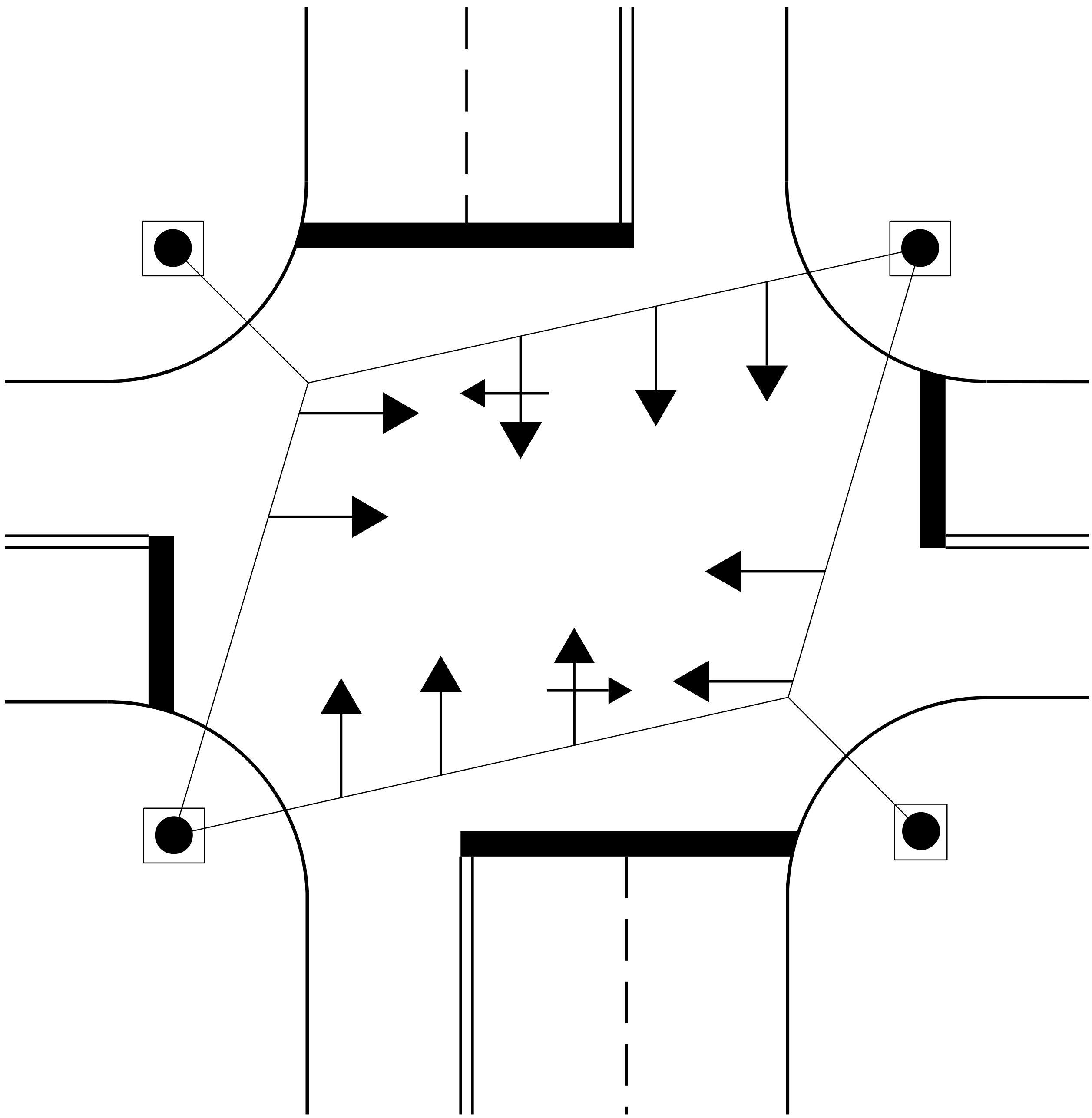
**CANTILEVER-, OR MAST-ARM-, MOUNTED SIGNAL,
ADVANTAGES AND DISADVANTAGES**

Figure 77-4F



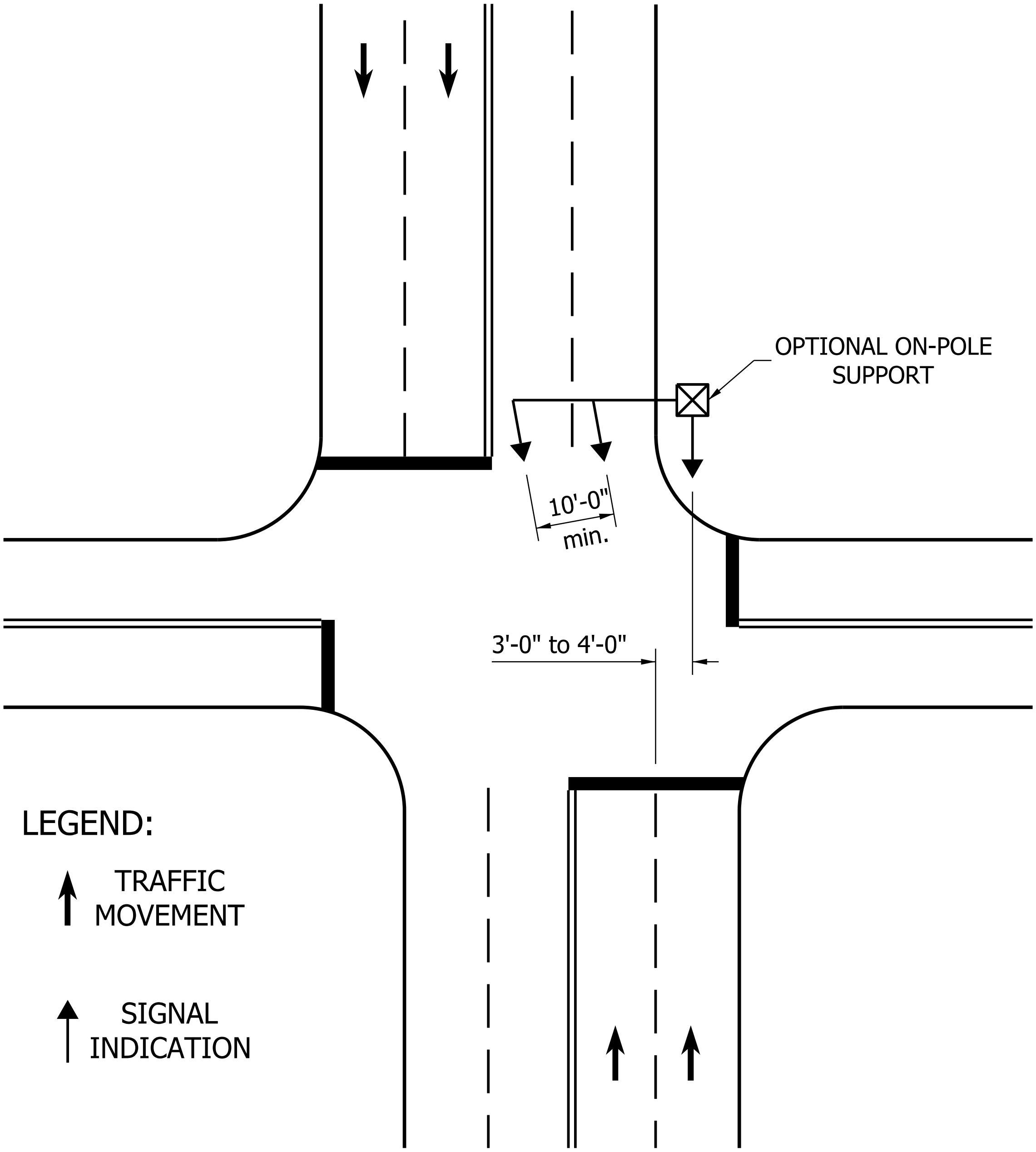
COMBINATION SIGNAL-LUMINAIRE POLE

Figure 77-4G



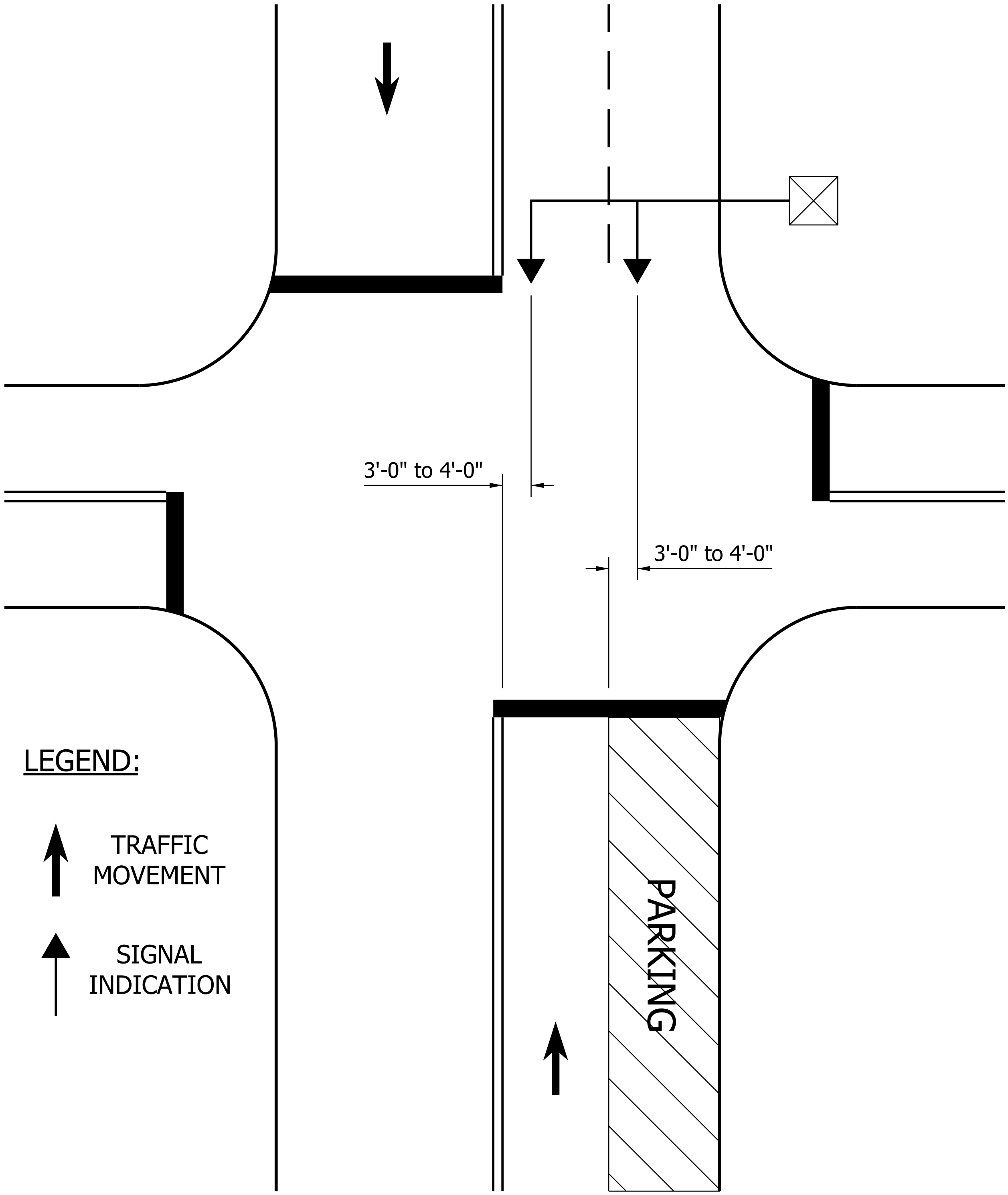
CABLE-SPAN MOUNTED SIGNAL
CONFIGURATION

Figure 77- 4H



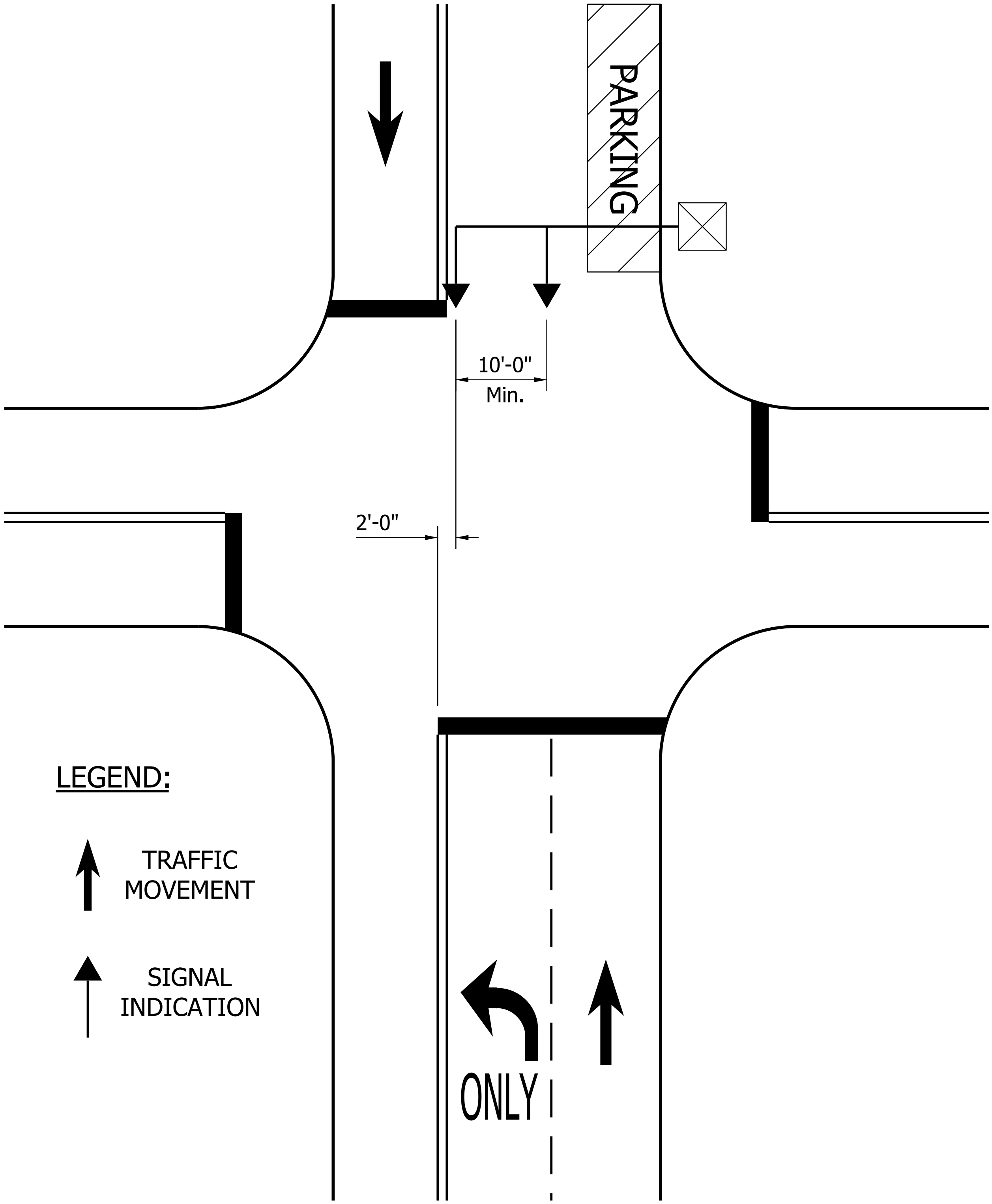
SIGNAL PLACEMENT
OFFSETTING INTERSECTION

Figure 77-5A



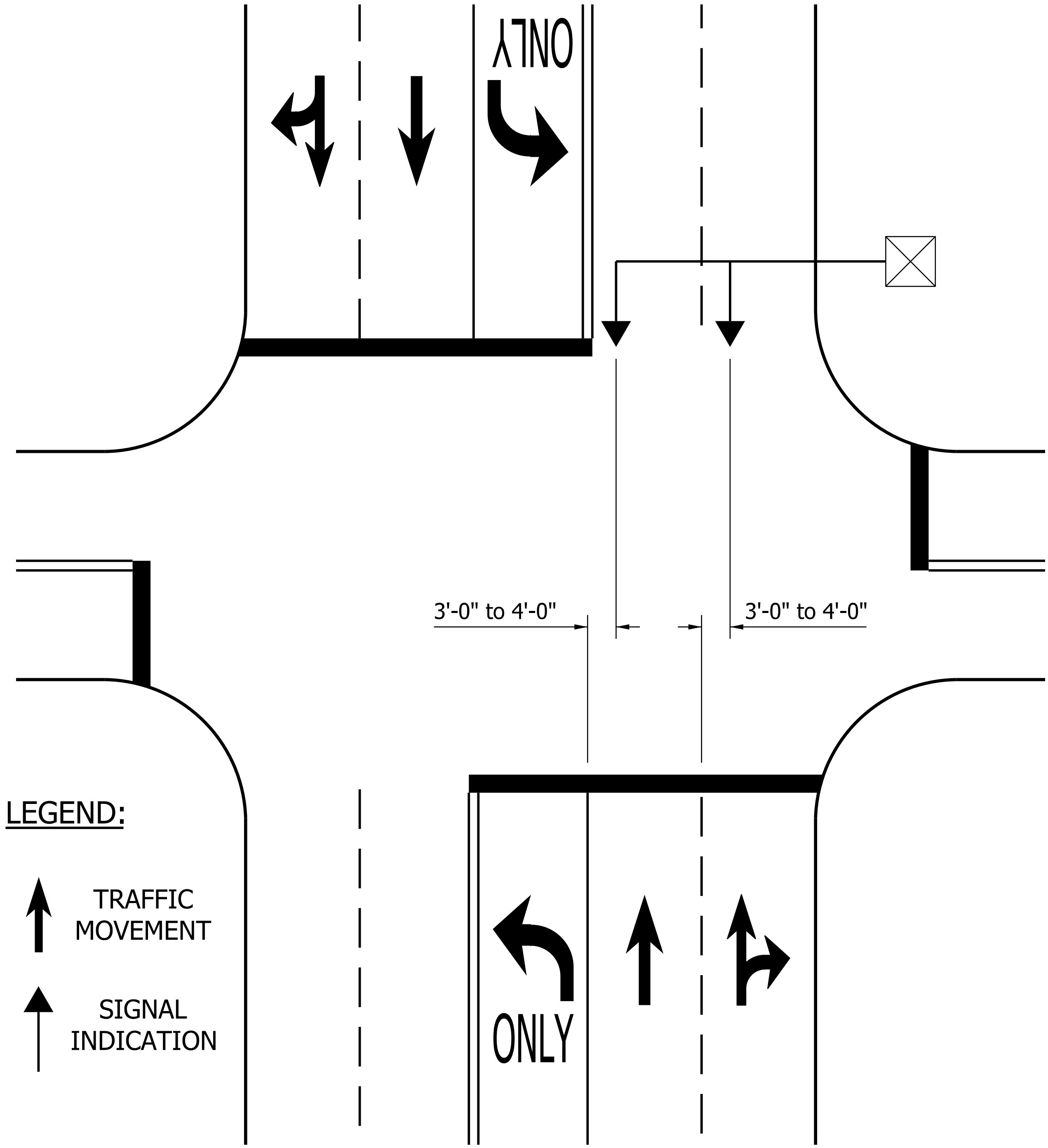
SIGNAL PLACEMENT
URBAN AREA -- NO LEFT-TURN LANE

Figure 77-5B



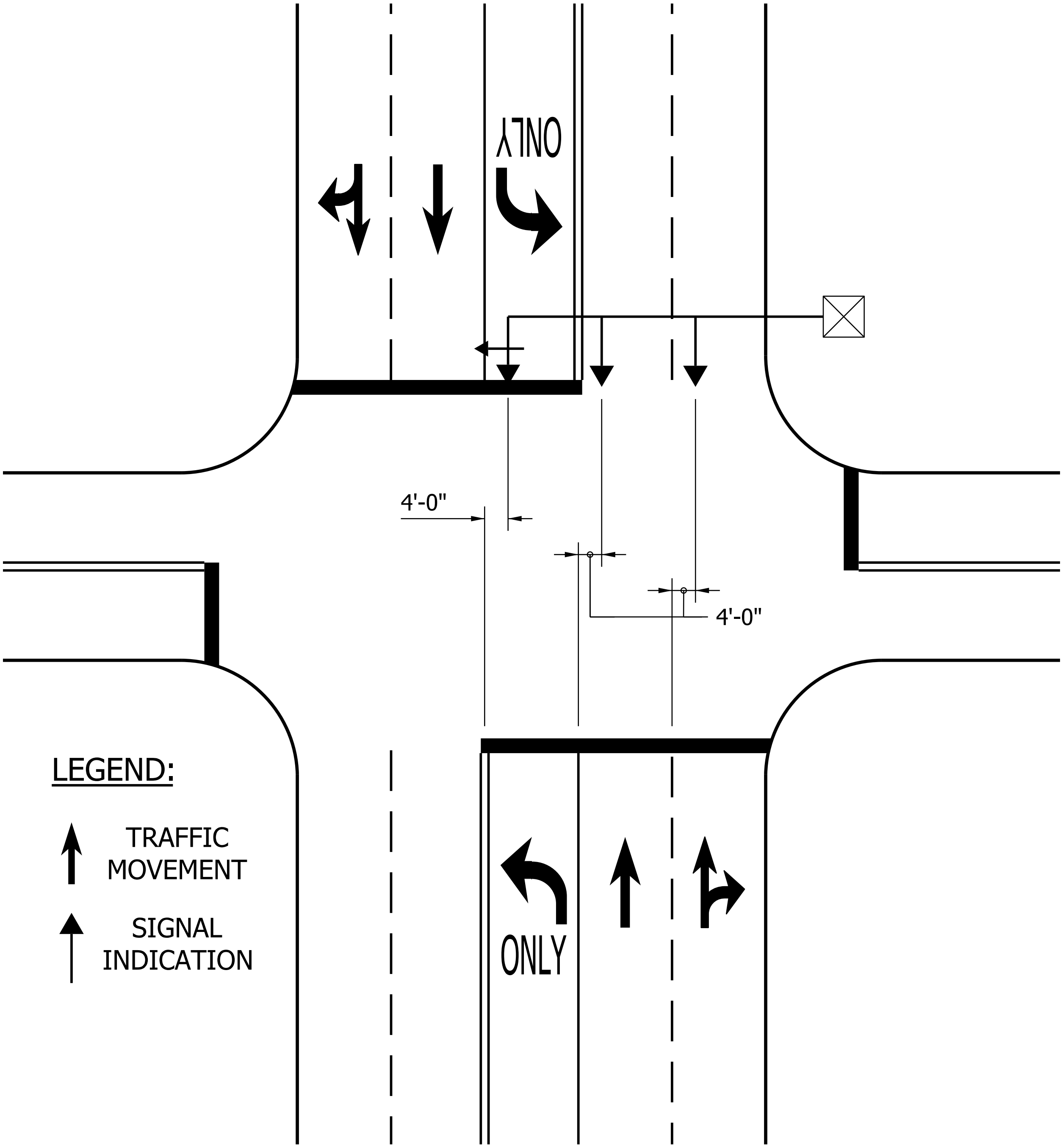
SIGNAL PLACEMENT
URBAN AREA -- LEFT-TURN LANE

Figure 77-5C



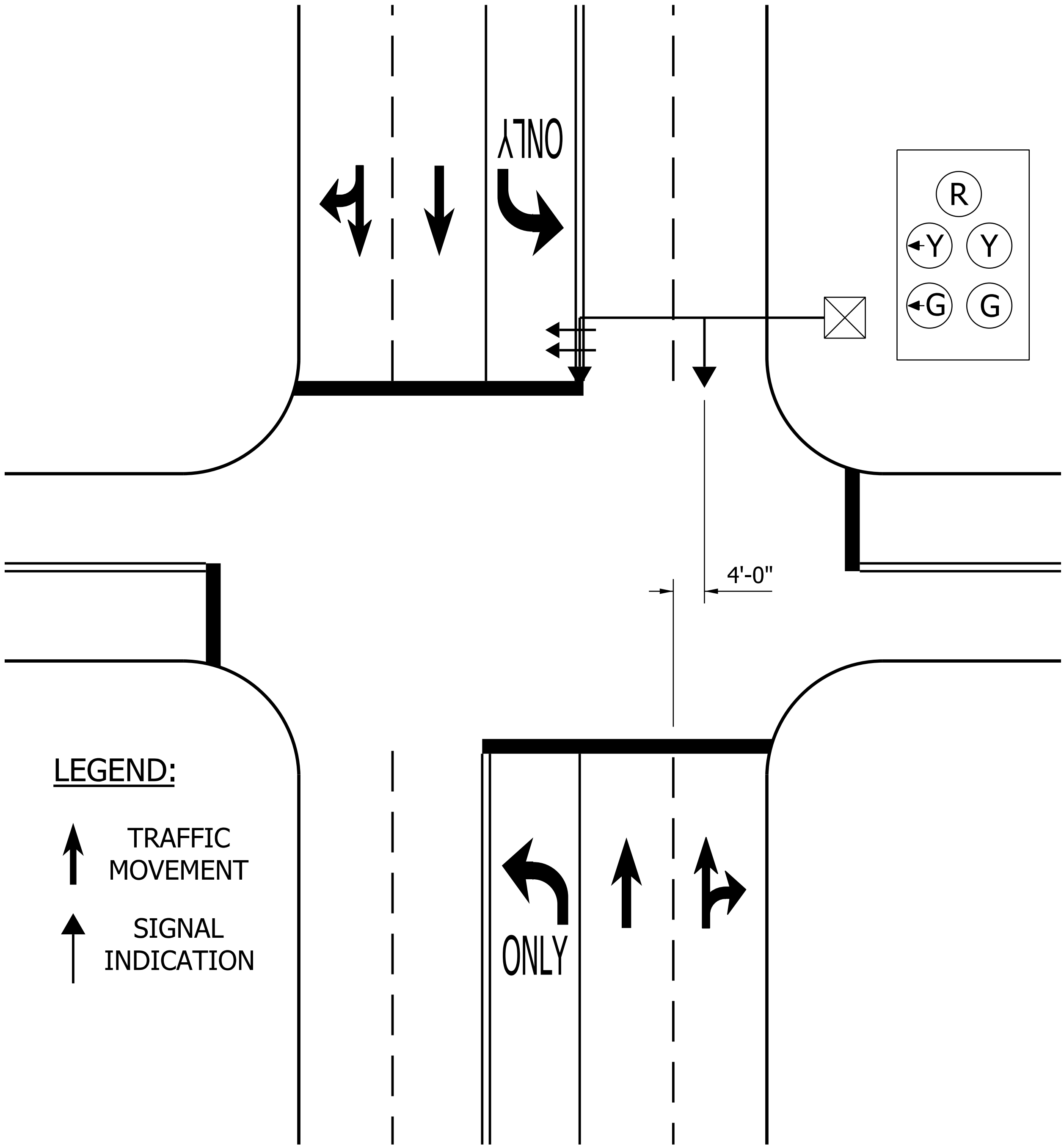
SIGNAL PLACEMENT
UNPROTECTED LEFT-TURN MOVEMENT

Figure 77-5D



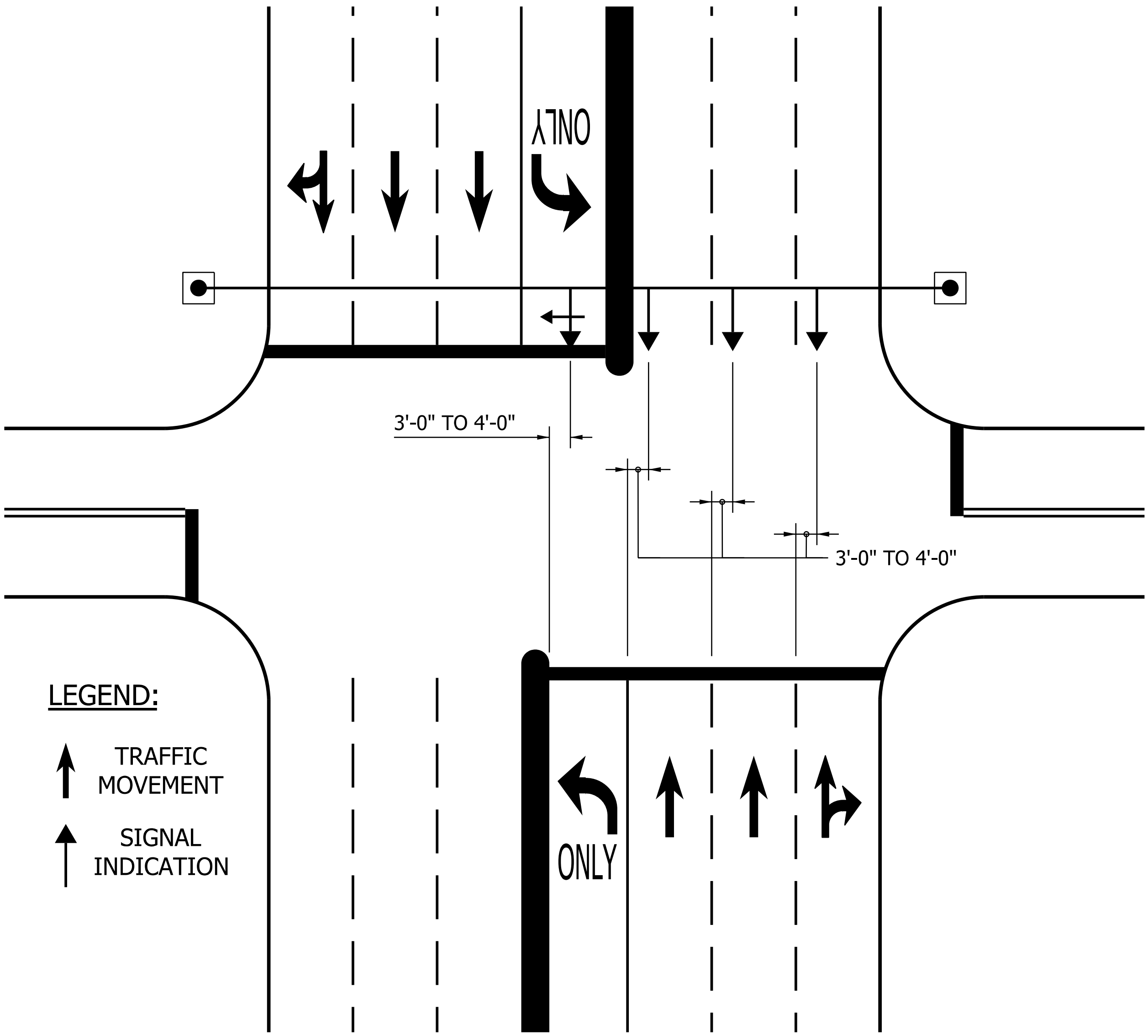
SIGNAL PLACEMENT
PROTECTED LEFT-TURN PHASE

Figure 77-5E



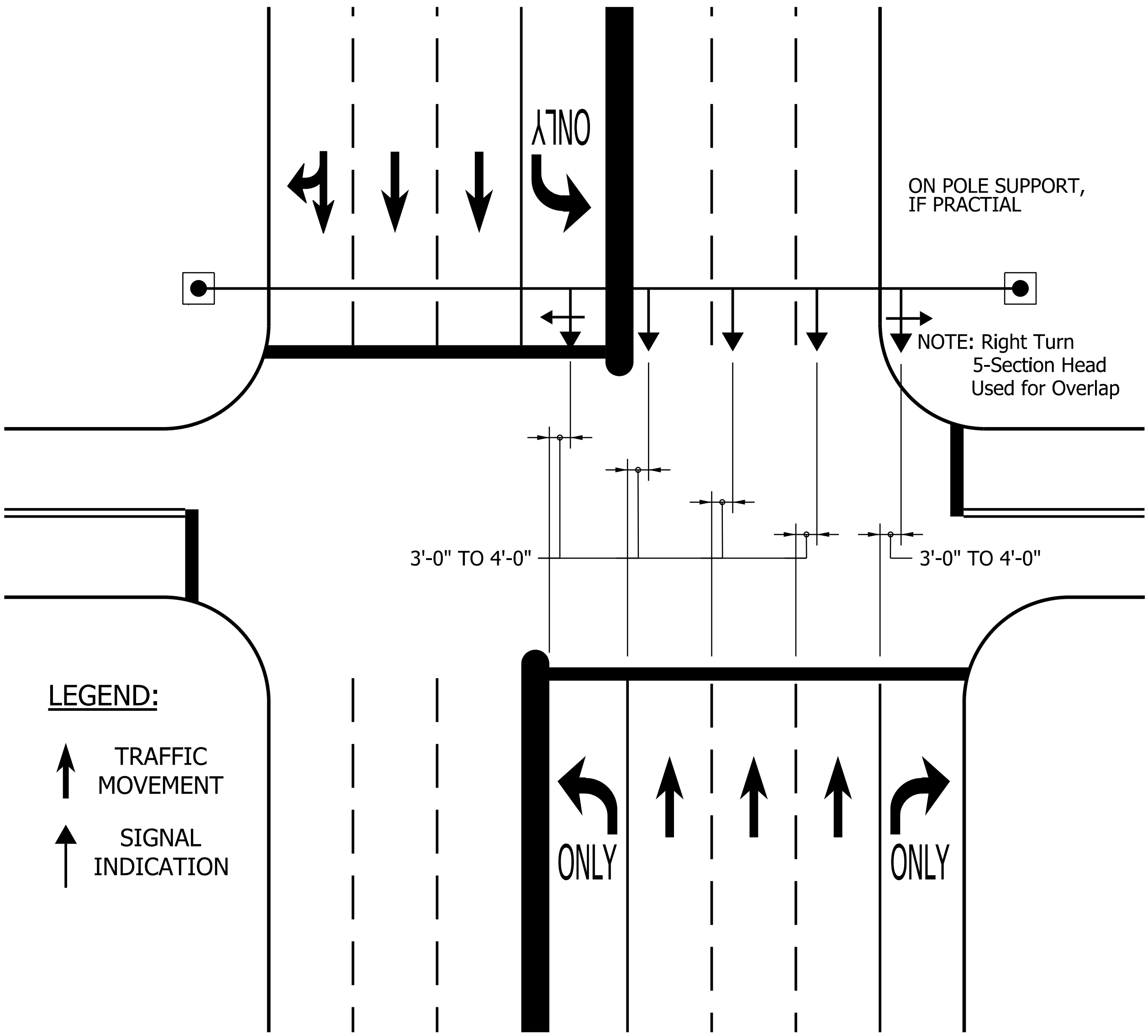
SIGNAL PLACEMENT
PROTECTED LEFT-TURN PRASE OR
PERMISSIBLE LEFT-TURN MOVEMENT

Figure 77-5F



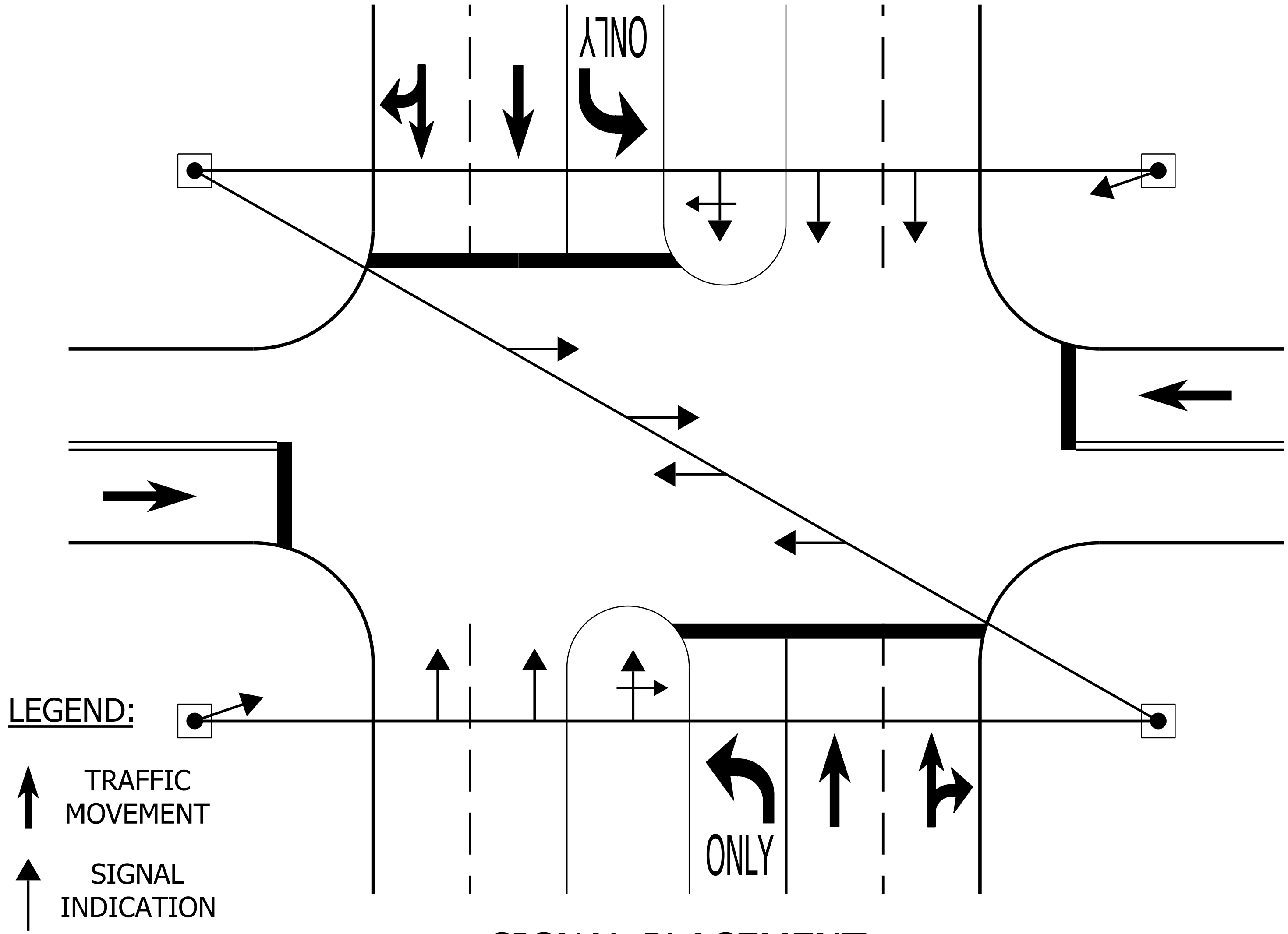
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH WITH LEFT-TURN LANES

Figure 77-5G



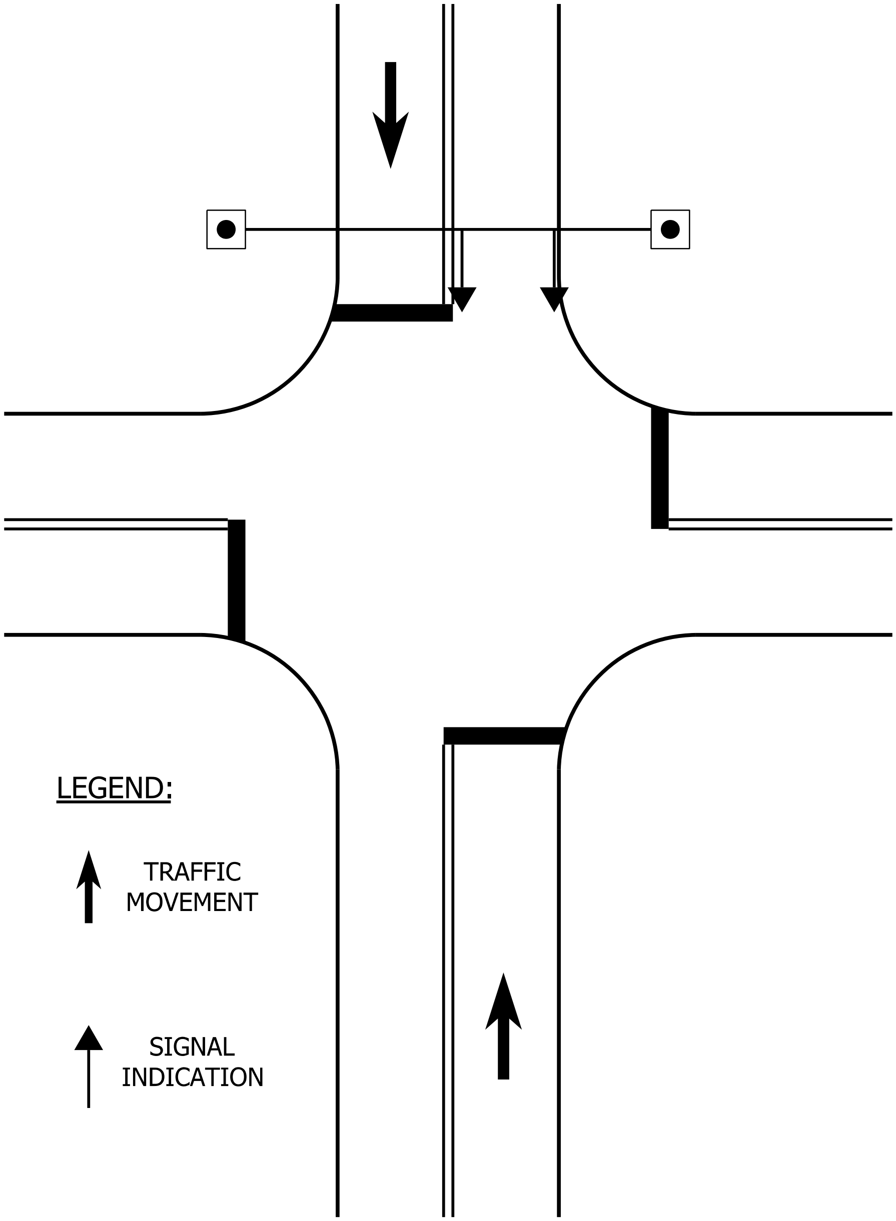
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH WITH LEFT- AND RIGHT-TURN LANES

Figure 77-5H



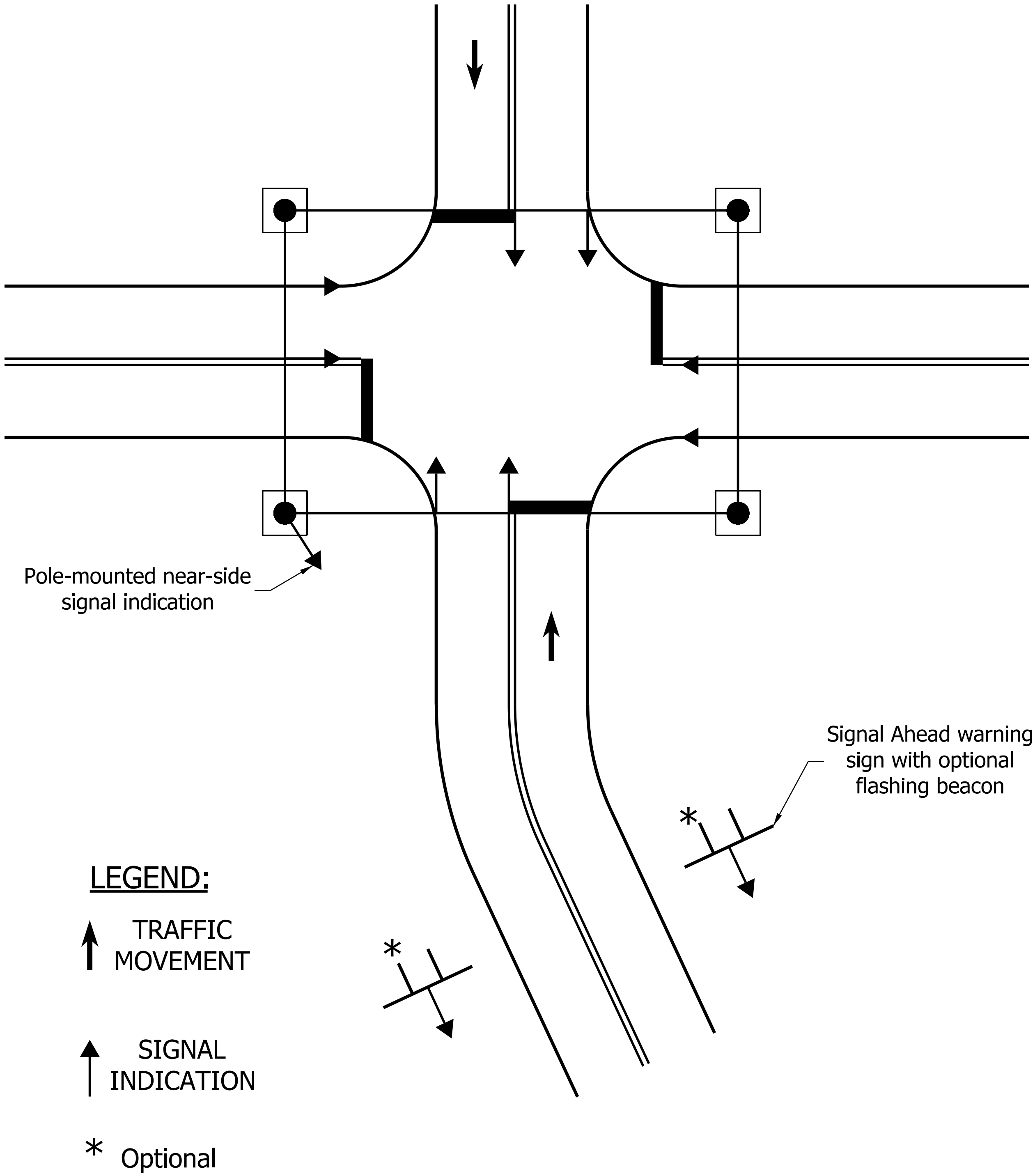
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH, Z-SPAN WITH SUPPLEMENTAL FAR-SIDE HEADS

Figure 77-5I



SIGNAL PLACEMENT
RURAL ONE LANE APPROACH,
WITH TRUCK OBSTRUCTION

Figure 77-5J



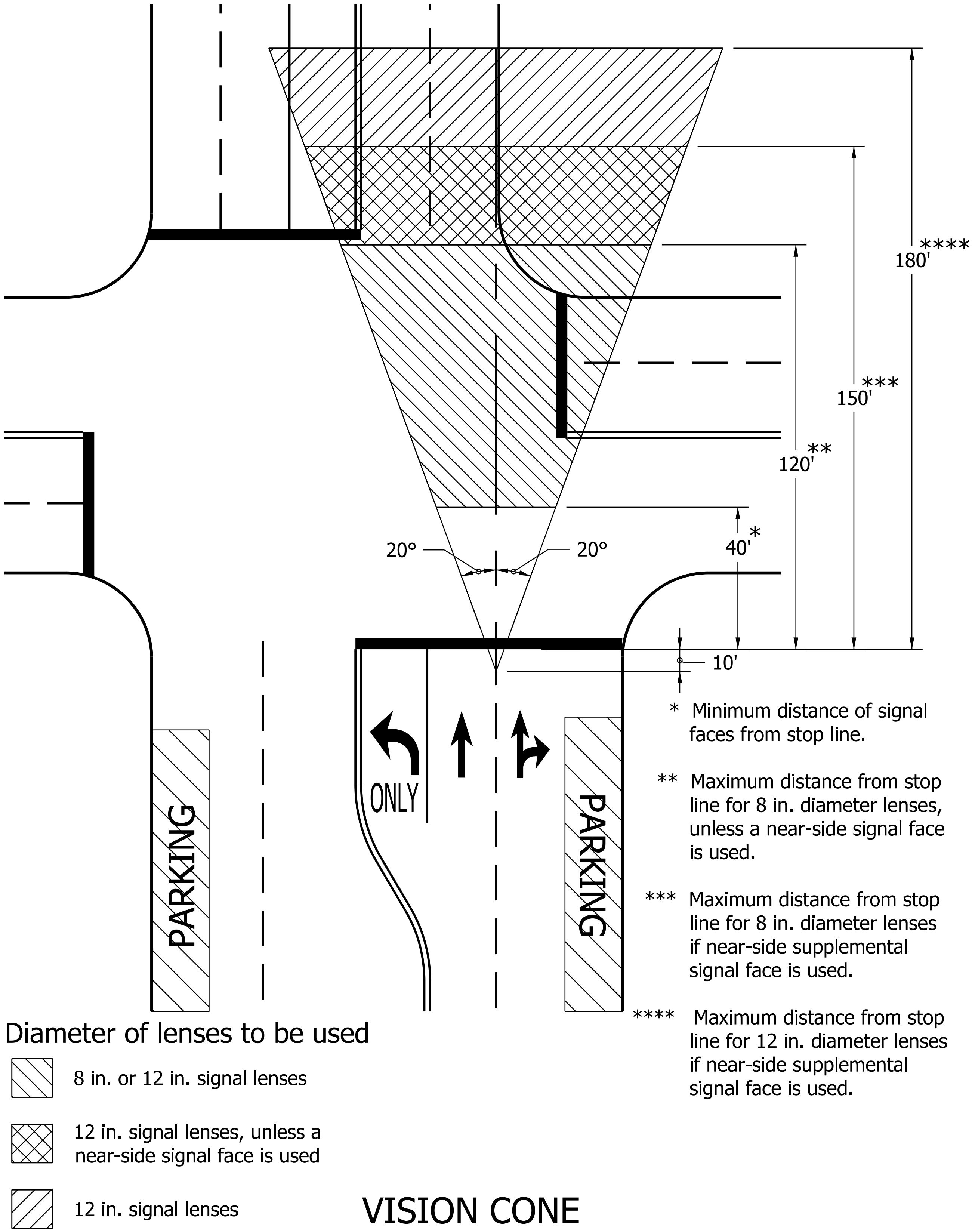
SIGNAL PLACEMENT,
RURAL ONE LANE APPROACH WITH OBSTRUCTED
SIGHT DISTANCE, NEAR-SIDE SIGNAL INDICATION,
ADVANCE WARNING SIGNS AND FLASHERS

Figure 77-5K

85^{th} Percentile Speed, mph	Minimum Visibility Distance, ft
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

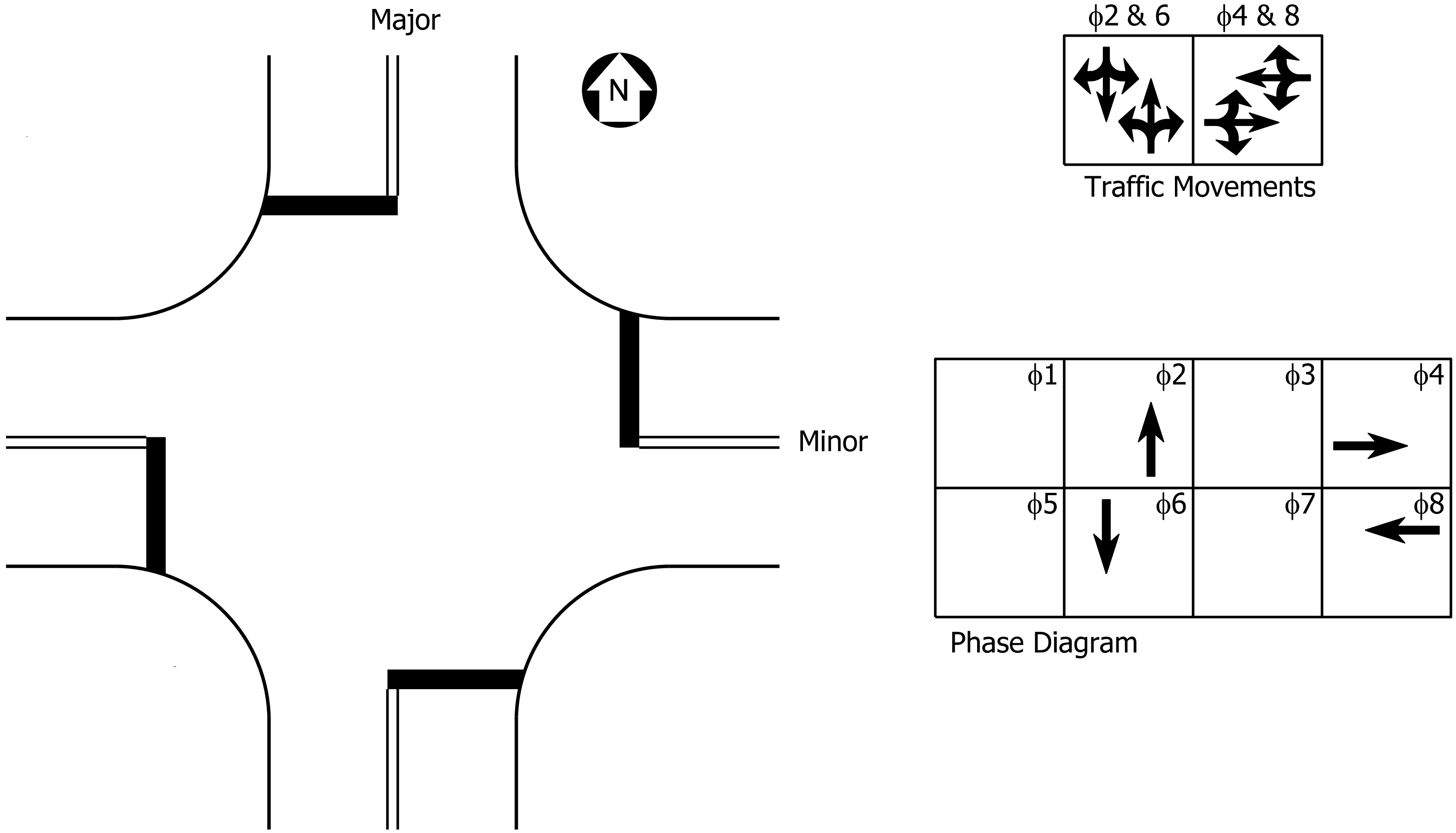
MINIMUM-VISIBILITY DISTANCE

Figure 77-5L



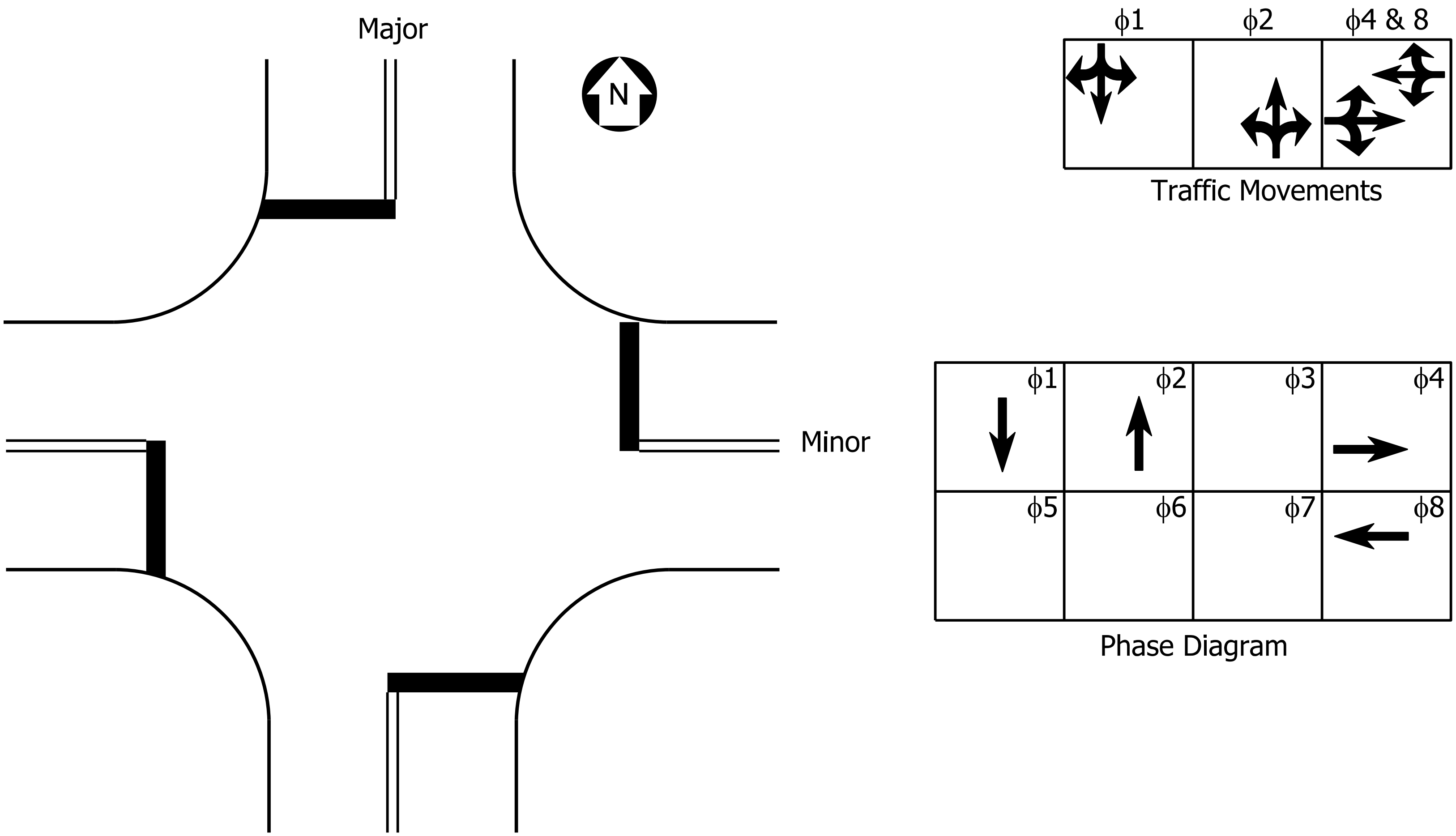
VISION CONE

Figure 77-5M



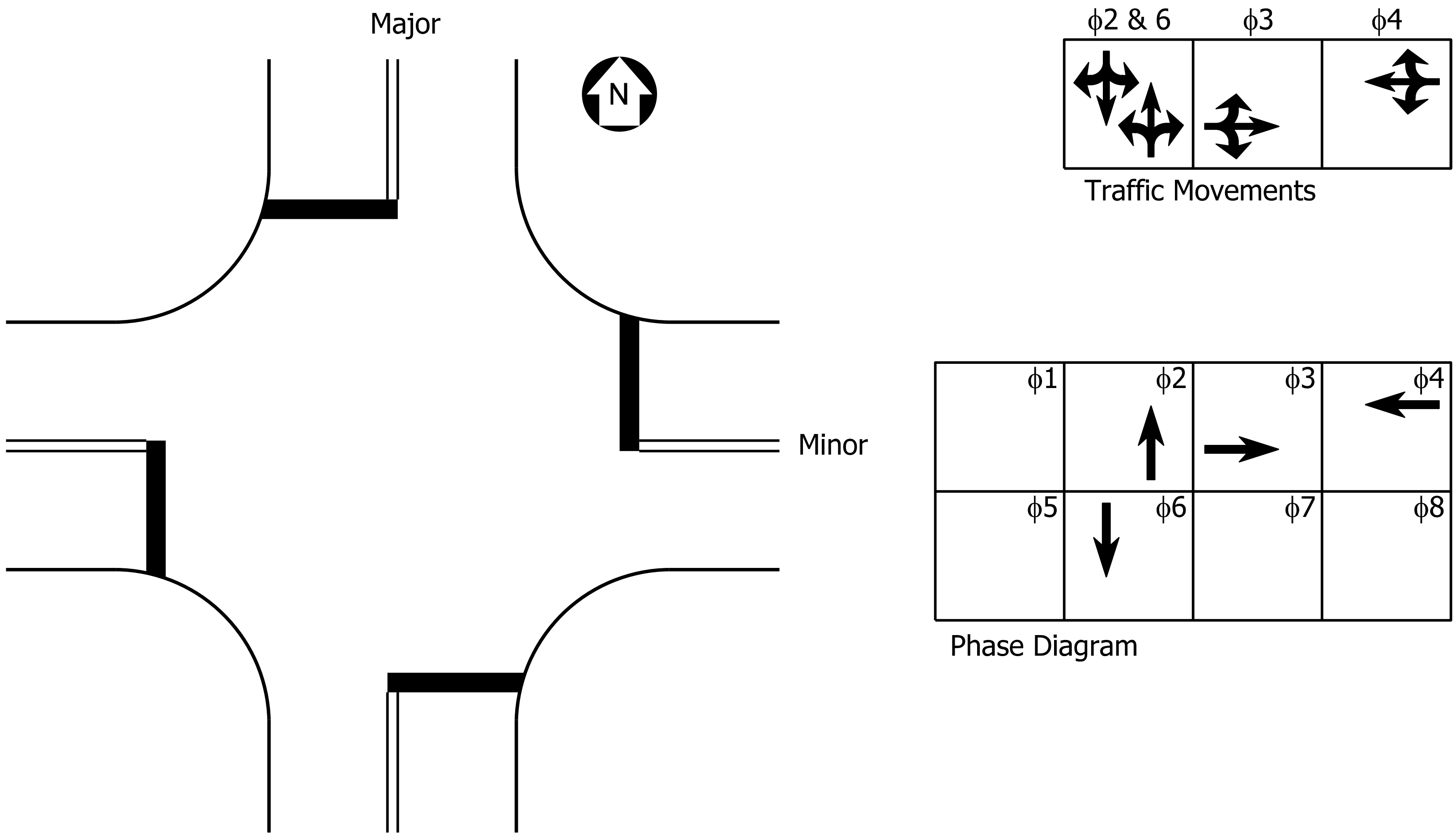
TWO-PHASE OPERATION

Figure 77-5N



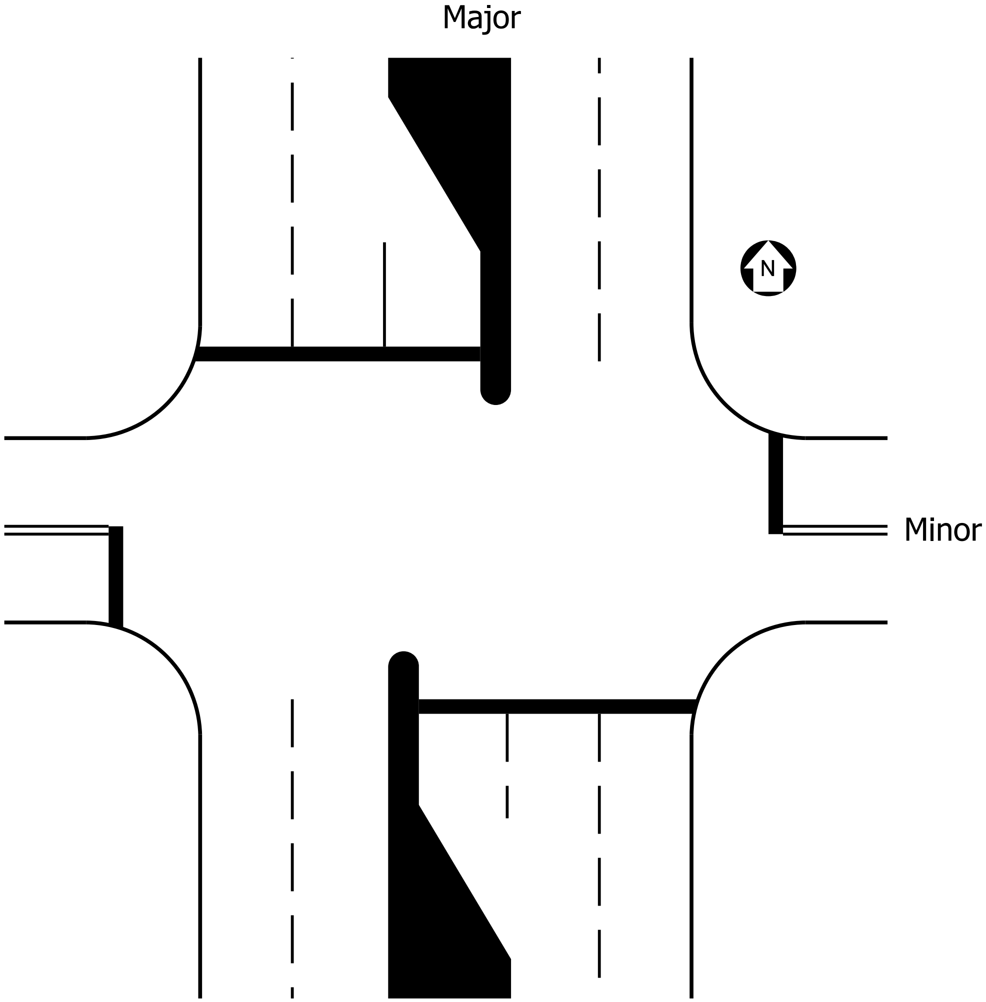
THREE-PHASE OPERATION
SEPARATE SPLIT PHASES
FOR MAJOR STREET

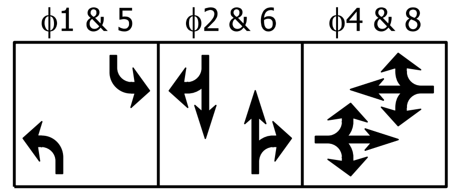
Figure 77-5 O



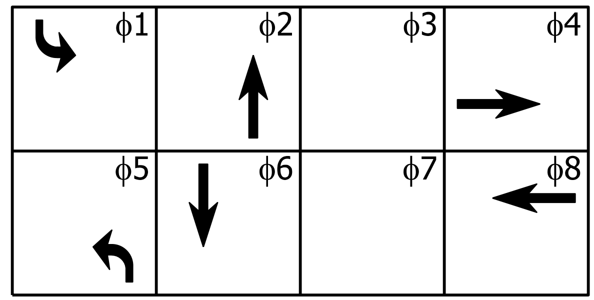
THREE-PHASE OPERATION
SEPARTE SPLIT PHASES FOR MINOR STREET

Figure 77-5P





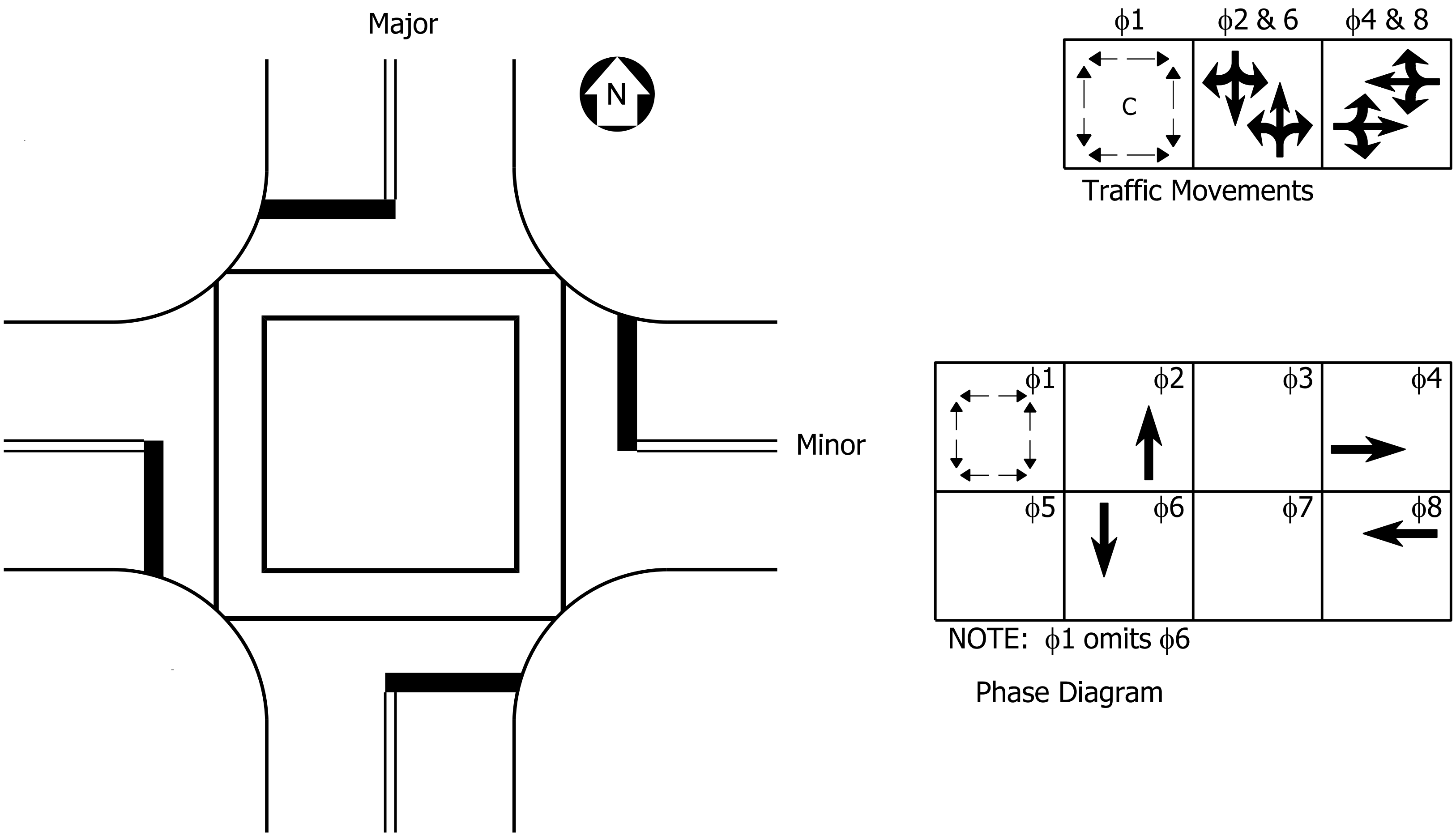
Traffic Movements



Phase Diagram

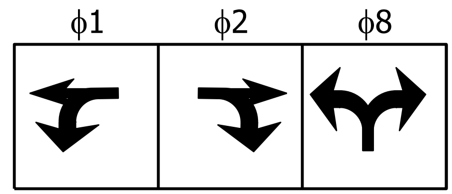
THREE-PHASE OPERATION
SEPRATE LEFT-TURN PHASE FOR MAJOR STREET

Figure 77-5Q

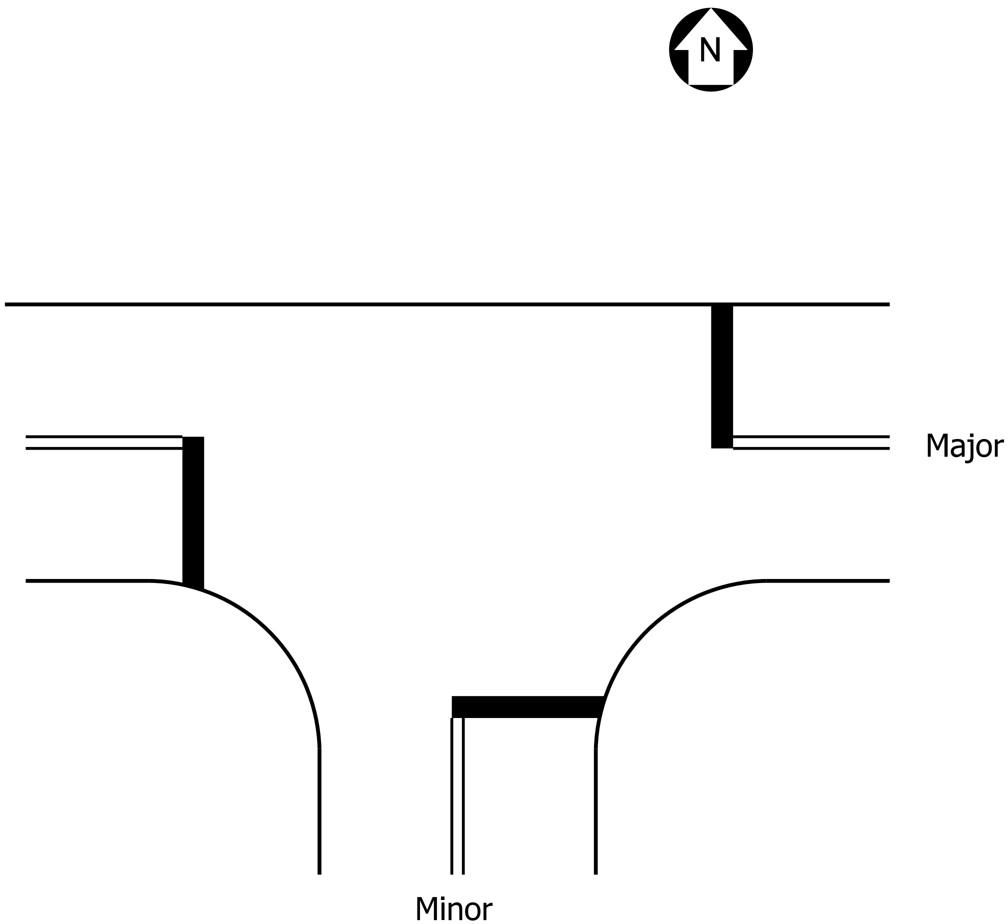


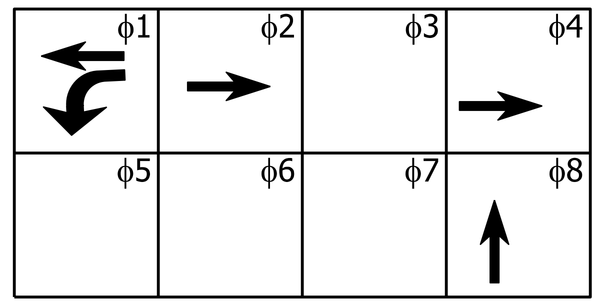
THREE-PHASE OPERATION
EXCLUSIVE PEDESTRIAN PHASE

Figure 77-5R



Traffic Movements

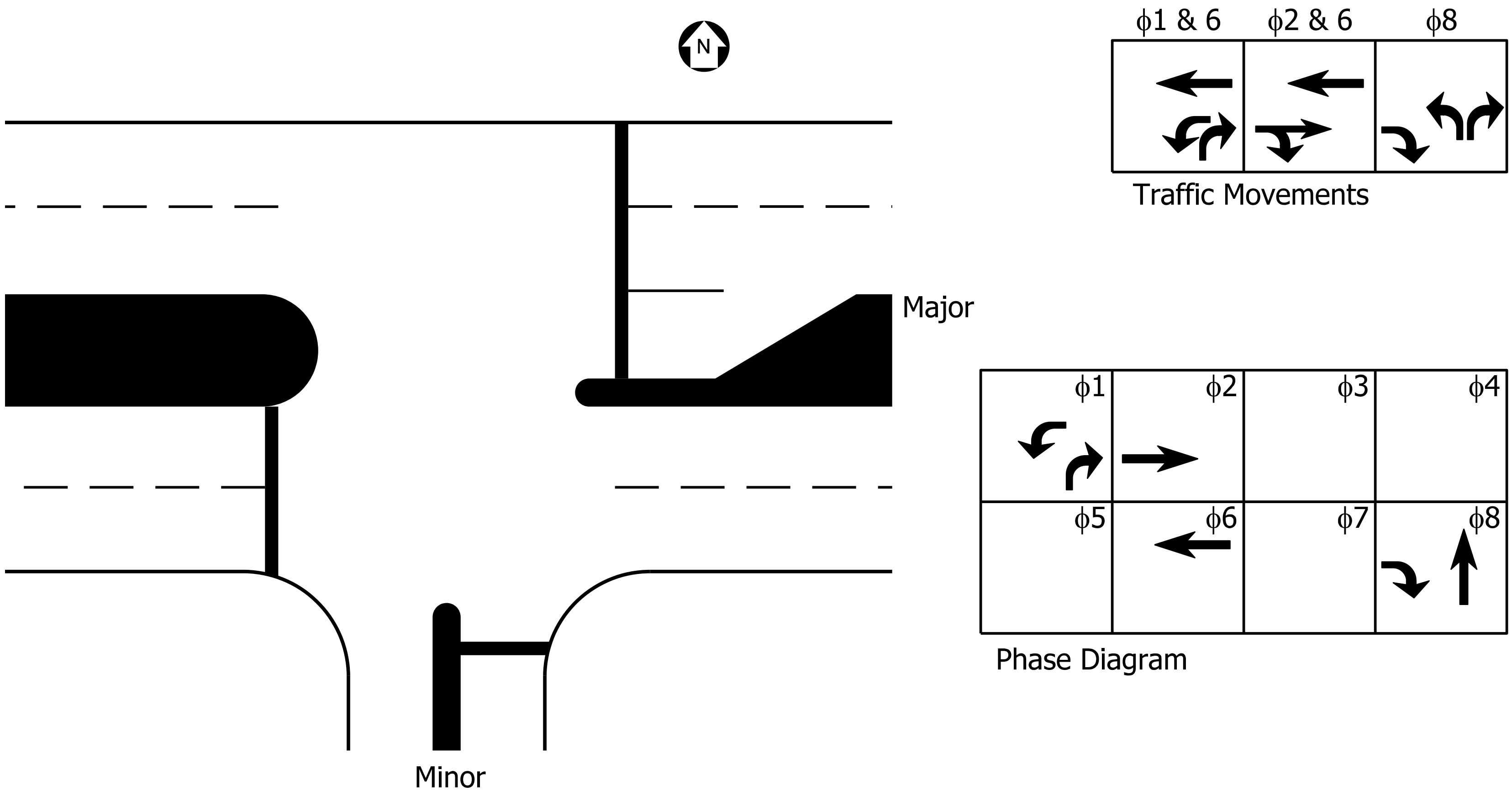




Phase Diagram

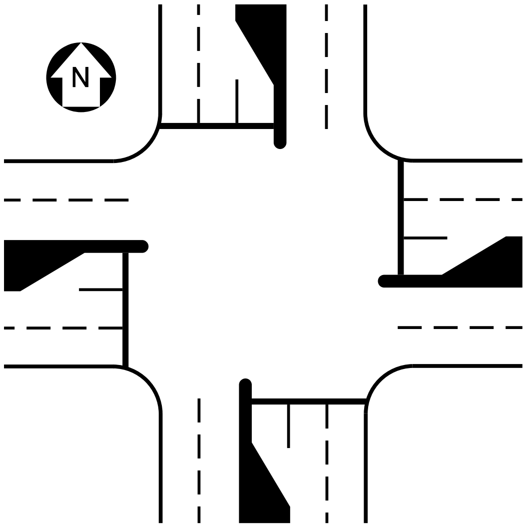
T-INTERSECTION
SINGLE LANE APPROACHES

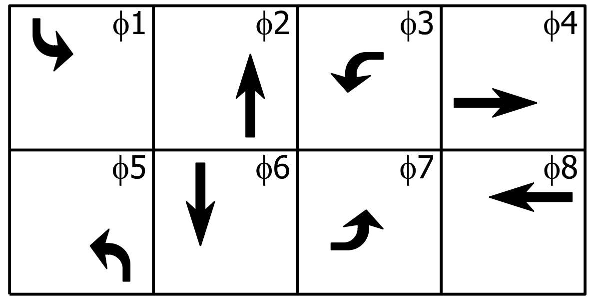
Figure 77-5S



T-INTERSECTION
MULTIPLE-LANES APPROACHES

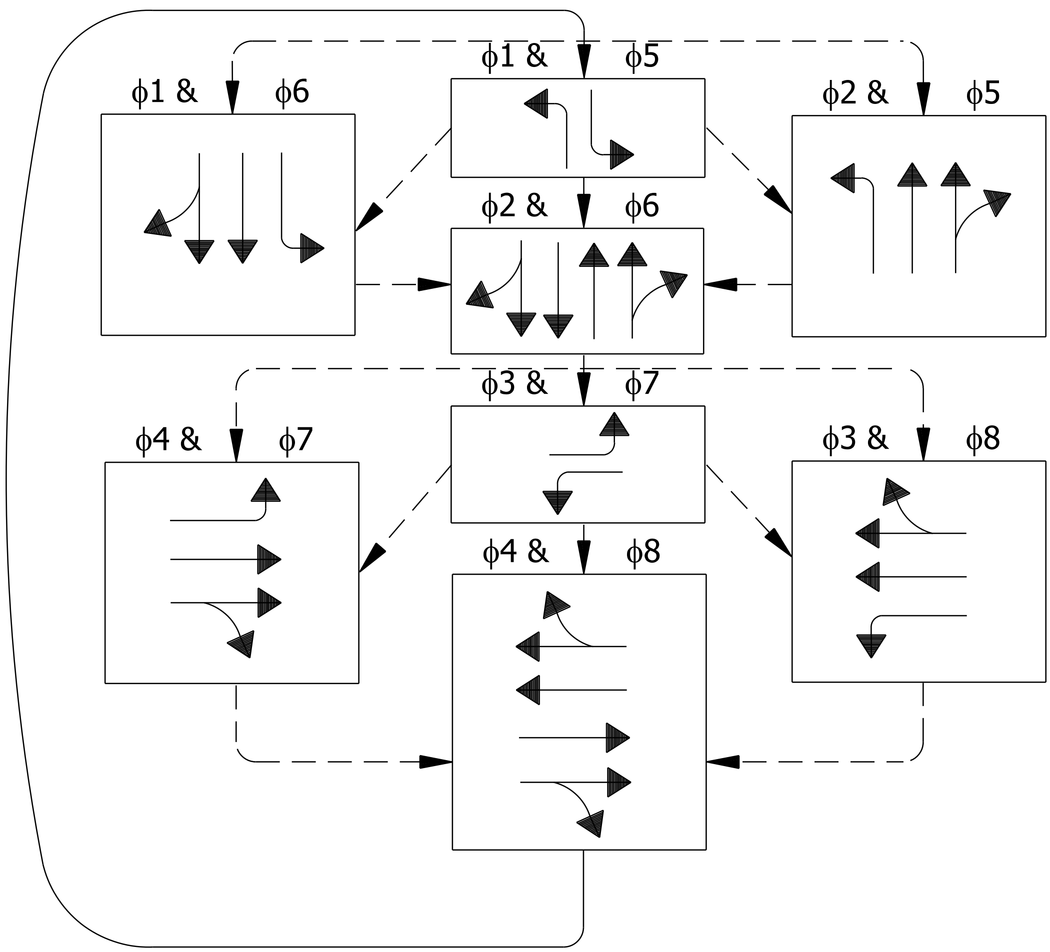
Figure 77-5T





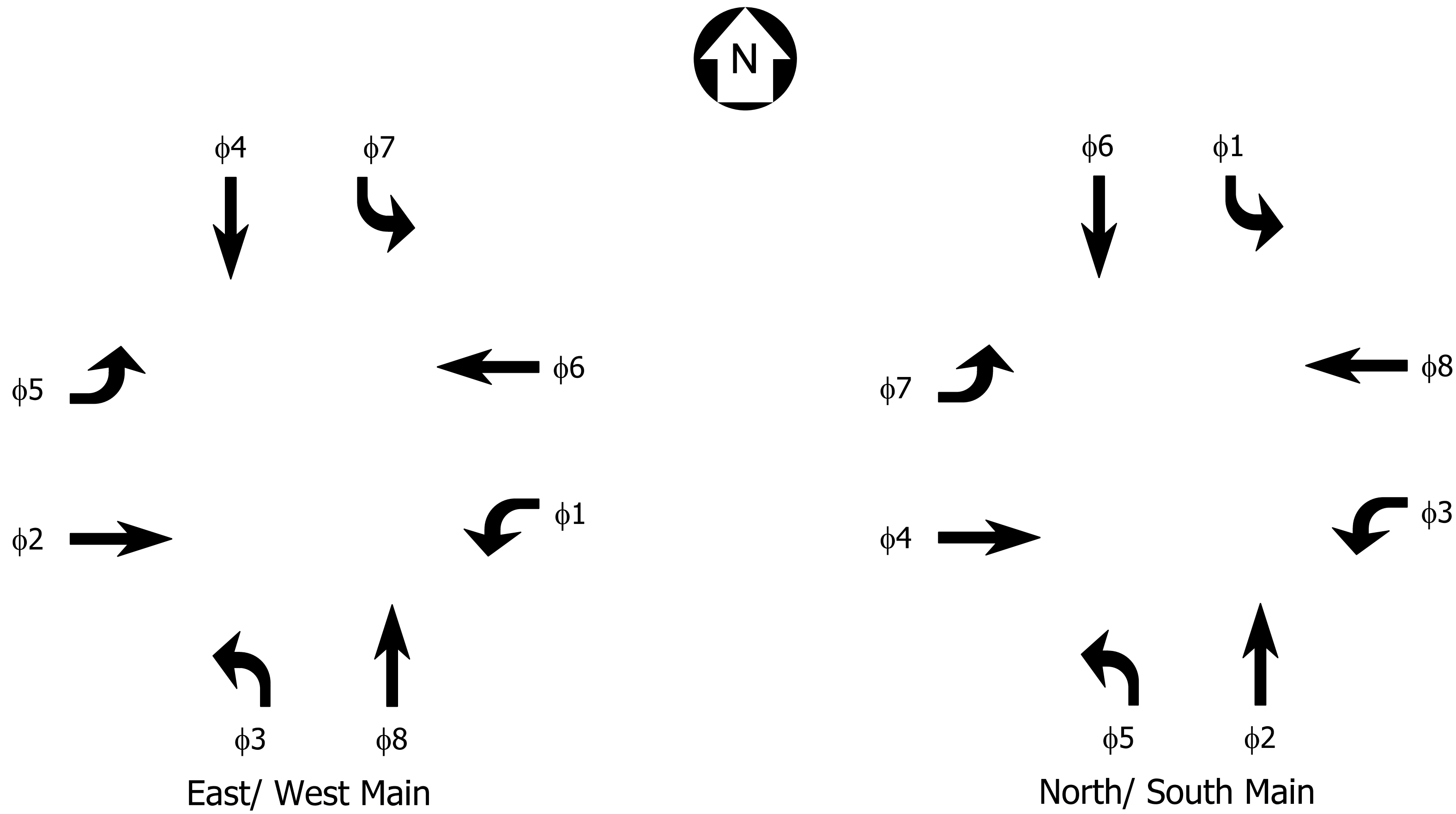
Phase Diagram

TRAFFIC MOVEMENTS



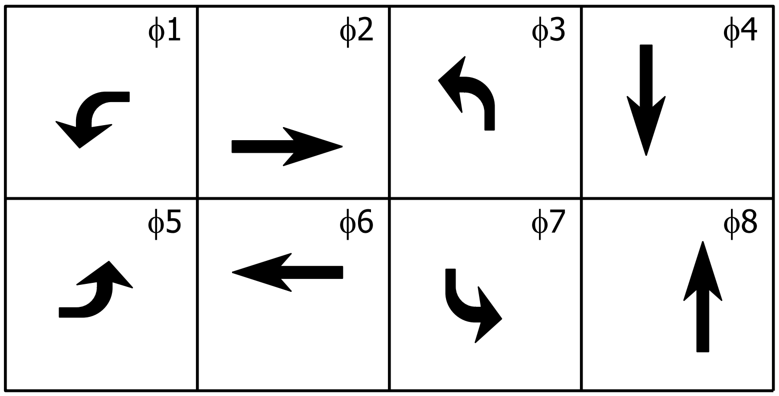
EIGHT-PHASE OPERATION, DUAL RING

Figure 77-5U

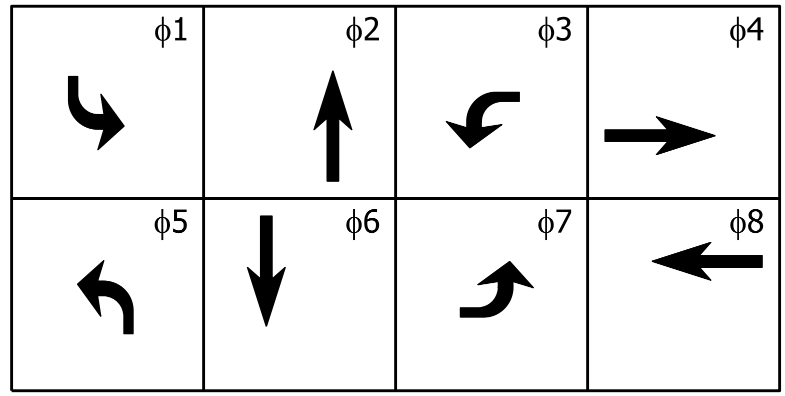


TYPICAL PHASE-NUMBERING SCHEMES

Figure 77-5V



East/ West Main



North/ South Main

TYPICAL PHASE DIAGRAMS

Figure 77-5W

LEADING-LEFT-TURN PHASE	
ADVANTAGES	DISADVANTAGES
• Increases intersection capacity of a 1- or 2-lane approach without a left-turn lane if compared with 2-phase traffic-signal operation. • Minimizes conflicts between left-turn and opposing straight-through vehicles by clearing the left-turn vehicles through the intersection first. • A driver tends to react quicker than with lagging-left operation.	• A left-turning vehicle completing its movement may delay the beginning of the opposing through movement once the green is exhibited to the stopped opposing movement. • Opposing movement may make a false start in response to the movement of a vehicle given the leading green. • Where there is no left-turn lane, an obstruction to the left-turn movement is created if a through vehicle is present.
LAGGING-LEFT-TURN PHASE	
ADVANTAGES	DISADVANTAGES
• Both directions of straight-through traffic start at the same time. • Approximates the normal driving behavior of a vehicle operator. • Provides for vehicle/pedestrian separation as pedestrians usually cross at the beginning of straight-through traffic. • Where pedestrian signals are used, pedestrians have cleared the intersection by the beginning of the lag-green interval. • Cuts off only the platoon stragglers from adjacent interconnected intersections.	• A left-turning vehicle can be trapped during the left-turn yellow change interval as opposing through traffic is not stopping as expected. • Creates conflicts for opposing left turns at start of lag interval because an opposing left-turning driver expects both movements to stop at the same time. • Where there is no left-turn lane, an obstruction to the through movement during the initial green interval is created.

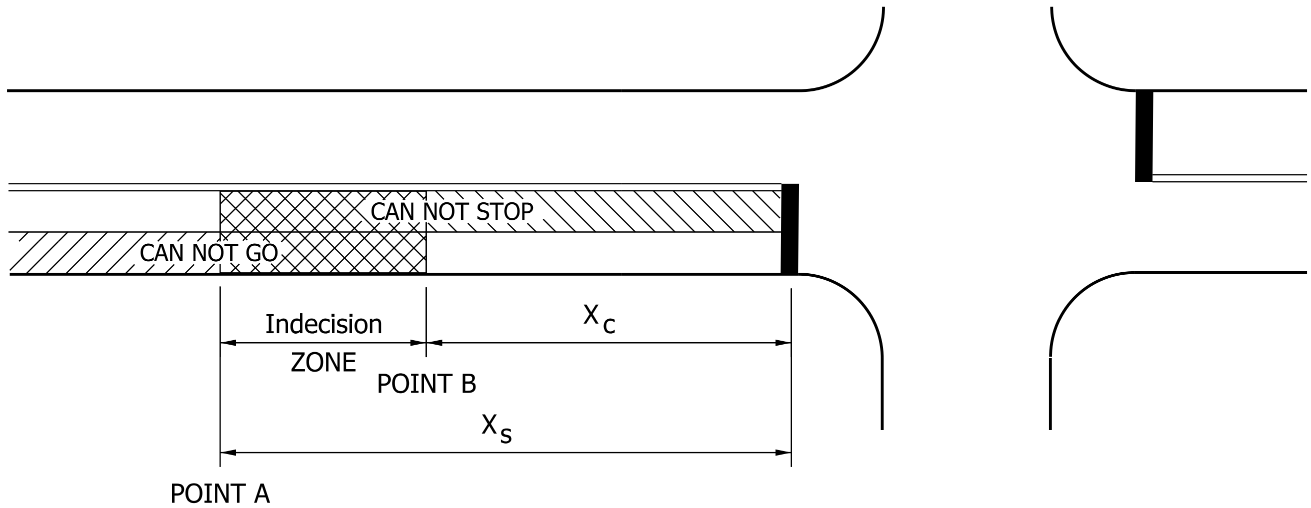
Notes:

1. *The disadvantages inherent in the lagging-left operation are such that its use is restricted to an interconnected or pre-timed operation, or to an actuated-control operation, such as a T intersection.*

2. *The lagging-left turn phase is acceptable where both opposing through movements are stopped at the same time.*

COMPARISON OF LEFT-TURN-PHASE ALTERNATIVES

Figure 77-5X



Note:

1. X_C = Maximum distance upstream of stop line from which a vehicle can clear the intersection during the yellow interval.

2. X_S = Minimum distance upstream of stop line where the vehicle can stop completely after the beginning of the yellow interval.

3. At Point A, 90% of the drivers will decide to stop at the onset of the yellow indication, while 10% of the drivers will continue through the intersection.

4. At Point B, 10% of the drivers will decide to stop at the onset of the yellow indication, while 90% of the drivers will continue through the intersection.

5. For further information on indecision zone, see FHWA Traffic Detector Handbook.

INDECISION ZONE

Figure 77-5Y

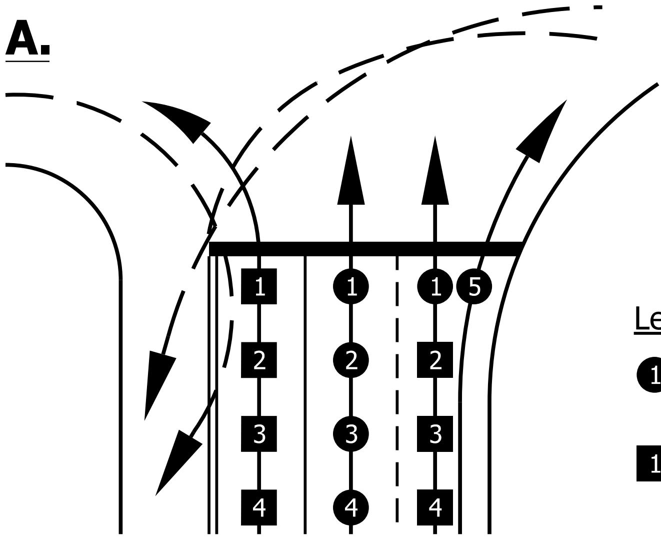
Approach Posted Speed (mph)	Passage Time from Detector to Stop Line (s)						
	1	2	3	4	5 [1]	6	7
20	29	53	87	116	145	174	193
25	36	78	108	144	180	216	252
30	44	88	132 [2]	176	220	264	308
35	51	102	153	204	255	306	357
40	59	113	177	236	295	354	413
45	66	132	198	264	330	396	462
50	73	146	219	292	365	438	511
55	81	162	243	324	405	486	567
60	88	176	264	352	475	528	616
65	95	190	285	380	550	570	665
Legend:	000	Basic Ctrlr.		000	Variable Initial Only		
	000	Density		000	Indecision Zone		

[1] *INDOT uses 5 s passage time.*

[2] *This value is also in the indecision zone.*

DETECTION SETBACK DISTANCE (ft)

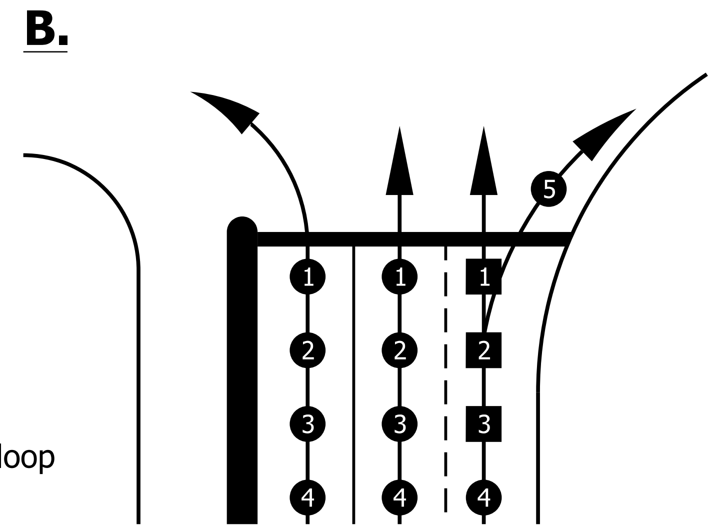
Figure 77-5 Z



Legend

● -Counting Detector loop

■ -Non-Counting Detector loop



Left - Turn Lanes

Dotted lines or staggered stop lines as shown in diagram A can be used to reduce left-turn encroachment onto the left-turn lanes.

A median as shown in diagram B will eliminate such encroachment onto the left-turn lanes.

If counting with 4 loops, the lane width should remain 12 ft (3.6 m) to prevent a vehicle from missing the front loop.

Through Lanes

The through lanes should not have encroachment or early-departure concerns. If a vehicle squarely enters the loop system and crosses the center of each loop, counting with 4 loops is preferred.

Right - Turn Lanes

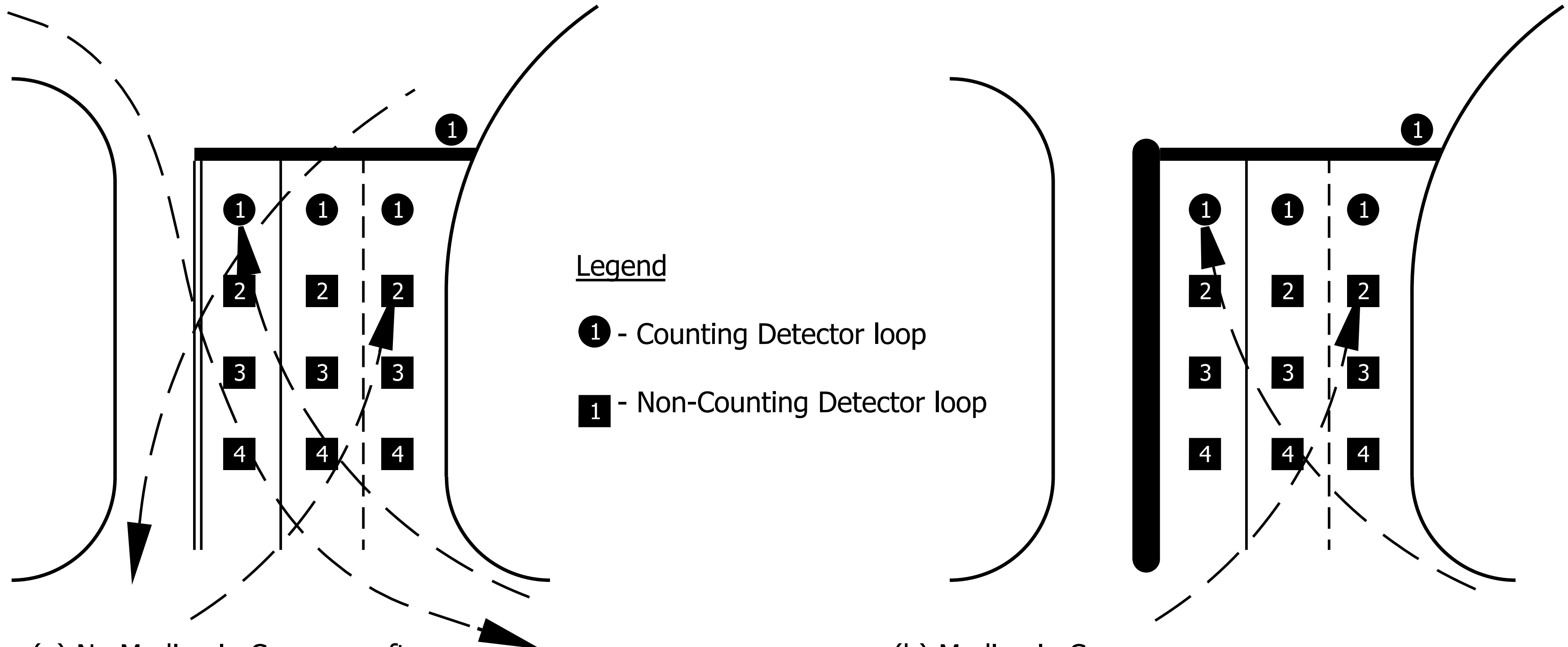
If the lane at the stop line is wider than 12 ft as shown in diagram A, a vehicle will depart before crossing loop 1. Counting with loops 1 and 5 will provide accurate through-lanes and right-turn-lane counts.

If loop 5 is beyond the stop line as shown in diagram B, a vehicle will depart before crossing loop 1. Counting with loops 4 and 5 will provide accurate through-plus-right-turn-lanes and right-turn-lane counts.

Note: The minimum distance between loops 1 & 5 should be 6 ft.

COUNTING - LOOP SELECTION
GENERAL

Fig. 77-5AA



(a) No Median in Crossovereft

- A vehicle entering the detection zone will often cross loops in one lane to get to the desired lane. A vehicle turning off the main road will often cross these loops, causing them to overcount. This makes counting difficult.

  Access should be provided for the design vehicle.

(b) Median in Crossover

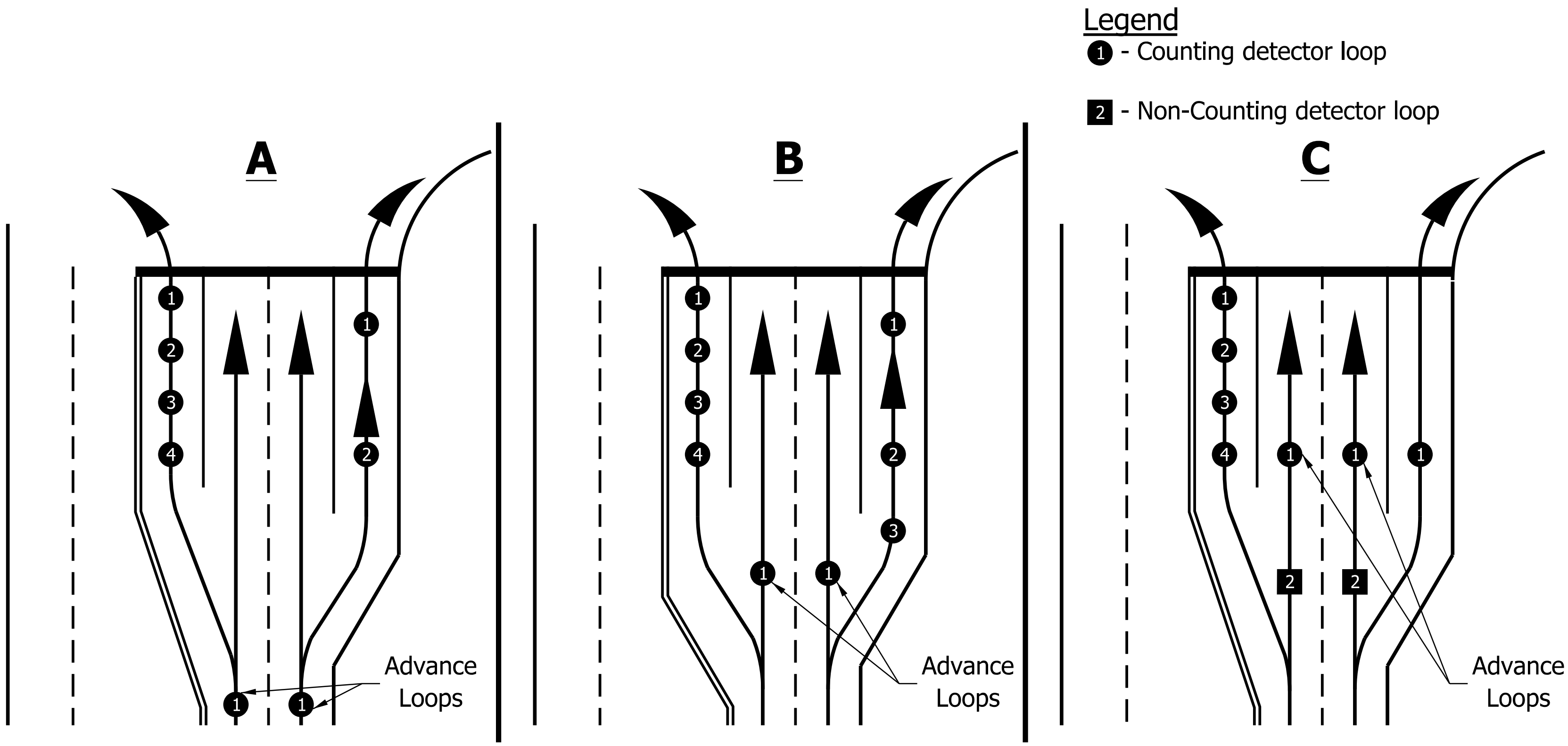
- A raised median will channel a vehicle turning off the main road, and will keep it out of the lanes being counted.

  A median will eliminate turn encroachment.

  Once a vehicle is channeled away from the counting loops into its intended lane, loop 1 can be used to provide accurate counts.

COUNTING - LOOP SELECTION FRONTAGE ROAD OR PARKING LOT

Fig. 77-5BB



* Advance counting-loop selection is based on the length of the storage lanes and placement of such loops based on the posted speed limit. Counting can be done if the advance loops are located ahead of the channelization lanes as shown in diagram A. Counting can still be done if the advance loops are located after the beginning of the channelization lanes as shown in diagram B.

* The posted speed limit can be such that the placement of the advance loops is where a vehicle will be maneuvering to the left- or right-turn lane as shown in diagram C. The advance loops should be placed in the same longitudinal location as left-turn-lane loop 4 or the right-turn-lane loop.

* The right-turn-lane loop can be placed in the same longitudinal location as the advance loops where the lane width is still 12 ft (3.6 m), as shown in diagram C.

* The same handhole should be used to minimize costs.

COUNTING - LOOP SELECTION
ADVANCE COUNTING LOOPS

Figure 77-5CC

Table of Contents

List of Figures

CHAPTER SEVENTY-EIGHT

HIGHWAY LIGHTING

78-1.0 GENERAL

The purpose of highway lighting is to provide a safe and comfortable environment for the night-time driver. Due to the voluminous nature of highway-lighting-system design, it is impractical for this Chapter to provide a complete highway-lighting-design guide. For additional design information, the designer is encouraged to review the latest edition of the references listed in Section 78-1.01. The intent of this Chapter is to provide the user with a synopsis of the highway-lighting-design process and to provide INDOT's criteria, policies, and procedures regarding these issues.

78-1.01 References

For additional information on highway lighting, the designer should review the publications as follows;

1. *An Informational Guide for Roadway Lighting*, AASHTO;

2. *Roadway Lighting Handbook*, FHWA;

3. *Roadway Lighting Handbook*, Addendum "Designing the Lighting System - Using Pavement Luminance," FHWA;

4. *Roadway Lighting*, RP-8, Illuminating Engineering Society (not used on an INDOT project);

5. NCHRP Report No. 152, *Warrants for Highway Lighting*, TRB (not used on an INDOT project);

6. NCHRP Report No. 256, *Partial Lighting of Interchanges*, TRB (not used on an INDOT project);

7. Chapter Forty-nine, "Roadside Safety," *Indiana Design Manual*, INDOT;

8. *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, AASHTO;

9. INDOT *Standard Drawings*, INDOT;

10. INDOT *Standard Specifications*, INDOT;

11. National Electrical Code; and

12. National Electric Safety Code.

78-1.02 Definitions of Terms

The following defines the more commonly used terms in highway lighting.

1. Average Maintained Illuminance. The average level of horizontal illuminance on the roadway pavement once the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average footcandles for the pavement area.

2. Candela (cd). The unit of luminous intensity.

3. Candela per Square Foot (cd/ft^2). The unit of photometric brightness (luminance). The unit is equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one1 lm/ft^2 or the average luminance of a surface emitting or reflecting light at that rate.

4. Effective Mounting Height. The vertical distance between the foundation of the light standard and the center of the light source in the luminaire.

5. Glare. The optical sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted and which causes annoyance, discomfort, or loss in visual performance and visibility.

6. Illuminance. The density of the luminous flux incident on a surface. It is the quotient of the luminous flux divided by the area of the surface where the latter is uniformly illuminated.

7. Lamp Lumens Depreciation Factor (LLD). A depreciation factor that indicates the decrease in a lamp's initial lumen output over time. For design calculations, the initial lamp lumen value is reduced by an LLD to compensate for the anticipated lumen reduction.

8. Longitudinal Roadway Line. A line along the roadway parallel to the curb or shoulder line.

9. Lumen (lm). A unit of measure of the quantity of light.

10. Luminaire. A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

11. Luminaire Dirt Depreciation Factor (LDD). A depreciation factor that indicates the expected reduction of a lamp's initial lumen output due to the accumulation of dirt on or within the luminaire over time.

12. Luminance. The luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction.

13. Footcandle. The illuminance on a surface of 1 ft^2 in area on which there is uniformly distributed a light flux of one lm, or the illuminance produced on a surface for which all points are at a distance of 1 ft from a uniform point source of one cd.

14. Maintenance Factor (MF). A combination of light-loss factors used to denote the reduction of the illumination for a given area after a period of time compared to the initial illumination on the same area (MF = LLD x LDD).

15. Mounting Height. The vertical distance between the roadway surface and the center of the light source in the luminaire.

16. Nadir. The vertical axis which passes through the center of the luminaire light source.

17. Spacing. The distance in feet between successive lighting units.

18. Transverse Roadway Line. A line across the roadway that is perpendicular to the curb or shoulder line.

19. Uniformity Ratio. The ratio of average maintained lux of illuminance on the pavement to the maintained lux at the point of minimum illuminance on the pavement. A uniformity ratio of 3:1 means that the average lux value on the pavement is three times the lux value at the point of least illuminance on the pavement.

78-1.03 State and Local Responsibilities

The following describes the responsibilities between the Department and a local government agency for a lighting installation along a State-maintained highway.

1. INDOT Jurisdiction. The Department may illuminate a portion of a State, U.S., or Interstate highway outside incorporated city or town limits that satisfies the warranting conditions provided in Section 78-2.0. INDOT will not provide illumination inside city or town incorporated limits, except along an Interstate route.

2. Local Jurisdiction. A local governmental agency may install lighting along a State highway within its jurisdictional limits provided the agency finds sufficient benefit in the form of convenience, safety, policing, community promotion, public relations, etc. The local agency will develop appropriate warranting guidelines for installing lighting. If the city or town has not developed warrants, the Department warrants in Section 78-2.0, or those listed in the references in Section 78-1.01, should be considered. The local agency will be responsible for installing, maintaining, and operating the lighting facilities. The plans for lighting a State highway within local jurisdictional limits must meet Department criteria and must receive INDOT approval through a formal agreement prior to installation. The plans should be submitted for review to the Highway Operations Division's Office of Traffic Engineering.

3. Installation. Installation by the Department will be done under the Department's normal programming and contracting procedures. The installation, however, may be performed through an agreement with a utility company.

4. Operation. For each location where the Department is responsible for paying the energy costs, an agreement must be negotiated between the local utility company and the Department for payment of the electrical current. The current may or may not be metered. All bills should be submitted through the district Office of Traffic for payment.

5. Maintenance. Maintenance of a Department lighting system may be furnished by agreement with a local utility company, by an independent lighting contractor, or by trained INDOT personnel.

6. Agreement. An agreement for a Department lighting system should be prepared according to INDOT agreement policy. According to Indiana Code (IC, 8-23-22-2, and amendments thereto), the Department is required to enter into an agreement for sharing the utility costs.

7. Existing System. Where an agreement between INDOT and a local agency on maintenance and operation of an existing lighting system along a State-maintained highway cannot be resolved, the following will apply.

a. If a system installed by the Department is annexed into the city or town corporate limits and the local agency does not agree to take over the maintenance and operation costs, the system should be considered for removal if a cost analysis shows such action to be cost effective. A removal study as defined in Section 78-2.10 should be conducted.

b. If the system was installed by the local agency and the local agency is no longer willing to pay for the operation and maintenance costs, INDOT will determine if the system is warranted. If it is warranted and is outside the incorporation limits, the Department may take over the responsibilities for maintaining and operating the system. If the system is not warranted, the local agency may be requested to remove the system. If the local agency will not remove the system, the Department may remove it as described in Section 78-2.10.

c. If the system was installed in accordance with an agreement entered into between the Department and the local governmental agency, and the agency is no longer abiding by the stipulations of the agreement, the Department may conduct a study to determine if the system is warranted. If continuation of the system is not found to be cost effective, INDOT may remove it as described in Section 78-2.10.

8. Other Construction Project. Where a proposed construction project (e.g., roadway reconstruction project) is within city or town incorporation limits, the following will apply relative to lighting.

a. If the existing lighting system is owned by the local agency and the project requires the system to be relocated, INDOT will be responsible for all relocation expenses.

b. If the existing lighting system is owned by a utility company and the project requires the system to be relocated, the utility company will be responsible for all relocation expenses.

c. If there is no existing lighting and it is requested by the local agency, INDOT will include the lighting system in the project if the local agency agrees to pay for all installation costs and will take responsibility for the operation and maintenance of the system.

d. If the existing luminaire arms are mounted on utility company poles and the lighting hardware is owned by the local agency, INDOT will be responsible only for the relocation expenses associated with the lighting hardware, if requested by the local agency. No upgrades in the existing lighting are accomplished under this option.

78-1.04 Lighting Studies

If a request is made for a new lighting installation along a State-maintained highway outside of incorporation limits, the following procedure should be used.

1. Lighting Request. The local agency or other local group seeking the lighting system is required to submit a request to the district Traffic Team petitioning the Department to consider the installation of a new lighting system along the State highway.

2. Lighting Study. The district Traffic Team will conduct a study to determine if the request justifies further action. Each lighting study report should include the Highway Lighting Accident Warrant Analysis.

3. Programming. If the location warrants lighting and it is outside the corporate limits, the district Traffic Team will request the Planning Division to initiate a project to provide lighting at the location.

78-2.0 WARRANTS

Providing lighting along every highway is not practical or cost effective. The district Traffic Team will be responsible for determining if the lighting system is economically justified along a State-maintained highway. It is the Department's practice to only provide lighting if there is an average of seven night accidents per year, and the night-to-day ratio of accidents is greater than 0.5. A blank Highway Lighting Accident Analysis Worksheet is shown as Figure 78-2B. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/. The appendices referred to in the worksheet are shown in Figure 78-2C. Local officials may determine the feasibility of providing lighting within city or town limits. A location which satisfies these warrants does not obligate INDOT to provide funding for the requested highway lighting project. INDOT's objective is to identify each roadway which should be considered in the process of setting priorities for the allocation of available funding to a roadway-lighting project. For a lighting system to be considered, it should satisfy the warrants provided below.

78-2.01 Freeway

Where warranted, INDOT is responsible for providing highway lighting along each Interstate route or other State-maintained freeway outside corporate limits. A city or town is responsible for lighting along a non-Interstate-route freeway which is within its corporate limits. Continuous freeway lighting (CFL) should be considered where one or more of the following warrants are satisfied.

1. Accidents. CFL should be considered where there are a significant number of nighttime accidents that can be attributed to the lack of lighting and where it can be supported by a cost-effective analysis.

2. Nearby Development. CFL should be considered, for a length of at least 2.0 mi, where the freeway passes through a substantially-developed suburban or urban area, and where one or more of the conditions exist as follows:

   a. the nearby local traffic operates on a street system that has some form of complete street lighting and which has some parts that are visible from the freeway;

   b. the freeway passes through a series of developments such as a residential, commercial, industrial, or civic area, college, park, terminal, etc., that has roads, streets and other areas that are lighted;

   c. separated cross streets, both with and without connecting ramps, are within 0.5 mi of each other and are lighted as part of the local street system; or

   d. the freeway cross-section elements (e.g., median, right of way) are substantially narrower than desirable widths used for a rural section due to high right-of-way costs and adjacent developmental restrictions.

3. Interchange. CFL should be considered where 3 or more successive interchanges are illuminated and have an average spacing of 1.5 mi or less between them. Where CFL is provided through the interchange, complete interchange lighting should also be provided. See Section 78-2.02 for additional information on interchange lighting.

78-2.02 Interchange

Interchange lighting can consist of either complete interchange lighting (i.e., all ramps, the mainline, and the cross street are lighted) or partial interchange lighting (e.g., gores, intersection). The Department's practice is that, once it has been determined that continuous freeway lighting is warranted, complete interchange lighting should also be provided. Interchange lighting along an unlighted freeway should be considered where the following conditions occur.

1. Accidents. Lighting may be warranted where there are significant numbers of nighttime accidents that can be attributed to the lack of lighting and where it can be supported by a benefit/cost analysis. Once lighting is considered warranted, the choice between

complete and partial interchange lighting will be determined based on ramp traffic volume. Complete interchange lighting will be provided where the total current average nighttime volume of all ramp traffic entering or leaving the freeway within the interchange area exceeds the value shown in Figure 78-2A, Minimum Traffic Volume for Complete Interchange Lighting. If only partial lighting is considered cost effective, then only partial lighting should be provided regardless of the traffic volume.

2. Nearby Development. Complete interchange lighting should be considered where nearby development, commercial or industrial, is lighted and is located within the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 mi or more on each side of the interchange.

3. Ramp Terminal. The intersection of the ramps and the crossroad at an interchange may be considered as a separate intersection or as part of the interchange depending on the condition and location of accidents.

78-2.03 Warrants for Street or Highway Other Than a Freeway

Where warranted, the Department is responsible for installing and maintaining a lighting system on a State-maintained highway outside city or town corporate limits.

Lighting should be considered where a highway section or intersection has a significant number of accidents (an average of at least seven nighttime accidents per year) that can be attributed to the lack of lighting and where the night-to-day accident ratio is greater than 0.5. The lighting system must also be shown to be cost effective using the Highway Lighting Accident Warrant Analysis Worksheet shown as Figure 78-2B. A highway section where lighting should be considered is that with a relatively high potential for numerous accidents, such as a section with numerous driveways, channelized islands, significant commercial or residential development, a high percentage of trucks, or geometric deficiencies.

Where a State-maintained highway intersects with or closely parallels local streets with existing lighting or which may have future lighting, provisions should be made for possible future illumination on the State-maintained highway.

78-2.04 Highway-Sign Lighting

A sign may be internally illuminated or externally illuminated by a direct source. Street or highway lighting does not satisfy the requirements for sign illumination. Section 75-2.03 provides the Department guidelines for sign illumination.

78-2.05 Rest Area

Lighting will be provided for all areas within a rest area that have pedestrian activities. Rest area ramps are also lighted, especially if continuous lighting is provided on the freeway. Highway-type light standards and luminaires should be used to light the parking areas as well as the ramps.

78-2.06 Truck Weigh Station

Each permanent truck weigh station should be lighted where weighing will occur after daylight hours. Highway-type light standards and luminaires should be used to light the weighing area, parking areas, speed change lanes, and ramps. Lighting may be provided for the sign preceding a truck weigh station which indicates that the station is open or closed.

78-2.07 Bridge Structure

The designer should consider the following in determining the need for lighting on a bridge structure.

1. Lighted Approaches. Lighting should be placed across or under a bridge where one or both approaches have or are planned to have lighting. Ownership of the lighting will be determined in the same manner as for a roadway.

2. Geometrics. Lighting may be considered for a long, narrow bridge even though the approaches are not lighted. Lighting should be considered where there is unusual or critical roadway geometry under or adjacent to the underpass area.

78-2.08 Tunnel

The lighting of a tunnel should be in accordance with the AASHTO *An Informational Guide for Roadway Lighting.*

78-2.09 Other Location

In addition to the above, lighting should be considered at the locations as follows:

1. commuter park-and-ride lot;
2. bikeway;

3. walkway; or
4. other pedestrian facility.

The need for lighting at one of these locations will be determined as required for each situation.

78-2.10 Reduction or Removal of Lighting

Where an existing highway lighting system is no longer warranted, feasible, or cost effective, it should be considered for reduction in the lighting level or be removed. Where light levels are reduced, they should not be reduced below the criteria described in Section 78-6.0. Prior to reducing lighting or removing the system, an engineering investigation will be required. Concurrence by the Production Management Division and approval by the Commissioner will be required. If Federal-aid funds were used for the original installation and the project is on the National Highway System and is not exempt from FHWA oversight, a copy of the report should be submitted to the FHWA.

If determining whether an existing lighting system should be removed or the lighting reduced, the designer should consider the following.

1. Freeway Lighting. Remove or reduce continuous freeway lighting where a cost analysis shows that such action would be cost effective. The cost analysis will be similar to the one prepared for the installation of a new lighting system, however, this study will need to consider the increase in accidents and cost to remove the system. Assume a 50 percent increase in nighttime accidents over a period of three years for analysis purposes.

2. Interchange Lighting. Reduce complete interchange lighting to partial interchange lighting where the average ramps' traffic volume falls below that shown in Figure 78-2A, Minimum Traffic Volume for Complete Interchange Lighting. An engineering analysis will be required to determine the extent of lighting reduction. Removal of complete or partial lighting will require a cost analysis to determine the cost effectiveness of removing the lighting system. Assume a 50 percent increase in nighttime accidents for analysis purposes.

3. Non-Freeway Lighting. Where lighting is no longer warranted on a non-freeway section, a benefit/cost analysis should be conducted to confirm that the lighting is no longer warranted. Section 78-1.03 describes the procedures for removal of lighting if the local agency no longer can or is willing to pay the maintenance and operation costs for the lighting system.

4. Sign Lighting. Removal of sign lighting may be considered where the traffic volume for a ramp falls below that shown in Figure 75-2A. A minimum of three traffic-volume

counts should be conducted to justify the removal of lighting. Counts should not be taken less than 9 months or more than 2 years apart. The counts should show either steady or declining nighttime volumes. Counts from other studies may be used.

5. Obsolete or Substandard System. Where it has been determined that a lighting system is obsolete, substandard, or is beyond its useful service life, it should be removed, replaced, or modified. An engineering investigation should be conducted to determine the appropriate action. If removal is considered, local input should be included in the investigation. A new replacement system should only be installed if it satisfies the warrants for a new system. Current accident data may be used for the analysis. However, the data should be adjusted to reflect the expected increase in accidents if the system is removed.

To study the effects of removing or reducing lighting, the Department may turn off part or all of the system. This may only be performed after an engineering analysis has been conducted to determine the expected effect of turning the lights off. This study period should not be less than one year or more than four years. After the study has been completed, the system may be either re-energized or removed.

After the decision has been made to remove or reduce the level of highway lighting, the lights should be turned off but left in place for a period of at least one year and not longer than four years. An accident analysis study will be required during this time period to determine the effects of the reduced lighting. A final cost analysis will be required with the updated accident and capital-improvement data. A system removal will be accomplished either by State forces or by a contractor as part of other project work.

78-3.0 LIGHTING EQUIPMENT

A number of options are available to the designer in selecting luminaire equipment that will satisfy the desired design criteria. Figure 78-3A, Typical Luminaire, provides an illustration of the various parts of the lighting standard and luminaire. In addition to the INDOT *Standard Drawings* and the INDOT *Standard Specifications*, the following provides guidance regarding INDOT's preferred lighting equipment.

The designer should ensure that the selected equipment is in accordance with standard hardware designs. Specialized equipment and designs can significantly increase the installation and maintenance costs, thereby reducing the cost effectiveness of the lighting system.

78-3.01 Foundation

Upon determining the foundation design, the designer should consider the following.

1. Material. Each foundation for a permanent installation should be of Class A concrete. It may be either cast-in-place or precast.

2. Design. The INDOT *Standard Drawings* provide the details for depth, width, reinforcing, etc., for both conventional and high-mast light standards. For a high-mast foundation, a soil survey may be required to determine if additional support may be required.

3. Placement and Grading. The INDOT *Standard Drawings* and Section 78-6.05 provide the Department's criteria for the placement of a light standard relative to the roadway and ditch lines. They also provide criteria for grading around the light-standard foundation.

78-3.02 Light Standard, or Pole

A major factor in highway lighting design is the selection of the luminaire and the mounting height. A higher mounting height will reduce the number of light standards required. The INDOT *Standard Specifications* and the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* provide the Department's criteria for light standards. The following describes the light standards used by the Department.

1. Conventional. This pole type is used most often. It has a mounting height ranging from 30 ft to 50 ft. INDOT practice is to use a light pole with a mounting height between 40 ft and 50 ft. The recommended minimum mounting height is 40 ft.

2. High-Mast. A high-mast pole can range from 80 ft to 200 ft in height. This is an excellent choice where there is a large area that requires lighting (e.g., interchange). The use of high-mast lighting and higher-wattage lamps greatly reduces the number of poles, yet retains the quality of the lighting. The designer should consider using high-mast lighting where practical.

3. Materials. Light standards for a permanent installation are made of galvanized steel, stainless steel, or aluminum. Wood poles are used as service poles or for temporary lighting (e.g., in a construction zone). High-mast poles are made of weathering steel. The INDOT *Standard Specifications* provide the material requirements for light standards used by INDOT.

4. Base. Unless otherwise protected, a breakaway base should be provided for all each light pole within the clear zone along a rural or high-speed urban highway. However, where pedestrians are commonly present, a breakaway base should not be used. Section 78-6.05

provides additional criteria on the appropriate application of where to use a breakaway or non-breakaway base. Each breakaway base should be in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The base types include the following.

a. Breakaway Transformer Base. A transformer base consists of an aluminum apron between the concrete foundation and the base of the pole. The breakaway transformer base is designed to be struck by a car's bumper. Once hit, the base deforms and breaks away. All wiring inside the base must also be connected to the breakaway device. INDOT's practice is to use the cast-aluminum transformer base.

b. Non-Breakaway Steel Transformer Base. A steel transformer base is similar in design to an aluminum base. However, it is not in accordance with the AASHTO breakaway criteria. Section 78-6.05 discusses the appropriate locations where a breakaway base is not required.

c. Breakaway Support Coupling. A breakaway support coupling is an aluminum connector or sleeve which is designed to shear when the pole is hit. The bottom of the coupling is threaded onto the foundation anchor bolts, and the light standard is attached to the top of the coupling. Four couplings are used with each light standard. Support couplings are 5 in. long.

d. Anchor Base. An anchor base is a metal plate which is welded to the bottom of the luminaire support. The plate allows the post to be bolted to the foundation without an intermediate breakaway device or to a breakaway coupling, slip plate, or transformer base.

5. Structural Design. Each light standard should be in accordance with the structural-design criteria described in the INDOT *Standard Specifications*, including the criteria for wind loading, maximum horizontal deflection, maximum stresses, luminaire loads, material strengths, welds, bolts, etc.

6. Effective Mounting Height. A light standard must be constructed so that it provides a luminaire mounting height above the roadway pavement as shown in Figure 78-3A, Typical Luminaire. After determining the mounting height, the appropriate pole length can then be determined.

78-3.03 Mast Arm

A mast arm allows placement of the light source near the edge of the travel lane. The use of a longer mast arm is recommended, although the initial costs may be higher. A longer mast arm allows the pole to be placed farther from the traveled way, thus providing a safer roadside environment. Otherwise, the use of a longer mast arm may have a negative effect on the loading capabilities of the base. In addition to the INDOT *Standard Specifications*, the following provides information and design guidance on the mast arms used by INDOT.

1. Material. Mast arms are made of the same material as the light standard.

2. Aluminum Mast Arm. The following should be used to determine the appropriate mast-arm type.

   a. Less than 8 ft. This may be either of the single-member or the truss-type design. The design should be consistent with other nearby mast arm types.

   b. 8 ft or Longer. This should be of only the truss-type design.

3. Galvanized Steel Pole. A constant-cross-section mast arm may be used. The mast arm should be of the truss-type design, fabricated from a 2-in. diameter steel pipe.

4. Bridge. Each mast arm for a bridge-deck light standard should be of the truss-type design.

5. Rise. Figure 78-3B, Mast Arm Rise Versus Length, provides the maximum rise (see Figure 78-3A) that should be used based on the mast-arm length.

78-3.04 Luminaire

A luminaire is defined as a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute light. The following and the INDOT *Standard Specifications* provide the Department's criteria for luminaire hardware. Section 78-6.03 discusses the various light distributions for a luminaire. For additional information, the designer should contact the Highway Operations Division's Office of Traffic Engineering for the latest products and specifications.

78-3.04(01) Light Source

There are numerous light sources for highway lighting. However, there are only a few practical choices when considering availability, size, power requirements, and cost effectiveness. Only a high-intensity discharge light source should be used. The following provides information on the recommended light sources that may be used.

1. High-Pressure Sodium (HPS). Due to its excellent luminous efficiency, power usage, and long life, HPS is the only light source that INDOT is using for each new installations of conventional or high-mast lighting. The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a sodium-and-mercury vapor.

2. Low-Pressure Sodium (LPS). Low-pressure sodium is considered one of the most efficient light sources. Its disadvantage is that it requires long tubes and has poor color quality. INDOT does not allow the use of LPS in a State-controlled system. However, a local agency may consider the use of an LPS lighting source. The LPS lamp produces a yellow light by passing an electrical current through a sodium vapor.

3. Mercury Vapor (MV). Prior to the introduction of HPS, mercury vapor was the most commonly used light source. A local agency may still install the MV light source for a new installation to match an existing installation. However, INDOT does not allow the use of MV for conventional or high-mast lighting in a new installation. MV usage by INDOT is limited to overhead-sign lighting. The mercury-vapor lamp produces a bluish-white light.

4. Metal Halide (MH). A metal-halide lamp produces better color at higher efficiency than an MV lamp. However, life expectancy for an MH lamp is shorter than for HPS or MV. An MH lamp is also more sensitive to lamp orientation than another light source. The MH lamp is used for lighting a sports arena or major sports stadium, for high-mast lighting, or for lighting a downtown area or park. Metal halide produces good color rendition. Light is produced by passing a current through a combination of metallic vapors.

78-3.04(02) Optical System

The optical system consists of a light source, a reflector, and usually a refractor. The following discusses the optical system of a luminaire.

1. Light Source. Section 78-3.04(01) discusses the recommended high-intensity light sources that should be considered.

2. Reflector. The reflector is used in optical control to change the direction of the light rays. Its purpose is to take that portion of light emitted by the lamp that otherwise would be lost or poorly utilized, and to redirect it to a more desirable distribution pattern. A reflector is designed to work either alone or with a refractor. Reflectors can be classified

into two types, specular or diffuse. A specular reflector is made from a glossy material that provides a mirror-like surface. A diffuse reflector is used where the intent is to spread the light over a wider area.

3. Refractor. The refractor is another means in optical control to change the direction of the light. A refractor is made of a transparent, clear material, usually high-strength glass or plastic. Plastic is used in a high-vandalism area. However, plastic may yellow over time due to heat and ultraviolet exposure. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light reflected off the reflector. It can also be used to control the brightness of the lamp source.

78-3.04(03) Ballast

Each luminaire must include a built-in ballast. A ballast is used to regulate the voltage to the lamp to ensure that the lamp is operating within its design parameters. It also provides the proper open-circuit voltage to start the lamp. INDOT uses the auto-regulator type ballast with an input voltage variation of ±10% of the rated operating voltage specified. Figure 78-5A, Lamp Data, provides the approximate expected operating wattage for a ballast based on the lamp wattage.

78-3.04(04) Housing Unit

Luminaire housing requirements are dependent upon the application type. When selecting a luminaire housing, the designer should consider the following.

1. Roadway-Lighting Luminaire. A roadway-lighting-luminaire housing or specular-reflector holder is made of aluminum with a weatherproof finish. The housing unit should allow access from the street side and allow for adjustments to the light. The luminaire should also have a high-impact, heat-resistant, glass, prismatic refractor. The unit should be sealed to ensure that dust, moisture, and insects will not be able to enter the inside of the luminaire.

2. Sign Luminaire. A sign luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield and an aluminum shield that blocks the view of the refractor from an approaching motorist. The unit is attached to the sign walkway as shown on the INDOT *Standard Drawings*. The mounting attachment is adjustable to allow for directing the light onto the sign.

3. Underpass Luminaire. An underpass luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield. The ballast may be placed as shown on the INDOT *Standard Drawings*. An

underpass luminaire may be attached to the vertical-side surface of a bridge bent structure, or may be suspended by the use of a pendant.

4. High-Mast Luminaire. A high-mast luminaire is an enclosed aluminum unit with a reflector and a borosilicate glass refractor. The unit should be sealed to ensure that dust, moisture, or insects will not be able to enter the inside of the luminaire. The luminaire is attached to the mast ring. The mounting attachment is adjustable to allow for directing the light.

78-3.05 Other Equipment

In developing a highway-lighting system, there are numerous components of the equipment design that can affect the design. Many of these elements are addressed in the INDOT *Standard Drawings*, the INDOT *Standard Specifications* and the manufacturer's criteria. Some of these elements include the following.

1. Electric Components. The above sources discuss electrical components, including ballasts, fuses, photoelectric controls, wiring, conduit, handholes, connections, breaker boxes, circuit breakers, relay switches, etc.

2. High-Mast Light Standard. Some of the additional components for a high-mast standard include the luminaire ring assembly for attaching a luminaire, head frame assembly, winch assembly, external drive system used to lower the luminaire for maintenance, cable terminator, and lightning rod.

78-4.0 LIGHTING METHODOLOGIES

The lighting-design methodologies are those for illuminance, luminance, and small-target visibility. The Illuminating Engineering Society (IES) of North America has been the leader in the development of these procedures. INDOT policy is to use only the illuminance methodology in its design of highway lighting. For additional information on these procedures, the designer should review the references listed in Section 78-1.01.

78-4.01 Illuminance

The illuminance methodology is the oldest and simplest to use. Illuminance is defined as the density of the luminous flux incident on a surface measured in footcandles. The methodology is concerned with the measurement of the light's intensity striking a particular point on the pavement. The brightest spot will occur directly under the luminaire and diminish the farther a motorist is away from the source. The disadvantage of this methodology is that one does not see incident light, but instead sees the light reflected from an object or surface. This sensation is known as brightness, with objects distinguished by the difference in brightness or contrast. Brightness can be expressed mathematically as luminance, or the luminous intensity per unit area directed towards the eye.

The factors in illuminance methodology are the measurement of average maintained horizontal illumination, E_h, and the uniformity ratio of the average-maintained illuminance to the minimum-maintained illuminance.

78-4.02 Luminance

Luminance is defined as the luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction. It is measured in candelas per square foot. The luminance methodology is concerned with the measurement of light from the luminaire reflecting off the pavement surface to the motorist's eyes. This measurement is affected by the pavement's reflectivity characteristics. To obtain the lighting measurements for the roadway, readings are taken from a set of observation points spread across the roadway in a grid pattern. Compared to the illuminance methodology, the luminance methodology is considered a more-accurate representation of the motorist's visibility requirements. However, the methodology is significantly more complicated to understand and use. Also, the pavement reflectivity must be estimated for the current time and for the future.

The design factors in luminance design include average maintained luminance L_{avg}, minimum luminance, L_{min}, maximum luminance, L_{max}, maximum veiling luminance, L_v, and ratios of L_{avg} to L_{min}, L_{max} to L_{min}, and L_v to L_{avg}. The Department is not using this methodology in lighting-determination design.

78-4.03 Small-Target Visibility (STV)

IES has proposed the STV methodology in an effort to better-define actual visibility requirements of the motorist. This methodology is similar to the luminance methodology in measurement of the light's reflectivity but, instead of measuring the pavement's reflectivity, it measures the reflectivity of a 7-in. diameter flat, square target with 20% diffuse reflectance against the pavement background. The target is perpendicular to the roadway surface and is always located a fixed distance of 270 ft ahead of the observer. The observer's target sight line is parallel to the centerline of the roadway. The STV methodology is significantly more complex than the other methodologies and is considered impossible to calculate manually, therefore, a computer is required. INDOT does not recommend the use of the STV methodology.

78-5.0 DESIGN PROCEDURE

The following provides guidelines on the lighting-design procedure used by INDOT. For additional design information, the designer should also review the references listed in Section 78-1.01.

Lighting-system design may require several iterations to produce an acceptable design. After the first run, if the design criteria are not satisfied the designer will need to change the initial parameters (e.g., pole spacing, mounting height, luminaire wattage) and recheck the design to determine if it then satisfies the criteria. This process is repeated until the design is optimized and all criteria are satisfied.

78-5.01 Computerized Design

To determine an acceptable lighting system requires numerous iterations using numerous variables. The chance for error in manually solving its equations is high. Therefore, the designer should use one of the commercial computer software packages that are available.

Each software package requires the same input and performs the same calculations. However, the method of input may vary significantly. With the proliferation of software programs, the user should first determine which programs are currently acceptable to INDOT. The Department is using the PC-based program ILLUM$, developed by General Electric, for its lighting calculations. ILLUM$ is used to generate templates for design and to check lighting levels and uniformity.

For a lighting design prepared by a consultant, it should provide the Production Management Division's Traffic Review Team with the design data inputs and reports.

78-5.02 Design Process

The following provides the procedural steps in designing a lighting system.

1. Assemble Information. Assemble all necessary information. This includes the following:

    a. contact the Traffic Review Team for the current design policies and procedures applicable to the project, sample plans, schedules, pay quantities, and example calculations;

b. gather roadway and bridge plans including plan and profile sheets and details sheets (e.g., those for overhead signs);

c. determine existing and expected utility locations;

d. discuss special considerations with the road or bridge designer;

e. conduct field reviews; and

f. if a local-agency project, hold discussions with local officials.

2. Determine Classifications. Determine the roadway classification and environmental conditions. If not already included in the project report, this information can be obtained from the Environmental Policy Team. The roadway classifications, for lighting purposes, are defined in Section 78-6.01.

3. Select Design Criteria. Based on the above information, the designer will select the pertinent design methodology (see Section 78-4.0) and the appropriate criteria based on the classification selected in Step 2; see Section 78-6.02. For an INDOT-route lighting project, only the illuminance design methodology should be used.

4. Select Equipment. In the preliminary design, the designer will need to make some initial assumptions regarding the equipment composition. This includes mounting height, pole setback distance, light source, mast-arm length, lamp wattage, etc. INDOT's practice is to use a 40-ft height pole with HPS lamps of 250-W or 400-W. Figure 78-5A, Lamp Data, provides the information on lighting levels for various lighting sources. See Sections 78-3.0 and 78-6.03 for additional details on equipment selection. After selecting the luminaire equipment, the designer will also need to obtain the photometric data sheet from the manufacturer for the luminaire selected.

5. Select Layout Arrangement. Section 78-6.04 provides information on the commonly used lighting arrangements. The selection of the appropriate layout design depends upon local site conditions and the engineer's judgment. Section 78-6.05 provides the roadside-safety considerations in selecting the lighting arrangements. Section 78-6.06 provides other layout considerations.

6. Luminaire Spacing. For an INDOT-route lighting project, use the illuminance methodology to determine the appropriate luminaire spacing. This step is conducted by the computer. For hand calculation, Equation 78-5.1 should be used. Sections 78-1.02 and 78-6.03 define the variables used in the equation.

$$S = \frac{(LL)(CU)(LLD)(LDD)}{WE_h} \qquad \text{(Equation 78-5.1)}$$

Where:

Where:	S	=	Luminaire Spacing (ft)
	LL	=	Initial Lamp Lumens
	CU	=	Coefficient of Utilization
	LLD	=	Lamp Lumen Depreciation Factor
	LDD	=	Lamp Dirt Depreciation Factor
	E_h	=	Average Maintained Level of Illumination (ft-cd)
	W	=	Width of Lighted Roadway (ft)

7. Check Uniformity. Once the spacing has been determined, the designer should check the uniformity of light distribution and compare this to the criteria selected in Step 3. Use Equation 78-5.2 to determine the uniformity ratio. Section 78-7.0 provides an example for calculating the uniformity ratio.

$$Uniformity\ Ratio = \frac{Average\ Maintained\ Illumination\ Value}{Minimum\ Maintained\ Illumination\ Value} \qquad \text{(Equation 78-5.2)}$$

8. Select Optimum Design. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if one design satisfies the criteria. There is often more than one satisfactory alternative.

9. Electric Design. Once the number, size, and location of the luminaires are determined, the designer will need to determine the appropriate electric voltage drop for the system. Section 78-6.07 provides information on how to determine the voltage drop for the lighting system.

10. INDOT Pre-Design Approval. For a consultant-designed project, the consultant should discuss the optimum alternatives with the Traffic Review Team prior to preparing the plans in order to expedite project development. Upon approval from INDOT, FHWA if necessary, and the local utility company, the final development of the plans may proceed.

11. Prepare Plans. Once the final design has been selected, the lighting designer will prepare and submit to the Traffic Review Team the plan sheets, quantities, cost estimate, voltage drop calculations, circuit schematic layouts, and special provisions that are required for review.

78-6.0 DESIGN CONSIDERATIONS

In designing a lighting system, there are many elements or factors the designer must consider. To help the designer in this process, the IES has standardized many of these elements. However, not all elements are appropriate. In addition to the following, Figure 78-6A, INDOT Lighting Design Parameters, provides guidance regarding the design values used for a lighting design.

78-6.01 Roadway Classification

In selecting the appropriate design criteria, the designer must determine the highway's functional classification (Section 78-5.02, Step 2). The following definitions are used to define roadway classification for highway-lighting purposes only.

1. Freeway. A divided major roadway with full control of access and with no crossings at grade. This definition applies to a toll or non-toll road. An Interstate highway is a freeway.

2. Expressway. A divided major roadway for through-traffic with partial control of access and with interchanges at major crossroads. An expressway for noncommercial traffic within a park or park-like area is considered a parkway.

3. Arterial. That part of the roadway system which serves as the principal network for through-traffic flow. Such a route connects areas of principal traffic generation and important rural highways entering a city. For an INDOT project, use the city-street design criteria.

4. Collector. This is a distributor or collector roadway servicing traffic between an arterial and local roadway. This is used for traffic movements within a residential, commercial or industrial area. For an INDOT project, use the city-street design criteria.

5. Local Road. This is used for direct access to residential, commercial, industrial, or other abutting property. It does not include a road which carries through traffic. A long local road will be divided into short sections by collectors. For an INDOT project, use the city-street design criteria.

6. Sidewalk. A paved or otherwise improved area for pedestrian use, located within the public-street right of way which also includes the roadway for vehicular traffic.

7. Pedestrian Walkway. A public walk for pedestrian traffic not necessarily within the right of way for a vehicular-traffic roadway. This includes a skywalk or pedestrian overpass, sub walk or pedestrian tunnel, walkway providing access to a park or block interior, or mid-block street crossing.

8. Isolated Interchange. A grade-separated roadway crossing which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

9. Isolated Intersection. The area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. One type of isolated intersection is the channelized intersection in which traffic is directed into definite paths by means of islands with raised curbs.

10. Bikeway. A road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facility is designed for the exclusive use of bicyclists or will be shared with other transportation modes.

    a. Type A: Designated Bicycle Lane. A portion of roadway or shoulder which has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor-vehicle traffic with a paint stripe, curb, or other similar device.

    b. Type B: Bicycle Path. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadway for motor-vehicle traffic with an open space or barrier.

78-6.02 Design Criteria

The lighting criteria vary according to the design methodology, highway classification, area classification, and pavement type. The following provide AASHTO and INDOT lighting design criteria.

1. Figure 78-6B provides the recommended INDOT roadway-illuminance-design criteria.

2. The AASHTO *An Informational Guide for Roadway Lighting* provides the recommended illuminance-design criteria for a pedestrian walkway, bikeway path, or local-agency project.

78-6.03 Equipment Considerations

Figure 78-6C, Luminaire Geometry, illustrates the common terms used in defining and designing luminaires (e.g., mounting height, overhang, rotation). The following discusses other equipment considerations for design.

78-6.03(01) Light Distribution

In determining the lighting-design layout, the designer must know the expected light distribution for the luminaire. The designer may obtain photometric data from luminaire manufacturers. The proper distribution of light from the luminaire is a major factor in the design of efficient lighting. Figure 78-6D, Luminaire Classification System, provides three IES classifications for luminaire light distributions: width, spacing, and glare control. Figure 78-6E, Guide for Luminaire Lateral Light Type and Placement, provides additional guidance on the selection of luminaires based on these classifications. Figure 78-6F, Plan View for Luminaire Coverage, illustrates a plan view of a roadway which has been modified to present a series of Longitudinal Roadway Lines (LRL) and Transverse Roadway Lines (TRL) and how these distribution factors are interrelated to each other. The following briefly describes these classifications.

1. <u>Vertical Light Distribution</u>. Vertical light distribution can be short, medium, or long. The selection of a vertical light distribution is dependent upon the mounting height and light source. Pavement brightness is increased if the vertical light angle is increased. The following defines the vertical-light distribution types.

    a. Short Distribution. The maximum luminous intensity strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum spacing is 4.5 mounting heights.

    b. Medium Distribution. The maximum luminous intensity is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum spacing is 7.5 mounting heights. This is the most commonly-used distribution type.

    c. Long Distribution. The maximum luminous intensity is between 3.75 and 6.0 mounting heights from the luminaire. The theoretical maximum spacing is 12 mounting heights.

2. <u>Lateral Light Distribution</u>. The IES has developed the lateral light distributions which are provided in Figure 78-6F. The following provides information on the placement for lateral light distribution.

    a. Type I. The luminaire is placed in the center of the street or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are also considered a modified form of Type I.

    b. Type I, 4-Way. The luminaire is placed in the center of the intersection and distributes the light along the four legs of the intersection. This type applies to high-mast lighting.

c. Type II. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is applicable to a narrow-width street.

d. Type II, 4-Way. The luminaire is placed at one corner of the intersection and distributes the light along the four legs of the intersection.

e. Type III. The luminaire is placed on the side of the street or edge of area to be lighted. It produces an oval-shaped lighted area and is applicable to a medium-width street.

f. Type IV. The luminaire is placed on the side of the street or edge of area to be lighted. It produces a wider, oval-shaped lighted area and is applicable to a wide street.

g. Type V. The luminaire is placed in the center of the street, intersection, or area where lighting is required. It produces a circular, lighted area. Type V can be applied to high-mast lighting.

3. Control of Distribution. As the vertical light angle increases, discomforting glare also increases. To distinguish the glare effects on the motorist from the light source, IES has defined the glare effects as follows.

   a. Cutoff. This occurs where the luminaire's light distribution is less than 25,000 lm at an angle of 90 deg above nadir (vertical axis), and less than 100,000 lm at a vertical angle of 80 deg above nadir.

   b. Semi-cutoff. This occurs where the luminaire's light distribution is less than 50,000 lm at an angle of 90 deg above nadir, and less than 200,000 lm at a vertical angle of 80 deg above nadir. This is the distribution used for lighting design.

   c. Non-cutoff. This occurs where there is no limitation on the zone above the maximum luminous intensity.

78-6.03(02) Mounting Height

A higher wattage bulb allows the use of a higher mounting height, fewer luminaries, and fewer support poles, and still maintains the lighting quality. A higher mounting height tends to produce the most efficient design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric testing results are required to determine the appropriate adjustments for mounting height.

78-6.03(03) Coefficient of Utilization

The coefficient-of-utilization curve defines the percentage of bare lamp lumens that are required to light the desired surface. Figure 78-6G illustrates a sample coefficient-of-utilization curve. The curve and the Isolux diagram are used to determine the amount of illumination to a given point on the pavement. The curve provides a value for the street side of the luminaire and the private-property side. If the luminaire is located over the roadway, the private-property-side value should also be used to determine the level of illumination. The manufacturer is required to provide these charts with its photometric testing results.

78-6.03(04) Light-Loss Factor (Maintenance Factor)

The efficiency of a luminaire is reduced over time. The designer must estimate this reduction to properly estimate the light available at the end of the lamp-maintenance life. The maintenance factor may range from 0.50 to 0.90, with the optimum range from 0.65 to 0.75. Figure 78-6A, INDOT Lighting Design Parameters, provides the factors used for designing a lighting system. The maintenance factor is the product of the following.

1. Lamp Lumen Depreciation Factor (LLD). As the lamp progresses through its service life, the lumen output of the lamp decreases. The initial lamp lumen value is adjusted by means of a lumen depreciation factor to compensate for the anticipated lumen reduction. This ensures that a minimum level of illumination will be available at the end of the assumed lamp life, even though lamp lumen depreciation has occurred. This information should be provided by the manufacturer. An LLD factor of 0.90 should be used. If deemed necessary, another value may only be used with approval from the Office of Traffic Engineering.

2. Luminaire Dirt Depreciation Factor (LDD). Dirt on the exterior and interior of the luminaire, and to some extent on the lamp, reduces the amount of light reaching the roadway. Various degrees of dirt accumulation may be anticipated depending upon the area in which the luminaire is located. Industry; exhaust of vehicles, especially large diesel trucks; dust; etc., all combine to produce dirt accumulation on the luminaire. A higher mounting height, however, tends to reduce vehicle-related dirt accumulation. Information on the relationship between the area and the expected dirt accumulation is shown in Figure 78-6H. An LDD factor of 0.87 should be used. This is based on a moderately-dirty environment and three years' exposure time. If deemed necessary, another value may only be used with approval from the Office of Traffic Engineering.

78-6.04 System Configuration

Figure 78-6 I, Lighting-System Configurations, illustrates the layout arrangements used. Figure 78-6 I also illustrates the recommended illuminance calculation points for the arrangements (Section 78-5.02, Step 7). INDOT does not place light standards in the median, as described below.

1. If no barrier is present, the light standards can be struck by traffic in both directions.

2. If a concrete barrier is present, the light standards are placed atop the barrier. A truck or bus hitting the barrier will lean substantially over the barrier and may strike the light standard.

3. Maintenance of the standards can be a safety concern for a maintenance crew situated in the median lane.

Figure 78-6J illustrates a layout for partial lighting of an interchange.

78-6.05 Roadside-Safety Considerations

The placement of a light standard should be such that it will not reduce roadside safety. However, the physical roadside conditions often dictate the light-standard location. The designer should consider such limitations in the design process. An overpass, sign structure, guardrail, roadway curvature, right-of-way limitation, gore clearance, proximity of another existing roadside obstacle, or the limitations of the lighting equipment are all factors that must be considered in design. The designer also must consider the roadway and area classification, design speed or posted speed limit, safety, aesthetics, economics, environmental impacts, etc., while accounting for the physical limitations.

There should be adequate right of way, driveway control, or utility clearance to allow the placement of the proposed light standards according to the safety requirements. Otherwise, additional right of way, driveway control, or utility relocations will be required. The designer should consider the following when determining the location of light poles relative to roadside safety.

1. <u>Breakaway</u>. A conventional light pole placed within the clear zone or the obstruction-free zone will be provided with a breakaway device except at a location with a sidewalk. In addition, the designer should consider the following.

a. Pedestrians. A pole should not be mounted on a breakaway device in an area, including a rest area, where pedestrian traffic exists or is expected.

b. Support. The maximum projection of the portion of a breakaway lighting support that remains after the unit has been struck is 4 in. (see Figure 78-6K, Breakaway Support Stub Clearance Diagram).

c. Breakaway Device. Each breakaway device should be in accordance with the applicable AASHTO requirements for structural supports. It may be one that has been approved for use as a breakaway device; see Section 78-3.0.

d. Wiring. Each pole that requires a breakaway device should be served by underground wiring and should be designed with breakaway connections.

2. <u>Grading</u>. A breakaway light standard, except one shielded by guardrail, should not be located where the opportunity exists for it to be struck more than 9 in. above the point of vehicular bumper impact. Normal bumper height is 1’-6”. To avoid a light standard being struck at an improper height, it should be placed as follows.

   a. Fill Slope Flatter than 6:1. There are no restrictions on placement of the light standard nor is special grading required. A light standard should be placed 20 ft from the edge of the travel lane or 10 ft from the edge of shoulder.

   b. Fill Slope of 5:1 or 6:1. The grading plan shown on the INDOT *Standard Drawings* should be followed. A light standard should be placed 20 ft from the edge of the travel lane or 10 ft from the edge of shoulder.

   c. Fill Slope of 4:1 or Steeper. A light standard should be offset 3 ft from the edge of shoulder or 12 ft from the edge of the travel lane, whichever is greater. Grading should be provided as shown on Figure 78-6L, Light-Standard Treatment (Fill Slope of 4:1 or Steeper).

   d. Cut Slope. The grading plan as shown on the INDOT *Standard Drawings* should be used to determine the placement of a light standard.

3. <u>Gore Area</u>. A pole should be located to provide adequate safety clearance in the gore area of an exit or entrance ramp, with a minimum of 50 ft (see Figure 78-6M, Pole Clearance for Ramp Gore).

4. <u>Horizontal Curve</u>. A pole should be placed on the inside of a sharp curve or loop.

5. <u>Maintenance</u>. In determining a pole location, the designer should consider the hazard which will be encountered while future maintenance is being performed on the lighting equipment.

6. <u>Barrier</u>. The placement of a light standard in conjunction with a roadside barrier should be as described in Section 49-5.0. In addition, the designer should consider the following.

   a. Placement. A light standard should be placed behind the barrier.

   b. Deflection. A pole behind guardrail should be offset by at least the deflection distance of the guardrail (see Section 49-5.01). This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in an extreme side-slope condition, or if the pole is located within the approach end of the railing, a breakaway device should be added. INDOT practice is to always use a breakaway device behind guardrail.

   c. Concrete Median Barrier. A pole that is shielded by a rigid or non-yielding barrier will not require a breakaway device. However, INDOT practice is to always use a breakaway device behind a rigid or non-yielding barrier.

   d. Impact Attenuator. A pole, either with or without a breakaway device, should be located such that it will not interfere with the functional operation of an impact attenuator or other safety breakaway device.

7. <u>Protection Feature</u>. A feature such as a curb, barrier, or other obstacle constructed primarily to protect a light pole, should not be used.

8. <u>High-Mast Tower</u>. An unprotected high-mast tower should be at least 75 ft from the nearest edge of the mainline or ramp travel lane. The minimum clear distance will be the roadway clear-zone width through the area where the high-mast lighting is located. Access for service vehicles should be provided for each high-mast tower or service pole.

9. <u>Existing Installation</u>. An existing breakaway light standard should be evaluated to determine if it is necessary to relocate it, re-grade around its base, or upgrade the breakaway mechanism to current criteria. The determination of the work necessary on an existing breakaway light standard involves a review of numerous variables. Therefore, this decision must be made by the Office of Traffic Engineering. If Federal-aid funds will be used for construction, the project is on the National Highway System, and it is not exempt from FHWA oversight, then the FHWA should also be consulted.

78-6.06 Other Considerations

The designer should review the following if designing of a lighting system.

1. Sign. A pole should be placed to minimize interference with the motorist's view of a highway sign. The luminaire brightness should not detract from the legibility of the sign at night.

2. Overhead Sign. An existing overhead sign's lights should be tied into the new lighting system's circuits.

3. Structure. A pole should be placed sufficiently far enough away from an overhead bridge or overhead sign structure so that the light from the luminaire will not cast distracting shadows on the roadway surface or produce unnecessary glare for the motorist.

4. Tree. A tree should be sufficiently pruned so that it do not cause shadows on the roadway surface or reduce the luminaire's efficiency. The luminaire should be designed with the proper height and mast-arm length to reflect the effect a tree will have on lighting distribution.

5. Retaining Wall. A pole may be located either on top of or behind a retaining wall. A pole mounted atop a retaining wall will require consideration in the retaining-wall design.

6. Median. Although not desirable, a pole may be placed in a median where the width of the median is adequate or if a barrier will be used. The median width should be equal to or greater than the pole's mounting height. Where used, twin poles should have the same mast-arm lengths on each side.

78-6.07 Voltage Drop Determination

A highway-lighting distribution circuit consists of two 240-V circuits provided by a multiple-conductor armored cable. Power supply to the lighting system is 240/480 V, single phase, 60-cycle alternating current. The lights are alternately connected to each side of the four-wire circuit. Ground rods are provided at each light standard. Voltage drop should not be over 10% to the last light in the circuit. Figure 78-6N provides the design amperages for various luminaires. Figure 78-6 O provides resistances for various wire types. Equation 78-6.1 should be used to determine the voltage drop between two adjacent luminaires.

$$E = IR \qquad \text{(Equation 78-6.1)}$$

Where:

E = voltage, or electric potential (volt)
I = current (ampere/mile)
R = resistance (ohm)

The following example illustrates how to calculate the voltage drop for a lighting system.

* * * * * * * * * *

Example 78-6.1

Given: Figure 78-6P, Voltage Drop Calculations (Example 78-6.1), illustrates a single-phase, three-wire balanced load circuit. The circuit includes eight 400-W HPS roadway luminaires with a branch circuit to two 250-W MV sign luminaires. The wire for roadway luminaires is #4 copper and to the sign luminaires #10 copper.

Problem: Determine the voltage drop of the circuit and the percent voltage drop to the last lamp.

Solution: Working from the last luminaire on each branch, the voltage drop can be determined for each circuit branch using Equation 78-6.1 and Figures 78-6N and 78-6 O.

1. Determine the voltage drop for Branch Circuit A:

Luminaire #9 to Luminaire #7: $E_9 = \frac{(2)(1.62)(200)}{5280} = 0.123\ V$

Luminaire #7 to Luminaire #5: $E_7 = \frac{(4)(1.62)(200)}{5280} = 0.245\ V$

Luminaire #5 to Luminaire #3: $E_5 = \frac{(6)(1.62)(200)}{5280} = 0.368\ V$

Luminaire #3 to Luminaire #1: $E_3 = \frac{(8)(1.62)(200)}{5280} = 0.491\ V$

Luminaire #1 to Service Point: $E_1 = \frac{(10)(1.62)(300)}{5280} = 0.920\ V$

Total voltage drop for Branch Circuit A:

0.123 + 0.245 + 0.368 + 0.491 + 0.920 = 2.147 V

2. Determine the voltage drop for Branch Circuit B:

Luminaire #8 to Luminaire #6: $E_8 = \frac{(2)(0.0162)(200)}{5280} = 0.123\ V$

Luminaire #6 to Point H: $E_6 = \frac{(4)(1.62)(150)}{5280} = 0.184\ V$

Luminaire #11 to Luminaire #10: $E_{11} = \frac{(1.4)(6.55)(12)}{5280} = 0.021\ V$

Luminaire #10 to Point H: $E_{10} = \frac{(2.8)(6.55)(50)}{5280} = 0.174\ V$

Point H to Luminaire # 4: $E_H = \frac{(6.8)(1.62)(50)}{5280} = 0.104\ V$

Luminaire #4 to Luminaire #2: $E_4 = \frac{(8.8)(1.62)(200)}{5280} = 0.540\ V$

Luminaire #2 to Service Point: $E_2 = \frac{(10.8)(1.62)(450)}{5280} = 1.491\ V$

Total voltage drop for Branch Circuit B:

0.123 + 0.184 + 0.021 + 0.174 + 0.104 + 0.5405 + 1.491 = 2.636 V

3. Determine the percent voltage drop:

From observation, Branch Circuit B has the most critical voltage drop, 2.636 V versus 2.147 V.

$\left(\frac{2.636}{240}\right)(100\%) = 1.099\%$, which is less than10%.

Therefore, the design is within the allowable voltage drop.

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78-7.0 HIGH-MAST LIGHTING DESIGN [Rev. Jan. 2011]

The design of a high-mast lighting system consists of the same design procedures as discussed in Section 78-5.02. The following should also be considered:

1. Lighting Source. A 1000-W high pressure sodium light source should be used. The number of required luminaires should be determined based on the area to be lighted as shown in Figure 78-7A.

2. Estimated Mounting Height. This can range from 100 to 200 ft. Once determined, it should be specified to the higher 5-ft increment. An EMH of 100 to 160 ft has proven to be the most practical. An EMH of 165 ft or greater requires more luminaires to maintain the illumination level. However, such an EMH allows for fewer towers and provides

better uniformity. Use of such an EMH should be confirmed with the district traffic engineer.

3. Location. In determining the location for a tower, the plan view of the area should be reviewed to determine the more critical areas requiring lighting. In selecting the appropriate location for a tower, the following should be considered.

   a. Critical Area. A tower should be located such that the highest localized level of illumination occurs within a critical-traffic area, e.g., freeway/ramp junction, ramp terminal, merge point.

   b. Roadside Safety. A tower should be located a sufficient distance from the roadway so that the probability of a collision is virtually eliminated. It should not be placed at the end of a long tangent.

   c. Sign. A tower should be located so that it is not within a motorist's direct line of sight to a highway sign.

4. Design. The methodologies for checking the adequacy of uniformity are the point-by-point method and the template method. The point-by-point method checks illumination by using the manufacturer's Isolux diagram. The total illumination at a point is determined as the sum of the contributions of illumination from all luminaire assemblies within the effective range of the point. The template methodology uses isolux templates to determine the appropriate location for each tower. The templates may be moved to ensure that the minimum-maintained illumination is provided, and that the uniformity ratio has been satisfied. Section 78-8.0 provides an example of using the template methodology.

   A retaining wall should be included with the concrete pad at the base of the tower if the surrounding ground's slope is steeper than 5:1. The height of the retaining wall should be determined from Figure 78-7B.

5. Foundation and Soil Test. After the final location of each tower is determined, a geotechnical investigation should be requested from the Office of Geotechnical Engineering. The standard foundation of 20-ft depth and 4-ft diameter should be specified for each tower with the soil properties as follows.

   a. Soft Clay. Undrained shear strength of 750 lb/ft^2, density of 120 lb/ft^3, and strain of 0.01 at half the maximum stress for an undrained triaxial test. The soil should not include excess rock.

b. Sand. Angle of internal friction of 30 deg, density of 115 lb/ft^3, and modulus of subgrade reaction of 20 $lb/in.^3$ The soil should include a minimum of gravel or clay.

If a tower of 180 ft or higher is required where soil is sandy, a foundation of 22-ft depth and 4.5-ft diameter should be specified, and its details should be shown on the plans.

The standard foundation has been designed with the assumption that no groundwater is present. The Office of Geotechnical Engineering should be contacted if groundwater is present or if excess rock is present in clay soil.

For other soil conditions or properties, the Office of Geotechnical Engineering may recommend an alternate foundation. Such alternate foundation should be shown on the plans.

6. Information to be Shown on Plans. This includes the tower location, foundation details if not standard, estimated mounting height, retaining-wall height if applicable, and number of luminaires.

78-8.0 EXAMPLE COMPUTATIONS

The following examples are provided to illustrate how to manually design a lighting system using the illuminance methodology. Example 78-8.1 illustrates a design using conventional light standards. Example 78-8.2 illustrates the template methodology for high-mast lighting. Although these examples use the manual-calculation procedures, a computer should be used to design the system.

* * * * * * * * * *

Example 78-8.1

Given: Urban collector through a commercially-developed area.

Problem: Design a lighting system.

Solution: Using the steps provided in Section 78-5.02 and the design considerations in Section 78-6.0, the design should proceed as follows.

1. Assemble Information. Plan and profile sheets should be provided by the road designer. A field review is held with local officials on-site. From the plans the following information is determined.

Roadway Width: 60 ft, consisting of four 12-ft lanes with a 12-ft two-way left-turn lane in the median. See Figure 78-8A, Urban Collector Highway (Example 78-8.1).

Design Speed: 45 mph

Surface Type: HMA pavement with 6-in. height concrete curbs on both sides

Pedestrians: No pedestrians are expected near the roadway

Terrain: Flat

2. Determine Classification. Using the data collected in Step 1 and Section 78-6.01, the roadway classification is a collector/city street.

3. Select Design Criteria. From Figure 78-6B, Illuminance Design Criteria, the lighting design should satisfy the criteria as follows:

   Average Illuminance, E_h = 97 ft-cd
   Uniformity Ratio = 4:1

4. Select Equipment. The equipment is selected as follows:

   Light Source = 400-W HPS (Figure 78-6A, Lighting-Design Parameters)
   Mounting Height, *MH* = 40 ft (Figure 78-6A)
   Mast-Arm Length = 10 ft
   Luminaire Distribution: Medium, Type II, Semi-Cutoff glare control (M-S-II)
   Effective Mounting Height = 40 ft
   Initial Lamp Lumens, *LL* = 50,000 lm (Figure 78-5A, Lamp Data)
   Coefficient of Utilization, *CU* = 0.48 (Manufacturer's Data, Figure 78-8B, Coefficient-of-Utilization Curve, M-S-II Luminaire)
   Lamp Lumen Depreciation Factor, *LLD* = 0.90, from Section 78-6.03(04)
   Luminaire Dirt Depreciation Factor, *LDD* = 0.87, from Section 78-6.03(04)

5. Select Layout. The roadway-width to mounting-height ratio is 60/40 = 1.5. From Figure 78-6E, Guide for Luminaire Lateral Light Type and Placement, use Type II with a staggered arrangement. Due to right-of-way restrictions, the poles can only be placed 10 ft behind the curb.

6. Determine Luminaire Spacing. Using Equation 78-5.1, the luminaire spacing can be determined as follows:

$$S = \frac{(LL)(CU)(LLD)(LDD)}{WE_h}$$

$$S = \frac{(50{,}000)(0.48)(0.90)(0.87)}{(0.84)(60)}$$

S = 380 ft

7. Check Uniformity. Using Equation 78-5.2, the manufacturer's isolux diagram, from Figure 78-8C, Sample Isolux Diagram (Example 78-8.1), and Figure 78-6 I, Lighting System Configurations, the following steps are used to check the lighting uniformity.

   a. Setup. The roadway geometrics are superimposed on the isolux diagram. With the 10-ft mast arm length, the luminaire is directly over the curb line. The curb line can be placed on the line directly below the luminaire (the 0 line). The lateral width of the roadway is 60 ft and the mounting height is 40 ft, the lateral (or transverse) ratio is 60/40 = 1.5. This is marked opposite the curb line on the Isolux diagram.

   b. Determine Checkpoints. From Figure 78-8A, determine the necessary checkpoints (S = 680 ft).

   c. Determine Contributing Luminaries. For a staggered arrangement, the lighting levels need only be checked for the selected luminaire and the luminaires directly opposite the luminaire on both sides. Lighting levels from other luminaires will have a minimal effect and therefore are not considered.

   d. Determine Transverse and Longitudinal Ratios. The ratios for each of the three luminaires are shown in Figure 78-8D, Unadjusted Illumination Value (Example 78-8.1). These ratios are determined by measuring the distance and dividing it by the mounting height.

   e. Determine Illumination Level. Using the ratios determined in Step 7d and the Isolux diagram in Figure 78-8C, the illumination level is determined and shown in Figure 78-8D. From Figure 78-8D, the critical location is found to be at Point B (0.03 ft-cd).

   f. Adjust Minimum Level. The value shown in Figure 78-8D is based on 1000 initial lamp lumens, 30-ft mounting height, and clean lamps. Therefore, Point B must be adjusted as follows:

   LL = 50 (50,000 Initial Lamp Lumens, Step 4)

MH	=	0.58 (Figure 78-8C)
LLD	=	0.90 (Step 4)
LDD	=	0.87 (Step 4)
E_h	=	(0.03)(50)(0.58)(0.90)(0.87) =6.8 ft-cd

g. Determine Uniformity Ratio. Using Equation 78-5.2, the uniformity ratio is determined as follows:

$$\text{Uniformity Ratio} = \frac{30}{6.8} = 4.4:1$$

This ratio is greater than the 4:1 maximum determined in Step 3; therefore, this design arrangement would not be acceptable.

8. Optimize Design. From Step 7, it can be seen that the design would not satisfy the light-illumination criteria. However, if this design did satisfy these criteria it may not be the most cost-effective design. Two or three runs assuming different mounting heights, spacings, wattages, etc., should be performed to determine the most efficient design. The system with the highest mounting height and longest spacing will provide the most cost-effective design.

* * * * * * * *

Example 78-8.2

Given: Urban cloverleaf interchange (see Figure 78-8E, Urban Interchange Lighting).

Problem: Design a lighting system using high-mast lighting and the template methodology.

Solution: Using the steps described in Section 78-5.02 and the design considerations in Sections 78-6.0 and 78-7.0, the design should proceed as follows.

1. Assemble Information. Plan and profile sheets should be provided by the road designer. A field review is held on-site. The following information gained from the plans.

Area: 9,700,000 ft^2 (see Figure 78-8E)
Design Speed: 70 mph
Surface Type: Concrete pavement with concrete shoulders
Terrain: Flat
Clear Zone: 30 ft (see Figure 49-2A)

2. Determine Classification. Using the data collected in Step 1 and Section 78-6.01, the roadway classification is freeway.

3. Select Design Criteria. From Figure 78-6B, Illuminance Design Criteria, the lighting design should satisfy the criteria as follows.

   Average Illuminance, E_h = 86 ft-cd
   Uniformity Ratio = 4:1

4. Select Equipment. The equipment is selected as follows:

   Light Source = 1000-W HPS (Section 78-7.0)
   Mounting Height (*MH*) = 100 ft (assumed)
   Luminaire Distribution = Short, Type V, Cutoff glare control (S-C-V)
   Effective Mounting Height = 100 ft
   Initial Lamp Lumens, *LL* = 140,000
   Lamp Lumen Depreciation Factor, *LLD* = 0.90 (Section 78-6.03(04))
   Luminaire Dirt Depreciation Factor, *LDD* = 0.87 (Section 78-6.03(04))

5. Design Template. A template is required which shows the minimum-initial illumination required from one luminaire with a perimeter of one-half that value. The following steps are used.

   a. Determine the Minimum-Maintained Illumination, *MMI*:

$$MMI = \frac{Average\ Maintained\ Illumination}{Average\text{ - }to\text{ - }Minimum\ Ratio} = \frac{8.6 \quad ft-cd}{4:1} = 22 \quad ft-cd$$

   b. Determine the Minimum-Initial Illumination, *MII*:

$$MII = \frac{MMI}{(LLD)(LDD)} = \frac{22}{(0.90)(0.87)} = 27.5 \quad ft-cd$$

   c. Determine the *MII* from one luminaire. Assume 4 luminaires per pole.

$$MII\ /\ Luminaire = \frac{MMI}{No.\,Luminaires\ /\ pole} = \frac{27.5 \quad ft-cd}{4} = 6.9 \quad ft-cd$$

   d. At least two poles will contribute to the minimum illumination.

$$1/2\ MII\ /\ Luminaire = (1/2)(6.9) = 3.5 \quad ft-cd$$

e. From the Isolux diagram for a 1000-W HPS luminaire (see Figure 78-8F), the *MII* per luminaire and 2 *MII* per luminaire distances are determined.

If the mounting height selected for the installation differs from that on the photometric test report, the proper correction factor has to be applied. Also, if the value on the test report is per 1000 lamp lumens, a factor for actual initial lamp lumens has to be included in the computations.

f. Using the longitudinal- or transverse-distance-to-mounting-height ratio of the Isolux diagram as a scale, make a template to fit the scale of the plans used for the lighting layout. Use 2 *MII* / luminaire as the perimeter of the template and show *MMI* / luminaire as a broken line on the template.

6. Determine Pole Locations. Start by placing the poles at the critical points. For an interchange, this is the gore area. The poles should be placed at least 75 ft from the edge of the mainline travel lane. The minimum clear-zone width will be acceptable, as shown in Figure 78-8G, Interchange Lighting Layout (Example 78-8.2).

7. Determine the Coefficient of Utilization. Using the 2 *MII* / luminaire line in Figure 78-8F, the coefficient of utilization can be determined (*CU* = 0.25). For Type V light distribution, the value for the street and private-property side is the same. Because the street and private-property sides are fully utilized, the *CU* value can be doubled (*CU* = 0.50).

8. Determine Average-Maintained Illumination, *AMI*.

$$AMI = \frac{(No. Poles)(LL)(CU)(LLD)(LDD)(3.2796)}{Total\ Area}$$

From Step 6, 9 poles were used; therefore:

$$AMI = \frac{(9)(140{,}000)(0.50)(0.90)(0.87)(3.2796)}{9{,}700{,}000\ ft^2} = 19.4 \quad ft-cd$$

9. Check *MMI*. The designer must check the layout to ensure that the minimum requirements are satisfied. This will involve checking the points where the lowest illumination levels appear to be. The actual values are determined using Figures 78-8F and 78-8G. Figure 78-8H, Unadjusted Illumination Value (Example 78-8.2), provides the illumination calculations for the selected points. The critical location is found to be at Point B (7.3 ft-cd). This value must be adjusted by the light loss factors as follows:

$MMI = (7.3)(0.90)(0.87) = 5.7$ ft-cd

10. Determine Uniformity Ratio. Using Equation 78-5.2, the uniformity ratio is determined as follows:

$$\mathit{Uniformity\ Ratio} = \frac{19.4}{5.7} = \mathit{3.40 : 1}$$

This ratio is less than the 4:1 maximum determined in Step 3; therefore, this design arrangement would be acceptable.

11. Final Check. Because 4 luminaires per pole were assumed, the average-maintained illumination would be as follows:

(4)(1.80) = 78 ft-cd

* * * * * * * * * *

Interchange Type	Night Volume of Ramp [1] (Avg. / Ramp / Night) [2]
Diamond	750
Cloverleaf	375
Directional / Semi Directional	375

Notes:

1. *For a volume lower than that listed, the interchange should only have partial lighting. Partial lighting may also be used at an interchange with a volume higher than that shown in the table.*

2. *For design purposes, night consists of the time between 7:00 p.m. and 7:00 a.m.*

MINIMUM TRAFFIC VOLUME FOR COMPLETE INTERCHANGE LIGHTING

Figure 78-2A

HIGHWAY-LIGHTING ACCIDENT-WARRANT ANALYSIS WORKSHEET

Route: Location:

Municipality: County:

Analysis Made By: Date:

1. Determination of Need for an Accident Analysis

This analysis section must be completed for each individual intersection, interchange, or continuous section of roadway of 1.5 km (1 mi) or less excluding intersections or interchanges. Intersections, interchanges, or continuous sections of roadway should not be combined for a single analysis for all.

a.	Accident Study Year:					TOTAL
b.	Number of months studied in each year:	+	+		=	
c.	Number of Nighttime Accidents:	+	+		=	
d.	Number of Daytime Accidents:	+	+		=	
e.	Total Number of Accidents: (Lines 1c + 1d.)	+	+		=	
f.	Night to Day Ratio: (Line 1c divided by 1d.)	+	+		=	
g.	Number of Years Studied: (Line 1b Total divided by 12.)	+	/	12	=	
h.	Average Number of Nighttime Accidents Per Year: (Line 1c Total divided by Line 1g.)		/		=	
i.	Average Number of Daytime Accidents Per Year: (Line 1d Total divided by Line 1g.)		/		=	
j.	Average Night to Day Ratio: (Line 1h divided by Line 1i.)		/		=	

2. Type of light standards to be used:

   ☐ Conventional Unit Only
   ☐ Combination Tower and Conventional Units

3. Type of Lighting System: (Check One)

   ☐ Intersection
   ☐ Partial Interchange
   ☐ Full Interchange

4. Installation Costs: (Use Appendix A)

   a. Construction Cost: $

   b. Mobilization-Demobilization and Maintenance of Traffic Costs:
      (Line 4a) $ x 0.07 = $

   c. Design and Construction Administration Costs:
      (Line 4a) $ x 0.10 = $

   d. Total Installation Costs:
      (Line 4a + 4b + 4c) $

5. Annual Operating and Maintenance Cost: (Use Appendix B)

   a. Operation and Maintenance Costs: $

   b. Administration Costs:
      (Line 5a) $ x 0.10 = $

   c. Operating and Maintenance Cost Per Year:
      (Line 5a + 5b) $

   d. Total Operating and Maintenance Cost = Present worth of costs over the 20-year service life.

      = Yearly Cost (Line 5c) x Present Worth Factor

      = $ x 13.5903 = $

   e. Total Cost = Total Installation Cost + Total Operating and Maintenance Cost

      = (Line 4d) $ + (Line 5d) $ = $

6. Annual Safety Benefits: (Use Appendix C)

							TOTAL
a.	Accident Study Year (Same as Section 1)						
b.	Number of Months Studied in Each Year (Same as Section 1)		+		+		=
c.	Number of Vehicles Involved, Nighttime Only		+		+		=
d.	Number of Injuries, Nighttime Only		+		+		=
e.	Number of Deaths, Nighttime Only		+		+		=
f.	Number of Years Studied: (Line 6b Total divided by 12.)				/	12	=
g.	Average Number of Nighttime Vehicles Involved Per Year: (Line 6c Total divided by Line 6f.)				/		=
h.	Average Number of Nighttime Injuries Per Year: (Line 6d Total divided by Line 6f.)				/		=
i.	Average Number of Nighttime Deaths Per Year: (Line 6e divided by Line 6f.)				/		=

j. Accident Reduction Factor (from Appendix D): = _____

k. Reduction in Accident Costs Per Average Year due to Highway Lighting Being Installed:

Type of Damage: (No./Yr.)		Unit Cost (Appendix C)		Reduction Factor		Savings Per Year
Vehicles (Line 6g)	x	$	x		=	$
Injuries (Line 6h)	x	$	x		=	$
Deaths (Line 6i)	x	$	x		=	$
Total Yearly Benefit: (sum of all three lines)						$

l. Assumptions:

Service Life	=	20 Years
Interest Rate	=	4%
Inflation Rate	=	0%
Net Salvage Value	=	$0

m. Traffic Growth Factor = (from Appendix E)

n. Total Benefits:

B = Present worth of the benefits over the 20-year service life
= Total Yearly Benefit (Line 6k) x Present Worth Factor x Traffic Growth Factor (Line 6m)

= $ x 13.5903 x

= $

7. Benefit / Cost Ratio, B/C:

B/C = (Line 6n divided by Line 5e)
= $ / $

APPENDIX A
INSTALLATION COSTS (1994 Figures)

Fully-Lighted Interchange

1.	Diamond:	Conventional	$324,000
		Tower and Conventional	280,000
2.	Cloverleaf:	Conventional	$416,000
		Tower and Conventional	350,000
3.	Partial Cloverleaf:	Conventional	$208,000
		Tower and Conventional	175,000

Partially-Lighted Interchange (Conventional Devices Only)

1.	Diamond:	$50,000
2.	Cloverleaf:	104,000
3.	Partial Cloverleaf:	50,000

Continuous and Intersection Lighting

1.	Continuous, per kilometer	4 Lanes	$95,000
		2 Lanes	47,000
	Continuous, per mile	4 Lanes	$153,000
		2 Lanes	76,000
2.	4-Way Intersection	4 Lanes	$40,000
		2 Lanes	25,000
3.	T-Intersection		$20,000

APPENDICES FOR HIGHWAY LIGHTING
ACCIDENT WARRANT ANALYSIS WORKSHEET

Figure 78-2C

APPENDIX B
ANNUAL OPERATION AND MAINTENANCE COSTS (1994 Figures)

Fully-Lighted Interchange

1.	Diamond:	Conventional	$25,700
		Tower and Conventional	19,300
2.	Directional:	Conventional	$52,700
		Tower and Conventional	37,800
3.	Cloverleaf:	Conventional	$51,200
		Tower and Conventional	37,400
4.	Partial Cloverleaf:	Conventional	$31,300
		Tower and Conventional	19,500

Partially-Lighted Interchange

1.	Diamond:	$12,100
2.	Directional:	30,800
3.	Cloverleaf:	35,300
4.	Partial Cloverleaf:	8,800

Continuous and Intersection Lighting

			Per Kilometer	Per Mile
1.	Continuous	4 Lanes	$12,700	$20,400
		2 Lanes	5,800	9,300
2.	4-Way Intersection	4 Lanes / 4 Lanes	$5,600	
		4 Lanes / 2 Lanes	4,200	

APPENDICES FOR HIGHWAY LIGHTING
ACCIDENT WARRANT ANALYSIS WORKSHEET

Figure 78-2C (Cont’d.)

3.	T-Intersection	4 Lanes / 4 Lanes	$3,300
		4 Lanes / 2 Lanes	2,700
		2 Lanes / 2 Lanes	2,300

APPENDIX C
COST OF MOTOR VEHICLE ACCIDENTS (1994 Figures)

Cost per Vehicle Involved:	$1,400
Cost per Injured Person:	$11,000
Cost Per Each Death	$450,000

APPENDIX D
ACCIDENT REDUCTION FACTORS

Improvement	Factor
Install New Lighting at Intersection / Interchange	0.37
Modernize Lighting at Intersection / Interchange	0.25
Install New Lighting at Bridge	0.59
Install New Lighting at Underpass	0.10

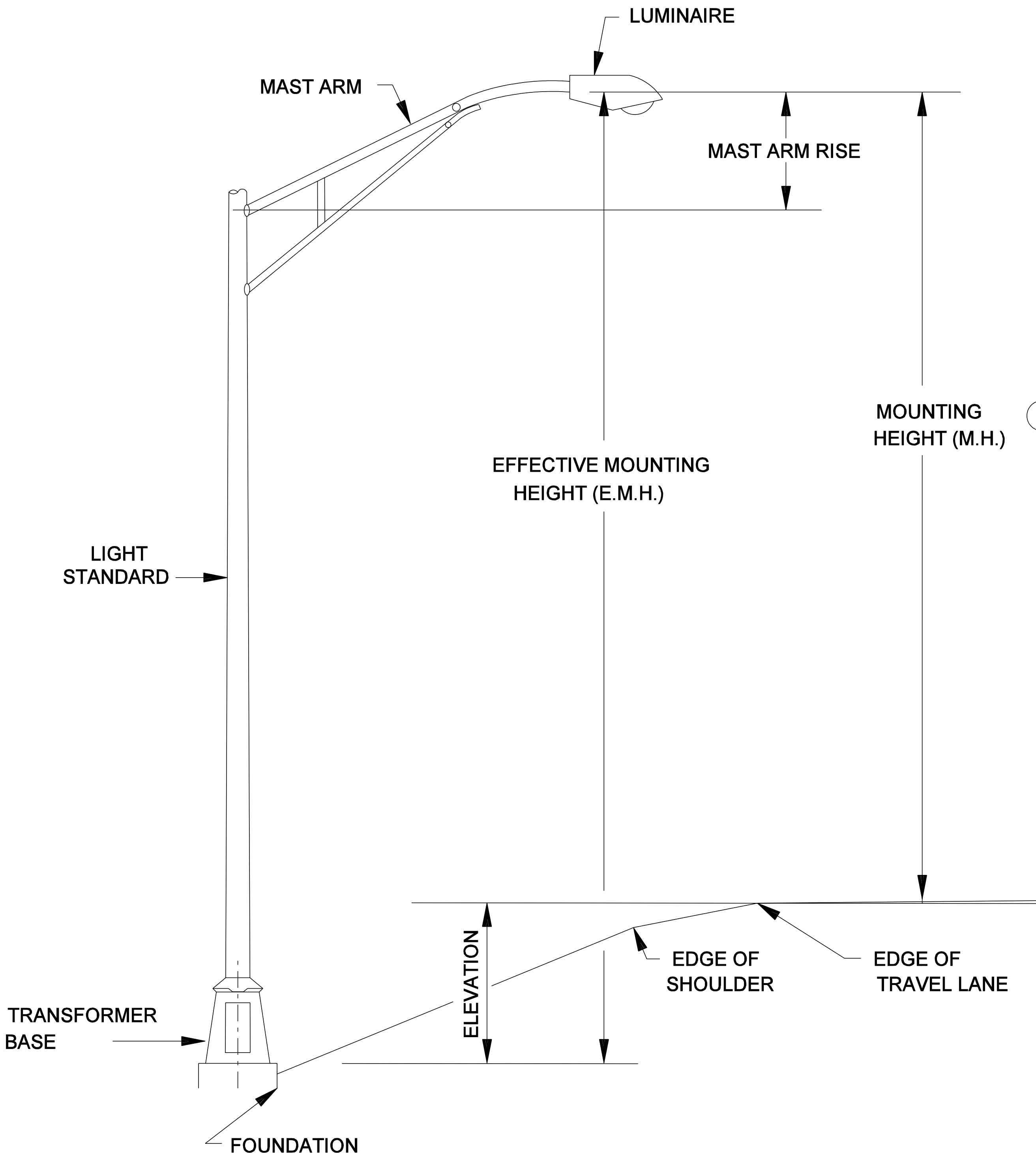
APPENDIX E
TRAFFIC GROWTH FACTORS

Determination of factor assumes 4% interest rate and 20-year service life.
Unless otherwise specified, assume a traffic growth rate of 2%.

Traffic Growth Rate	Traffic Growth Factor
1%	1.075
2%	1.150
3%	1.225
4%	1.300
5%	1.375

APPENDICES FOR HIGHWAY LIGHTING
ACCIDENT WARRANT ANALYSIS WORKSHEET

Figure 78-2C (Cont'd.)



1 INDOT TYPICALLY USES MOUNTING HEIGHTS OF 40 ft.

TYPICAL LUMINAIRE

Figure 78-3A

Mast-Arm Length (ft)	Maximum Rise (ft)
9 or Less	4
10 to 14	5
15 to 19	5.5
20 to 25	6
26 to 30	8

MAST-ARM RISE VERSUS LENGTH

Figure 78-3B

Lamp Wattage [a]	Approx. Ballast Wattage [b]	Total Wattage	Initial Lumens	Mean Lumens	Average Life (h)
MERCURY VAPOR					
100	35	135	4040	3415	24000+
100 DX	35	135	4425	3620	24000+
175	35	205	7975	7430	24000+
175 DX	35	205	8600	7640	24000+
250 [c]	35	285	11825	10625	24000+
250 DX	35	285	12775	10790	24000+
400	55	455	21000	19150	24000+
400 DX	55	455	23125	19840	24000+
700	65	765	40500	36250	24000+
700 DX	65	765	42750	36045	24000+
1000	90	1090	56150	48400	24000+
1000 DX	90	1090	63000	48380	24000+
HIGH-PRESSURE SODIUM					
50	18	68	3650	3285	24000
70	20	90	5800	5220	24000
100 [d]	35	135	9500	8550	24000
150	45	195	16000	14400	24000
200	50	250	22000	19800	24000
250 [e]	60	310	27500	24750	24000
250 S	60	310	30000	27000	24000
310	70	380	37000	33300	24000
400 [e]	85	485	50000	45000	24000
1000 [f]		1100	14000	12600	28500
LOW-PRESSURE SODIUM					
18	14	32	1800	1720	10000
35	25	60	4800	4570	18000
55	30	85	8000	7610	18000
90	35	125	13500	12850	18000
135	40	175	22500	21400	18000
180	50	230	33000	31400	18000

Notes:

a *The common wattages are shown. For others refer to the IES* Lighting Handbook.
b *Shown as the highest loss found for the commonly-used ballast types.*
c *Used for sign illumination.*
d *Used for a highway underpass.*
e *Used for conventional highway lighting.*
f *Used for high-mast lighting.*

LAMP DATA

Figure 78-5A

Lamp Lumen Depreciation Factor, *LLD*	0.90
Luminaire Dirt Depreciation Factor, *LDD*	0.87
Percent of Voltage Drop Permitted	10%
Pole Height	40 ft
Lamp Size	150 W, HPS (Underpass) 250 W or 400 W, HPS (Conventional) 1000 W, HPS (High-Mast)

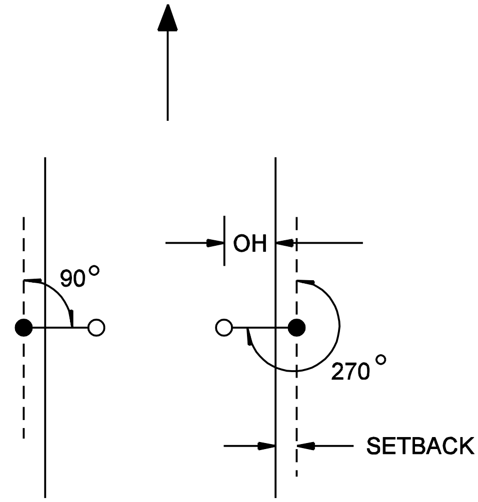
LIGHTING-DESIGN PARAMETERS

Figure 78-6A

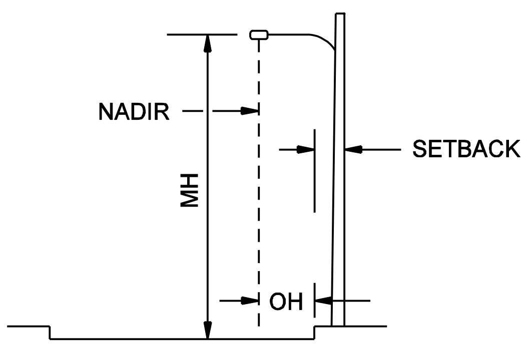
Roadway Classification	Average Maintained Horizontal Illuminance, E_h (ft-cd)	Uniformity Ratio
Interstate Route or Other Freeway	0.7	4:1
Expressway	1.1	3:1
Intersection or City Street	0.8	4:1
Weigh Station or Rest Area Ramp	0.6	3:1
Weigh Station or Rest Area Parking Area	1.0	4:1

ILLUMINANCE DESIGN CRITERIA

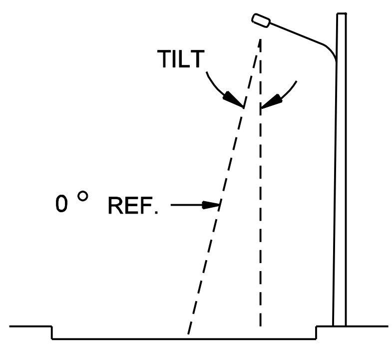
Figure 78-6B



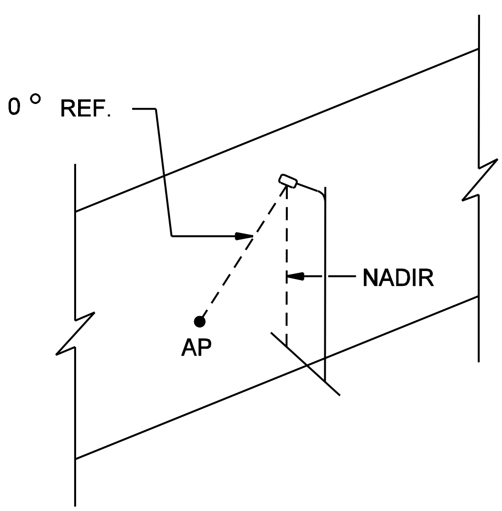
ORIENTATION ANGLE
OVERHANG (OH)
(PLAN VIEW)



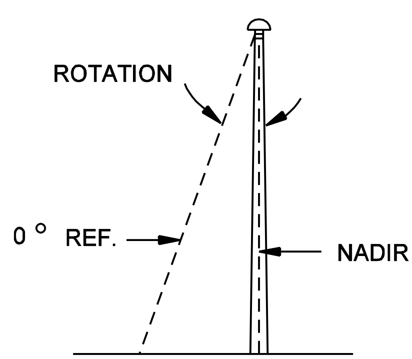
MOUNTING HEIGHT (MH)
(PROFILE VIEW)



TILT ANGLE



AIMING POINT (AP)



ROTATION ANGLE

LUMINAIRE GEOMETRY

Figure 78-6C

Spacing Classification	Definition	Spacing Distance
S	Short	4 times *MH* or less
M	Medium	5 times *MH* or less
L	Long	More than 5 times *MH*
Width Classification	Pavement Mounting Location	Roadway Width Served
Type I	Center	2 times *MH* or less
Type II	Edge	*MH* or less for one-side mounting 2 times *MH* or less for both-sides mounting
Type III	Edge	1.5 times *MH* or less for one-side mounting 3 times *MH* or less for both-sides mounting
Type IV	Edge	2 times *MH* or less for one-side mounting 4 times *MH* or less for both-sides mounting
Type V	Center	4 times *MH* or less
Glare-Control Classification	Definition	Control Requirement
C	Cutoff	Strict control of lighting above 80 deg vertical
S	Semi-Cutoff	Medium control of lighting above 80 deg vertical
N	Non-Cutoff	No control of lighting above 80 deg vertical

Notes:

1. MH = *mounting height.*

2. *The complete luminaire classification consists of the spacing, width type, and glare control, in sequence. Example: M-III-S.*

3. *There is no assurance that these values will be achieved by a luminaire which satisfies the classification requirements and is used as shown above.*

4. *INDOT does not use all of the IES classifications listed above. The designer should review Section 78-6.03(01) or contact the Office of Traffic Engineering to determine the luminaire classifications used by INDOT.*

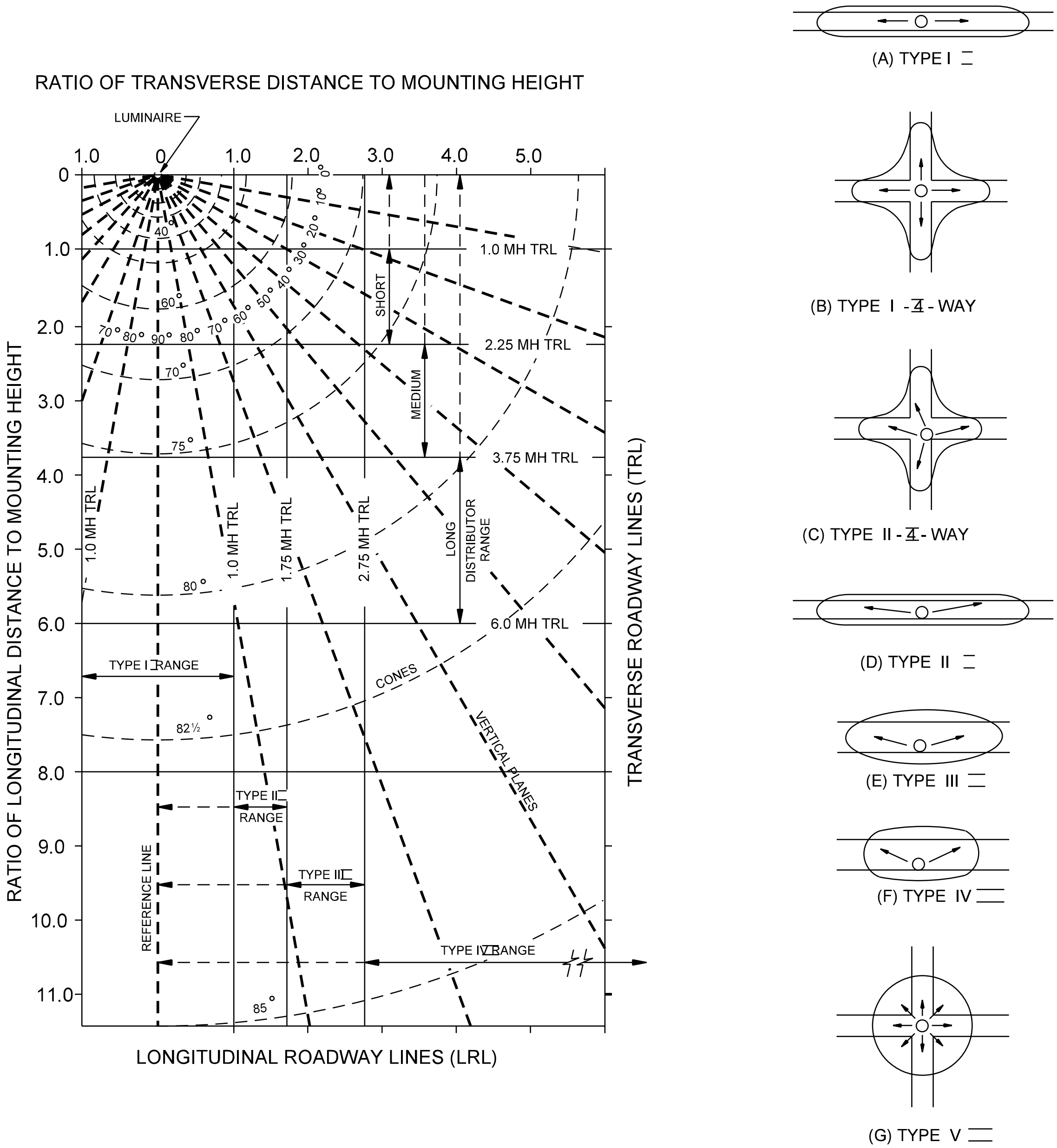
LUMINAIRE CLASSIFICATION SYSTEM

Figure 78-6D

Arrangement	One Side or Staggered	Staggered or Opposite	Twin Mast Arms (Median Mounting)	At-Grade Intersection or High-Mast
Lateral Placement	Pavement Width to 1.5 MH	1.5 MH plus Pavement Width	Pavement Width to 1.5 MH, Each Pavement	Pavement Width to 2.0 MH
Light Type	II, III, or IV	III or IV	II or III	IV or V

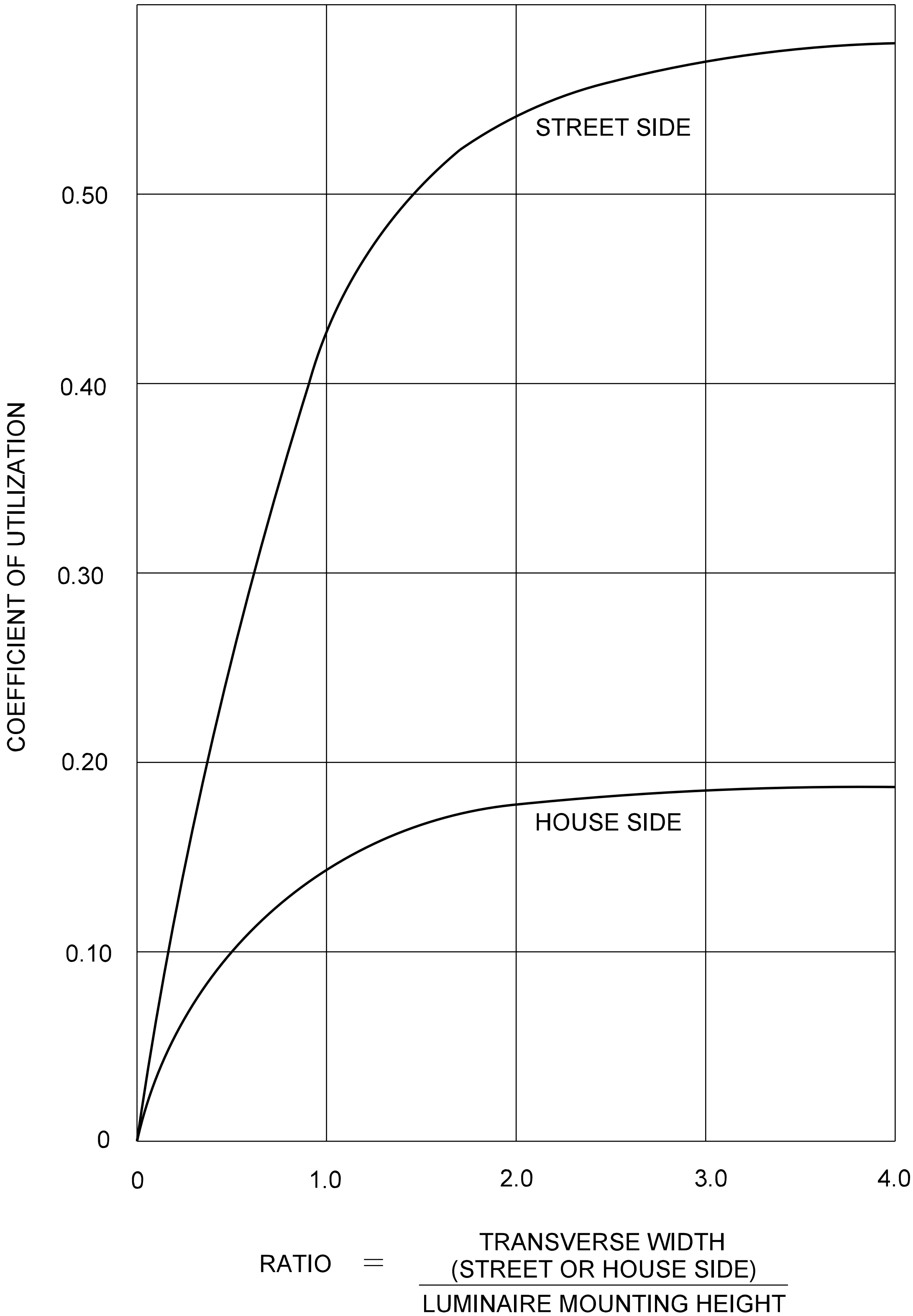
LUMINAIRE LATERAL PLACEMENT AND LIGHT TYPE

Figure 78-6E



PLAN VIEW FOR LUMINAIRE COVERAGES

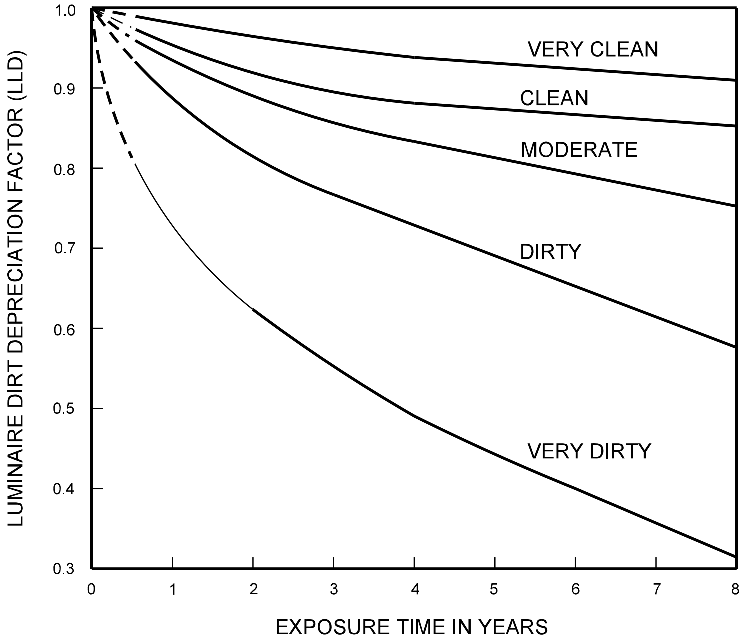
Figure 78-6F



Note: The coefficient-of-utilization curve will vary with various manufacturers and equipment types.

SAMPLE COEFFICIENT-OF-UTILIZATION CURVE

Figure 78-6G



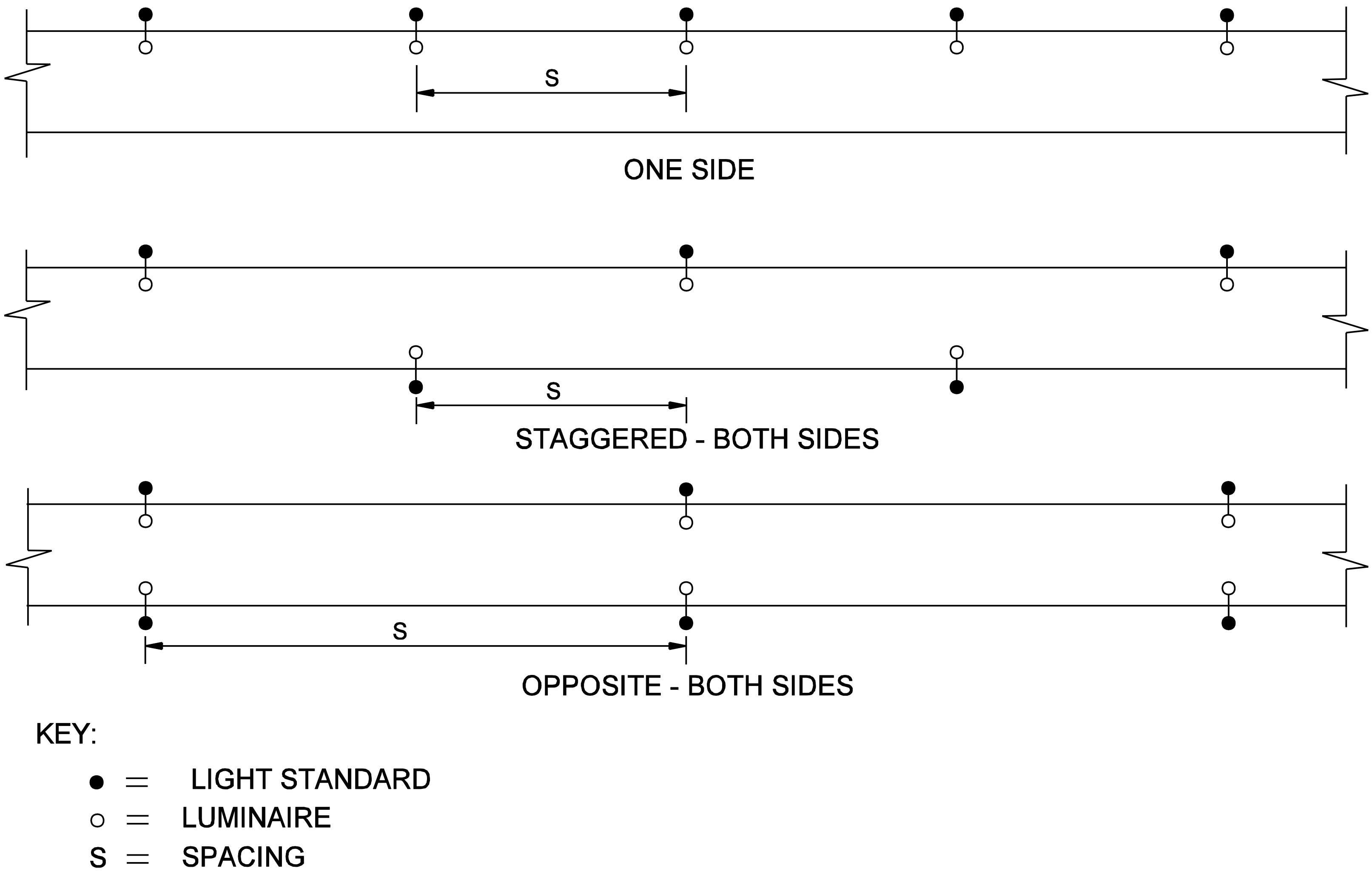
Notes:

1. *VERY CLEAN - No nearby smoke or dust-generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more than 150 micrograms per cubic foot.*
2. *CLEAN - No nearby smoke or dust-generating activities. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per cubic foot.*
3. *MODERATE - Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic foot.*
4. *DIRTY - Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaries.*
5. *VERY DIRTY - As above, but the luminaries are commonly enveloped by smoke or dust plumes.*

ROADWAY LUMINAIRE DIRT DEPRECIATION FACTORS

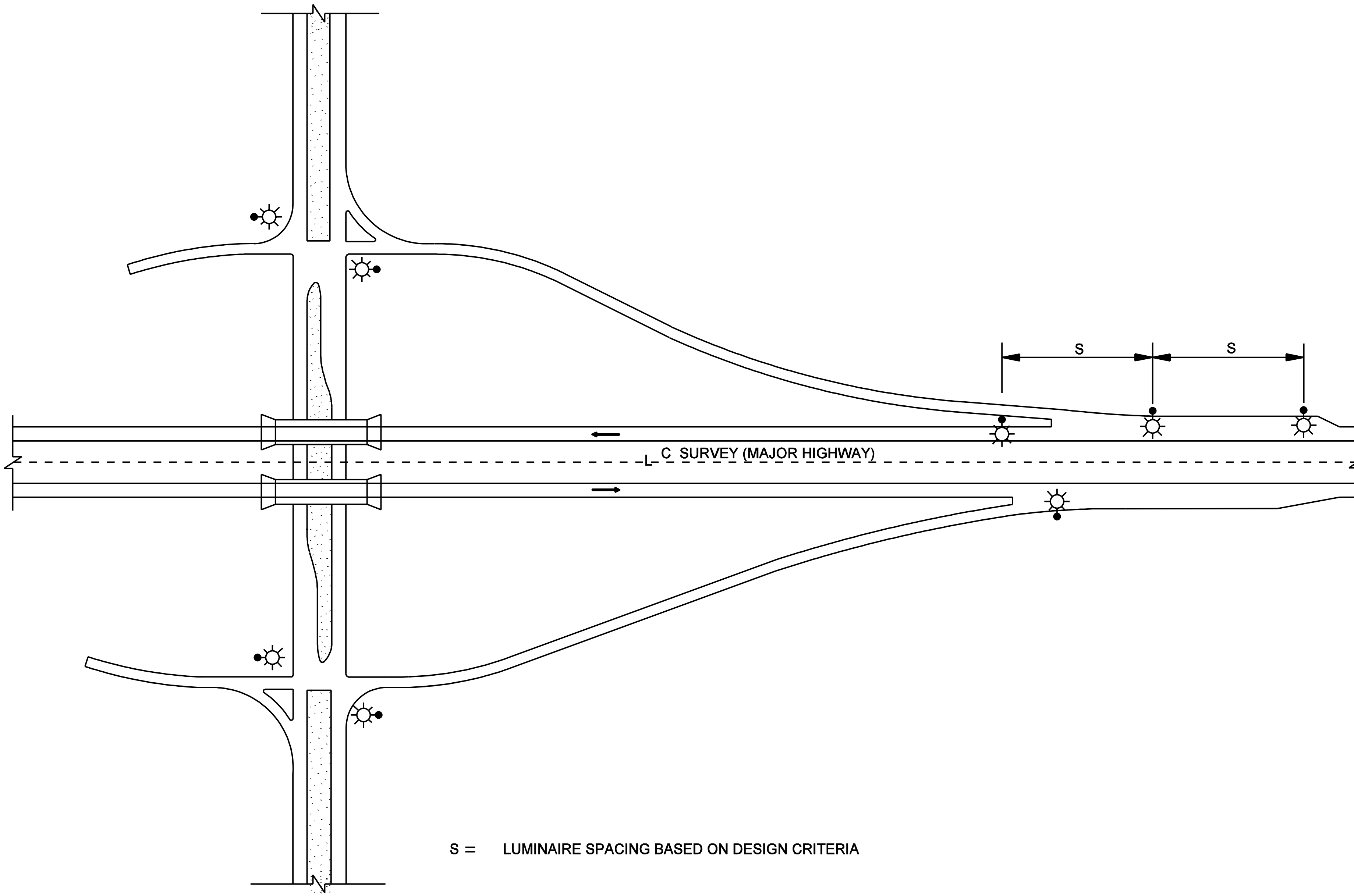
Figure 78-6H

TYPICAL MOUNTING CONFIGURATIONS
(LUMINANCE PATTERNS REPEAT AT SPACING BOUNDARIES INDICATED)



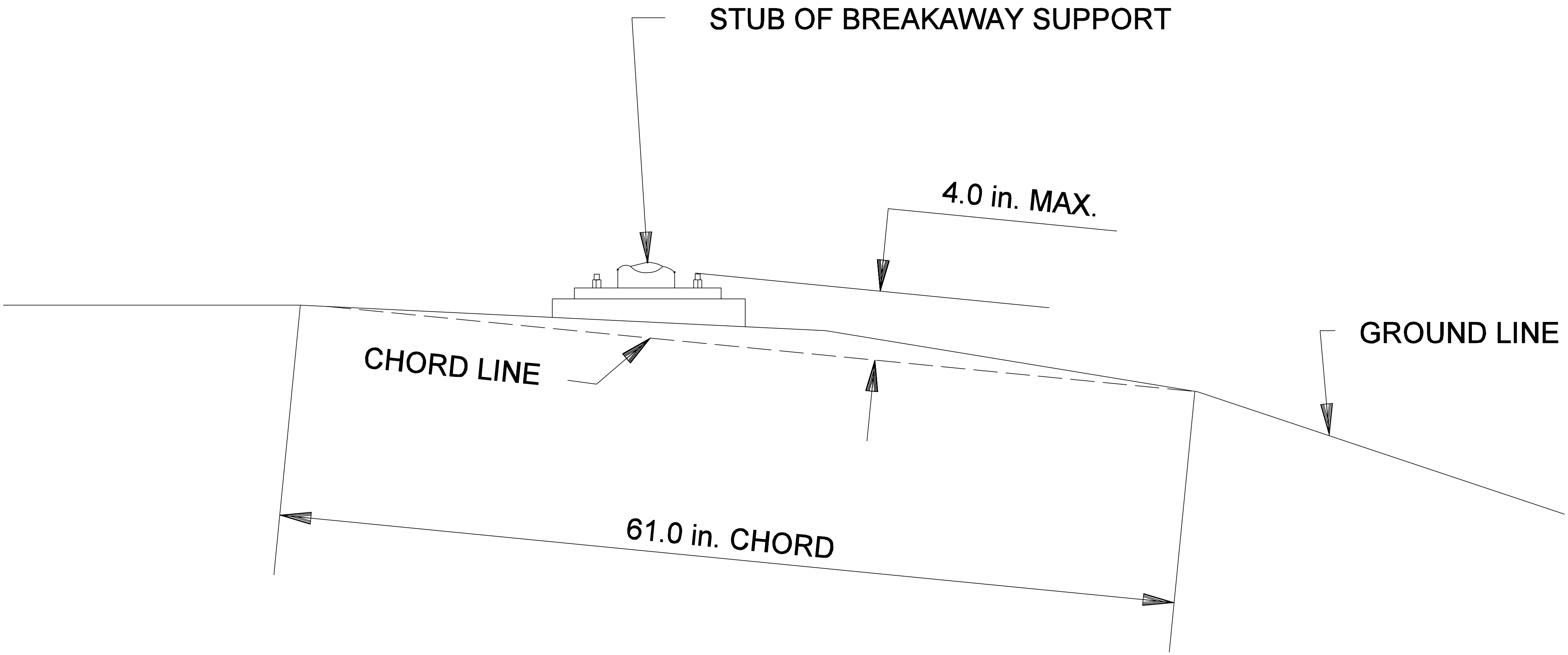
LIGHTING SYSTEM CONFIGURATIONS

Figure 78-6I



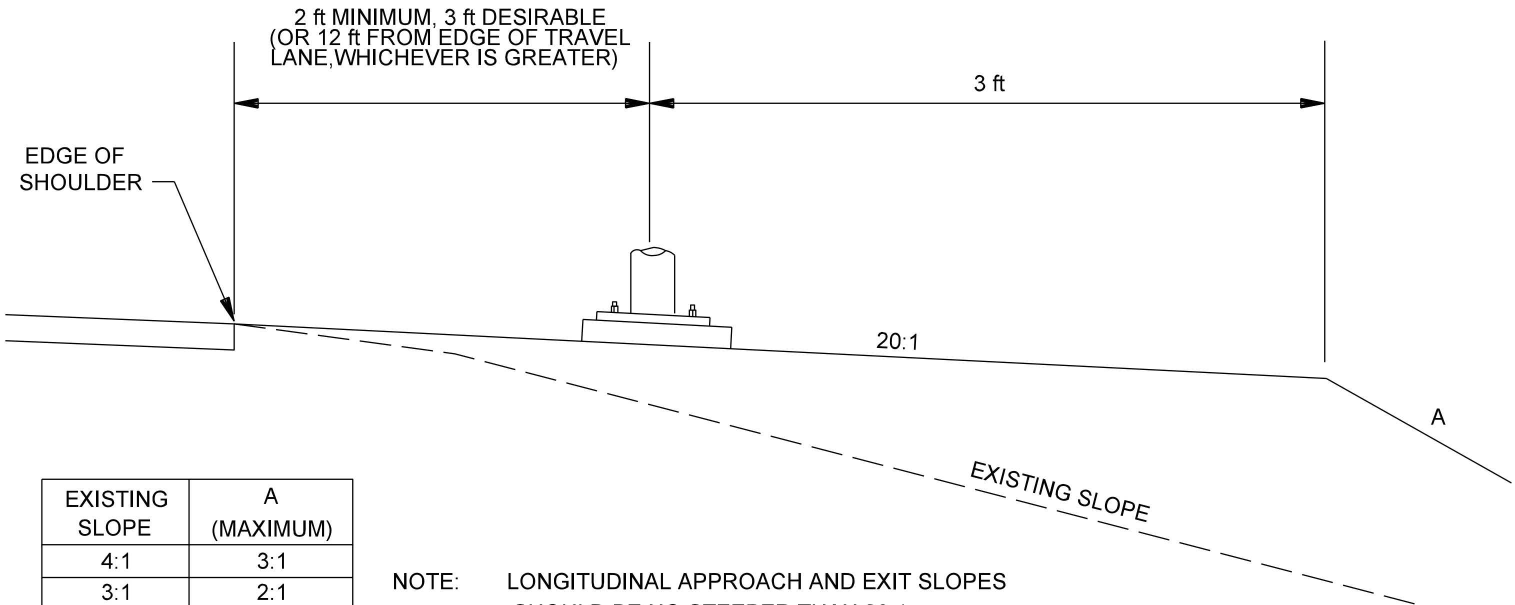
PARTIAL INTERCHANGE LIGHTING

Figure 78-6J



BREAKAWAY SUPPORT STUB CLEARANCE DIAGRAM

Figure 78-6K

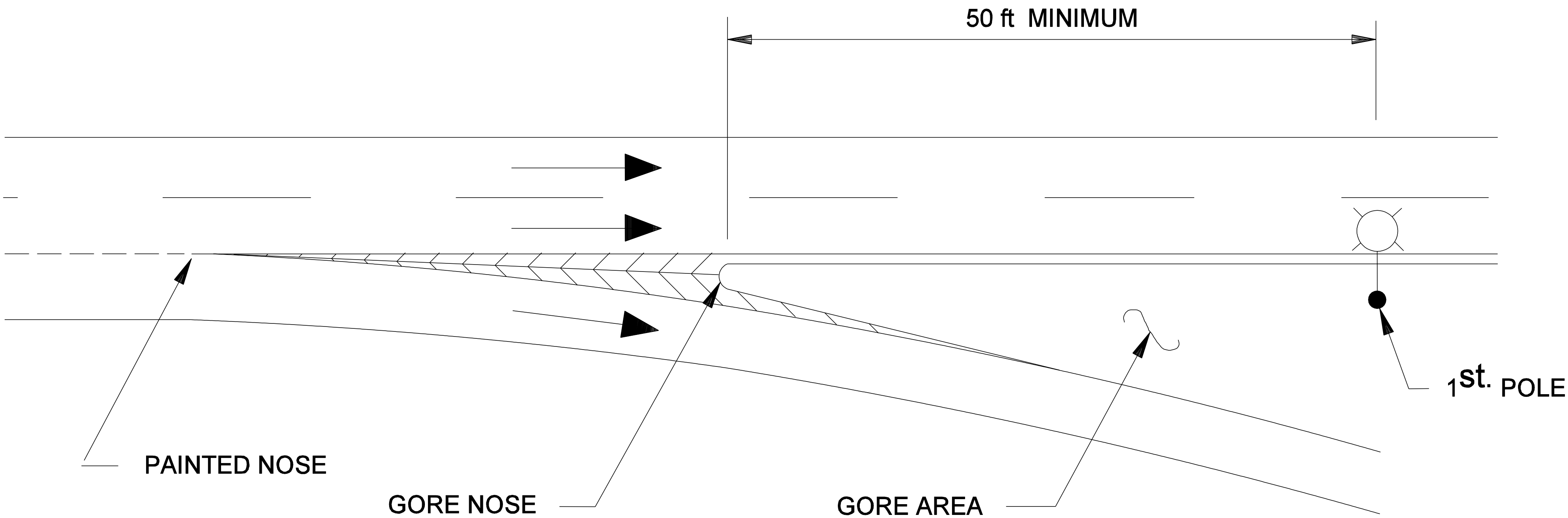


EXISTING SLOPE	A (MAXIMUM)
4:1	3:1
3:1	2:1
2:1	1.5:1

NOTE: LONGITUDINAL APPROACH AND EXIT SLOPES SHOULD BE NO STEEPER THAN 20:1

LIGHT STANDARD TREATMENT
(Fill Slope 4:1 or Steeper)

Figure 78-6L



POLE CLEARANCES FOR RAMP GORES

Figure 78-6M

LAMP WATTAGE, TYPE	LINE VOLTAGE		
	120	240	480
250 W, MV	2.7	1.4	0.7
400 W, MV	4.2	2.1	1.1
150 W, HPS	1.7	0.9	0.5
250 W, HPS	2.9	1.4	0.7
400 W, HPS	3.9	2.0	1.0
1000 W, HPS	9.0	5.0	2.5

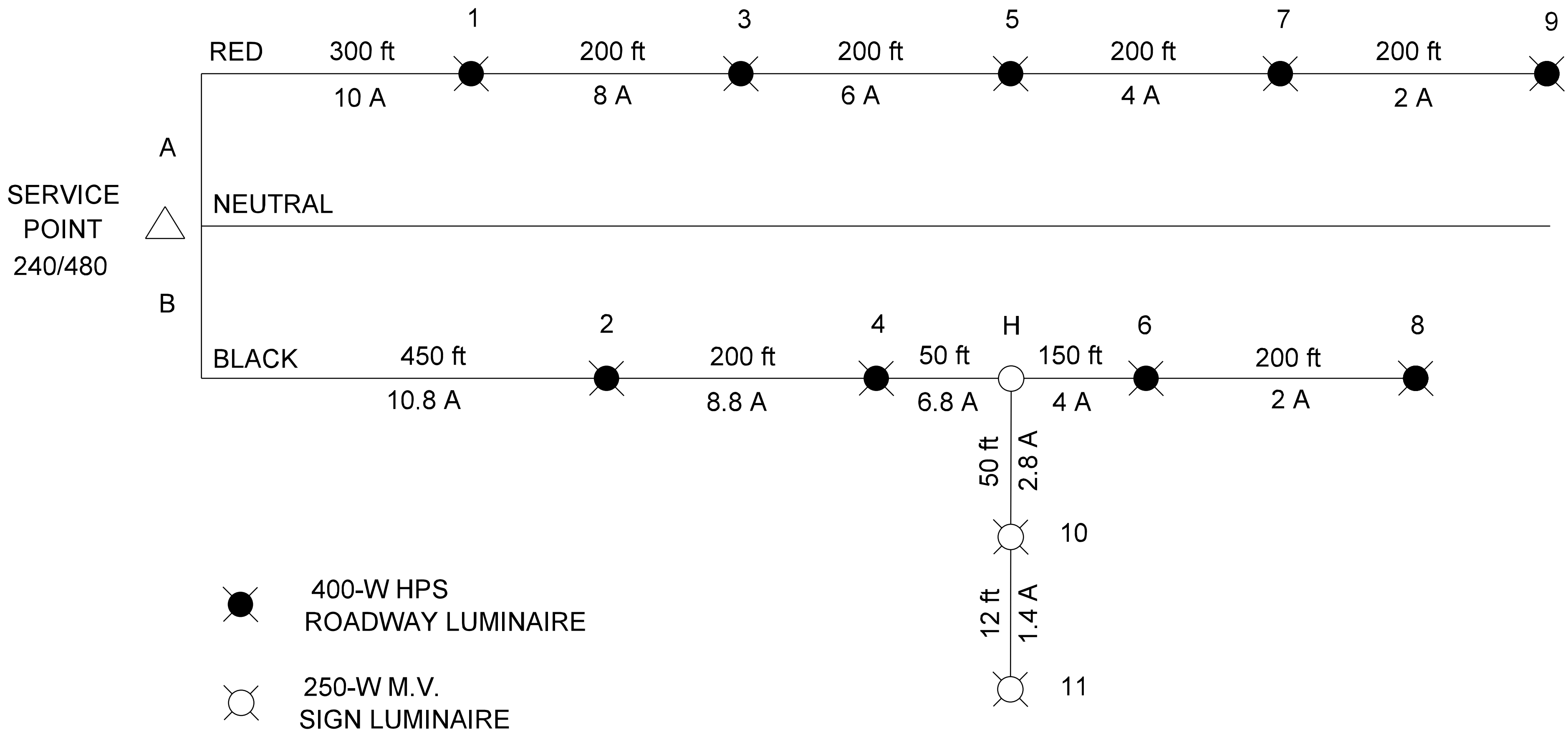
DESIGN AMPERAGES FOR VARIOUS LUMINAIRES

Figure 78-6N

WIRE SIZE (AWG)	RESISTANCE (ohms/mile)
10	6.55
4	1.62

COPPER-WIRE RESISTANCE

Figure 78-6 O



VOLTAGE DROP CALCULATIONS
(Example 78-6.1)

Figure 78-6P

Estimated Mounting Height, EMH (ft)	Lumens	Number of Luminaires
100	400,000	4
105 ≤ EMH ≤ 120	600,000	4 or 6
125 ≤ EMH ≤ 150	800,000	6 or 8
155 ≤ EMH ≤ 200	1,600,000	6, 8, 10, or 12

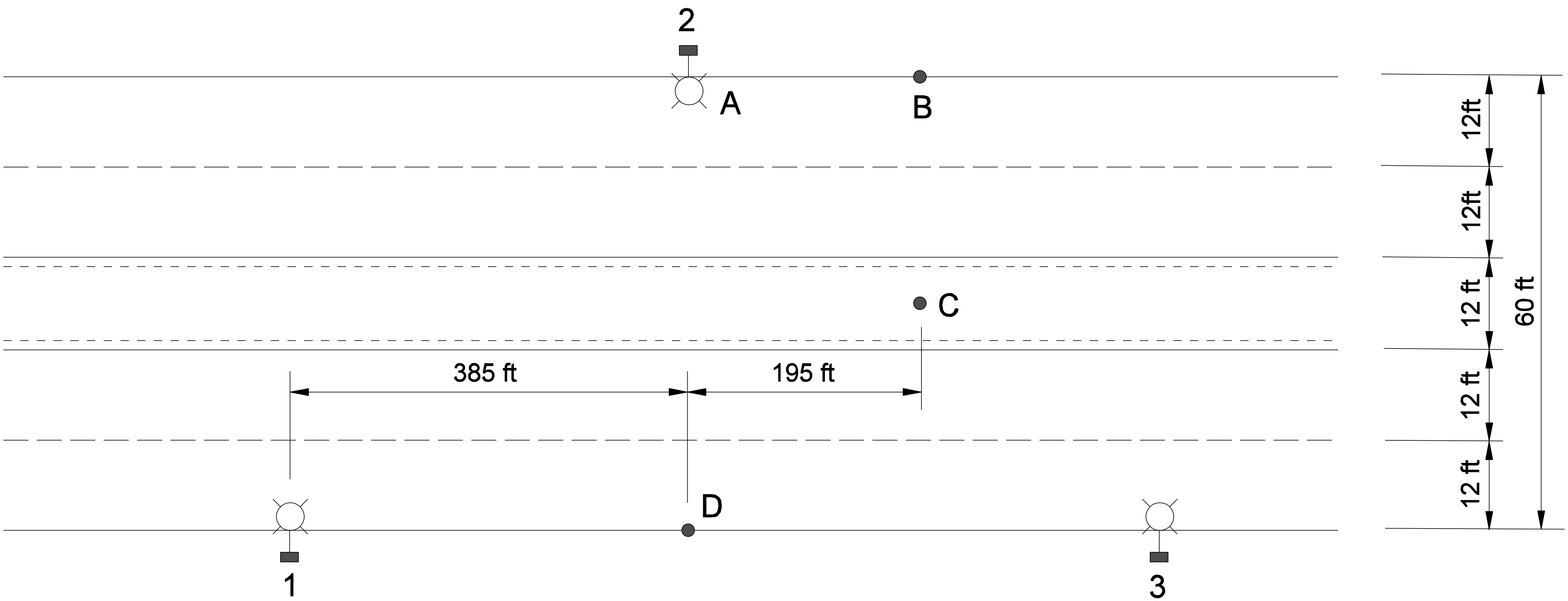
NUMBER OF LUMINAIRES FOR HIGH-MAST TOWER

Figure 78-7A

Slope, S:1	Height (ft)
$2{:}1 \le S \le 3{:}1$	3
$3{:}1 < S \le 4{:}1$	2
$4{:}1 < S < 5{:}1$	1.5

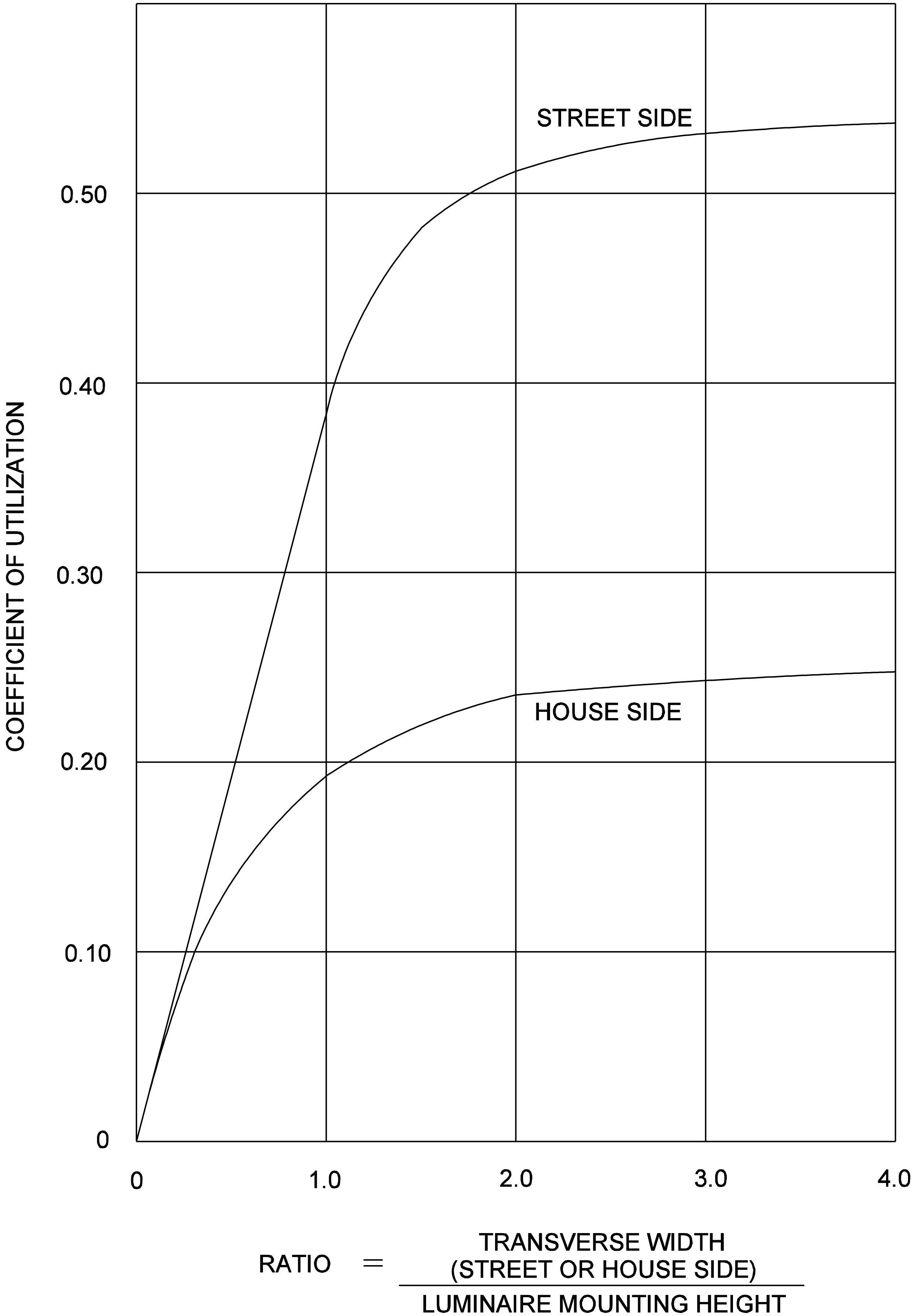
HEIGHT OF RETAINING WALL AT HIGH-MAST-TOWER CONCRETE PAD

Figure 78-7B



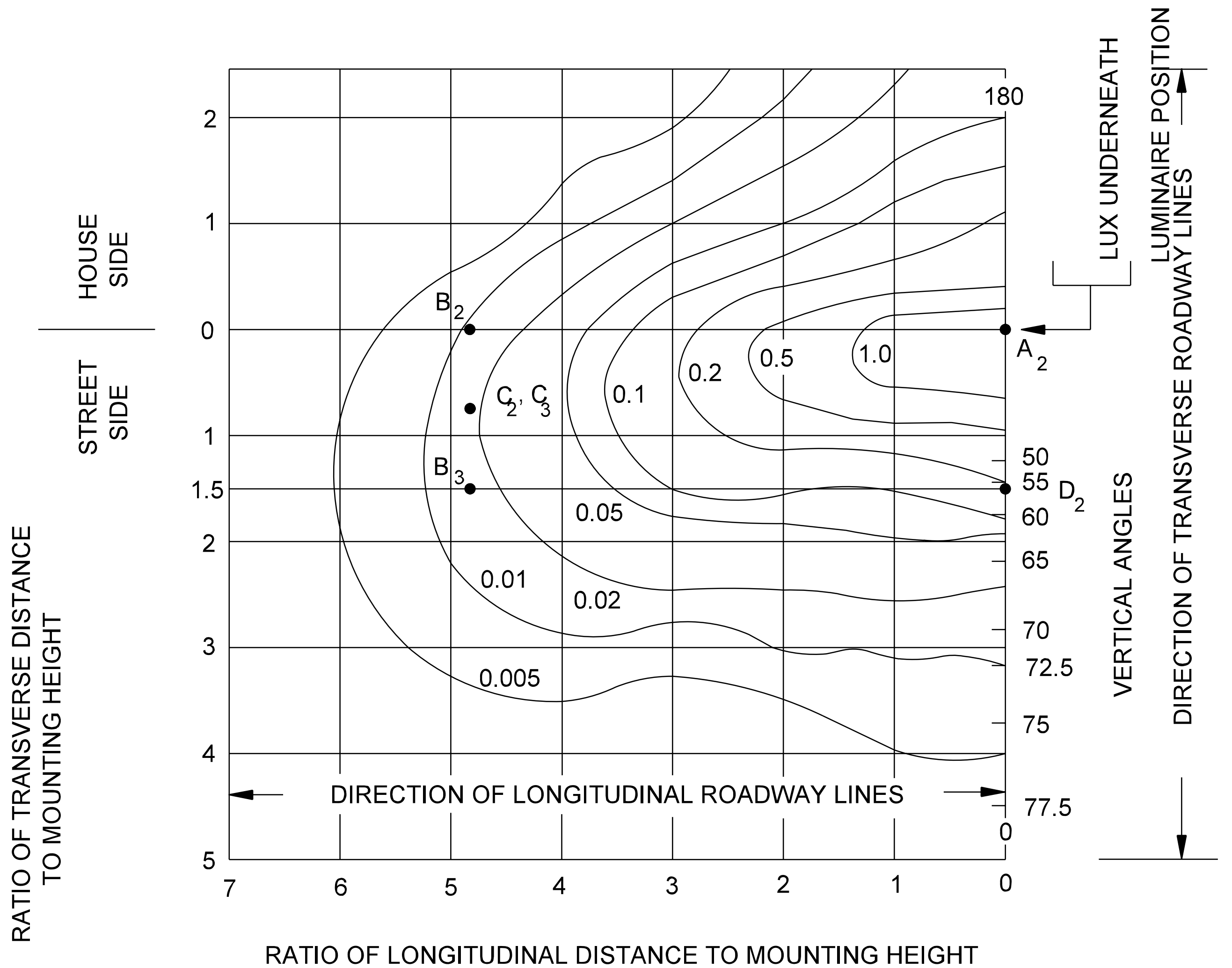
URBAN COLLECTOR LIGHTING
(Example 78-8.1)

Figure 78-8A



COEFFICIENT-OF-UTILIZATION CURVE
(M-S-II Luminaire)

Figure 78-8B



Note: Isolux diagram of horizontal lux on pavement surfaces for a luminaire providing a medium semi-cutoff, Type III light distribution (per 1000 initial lamp lumens). The isolux multiply the values of isolux shown by the factors below

Mounting Height (ft):	*24*	*27*	*30*	*33*	*36*	*39*	*42*	*45*
Factor:	*1.27*	*1.00*	*0.81*	*.087*	*0.58*	*0.38*	*0.41*	*0.38*

SAMPLE ISOLUX DIAGRAM
(Example 78-8.1)

Figure 78-8C

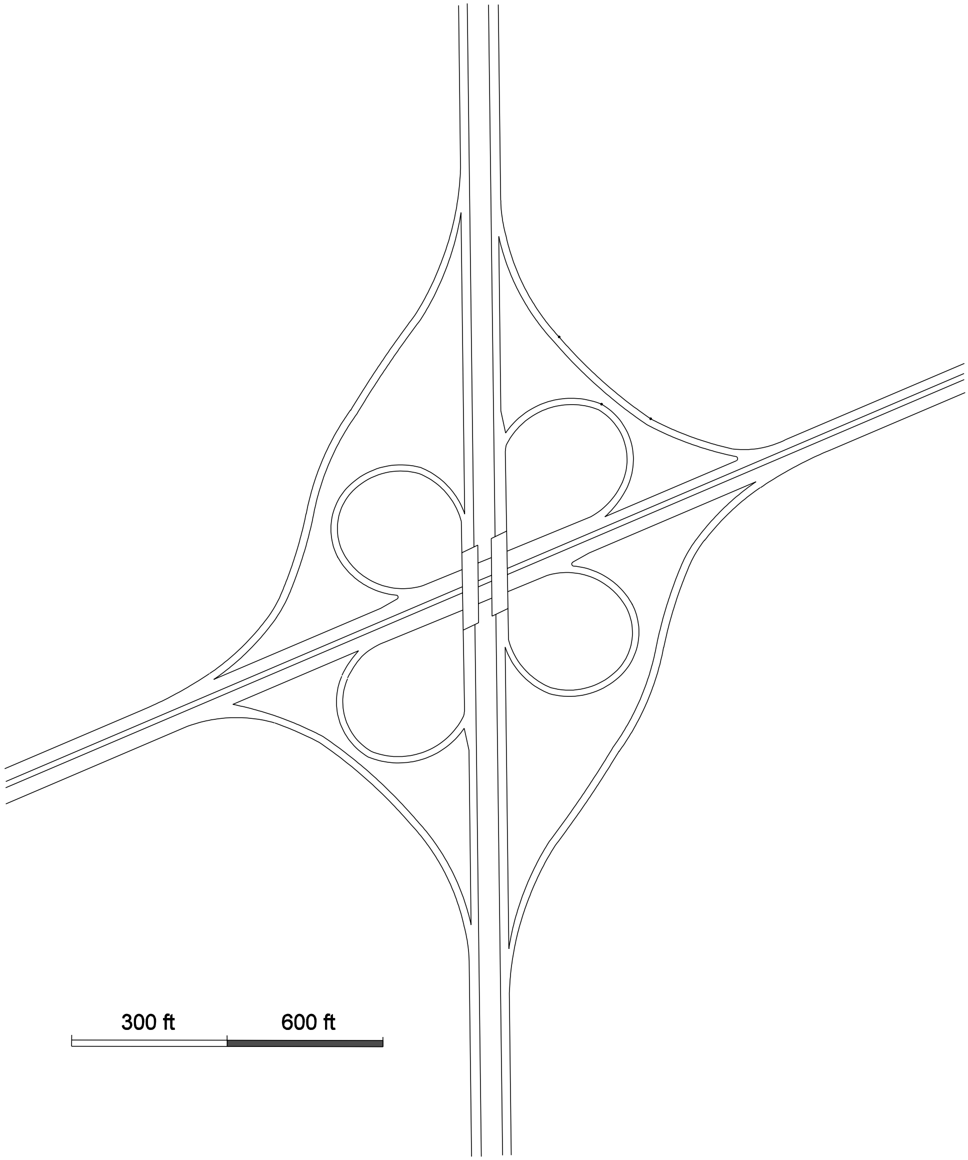
Check-point	Luminaire	Transverse		Longitudinal		Illumination (ft-cd)	
		Dist. (ft)	Ratio	Dist. (ft)	Ratio	Contrib.	Total
A	1	60	1.5	380	9.67	NEG.	13.45
	2	0	0	0	0	13.45	
	3	60	1.5	380	9.67	NEG.	
B	1	--	--	---	---	NEG.	0.33
	2	0	0	190	4.83	0.11	
	3	60	1.5	190	4.83	0.22	
C	1	--	--	---	---	NEG.	0.44
	2	30	0.75	190	4.83	0.22	
	3	30	0.75	190	4.83	0.22	
D	1	0	0	380	9.67	NEG.	1.94
	2	60	1.5	0	0	1.94	
	3	0	0	380	9.67	NEG.	

Notes:

1. *The transverse ratio is the transverse distance divided by the mounting height.*
2. *The longitudinal ratio is the longitudinal distance divided by the mounting height.*
3. *Neglig. = negligible contribution.*

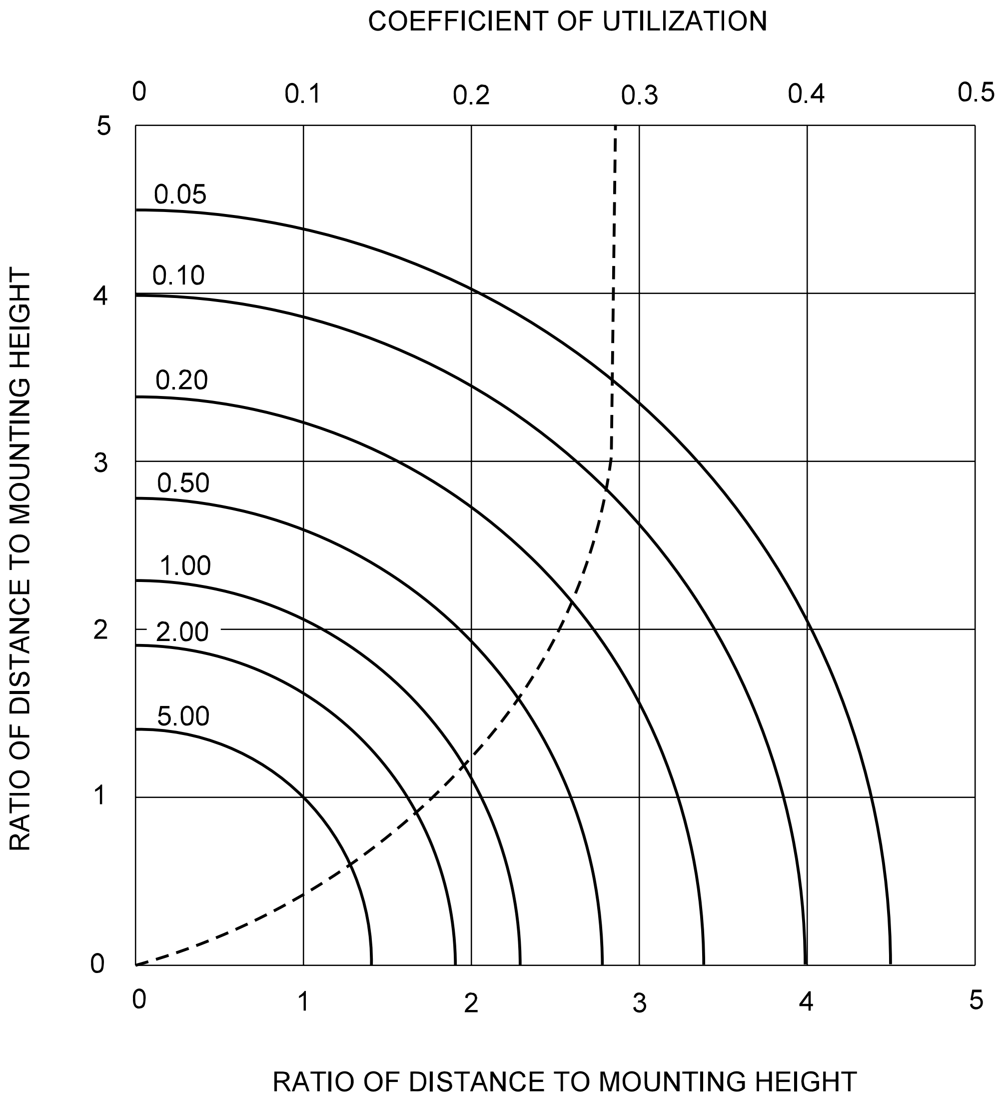
UNADJUSTED ILLUMINATION VALUES, EXAMPLE 78-8.1

Figure 78-8D



URBAN INTERCHANGE LIGHTING
(Example 78-8.2)

Figure 78-8E

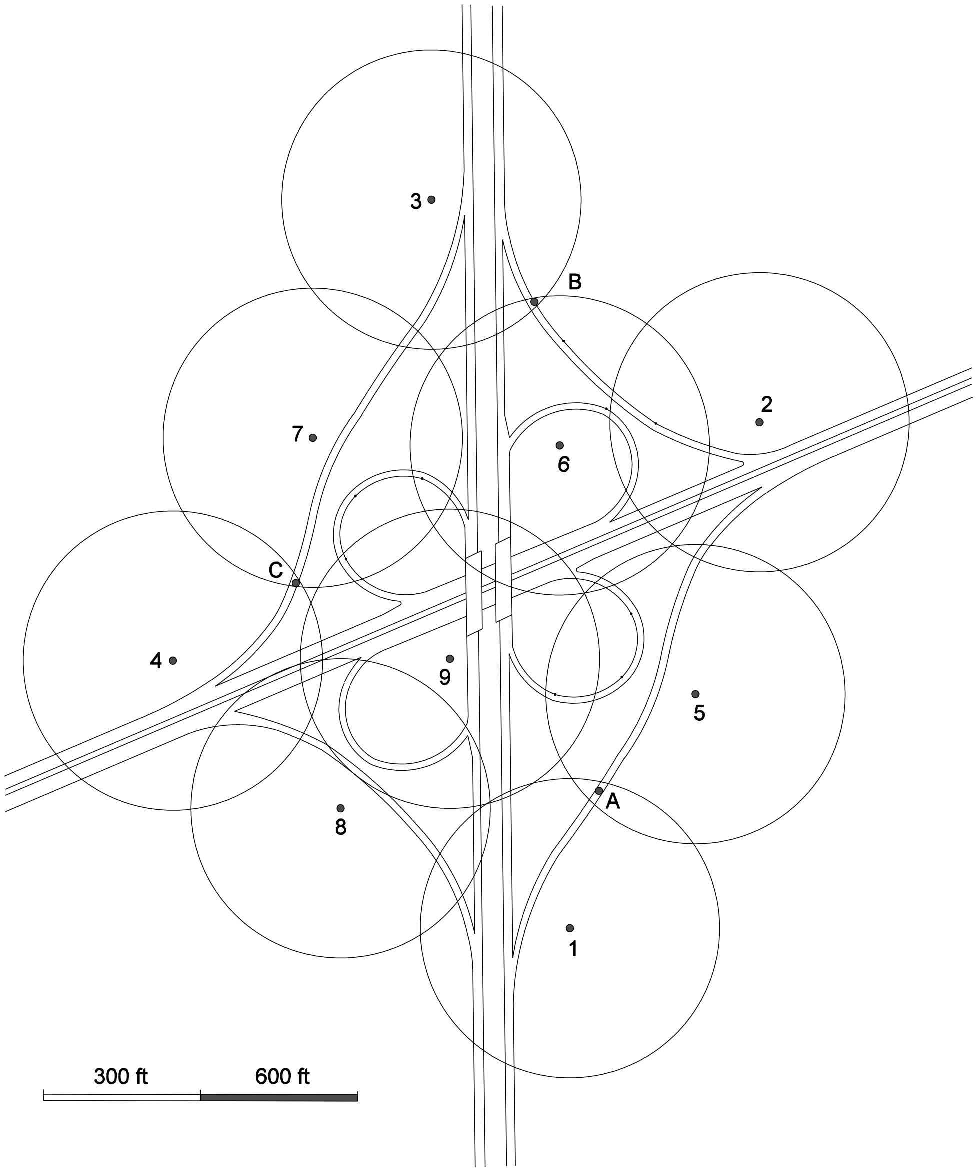


Note: Isolux diagram of horizontal lux on pavement surfaces for a luminaire providing a medium semi-cutoff, Type III light distribution (per 1000 initial lamp lumens). The isolux multiply data are based on a luminaire mounting height of 100 ft. For other mounting heights,the values of isolux shown by the factors below.

Mounting Height (ft):	*60*	*70*	*80*	*90*	*100*	*110*	*120*
Factor:	*2.78*	*2.04*	*1.56*	*1.23*	*1.00*	*0.83*	*0.69*

SAMPLE ISOLUX DIAGRAM
(Example 78-8.2)

Figure 78-8F



INTERCHANGE LIGHTING LAYOUT
(Example 78-8.2)

Figure 78-8G

Check-point	Mast No.	Distance from Mast (ft)	Illumination (ft-cd)	
			Contribution	Total
A	1	290	4.41	9.79
	5	290	4.41	
	9	400	0.97	
B	3	300	3.66	7.32
	6	300	3.66	
C	4	300	3.66	9.04
	7	300	3.66	
	9	360	1.72	

UNADJUSTED ILLUMINATION VALUES
(EXAMPLE 78-8.2)

Figure 78-8H

CHAPTER 503

Traffic Maintenance

Design Memorandum	Revision Date	Publication Date*	Sections Affected
12-07	May 2012	Jan. 2013	83-2.06, Figure 83-2E
12-10	June 2012	Jan. 2013	83-2.03

*Revisions will appear in the next published edition of the *Indiana Design Manual*.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER EIGHTY-ONE

TRANSPORTATION MANAGEMENT PLANS

81-1.0 GENERAL

81-1.01 Purpose

A transportation management plan (TMP) is an overall strategy for accommodating traffic during construction. The TMP not only must address the alternatives confined to the project site, but it must also evaluate the impact traffic will have on the entire corridor. The TMP will address the proposed traffic-control plan, alternative traffic control applications, the effect traffic will have on other facilities, local concerns, cost effectiveness of various alternatives, etc. For a large project, a TMP team may be organized during the preliminary-engineering stage to study the traffic-control alternatives and their effect on the corridor.

The TMP includes the traffic-control plan (TCP). The major difference between a TMP and a TCP is that the TCP focuses on the maintenance and protection of traffic within the construction zone, and the TMP addresses project-related impacts throughout the project corridor and sometimes beyond. The designer will be responsible for incorporating the TMP objectives into the TCP. Changes made during the preparation of the TCP will affect the overall TMP. For example, a lane closure which causes a large queue on a freeway may cause traffic to divert to a nearby urban arterial. This may require signal coordination, lane widening, turn restrictions, etc., on the arterial to improve its capacity. Chapter Eighty-two discusses INDOT criteria for a TCP. If the TMP was not developed during the preliminary-engineering stage, it will be the designer's responsibility to ensure that a reasonable transportation-management strategy has been incorporated into the TCP.

81-1.02 Application

A formal transportation-management plan will most often not be required. However, the concepts discussed in this Chapter should be considered for each project. A formal TMP, including a TMP team, may be considered for a project that has one or more of the characteristics as follows:

1. the project scope of work consists of major reconstruction or new construction (e.g., 4R Interstate-route);

2. high traffic volume;

3. is in an urban or suburban area;

4. there may be significant detrimental impacts on mobility for either through or local trips in the corridor;

5. the facility's capacity will be significantly reduced (e.g., lane, ramp, or interchange closure);

6. alternate routing will be necessary (e.g., detour routing for hazardous materials);

7. there will be significant impacts on local communities and businesses (e.g., emergency vehicles, school buses);

8. timing and seasonal impacts may be significant; or

9. there will be significant grade changes.

Where a series of proposed projects are along the same corridor or along corridors of close proximity, a single TMP covering all such projects should be used. If circumstances prohibit a single TMP, the individual TMPs should be coordinated.

81-1.03 TMP Development

81-1.03(01) Procedure

Where a TMP is used, the following procedure applies.

1. TMP Determination. The Environmental Policy Team, with input from the district, the Office of Urban and Corridor Planning, and the Office of Pavement Engineering, will determine if there is a need for a TMP during the scoping process. The Environmental Policy Team will collect the initial data and conduct the initial analyses to determine whether or not a TMP will be required.

2. TMP-Team Selection. Once it has been determined that a TMP is required, the Environmental Policy Team will initially recommend who the TMP team representatives will be, based on the purpose, goals, and constraints of the TMP. Section 81-1.03(02) lists the members for a TMP-team project.

3. TMP-Team Responsibilities. Section 81-1.03(03) discusses the TMP-team responsibilities during the scoping process, project design, and construction. The expected level of traffic impact will dictate the extent and nature of the TMP team's responsibilities.

4. Preliminary Engineering Studies Report. The Office of Environmental Services' Environmental Policy Team will incorporate the TMP recommendations into the Engineer's Report. If improvements are required to other facilities (e.g., widening of detour route), it is important that these improvements be implemented as soon as practical prior to construction of the mainline facility. Local agencies should be provided sufficient opportunity to complete their improvements before construction begins. Agreements may be necessary between the State and local agencies to determine cost sharing arrangements or approval of a local road as an alternate route.

5. Design. During the design phase, it will be the designer's responsibility to implement the recommendations of the TMP team. The designer may be required to collect additional data and conduct additional analyses, as necessary. The TMP team should be consulted if design or TCP decisions dictate a revision to the proposed TMP. During this project stage, representatives from local agencies, businesses, homeowner associations, etc., may be added to the TMP team.

6. Construction. The TMP will be implemented during construction. All significant proposed changes to the TMP by the district or the contractor must be reviewed with the TMP team prior to implementation. For a larger project, the district will appoint a TMP coordinator. A public-relations campaign may be required prior to construction. During construction, the district will be responsible for collecting data on the TMP so that the TMP team can prepare a report on the successes and failures of the TMP. See Item 7 below to determine the applicable data to be collected.

7. Final Report. Upon project completion, the TMP team will prepare a report identifying the successes and failures of the TMP. This report should discuss the following:

   a. an overall statement reflecting the usefulness of the TMP;
   b. where changes were necessary to correct oversights in the TMP;
   c. what changes were made to the original plan and if they were successful;
   d. public reaction to the TMP;
   e. the average delay time encountered (e.g., average queue length, slowdown extent);
   f. identification of the peak loading times;
   g. frequency of legitimate complaints and the nature of the complaints;
   h. types of accidents that occurred during construction;
   i. suggested improvements or changes for similar future projects; and
   j. what areas of the TMP were successfully implemented.

81-1.03(02) TMP Team

A well-balanced TMP team is an important ingredient for a successful project. The variety of disciplines represented presents an effective liaison group to meet the various needs of a TMP. Depending on the project logistics, the team composition may vary from project to project. The Office of Environmental Services' Environmental Policy Team will determine the team's composition. The TMP team may include representatives from the entities as follows:

1. Office of Traffic Engineering;
2. Office of Environmental Services, Environment Assessment Team;
3. Production Management Division;
4. district Office of Traffic;
5. district Office of Design;
6. District Construction Team;
7. Traffic Control Review Committee;
8. FHWA;
9. Local government agency;
10. Planning Division;
11. Office of Communications; and
12. others as deemed necessary (e.g., State Police, hospitals, etc.).

81-1.03(03) TMP-Team Responsibilities

The anticipated traffic impacts will dictate the extent and nature of the TMP team's responsibilities. These may include all or part of the functions as follows:

1. collecting data (e.g., traffic counts, accident history, roadway geometrics, proposed developments, operating speeds);

2. conducting analyses (e.g., capacity analyses, traffic impact studies, safety studies, queuing analysis);

3. reviewing design alternates;

4. reviewing traffic-control alternates;

5. reviewing the adequacy of alternate routes (e.g., geometrics, capacity, safety, structural);

6. reviewing on-site and off-site traffic operational improvements (e.g., signal improvements, parking restrictions);

7. reviewing construction phasing and scheduling alternates;

8. determining the cost of various options and improvements;

9. determining which options are the most cost effective;

10. coordinating with local officials and businesses;

11. coordinating funding and timing with other projects within the corridor;

12. coordinating the design with other TMP plans in the region;

13. planning for emergency responses (incident management);

14. planning rideshare and transit strategies;

15. providing recommendations for the Engineer's Report;

16. reviewing design and TMP changes made by the designer to ensure that they satisfy the TMP objectives;

17. reviewing proposed changes made by the contractor or project engineer during construction; and

18. evaluating and preparing a report on the successes and failures of the TMP after construction.

81-1.04 Public-Relations Information

For a TMP to be successful, it often requires public involvement and revision of its traveling habits. The following discusses how the public can become informed and involved in the TMP.

1. Public-Relations Campaign. It is important that the public be informed initially and be kept informed in a timely manner to ensure that the TMP will work. The elements of a public-relations campaign to be considered where significant impacts to traffic are expected are as follows:

    a. information provided to news media;
    b. television advertisements;
    c. radio advertisements;
    d. brochures to be passed out to motorists at key locations;
    e. information given to motorists at rest area or welcome centers; or
    f. contacting local businesses with large numbers of affected employees or customers.

2. Car and Van Pooling. Car and van pooling campaigns may be considered where it may be expected to reduce the number of vehicles through a work zone and where it appears practical to expect a successful campaign.

3. Charter Bus. A charter bus may be considered where it could be expected to draw a large number of users along a corridor and where it can be shown to be more cost effective than other alternatives.

4. Transit Incentives. Transit incentives provided to transit customers and companies may be considered where it can be shown to be more cost effective than other alternatives.

81-2.0 TRAFFIC-CONTROL MANAGEMENT

81-2.01 Terminology

The following definitions are used to define the time required for construction, maintenance, or utility work.

1. Mobile Work Zone. A work site that is continuously being moved during the period while work is actively in progress.

2. Short-Duration Work Zone. A work site that occupies a location for up to 1 hour.

3. Short-Term Stationary Work Zone. A work site that requires traffic control in the same location and where the activity lasts from 1 to 12 hours.

4. Intermediate-Term Stationary Work Zone. A work site that requires traffic control in the same location and occupies a location from overnight to 3 days.

5. Long-Term Stationary Work Zone. A work site that requires traffic control in the same location and where the activity lasts longer than 3 days.

81-2.02 Work-Zone Type

The work zone types that may be considered in a TMP are described below. A work site which is completely off the roadway and does not disrupt traffic is not addressed, as it will not have a major effect on traffic.

1. Lane Constriction. This work-zone type is configured by reducing the width of one or more lanes to retain the number of lanes normally available to traffic. An example of lane

constriction is shown in Figure 81-2A. This application is the least disruptive work-zone type, but it is only appropriate if the work area is mostly outside the normal traffic lanes. Narrow lane widths may reduce the facility's capacity, especially where there is significant truck traffic. The use of a shoulder as part of the lane width will help reduce the amount of lane-width reduction that may be required. Where this application is applied for a long-term work zone, the current lane markings must be obliterated to avoid motorist confusion. Section 82-3.02 discusses the minimum lane width that must be provided.

2. Lane Closure. This work-zone type closes one or more normal traffic lanes. A lane-closure example is shown in Figure 81-2B. Capacity and delay analyses may be required to determine whether serious congestion will result from a lane closure. Use of the shoulder or median area as a temporary lane will help mitigate the problems arising from the loss in capacity. Upgrading or replacement of existing pavement or placement of temporary pavement may be necessary.

3. One-Lane, Two-Way Operation. This work-zone type involves utilizing one lane for both directions of traffic. Figure 81-2C illustrates a one-lane, two-way operation work zone. Flaggers or signals are used to coordinate the two directions of traffic. Signing alone may be sufficient for a short-term work zone on a very low-volume, 2-lane road. This work-zone type is applicable only for a low-volume road or for a short-term. INDOT has developed a computer program, WORK, which determines the expected delays and queue lengths for this work-zone type.

4. Runaround. This work-zone type involves the total closure of the roadway (one or both directions) where work is being performed and the traffic is rerouted to a temporary roadway constructed within the highway right-of-way. A runaround example is shown in Figure 81-2D. This application may require the purchase of temporary right of way and requires extensive preparation of the temporary roadway.

5. Intermittent Closure. This work-zone type involves stopping all traffic in one or both directions for a relatively short period of time to allow the work to proceed. This application is illustrated in Figure 81-2E. After a specific time, depending on traffic volume, the roadway is re-opened and all vehicles can travel through the area. This application is appropriate only on a low-volume roadway or at times of very low volume (e.g., Sunday morning).

6. Use of Shoulder or Median. This work-zone type involves using the shoulder or the median as a temporary traffic lane. Figure 81-2F illustrates an example. To use this technique, it may be necessary to upgrade the shoulder to adequately support the anticipated traffic loads. This technique may be used in combination with other work-zone types or as a separate technique.

7. Crossover. This work-zone type involves routing all or a portion of one direction of the traffic stream across the median to the opposite traffic lanes. This application can also incorporate the use of the shoulder or a lane constriction to maintain the same number of lanes. Examples of crossovers are shown in Figure 81-2G. Section 82-3.0 discusses the geometric design criteria that should be used to develop a crossover. Item 8 below addresses two-way traffic on a divided facility.

8. Two-Way Traffic on Divided Facility. This work-zone type involves transferring traffic from a divided facility to two-way operations on one roadway. This application requires consideration in the planning, design, and construction phases. This application should be used only if one or more conditions can be applied as follows:

   a. an alternate suitable detour is unavailable or is not cost-effective;
   b. the use of temporary lanes or shoulders are impractical;
   c. construction cannot reasonably occur with one lane open;
   d. construction time will be significantly reduced using this option;
   e. all safety issues can be reasonably addressed; or
   f. pavement and shoulder structures can be reasonably upgraded.

   A crossover as discussed in Item 7 above will be required for this application. Section 82-6.02 discusses the design issues relative to designing a two-way application (e.g., maximum length). If this application is used, opposing traffic must be separated with positive barriers, drums, cones, or vertical panels throughout the length of the two-way operation. Section 83-3.0 discusses the channelization devices that may be used with this layout. One construction technique involves the reconstruction of the shoulder to allow it to be used as a travel lane. Once traffic is shifted to a two-way operation, the availability of the shoulder as a third lane provides for an improved buffer between the bidirectional traffic and may facilitate emergency access.

9. Detour. This work-zone type involves total closure of the roadway (one or both directions) where work is being performed and rerouting the traffic to existing alternate facilities. This application is desirable where there is unused capacity on a road running parallel to the closed roadway. In addition to maintaining an official detour, INDOT may be required to repair a county highway being used as an unofficial detour, per current detour policy.

81-2.03 Work-Zone Traffic-Control Strategy

Selection of the appropriate work-zone type represents one of the most significant elements of a control strategy. Other elements of a control strategy that should be considered include length of the work zone, time of work, number of lanes, widths of lanes, traffic speeds, or right of way. Considering these and other factors, reasonable alternatives can be narrowed to a select few for further review. Only a small number of feasible work-zone alternatives will emerge for a particular project and only one may be practical. Identification of these alternates at an early stage in the planning process can significantly reduce the analysis effort necessary.

Figure 81-2H provides guidelines for identifying feasible work-zone alternates based on roadway type, lane closure requirements, shoulder width, traffic volume, availability of right of way, and detour routes. However, every work-zone location will have a wide variation of conditions and an all-inclusive selection matrix is not practical.

In using Figure 81-2H, local policy and regulations should be recognized. Many jurisdictions have adopted safety regulations and public convenience policies as safeguards against the unacceptable impacts of work-zones. These regulations and policies may impose additional constraints regarding the types of control strategies that can be implemented. Knowing these constraints can help eliminate infeasible alternates from consideration. The public convenience policies or local regulations may specify peak hour restrictions, access requirements, noise level limitations, material storage and handling, excavation procedures, work-zone lengths, and number of traffic lanes that must remain open.

81-3.0 TRANSPORTATION-MANAGEMENT-PLAN STRATEGIES

In addition to the traffic-control strategies discussed in Section 81-2.0, the following provides brief summaries of the strategies that may be considered during the development of a TMP. These strategies must be reviewed and adjusted to meet each project location and situation. The strategies discussed below are not all-inclusive, and that other options may be applicable for the location under consideration.

81-3.01 Construction Phasing

How a project is constructed can greatly impact the traffic flow through the work area. The following discusses the basic construction phases for freeway reconstruction.

81-3.01(01) Reconstruction by Halves or Sides

This approach involves the reconstruction of all lanes in one direction while the opposing lanes share the same roadway with traffic in the other direction. This basic concept is illustrated in Figure 81-3A, Reconstruction by Halves or Sides. For a 6-lane facility, traffic is restricted to two lanes in each direction. This may require using the shoulders, reducing the lane widths, or providing minor widening. Under certain circumstances, depending on the median width and shoulder configuration, the inner lane of the two-way operation may not be readily accessible during an emergency.

Providing for emergency turnouts or emergency-vehicle access at appropriate intervals on the segment under construction may be considered. Some advantages and disadvantages of this strategy include the following.

1. Advantages.

    a. It provides an effective work area.
    b. Workers are well-separated from the traffic stream.
    c. Work-site access can be arranged with minimal interference from the general traffic flow.

2. Disadvantages.

    a. Crossovers are required.
    b. There is a need for positive separation of the traffic streams.
    c. There are potential emergency access problems in the inner lane.
    d. There may be problems at interchanges with traffic crossing the work zone.

81-3.01(02) Parallel or Adjacent Reconstruction

This approach involves a variety of lane-closure sequences. A typical sequence of this approach is as follows, which is also illustrated in Figure 81-3B, Parallel or Adjacent Reconstruction.

1. The existing shoulders are widened and strengthened.

2. Traffic is shifted to the shoulders to allow construction of the inner lanes and median reconstruction.

3. Traffic is then shifted to the newly-constructed inner lanes to allow reconstruction of the outer lanes.

4. After construction is completed, traffic is returned to the normal travel lanes.

An advantage of this strategy is that traffic need not cross over the median and does not operate in a two-way operation. Some of the disadvantages include the following:

1. it provides a more constrained work area for the contractor;
2. work crews are closer to moving traffic; and
3. access to the construction zone involves entry and exit from the travel lanes.

A 6-lane facility is reduced to 2 lanes in each direction and the above sequence is used. If closing the middle lane, it is preferable to keep the two through lanes on the same side of the construction zone (e.g., by using the shoulder) versus splitting the two lanes on either side of the construction zone.

81-3.01(03) Serial or Segmental Reconstruction

This strategy consists of permitting only short segments of the facility to be under construction at one time. This also requires one or more of the other concepts for traffic accommodation. An example of this application may include a bridge-deck replacement where each segment can be completed within a 12-hour time period. This concept is illustrated in Figure 81-3C, Serial or Segmental Reconstruction.

The advantages of this strategy include relatively short work zones, and few if any interchanges are impacted at one time. A disadvantage of this strategy is that the overall time period that the facility is under construction may be lengthened considerably because the construction for each segment will proceed independently. Therefore, the exposure to the potentially hazardous conditions of a work zone for both the traveling public and the work force may be substantially greater than with one of the other strategies.

81-3.01(04) Complete Closure

Complete closure of the facility or closure of one direction of travel may be an effective strategy. This strategy may also be effective for only certain hours of the day (e.g., 8 p.m. to 6 a.m. on weekdays and from 8 p.m. to 8 a.m. on weekends). Some of the advantages and disadvantages of this strategy include the following.

1. Advantages.
    a. Increases the safety for construction workers.
    b. Provides cost and time savings.
    c. Reduces the overall travel impacts to the public due to reduced construction time.
2. Disadvantages.
    a. Potentially significant short-term travel impacts to the public.
    b. Potential increase in traffic congestion on other routes.
    c. May need to construct a detour or runaround.
    d. Potential adverse impact on businesses due to trip suppression (not enough traffic).
    e. Potential adverse impact to businesses on alternate routes (too much traffic).

81-3.01(05) Combinations

A combination of construction sequences may be the best strategy. An example is reconstructing existing shoulders prior to the initiation of parallel construction activities. The sequence of construction can be as follows.

1. Phase A. Reconstruct shoulders as appropriate to allow one side of the roadway to accommodate four lanes.

2. Phase B. Shift traffic to the four available lanes on one side of the roadway.

3. Phase C. Shift traffic to the newly constructed side of the roadway using the additional reconstructed shoulder lane.

Other combination-type construction sequences involve the reconstruction of interchanges where both sequential and parallel activities may occur simultaneously. Ramps are reconstructed in a sequential arrangement, involving closure during construction with temporary detours to adjacent or alternate freeway-access points.

81-3.02 On-Site Strategies

81-3.02(01) Traffic-Control Devices

The following traffic-control devices applications may be considered when developing a TMP.

1. Changeable-Message Sign. This device may be used where a static sign message is not sufficient to handle the changing conditions of a work zone (e.g., lane closure, ramp closure, advise motorists of conditions for which they must possibly react).

2. Additional-Information Panel Sign. This may be used to give the motorist additional information about a work zone. The message should be pertinent to the likely conditions the motorist will encounter.

3. Traffic-Signals Interconnection. Consider interconnecting traffic signals where the benefit of moving traffic through a work zone more efficiently will be enhanced by adding interconnection between the traffic signals on the system.

4. Traffic-Signal Timing. Traffic-signal timing changes should be considered for all traffic signals within a work zone for which capacity improvements can be gained. Adding or deleting signal phases may be required for changes in travel patterns.

5. Highway-Advisory Radio. Consider using highway-advisory radio where changing work-zone conditions make it important to give the motorist a longer, more accurate message than can be obtained through the use of signs or other means. This option requires additional information and signing to alert motorists.

6. Temporary Work-Site Speed-Limit Sign. A reduced regulatory speed limit may be warranted where work activity may constitute a hazard to traffic, especially for a lane closure. The *Indiana Statutes* permit INDOT to establish a reduced work-site speed limit without an Official Action. Section 83-2.03 provides the criteria for establishing speed-limit signing in a construction zone.

7. Flashing-Arrow Sign. A flashing-arrow sign is used to supplement conventional traffic control devices. It is warranted where additional warning or directional information is required to assist in merging and controlling traffic through and around the work activity. Section 83-2.07 provides additional guidance for the use of a flashing-arrow sign.

81-3.02(02) Capacity

Each construction site will affect the capacity of the existing facility. The extent that the roadway is occupied for work and safety purposes will determine the number of strategies required to compensate for the loss of capacity. Some of the following capacity strategies may be considered when developing a TMP.

1. Temporary Parking Restriction. One option to increase capacity is to eliminate on-street parking to create an additional lane or to reduce traffic conflicts. However, the concerns of on-street parking for local businesses must be addressed. The elimination can be for only during a peak traffic-volume period or for the entire 24-h day.

2. Restriction of Trucks. Restriction of trucks may increase the facility's capacity. However consideration must be given to State or local ordinances, and the availability and suitability of alternate routes that the restricted trucks would be required to take.

3. Turn Restrictions. Turn restrictions should be considered where it may be necessary for capacity or safety reasons. The turn restrictions may be at intersections or drives. Turn restrictions can be for only during a peak traffic-volume period or for the entire 24-h day.

4. Reversible or Contra-Flow Lane. Consider the use of a reversible or contra-flow lane where the peak-traffic flow distribution is in one direction for a specified period of time. The use of such a lane may be limited in use due to the cost of providing and maintaining the daily changes required. There also may be safety considerations which will need to be evaluated if such a lane is contemplated.

5. High-Occupancy Vehicle (HOV) Lane. An HOV lane may be considered where a dedicated lane for high-occupancy vehicles is available and it is desired to discourage use of single-occupancy vehicles. The use of an HOV lane can be during a peak traffic-volume period or for the entire 24-h day. Due to the lack of driver familiarity with this type of lane, it is unlikely that its use will be appropriate.

6. Ramp Metering. Ramp metering may be considered where it is necessary to restrict the amount of traffic entering a freeway for capacity and safety reasons. Ramp metering may be used during peak traffic-volume period or for the entire 24-h day. The impact of ramp metering on an intersecting road will also need to be considered (e.g., traffic backup).

7. Six-Lane Facility. Where three lanes cannot be maintained in both directions, determine if three lanes can be provided in one direction with two lanes in the other direction.

81-3.02(03) Other On-Site Considerations

In addition to the above strategies, the following other on-site strategies may be considered in developing a TMP.

1. Ramp Closure (Short or Intermediate Term). This may be necessary for construction purposes. If a closure is required, additional signage will be necessary to forewarn the motorist. Signs should be posted on the affected ramp two weeks in advance to advise the motorist of the closure date or portion of the day during which the ramp will be closed.

2. Ramp Closure (Long Term). This may be necessary to construct or to improve traffic flow on the mainline. Local access and business impacts should be considered before deciding on a long-term ramp closure. Also consider the user costs for a detour route and the capacity and safety impact of the detour route. Two adjacent ramps should not be closed at the same time unless necessary for safety reasons.

3. Incident Management. Consider the use of on-site tow trucks for a freeway work zone with limited to unavailable shoulder width. They should also be considered where an accident or breakdown would seriously impact traffic flow and cause significant backups and delays.

4. Special Materials. Examine the use of fast-setting or precast concrete, or other special materials where traffic restrictions must be minimized (e.g., ramp, intersection).

5. Lane Rental by Contractor. In this application, a contractor formulates its bid around the number of hours that it expects to keep a number of lane-miles closed, and then can earn or

lose money if the actual number is higher or lower than that bid. This concept has not yet had widespread use.

6. Police Patrol for Speed Control. A police patrol may be required to ensure that vehicular speeds are at or below the posted speed limit, or for other safety reasons. Because this requires a special funding mechanism and special provisions, the designer will need to coordinate this with the Highway Operations Division.

7. Incentive/Disincentive. Consider adding an incentive/disincentive provision to minimize the time that a facility may be affected by construction. Section 81-3.05 discusses the types of work for which an incentive/disincentive provision should be considered.

8. A + B Bidding. If the impact of the construction on traffic is significant, the designer should consider the A + B bidding incentive. Section 81-3.06 provides information on A + B bidding.

81-3.03 Off-Site Strategies

Where construction will significantly impact the traffic flow away from the work zone, the following off-site strategies may be considered in the TMP.

1. Capacity Improvement. Additional improvements on the alternate route may be necessary for capacity reasons to handle the expected diversion of traffic. Examples of capacity improvement include prohibiting or restricting parking, turn restrictions, and truck restrictions, all as described in.81-3.02(01), additional pavement width, or adding a turn lane.

2. Trailblazing to Attraction or Point of Interest. Trailblazing may be necessary to guide the motorist to an attraction or point of interest where the normal route is closed or seriously restricted, or where an alternate route to the attraction or point of interest would assist traffic which would otherwise travel through the work zone.

81-3.04 Scheduling

Project scheduling can affect the overall success of the TMP. For example, restrictive scheduling may be required to facilitate the opening of a highway prior to a special event. In determining a construction schedule, the following should be considered.

1. Short Schedule. A schedule to minimize construction activities and disruption to traffic may be required if motorist user costs are expected to be excessive. However, a short schedule may increase the cost of the project.

2. Longer Schedule. A longer schedule of construction activities may be cost effective if it does not significantly increase the adverse impact to the motorist. The contractor may offer to provide a lower price for a longer schedule.

3. Time-of-Day or Day-of-Week Restriction. This type of restriction may be necessary if the work-zone capacity cannot accommodate the expected demand during a peak traffic period and other measures are not as cost effective. For example, night work may be required to allow longer work hours than can be provided between morning and afternoon peaks and to decrease the excessive traffic delays or congestion associated with lane closures during the daytime.

4. Project Staging. Project staging or completing smaller portions of a project one portion at a time may be necessary to limit disruption to traffic. However, construction activity in the same area over several seasons should be discouraged.

5. Combining with Other Work. Projects within a corridor may be combined or scheduled at the same time where practical, pending available funding, to minimize impacts to the motoring public.

81-3.05 Incentive/Disincentive Justification

Incentive/disincentive is used to minimize the time that a facility may be affected by construction. The contractor is provided additional funds if the project is completed early, or is assessed damages if the project is not completed on time. Due to administrative concerns of implementing this concept, limit incentive/disincentive to a project that has one or more of the characteristics as follows:

1. high traffic volume occurs in an urban area;
2. it completes a gap in the highway facility;
3. it severely disrupts traffic or highway services;
4. it significantly increases road user's costs;
5. it significantly impacts adjacent neighborhoods or businesses;
6. it replaces a major bridge that is out of service; or
7. it includes lengthy detours.

Figure 81-3D consists of the Department's worksheet for determining the appropriate incentive/disincentive amount. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/. An incentive/disincentive justification request should be forwarded to the Contract Administration Division's Office of Contracting as soon as practical due to the time required for the Central Office to process the request.

81-3.06 A + B Bidding

Where the impact of the work site is significant, an A + B bidding incentive may be used to encourage the contractor to minimize these impacts by reducing the exposure time. A + B bidding consists of two parts as follows.

1. Part A. The total dollar amount required to complete the work.

2. Part B. The total dollar amount based on peak- and non-peak-traffic-volume lane-closure periods, and the total contract days proposed by the contractor to complete the work.

Part A is determined using the contractor's unit prices and the estimate of quantities determined by the Department. Part B is established by adding together the costs for each of the following:

1. peak-traffic-volume lane-closure periods = (no. of periods) x (cost / lane / period);
2. non-peak-traffic-volume lane = (no. of periods) x (cost / lane / period); plus
3. Contract days = (no. of days) x (cost / day)

The contractor is required to estimate the number of periods that the facility will be closed during peak- and non-peak-traffic-volume hours and the overall number of calendar days required to complete the contract. The cost for each of the above items is determined by the Department and is the same for each bidder.

A + B bidding is used only for comparison purposes to determine a successful bidder. It is not used to determine payments to the contractor. A + B bidding is used in conjunction with incentive/disincentive as discussed in Section 81-3.05. Before adding an A + B bidding special provision to a contract, the designer should coordinate its use with the Highway Operations Division and the district construction engineer.

81-4.0 COST-EFFECTIVE ANALYSES

81-4.01 General

There may be more than one option that will address the problem of traffic congestion during construction. To determine the most appropriate option, the user will need to compare the benefits and costs of each to determine the most appropriate option. Chapter Fifty provides information on economic analyses relative to benefit/cost analysis and safety-cost analysis. The user should review Chapter Fifty in conjunction with the following to determine which option will be the most cost-effective.

A project may not have alternate methods of maintaining traffic. The user-cost calculations will not be required. However, for a project with incentive/disincentive, the user costs must still be determined.

There are computer programs available which the designer may use to determine the cost effectiveness of the various options and alternates. For a freeway, INDOT uses the QUEWZ program. The Department's application of this program is further described in Section 81-4.03.

81-4.02 Cost Evaluation

81-4.02(01) On-Site

If determining the costs of on-site options (e.g., runaround, lane closure, shoulder use), the designer should consider the following:

1. right-of-way cost (temporary and permanent);
2. additional construction costs;
3. effect on wetlands;
4. vehicular delay;
5. user costs (including detour user costs);
6. accident potential; and
7. driving time.

If determining the effect of each on-site option, the designer should also consider the effect the selected option will have on an unofficial detour (i.e., a detour which a motorist selects on his or her own to avoid the construction area). The designer should see the *INDOT Detour Policy* regarding an unofficial local detour.

81-4.02(02) Detour

For an official detour or unofficial detour, the designer must determine the total cost of the detour. To determine the daily detour user costs, use the following equations.

1. Detour User Cost = (Cost in Lost Time) + (Cost in Extra Distance Traveled).

2. Cost of Lost Time = (No. of vehicles detoured) x (increase in travel time per vehicle, h) x (value of motorist's time)

3. Increase in travel time = (length of detour, mi / average detour travel speed, mph) – (length of construction zone, mi / average travel speed through construction zone, mph)

4. Cost in Extra Travel Distance = (net increase in length of travel, mi) x (vehicle operating expense),

   Where:

   The net increase in length of travel distance is the difference between the detour and non-detour distances.

   The value of motorist time not only considers lost wages but also lost free time. A value from $10 to $15 per hour is used.

   The vehicular operating expense includes fuel, maintenance, and depreciation costs, and is set at $0.25 per mile.

In addition to the above detour user costs, the designer must add the cost for improvements needed to the detour route (e.g., repaving, pavement widening, signal improvements). The designer should also consider the effect the detour will have on the community and local businesses.

81-4.03 QUEWZ Program

The Department uses the computer program QUEWZ for a freeway project to determine the queue length and user costs that are associated with work-zone lane closures. Based on the type of lane closure, traffic volume, time schedules, etc., the program will provide the user with the expected queue length and estimated user costs. The Office of Environmental Services' Environment Assessment Team may use this program during the preliminary-engineering stage to compare the various options. The designer may use this program to ensure that the proposed traffic-control plan is still cost effective. The program user should review the user's manual to determine how to use the program.

81-4.03(01) Inputs

The user must provide inputs into the program as follows:

1. lane-closure configurations;
2. the schedule of work activities (e.g., work activity hours, lane-constriction hours); and
3. the traffic volume approaching the freeway segment.

The program provides default values for the following:

1. cost update factor;
2. percentage of trucks;
3. speeds and volumes at various points on a speed-volume curve;
4. capacity of a lane in the work zone;
5. maximum acceptable delay to the motorist; and
6. critical length of queue.

To obtain meaningful results, the designer should consider revising the default values to satisfy the site location. For example, the program assumes that if a queue lasts longer than 20 min some motorists will divert. To account for actual queues and the corresponding user costs, the designer may need to adjust the 20-min time frame to satisfy the project situation. The designer should review the user's manual to determine if the default values are applicable to the location under consideration.

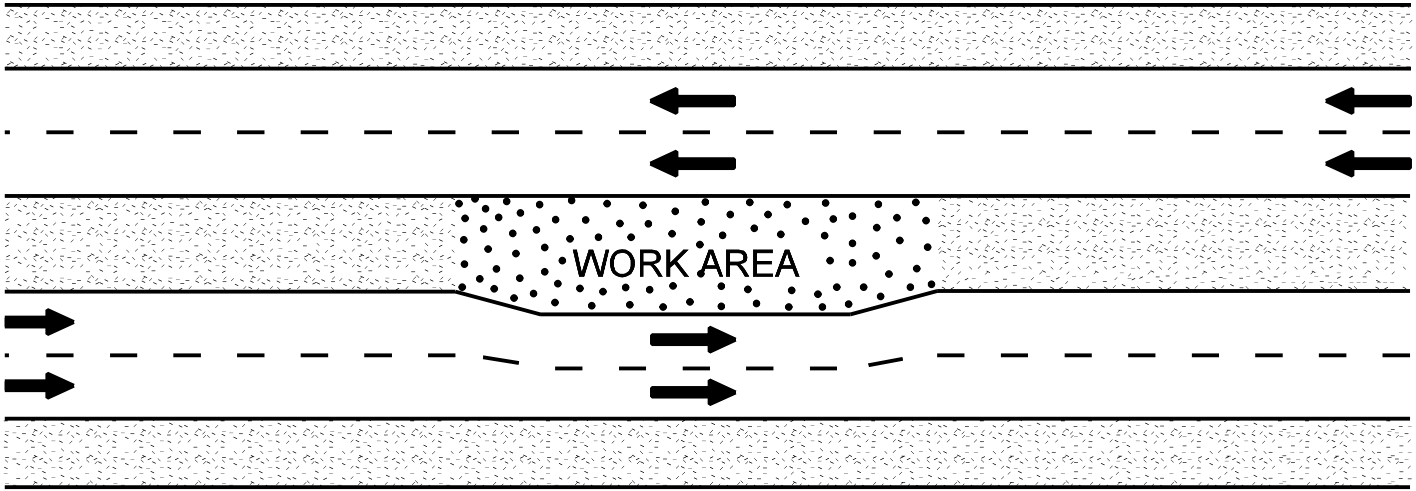
81-4.03(02) Outputs

QUEWZ has two output options: road-user cost and lane-closure schedule. The road-user-cost output option analyzes a specified lane-closure configuration and schedule of work activities, and provides estimates of traffic volume, capacity, speed, queue length, diverted traffic, and additional road user costs for each hour affected by the lane closure. The lane-closure-schedule option summarizes the hours of the day during which a given number of lanes can be closed without causing excessive queuing.

In addition to the values obtained from the program, supplemental user-cost calculations may be required where changes are expected based on existing traffic patterns and volume. Supplemental calculations for a detour are required where an exit or entrance ramp within the construction zone (including that using crossovers) will be closed and where the designer judges that the QUEWZ program is not properly estimating the full amount of diverting mainline traffic.

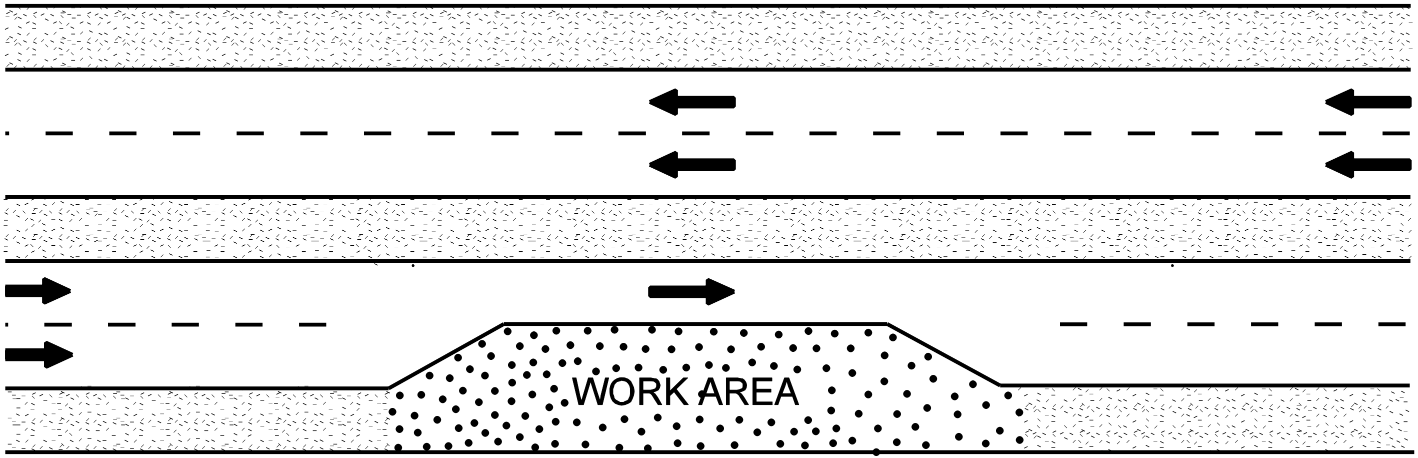
Additional detour user-cost calculations should be conducted if an exit ramp is to be closed. Experience has shown that most or all of the traffic that would have used a ramp if it was open will divert from the mainline before the construction zone. Therefore, the exit-ramp volume should be deleted from the input mainline volume before using QUEWZ.

A closed entrance ramp may or may not lead to changes in the input values for QUEWZ.



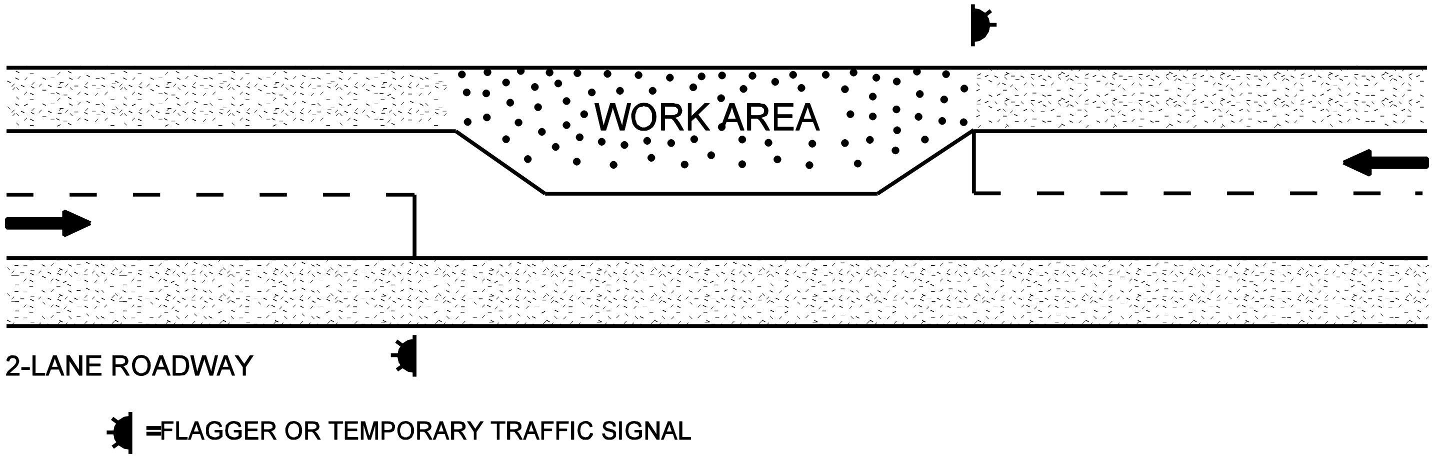
LANE CONSTRUCTION WORK ZONE

Figure 81-2A



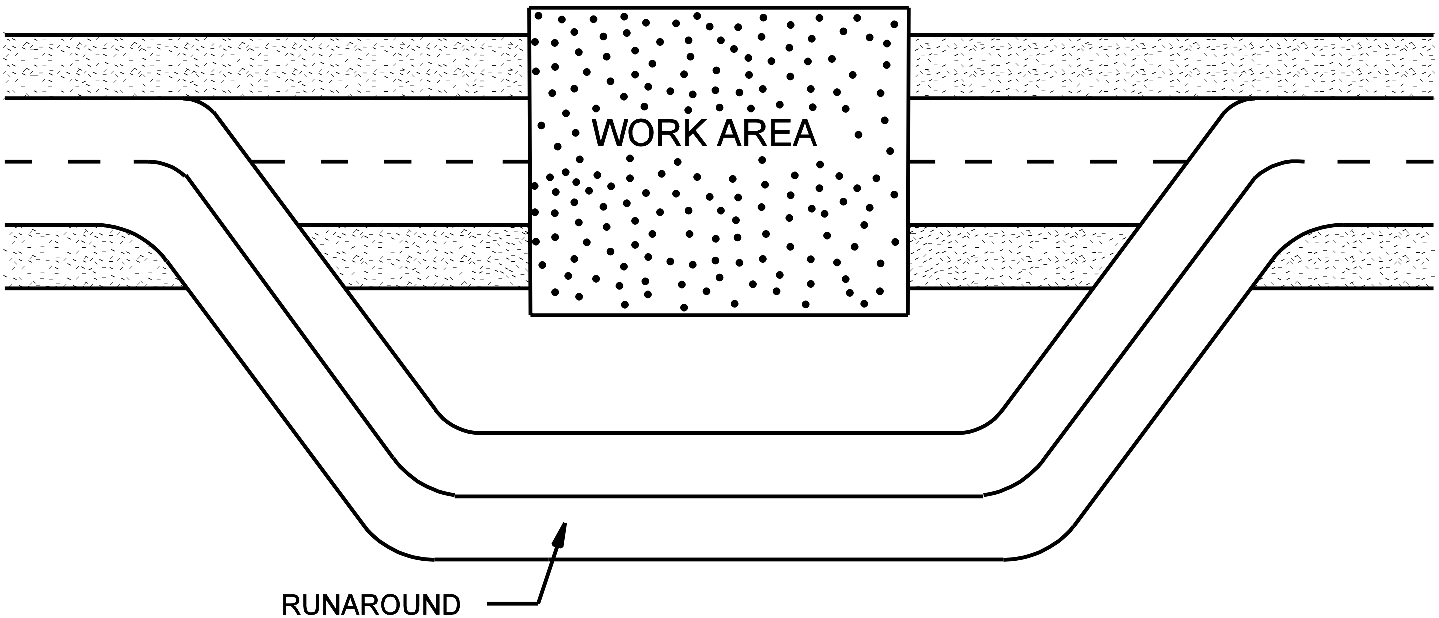
LANE CLOSURE WORK ZONE

Figure 81-2B



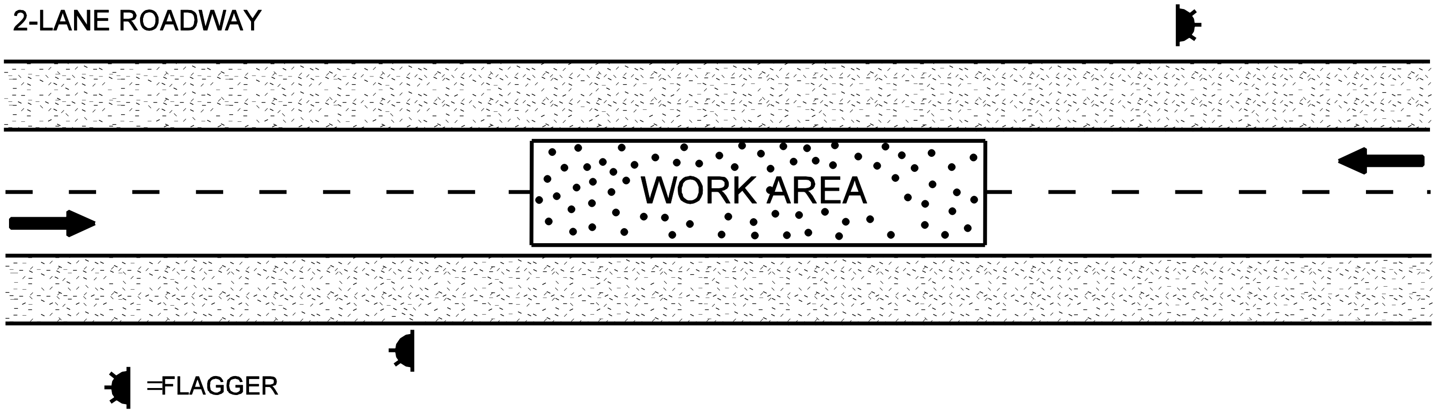
ONE-LANE, TWO-WAY WORK ZONE

Figure 81-2C



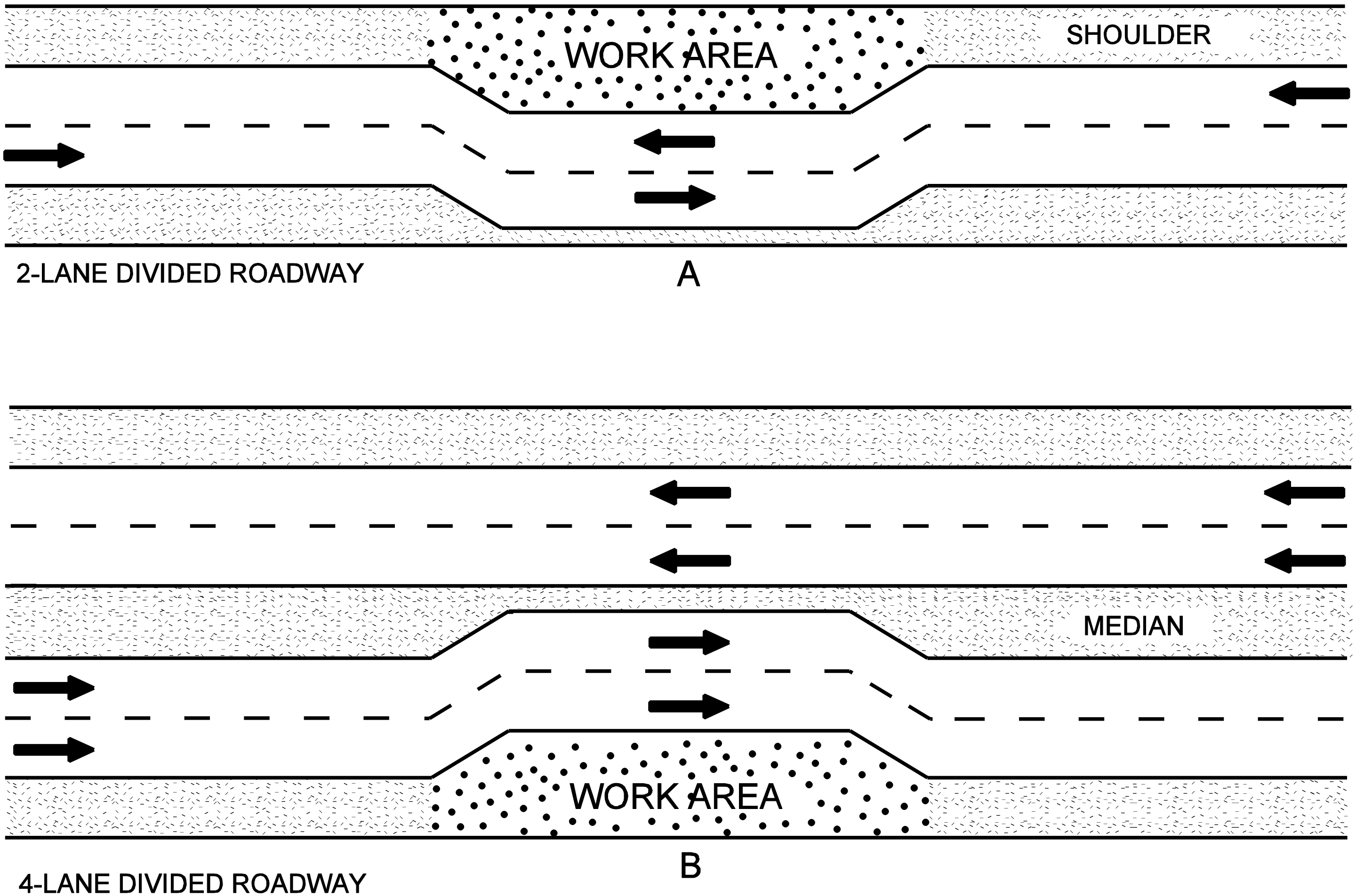
RUNAROUND WORK ZONE

Figure 81-2D



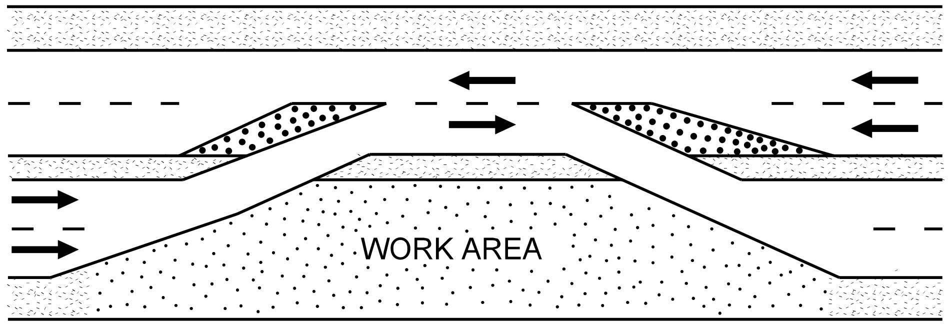
INTERMITTENT CLOSURE

Figure 81-2E

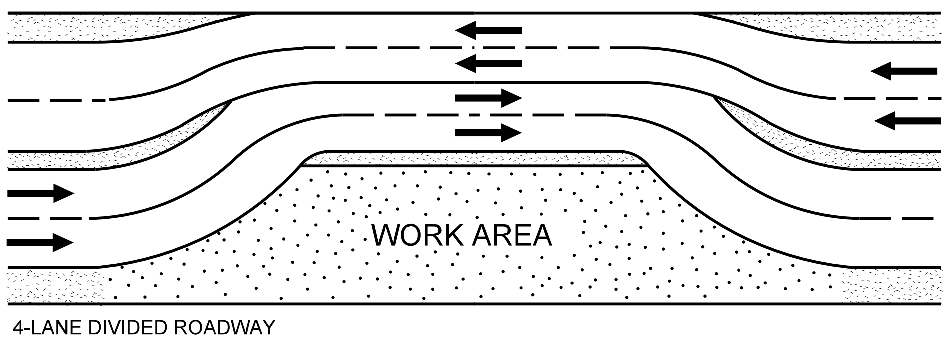


SHOULDER OR MEDIAN USE WORK ZONES

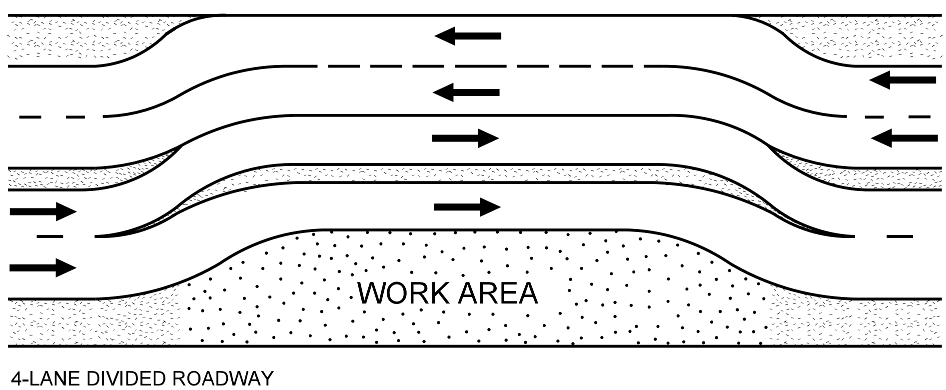
Figure 81-2F



A



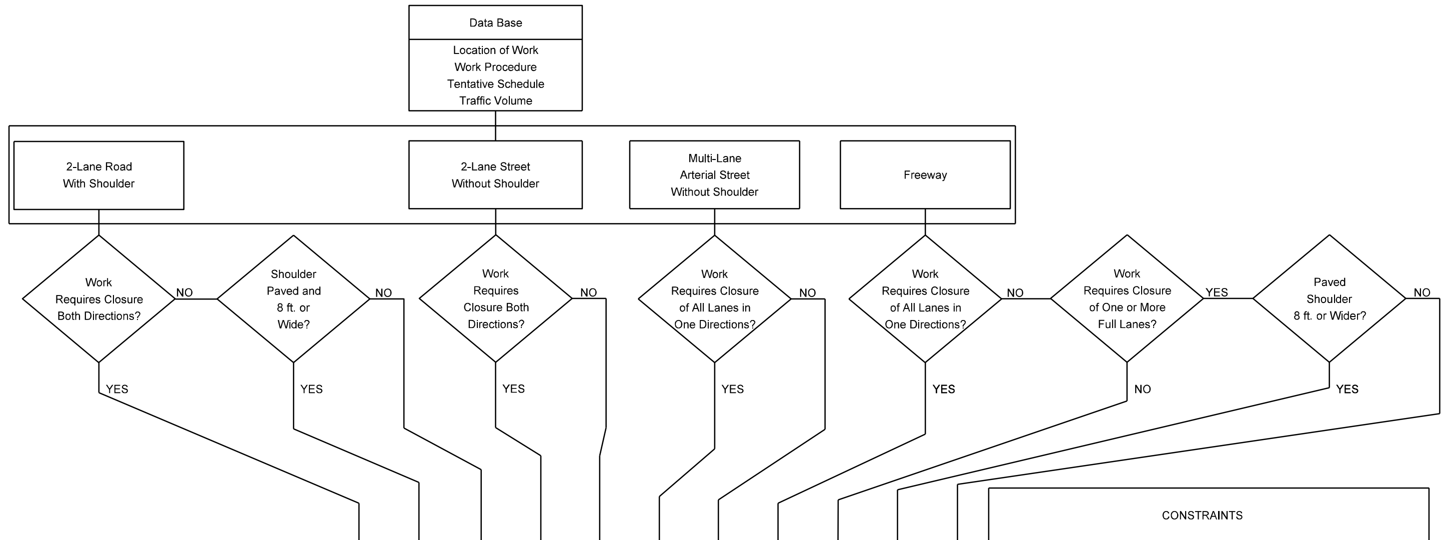
B



C

CROSSOVER WORK ZONES

Figure 81-2G



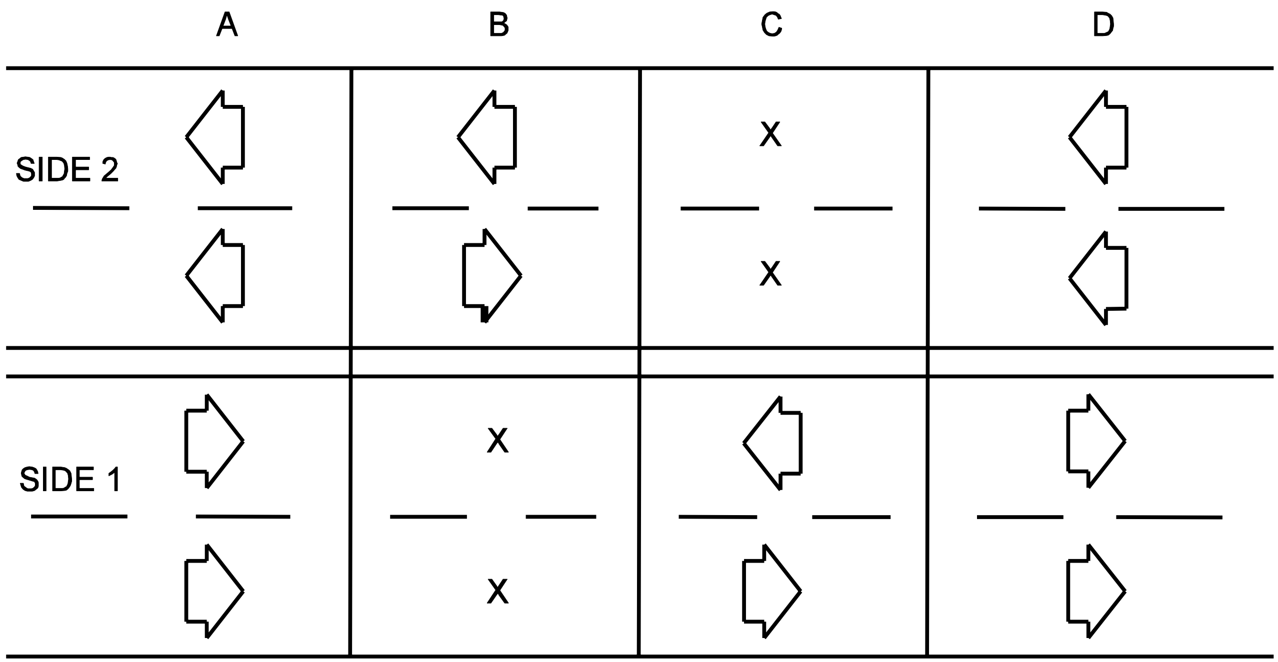
ALTERNATIVE WORK ZONE TYPES

												CONSTRAINTS
LANE CONSTRICTION (Use part of the shoulder if necessary)		√	√						√			Restripe lanes lines; keep lanes 10 ft. or wider. For freeways and other divided highways, the minimum lane width is 11 ft.
LANE CLOSURE							√		√	√	√	
ONE-LANE, TWO-WAY OPERATION		√	√		√							Traffic volume less than 1000 vehicles per hour both directions. (See INDOT computer program "WORK")
RUNAROUND	√		√					√				Sufficient right-of-way available.
INTERMITTENT TOTAL CLOSURE	√			√				√				Off-peak hours only.
USE OF SHOULDER (As a full lane)		√								√		May need to ugrade shoulder structure.
CROSSOVER						√		√				
TWO-WAY TRAFFIC ON DIVIDED FACILITIES						√		√				
DETOUR TO EXISTING ROAD	√		√	√	√	√	√	√		√	√	Resonable detour route (s) available. Maintain local access.

√ Fessible Alternatives

CHART FOR IDENTIFICATION OF FEASIBLE WORK ZONE TYPES

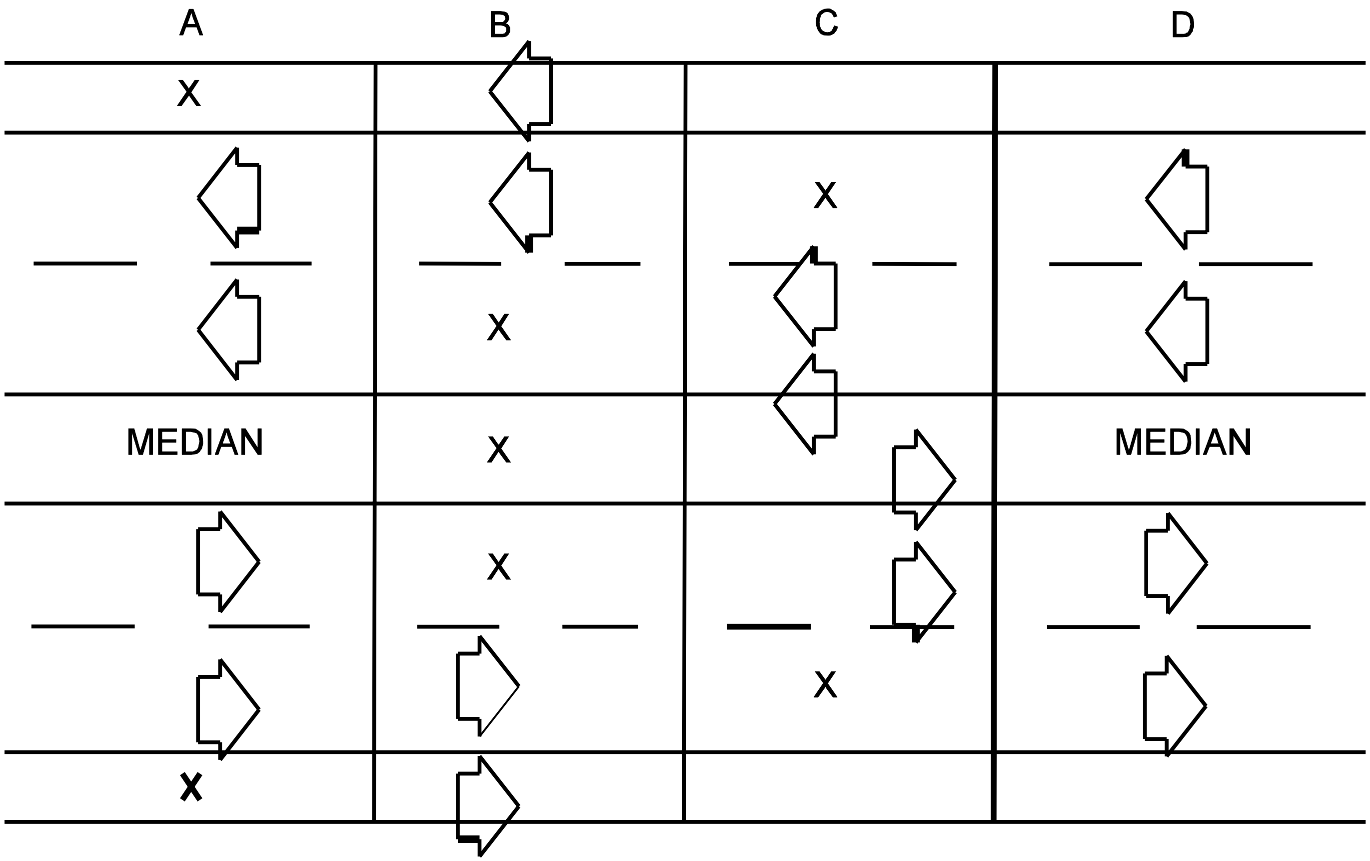
Figure 81-2H



A = Prior Construction
B = During Construction of Side 1
C = During construction of Side 2
D = Following Compleation
X = Construction Activity
⇦ = Traffic Flow

RECONSTRUCTION BY HALVES (SIDES)

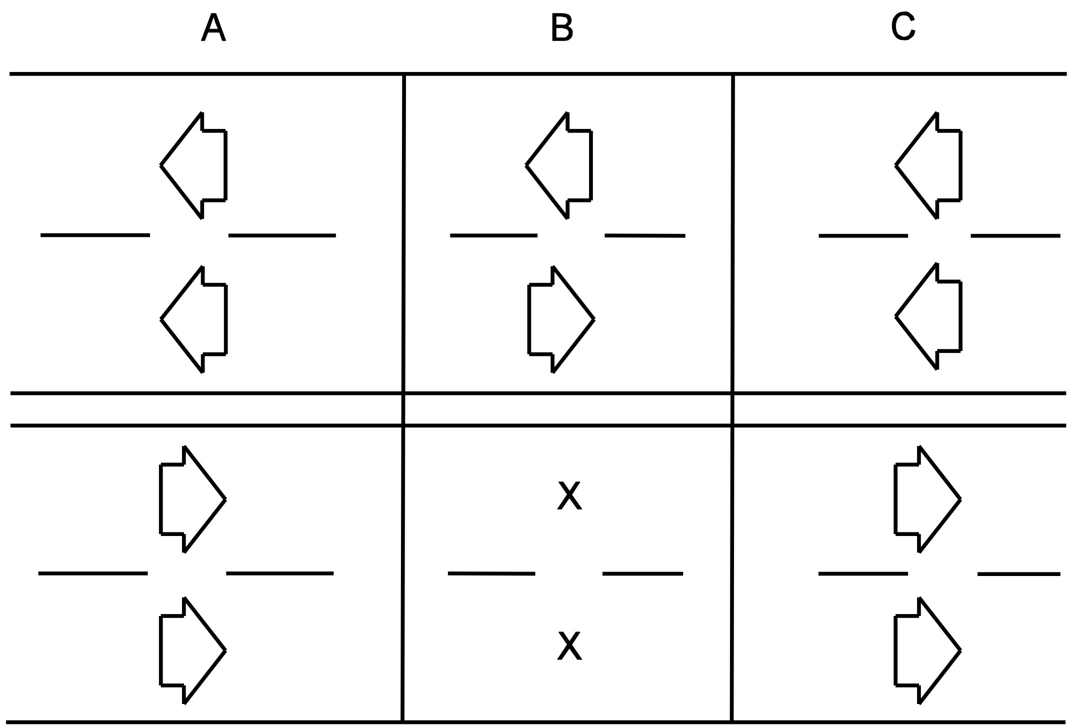
Figure 81-3A



A = Construction of Shoulder
B = Construction of Inner Lanes
C = Construction of Outer Lanes
D = Following Construction
X = Construction Activity
⇦ = Trafic Flow

PARALLEL/ ADJACENT RECONSTRUCTION

Figure 81-3B



A = Prior to Construction
B = During Construction of a Segment While Maintaining Two-Way Traffic Operation
C = Completion of Construction
X = Construction Activity
⇦ = Trafic Flow

SERIAL/SEGMENTAL RECONSTRUCTION

Figure 81-3C

INCENTIVE / DISINCENTIVE (I/D) AMOUNT DETERMINATION
English-Units Project

I. PROJECT CHARACTERISTICS

Route Contract No. Project No.
Des. No. District:
National Highway System (NHS) Route? ☐ Yes ☐ No
Location:
Estimated Start Date of Work:
Estimated Completion Date Without I/D:
Estimated Contract Amount: $
* Estimated Local-Traffic AADT: Trucks %
* Estimated Through-Traffic AADT: Trucks %
** Length of Local-Traffic Detour: mi
** Length of Through-Traffic Detour: mi

* Use best judgment for breakdown of traffic.
** Use official detour for through traffic.

II. I/D CONSIDERATIONS

Contract restrictions (e.g., utility adjustments, R/W acquisitions, permits, environmental constraints, closure times, special fabrication requirements):

Reasons for proposing I/D:

Critical construction elements:

Estimated Completion Date With I/D:
Estimated I/D Amount: $ per day
Proposed I/D Time: Calendar Days

Maximum I/D Adjustments = (I/D Amount) x (I/D Time):

$ x days = $

User Vehicle Costs (UVC): $0.25 / mi / veh (Autos & Trucks)
User Time Value (UTV): $5.00 / h / veh
Local Design Speed: mph
Through Design Speed: mph
Traffic Adjustment Factor (TAF): Suggested Value 0.35
(TAF normal range is 0.30 to 0.45)

NOTE: Use either of the following analyses depending on the type of project (road closure-detoured or through-traffic project). Various computer programs are available such as QUEWZ for estimating queue lengths and user costs that can be used in lieu of the following for freeway work-zone lane closures. Contact the Highway Operations Division's Traffic Control Team for details.

A. User Costs for Closure-Detoured Project

Local Traffic:

Vehicle Costs = (UVC) (AADT) (Local-Detour Length)
($0.25) ( ) (mi) = $

User Costs = (UTV) (AADT) (Local-Detour Length) (1/Design Speed)
($5.00) ( ) (mi) (1/) = $

Local-Road User Costs (LRUC) = (Vehicle Costs + User Costs)
$ + $ = $

Through Traffic:

Vehicle Costs = (UVC) (AADT) (Through-Detour Length)
($0.25) ( ) (mi) = $

User Costs = (UTV) (AADT) (Through-Detour Length) (1/Design Speed)
($5.00) ( ) (mi) (1/) = $
Through-Road User Costs (TRUC) = (Vehicle Costs + User Costs)
$ + $ = $

Site RUC = LRUC + TRUC
$ + $ = $

B. Disruption Costs for Through-Traffic Project

NOTE: The following analysis provides delay cost for through traffic only. If the project includes ramp or intersection closures, the analysis from Part A above can be added to the through-traffic disruption costs or other factors commensurate upon the scope of the particular project.

Vehicle Costs = (UVC) (AADT) (TAF)
($0.25) ( ) ( ) = $

User Costs = (UTV) (AADT) (TAF)
($5.00) ( ) ( ) = $

Traffic Disruption Costs = (Vehicle Costs + User Costs)
$ + $ = $

C. General Comments

D. Other Factors to Consider. Is the route on or near one or more of the following?

School: ☐ Yes ☐ No
Hospital: ☐ Yes ☐ No
Emergency Route: ☐ Yes ☐ No
Hazardous-Materials Route: ☐ Yes ☐ No
Special or Seasonal Event: ☐ Yes ☐ No
Local Business: ☐ Yes ☐ No

III. SUMMARY

Recommended Maximum I/D Time: Calendar Days
Recommended I/D Date:
Recommended Maximum I/D Amount: $ per Day
Is I/D amount > 5% of contract amount? ☐ Yes ☐ No

NOTE: If the I/D amount per day is greater than the Site RUC or Traffic User Costs, I/D is not justified.

IV. APPROVALS

A. <u>Non-NHS Project</u>

Prepared By: Date

Recommended By: ______________________________ Date ___________
Field Construction Engineer, Construction Mgmt.. Div.

If I/D $\leq$ 5% of contract amount,

Approved By: ______________________________ Date ___________
Director, Construction Management Division

If I/D > 5% of contract amount,

Approved By: ______________________________ Date ___________
Chief Highway Engineer

Received By: ______________________________ Date ___________
Contracting Office Manager, Contract Administration Division

B. NHS Project

Prepared By: Date

Recommended By: ______________________________ Date __________
Field Construction Engineer, Construction Mgmt.. Div.

Approved By: ______________________________ Date __________
Chief Highway Engineer

Received By: ______________________________ Date __________
Contracting Office Manager, Contract Administration Division

NHS Exemption: ☐ Yes ☐ No
If No, this document must be submitted to FHWA for approval.

Approved By: ______________________________ Date __________
Federal Highway Administration

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CHAPTER EIGHTY-TWO

TRAFFIC-CONTROL-PLAN DESIGN

To some extent, highway construction disrupts the normal flow of traffic and poses safety hazards to motorists, bicyclists, pedestrians and workers. Therefore, to alleviate potential operational and safety problems, INDOT requires that work-zone traffic control be considered on each highway construction project. The work-zone traffic-control plan may range in scope from very detailed plans, incorporation of unique or recurring special provisions, or to merely referencing the INDOT *Standard Drawings, Standard Specifications*, or *Manual on Uniform Traffic Control Devices (MUTCD)*. This Chapter provides the necessary information to develop a well-conceived work-zone traffic-control plan that minimizes the adverse effects of traffic disruption and hazards.

82-1.0 PRELIMINARY ENGINEERING

82-1.01 Responsibilities

The Office of Environmental Services' Environmental Policy Team is responsible for initially addressing work-zone traffic control. This information is to be included in the Engineer's Report. In determining the initial work-zone traffic control, the Environmental Policy Team will perform the following:

1. collect all necessary data (e.g. traffic counts, accident history, roadway geometrics, proposed development, operating speeds);

2. coordinate planning and scoping meetings with the applicable participants (e.g., designer, Office of Traffic Engineering, district Office of Design, Highway Operations Division, local officials);

3. conduct analyses (e.g., capacity analyses, traffic impact studies, safety studies, queuing analysis);

4. review design alternates;

5. review traffic-control alternates (e.g., detour, crossovers, runaround, lane closure). The preferred plan will be incorporated into the Report;

6. estimate the construction cost and economic impact of various options and improvements;

7. coordinate funding and timing with other projects within the corridor; and

8. if required, form a transportation-management-plan team and include the team's recommendations in the Report. Chapter Eighty-one provides information on the development of a TMP.

82-1.02 District Input

During the development of the Engineer's Report, the Environmental Policy Team will obtain the following information from the district.

1. The district's concurrence in the selected traffic-control alternate;
2. detour-route location and additional travel distance;
3. traffic projections anticipated to use detour;
4. anticipated delays to fire, police, emergency-medical, or postal service;
5. number of school buses using facility (additional delay and distance); and
6. local roads which may be used for official or unofficial detour.

82-1.03 Engineer's Report

The Environmental Policy Team will be responsible for incorporating the proposed work-zone traffic control plan in the Engineer's Report and ensuring that the following have been considered.

1. Traffic-Control Alternates. The Report will address the work-zone traffic-control information as follows:

   a. Applicability of INDOT *Standard Drawings*;
   b. alternate traffic-control strategies;
   c. alternate detour types and locations;
   d. construction scheduling and phasing requirements;
   e. alternate geometric design features;
   f. estimated costs for alternate traffic-control strategies; and
   g. special requirements of the work-zone traffic control.

2. Construction Operation Selection. The construction applications which may be considered are as follows:

   a. work beyond the shoulder;
   b. shoulder work and partial lane closure;

c. lane closure for a 2-lane highway;
d. single-lane closure for a 4-lane highway;
e. two-way traffic on a divided highway;
f. work within or near an intersection;
g. offset alignments; and
h. official or local detour (e.g., runaround, crossovers).

Chapter Eighty-one provides additional guidance for determining which of these construction applications may be appropriate.

3. Detour Location. The use of a detour (e.g., runaround, crossovers, alternate route) should be determined on a project-by-project basis. The detour location should be in accordance with the following:

   a. minimize impacts to adjacent developments (e.g., site access);
   b. minimize the magnitude and cost of utility relocations;
   c. minimize environmental impacts; and
   d. be offset a sufficient distance so that it will not interfere with construction.

   The Department may be required to repair local highways that may be damaged while being used as unofficial detour routes. See the *INDOT Detour Policy* for additional information. Investigations, details, and agreements with local officials may be required in subsequent phases.

4. Community Impact. The Report should address the impacts on neighborhoods, parks, schools, businesses, etc. A detour can significantly increase traffic through a community such that local traffic can no longer use the detour route. The Report should also address how the work-zone traffic control will affect fire, ambulance, police, and school-bus routes.

5. Interest Groups. The Report should address the concerns of local governments, agencies, public officials, or special interest groups (e.g., homeowner associations). If reasonable, changes should be made to the work-zone traffic control to address their concerns. Working with local officials and organizations early in project development can significantly reduce opposition to, or create support for, a project by addressing local concerns.

6. Transportation-Management Plan. Where a project does not warrant the development of a Transportation Management Plan (TMP), the Environmental Policy Team should still review Chapter Eighty-one for applicable guidelines and criteria that should be discussed during this phase. The conclusion of this phase should result in a reasonable traffic-control strategy for the project.

82-2.0 TRAFFIC-CONTROL-PLAN DEVELOPMENT

82-2.01 Responsibilities

It is the designer's responsibility to ensure that an adequate traffic-control plan (TCP) is developed. If the traffic-control requirements are not entirely included in the INDOT *Standard Drawings* or *Standard Specifications*, the designer should prepare a TCP that will adequately address all required non-standard traffic-control work for the project. The designer will be responsible for the following.

1. reviewing the information in the Engineer's Report or, if not available, contacting the appropriate entity or agency (e.g., traffic-design, FHWA) to obtain the necessary information;
2. evaluating the proposed design alternates (e.g., detour, crossovers, runaround, lane closure); see Chapter Eighty-one;
3. developing the geometric design for a specially-constructed detour (e.g., crossovers, runaround, offset alignment); see Section 82-3.0;
4. addressing the roadside-safety concerns within the construction zone (e.g., construction clear zone, temporary concrete barrier); see Section 82-4.0;
5. selecting and locating the required traffic control devices (e.g., pavement markings, barricades, signs); see Chapter Eighty-three;
6. developing and evaluating alternate construction sequences;
7. performing the necessary capacity and queuing analyses, if not already provided;
8. making a written request to the Office of Pavement Engineering regarding use of a shoulder or a portion of it for traffic maintenance. A copy of the request should be sent to the project manager. The request should include the construction-year AADT, percent trucks of AADT, and the approximate duration of traffic's shoulder use;
9. ensuring that the proposed traffic-control plan is discussed and reviewed during the Preliminary Field Check; and
10. coordinating with public-information officials to inform the public of proposed road closure, detour route, etc.

82-2.02 Plan Development

The TCP should be developed through the phases described below before it can be incorporated into the contract and approved for letting. The following describes the development of the TCP at each project phase.

1. Engineer's Report. The Environmental Policy Team will be responsible for determining the initial work-zone traffic control strategies to be used on the project. These should be shown in the Engineer's Report. If changes are made to the recommendations in the Report, the designer should notify the Environmental Policy Team of these changes.

2. Structure Type and Size (Bridge-Replacement Project) or Grade Review (Sight-Distance Improvement or Small Structure Replacement. At this plan development stage, the designer is responsible for contacting the appropriate district to obtain its input regarding traffic maintenance. Figure 82-2B is a blank memorandum copy which the designer should download, fill in the project information blanks, then transmit to the district. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/. District input should be solicited if a TCP is specified in the Engineer's Report. The district should provide the requested information to the designer.

3. Preliminary Field Check. During the Preliminary Field Check, review the proposed traffic-control strategy against actual and anticipated field conditions and be prepared to perform the following tasks.

   a. drive the local detour;

   b. determine the environmental effects of a crossover or runaround;

   c. estimate the extent and cost of property damage caused by a crossover or runaround, including additional right-of-way requirements and costs;

   d. determine the feasibility of maintaining traffic on the facility (e.g., roadway, bridge) while work is in progress;

   e. evaluate the need for scheduling work activities to avoid traffic delays during peak commute hours or local events;

   f. determine the effects on project constructability; and

   g. review the physical and operational elements of the TCP with other projects in the area to ensure that there are no conflicts with the proposed TCP.

At the conclusion of this phase, the preliminary geometric design, safety, and capacity analyses should be completed, and suggested plan modifications evaluated and reviewed. The designer should determine the proposed location of all traffic-control elements and special design elements (e.g., runaround, crossovers) and should establish the proposed construction phasing. The designer should contact the district for its input, even if the proposed TCP is recommended in the Engineer's Report.

4. Hearing. The plan and profile, cross-sections, construction schedule and phasing, and impact reports should be completed at this stage. Begin preparation of the required special provisions and the permit process. Prepare an estimate of the time required to re-open the facility (e.g., roadway, bridge) to traffic after construction starts.

5. Final Field Check. Review all issues emerging from the hearing stage and complete subsequent plan modifications. Review the project's physical and operational elements of the TCP with other projects in the area to ensure that there are no conflicts with the proposed TCP. Examples include detouring traffic onto a local road which is scheduled for reconstruction during the same time period, or closing a highly-traveled highway during special events or seasons. Coordinate with the Office of Communications so that they can begin to inform the public of road closures or alternate detour routes.

6. District Construction Engineer Review. After design approval, the designer should submit the proposed TCP to the district construction engineer. The district construction engineer will provide written comments or concurrence regarding the proposed TCP to the designer, with a copy to the appropriate Production Management Division office manager. The office manager will provide written comments or concurrence regarding the proposed TCP to the designer. If necessary, the designer will revise the proposed TCP until both district construction engineer and office manager concur.

7. Final Plans Review. Determine and check all quantity estimates. Complete the detail drawings and include all relevant special provisions in the contract documents. Do not show unofficial detour routes in the plans or special provisions.

The Department requires a coordinated team effort to develop and successfully implement a TCP. Figure 82-2A lists the participants involved in each phase of its development.

82-2.03 Traffic-Control Plan Content

The type and size of a project greatly impacts the amount of information required in the TCP. For example, for a traffic-signs project, the TCP may only be a listing of the appropriate INDOT *Standard Drawings*. However, for a freeway reconstruction project, the TCP may include full-size drawings, special details, special provisions, special task forces, etc. The TCP content will be determined on a project-by-project basis. The TCP may include the following.

1. Construction Plan Sheets. A reconstruction project will require detailed plans for accommodating traffic at each construction stage (e.g., specially-built detour, crossovers, staged construction). These plans may include geometric layout details, positive-protection strategies, the traffic-control devices, etc. A smaller project (i.e., partial 3R, traffic signs, signals, or a spot improvement) will rarely require this level of detail. Chapters Fourteen and Fifteen provide the Department's plans-preparation criteria (e.g., sheet sizes, scales, line weights, CADD symbols) which are also applicable to a TCP. The INDOT *Typical Plan Sheets* document provides traffic-maintenance detail sheet examples.

   A traffic-maintenance plan that requires at least one shoulder to carry traffic on a temporary basis during construction should include information regarding shoulder-corrugation installation requirements. A note should be included that reads, "Corrugations shall not be milled into the _____ shoulder between Sta. _____ and Sta. _____ until after traffic is no longer temporarily using the shoulder."

2. Special Provisions. Special provisions are used to explain special procedures, materials, or equipment used in the TCP that are not addressed in the INDOT *Standard Specifications*. The TCP may only consist of special provisions. Prior to developing a new special provision, the designer should first ensure that its requirements do not already appear in the INDOT *Standard Specifications* or recurring special provisions. Chapter Nineteen provides information on the requirements for preparing a special provision.

3. Traffic-Control Devices. Include a complete listing of the traffic-control devices required to direct traffic through the work zone in the TCP. This may include the number of drums, barricades, cones, signs, temporary pavement markings, warning lights, flashing-arrow signs or other devices required to implement the construction. Chapter Seventeen provides the Department's criteria for determining plan quantities.

4. Construction Sequence and Time. The TCP should include a proposed construction sequence.

5. Work Schedule. A special provision should identify restricted work schedules which the contractor will be required to follow (e.g., no construction work during specified hours or days).

6. Telephone Numbers. A special provision should require the contractor to provide names and telephone numbers of the contractor's superintendent and one other responsible employee.

7. Permits. For restricted-lane width, the district Office of Construction will be responsible for coordinating with the Planning Division's Office of Roadway Safety and Mobility after the contract is let to obtain the necessary permits to allow oversize vehicles through the work zone.

8. Agreement or Legal Release. An agreement or legal release may be required before INDOT can use a local facility as a detour route. The designer should initiate this process early in the design of the work-zone traffic control.

9. Media. The designer should inform the Office of Communications as to when and where there will be a major road or ramp closure or detour.

10. Pedestrians and Bicyclists. The TCP should address the safe accommodation of pedestrians and bicyclists through the work area. Construction phasing may need to be scheduled around non-peak pedestrian-traffic times.

11. Local Businesses and Residents. Maintain at least one reasonable access to each site of business establishment or residency. The designer should also ensure that these entities are kept informed of planned street, ramp or driveway closures.

12. Emergency Vehicles. The TCP should address the safe and efficient accommodation of emergency vehicles through the construction area.

13. Checklist. Section 82-7.0 provides a checklist which should be reviewed to ensure that all applicable work-zone traffic-control elements have been addressed in the TCP.

82-2.04 Design Considerations

The objective of the TCP is to provide an implementation strategy that will minimize the adverse effects of traffic disruption on motorists, pedestrians, bicyclists, or workers. Therefore, the designer should consider the following design considerations when developing the TCP. For a more in-depth analysis of these elements, the designer should review Chapter Eighty-one.

82-2.04(01) Engineering

The designer should consider the following engineering elements in developing the TCP.

1. Geometrics. The TCP should provide adequate facilities for a motorist to safely maneuver through the construction area, day or night. The design should avoid frequent and abrupt changes in roadway geometrics, such as lane narrowing, a lane drop, or a transition which

requires a rapid maneuver. Section 82-3.0 provides geometric design criteria for a construction zone.

2. Roadside Safety. Motorist, pedestrian, bicyclist, and worker safety is a priority element of a TCP and should be an integral part of each phase of the construction project (i.e., planning, design, and construction). Section 82-4.0 addresses the roadside-safety issues which are encountered during construction.

3. Highway Capacity. The TCP should, where practical, provide the capacity necessary to maintain an acceptable level-of-service for the traveling public. This may require converting a shoulder to a travel lane, eliminating on-street parking, constructing a temporary lane, opening additional lanes during peak traffic-volume periods, or expanding public transportation. Section 82-5.0 provides further information on highway-capacity issues.

4. Traffic-Control Devices. Traffic-control devices should be included in the TCP to safely direct vehicles through or around the construction zone. Chapter Eighty-three provides guidance on the selection and location of traffic-control devices.

5. Overhead Lighting. The design should maintain existing overhead lighting and consider the need for supplemental roadway lighting at a potentially hazardous site within the work area. Chapter Eighty-three discusses the use of construction-zone lighting.

82-2.04(02) Constructability

The designer should evaluate the construction sequence to identify safety, operational, or logistical problems and to facilitate the timely completion of the project. Some of the elements which should be evaluated include the following:

1. the maneuverability of traffic through horizontal or vertical alignments during all construction phases;

2. the separation of opposing traffic, workers, equipment, or other hazards;

3. the work area which will be used for equipment maneuverability; and

4. the access points to work sites or material-storage sites.

** *PRACTICE POINTER* **

Adequate working space between the traffic and the work area should be provided. This applies especially where construction is phased or if the project includes a temporary runaround.

82-2.04(03) Construction Design

Available construction options that may improve the TCP include the following:

1. the use of special materials (e.g., quick-curing concrete that can support vehicular loads within hours after pouring);

2. the use of special designs (e.g., using a precast box structure instead of a bridge or cast-in-place box structure);

3. scheduling requirements which will reduce traffic disruptions (e.g., working at night and during off-peak traffic-volume hours);

4. project phasing which will allow traffic to use the facility prior to project completion; or

5. contractor cost incentives/disincentive for early or late completion of construction for a facility with a high AADT. For a project with FHWA oversight, a contractor incentive is subject to approval by the FHWA.

Chapter Eighty-one provides additional information on construction alternates.

82-2.04(04) Economic or Business Impact

The designer should consider the economic impacts a TCP may have on road users, adjacent businesses, or residential developments. The designer should consider the following:

1. vehicular travel time;
2. fuel consumption;
3. vehicular wear;
4. air pollution;
5. access to residential developments;
6. patron access to businesses (e.g., restaurants, gas stations, stores);
7. employee or delivery access to commercial developments; and
8. shipments to manufacturing companies.

The designer should also review the TCP to ensure that it does not restrict access to businesses during peak retail shopping periods. For example, a road closure should not be made in the vicinity of a regional retail mall during the period from Thanksgiving to Christmas. Coordination with local businesses, developers, or other land owners should be made early in the development of the TCP. At least one access should be maintained to each development throughout the contract time.

82-2.04(05) Pedestrians and Bicyclists

Address the safe accommodation of pedestrians or bicyclists through the construction zone early in project development. Locations that would warrant pedestrian or bicyclist considerations include the following:

1. where a sidewalk traverses the work zone;
2. where a designated school route traverses the work zone;
3. where significant pedestrian or bicyclist activity or evidence of such activity exists; or
4. where existing land use generates such activity (e.g., park, school, shop).

The considerations to be made in addressing pedestrian or bicyclist accommodation through a construction zone are as follows:

1. physical separation of pedestrians and vehicles where practical;
2. providing temporary lighting for each walkway that is currently lighted;
3. directing pedestrians or bicyclists to a safe location (e.g., the other side of a street) where a pedestrian walkway or bicycle path cannot be provided;
4. staging construction operations such that if there are two walkways they are both not out of service at the same time;
5. planning the construction such that temporary removal of a sidewalk will occur in the shortest practical time or is scheduled around non-peak pedestrian traffic-volume times; or
6. for information on handicapped-accessibility criteria, see Section 51-1.0.

82-3.0 GEOMETRIC DESIGN

The following provides design criteria which apply to temporary crossovers on a divided highway, an existing roadway through a construction zone, or a detour specifically designed for construction project (e.g., crossovers, runaround). These criteria do not apply to a detour over existing routes.

82-3.01 Construction-Zone Design Speed

The construction-zone design speed applies to the design of the geometric elements through the work zone. It does not apply to the regulations that are used for posting the speed limit through the work zone. Regulatory speed limit is discussed in Section 83-2.03. In selecting the construction-zone design speed, the designer should consider the following.

1. Posted Speed Limit. The construction zone design speed should take into account the following:

   a. the posted speed limit of the facility immediately prior to the work zone;

   b. the anticipated posted work-zone speed limit through the work zone (see Section 83-2.03); and

   c. the posted speed limit of the facility before construction begins. The construction-zone design speed should not be more than 10 mph lower than the posted speed limit prior to construction.

2. Urban or Rural Area. The construction-zone design speed in a rural area should be higher than that in an urban area. This is consistent with the fewer constraints in a rural area (e.g., less development).

3. Terrain. A lower construction-zone design speed may be applicable to a rolling terrain. This is consistent with the higher construction costs as the terrain becomes more rugged.

4. Traffic Volume. The construction-zone design speed may vary according to the traffic volume. Therefore, consider a higher design speed as traffic volume increases.

The designer should work with the appropriate district traffic engineer to establish the construction-zone design speed for an INDOT route, or a local public agency's representative for a local-agency route. The designer should show the construction-zone design speed on the first sheet of the TCP.

If crossovers are used to maintain one lane of traffic in each direction on a rural Interstate route, the following will apply.

1. Use temporary concrete median barrier.

2. Unless the median shoulder is full depth, it is to be removed and replaced with a 6-ft width section with its pavement design to be requested by the designer.

3. The traffic maintenance should be as shown in Figure 81-3A(0).

4. Shoulder corrugations are to be milled into the new shoulder after traffic is crossed over to the other side.

82-3.02 Lane or Shoulder Width

There should not be a reduction in the roadway-cross-section width through the construction zone. However, this may not be practical. Section 83-3.02 provides the minimum taper rate that should be used on an approach to a lane-width reduction. The following lane and shoulder widths should be used in a construction zone.

1. Divided Highway. For a freeway or other divided highway, maintain a minimum 11-ft lane width with shoulders of 2 ft or wider. Under restrictive conditions, however, the designer may consider a 10-ft lane width if an alternate route is provided for wide vehicles.

2. Undivided Highway. Maintain a minimum 10-ft lane width and 1-ft shoulder width.

3. Runaround. Design a runaround with 12-ft lane width and 6-ft shoulder width.

4. Temporary Crossover. For 1-lane, one-way operations, the lane width should be 16 ft with 5-ft shoulder widths. For a multi-lane or multi-directional operation, each lane width should be 12 ft with 5-ft shoulder widths.

82-3.03 Transition Taper Rate

A lane closure, lane-width reduction, or lane shift requires the use of a transition taper to safely maneuver traffic around the encroaching restriction. Section 83-3.02 provides the minimum taper length for each taper application in a construction zone (e.g., lane closure, lane shift). Use the construction-zone design speed in selecting the appropriate taper rate from Section 83-3.02.

82-3.04 Sight Distance

For the approach to the first physical indication of the construction zone, the sight distance available to the motorist should be based on the decision-sight-distance criteria provided in Section 42-2.0

and, at a minimum, based on the stopping-sight-distance criteria provided in Section 42-1.0. Through the construction zone itself, the designer should ensure that at least the minimum stopping sight distance is available to the motorist. Unfortunately, the locations of many design features are often dictated by construction operations. However, an element may have an optional location. For example, a lane closure or transition should be located where the approaching motorist has decision sight distance available to the lane closure on transition. Throughout a horizontal curve in the construction area, the designer should check the horizontal clearance (i.e., the middle ordinate) of the horizontal curve using its radius and the minimum stopping sight distance for the construction-zone design speed (see Section 43-4.0). Figure 43-4B provides the horizontal-clearance criteria for each combination of minimum stopping sight distance and curve radius. The designer should also consider the percentage of trucks and other heavy vehicles in determining the controlling sight distance.

Computations must be submitted for horizontal stopping sight distance at the Grade Review or Structure Type and Size stage, or the next plan submission if the project is already beyond the Grade Review or Structure Type and Size stage, for a temporary runaround or other traffic-maintenance means. A statement that a temporary runaround is in accordance with the INDOT *Standard Drawings* is not sufficient to verify that adequate horizontal-alignment stopping sight distance is provided.

Computations must be submitted for intersection sight distance for each traffic-maintenance phase.

82-3.05 Horizontal Curvature

Design the horizontal curvature using the selected construction-zone design speed. Use AASHTO Method 2 for distributing superelevation and side friction to determine the radius and superelevation rate of the horizontal curve. In this method, superelevation is introduced only after the maximum allowable side friction has been reached. If compared to AASHTO Method 5, this approach results in no superelevation on a flatter curve (i.e., maintaining the normal crown through the curve) and a reduced rate of superelevation on a sharper curve. Figure 82-3A, Minimum Radius for Horizontal Curve in Construction Zones, provides the minimum radius (including the radius for retention of the normal crown section) for a horizontal curve through a construction zone based on AASHTO Method 2. For other horizontal-curvature elements (e.g., superelevation transition length), the criteria described in Chapter Forty-three is also applicable to a construction zone.

Where it is necessary to use the shoulder as a travel lane, the shoulder cross slope may be a concern on a horizontal curve (i.e., the slope may be in opposite direction than the superelevated section). One or more of the following options may be considered to alleviate this problem.

1. Rebuild the shoulder so that it has the proper superelevation rate based on the selected construction-zone design speed.

2. Install an advisory-speed plate for the horizontal curve,

3. Install buzz strips in conjunction with Item 2 above in advance of the temporary travel lane (see Figure 83-4A, Flare Rate for Temporary Concrete Median Barrier.

4. Prohibit trucks or other large vehicles from using the temporary travel lane.

5. Detour such large vehicles to other facilities.

82-3.06 Vertical Curvature

Design a sag vertical curve using the selected construction-zone design speed and the comfort criterion provided in Figure 82-3B. The comfort criterion is based on the comfort effect of change in vertical direction through a sag vertical curve because of the combined gravitational and centrifugal forces. The ride through a sag vertical curve is considered comfortable if the centripetal acceleration does not exceed 1 ft^2.

82-3.07 Cut or Fill Slope

Design a temporary cut or fill slope to satisfy the design criteria shown in Chapter Fifty-three and Section 45-3.0. However, a 3:1 fill slope may be used where there is sufficient clear-zone width available at the bottom of the slope (see Section 82-4.04). The use of a steeper fill slope may be considered, but it may require the installation of a roadside barrier.

Although a detour rarely involves excavation, a 3:1 cut slope is acceptable in place of the flatter slope required in Chapter Fifty-three. The use of a slope steeper than 3:1 for a cut depth of less than 10 ft may be acceptable under restrictive conditions.

The anticipated traffic volume and the length of time that the detour will be in place should be considered in determining the final cut or fill slope. Stable embankment material must be used and placed in accordance with the INDOT *Standard Specifications*.

Drainage should be considered between the work zone and the traffic in establishing the phases of construction.

82-3.08 Maximum Grade

The vertical grade should be designed using the 3R criteria for the appropriate functional classification, rural or urban environment, and construction-zone design speed.

82-3.09 Through-Lane Cross Slope

The 3R criteria should be used for the appropriate functional classification and rural or urban environment. If the existing shoulder is used for through traffic, a 4% cross slope will be acceptable.

82-3.10 Vertical Clearances

The 3R criteria should be used for the appropriate functional classification and rural or urban environment.

If the design for a temporary runaround or other traffic-maintenance consideration excluding a detour over existing roads is not in accordance with the criteria for Level One elements, a design exception will be required.

82-4.0 ROADSIDE SAFETY

Through a construction zone, a motorist is often exposed to numerous hazards (e.g., restrictive geometrics, construction equipment, opposing traffic). A complete elimination of construction-zone hazards is impractical. A motorist's exposure to potential hazards should be reduced. The following lists roadside-safety criteria which apply only to the roadside elements within the construction zone. These criteria do not apply to a detour over existing routes.

82-4.01 Positive Protection

The designer should consider a traffic-control method which does not require the use of positive protection, minimizes the hazard exposure, or maximizes the separation of workers and traffic. However, positive protection is often required.

Psitive-protection devices should be considered in each work-zone situation that places workers at increased risk from motorized traffic, and where positive-protection devices offer the highest potential for increased safety for workers and road users. The decision regarding the use of positive protection is to be documented and placed in the project file. Locations where positive protection should be considered include the following:

1. exposed end of temporary concrete barrier;
2. untreated guardrail end in a 2-way, 2-lane operation;

3. bridge pier;
4. bridge-railing end;
5. structure foundation (e.g., bridge falsework, sign foundation);
6. excavation or rock cut;
7. gap in median between dual bridges;
8. pavement edge or shoulder dropoff in excess of 12 in.; or
9. other location where construction will increase the potential hazards of existing conditions.

Each location listed above should be addressed separately in the documentation. Because each TCP is project-specific, the Department has not developed criteria for positive protection within a construction zone. However, considerations for assessing the need for positive protection are as follows:

1. duration of construction activity (14 days or less);
2. traffic volume (including seasonal and special-event fluctuations);
3. nature of hazard;
4. length and depth of dropoff;
5. construction-zone design speed;
6. highway functional classification;
7. length of hazard;
8. proximity between traffic and construction workers;
9. proximity between traffic and construction equipment;
10. adverse geometrics which may increase the likelihood of a run-off-the-road vehicle;
11. two-way traffic on one roadway of a divided highway;
12. transition area at crossover;
13. lane closure or lane transition;
14. work zone that provides workers no means of escape from motorists; or
15. construction-zone design speed is 45 mph or higher.

Other considerations may apply, as the above list is not considered to be all-inclusive. The decision regarding the use of positive protection should be documented and placed in the project file.

82-4.02 Appurtenance Type

In addition to Chapter Forty-nine and the INDOT *Standard Drawings*, the following provides additional information on roadside-safety appurtenances.

Positive guidance for crossed-over two-lane two-way traffic should be provided as follows.

1. Temporary concrete barrier and temporary solid yellow lines are to be used on a freeway.

2. Temporary tubular markers and temporary double solid yellow lines are to be used on a multi-lane divided roadway that is not a freeway.

3. Temporary double solid yellow lines are to be used on an urban or rural multi-lane undivided roadway.

Temporary asphalt divider is not to be used for separating traffic.

82-4.02(01) Guardrail

A temporary guardrail installation for an Interstate-route project should be in accordance with the permanent installation criteria described in Chapter Forty-nine and the INDOT *Standard Drawings*, except as shown in Figure 82-4B, Work-Zone Clear-Zone Width (ft). For short-term construction, the installation of new temporary guardrail is not practical.

The following should be used to determine the temporary guardrail length at each corner of a temporary bridge in a two-lane runaround. For a construction-zone design speed of 45 mph or lower, the minimum guardrail length is 50 ft. For a construction-zone design speed of 50 mph or higher, the minimum guardrail length is 100 ft.

A temporary guardrail run should continue until the guardrail warrant for an embankment as shown in Section 49-4.04 is satisfied. The design speed, and not the construction-zone design speed, should be used to determine the guardrail warrant for an embankment.

82-4.02(02) Temporary Traffic Barrier (TTB)

A TTB is used to provide protection to the motorist and the workers in the work zone. The primary functions of TTB are as follows:

1. to separate two-way traffic;
2. to protect workers and pedestrians;
3. to keep traffic from entering a work area (e.g., excavation, storage site); and
4. to protect construction elements (e.g., bridge falsework, exposed objects).

1. <u>Types of TTB</u>.

    a. Type 1. This type is used only to separate two-way traffic.

    b. Type 2. This type is used to separate traffic from the work zone. It should be used to protect traffic from an obstruction, including an elevation differential of greater than

6 in., which is inside the construction clear zone. It should also be used to shield traffic from an extreme hazard during construction that may necessitate consideration of a barrier between the construction clear zone and the permanent clear zone. For this situation, the designer should consider the construction-zone design speed, the extent of the obstruction, and the potential for an elevation differential, and use engineering judgment in determining whether a TTB is necessary.

c. Type 3. This is type 1 TTB which is to be left in place upon completion of the contract and becomes the property of the Department.

d. Type 4. This type is used as a readily-movable device to accommodate the shifting of traffic lanes possibly on a daily basis to better facilitate the directional distribution or other changing traffic volume during a day's peak traffic-volume hours. The barrier layout and signage for each phase, a staging-area diagram, and the location of the barrier-moving apparatus when it is not in use should be shown on the TCP. The size of the barrier-moving apparatus should be taken as 50 ft long by 16 ft wide.

2. <u>Construction Clear Zone and Flaring Considerations</u>. The terminal end of a TTB type 1, 2, or 4 should be flared away from the traveled way to a point outside the construction clear zone. Construction clear-zone width is shown in Figure 82-4B. The potentially hazardous conditions found within a construction zone warrant the use of considerable judgment when applying one of these widths. It is not necessary to adjust such width for horizontal curvature.

   Figure 82-4A, Flare Rate for Temporary Traffic Barrier, should be used to determine the desirable flare rate for the TTB based on the construction-zone design speed, and not a lower worksite speed limit.

   If a flared portion of TTB type 1 cannot be designed to end outside the construction clear zone, an acceptable construction-zone energy absorbing terminal as described in Section 83-4.02(03), Item 1, is required. A unit which has been successfully crash tested in accordance with NCHRP 350 Test Level 2 should be specified if the construction-zone design speed is 45 mph or lower. A unit which has been successfully crash tested in accordance with NCHRP 350 Test Level 3 should be specified if the construction zone design speed is 50 mph or higher.

   For a TTB type 2 or 4, if a field condition such as a public-road approach or drive renders the desirable flare rate impractical, the flare rate may range between 10:1 and 6:1. For a TTB type 2, the flare may be eliminated if the sharper flare rate cannot be attained. Such location and flare treatment should be shown on the TCP.

3. <u>Glare Screen</u>. A glare screen may be used in combination with TTB type 1 or type 3 to

eliminate headlight glare from opposing traffic. The application is at a crossover transition or in a 2-way, 2-lane operation. Guidance regarding consideration of a glare screen is described in Section 49-4.05(03), though INDOT has not adopted specific warrants for the use of a glare screen.

4. Anchoring. TTB type 1, 2, or 3 should be anchored where indicated on the INDOT *Standard Drawings*. The locations of anchored TTB should be shown on the plans.

5. Traffic-Control-Plan Information. Types, locations, and quantities of TTB, including locations and quantities of glare screens and energy absorbing terminals, along with flare rates should be shown on the TCP for each traffic-maintenance phase.

See Section 17-3.13 for information regarding determination of pay quantities.

82-4.02(03) End Treatment or Impact Attenuator

The following discusses the end treatments or impact attenuators that may be used.

1. Energy-Absorbing Terminal. The use of a construction-zone energy-absorbing terminal should be based on National Cooperative Highway Research Program *Report 350* Test Levels. The Test Level 3 (TL-3) terminal should be specified for an Interstate or other route with a construction-zone speed limit of 50 mph or higher. The TL-2 terminal should be specified for a non-interstate route with a construction-zone speed limit of 45 mph or lower. If a lower temporary worksite speed limit is to occasionally apply, each terminal's Test Level should still correspond to that for the construction-zone speed limit. The location of each terminal with its Test Level should be shown on the TCP.

2. Guardrail. The treatment for an exposed end of guardrail includes the following:

   a. connection to existing barrier;
   b. using an acceptable end treatment. Use the construction year AADT, and see Section 49-5.04(01);
   c. flaring the end to a point outside the construction clear zone; or
   d. burying the end in the backslope.

3. Gravel-Barrel Array. Due to the size of the array, a gravel-barrel array has limited application in a work zone.

4. Other. Other INDOT-approved end treatments may be applicable. Chapter Forty-nine provides information on some of the end treatments used by the Department. Provide the most applicable end treatment consistent with cost and geometric considerations.

82-4.03 Design/Layout

Where practical, a temporary roadside-safety appurtenance should be designed and located as determined in Chapter Forty-nine (e.g., deflection distance, length of need). However, it is not cost effective to satisfy the permanent-installation criteria due to the limited time a motorist is exposed to a construction hazard. The designer will need to evaluate the exposure time of the hazard in determining the need for installing a roadside-safety appurtenance. The following provides alternatives the designer may consider in designing and locating a temporary roadside-safety appurtenance within a construction zone.

1. Construction Clear Zone. Applying the clear-zone width as described in Chapter Forty-nine to a work zone is often impractical. Therefore, construction clear-zone width is shown in Figure 82-4B. However, the potentially hazardous conditions found within a construction zone warrant the use of engineering judgment in applying the construction clear-zone distance. It is not necessary to adjust the clear-zone-width value shown in Figure 82-4B for horizontal curvature.

2. Shoulder Widening. Where a temporary barrier is placed adjacent to a shoulder, it is not necessary to provide extra shoulder widening.

3. Flare Rate. A TCB terminal should be flared beyond the traveled way to a point outside the construction clear zone. Figure 82-4A provides the desirable flare rate for the TCB based on the selected construction-zone design speed. The designer should provide the flare rate unless extenuating circumstances render it impractical (e.g., stop condition, drive, intersection). See Section 82-4.03.

4. Opening. An opening in the barrier should be avoided. Where an opening is necessary, the barrier end should be shielded with acceptable end treatment as discussed in Section 83-4.03(03).

82-4.04 Pavement Edge Dropoff on Multilane Divided Highway

A pavement edge dropoff should be avoided immediately adjacent to a lane open to traffic during a construction activity such as shoulder rehabilitation or crossover construction.

In developing a traffic-maintenance plan, the desirable option is to close the lane adjacent to an edge dropoff. This will ensure that the edge dropoff is located outside the construction clear zone.

If the traffic lane adjacent to the edge dropoff cannot be closed for an extended period of time, a full-depth rehabilitated shoulder section should be provided that can be placed to within 3 in. of the top of pavement elevation before the end of a day's work. This should be done, for example, where the shoulder work is to be done at night so that all of the existing traffic lanes can be kept open during daylight hours. The pavement section required to fill a shoulder dropoff to within 3 in. of the top before exposure to adjacent traffic should be obtained from the Office of Pavement Engineering. A unique special provision will be required to address the time frame imposed on the contractor for bringing the shoulder paving up to the required grade. Also, drums should be placed on the shoulder dropoff, spaced as shown in Figure 83-3D, Suggested Maximum Spacing of Channelization Devices.

Where it is not feasible to limit exposure to the edge dropoff by the means described above, and the edge dropoff is greater than 3 in., one of the mitigating measures should be considered as follows:

1. Placing a temporary wedge of material along the face of the dropoff. The wedge should consist of asphalt material placed at a 45-deg angle or flatter. Warning signs should be placed in advance of and throughout the treatment. A 6-in. width solid edge line should be used to delineate the edge of the travel lane.

2. Placing drums along the traffic side of the dropoff and maintaining, if practical, a 3-ft width buffer between the edge of the travel lane and the dropoff. Warning signs should be placed in advance of and throughout the treatment.

3. Installing a temporary concrete barrier or other acceptable positive protection device with a buffer between the barrier face and the traveled way. An acceptable crashworthy terminal or flared barrier should be installed at the upstream end of the section. For nighttime use, standard delineation devices must supplement the barrier. Specifying the use of a temporary movable concrete barrier system will involve the use of proprietary materials.

If the work is to include deep milling or asphalt-pavement replacement, and the dropoff between adjacent lanes is greater than 1.5 in., mitigating measure No. 1 or No. 2 should be considered.

82-5.0 HIGHWAY CAPACITY

<u>82-5.01 Traffic-Capacity Analysis</u>

The need for a traffic-capacity analysis during the development of the TCP will be determined on a project-by-project basis. A freeway reconstruction project is a candidate for analysis, as is another project type under similar conditions. Maintaining an acceptable level-of-service during construction is especially important on a freeway or other high-speed rural highway.

The operational elements of a facility under construction (e.g., lane segments, ramp, intersection) should maintain a level-of-service which is not less than that provided by the facility prior to construction, although this is not always attainable. Achieving this may require the following:

1. converting a shoulder to a travel lane;
2. eliminating on-street parking (during peak traffic-volume hours or at all times);
3. constructing a temporary lane;
4. opening additional lanes during peak traffic-volume periods;
5. providing public transportation;
6. constructing a jug-handle type configuration for an indirect left-turn at an intersection;
7. closing or metering ramps at an interchange;
8. providing a turnout along long, restrictive stretch of highway construction;
9. constructing a passing blister at a T intersection;
10. providing a two-way, left-turn lane on an urban facility;
11. adjusting signal phasing and timing at an intersection;
12. providing an additional turn lane at an intersection;
13. lengthening a turn-lane storage bay;
14. adjusting acceleration or deceleration length at an interchange ramp;
15. closing an intersection;
16. restricting turns at an intersection;
17. providing extra pavement width;
18. providing signal or flagger control in a 1-lane, two-way operation;
19. public information; or
20. providing a temporary ramp connection.

82-5.02 Queuing Analysis

A TCP developed for a freeway reconstruction project should include, at a minimum, a queuing analysis to determine the anticipated traffic backups at particular times of the day. The results of the queuing analysis should be included with the proposed TCP and should be used to determine whether or not to consider the following:

1. restricting construction operations to off-peak traffic-volume hours or nighttime;
2. closing a ramp;
3. using alternate routes;
4. developing public relations strategies; or
5. temporary widening for an extra lane or for roadway capacity.

If a queuing analysis is required, the designer should use the FHWA computer program QUEWZ or other approved program to accomplish the task. QUEWZ is designed to evaluate a freeway work zone, but the designer may find it useful for another type of highway with 4 or more lanes. Section 81-4.0 provides additional information on the program. The program can provide the following:

1. estimation of vehicular capacity through a work zone;
2. calculation of average speed;
3. calculation of delay through a lane-closure section;
4. calculation of queue length;
5. estimate of percentage of diverted traffic; and
6. total user cost.

82-6.0 APPLICATIONS

Section 81-2.0 discusses the factors to consider in determining which construction application to use. The following provides the design considerations for such applications.

82-6.01 Lane or Shoulder Closure

In addition to the INDOT *Standard Drawings*, the designer should consider the following for a lane or shoulder closure.

1. Taper. A lane closure, lane-width reduction, or lane shift requires the use of a transition taper to safely shift traffic around the encroaching restriction. The designer should review Sections 82-3.03 and 83-3.02 regarding a transition taper.

2. Sight Distance. Provide decision sight distance to the beginning of the lane closure or transition. Section 82-3.04 provides additional information on sight distance within a construction zone.

3. Lane Width. Section 82-3.02 provides the Department's criteria for reduced lane width.

4. Shoulder Usage as Travel Lane. If the TMP involves placement of traffic on the shoulder or a portion of the shoulder, the designer should make a written request to the Office of Pavement Engineering, regarding the shoulder's use. The construction year AADT, percent trucks of AADT, and the approximate length of time during which traffic is expected to use the shoulder should be provided.

   The median shoulder should be replaced with a 6-ft width section. See the INDOT *Standard Drawings*. The proposed median shoulder for the new pavement section constructed in the first phase should also be 6 ft wide. Its pavement design should be provided by the Office of Pavement Engineering. Such shoulder will carry traffic during subsequent phases. The entire 6-ft width should remain in place. Shoulder corrugations are to be milled into the new shoulder after traffic is crossed over to the other roadway.

5. Lane Closure. The length of a lane closure should be held to a minimum so that the motorist is not passing a long section of a closed lane where no work activity is occurring.

6. Roadside Safety. A roadside barrier should not be used as a transition device. A transition should be provided with the appropriate traffic-control devices (see Chapter Eighty-three). Provide sufficient distance between the transition devices and roadside barrier to allow an errant motorist to safely return to the traveled way. A roadside barrier (e.g., temporary traffic barrier) may be used as a channelization device beyond the taper. When shifting traffic to be next to a roadside barrier, the shy distance, as discussed in Section 49-5.0, should be provided.

7. Traffic-Control Devices. Chapter Eighty-three and the INDOT *Standard Drawings* provide the Department's criteria for the placement of traffic-control devices.

8. Bridge. Figure 82-6A, Lane Closure on a Bridge, illustrates a TCP for closing a lane on a bridge-reconstruction or -rehabilitation project. Figure 82-6A is applicable to a 30-ft wide structure on a 4-lane divided facility. The designer will need to adjust the design for another situation. Figure 82-6A provides the detail for a left-lane closure. This detail may also be used for a right-lane closure.

9. Roadway Under Overpass Structure. Work may include full-depth bridge-deck patching, structure removal or placement not protected by a bridge railing, or other work activity that affects under passing lanes that are open to traffic. Such work may not take place directly above such lanes. Appropriate warning signs and traffic-control devices should be provided on the under passing roadway to warn motorists of lane closures for such work. Such signs and devices are required if no work is being done on the under passing roadway.

82-6.02 Two-Way Traffic on a Divided Highway

The following provides the considerations for where two-way traffic is to be placed onto a single roadway of a divided highway.

1. Length. The optimum segment length is less than 4 mi. Where the segment length exceeds 4 to 5 mi, operational efficiency may be severely reduced as traffic backs up behind slower vehicles.

2. Positive Protection.

a. Freeway. Temporary traffic barrier along with temporary solid yellow lines as shown on the INDOT *Standard Drawings* should be used within each crossover and between the crossovers to separate opposing traffic.

b. Other Multilane Roadway. Tubular markers should be used to enhance the delineation and separation of the opposing traffic flows on each side of a temporary double solid yellow line. The tubular markers are placed onto the pavement between the solid yellow lines as shown on the INDOT *Standard Drawings*.

   Where construction activities require temporary revision of traffic patterns within the construction zone to two-lane two-way operation at or near an intersection, the end of the temporary double solid yellow line should match the end of the existing broken white lane line.

   For a roadway with lanes which are narrower than 12 ft without paved or aggregate shoulders, compacted aggregate size No. 73 is required where slope and ditch conditions permit, as shown on the INDOT *Standard Drawings*. Such conditions must be assessed when developing the traffic-control plan. The cross slope of each temporary compacted aggregate shoulder is to be as shown on the INDOT *Standard Drawings*. Quantities for the compacted aggregate must be determined.

3. <u>Roadside Safety</u>. Where traffic is directed onto the opposing roadway, the designer should consider the effect this will have on the operational characteristics of roadside appurtenances. For example, an existing trailing end of an unprotected bridge railing may require an approach-guardrail transition or impact attenuator. A blunt guardrail terminal may need to be protected with an acceptable end treatment.

4. <u>Crossover</u>. The following should be considered in the design of a crossover.

   a. The taper for a lane drop should not be contiguous with the crossover. See Section 82-3.03 for the acceptable taper rate and length.

   b. The crossover should have a construction-zone design speed that is not more than 10 mph below the posted speed limit before the construction zone; see Section 82-3.01.

   c. The crossover design should accommodate the anticipated truck traffic of the roadway (e.g., surfacing width, loads).

   d. A clear recovery area should be provided adjacent to the crossover; see Section 82-4.04.

e. Temporary traffic barrier and the excessive use of traffic-control devices cannot compensate for a poor geometric design of a crossover.

f. Provide signing prior to the crossover to indicate the length of the 2-way, 2-lane section. In addition, signing may be provided within the 2-lane section indicating the remaining distance of the 2-lane section.

5. Interchange. Maintain access to a freeway interchange ramp if the work space is in the lane adjacent to the ramps. An additional crossover for the purpose of maintaining full interchange access may be required. If interchange access is not feasible or presents a capacity problem, a ramp should be closed using proper detour signing for alternative routes. Where a ramp closure is deemed necessary, early coordination should be conducted with local officials having jurisdiction over the affected crossroad or street. The designer should also check that sufficient deceleration or acceleration distance is maintained where there is work in the vicinity of an interchange ramp. If this is not practical, additional traffic control devices or closing the ramp may be required. The designer should review the safety aspects and conduct a capacity analysis to determine the appropriate action.

7. Capacity. Conduct a capacity analysis to ensure that traffic can be reasonably handled in the one lane. If not, an alternate construction application should be considered (e.g., lane shift to the shoulder).

   The needs of a left-turning motorist should be considered in developing a phased-construction scheme that reduces a 4-lane road to one lane in each direction.

82-6.03 Interstate-Highway Lane Closure

Past work-zone traffic-maintenance practices should be consolidated with new requirements to eliminate or reduce traffic delay caused by a work zone on an Interstate route. Central to this consolidation is managing the capacity to maintain traffic flow. Ultimately this will enhance customer satisfaction while traveling through such a work zone.

1. General Requirements. Figure 82-6B, Interstate-Route Lane-Closure Policy – Statewide, and Figure 82-6C, Interstate-Route Lane-Closure Policy – Selected Urban Areas, define the allowable times of the week or day during which lanes may be closed on an Interstate route. This policy is based on the threshold of lane restrictions which may generate up to a 1-mi queue or 10-min road user delay, and applies to each contracted expansion, preventative-maintenance, or planned-maintenance activity, except for a work activity denoted in INDOT's *Work Management System as Performance Standards* performed by INDOT personnel.

At the times when an Interstate route is designated as an alternate or detour route for another Interstate route, the allowable times for lane closure shown in the figures will not apply. Only work designated as an emergency may be performed during this time.

2. Determining Lane Closure Based on Maps in Figures. Figures 82-6B and 82-6C illustrate where and at what times a restriction may be present along a rural portion of an Interstate route.

Time descriptions are defined as follows:

a. Anytime. One lane may always be closed in each direction.

b. Weekend or Nighttime Only. One lane may be closed in each direction from Friday 9:00 p.m. through Monday 6:00 a.m., and weekdays from 9:00 p.m. to 6:00 a.m. along a route with significant commuter traffic.

c. Weekday or Nighttime Only. One lane may be closed in each direction except from Friday 6:00 a.m. to Sunday 9:00 p.m. along a route which experiences significant increases in traffic during the weekends.

d. Nighttime. One lane may be closed in each direction nightly from 9:00 p.m. to 6:00 a.m. along a route with heavy traffic where a queue longer than 1.0 mi can be expected during the daylight hours.

e. Executive Approval. Such approval is required for one lane to be closed in each direction along a rural four-lane route with Average Annual Daily Traffic (AADT) greater than 50,000. Except for a condition designated as an emergency, approval by the Chief Engineer for a Production Management Division-developed project, or the District Operations and Traffic Management Deputy Director for a district-developed project, is required before a lane closure may be shown on the TCP.

f. Minimum Two Lanes in Each Direction. A minimum of two lanes in each direction should be open at all times along an urban route with six total lanes and AADT greater than 100,000.

g. Minimum Three Lanes in Each Direction. A minimum of three lanes in each direction should be open at all times along an urban route with eight total lanes or more.

3. Determining Lane Closure Independent of Maps in Figures. If an operation is to restrict or extend a lane closure during times not shown on Figure 82-6B or 82-6C, the designer or planner should complete a quantitative analysis and a TMP with the request for an exception.

For each repair deemed an emergency, see Item 6 below.

The Office of Environmental Services' Environmental Policy Team, or district Office of Design should analyze the impact on the motoring public of a proposed lane closure not permitted by Figure 82-6B or 82-6C.

For contract work, the analysis should occur during the planning process after the pavement recommendation has been formulated, or if the need for bridge work has been determined. The analysis should always occur before beginning scoping of the final design.

For a Design-Build project, the Traffic Management Plan will be completed, approved, and reflected in the scope of services.

Analysis of a permit or force-account work-zone impact should occur prior to the implementation of a lane restriction.

4. Qualitative Analysis. A quantitative analysis should be performed to determine the queue length that will be generated if a lane closure is proposed for times not shown on Figure 82-6B or 82-6C.

   a. Projected Queue Shorter than Threshold Length. The final development process may commence. Documentation of the analysis must be retained on file. A work-zone strategy chosen that will result in impacts of less than the allowable delay thresholds but increases the project cost by 20% or $1,000,000 should be submitted to the Chief Engineer for approval.

   b. Projected Queue Equal to or Longer than Threshold length. An exception request should be submitted to the Chief Engineer or Deputy Commissioner of Highway Management. The exception request should identify the alternative selected as the preferred option and the reasoning for the selection. The exception request should also address the impact on the current INSTIP program if the request were to be denied.

5. Traffic Management Plan (TMP). The TMP should be completed for the strategy selected and should incorporate the applicable additional elements as follows:

   a. consideration of stakeholders' needs during the decision-making process;

   b. incident-management strategies;

   c. public-relations campaign; and

d. identification of alternate routes.

6. Emergency Repairs. Repair work deemed as an emergency which occur at times not shown on Figure 82-6B or 82-6C will not require prior approval before a lane closure action is taken. Such work includes, but is not limited to, pavement or bridge-deck failure, bridge-structure impact damage, roadside appurtenance, or slope stability. Notification of the closure must satisfy current Departmental procedures.

7. Routine District Maintenance. Some non-contractual routine maintenance activities, such as crack sealing, pavement markings, raised-pavement-markers restoration, etc., are performed on a recurring basis by district maintenance forces. Such activities are exempt from this policy and are addressed under a separate *District Maintenance Interstate Lane Closure Policy* developed by the districts and the Highway Operations Division.

8. Queue Analysis. The criterion used to determine the impact of a proposed work zone will be queue length. QuickZone, Quewz-92, Synchro/Simtraffic, Corsim, or a similar computer program may be used to model the expected queue that may be generated. Multiple stages of construction should be analyzed for each traffic-maintenance phase. The speed limit used in the computer models should be the posted legal construction-zone speed limit. Volume data supplied by INDOT for input into the models should be current (not older than three years), should account for seasonal traffic surges that may occur during construction, and should reflect current regional traffic patterns. Traffic volume should be expanded to the construction-year level through the use of growth factors. In an urban area where congestion occurs under normal unrestricted conditions, the queue length should be considered.

   Use of a microscopic model (Synchro/Simtraffic, Corsim, etc.) is encouraged for modeling of a work zone queue. The effect of a significant ramp merge on a queue should be included in the model.

   A vehicle will be considered part of a queue if its average operating speed is approximately 10 mph or lower. Discretion is required during both the analysis portion and field evaluation of the implemented work zone in determining what constitutes a queue. A condition that causes driver frustration due to stop-and-go operations should be considered a queue.

   The following thresholds should be used for the evaluation of a queue length as determined by the computer model.

   a. For a queue shorter than 1.0 mi., the work zone impacts are acceptable.

   b. For a queue of 1 mi or longer but shorter than 1.5 mi, the work-zone impacts are acceptable if the queue length exceeds 1 mi for 2 h or less. Where a queue is expected, additional advanced work-zone warning signing should be specified.

c. For a queue of 1 mi or longer for more than 2 h, or for a queue of 1.5 mi or longer for any period of time, the work-zone impacts are unacceptable. Alternate strategies should be considered based on this policy.

82-6.04 Runaround or Detour

In addition to the criteria shown on the INDOT *Standard Drawings*, a temporary runaround or specially-built detour should satisfy the geometric and roadside-safety criteria provided in Sections 82-3.0 and 82-4.0.

The embankment for a temporary runaround should be shown on the mainline cross sections.

If the AADT is 5,000 or greater, or if the percent trucks is 10% or greater, a project-specific pavement design is required for a temporary runaround. See the INDOT *Standard Drawings* for the pavement section to be used if the AADT is less than 5000, or if the percentage of trucks is less than 10%.

** *PRACTICE POINTER* **

Unofficial detour routes should not be shown on the plans or described in the special provisions.

A temporary runaround should be in accordance with the design criteria included herein. The following Level One elements should satisfy the criteria as follows.

	Element	Design Criterion
1.	Design speed	Section 82-3.01
2.	Lane width	Section 82-3.02
3.	Shoulder width	Section 82-3.02
4.	Bridge width	Standard Specifications Section 713.04
5.	Structural capacity	Standard Specifications Section 713.04
6.	Horizontal curvature	Figure 82-3A
7.	Superelevation transition length	Section 82-3.05 and Chapter 43

8a.	Stopping sight distance at horizontal curve	Section 82-3.04. Design speed should be used in the construction zone. Section 43-4.0
8b.	Stopping sight distance at vertical curve	Sag: Section 82-3.06; Crest: Section 82-3.04 and Chapter 44.
9.	Maximum grade	3R criteria for the design speed for the construction zone, appropriate functional classification, and rural or urban environment.
10.	Through lane cross slope	3R criteria for the appropriate functional classification and rural or urban environment. If the existing shoulder is used for through traffic, 4% cross slope will be acceptable.
11.	Superelevation rate	Section 82-3.05
12.	Vertical clearance	3R criteria for the appropriate functional classification.
13.	Americans with Disabilities Act requirements	Section 51-1.08, where sidewalk exists prior to construction.
14.	Bridge-railing safety performance	Standard Specifications Section 713.04

If the design for a temporary runaround or other traffic-maintenance means does not satisfy the above criteria, a design exception must be requested. The procedure established in Section 40-8.0 should be followed.

The INDOT reviewer should verify that the above criteria are satisfied as part of the limited review of a consultant-designed project.

A TCP checklist is shown as Figure 82-7A. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/.

Participant	Project Stage				
	Scoping of Project	Prelim. Field Check	Hearing	Final Field Check	Final Plan Review
Designer	X	X	X	X	X
Office of Environmental Services	X	X	X	X	X
Consultant (if applicable)		X	X	X	X
District	X	X		X	X
Federal Highway Administration (if applicable)	X	X		X	
Communications Division (if applicable)	X		X	X	
Local Public Agency (City or Town, County, School, Fire Department)	X	X	X		X
Highway Operations Division (TMP)	X	X		X	

PARTICIPANTS DURING TRAFFIC-CONTROL-PLAN DEVELOPMENT

Figure 82-2A

TRAFFIC-MAINTENANCE QUESTIONNAIRE
English-Units Project

, 20

MEMORANDUM

TO:
District Deputy Director

ATTENTION:
District Traffic Office Manager

ATTENTION:
District Design Office Manager

FROM:
Project Manager

SUBJECT: Traffic Maintenance for English-Units Project

Route:
Des.:
Project No.:
Bridge File:
Location:
County:
Description:

We are preparing plans for the project identified above and are in the process of evaluating the relative merits of a temporary bridge and runaround, maintaining traffic through the project limits, or a detour during the construction period. In order that district input may be considered in this decision, we ask that you complete the blanks in this memorandum and return it to:

Project Manager
Indiana Department of Transportation
100 North Senate Ave., Room N642
Indianapolis, IN 46204-2216

If a detour is recommended, please submit the official detour map and signage with this memorandum with the blanks filled in. If the official detour route is totally over local roads, please initiate early coordination with the affected local public agency or agencies regarding the unofficial detour route.

The Engineer's Report recommended the following:
a temporary runaround should be used;

traffic should be maintained through the project limits;
an official detour should be used.

The AADT during the construction year is

A. TRAFFIC-MAINTENANCE OPTIONS ANALYSIS

1. OPTION 1: TEMPORARY RUNAROUND

RUNAROUND COMPUTATIONS FURNISHED BY DESIGNER

Length of Runaround, ft* x Cost per Foot**	ft x $ = $
Length of Temporary Bridge x $1,000/ft or Cost of Pipe	ft x $1,000 = $ $
Total Runaround Cost (Total Cost Option 1)	$

* Length of Runaround = Distance from tie-in point to tie-in point minus Length of Temporary Bridge.

** For average fill height ≤ 6 ft, use $120/ft
For average fill height > 6 ft, increase as necessary

2. OPTION 2: TRAFFIC MAINTAINED THROUGH PROJECT LIMITS

Length of Roadway Treatment, ft* x Cost per Foot*	ft x $ = $
Length of Temporary Concrete Barrier x Cost per Foot	ft x $ = $
Cost of Crossovers	$
Total Maintained-Traffic Cost (Total Cost Option 2)	$

3. OPTION 3: INDOT-ROUTES OFFICIAL DETOUR

a. Best available official detour route over INDOT routes:

b. Extra distance to be traveled by through traffic using this route: mi

c. Percent of the traffic which would use this detour route: %

d. Road(s) that would be used as an unofficial detour route:

(1) Existing condition and type of pavement for each road, (i.e., good, very good, rutted, gravel, asphalt, etc.)

(2) Distance over the above unofficial detour route: mi

INDOT-ROUTES OFFICIAL-DETOUR COMPUTATIONS

Detour	Through	Local
Detour Duration (days)		
Extra Distance (mi)		
Vehicles per Day		
User Cost per Mile	$0.30	$0.30
Total User Cost	$	$

User Cost = Detour Duration x Extra Distance x Vehicles per Day x $0.30/mi

e. Total User Cost = Through User Cost + Local User Cost. Therefore, Total User Cost = $.

f. Estimated payment to local public agencies due to use of unofficial detour route = $.

Total Cost Option 3 (e + f) $

4. OPTION 4: LOCAL-ROADS OFFICIAL DETOUR

a. Best available official detour route over local roads. It is feasible for this route to include one or more INDOT routes.

b. Extra distance to be traveled by through traffic using this route: mi

c. Percent of the traffic which would use this detour route: %

d. Cost to upgrade the local roads to accommodate INDOT traffic: $

e. Existing condition and type of pavement for each road. (i.e., good, very good, rutted, gravel, asphalt, etc.)

LOCAL-ROADS OFFICIAL DETOUR COMPUTATIONS

Detour	Through	Local
Detour Duration (days)		

Extra Distance (mi)		
Vehicles per Day		
User Cost per Mile	$0.30	$0.30
User Cost	$	$
Cost to Improve Local Roads (See Item 3b)	$	n/a

User cost = Detour Duration x Extra Distance x Vehicles per Day x $0.30/mi

Total User cost = Through User Cost + Local User Cost + Cost to Improve Local Roads. Therefore, Total Cost Option 4 = $

B. AFFECTS OF PROJECT WORK ON PUBLIC SERVICES

1. TIME DELAYS

   Fire and police protection: min
   Emergency medical service: min
   Postal service: min

2. SCHOOL BUSES

   Number of school buses using the facility per day:
   Additional travel distance required per bus: mi
   Total additional school-bus travel distance required mi

3. BUSINESSES AND PUBLIC FACILITIES

   Businesses or public facilities which are sensitive to the presence of this road work, and the degree of impact the work would have:

C. DISTRICT RECOMMENDATION

1. RECOMMENDATION:

   Rationale for this recommendation if it is different than what is included in the Engineer's Report:

2. DETOUR ROUTE MARKER ASSEMBLIES:

   If an official detour is recommended, detour route marker assemblies will be required.

3. MAP OF OFFICIAL DETOUR:

   If an official detour is recommended, a map of the detour with sign locations is shown on an accompanying sheet.

Construction Zone Design Speed, V (mph)	f_{max} for Open-Roadway Conditions	Normal Crown Section Minimum Radius, R_{min} (ft), e = -0.02	Superelevated Section Minimum Radius, R_{min} (ft), e= +0.08
20	0.17	180	110
25	0.17	280	170
30	0.16	430	250
35	0.15	630	360
40	0.15	820	470
45	0.14	1130	620
50	0.14	1390	760
55	0.13	1840	960

Notes:

1. *Curve Radius. The radius is calculated from the equation as follows:*

$$R_{\min} = \frac{V^2}{15(e + f_{\max})};$$

Value shown in the table for design has been rounded up to the next higher 10-ft increment.

2. *Normal-Crown Section. If the normal-crown section is maintained through the horizontal curve, the superelevation rate is -0.02 assuming a typical cross slope of 2%. Therefore, the R_{min} column with e = -0.02 lists the minimum radius which can be used if retaining the normal section through the horizontal curve.*

3. *Other Radius. For a proposed radius or superelevation rate intermediate between the table values, the equation in Note 1 may be used to determine the proper curvature layout. For example, if the construction-zone design speed is 55 mph and the proposed curve radius is 1000 ft, the superelevation rate is determined as follows:*

$$e = \frac{V^2}{15R} - f$$

$$e = \frac{(55)^2}{(15)(1000)} - 0.12$$

$$e = +0.07$$

MINIMUM RADIUS FOR HORIZONTAL CURVE IN CONSTRUCTION ZONE

Figure 82-3A

Construction-Zone Design Speed (mph)	Calculated *K* Value ($K = V^2/46.5$)	*K* Value Rounded For Design
20	8.6	9
25	13.4	14
30	19.4	20
35	26.3	27
40	34.4	35
45	43.5	44
50	53.8	54
55	65.1	66

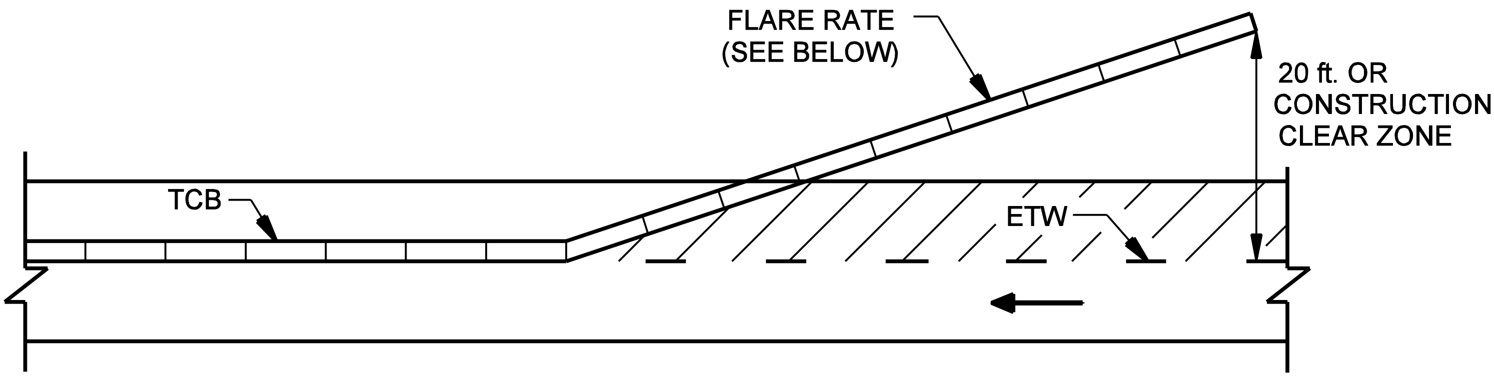
$$L = \frac{AV^2}{46.5} = KA$$

Where:

L = *Length of vertical curve, ft*
A = *Algebraic difference between grades, %*
K = *Horizontal distance required to effect a 1% change in gradient*
V = *Design speed, mph*

_K_ VALUE FOR SAG VERTICAL CURVE
(Comfort Criteria in a Construction Zone)

Figure 82-3B



Construction Zone Design Speed (mph)	Flare Rates
≤ 40	10:1
45	12:1
50	14:1
55	16:1

FLARE RATES FOR TEMPORARY CONCRETE MEDIAN BARRIER
(Construction Zones)

Figure 82-4A

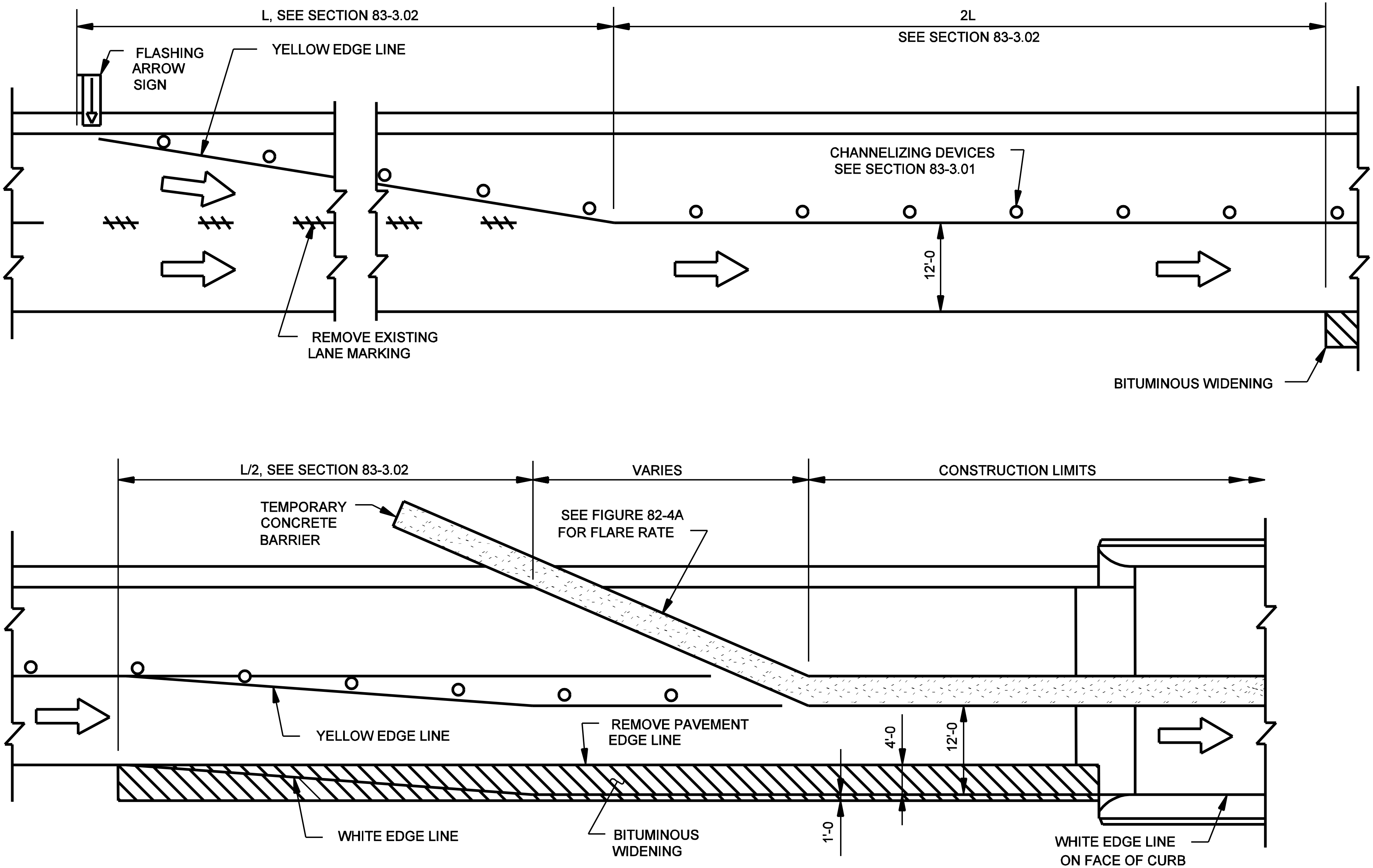
Construction-Zone Design Speed	Cut Slope 3:1	Cut Slope 4:1	Cut Slope 5:1	Cut Slope 6:1	Flatter Than 6:1	Fill Slope 6:1	Fill Slope 5:1	Fill Slope 4:1	Fill Slope 3:1
40 mph or lower	8	8	8	8	8	8	8	8	10	See Note 2
45 mph	8	8	8	8	8	8	10	10	12	
50 mph	8	10	10	10	10	10	12	13	15	
55 mph	8	12	12	12	12	12	13	15	18	

Notes:

1. *Width is measured from the edge of traveled way.*
2. *For a facility with 3:1 fill slopes, the clear-zone width shown above should be used in conjunction with the procedures described in Section 49-2.03(01).*

CLEAR-ZONE WIDTH (ft)
FOR CONSTRUCTION ZONE

Figure 82-4B



LANE CLOSURES ON BRIDGES

Figure 82-6A

INTERSTATE HIGHWAYS LANE CLOSURE POLICY

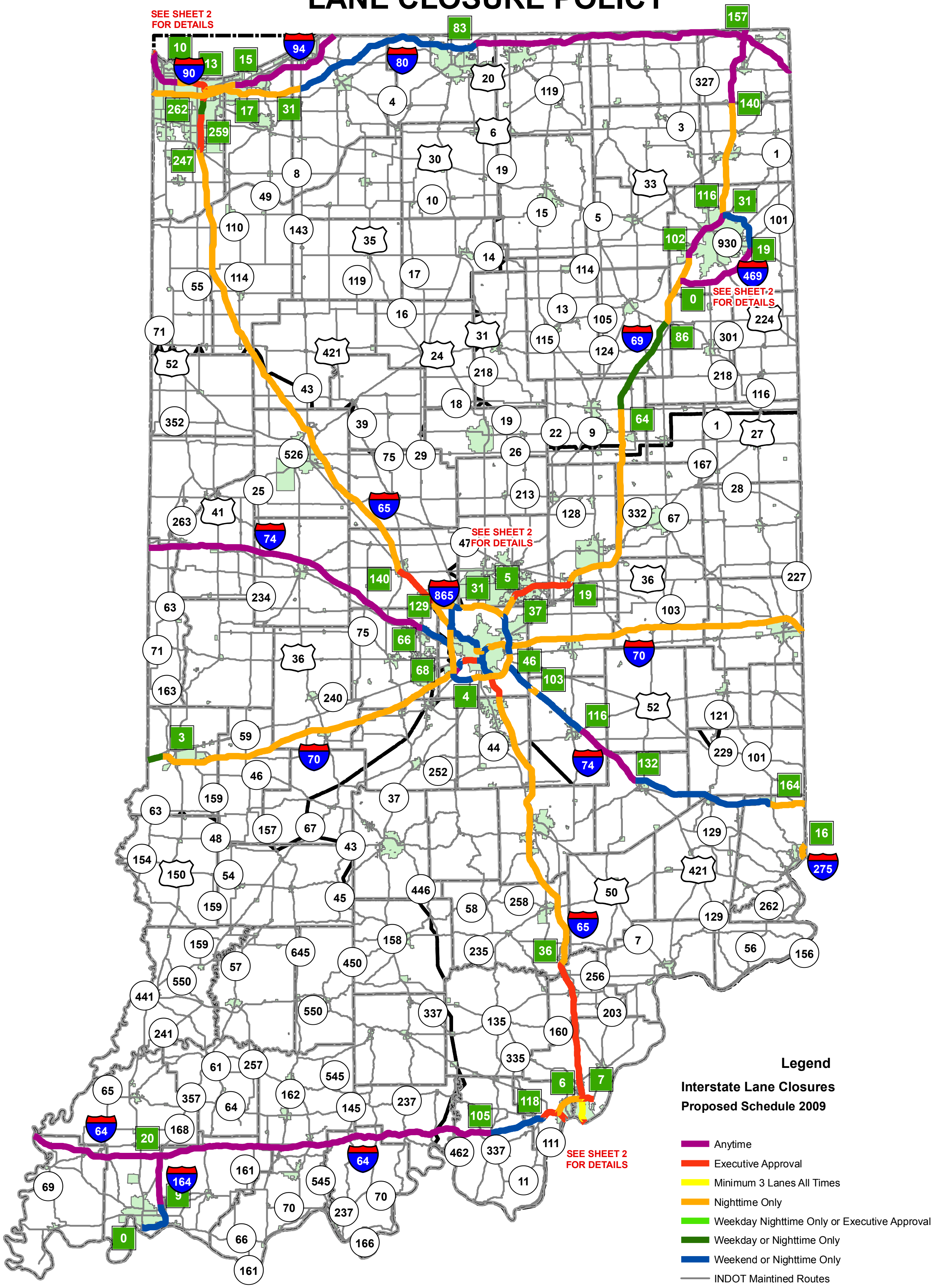
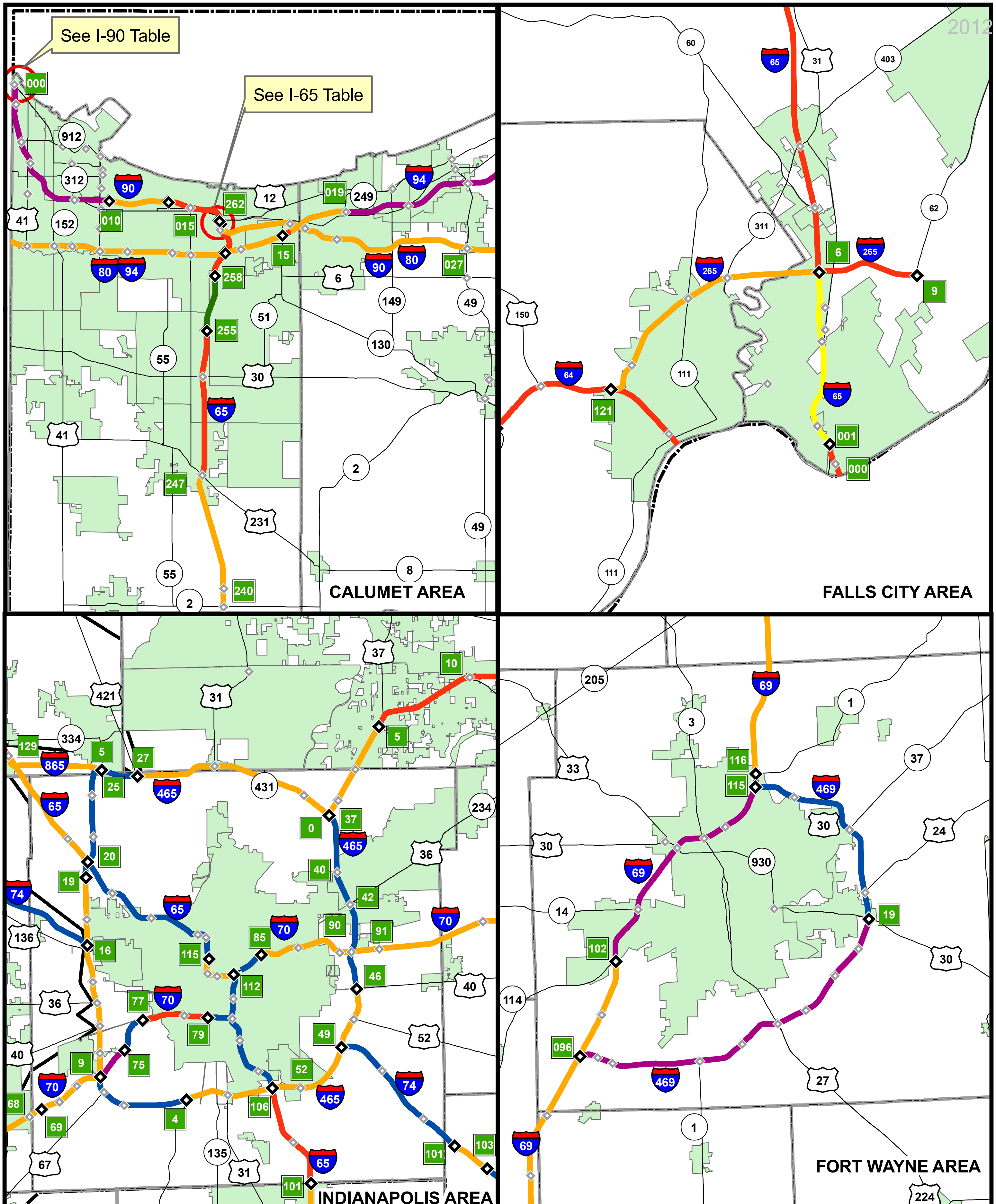


Figure 82-6B



Interstate Lane Closures

- Executive Approval
- Minimum 3 Lanes All Times
- Nighttime Only
- Anytime
- Weekday Nighttime Only or Executive Approval
- Weekday or Nighttime Only
- Weekend or Nighttime Only

- INDOT Maintained Routes
- District Boundaries
- Incorporated Areas

Interchange Locations

- Primary
- Secondary

Figure 82-6C

INTERSTATE LANE CLOSURE POLICY
JULY 2009
SHEET 2 of 2

TRAFFIC-CONTROL-PLAN CHECKLIST Route Des GENERAL INFORMATION		YES	NO	n/a	On Plans
1.	Has a transportation management plan been developed?	☐	☐	☐	☐
	a. Have all recommendations been implemented?	☐	☐	☐	☐
	b. Has Environmental Policy Team been notified of major changes?	☐	☐	☐	☐
2.	Have all applicable work-zone types listed below been adequately considered?				
	a. Work outside of roadway	☐	☐	☐	☐
	b. Lane constriction	☐	☐	☐	☐
	c. Lane closure	☐	☐	☐	☐
	d. One-lane, two-way operation	☐	☐	☐	☐
	e. Runaround	☐	☐	☐	☐
	f. Intermittent closure	☐	☐	☐	☐
	g. Use of shoulder or median as travelway	☐	☐	☐	☐
	h. Crossovers	☐	☐	☐	☐
	i. Two-way traffic on one roadway of divided facility	☐	☐	☐	☐
	j. Detour	☐	☐	☐	☐
3.	Has all information listed below been incorporated into the contract plans?				
	a. INDOT *Standard Drawings*	☐	☐	☐	☐
	b. INDOT *Standard Specifications*	☐	☐	☐	☐
	c. Recurring special provisions	☐	☐	☐	☐
	d. Unique special provisions	☐	☐	☐	☐
	e. Detail plans	☐	☐	☐	☐
4.	Will extra publicity be required prior to letting (e.g., radio, T.V., newspaper, clubs)?	☐	☐	☐	☐
5.	The contractor can restrict the roadway during:				
	a. Morning or evening rush hour				
	i. One direction	☐	☐	☐	☐
	ii. Both directions	☐	☐	☐	☐
	b. Local celebration	☐	☐	☐	☐
	c. Holidays or weekends	☐	☐	☐	☐
	d. Other special event:	☐	☐	☐	☐
	e. Overnight	☐	☐	☐	☐
6.	Nighttime hours of operation required? If Yes, When?	☐	☐	☐	☐
	a. Between p.m. and a.m.				
	b. Are special precautions needed (e.g., lighting, clearance lights on equipment)?	☐	☐	☐	☐

GENERAL INFORMATION (Cont'd.)	YES	NO	n/a	On Plans
7. Are there changes that cannot be made concurrently for traffic routing, fire, police, etc.? If Yes, What?	☐	☐	☐	☐
8. Can two adjacent street or road crossings be closed at the same time? If Yes, where or which ones?	☐	☐	☐	☐
9. Will the source of material from off the project site interfere with traffic?	☐	☐	☐	☐
a. On and off project limits	☐	☐	☐	☐
b. Certain roads may not be used (e.g., environmental, recreational). If Yes, which ones?	☐	☐	☐	☐
10. Is the contractor required to provide advance notice for a change in traffic pattern?	☐	☐	☐	☐
11. The starting or completion date is controlled by:				
a. School closings or openings	☐	☐	☐	☐
b. Holiday:	☐	☐	☐	☐
c. Other projects	☐	☐	☐	☐
d. Sporting event:	☐	☐	☐	☐
e. Other:	☐	☐	☐	☐
12. Are there present or future contracts in the immediate area that may affect traffic or the Contractor's operations?	☐	☐	☐	☐

DETOUR	YES	NO	n/a	On Plans
1. Will traffic be detoured? If Yes, is the detour adequate in terms of:	☐	☐	☐	☐
a. Weight restriction	☐	☐	☐	☐
b. Height – width	☐	☐	☐	☐
c. Wide load	☐	☐	☐	☐
d. Capacity	☐	☐	☐	☐
e. Adequate traffic-control devices	☐	☐	☐	☐
f. Railroad crossing and controls	☐	☐	☐	☐
g. Geometrics (turning radius, etc.)	☐	☐	☐	☐
h. Restriction on bridge or other structure	☐	☐	☐	☐
If No for a. through h., what correctives can be taken?				
2. Will trucks using the detour conflict with other traffic using the detour?	☐	☐	☐	☐

DETOUR (Cont'd.)		YES	NO	n/a	On Plans
3.	Will there be other construction along the detour that can influence traffic flow?	☐	☐	☐	☐
4.	Have other affected Districts or States been notified?	☐	☐	☐	☐
5.	If the detour is to be established on other than a State highway, has contact been made with:				
	a. County?	☐	☐	☐	☐
	b. City?	☐	☐	☐	☐
	c. Town?	☐	☐	☐	☐
6.	Will there be an unofficial detour?	☐	☐	☐	☐
	If Yes, has a Letter of Understanding been sent to the local officials?	☐	☐	☐	☐
7.	Will all fronting businesses have acceptable ingress and egress?	☐	☐	☐	☐
8.	Can the detour be continued over winter (snow removal)?	☐	☐	☐	☐
9.	Are alternate routes available to local motorists?	☐	☐	☐	☐
10.	Should the following be contacted?				
	a. Public-school system	☐	☐	☐	☐
	b. Public-transit system	☐	☐	☐	☐
	c. Police, fire, or ambulance services	☐	☐	☐	☐
	d. Postal mail-route service	☐	☐	☐	☐
	e. Others:	☐	☐	☐	☐
	If any Yes, list who and when, with telephone numbers.				
11.	Has the District established a detour route?	☐	☐	☐	☐
WORK ZONE		**YES**	**NO**	**n/a**	**On Plans**
1.	Will capacity be restricted? If Yes, what is extent of restriction?	☐	☐	☐	☐
	a. Where will excess traffic be diverted?				
	b. Can an alternate route handle the traffic?	☐	☐	☐	☐

WORK ZONE (Cont'd.)		YES	NO	n/a	On Plans
2. How will staging be addressed (e.g., lengths of times of permitted construction)?					
	a. As shown on plans	☐	☐	☐	☐
	b. Have the contractor provide a plan	☐	☐	☐	☐
	c. The contractor may stage work differently than shown on plans	☐	☐	☐	☐
3. Where runaround or temporary widening is required:					
	a. What criteria should be applied regarding:				
	i. Design speed? mph ii. Lane widths? ft iii. Alignment? iv. Pavement thickness? in. v. Pedestrian traffic?				
	b. Has the location been determined?	☐	☐	☐	☐
4. Number of lanes maintained in each direction:					
	a. At all times, ☐ One ☐ Two				
	b. During rush hours, ☐ One ☐ Two ☐ Three				
	c. Reversible lanes required, ☐ One ☐ Two				
5. What is the facility's traffic-carrying capability considering the effect of winter:					
	a. Adequate	☐	☐	☐	☐
	b. Special traffic-control devices are required	☐	☐	☐	☐
	c. Procedure modifications are necessary for snow removal and maintenance	☐	☐	☐	☐
	d. Modifications are required to the pavement structure:				
	i. HMA Base	☐	☐	☐	☐
	ii. HMA Base and Surface	☐	☐	☐	☐
TRAFFIC-CONTROL DEVICES		YES	NO	n/a	On Plans
1. Traffic-control signing layout will be:					
	a. Shown on the plans	☐	☐	☐	☐
	b. Available prior to contract letting	☐	☐	☐	☐
	c. Consisting of special traffic delay or advance signs	☐	☐	☐	☐
	d. That for temporary crossover, designed to match INDOT *Standard Drawings*	☐	☐	☐	☐
2. Will the effects of construction operation require sign message modifications to permanent signage?		☐	☐	☐	☐

TRAFFIC-CONTROL DEVICES (Cont'd.)		YES	NO	n/a	On Plans
3.	Are temporary traffic signals required?	☐	☐	☐	☐
	a. Equipment type:				
	i. Manual	☐	☐	☐	☐
	ii. Fixed timed	☐	☐	☐	☐
	iii. Actuated	☐	☐	☐	☐
	b. Will existing signals need to be kept operational?	☐	☐	☐	☐
	c. Has an agreement been reached with the local municipality?	☐	☐	☐	☐
4.	Will temporary street lighting be needed? If Yes, what type of equipment?	☐	☐	☐	☐
	a. Wood poles	☐	☐	☐	☐
	b. Breakaway poles	☐	☐	☐	☐
	c. Agreement with power company required?	☐	☐	☐	☐
5.	Which temporary pavement markings are required?				
	a. Paint	☐	☐	☐	☐
	b. Tape	☐	☐	☐	☐
	c. Raised pavement markers	☐	☐	☐	☐
6.	Striping removal required of:				
	a. Center line / Lane lines	☐	☐	☐	☐
	b. Right edge line	☐	☐	☐	☐
	c. Left edge line	☐	☐	☐	☐
	d. Both edge lines	☐	☐	☐	☐
7.	Flashing warning lights required for:				
	a. Equipment kept overnight within 30 ft of traveled way	☐	☐	☐	☐
	b. All barricades and warning signs	☐	☐	☐	☐
	c. Construction roadside hazards	☐	☐	☐	☐
8.	Steady-burn warning lights required for:				
	a. Edge of travelway, dropoff of in.	☐	☐	☐	☐
	b. Channelizing traffic	☐	☐	☐	☐
9.	Have speed limits been considered? If Yes, what limits?	☐	☐	☐	☐
	a. Work zone, mph				
	b. Worksite, mph				
	c. Minimum, mph				
	d. Advisory, mph				

ROADSIDE SAFETY		YES	NO	n/a	On Plans
1. Temporary barriers					
	a. Required for traffic protection	☐	☐	☐	☐
	b. Required for workers' protection	☐	☐	☐	☐
	c. Delineation of barriers provided by:				
	i. Electrical devices	☐	☐	☐	☐
	ii. Reflectorization	☐	☐	☐	☐
	d. Upon completion of project, retained by:				
	i. Department	☐	☐	☐	☐
	ii. Contractor	☐	☐	☐	☐
2. Will temporary impact attenuators be required? If Yes, Type		☐	☐	☐	☐
3. Extra protection will be required for:					
	a. Pedestrians	☐	☐	☐	☐
	b. School area and crossings	☐	☐	☐	☐
	c. Playground or park	☐	☐	☐	☐
	d. Type of protection:				
4. Where may the contractor store equipment, construction material, or waste material?					
	a. On site with flashers or other protection	☐	☐	☐	☐
	b. 30 ft or more from edge of traveled way	☐	☐	☐	☐
	c. Designated storage site	☐	☐	☐	☐
5. Where may contractor's employees park personal vehicles?					
	a. On-site	☐	☐	☐	☐
	b. Off-site	☐	☐	☐	☐

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER EIGHTY-THREE

TRAFFIC-CONTROL DEVICES IN A CONSTRUCTION ZONE

83-1.0 GENERAL

The proper use of traffic control devices is critical to both public and worker safety and has been proven to significantly reduce accidents in a construction zone. This Chapter provides supplemental information on these devices and provides specific Department policies and procedures. For additional information, the designer is encouraged to review the references listed in Section 83-1.01.

83-1.01 References

For additional information on the design, application, and placement of traffic control devices in a work area, the designer is referred to the latest editions of the publications as follows:

1. *Manual on Uniform Traffic Control Devices* (*MUTCD*), FHWA;
2. INDOT *Standard Drawings*;
3. INDOT *Standard Specifications*;
4. *Indiana Design Manual*, Chapter Seventy-five – Highway Signs;
5. *Indiana Design Manual*, Chapter Seventy-six – Pavement Markings;
6. *Indiana Design Manual*, Chapter Seventy-seven – Traffic Signals;
7. *Indiana Design Manual*, Chapter Seventy-eight – Highway Lighting.

The INDOT publications can be obtained by contacting the Contract Administration Division. For other publications, the indicated source should be contacted.

83-1.02 MUTCD Context

Throughout the *MUTCD*, the words shall, should, and may are used to describe the appropriate application each traffic-control device. The *MUTCD* defines the terms as follows:

1. Shall. A mandatory condition. Where certain requirements in the design or application of a device are described with the "shall" stipulation, it is mandatory that if an installation is made that these requirements be met.

2. Should. An advisory condition. Where the word should is used, it is considered to be advisable usage, recommended but not mandatory.

3. May. A permissive condition. No requirement for design or application is intended.

83-1.03 Official Action

An Official Action is required if a proposed change is made to a facility's regulatory control. For example, an Official Action is required where a proposed change is made regarding a parking restriction, intersection control, no-passing zone, traffic signal, or work-zone speed limit. However, Indiana Statutes provide for the establishment of an enforceable reduced speed limit in a work site without an Official Action (see Section 83-2.03). For a State-controlled facility, the designer must contact the appropriate INDOT district traffic engineer and obtain a copy of the approved Official Action, and include it in the contract documents. For a locally-controlled facility, approval (i.e., local ordinance) must be obtained from the appropriate jurisdiction.

83-2.0 HIGHWAY SIGNS

In a construction zone, a regulatory sign is used to temporarily override an existing mandate or prohibition (e.g., reduced speed limit). A warning sign is used in advance of the construction area to indicate a potentially-hazardous condition. A guide sign is used to inform the motorist of a detour route, destination, or point of interest.

The INDOT *Standard Drawings*, the INDOT *Standard Specifications*, and *MUTCD* Part VI provide the Department's criteria for the design, application, and placement of signs in a construction zone. This Section provides the designer with supplemental information on the application of a highway sign. The designer should review Chapter Seventy-five and the *MUTCD* regarding permanent signs.

83-2.01 Sign-Legend Measurement Units

Regulatory or advisory speed limit, distance message, or other sign legend displayed in a construction zone will remain in English units until notified otherwise. Figure 83-2A provides guidelines for converting English units to metric.

83-2.02 Placement

The uniform placement of construction signing, although desirable, is not always practical. Road geometrics or other factors often dictate a more advantageous placement. The designer should consider the following guidelines together with established criteria in determining the placement of construction signing.

1. Permanent Sign. A construction sign in close proximity to a permanent sign should be reviewed after the theoretical temporary sign location has been determined. For example, the permanent sign should not block the view of the temporary sign nor convey conflicting information. The designer should also avoid creating an information overload by placing too many signs near each other.

2. Intersection. If construction signing is warranted near an intersection, the designer should consider placing the temporary sign beyond the intersection. On the intersection approach, a permanent sign provides control and directional information to the motorist. Locating a construction sign beyond the intersection will usually enhance a motorist's comprehension of the sign.

3. Roadside Barrier. The designer should consider placing a temporary construction sign behind an existing roadside barrier if practical. This will reduce the probability that it will be impacted.

83-2.03 Regulatory Signing

83-2.03(01) Work-Zone and Work-Site Speed Limit Signing [Rev. Mar. 2011]

Different speed limits may apply based on whether the speed limit is within the work zone or if it is within a work site. The work-zone speed limit applies throughout the project. A work-site speed limit applies to a specific location within the work zone where work is actually occurring. The following provides guidance in the selection and implementation of a work-zone or work-site speed limit.

1. Work-Zone Speed Limit. The work-zone speed limit will be determined based on the construction-zone design speed, traffic volume, work type, geometrics, project length, etc. The work-zone speed limit should not exceed the construction-zone design speed through the construction area. Section 82-3.01 provides guidance on the selection of a construction-zone design speed. If the work-zone speed limit is different than the existing posted speed limit prior to the start of construction, an Official Action as discussed in Section 83-1.03 will be required.

2. Work-Site Speed Limit. Indiana Statutes permit INDOT to establish a work-site speed limit without an Official Action. They also stipulate that the work-site speed limit will either be 45 mph, or 10 mph below the original posted speed limit, whichever is lower. The work-site

speed limit will only be applicable where and while work is actually in progress and workers are present.

3. Sign Size and Assembly. A work-zone or work-site speed-limit-sign assembly should be placed according to the *MUTCD* and should be of a size specified for the facility. Each work-site assembly should include a "Worksite" plate mounted above the regulatory sign.

4. Flashing Beacon. Each work-site speed-limit-sign assembly should incorporate strobe-type flashing beacons with one mounted at each upper corner of the regulatory sign. A "When Flashing" plate should be placed below the sign. The beacons should be activated only while work is in progress and workers are present. The device provides for both worker and public safety without imposing unnecessary travel delays during non-working periods.

5. Selection. Figure 83-2B provides suggested work-zone and work-site speed limits for a freeway based on the type of facility and the proposed construction application.

6. Location and Spacing. In determining the location and spacing of signs, the following will apply.

    a. Work-Zone Sign. The designer should coordinate with the district traffic engineer to determine the appropriate beginning and ending locations for the work-zone speed limit. A work-zone speed limit signs should be placed prior to the construction zone and after each interchange entrance ramp within the construction zone. The reduced-speed zone should begin prior to an expected queue backup due to a lane closure, lane restriction, etc.

    b. Work-Site Sign. The INDOT *Standard Specifications* provide the guidelines for determining the appropriate location for a work-site speed-limit-sign assembly.

7. Rural Area. The regulatory sign, R2-15b, "Reduced Speed XX Ahead" should not be specified. Instead, reduced-speed-limit warning sign W3-5 or W3-5a should be specified. The details are shown on the INDOT *Standard Drawings*. Only one of the sign designations should be specified for the entire project.

8. Divided Facility. An assembly should be placed on each side of each roadway.

83-2.03(02) "Stop" or "Yield" Sign

Each specific site may warrant the use of other regulatory-sign changes. For example, the installation of a "Stop" or "Yield" sign may be considered at a previously uncontrolled merge and acceleration area if the taper length is reduced during construction operations. An Official Action, as described in Section 83-1.03, must be coordinated through the district traffic engineer. Based on *MUTCD* guidelines, the implementation of a “Stop Ahead” or “Yield Ahead” sign may also be considered.

83-2.03(03) Selective-Exclusion Sign

Where a lane shift occurs through a construction zone and the lane shift requires the use of the shoulder as a travel lane, the designer may consider the use of a selective-exclusion sign to assign heavy-truck traffic to lanes on the pavement proper (i.e., a heavy truck is not be permitted to use the shoulder as a travel lane). An Official Action, as described in Section 83-1.03, must be coordinated through the district traffic engineer.

83-2.04 Advance-Warning Sign

A warning sign is used to alert the motorist of a potentially hazardous condition on or adjacent to the roadway. The unnecessary use of this type of sign may breed motorist disrespect for signing in general. The designer should therefore only use the minimum number of warning signs necessary to adequately warn the motorist. The following provides additional information on the sequence and placement of advance warning signs.

A warning sign is used in an advance warning, transition, or activity areas of a construction zone. The advance-warning area is the first opportunity to inform a motorist regarding the safe negotiation of the upcoming construction activity. The designer should consider the following in determining the sequence and placement of advance-warning signs.

1. road facility type and location;
2. traffic volume and mix;
3. posted speed limit;
4. construction activity type and location; and
5. actual or anticipated field conditions.

Based on these factors, the advance-warning area may warrant either a single warning sign or a multiple sign sequence. An advance-warning sign sequence may be classified as A, A-B, or A-B-C. Figure 83-2C, Advance-Warning Signs, and the *MUTCD* provide applications for each sequence classification. The following describes each sign sequence category and its application.

1. A Sequence. This consists of a single sign placed upstream from the nearest point of transition or restriction. The designer should consider the sequence for work outside a shoulder.

2. A-B Sequence. This is a two-sign configuration within the advance-warning area. The B sign is placed upstream from the A sign. The sequence should be considered for a construction activity as follows:

   a. work on a shoulder;
   b. interior-lane closure on a roadway with 3 or more lanes; or
   c. lane closure on a minor street.

3. A-B-C Sequence. This consists of three or more signs within the advance-warning area. The C sign is placed upstream from the B sign. The sequence should be considered for a construction activity as follows.

   a. road closure with traffic diversion;
   b. lane closure for one-lane, two-way traffic control; or
   c. lane closure for a highway with 4 or more lanes or a freeway.

The use of a multiple advance-warning sign sequence is required on a limited access facility with a higher speed or a facility with construction activities which present the motorist with major decision points (e.g., lane closure, multiple-lane shift, queue backup). Advance warning signs tend to be spread out over a greater distance on such a facility to provide the motorist with adequate time and distance to safely negotiate the downstream construction activity.

Figure 83-2C provides the suggested sign-placement distance for each facility type. The columns headed A, B, and C represent the distances between signs and should be used to mark the theoretical sign location. The designer should use these distances as a starting point and adjust each sign location as necessary based on actual and anticipated field conditions (e.g., sign location relative to a crest vertical curve, line of sight obstruction). Figure 83-2C should be used in conjunction with each construction activity discussed above and with the diagrams shown in the *MUTCD*. The warning-sign placement distances shown in Figure 75-4A are not directly applicable to a work-zone application.

83-2.05 Guide Sign

The references in Section 83-1.01 provide the Department's criteria for the placement, design, and application of a guide sign. The designer should also review applicable criteria for permanent guide signs in Section 75-5.0 and in the *MUTCD*. The following provides supplemental information on the use of a guide sign in a construction zone.

1. Panel Sign. A guide sign is warranted in a construction zone or alternate route where a temporary route change is necessary. For example, the designer may consider using a large panel sign for a ramp or lane closure, e.g., "Ramp ___ Closed Use Ramp ___," "Ramp ___

Closed (date)". See the INDOT *Standard Drawings* for information for determining the size of a panel-sign support.

2. Other. Route markers, street-name signs, special-information signs, directional, or detour signs may also be warranted based on the particular work on the facility.

3. Worksite Increased-Penalty Signs. Signs are required which inform the motorist of increased penalties for moving violations.

   Sign messages and details are shown on the INDOT *Standard Drawings*.

   The XG20-7 sign, 78 in. x 42 in., should be specified for a rural area with sufficient right of way to accommodate the sign. It should be specified for an urban area with a posted speed limit of 40 mph or higher, and sufficient right of way to accommodate the sign.

   The XG20-7a sign, 60 in. x 36 in., should be specified for an urban area with a posted speed limit of 35 mph or lower, under one of the conditions as follows:

   a. the existing conditions outside the edge of pavement make installation of driven posts impractical, or

   b. the width of the right of way outside of the edge of pavement is not sufficient to accommodate the XG20-7 sign.

   The XG20-7b and XG20-7c signs, both 48 in. x 48 in., should be specified to be used in series with each other, and should be used under one of the conditions as follows:

   a. the project is in a rural area where the right-of-way width outside of the edge of pavement is not sufficient to accommodate the XG20-7 sign; or

   b. the project is a moving operation where construction signs are set and removed each day to accommodate the changing location of the work.

   The following guidelines should also be used to determine the location and quantity of the signs.

   a. Signs are required for each project in which traffic will travel through an active construction zone marked by "Road Construction Ahead" and "End Construction" signs.

   b. An XG20-7 or XG20-7a sign, where warranted, should be placed in advance of the first "Road Construction Ahead" sign for each direction of travel on the project mainline. The advance distance should be 500 ft in a rural area, or 100 ft in an urban area.

c. XG20-7c and XG20-7b signs, where warranted, should be placed in advance of the first "Road Construction Ahead" sign for each direction of travel on the project mainline. The advance distance for the XG20-7c sign should be 1000 ft in a rural area, or 200 ft in an urban area. The advance distance for the XG20-7b sign should be 500 ft in a rural area, or 100 ft in an urban area.

d. Signs should not be placed on side roads or ramps leading into a construction zone.

e. Signs are not required if the active construction zone is completely isolated from live traffic, i.e., a full road closure with a detour, or construction along a new alignment.

The location of each sign should be indicated as for other construction signs shown on the traffic-maintenance plan.

83-2.06 Portable Changeable Message Sign

A portable changeable message sign (PCMS) is effective in communicating the construction-zone information to the general public. INDOT's practice is to use PCMS on each applicable freeway construction project. The use of a PCMS on another type of facility should be determined on a project-by-project basis based on road alignment, traffic routing, or other situation requiring advance warning and information. For each facility, the applications where the PCMS device may be effectively used in construction zones are as follows:

1. where speed is expected to drop substantially;
2. where significant traffic queuing and delays are expected;
3. where a change in road alignment or surface conditions are present;
4. to provide advance notice of a ramp, lane, or road closure;
5. to notify or direct motorists to alternate routing; or
6. to show a work-site speed limit as supplemental to other regulatory signs.

The *MUTCD* provides the design and application criteria relative to a PCMS. The designer should also consider the following in specifying a PCMS.

1. Display. The display should provide not more than the maximum amount of information that can be read and comprehended by the motorist at a quick glance (i.e., no rolling message). A PCMS is capable of displaying three lines of eight characters each. There should be not than three messages phased in order to provide readability and comprehension. Each message should be able to stand alone. For a multiple message, use two signs.

2. Location. The sign should be visible from 2500 ft under ideal day or night conditions. The first message should be legible at a minimum distance of 650 ft from each lane. A PCMS should be placed in advance of other advance-warning signs. If two signs are needed to communicate a multiple message, they should be placed on the same side of the roadway and separated by at least 1000 ft. A PCMS is placed on the shoulder, but if practical may be farther from the traveled way. Overhead placement may also be considered.

3. Traffic-Control Devices. A PCMS may be used as a supplement, but it should not be used as a substitute to the proper use of other traffic-control devices.

4. Flashing-Arrow Sign. A PCMS should not be used as an alternative to a flashing-arrow sign. However, a PCMS may be used to simulate an arrow display in a message.

83-2.07 Flashing-Arrow Sign

A flashing-arrow sign is used to supplement other traffic-control devices. It is used where additional warning and directional information is required to assist in merging and controlling traffic through or around the work activity. A flashing-arrow sign should be used on each freeway construction project requiring a lane closure. For another site, the designer will determine the need for a flashing-arrow sign on a project-by-project basis. The applications where a flashing-arrow sign may be considered are as follows:

1. work in vicinity of an entrance or exit ramp;
2. median crossover on a freeway;
3. interior or double-lane closure on a freeway or other roadway of 4 or more lanes;
4. right-lane closure on the far side of an intersection; or
5. mobile operation on a shoulder or roadway of 4 or more lanes.

The INDOT *Standard Drawings*, the INDOT *Standard Specifications*, and the *MUTCD* provide the Department's criteria for the placement, design, and application of a flashing arrow sign. The *MUTCD* also includes application diagrams. The following provides the designer with supplemental information on the use of a flashing-arrow sign.

1. Display. The applicable display modes are as follows.

   a. Flashing Arrow or Sequential Arrow. This is used for a left- or right-lane shift or diversion.

   b. Flashing Double Arrow. This is used for an interior-lane closure where traffic is permitted to either travel left or right around the work activity.

2. Use and Location. The flashing-arrow sign should be located at the beginning of a lane-merge taper. For a stationary activity, locate the sign on the shoulder or in the closed lane behind a channeling or barricade device. For a mobile operation, locate a mounted sign at the rear of the activity upstream of the maintenance vehicles. Where used in the vicinity of a ramp, median crossover, or side-road intersection, the flashing-arrows sign placement should not confuse the motorist. Figure 83-2D provides the recommended usages and the minimum legibility distances under ideal day or night conditions.

3. Two-Lane, Two-Way Operation (TLTWO). A flashing-arrow sign should not be used to shift traffic in a TLTWO.

4. Shoulder or Roadside Activity. A flashing-arrow sign should only be used in the flashing caution mode for a shoulder or roadside work activity.

5. Flagger. A flashing-arrow sign should not be used if a flagger is used for traffic control at the work site.

6. Multiple-Lane Closure. The designer should consider using multiple flashing-arrow signs for a multiple-lane closure. In this situation, a flashing-arrow sign should be located at the beginning of each lane-merge taper. The designer should not use a flashing-arrow sign to laterally shift multiple lanes of traffic.

7. Traffic-Control Devices. The flashing-arrow sign may be used as a supplemental traffic-control device, but it should not be used as a substitute to the proper use of signs, pavement markings, or lighting in a construction zone. The flashing-arrow sign should not replace other required signing.

83-3.0 CHANNELIZATION DEVICES

The INDOT *Standard Drawings*, the INDOT *Standard Specifications*, and the *MUTCD* provide the Department's criteria for the selection, application, and placement of channelization devices. The *MUTCD* also includes application diagrams for the use of these devices.

83-3.01 Types

There are a number of channelization devices available, each having its specific application in a construction operation (e.g., crossover, runaround, lane closure, road closure, or 2-lane, two-way operation). The following channelization devices are used in a construction zone.

1. Barricade.

   a. Type I or Type II Barricade. INDOT does not use this type of barricade.

   b. Type III Barricade. This is used to close a roadway. Section 83-3.04 provides the guidelines for its application and placement.

2. Drums. Drums are used in a linear series to channelize and delineate the desired travel path. They may also be used individually or a group to mark a specific location. They are used for channelization and can be easily shifted to accommodate changing conditions within the construction zone. However, for a temporary lane closure during daylight hours, cones, tubular markers, or vertical panels may be used in lieu of drums.

3. Cones. Traffic cones are channelization devices used to delineate a travel path, divide opposing traffic lanes, divide traffic lanes in the same direction, or delineate a short-duration construction, maintenance, or utility activity.

4. Tubular Markers or Vertical Panels. These devices are used to channel traffic, divide opposing lanes of traffic, or divide travel lanes in place of drums where space is limited. Tubular markers and vertical panels have less visible area than other devices and should be used only where space restrictions do not allow for use of more-visible devices. These devices are to be used a divided non-freeway.

5. Temporary Asphalt Divider. This device should not be used for separating traffic.

6. Temporary Concrete Barrier (TCB). TCB should only be used where positive protection is desired, and not based on channelization needs. This device should be used on a freeway. The TCB should be located behind and in conjunction with supporting channelization devices, delineators, or pavement markings. Section 82-4.03 provides information on the application and placement of the TCB. Delineators and steady-burning lamps should also be attached to the TCB. However, where used between lanes in a 2-lane, two-way operation, experience has shown that opposing vehicular headlights wash out the lamp and cannot be safely maintained. Therefore, lamps should not be used in this situation.

7. Delineators. Delineators provide retro-reflection from headlights and are supplemental devices used to indicate the roadway alignment and the intended path through the construction zone. Delineators are used along the pavement edge in a runaround operation and are attached to the TCB.

8. Longitudinal Pavement Markings. The application of pavement markings is provided in Section 83-4.0. Longitudinal pavement markings should only be used in combination with other primary channelization devices to delineate the desired travel path. A temporary

double solid yellow line should be used in conjunction with tubular markers or vertical panels or TCB. Markings should also be used on each undivided roadway of 4 or more lanes. Revisions to existing pavement markings are not required for a temporary daylight lane closure.

Channelization devices are used in a construction zone to warn the motorist of work activities in or near the traveled way, to protect workers in the area, and to guide the motorist or pedestrian safely through and around the work site. Because each construction project differs, the selection, application, and location of these devices should be determined on a project-by-project basis.

83-3.02 Taper Length

The required length of tapered section delineated by channelization devices is shown on the INDOT *Standard Drawings*. Figures 83-3B and 83-3C provide the minimum taper requirement for each taper application in a construction zone (e.g., lane closure, lane shift).

83-3.03 Spacing

As with a transition taper, the longitudinal spacing of channelization devices is dependent on vehicular speed. In a 1-lane, two-way traffic operation, the spacing at a tapered section should be 10 ft for a 50-ft taper length, or 20 ft for a 100-ft taper length. A device spacing of 20 ft should be used for an Interstate-route taper. Tubular markers should be at 50-ft spacing. Figure 83-3D provides suggested spacing of channelization devices for other conditions. Unless otherwise specified, the maximum spacing of drums, cones, or vertical panels should be based on Figure 83-3D.

83-3.04 Type III Barricade

The Department uses a type III-A or type III-B barricade for a road closure. The Type III-A barricade is used where traffic is not allowed behind the barricade. Reflectorized rails are used only on the side facing traffic. The Type III-B barricade is used where traffic is allowed behind the barricade. Reflectorized rails are required on both sides of the barricade. The designer should also consider the following.

1. Materials. A type III barricade is constructed with three 12-ft sections mounted on skid-type supports or on posts driven into the ground. Use a skid-mounted barricade where the barricade is to be located on the traveled way or shoulder. Use a post-driven barricade where the barricade is to be outside of the paved portion of the roadway.

2. Complete Closure. A type III-A barricade should extend completely across the roadway and across a roadway side slope that is 3:1 or flatter within the right of way. During non-working hours, openings are not allowed within the barrier assembly.

3. Divided Highway. Where one set of lanes of a divided facility is closed to traffic, a type III-A barricade will be required across the pavement area and on slopes which are 3:1 or flatter from the right-of-way line to the centerline of the median. An additional barricade will be required across the closed portion where the facility intersects with a local road (e.g., county road, drive). An additional barricade will be required where a bridge or pipe is to be removed; see Item 6.

4. Crossover. Specify a type III-B barricade where a crossover on a divided facility is required because one set of lanes is closed for construction and two-way traffic is being maintained on the other set.

5. Local Traffic. If local traffic is allowed to use the facility under construction, use a type III-B barricade at the beginning and end portions of the closed road. Each barricade should extend onto side slopes of 3:1 or flatter, within the highway right-of-way. An additional barricade will be required where a bridge or pipe is to be removed, see Item 6.

6. Bridge or Pipe Removal. Where there is a possibility that a vehicle could be on a closed facility and where there is a bridge removal, pipe removal, or other hazard location, provide an additional type III barricade within 150 ft of the hazard.

7. Road-Closure-Sign Assembly. Where a type III barricade is used, the designer is required to show a road-closure-sign assembly on the plans. However, do not use such a sign assembly next to a lane closure where adjacent lanes remain open to traffic, or where a barricade is specified for closure of a lane on an undivided facility of 4 or more lanes where the remaining lanes are being used to maintain traffic.

83-4.0 PAVEMENT MARKINGS

The INDOT *Standard Drawings* and the *MUTCD* provide the Department’s criteria for the selection, application, and placement of pavement markings in a construction zone. The INDOT *Standard Specifications* provides additional information on temporary-pavement-marking material usage. The following provides supplemental guidelines to these sources.

83-4.01 Types

83-4.01(01) Paint

Quick-drying traffic paint is a low-cost, temporary pavement marking. To improve reflectivity, glass beads are required. Temporary paint is a non-removable type of temporary pavement marking. The Department does not desire the use of temporary paint markings on a final pavement surface. However, temporary paint may be the most suitable choice under certain conditions, particularly if temporary markings are anticipated to be in place through the winter months.

83-4.01(02) Temporary Raised Pavement Markers

In a high-traffic-volume location, raised temporary pavement markers should be considered as a supplemental device to improve delineation through the construction zone. Typical locations include center line, lane line, gore area, or where there are changes in the alignment (e.g., lane closure, lane shift). For a center line or lane line, temporary raised pavement markers are placed at the midpoint in the each gap, i.e., every 40 ft. For a taper, gore, etc., the raised markers should be spaced at 20 ft. Temporary raised pavement markers must be removed prior to the placing of the next pavement course.

83-4.01(03) Temporary Pavement-Marking Tape

Temporary pavement-marking tape is an excellent material choice where there is a change to the traffic pattern during construction (e.g., crossover switch). Temporary tape can be easily and quickly installed and, if necessary, easily removed. Disadvantages of temporary tape are that it tends to move or break up under heavy traffic volume, and that it is not suitable for usage during the winter months. Temporary pavement-marking tape requires significant maintenance in comparison to temporary paint. The following describes the temporary pavement-marking tapes used by the Department.

1. Type I. Type I tape may be used as a temporary center line, lane line, or no-passing-zone line that is placed parallel to the normal pavement marking pattern, or as a temporary transverse marking or pavement-message marking. It should also be used where pavement markings are placed at an angle to the normal pavement-marking pattern (e.g., taper for lane closure, lane shift). Type I tape is a removable type of temporary pavement marking.

2. Type II. Type II tape is used on a pavement which is expected to be removed or covered by additional pavement courses. It may be used as a center line, lane line, or edge line that is parallel to the normal pavement markings. It also may be used as a center line or lane line on a resurfacing overlay course. Type II tape is a non-removable type of temporary pavement marking.

83-4.01(04) Thermoplastic or Epoxy Markings

Thermoplastic or epoxy markings are used in a construction zone only if the traffic volume is high, and the temporary traffic pattern will be in place for over one year. Thermoplastic or epoxy markings are non-removable types of pavement markings.

83-4.01(05) Buzz Strips

Buzz strips are used on a high-speed facility of 4 lanes or more in advance of a lane closure, alignment change, or stop condition to warn the motorist of the impending change. They are made with extruded material or repeated passes of pavement-marking tape to reach a ¼-in. height. Figure 83-4A illustrates the typical layout for buzz strips with a lane closure. The spacing criteria are also applicable to the other conditions listed above.

83-4.02 Application

The application of temporary pavement markings in a construction zone depends on facility type, project duration, project length, and anticipated traffic volume. The phasing of temporary traffic control during construction should be considered. The temporary pavement markings should be selected that are best suited to the anticipated conditions and are most economical for the project. The removal of a removable temporary pavement marking is included in the removable-temporary-pavement-marking quantity. If non-removable markings that must be removed are selected as part of the planned traffic-maintenance plan, a quantity for removal of the non-removable markings is required. If non-removable temporary pavement markings are necessary on a final surface, placement of the temporary markings should be indicated to be as near as possible to the location of the final permanent pavement markings.

83-5.0 TRAFFIC SIGNAL

83-5.01 Location

The use of a temporary traffic signal in a construction zone will be determined on a project-by-project basis. The warrant criteria for permanent installations in Section 77-2.0 should be used to help determine if a temporary traffic signal is warranted. However, the traffic volume expected during construction should be used for the warrant analysis. An Official Action, as described in Section 83-1.03, must be coordinated through the district traffic engineer. Locations where a temporary-signal installation may be used include the following:

1. intersection where an existing signal must be maintained;

2. existing non-signalized intersection or drive where construction patterns and traffic volume now warrant a signal;

3. temporary haul road or other temporary access point;

4. long-term one-lane, two-way traffic operation (e.g., bridge lane closure); or

5. crossroad or ramp intersection where there is an increase in traffic or there is a decrease in capacity due to the construction.

83-5.02 Application

The designer should consider the following.

1. Design. The designer should determine the impacts that a construction activity has on existing signal operations and should attempt to maximize the level-of-service. For example, the designer should consider the following:

   a. recommend re-timing or re-phasing the signal to compensate for changes in traffic volume, mix, or patterns, and for changes in lane designation or intersection-approach geometrics; and

   b. physically relocating poles or adjusting signal heads to maintain compliance with the MUTCD.

   Chapter Seventy-seven and the *MUTCD* provide design information for a traffic signal.

2. Bridge. If a lane is expected to be closed overnight, a temporary signal should be considered.

3. Plan Sheets. Show each temporary-signal installation in the traffic-maintenance plan.

83-6.0 HIGHWAY LIGHTING

83-6.01 Types

The lighting devices that are used in a construction zone are as follows:

1. hazard-identification beacons (flashing warning lights);

2. steady-burning warning lamps;
3. warning lights;
4. floodlights; and
5. conventional highway lighting.

83-6.02 Warrants

Hazard-identification beacons, steady-burning electric lamps, and warning lights are used to supplement signs, barriers, or channelization devices, and emphasize specific signs, hazard areas, and the desired travel path. The warrants for lighting devices should satisfy the *MUTCD*. Floodlights are used to illuminate the work area during a nighttime operation (e.g., flagger station, equipment crossing, area requiring supplemental lighting).

For conventional highway lighting, the need for temporary lighting will be determined on a project-by-project basis. Existing highway illumination should be maintained unless discontinuance of the highway illumination is specifically permitted. The warrants provided in Section 78-2.0 for permanent highway lighting should be reviewed to assist in determining the need for temporary lighting. The designer should consider the use of temporary lighting with the characteristics as follows:

1. high traffic volume;
2 high traffic speed;
3. heavy queuing or congestion;
4. area with complicated traffic maneuvers (e.g., freeway crossover, intersection); and
5. other area where a hazardous location may exist.

If existing light standards are removed or if bulbs are shut off during construction, the designer should consider providing temporary lighting until permanent lighting is reinstalled. In a construction zone, the Department uses high-pressure sodium lamps mounted on temporary wood posts. However, the designer may consider portable lighting as an option. Chapter Seventy-eight provides additional information on the design of highway lighting.

English-Units Value	Metric-Units Equivalent
SPEED LIMIT	
30	50
35 or 40	60
45	70
50	80
55	90
60 or 65	100
70	110
LONGITUDINAL DISTANCE	
500 ft	150 m
1000 ft	300 m
1500 ft	450 m
¼ mi	400 m
½ mi	800 m
1 mi	1.5 km
2 mi	3 km

ENGLISH-TO-METRIC UNITS CONVERSION

Figure 83-2A

Existing Facility and Construction Type	Existing Posted Speed		
	50 mph	55 mph	65 mph
4-lane Interstate with crossover to a 2-lane facility	n/a	WZ 45 mph with TCB WS 45 mph	WZ 55 mph with TCB WS 45 mph
4-lane Interstate with lane closure without a crossover	n/a	WS 45 mph	WZ 55 mph WS 45 mph
6-lane Interstate with crossover to a 4-lane facility with TCB	WS 40 mph	WS 45 mph	WZ 55 mph WS 45 mph
6-lane Interstate with lane closure without a crossover	WS 40 mph	WS 45 mph	WZ 55 mph WS 45 mph
Non-Interstate divided highway with crossover	Project-by-project	WZ 45 mph with TTM & TDSYL WS 45 mph	WZ 55 mph with TCB or TTM & TDSYL. WS 45 mph
Non-Interstate divided highway with lane closure without a crossover	Project-by-project	WS 45 mph	WZ 55 mph WS 45 mph

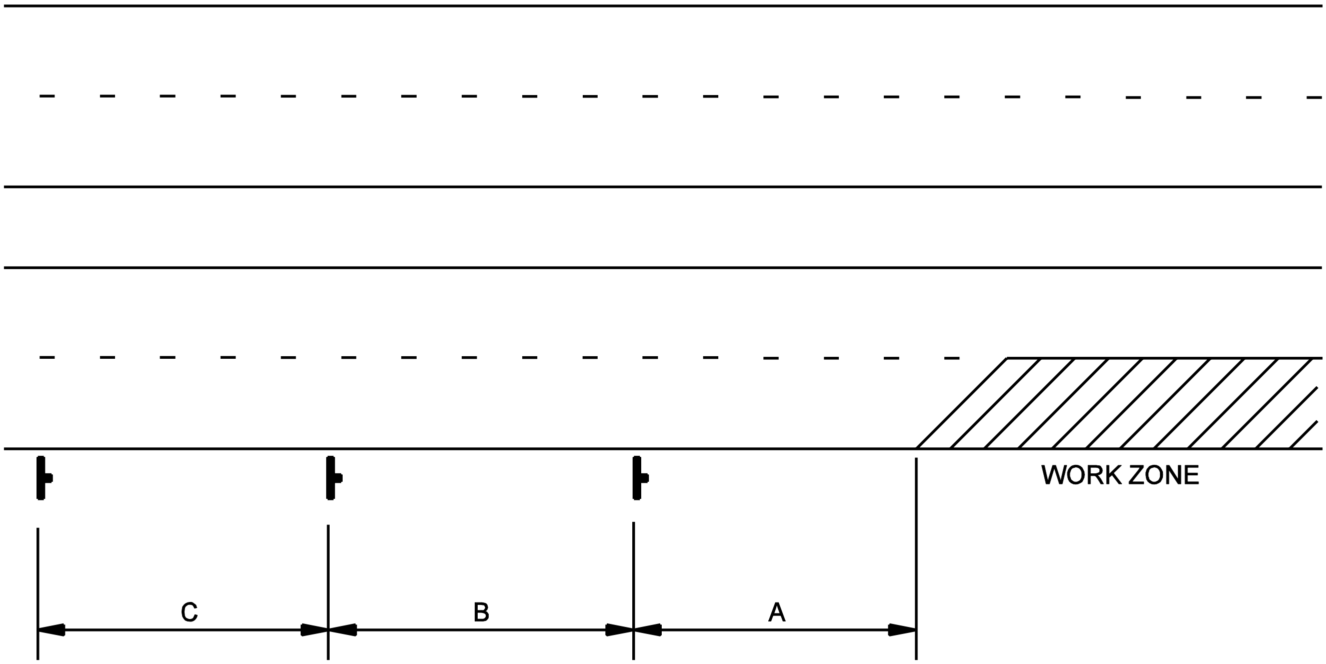
Where:

WS = Work-Site Speed Limit (Indiana Statutes)
WZ = Work-Zone Speed Limit (Official Action)
TCB = Temporary Concrete Barrier
n/a = Not Applicable
TTM = Temporary Tubular Markers
TDSYL = Temporary Double Solid Yellow Line

Note: Speed limit may vary based on circumstances and actual field conditions.

SUGGESTED DIVIDED-HIGHWAY SPEED LIMIT IN WORK ZONE OR WORK SITE

Figure 83-2B



Road Type	Distance Between Signs (ft)		
	A	B	C
Urban (45 mph or lower)*	200	200	200
Urban (50 mph or higher)*	350	350	350
Rural	500	500	500
Freeway/Expressway	1000	1600	2600

* Posted Speed Limit of Facility

Notes:

1 *Distance "A" is for marking the locationof warning sign "A" up stream from the transition or point of restriction in the construction zone.*

2 *Distance "B" is the location of warning sign "B" upstream from the location of "A" in two and three sequence signing arrangements.*

3 *Distance "C" is the location of warning sign "C" upstream from sign "B" when three or more signs are used within the advanced warning area.*

4 *For for or more signs, the spacing will be determined on a case-by-case basis.*

ADVANCED WARNING SIGNS

Figure 83-2C

Panel Type [1]	Permitted Use	Minimum Legibility Distance [2]
A	Permitted on facility with speed lower than 35 mph. Appropriate for use on low-speed urban facility.	2600 ft
B	Appropriate for intermediate-speed facility, or for maintenance or mobile operation on high-speed roadway. Not used by INDOT.	4000 ft
C	Permitted on every facility. Appropriate for use on a high-speed, high-volume traffic-control project.	5200 ft

Notes:

1. *For panel type, see the INDOT* Standard Specifications *and* Federal MUTCD *Part VI.*
2. *Minimum legibility distance under ideal day or night conditions.*

SUGGESTED USE AND LOCATION OF FLASHING-ARROW SIGN

Figure 83-2D

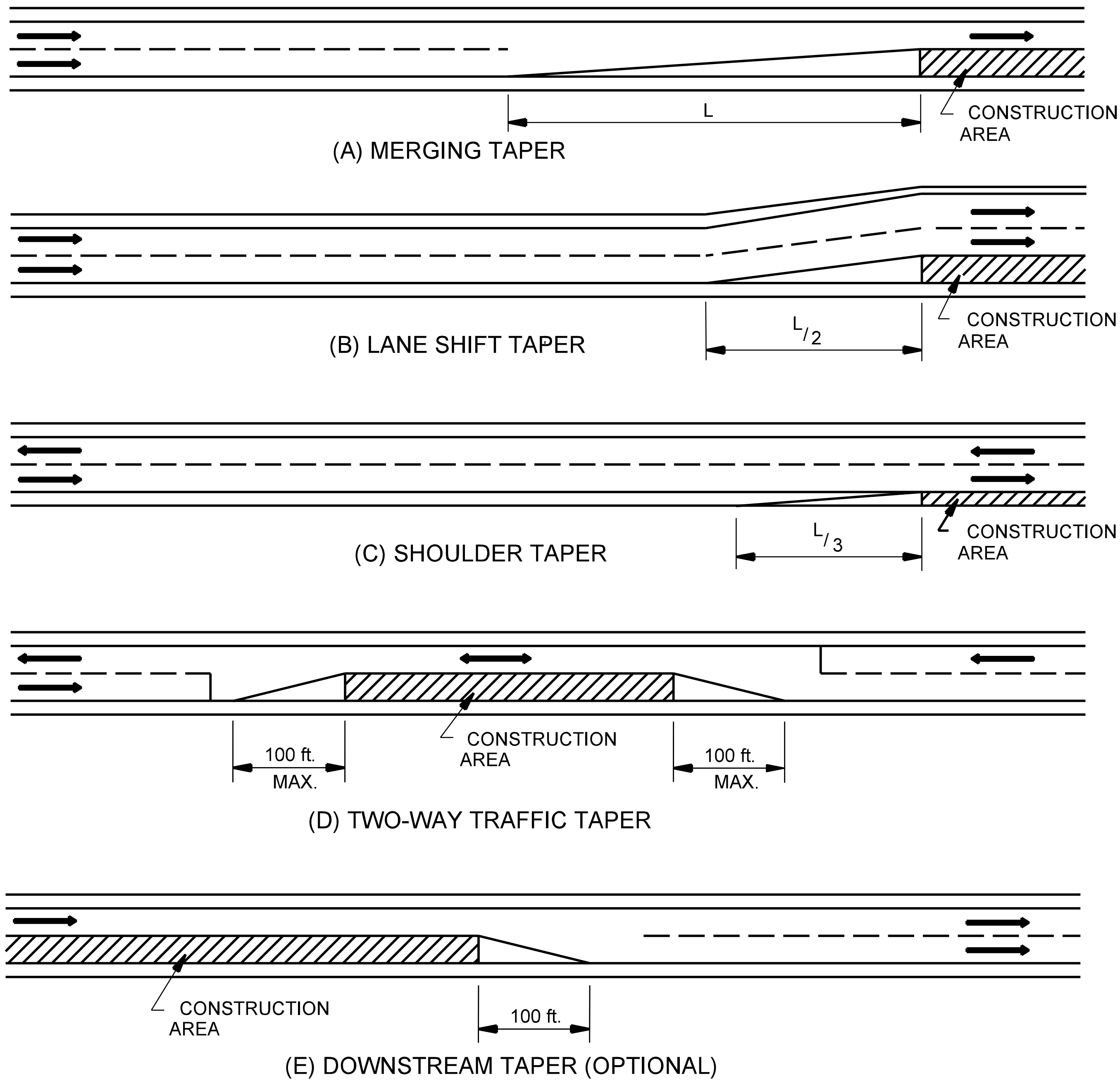
Taper Type		Minimum Length
Upstream	Merging	*L*
	Shifting [3]	½ *L*
	Shoulder	$^{1}/_{3}$ *L*
	Two-Way Traffic	100 ft
Downstream (optional)		100 ft per Lane

Notes:

1. *See the INDOT* Standard Drawings *for* L.
2. *Figure 83-3C illustrates the permissible taper types.*
3. *May be used for determining buffer-zone length.*

TAPER-LENGTH CRITERIA FOR CONSTRUCTION ZONE

Figure 83-3B



Note: See the INDOT Standard Drawing for "L".

TAPER LENGTH CRITERIA FOR CONSTRUCTION ZONES
(Application)

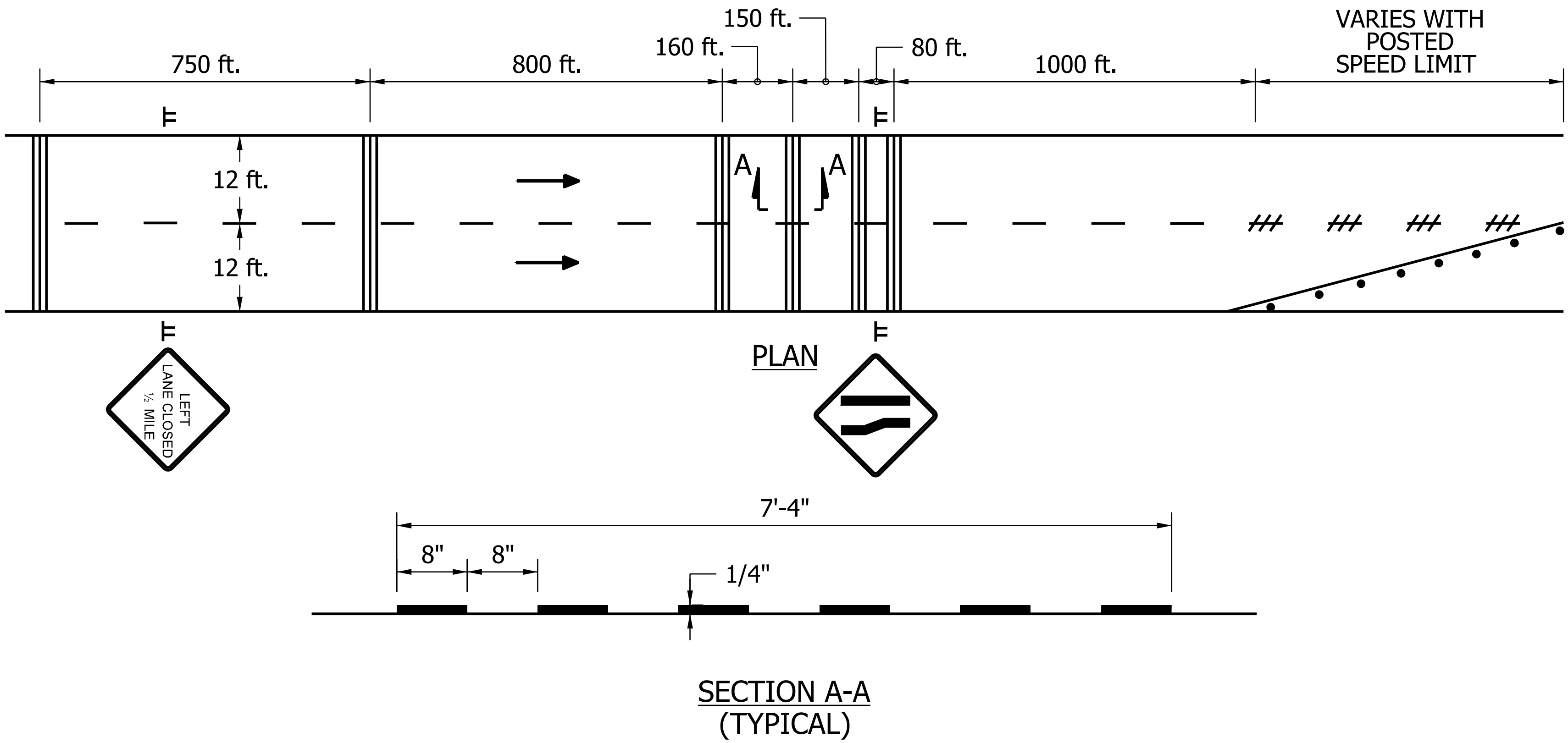
Figure 83-3C

Construction-Zone Design Speed (mph)	Suggested Maximum Spacing (ft)	
	Tapered Section	Tangent Section
25 *	20 *	40
30	30	60
35	35	70
40	40	80
45	45	90
50	50	100
55	55	110
60	60	120

* *For a speed of 25 mph or lower, spacing should not be less than 20 ft.*

SUGGESTED MAXIMUM SPACING OF CHANNELIZATION DEVICES

Figure 83-3D



BUZZ STRIPS

Figure 83-4A