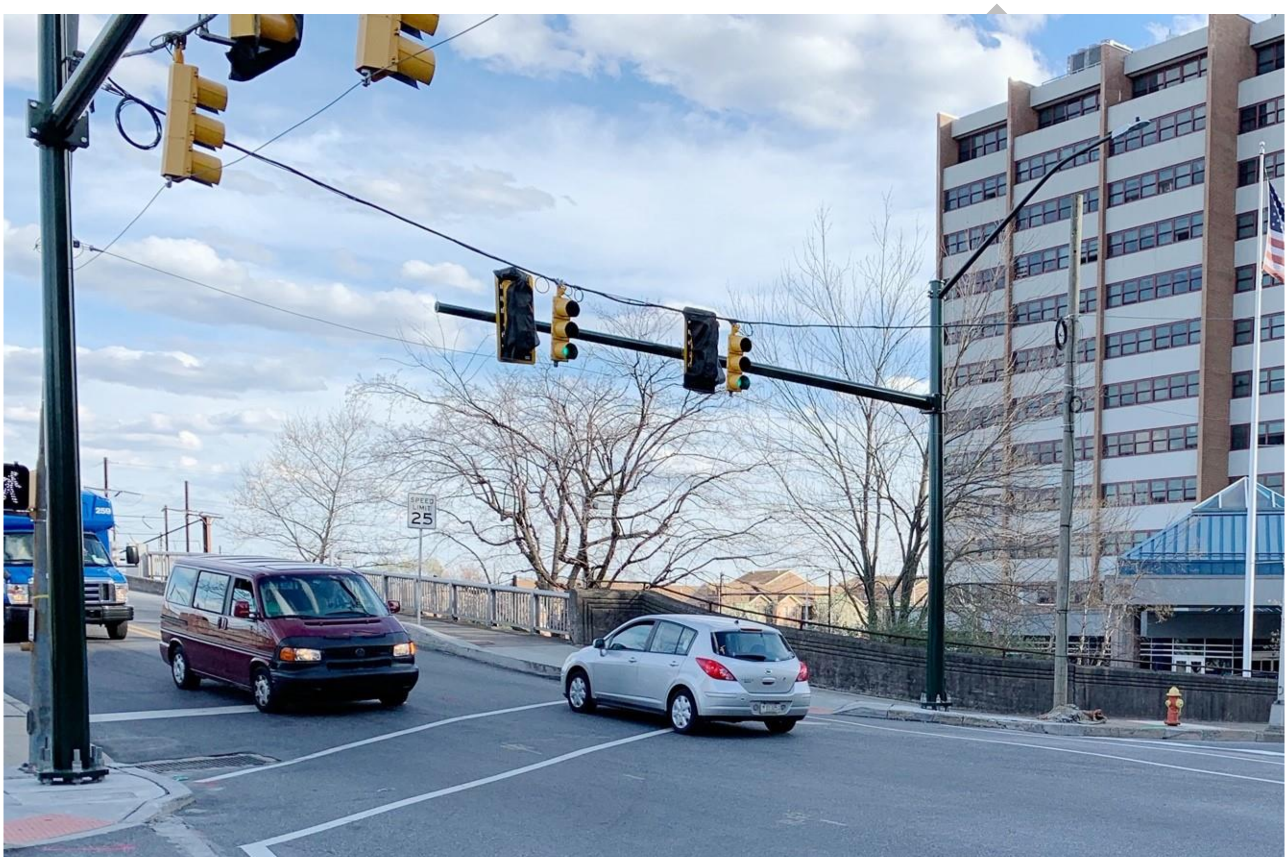
Traffic Signal Design Handbook



Bureau of Operations

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DEPARTMENT OF TRANSPORTATION
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There are hyperlinks throughout this document that should provide network connections to other publications, regulations, Vehicle Code, etc. There are also hyperlinks that reference other sections, exhibits, or appendices within this Handbook, and these should assist you in navigating.

Internet links often change without notice and may change more frequently than updates to this publication. Updated links will be maintained on the PennDOT Traffic Signal Portal. Please use the signal portal if the links in this publication are broken.

Although not obvious by their color, the Table of Contents and the List of Exhibits also work as hyperlinks. Simply, left click on the section or exhibit number, title, or page number and your computer should take you to the proper page.

You may also find the bookmarks on the left side of the screen helpful.

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APPENDIX A: GLOSSARY

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PART I
GENERAL

1. INTRODUCTION

1.1 Publication Purpose

This publication provides designers and engineers with Department policies, procedures, and guidance relative to the design of new traffic signals or modifications to existing traffics signals in Pennsylvania. The design standards in this publication assume that traffic signal control has already been deemed appropriate and justified for the location through an engineering study.

The design standards in this publication apply to all traffic signals in Pennsylvania. Local preferences may be adopted where flexibility is provided in the standards, but such preferences shall not conflict with the standards.

There are two primary purposes for traffic signal design:

- ✓ To develop plans and specifications for construction of traffic signals.
- ✓ To prepare the condition diagram which is incorporated as part of the traffic signal permit to document the required traffic signal operation and associated equipment.

Signal design encompasses a variety of items which must be considered prior to and during the development of traffic signal permit drawings, construction plans, and specifications. Drawings and specifications define the proposed work to ensure that the traffic signals will operate in a safe and efficient manner. Drawings include those items required by regulations, including, but not limited to, a plan view of the location, traffic signal equipment and layout, phasing diagram, timing plans, required signing and markings, construction details, and tabulations.

The term highway "traffic signal" describes all power-operated traffic control devices by which traffic is warned or directed to take some specific action. **Exhibit 1-1** shows the various types of highway traffic signals.

Exhibit 1-1 Types of Highway Traffic Signals

Highway Traffic Signals

- Power-operated traffic control device
- Traffic warned or directed to take some specific action

Traffic Control Signal

- Traffic is alternately directed to stop and permitted to proceed

Traffic Control Signal

- Red-Yellow-Green (R-Y-G) signal

Special Traffic Control Signals

Emergency Vehicle Traffic Control Signal

- Assigns right-of-way to authorized emergency vehicle

Ramp Control Signal

- Aka **"Ramp Meter"**
- Control flow onto freeway from ramps

Temporary Traffic Control Signal

- Control signal installed for a limited time

Portable Traffic Control Signal

- Temporary traffic control signal designed to be easily transported

Beacon

- Aka **"Flashing Warning Device"**
- One or more signal sections that operate in flashing mode

Warning Beacon

- Supplement an appropriate warning or regulatory sign or marker

LED Edge Lit Sign

- LED units within the legend or symbol and in the border of a sign
- Used to improve conspicuity and/or increase legibility of sign legends and borders

Stop Beacon

- Supplements a STOP sign, DO NOT ENTER sign, or WRONG WAY sign

Intersection Control Beacon

- Controls two or more directions of travel at an intersection

Speed Limit Beacon

- Supplements a SPEED LIMIT sign

Lane-Use Control Signal

- Control signal that permits or prohibits the use of specific lanes of a street or highway

Moveable Bridge Signal

- Notifies traffic to stop during periods when roadway is closed to allow bridge to open

In-Roadway Lights

- Installed in the roadway surface to warn road users that they are approaching a condition on, or adjacent to, the roadway
- May be considered (on a project-by-project basis) for use at:
  - Marked school crosswalks
  - Marked midblock crosswalks
  - Other roadway situations involving marked pedestrian crossings

Toll Plaza Signal

- Indicates open or closed status of toll plaza lanes

Hybrid Beacons
Not used in Pennsylvania

Emergency Vehicle Hybrid Beacon

Pedestrian Hybrid Beacon

Not Traffic Signals

Power-operated signs; Steadily -illuminated pavement markers; Warning lights; Steady -burning electric lamps.

1.2 Publication Organization

The publication is organized and grouped into PARTS (PART I through PART VI) based on over-arching subject areas, as shown in **Exhibit 1-2**. Each PART is then comprised of individual chapters, which contain detailed content for that subject area.

Exhibit 1-2 Publication 149 Organization

PARTS		Chapter	Title
PART I General	Introduction	**1**	Introduction
PART II Design Context-Traffic Control Signals	Defines the big-picture, design box (context, constraints, considerations) that a traffic control signal design needs to understand, fit into, and be attentive to.	**2**	Network Context
		3	Intersection Context
		4	Operational Context
		5	Traffic Control Signal Design Constraints
PART III Design Elements/Criteria-Traffic Control Signals	Defines the various physical and operational design elements and criteria that need addressed and pulled together for a complete traffic control signal design. Each chapter addresses a separate topic (accommodation type, individual equipment component, etc.) and provides detailed information for that topic.	**6**	Design Elements Introduction
		7	Utilities
		8	Pedestrians
		9	Bicycles
		10	Operations
		11	Preemption and Priority Control
		12	Supports
		13	Controller Assembly
		14	Systems & Communications
		15	Electrical Distribution
		16	Signal Heads
		17	Detectors
		18	Adaptive Signal Control Technology (ASCT) System
		19	Pavement Markings & Signs
		20	Intersection Lighting
		21	Other Attachments to Traffic Signals
		22	Advance Red Signal Warnings
PART IV Special-Use Traffic Signals	Defines various special-use traffic signals, other than the typical R-Y-G traffic control signal. Each chapter addresses a separate special-use signal type and provides detailed information for that signal.	**23**	Temporary Traffic Control Signals
		24	Emergency Vehicle Access, Traffic Control Signal
		25	Freeway Entrance Ramp, Traffic Control Signal (Ramp Metering)
		26	One-Lane, Two-Way Facilities, Traffic Control Signal
		27	Lane-Use, Control Signals
		28	Toll Plaza, Traffic Signals
		29	Movable Bridge, Traffic Signals
PART V Other Misc. Traffic Signals	Defines flashing warning devices. Each chapter addresses a separate flashing warning device type.	**30**	Flashing Beacons (Flashing Warning Devices)
		31	Hybrid Control Beacons
		32	In-Roadway Warning Lights
PART VI Plans, Specifications & Estimates (PS&E) Package / Bid Package	A complete design culminates in the development of Plans, Specifications & Estimates (PS&E) / Bid Package. Each chapter defines and addresses each of these components (plans, specifications, and estimates).	**33**	Traffic Control Signal Plans
		34	Other Traffic Signal Plans
		35	Bid Proposal (Package)
		36	Cost Estimates

1.3 PennDOT Traffic Signal Publications

Although this publication is dedicated to the design aspects of traffic signals, it is important to understand the overall picture regarding traffic signals.

- ✓ **Laws and Regulations –** federal and state laws & regulations dictate various authorities, requirements, and role responsibilities regarding traffic signals.
- ✓ **Planning** - traffic signals must be planned, funded, and approved with engineering studies including warrant analysis prior to installation and activation.
- ✓ **Design –** traffic signals must be designed in accordance with federal and state standards and policies.
- ✓ **Construction –** traffic signals must be installed, modified, and reconstructed in accordance with approved plans and specifications.
- ✓ **Maintenance –** operating traffic signals must be supported with response & preventative maintenance to sustain intended performance and longevity of the signal locations.

Exhibit 1-3 shows the applicable laws, regulations and primary publications for the design, construction, and maintenance of traffic control signals.

While **Exhibit 1-3** lists various Department publications under the Planning & Programming, Design, Construction and Maintenance bins, the design of traffic signals will involve some of these publications, regardless of the area they are assigned.

In fact, there are references throughout this publication to Publications 35, 111, 148, 408, etc.

Exhibit 1-3 Applicable Laws, Regulations, and Publications and References

Laws		Title 75 Pa.C.S. Vehicles Chapter 61	Title 74 Pa.C.S. Transportation Chapter 92	
Regulations		United States Code (USC) 23 CFR, Part 655 36 CFR, Part 1190	Manual on Uniform Traffic Control Devices (MUTCD)	Title 67 Pa. Code Chapters 205, 212, and 441
PennDOT Publications	**Planning & Programming**	Pub 10 Design Manual Part 1	Pub 851 TSMO Guidebook: Part I, Planning	
PennDOT Publications	**Design**	Pub 13 and Pub 13M[1] Design Manual Part 2	Pub 14M Design Manual Part 3	Pub 16 Design Manual Part 5
PennDOT Publications	**Design**	Pub 46 Traffic Engineering Manual	Pub 51 Bid Package Preparation Guide	Pub 149 Traffic Signal Design Handbook
PennDOT Publications	**Design**	Pub 212 Official Traffic Control Devices	Pub 236 Handbook of Approved Signs	Pub 852 TSMO Guidebook: Part II, Design
PennDOT Publications	**Construction**	Pub 35 (Bulletin 15) Qualified Products List for Construction	Pub 72M Roadway Construction Standards	Pub 111 Traffic Control – Pavement Markings & Signing Standards (TC-8700 Series)
PennDOT Publications	**Construction**	Pub 148 Traffic Signal Standards (TC-8800 Series)	Pub 213 Temporary Traffic Control Guidelines	Pub 408 Highway Construction Specifications
PennDOT Publications	**Construction**	Pub 647 ITS Standard Drawings (ITS-1200 Series)	Pub 669 Traffic Signal Inspection Pocket Guide	
PennDOT Publications	**Maintenance**	Pub 23 Maintenance Manual	Pub 191 Traffic Signal Maintenance Manual	

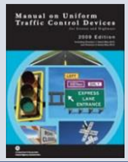
[1]Pub 13M, Highway Design, is being replaced by Pub 13, Contextual Roadway Design. As content is added to Pub 13, the content is being removed from Pub 13M.

Publications are available electronically from PennDOT's Traffic Signal Portal or PennDOT's Website. The Traffic Signal Portal also contains any policy issued by Strike-off Letter which has not yet been incorporated into publications.

1.4 Key External Publications & Resources

In addition to PennDOT's reference resources presented in **Exhibit 1-3**, there are three key external reference resources that apply to signal design in Pennsylvania, as shown in **Exhibit 1-4**.

Exhibit 1-4 Key External Publications and Resources

Title	Description and Web link
Manual on Uniform Traffic Control Devices (MUTCD)	 The MUTCD defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public travel.
Signal Timing Manual - Second Edition (STM2)	 TRB's National Cooperative Highway Research Program (NCHRP) Report 812: Signal Timing Manual - Second Edition, covers fundamentals and advanced concepts related to signal timing. the Signal Timing Manual – Second Edition (STM2)
Public Right-of-Way Accessibility Guidelines (PROWAG)	The Public Right-of-Way Accessibility Guidelines (PROWAG) is a regulation issued by the United States Access Board to address access to sidewalks and streets, crosswalks, curb ramps, pedestrian signals, on-street parking, and other components of public rights-of-way. These guidelines also review shared use paths, which are designed primarily for use by bicyclists and pedestrians for transportation and recreation purposes.

1.4.1 MUTCD

The Commonwealth of Pennsylvania has adopted the *Manual on Uniform Traffic Control Devices* (MUTCD), as published by the Federal Highway Administration per Title 67 Pa. Code, §212.2. The MUTCD is adopted in its totality except where Title 67 Chapter 212 indicates otherwise. References in this publication refer to the sections, tables, and figures in the 11th edition of the MUTCD.

All traffic signal designs must comply with the MUTCD, except where modified by Pennsylvania regulation. The following modifications are made to the MUTCD in 67 Pa. Code Chapter 212:

- ✓ §212.302(a): During flashing operation, a minimum of two vehicular signal heads on each approach must be flashed for the through movement. Any other signal heads may be blanked out.
- ✓ §212.302(b): Channelized right-turn movements may not be included in any warrant analysis; the crash warrant may consider both reportable crashes, and nonreportable crashes that are documented in police files; and the ADT volume warrant, is added.
- ✓ §212.303: New pedestrian-control signals must use symbolized messages (walking person symbolizing WALK and upraised hand symbolizing DON'T WALK), but signals using word messages WALK and DON'T WALK may be retained for their useful service life.

1.4.2 Signal Timing Manual, Second Edition (STM2)

The full value of any signal installation is realized only when it is operating in a manner that is consistent with traffic demands. Poor signal timing can cause disrespect of the traffic control signal and reduced observance of traffic control signal indications that may affect intersection safety.

The STM2 shall be used by designers for the design of operational aspects of traffic control signals in Pennsylvania. The STM2,

- ✓ is a comprehensive guide for designers regarding signal timing principles, practices, and procedures.
- ✓ provides focused information written for new practitioners and those desiring a better understanding of signal timing fundamentals.

A traffic signal designer should have a thorough understanding of the concepts (fundamental and advanced) presented in the STM2 before being responsible for traffic signal operational designs.

Refer to **Exhibit 10-1** for a detailed outline of topics presented in the STM2.

1.5 Traffic Signal Permit

PennDOT approval of traffic signals in accordance with the Vehicle Code and Chapter 212 is through a permitting process, as defined in Publication 46, Chapter 4. The term "permittee" is used to define the owner of a traffic signal who has been issued a permit by PennDOT to install or modify the signal. The "permittee" includes municipalities, local authorities, counties, and PennDOT, as may be defined in statute or regulation.

The traffic signal permit is an official document issued by the Department to the municipalities for each traffic signal, and it identifies the approved design and operation of the traffic signal.

Additional information regarding traffic signal permits is contained in Publication 46.

1.5.1 Traffic Control Signal Permit

The traffic signal permit contains information regarding the operation of the traffic signal and the placement of signal equipment, signing, and markings. The traffic signal permit includes the following:

- ✓ Form TE-964, Traffic Signal Permit (Sheet 1)
- ✓ Permit Plan (Condition Diagram, 1 or more sheets)
- ✓ Coordination/System Timings, if applicable (may be included on condition diagram, a separate sheet, or reference a separate System Permit)

1.5.2 Flashing Warning Device Permit

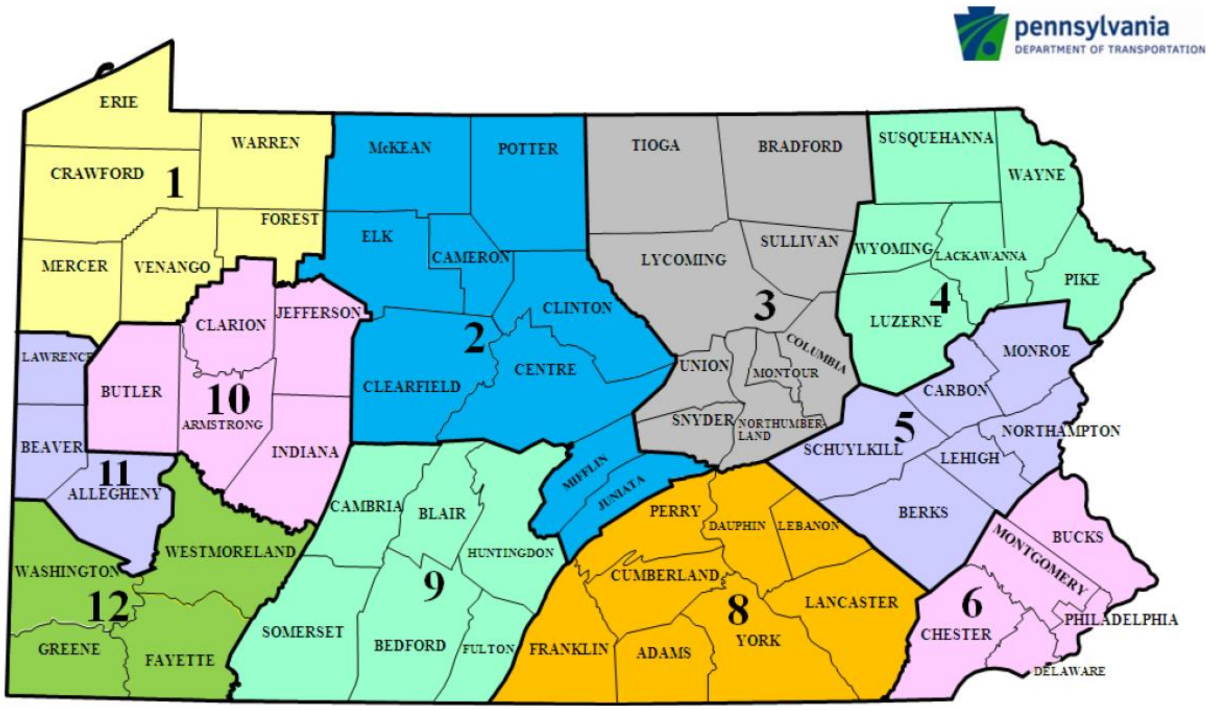
The flashing warning device permit contains information regarding the operation of the flashing warning device and the placement of the equipment, signing, and markings. The flashing warning device permit includes the following:

- ✓ Form TE-670, Flashing Warning Device Permit
- ✓ Permit Plan (Condition Diagram, 1 or more sheets)

1.6 PennDOT Traffic Signal Contacts

Questions relative to the design, construction, maintenance, and operation of a traffic signal should be directed to the appropriate PennDOT Engineering District Traffic Unit (see **Exhibit 1-5**). District and Central Office contact information is maintained on the Traffic Signal Portal. These individuals will be able to either answer questions directly or provide additional guidance as to the proper contact person.

Exhibit 1-5 PennDOT Engineering Districts



1.7 Definitions and References

APPENDIX A is a glossary that includes definitions of many words and terminology, and a description of various Department publications. Therefore, when these words, terminology and publications are referenced in these chapters, they have the meanings indicated.

1.8 Miscellaneous Reference Documents

A list of miscellaneous reference documents with links to the original source material is contained on the Traffic Signal Portal.

PART II
DESIGN CONTEXT -
TRAFFIC CONTROL SIGNALS

2. NETWORK CONTEXT

2.1 General

Traffic control signal designers shall consider the adjacent surroundings to develop safe and effective designs. Some common network context considerations are as follows:

- ✓ Proximity to existing signalized intersections
- ✓ Proximity to adjacent intersections/driveways
- ✓ Roadway approach geometry
- ✓ Nearby Railroad & Transit grade crossings

For additional information, see the following sections in this chapter.

2.2 Operating Objectives

The main objective to be attained by the installation of traffic control signals is the assignment of right-of way to improve safety and traffic flow through the intersection, corridor, or network. However, the context of the operating objectives, and thus the strategies/tactics involved, may be different depending upon various situations:

- ✓ Intersection vs. Network
- ✓ Light vs. Congested Flow

The Exhibits below provide information on traffic control signal operating objectives:

- ✓ **Exhibit 2-1**, Traffic Control Signal Objectives
- ✓ **Exhibit 2-2**, Traffic Control Signal Strategies, Tactics, and Measurement Targets
- ✓ **Exhibit 2-3**, Change in Context/Objectives (Light to Congested Traffic Flow)
- ✓ **Exhibit 2-4**, Change in Context/Objectives (Intersection to Network)

Exhibit 2-1 Traffic Control Signal Objectives

<table>
<tr><th>Safety</th><td colspan="3">Assign right-of-way safely</td></tr>
<tr><th rowspan="4">Operations</th><th>Flow</th><th>Intersection</th><th>Network</th></tr>
<tr><th>Light</th><td>Minimize phase failures[1]</td><td rowspan="2">Smooth flow</td></tr>
<tr><th>Uncongested</th><td>Equitable service</td></tr>
<tr><th>Congested</th><td>Maximize throughput</td><td>Manage queues</td></tr>
<tr><th rowspan="2">Organizational</th><td colspan="3">Responsive to stakeholder needs</td></tr>
<tr><td colspan="3">Comply with agency policies and standards</td></tr>
<tr><th rowspan="3">Maintenance</th><td colspan="3">Minimize life cycle costs</td></tr>
<tr><td colspan="3">Sustain infrastructure state of good repair</td></tr>
<tr><td colspan="3">Sustain system and technology reliability/state of good repair</td></tr>
</table>

[1] A phase failure occurs when a phase is unable to serve all its demand within one signal cycle. Users affected by a phase failure will incur much more delay than those who only had to wait through one cycle.

Exhibit 2-2 Traffic Control Signal Strategies, Tactics, and Measurement Targets

Objective	Strategy	Tactics	Measurement Targets
Assign right-of-way safely	Design intersection and signal operation to serve all users safely	▪ Physical: Heads, Poles, Pushbuttons, Detectors, Cabinets, Signing, Markings ▪ Timings: Clearances ▪ Phasing: Protected, Unprotected, Simultaneous	▪ Good visibility ▪ Abundant clarity ▪ MUTCD compliance ▪ Low crash history
Minimize phase failures	Serve all waiting users	Actuation: ▪ Detectors ▪ Generation extension/gap timing ▪ Generous max times	▪ Green time is adequate most of the time. ▪ Acceptable range of delay for all users ▪ No consecutive phase failures
Smooth network flow	Progression	Coordination (Pipeline): ▪ Controllers ▪ Communications ▪ System Software ▪ Timings: Cycle, Offset, Split, Sequence	▪ Maximize bandwidth ▪ Minimize arterial stops (number and duration) ▪ Side street delay at acceptable level
Maximize throughput	Fully utilize green time	▪ Disciplined Timings: Cycle, Split, Maximum Green, Reservice ▪ Detection: Residual Queuing	▪ High phase utilization ▪ Low unused green ▪ Low growth of residual queue ▪ High flow
Manage queues	Metering flow	▪ Disciplined Timings: Splits, Maximum Green, Reservice ▪ Detection: Queue Overflow	▪ Queue length at intended locations ▪ High throughput (at bottleneck)
Responsive to stakeholder needs	Response Maintenance	▪ Maintain enough spare equipment to restore full operation in timely manner ▪ Provide on-call staffing or contractors to respond to emergencies 24/7/365	▪ Average response time ▪ Average time to complete repair ▪ Percent of response calls fixed with parts from inventory
Comply with agency policies and standards	Design Modifications	▪ Physical: Heads, Poles, Pushbuttons, Detectors, Cabinets, Signing, Markings ▪ Timings: Clearances	▪ Minimize non-compliance elements ▪ ADA and PROWAG compliance
Minimize life cycle costs	Preventative Maintenance	▪ Assign expected lifespan to each traffic control signal element, beyond which failure rate or performance is likely to be unacceptable, and plan for timely replacement	▪ Minimize operating equipment beyond expected lifespan ▪ Minimize emergency calls per intersection
Sustain infrastructure state of good repair	Preventative & Response Maintenance	▪ Schedule repair/replacement of components when potential failure is identified through preventative maintenance activities ▪ Provide on-call staffing or contractors to complete emergency repairs in a timely manner	▪ Minimize component failures ▪ Minimize down time for permitted traffic control signal operation
Sustain system and technology reliability/state of good repair	Preventative & Response Maintenance	▪ Schedule repair/replacement of components when potential failure is identified through preventative maintenance activities ▪ Provide on-call staffing or contractors to complete emergency repairs in a timely manner	▪ Minimize down time for communication systems ▪ Minimize down time for detectors

Exhibit 2-3 Change in Context/Objectives (Light to Congested Traffic Flow)

	Light Flow	Congested Flow
Timing	Abundant to serve all waiting vehicles	Disciplined to make use of all green time
Gap Timing	Abundant	Aggressive (One tactic: volume-density variable gap)
Max Timing	Abundant	May get shorter
Measurement Target	Low phase utilization	High phase utilization Queue management

Exhibit 2-4 Change in Context/Objectives (Intersection to Network)

	Intersection	Network
Timing	Actuation dominant	Coordination dominant
Green	Equitable	Arterial and/or Grid
Purpose	Access	Pipeline
Measurement Target	Phase utilization	Coordination diagrams & arterial arrivals on green

2.3 Traffic Control Signal Spacing

The following network context considerations should influence signal spacing along with the operational objectives:

- ✓ Preserving smooth flow and progression on arterial roadways (pipelines)
- ✓ Queue storage between intersections
- ✓ Minimize “stop and go” driving with associated rear-end collision risks and increased air pollution.
- ✓ Providing controlled pedestrian crossings at an appropriate interval if midblock crossing opportunities are unavailable or undesirable.
- ✓ Minimizing acceleration and deceleration delays for transit vehicles and/or freight

Where smooth flow is the primary objective, the ideal spacing for traffic control signals depends on vehicle speed, cycle length, and whether one-way or two-way progression is desirable. For closely spaced signalized intersections in urban areas, where signal spacing is less than ¼ mile, microsimulation can be a powerful tool to analyze queuing, spill-back potential, and safety performance. For rural, high-speed (55 mph) roadways, signals should be located at least ½ mile apart.

Refer to Chapter 6 of NCHRP Report 900, *Guide for the Analysis of Multimodal Corridor Access Management*, for additional considerations.

PennDOT regulations and policy relating to access management and driveways are in Pa. 67 Chapter 441, Publication 282, and Publication 574.

The District Traffic Engineer must approve the appropriate signal spacing in conjunction with the warrant analysis for new signal installations.

2.4 Traffic Control Signal Coordination

To maximize the effectiveness of traffic control signal coordination, the following factors should be considered: traffic control signal spacing, traffic flow characteristics, and traffic control signal cycle lengths. Although these factors are closely related, they could be considered independently for evaluation.

The MUTCD states that traffic control signals within ½ miles of one another along a major corridor or in a network of intersecting routes should be considered for coordination. Other factors such as grades, curves, and operating speeds may also need to be considered in conjunction with signal spacing.

The goal of traffic control signal coordination is to establish platoons or tight groups of vehicles that can move easily from one intersection through another without stopping. The ideal condition for establishing these platoons is to have the traffic control signals uniformly spaced. When signals are spaced too far apart, traffic may not form these platoons thereby undermining the effectiveness of signal coordination. In addition, uneven or closely spaced traffic control signals and mid-block traffic generators can also reduce the effectiveness of platoon formation therefore reducing arterial travel speeds, resulting in an excessive number of stops, even under moderate traffic volumes.

2.4.1 Coordination Advantages and Disadvantages

Some of the advantages of traffic control signal coordination are:

- ✓ Improves mobility and access through the area.
- ✓ Reduces vehicle accidents in the area.
- ✓ Reduces energy and fuel consumption.
- ✓ Reduces stops.
- ✓ May control travel speeds
- ✓ Provides environmental benefits from reduced vehicle emissions.
- ✓ Ability to monitor daily traffic operations (UTCS and Closed-Loop)

Some of the disadvantages of traffic control signal coordination are:

- ✓ May increase the waiting time (delay) for some side streets and left turn movements.
- ✓ Increase in travel speeds may have a negative impact in the community.
- ✓ May attract additional traffic through the corridor.
- ✓ Maintenance and equipment costs may be high based on the type of hardware and software used.
- ✓ May require advanced staff qualifications for maintenance and monitoring of daily operations.

2.5 Traffic Control Signal Analysis Tools

The previous sections discuss some of the factors to consider when determining if adjacent traffic control signals should be coordinated along with some of the advantages and disadvantages to coordination. In addition to the elements previously mentioned, an engineering analysis with a traffic software tool should be considered. Refer to Publication 46, Chapter 12 for information on traffic engineering software that is supported by PennDOT.

For instance, the software package Synchro includes a tool called the Coordinability Factor (CF) which can be used to assist in determining coordination needs. This feature considers the travel time between intersections (hence, considering distance and speed), the traffic volumes on the main street and side street, the natural cycle of the adjacent signals, and the storage space between the intersections. Using this information, Synchro will provide a score on the desirability of coordinating (or not coordinating) the adjacent intersections.

Along with the CF, a traditional analysis could be performed for the network with and without coordination using tools such as Transyt-7F, Synchro, PTV Vistro and SimTraffic. Network wide and arterial measures such as delay, travel time, fuel usages, emissions and others could be compared between the alternatives.

The above analysis would be used in helping shape the decision on whether to coordinate or not. However, engineering judgment should also be exercised when making the final decision and qualitative, along with the previously discussed quantitative measures need to be considered.

2.6 Roadway Approach Geometry

The roadway approach geometry leading into a traffic control signal location impacts visibility to traffic control signal indications, conflicting movements, and queued traffic ahead. The geometry may also impact approach speeds and stopping distance.

It is important that signal locations are designed so that drivers have appropriate time to recognize there is a signal ahead and to respond to changing assignments of right-of-way. Approach signage shall be located for motorists to identify and maneuver into the proper lane for the desired movement at the intersection.

2.7 Nearby Railroad/Transit Grade Crossings

The Pennsylvania Public Utility Commission (PUC) has jurisdiction over all highway-railroad crossings, whether crossing a highway at grade, above grade, or below grade. If traffic control signals are to be located within 300 feet of a railroad or transit highway grade crossing, refer to Publication 46, Chapter 4 for information and procedures that need followed with the PUC. Additional information related to grade crossings is in Part 8 of the MUTCD and Publication 371.

The following information should be obtained from the railroad company during Stage 1 of the process outlined in Publication 46:

- ✓ The name(s) of the railroad or others using the crossing
- ✓ The type of crossing (freight, shifting, spur, etc.)
- ✓ The number of crossings per day
- ✓ The approximate time of crossing(s), or number per hour in case of a trolley crossing
- ✓ The average length of time it takes the train to clear the area of the intersection
- ✓ The type and operation of crossing protection currently in use [If flashers, gates, bells, or combinations of these are present, determine the time element (maximum – minimum) that they are in operation prior to the time a train or transit vehicle reaches the crossing.]
- ✓ The train speed on each approach to the crossing (track speeds)
- ✓ The number and position of the tracks should be shown on the condition diagram

A Diagnostic Team must be established at the beginning of the project prior to beginning design of the highway traffic signal. The functions of the Diagnostic Team are described in Part 8 of the MUTCD. The team should consist of all stakeholders involved in the design, approval, operation, and maintenance of the grade crossing and highway traffic signal. At a minimum, for locations involved highway traffic signals, the Diagnostic Team should include:

- ✓ The design engineer
- ✓ PennDOT representatives from all applicable units (Traffic, Utilities, Project Management, etc.)
- ✓ Operating railroad
- ✓ PA Public Utilities Commission
- ✓ Signal controller expert for the make and model to be used
- ✓ Municipality (including the municipal traffic engineer)
- ✓ Developer (if involved)

Where feasible, consider operating traffic control signals near grade crossings so that vehicles are not required to stop on the tracks, even though in some cases this will increase the waiting time. The exact nature of the display and location of the signals to accomplish this will depend on the physical relationship of the tracks to the intersection area.

Highway traffic signals shall not be used on mainline railroad crossings in lieu of flashing light signals. However, at industrial track crossings and other places where train movements are very slow (as in switching operations), highway traffic control signals may be used in lieu of conventional flashing light signals to warn vehicle operators of the approach or presence of a train. The provisions relating to traffic signal design, installation, and operation are applicable as appropriate where highway traffic signals are so used.

Refer to **Chapter 11** for Preemption and Priority Control regarding traffic control signals near existing grade crossings.

3. INTERSECTION CONTEXT

3.1 General

The traffic control signal designer shall consider the immediate environment to develop safe and effective designs. Publication 13M addresses geometric constraints for intersections, and intersections with traffic control signals.

It is often the case that traffic control signals are designed and installed at intersection locations that have been in existence for some time. These intersections have various existing intersection constraints that may impact the traffic control signal design and need considered, such as the following:

- ✓ Intersection geometry/sight distances
- ✓ Right-of-way and roadway widths
- ✓ Pavement condition
- ✓ Utilities (overhead & buried)
- ✓ Land use (adjacent properties, businesses, etc.)

For additional information, see the following sections in this chapter and **Chapter 10.2.2** for potential intersection data collection requirements.

3.2 Geometry and Sight Distance Constraints

Intersection geometry/sight distance may constrain a traffic control signal design in the following ways:

- ✓ Location of signal poles
- ✓ Signal head approach targeting
- ✓ Curb radii and stop line locations for accommodating truck turning paths.
- ✓ Curb radii, channelized islands, and refuge islands impact pedestrian crossing distance and associated pedestrian clearance intervals.
- ✓ Restrictions of certain movements, such as No Turn on Red (NTOR)
- ✓ Operations Phasing/Timing
    - Special phasing for offset intersection approaches
- ✓ Conflicting turning paths that can't operate at the same time.
    - Intersection widths, grades, and stop line locations impact needed clearance intervals.
- ✓ Advance warning prior to the back of queue upstream of the intersection
- ✓ Need for geometric and sight distance improvements.
- ✓ Traffic control signal equipment may limit visibility to pedestrians.

For new or reconstructed intersections, these issues should be considered as part of the roadway design to ensure operational efficiency of the traffic control signal. When traffic control signals are installed at existing intersections, consider methods to minimize operational impacts within the limitations of the project scope.

3.2.1 No Turn on Red (NTOR) Restrictions

No Turn on Red restrictions shall be supported by an engineering study using Form TE-118 using the criteria in MUTCD Section 2B.60 and 67 Pa. Code §212.116.

When the turning movement is allowed from more than one lane on a specific approach, the turn on red may be prohibited in accordance with 67 Pa. Code §212.116(a)(1)(v), but the turn on red may be permitted for one lane with appropriate signage (see **Section 19.3.2**).

3.2.2 Positive Offset for Opposing Left-Turn Lanes

Sight distance is important for drivers to identify acceptable gaps in opposing traffic. A left-turning vehicle in an opposing left-turn lane can obstruct the view of oncoming vehicles. **Exhibit 3-1** shows three potential left-turn lane lateral offset situations.

Opposing left-turn lanes should be designed to provide positive offset to minimize the obstruction of sight distance, as discussed in NCHRP Report 500 Volume 12: "A Guide for Reducing Collisions at Signalized Intersections." To accomplish this, align the left edge of both left-turn lanes to the left of the right edge of the opposing left-turn lane as illustrated in **Exhibit 3-2**. A minimum 3-foot positive offset will usually eliminate the sight-distance problem cause by a vehicle in the opposing left-turn lane.

On undivided highways, this positive offset can sometimes be provided by the use of solid channelizing lines in accordance with the following figure from the FHWA *Travel Better, Travel Longer: A Pocket Guide to Improve Traffic Control and Mobility for Our Older Population*.

Exhibit 3-1 Left-Turn Lane Lateral Offset Situations

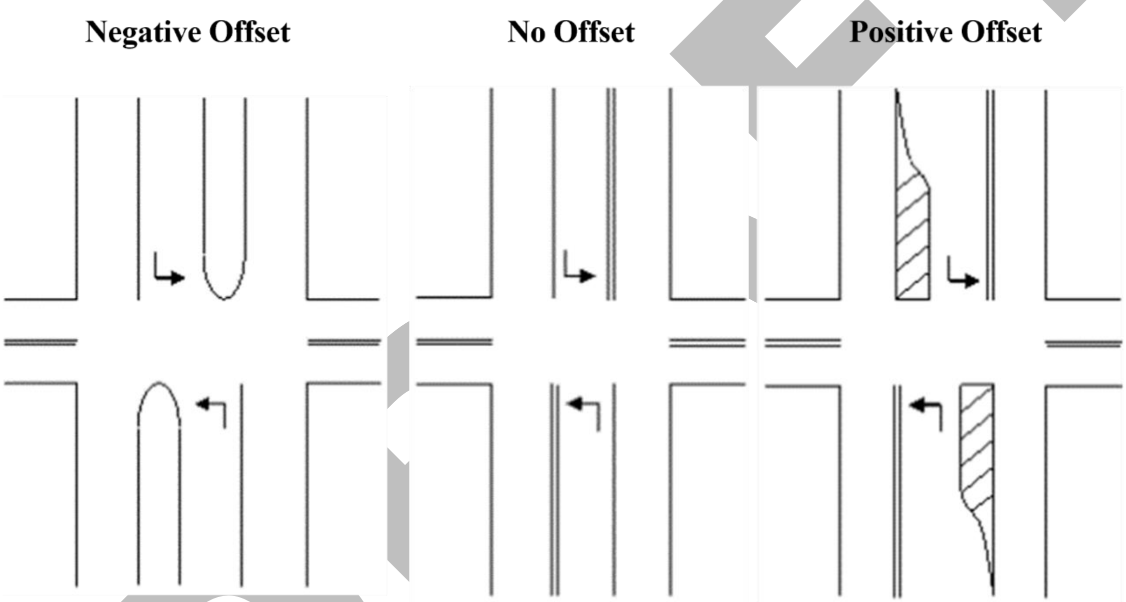
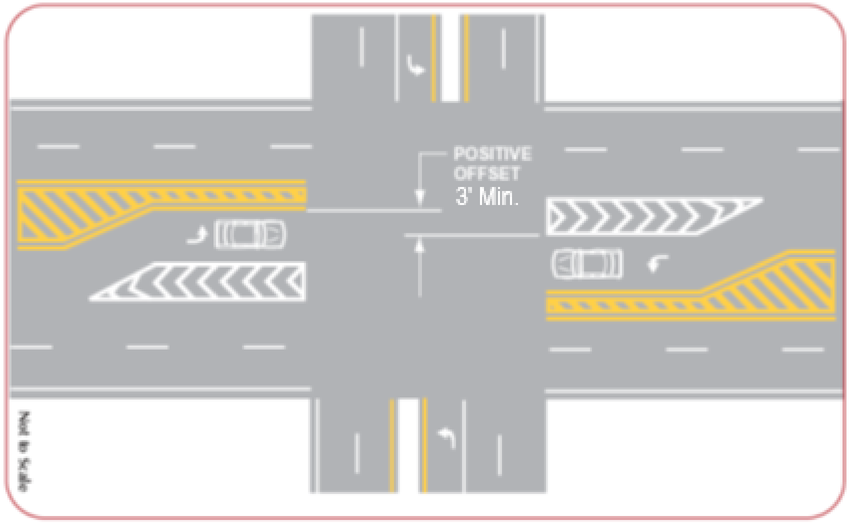


Exhibit 3-2 Positive Offset for Left-Turn Lanes



3.3 Roadway and Right-of-Way Width Constraints

Roadway and right-of-way width may impact a traffic control signal design in the following ways:

- ✓ Location of signal poles/equipment
- ✓ Number of lanes/widths of lanes
- ✓ Dedicated turn lanes (right and/or left)
- ✓ Operations Phasing
- ✓ Need for pavement widening.
- ✓ Pedestrian accommodations
- ✓ Need for additional right-of-way.

The traffic signal owner must have the legal ability to access all components on the traffic signal permit, including support poles, conduit, junction boxes, in-pavement detectors, and signs. If these components are not located within existing public right-of-way, then additional right-of-way or an easement must be obtained.

3.4 Pavement Condition Constraints

Pavement condition may impact a traffic control signal design in the following ways:

- ✓ Use of in roadway detector sensors
- ✓ Adherence of pavement markings
- ✓ Need for pavement improvements.

3.5 Utility Considerations

Utilities include diverse types of infrastructure, such as electric lines, telephone lines, gas lines, and stormwater facilities. Utility locations may impact a traffic control signal design in the following ways:

- ✓ Underground utilities (excavations, trenching, foundations, etc.)
- ✓ Overhead utilities (interference with pole locations, signal head visibility, etc.)
- ✓ Interference with pedestrian accommodations (underground and/or overhead utilities)
- ✓ Need for utility relocations or traffic control signal design changes to avoid utilities.

3.6 Adjacent Property Considerations

Adjacent properties may involve businesses, commercial residences, and private residences. It is important to consider the needs of these adjacent property owners and occupants so that the design of the traffic control signal doesn't impose undue hardships and strained long-term relations. These considerations will involve the traffic control signal equipment location and placement relative to the adjacent property, and how these equipment placements will impact and affect the adjacent property owners/occupants. Some examples considerations are as follows:

Adjacent business considerations (avoid blocking or restricting):

- ✓ Business signs
- ✓ Business storefront/display window
- ✓ Business store ingress/egress

Adjacent residence considerations:

- ✓ Proximity of windows, bedrooms (signal indications/luminaire, light noise/visibility impacts)
- ✓ Home walkway ingress/egress
- ✓ Impacts to landscaping, such as shrubbery and trees
- ✓ Aesthetics

See **Exhibit 3-3** for an actual example of how a mast arm was located between two storefronts so as not to block either one.

Exhibit 3-3 Pole Location for Adjacent Property Considerations

4. OPERATIONAL CONTEXT

4.1 General

The purpose or reason for any traffic control signal is the assignment of right-of-way to improve traffic flow and safety. Therefore, how a signal operates in the assignment of right-of-way for its various users is of key importance.

Traffic control signal design needs to consider various operations factors that may impact the design, such as the following:

- ✓ Intersection Users
  - Vehicular Traffic: volumes, movements, and vehicle types/percentages
  - Pedestrian Traffic: volumes and requirements (ADA, etc.)
  - Bicycle Traffic: volumes and requirements
- ✓ Land use context
- ✓ Preemption and priority controls
- ✓ Crash history

For additional information, see the following sections in this chapter. The FHWA Traffic Signal Timing & Operations Strategies website may also be a resource for various strategies related to timing & operations.

4.2 Intersection User Considerations

The traffic control signal must effectively serve all users traversing the intersection through the assignment of right-of-way. The intersection may include users with various modes of transportation, including motor vehicles, pedestrians, and bicycles.

4.2.1 Vehicular Traffic

Vehicular traffic demands require careful consideration as part of the traffic control signal design as they impact the operational efficiency of a signalized intersection and/or corridor. These demands include considering the following vehicular traffic volume breakouts:

- ✓ By time (time of day, day of week, special events/time of year, etc.)
- ✓ By movements (through, left-turns, right-turns)
- ✓ By vehicle classification (cars, trucks, buses, motorcycles, etc.)
- ✓ By vehicle use (freight, transit, ride share, private use, etc.)

The composition of vehicle traffic may show the need for physical intersection modifications, such as turning radii improvements to accommodate trucks, signal head placement to provide visibility for vehicles following tall trucks, or dedicated turn lanes because of heavy turn movements, etc. The composition of vehicle traffic may also impact timing parameters (see **Chapter 10**) due to acceleration and deceleration characteristics and different headways.

See **Chapter 10.2.2** for potential traffic data collection requirements.

4.2.2 Pedestrian Traffic

Pedestrians are vulnerable road users without the protection of a vehicle, and pedestrians require careful consideration as part of the traffic control signal design to reduce the risk and severity of vehicle-pedestrian crashes.

See **Chapter 8** for pedestrian study requirements as part of the traffic control signal design.

4.2.3 Bicycle Traffic

Bicycles represent an important mode of transportation throughout Pennsylvania; therefore, bicycle accommodations shall be made as a routine and integral element of planning, project development, design, construction, operations, and maintenance.

On roadways, bicycle riders have the same rights as the driver of a vehicle in accordance with 75 Pa.C.S. §3501. Bicycles may be ridden on a sidewalk or pedalcycle path in accordance with 75 Pa.C.S. §3508, but the bicyclist must yield the right-of-way to pedestrians. When a bicyclist riding on the sidewalk reaches a signalized intersection, the bicyclist must either move into the roadway and operate in accordance with the rules of the road as a vehicle, or the bicyclist must dismount from the bicycle and use the crosswalk as a pedestrian.

See **Chapter 9** for bicycle study requirements as part of the traffic control signal design.

4.3 Land Use Context

Land use context surrounding the signalized intersection may also have impacts on the operational design of the traffic control signal due to differing traffic demand patterns. Land use contexts can be of the following types:

- ✓ Residential
- ✓ Commercial
- ✓ Industrial
- ✓ Mixed

Depending upon the land use context (and community context), traffic demand volumes/patterns may be significantly different.

- ✓ Commuter traffic (high through movements) vs. Local traffic (ingress/egress of traffic)
- ✓ Commercial strip corridors (lots of entering/exiting turning traffic)
- ✓ Special events, such as sports complexes, with large enter/exit demands at specific times.
- ✓ High pedestrian traffic (neighborhoods or tourist destinations)

Existing and future land use context should be considered when designing a signalized intersection or system.

For addition information, see Publication 10 (DM-1 series) and Publication 13M (DM-2).

4.4 Preemption and Priority Controls

Traffic control signals may be designed and operated to respond to certain classes of approaching vehicles by altering the normal signal timing and phasing plan(s) during the approach and passage of those vehicles. The alternative plan(s) may be as simple as extending a currently displayed green interval or as complex as replacing the full set of signal phases and timing. A traffic control signal design needs to carefully consider the need for preemption or priority control for select classes of vehicles and/or select operational conditions.

Preemption control is typically given to trains, boats, emergency vehicles, and/or light rail transit.

Priority control is typically given to certain non-emergency vehicles such as light-rail transit vehicles operating in a mixed-use alignment and buses.

Preemption or priority control of traffic control signals may also be a means of assigning priority right-of-way at certain non-intersection locations such as on approaches to one-lane bridges and tunnels, movable bridges, highway maintenance and construction activities, metered freeway entrance ramps, freeway exit ramp queue preemption, and transit operations.

The installation of train preemption at a new or existing signalized intersection will require evaluation of the left-turns. Termination of one or more through phases at the beginning of train pre-emption may cause a left-turn trap to occur depending on the phase sequencing. Protected-only left turn phasing should be considered at these locations.

If the left-turn phase would not normally be warranted, capacity analysis should be completed comparing the intersection levels of service and delays with and without the left turn phase. If inclusion of the left-turn phase results in unacceptable additional intersection delays, the use of a W25-1 “Oncoming Traffic has Extended Green” sign should be considered in lieu of the left-turn phase.

See **Chapter 11** for design details of Preemption and Priority Controls of Traffic Control Signals.

4.5 Crash History

As part of a new traffic control signal design, or design modifications to an existing signalized intersection, the designer should analyze operational issues that result in:

- ✓ Existing/historic traffic crash patterns at the intersection
- ✓ User operational risk and safety complaints at the intersection (with or without crashes)

The designer should consider mitigation of these crashes and/or operational issues by incorporating cost-effective safety improvements into the project design.

Publication 638 (Chapter 5) defines in detail the process for identifying, studying, and defining appropriate improvements to reduce the potential for future crashes at project specific locations, as briefly summarized below:

- ✓ Analyze crash data from the past 5 years to determine if any crash patterns emerge.
- ✓ Identify appropriate countermeasures that may reduce the potential for future crashes using the crash patterns/characteristics from the crash analysis.
- ✓ Select countermeasures using Crash Modification Factors (CMFs) in the CMF Clearinghouse. Select appropriate countermeasures based on the crash patterns, which are associated with the countermeasure. Publication 638, and Publication 638A shall be referenced for guidance on how to apply and use these CMFs.

Exhibit 4-1 lists some example countermeasures at signalized intersections, which can be analyzed to see the potential safety impact of implementing that countermeasure:

> Engineering judgment is required to determine which crashes are attributable to the intersection:
>
> - ✓ To determine if a crash is attributable to an intersection, review crash descriptions for all crashes occurring within proximity to the intersection to validate actual crash location and cause.
> - ✓ Extending 250 feet in each direction from the center of the intersection is typically sufficient unless queues from the intersection regularly extend further or the intersection has an unusually large geometry (offset legs, channelized turn bays with large radii, etc.).

Exhibit 4-1 Example Safety Countermeasures

Countermeasures	Crash Reduction
Backplates with reflectorized borders	Angle crashes
Leading pedestrian interval	Pedestrian crashes
Pedestrian countdown signals	Pedestrian crashes
Crosswalk visibility enhancements	Pedestrian crashes
Effect of right turn on red on pedestrians & bicycle crashes	Pedestrian/Bicycle crashes
Re-timing of traffic control signal change intervals (Yellow and/or Red)	Angle & Rear-end crashes
Inclusion of left-turn lanes at intersections that have a history of left turn movement crashes	Angle crashes
Left turn phasing (protected, protected/permissive, or split phasing)	Angle & Pedestrian crashes
Dilemma zone protection	Angle & Rear-end crashes
Intersection geometric improvements	Angle & Rear-end crashes

For addition details, guidance, and information, see the following references:

- ✓ Publication 638 (District Highway Safety Guidance Manual)
- ✓ Publication 638A (Pennsylvania Safety Predictive Analysis Methods Manual)
- ✓ Publication 13M (information on the requirements/process for developing design plans for left turn lanes and left turn phases)
- ✓ Crash Modification Factors Clearinghouse (CMF)
- ✓ FHWA Proven Safety Countermeasures
- ✓ FHWA Intersection Safety
- ✓ NCHRP Report 500 Volume 12, A Guide for Reducing Collisions at Signalized Intersections
- ✓ Intersection Control Evaluation (ICE) policy
- ✓ Safe System Project-Based Alignment Framework

5. TRAFFIC CONTROL SIGNAL DESIGN CONSTRAINTS

5.1 General

The design of traffic control signals on all streets and highways shall conform to this Publication and the following:

- ✓ Federal Statutes (**Section 5.2**)
- ✓ Federal Regulations (**Section 5.3**)
- ✓ Pennsylvania Statutes (**Section 5.4**)
- ✓ Pennsylvania Regulations (**Section 5.5**)
- ✓ PennDOT Policies (**Section 5.6**)

Other traffic control signal related references are listed in **Exhibit 1-3** of this Publication.

Traffic control signals should be:

- ✓ Designed using the Department's standard construction specifications, standard drawings, and available ECMS Master Items. Designs should only deviate from standard specifications and items in unusual cases where the standards cannot be used due to unique project-related situations as indicated in **Section 5.7.**
- ✓ Constructed using the Department's qualified products and materials listed in Publication 35 (Bulletin 15), see **Section 5.5.2** and **Section 5.6.1,** except for unique project-related situations as indicated in **Section 5.8.2.**

5.2 Federal Statutes

Federal statutes are passed by both the United States Senate and the United States House of Representatives. Statutes become law when signed by the President of the United States or Congress overrides the President's veto. Federal statutes are officially compiled and codified in the United States Code.

5.2.1 Americans with Disabilities Act

The Americans with Disabilities Act (ADA) of 1990 is a federal civil rights statute that prohibits discrimination against people with disabilities. ADA implementing regulations for Title II prohibit discrimination in the provision of services, programs, and activities by state and local governments.

For additional detailed information see the following:

- ✓ Publication 13M (DM-2) (Chapter 6)
- ✓ **Section 8.3** of this publication
- ✓ Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG) regulation adopted by the U.S. Access Board

5.3 Federal Regulations

Federal regulations are promulgated to carry out rulemaking authority granted by federal statutes to federal agencies. Regulations normally carry the force of law. Prior to taking effect, regulations are proposed and published in the Federal Register, with a public comment period. After the federal agency addresses the public comments, the final rule is published in the Federal Register. Federal regulations are compiled into the Code of Federal Regulations (CFR).

5.3.1 Manual on Uniform Traffic Control Devices

The MUTCD is adopted by reference in accordance with Title 23, United States Code, §109(d) and Title, Code of Federal Regulations, Part 655.603.

All traffic control signal designs must comply with standards in the MUTCD. Deviation from MUTCD guidance may be justified with engineering judgment (see Section 1D.03 of the MUTCD).

While all of MUTCD Part 4 applies to highway traffic control signals, Chapters 4D, 4E, and 4F present the features of traffic control signals that are of interest to road users, such as the location, design, and meaning of the signal indications. Uniformity in these design features is especially important for the safety and efficiency of operations.

MUTCD, Chapters 4D, 4E, and 4F include these and other standard design features:

- ✓ Meaning of vehicular signal indications (Chapter 4A)
- ✓ Signal indications – Design, illumination, color, and shape
- ✓ Size of vehicular signal indications
- ✓ Positions of signal indications within a face
- ✓ Number of signal faces on an approach
- ✓ Signal indications for left-turns and right-turns
- ✓ Lateral and longitudinal positioning of signal faces
- ✓ Mounting heights and lateral offsets of signal faces

The Commonwealth of Pennsylvania's adoption of the MUTCD is described in **Section 1.3**.

5.4 Pennsylvania Statutes

Pennsylvania statutes, often referred to as Acts, are passed by both the houses of the Pennsylvania General Assembly. Statutes become law when signed by the Governor, the General Assembly overrides the Governor's veto, or the bill becomes law without the Governor's signature after 10 days. Individual acts are often referred to by the sequential number of passage in a calendar year, such as Act 89 of 2013, which was the 89th act approved in 2013. Acts may create new law, amend Consolidated Statutes, or amend prior unconsolidated statutes.

The following statutes are relevant for traffic control signal design:

- ✓ Title 74 Pa.C.S. Transportation Chapter 92 (Traffic Signals)
- ✓ Title 75 Pa.C.S. Vehicle Code
  - Chapter 31, Subchapter B (Traffic Control Devices)
  - Chapter 61 (Powers of Department and Local Authorities)

5.5 Pennsylvania Regulations

Pennsylvania regulations are promulgated to carry out rulemaking authority granted by Pennsylvania statutes to state agencies. Regulations normally carry the force of law. Prior to taking effect, regulations are proposed and published in the *Pennsylvania Bulletin*, with a public comment period. After the state agency addresses the public comments, the final regulation is published in the *Pennsylvania Bulletin*. State regulations are compiled into the *Pennsylvania Code* (Pa. Code).

5.5.1 Title 67 Pa. Code Transportation

Chapter 212 (Official Traffic-Control Devices)

Chapter 212 is Pennsylvania's official state supplement to the MUTCD, in accordance with 23 CFR §655.603(b). Additionally, §212.12 lists seven PennDOT publications which also supplement the MUTCD, which includes this publication. Those seven publications are also considered to be part of Pennsylvania's official state supplement.

Other PennDOT Regulations

- ✓ Chapter 205 (Municipal Traffic Engineering Certification)
- ✓ Chapter 441 (Access to and Occupancy of Highways by Driveways and Local Roads)

5.5.2 Manufacture and Sale of Traffic Signal Equipment/Bulletin 15

PennDOT is required to approve all traffic-control devices available for manufacture and sale in Pennsylvania in accordance with 75 Pa. C.S. §6127 and Title 67 Pa. Code §212.8(b)(4), which includes the following traffic signal equipment:

- ✓ Controller units
- ✓ Signal heads—lane-use traffic control, pedestrian, and vehicle
- ✓ Detectors—pedestrian and vehicle
- ✓ Load switches
- ✓ Flasher units
- ✓ Time clocks
- ✓ Relays
- ✓ Preemption and priority control equipment
- ✓ Electrically-powered signs—variable speed limit signs, blank-out signs, and internally illuminated signs, including School Speed Limit Signs
- ✓ Portable traffic-control signals
- ✓ Local intersection coordinating units
- ✓ Dimming devices
- ✓ In-roadway warning lights
- ✓ Auxiliary devices and systems

Traffic control devices approved by PennDOT for sale in Pennsylvania are contained in Publication 35 (Bulletin 15). Traffic signal owners shall only use approved equipment when installing, modifying, or repairing traffic signals.

In addition to the regulations for sale of traffic control devices described above, PennDOT also approves construction materials related to traffic signals, including structural steel and aluminum. These construction materials are also listed in Publication 35 (Bulletin 15) and should be used for all traffic signal work, including maintenance.

5.6 PennDOT Policies

PennDOT policies are established through publications, strike-off letters, and other officially issued documents approved by PennDOT authorized officials. Although policies do not carry the force of law, they may be tied to sources of funding and/or referenced in legal agreements. For example, many PennDOT publications are incorporated by reference into Traffic Signal Permits and Traffic Signal Maintenance Agreements between municipalities and PennDOT.

5.6.1 Publication 408, Traffic Signal-Related Specifications & Items

Designers should be familiar with the specifications, and related ECMS Master Items, that apply to the design (and construction) of traffic control signals. The highway specifications in Publication 408 apply to the following:

- All construction projects let by PennDOT.

- Any work completed under a PennDOT Highway Occupancy Permit in accordance with Title 67 Pa. Code §441.6(3).
- Locally let projects involving state or federal funding where the project agreement requires compliance with Publication 408 (including, but not limited to, ARLE and Green Light-Go).
- Locally let projects using liquid fuels tax funds.
- Any project which includes specifications that incorporate Publication 408 by reference.

Use of standard Master Items in ECMS ensures compliance with Title 67 Pa. Code §212.8(b)(4), which requires PennDOT approval of all traffic-control devices available for manufacture and sale in Pennsylvania. Traffic control devices approved by PennDOT for sale in Pennsylvania are listed in Publication 35 (Bulletin 15). Bulletin 15 product/material listings are organized by their corresponding Publication 408 specification section as shown in **Exhibit 5-1**.

Key specifications for Traffic Control Signals are shown in **Exhibit 5-1**. Other sections of Publication 408 may affect the traffic signal design, such as signs, pavement markings, intelligent transportation system (ITS) devices, etc.

Exhibit 5-1 Key Specifications for Traffic Control Signals

Pub 408 Section	Title	Master Items
950	Traffic Signals -General	0950 Series
951	Traffic Signal Supports	0951 Series
952	Controller Assembly	0952 Series
953	Systems & Communications	0953 Series
954	Electrical Distribution	0954 Series
955	Signal Heads	0955 Series
956	Detectors	0956 Series
957	Advanced Traffic Signal Technology	0957 Series
958	Temporary Traffic Control Signals	0958 Series

5.6.2 Publication 148, Traffic Standards-Signals

Along with the specifications in Publication 408, the signal standards listed in Publication 148 regulate a traffic control signal design. These TC-Signal Standards (8800 series) provide the designer (and contractor) with essential information, such as:

- ✓ Typical drawings
- ✓ Typical sections
- ✓ Details
- ✓ General Notes

Exhibit 5-2 shows the TC-Signal standards that are available in Publication 148.

Exhibit 5-2 Pub 148 Traffic Control (TC) Standards

Traffic Standards-Signals (8800 Series)	
TC-8801	Traffic Signal Supports
TC-8802	Controller Assembly
TC-8803	Miscellaneous (Pedestrian-related)
TC-8804	Electrical Distribution
TC-8805	Signal Heads
TC-8806	Detectors

5.6.3 Traffic Control-Pavement Markings & Signing Standards

Exhibit 5-3 shows the TC-Pavement Marking & Signing Standards in Publication 111 and Publication 236.

Exhibit 5-3 Pavement Marking & Signing Standards

Pavement Marking & Signing Standards	
TC-8600 series (Pub 111)	Pavement markings/delineators
TC-8700 series (Pub 111)	Signing
Publication 236	Handbook of Approved Signs

5.7 Use of Standard Protocols-Signal Phasing and Timing

At the heart of a traffic control signal design is the development of the signal's operation, the way it assigns right-of way to the various approaches and movements. This in fact is the sole reason that a traffic control signal is needed and installed.

The development of the traffic control signal's phasing and timing is controlled by standard protocols and concepts so that there is national uniformity in the design and operation of these signal timing plans, including how the controller units work based upon these standard protocols.

For complete information regarding these standard protocols, and operations requirements, refer to the following:

- ✓ Signal Timing Manual – Second Edition (STM2)
- ✓ NTCIP 1202, Object Definitions for Actuated Traffic Signal Controller (ASC) Units
- ✓ **Chapter 10** of this publication

5.8 Project Specific Constraints

Each project will have specific needs, requirements and/or unique project-related situations that need to be considered by the traffic control signal design.

5.8.1 Project Type/Scope

Every project has a scope of work that needs to be implemented within the bounds of the design requirements for that project, and type of project. As an example, a brand-new signal design/installation may require items that are not required on an existing signal modification project. This is similar to new highway construction design requirements versus differing rehabilitation work design requirements. **See Section 6.2** for additional details.

5.8.2 Unique Project-Related Situations

The majority of traffic control signals should be able to be designed (and constructed) using the Department's standard construction specifications, standard drawings, and available ECMS Master Items. Using standard specifications and items has the following benefits:

- ✓ Item Price History
  - Consistent bidding methods help track costs allowing for better estimates during project design.
- ✓ Less Risk
  - Contractors know they can use Bulletin 15 qualified items.
- ✓ Contractors don't have to include any risk factor into bid price for having items approved after project is let.
- ✓ Less Review Time
  - Bulletin 15 qualified items can be approved without needing any detailed review of catalog specifications to confirm contract specification is met.

Designs should only deviate from standard specifications and items in unusual cases where the standards cannot be used due to unique project-related situations. For PennDOT-let projects, all project-specific special provisions relating to traffic control signals must be reviewed and approved by the Chief of the TSMO Arterials and Planning Section prior to advertisement in ECMS. See **Section 35.3** for additional information.

Permittee Requests/Requirements

As traffic control signals are owned and maintained by the Permittee, it is not uncommon for a Permittee to request certain things as part of the signal design. As an example, a Permittee may request a specific type/brand of controller unit as part of the design (and installation) for equipment synchronization purposes. Any such Permittee requests need to be evaluated for legitimacy, and follow the procedures in the following publications:

- ✓ Publication 46, Chapter 4.7 (Request for Proprietary Specifications), and
- ✓ Publication 51 (Patented/Proprietary Materials, Products, Processes).

There may also be legitimate Permittee signal requirements that do not require proprietary or special approvals, and these should be incorporated accordingly.

5.8.3 Unified Command and Control (UCC) Integration

Traffic signals meeting the following criteria should have the ability to be operated and monitored from a PennDOT Regional Traffic Management Center (RTMC) by having a controller unit with full functionality with the Department's Unified Command and Control (UCC) software:

- ✓ Traffic signals located on roadways in the 511PA Core Roadway Network
- ✓ Traffic signals along detour routes used for incident management of the 511PA Core Roadway Network
- ✓ Traffic signals which are operated with adaptive signal control technology (ASCT)

UCC integration may also be considered for other traffic signals if a use case for remote monitoring and operation is identified through consultation with the RTMC.

When UCC integration is included as part of the traffic signal design, the designer should discuss with Department's RTMC to understand any requests or requirements that RTMC may want as part of the design.

PART III
DESIGN ELEMENTS/CRITERIA - TRAFFIC CONTROL SIGNALS

6. DESIGN ELEMENTS INTRODUCTION

6.1 General

A traffic control signal design incorporates various physical and operational design elements and criteria. For the designer, the physical aspect of a traffic control signal design is comprised of more than just simply the R-Y-G signal heads that the motorist sees.

A traffic control signal design must develop a complete physical layout of the signal or signal system, as follows:

- ✓ Physical intersection layout of traffic control signal
- ✓ Physical layout of coordinated traffic control signal system

In the development of these physical layouts, there are various design elements/criteria that need to be addressed and pulled together, including the operational design elements, culminating into a complete traffic control signal design.

The remaining chapters in PART III **(Chapters 7-21)** will address in more detail the following design elements/criteria that need to be addressed:

- ✓ Utilities
- ✓ Pedestrian accommodations
- ✓ Bicycle accommodations
- ✓ Signal operations
    - Phasing, timing, control types, coordination
- ✓ Preemption and priority control
- ✓ Traffic control signal components
    - Supports, controller assembly, system/communications, electrical distribution, signal heads, detectors, advanced technology.
- ✓ Pavement markings and signs
- ✓ Intersection lighting
- ✓ Advanced warning beacons/flashers & internally illuminated advanced warning signs.

This complete design is presented as a Plans, Specifications & Estimates (PS&E) Package/Bid Package, see PART VI (**Chapters 32-35)** for additional information.

6.2 Project Scope

Traffic control signal project scopes can vary from a simple intersection controller retiming to a new traffic control signal installation, and everything in between. These variations in project scope are defined as project levels, and are presented and defined in the following exhibits:

- ✓ **Exhibit 6-1** shows these project levels which are used throughout this publication to establish applicability of design criteria.
- ✓ *** If** a CADD drawing of the existing permit it available, it should be used rather than marking up a PDF plan.
- ✓ Exhibit 6-2 shows various scope of work items for these project level definitions.

The overall project level is the highest level of any activity included in the scope of work listed in *** If** a CADD drawing of the existing permit it available, it should be used rather than marking up a PDF plan.

Exhibit 6-2.

Exhibit 6-1 Traffic Control Signal Project Levels

Level	Title	Definition	Permit Update Work Required
0	Equipment Upgrades	Replacement, upgrade, or addition of traffic control signal equipment which does not impact information shown on the traffic control signal permit condition diagram	Not Required
1	Retiming	Limited to timing/phasing modifications which are accomplished with existing equipment	MST, Coordination, or System Plan only
2	Minor Alterations	Modifications to items shown on the traffic signal permit condition diagram, but does not include replacement or installation of traffic control signal supports (mast arms, strain poles, pedestals, or stub poles)	Markup of existing permit is acceptable*
3	Major Alterations	Modifications to the traffic control signal which include replacement or addition of traffic control signal poles, but retain some existing traffic control signal equipment	New CADD drawing required
4	New Construction/ Replacement	Installation of: ▪ a new traffic control signal at an intersection not currently signal-controlled, or ▪ full modernization/replacement of all traffic control signal equipment at an existing signalized intersection	New CADD drawing required

* If a CADD drawing of the existing permit it available, it should be used rather than marking up a PDF plan.

Exhibit 6-2 Scope of Work Project Level Definitions

Project Scope of Work	Project Level
Retiming and Optimization	1
Signing Modification	2
Pavement Marking Modification	2
Add Backplates	0
Support Relocation w/ no Road Improvements	3
Detection Modification (change of detection technology)	2
Detection Area Modification	2
Emergency Preemption Added	2
Incandescent to LED	0
Install countdown pedestrian timers	2
Controller upgrade	0
Interconnection or System Installation	1 or 2
Phasing Modification (including changes to left turn phasing)	2 or 3*
Curb Ramp Installation/Modifications	2 or 3*
Installation of Accessible Pedestrian Signals	2 or 3*
Signal Support Relocation Because of Road Improvements	3
Rail Preemption Added	2
Construct a Turning Lane	2 or 3*
Addition of Bike Facilities	2 or 3*
Construct Another Leg to Intersection	3
Full Modernization	4
New Traffic Control Signal	4

*Normally level 2 but could be level 3 if the work triggers the need for new or relocated poles.

6.2.1 Plan Requirements

Plan requirements for various project levels are shown in **Exhibit 6-3**. See **Chapter 33** for a description of the various types of plans referred to in **Exhibit 6-3**.

Exhibit 6-3 Plan Requirements

Project Level (see **Exhibit 6-1**)	Level 4 Project	Level 3 Project	Level 2 Project	Level 1 Project	Level 0 Project
Construction Plan	▲***	▲***	▲***	-	-
Tab Sheets	▲	▲	▲	-	▲
Permit Plan	✓**	✓**	✓**	✓**	-
System Permit Plan	✓*	✓*	✓*	✓*	-

✓ Required
▲ A construction plan and tab sheet are required for federal and state funded projects. A construction plan and tab sheet are not required for local or private funded projects. However, the Department must receive a detailed scope of work describing the physical changes to an existing traffic control signal installation and operation. The Department will review a construction plan and tab sheets if so requested.
***** Provide a new system plan if the new signal or upgrade affects the information on an existing system plan (e.g., adding an intersection to the system, # and location of detection zones, phase numbers, # of lanes, etc.) or creates the need for a new system plan where none existed previously.
****** If changes occurred during construction, provide as-built signal permit plan at the end the Operational Testing and Guarantee period (see Publication 46 Section 4.9).
*** If changes occurred during construction, provide as-built construction plans in accordance with Publication 408.

6.2.2 Project scope requirements

Primary project objectives should define the project scope requirements and hence the project level. Keeping the project scope focused on accomplishing the project objectives can assist in eliminating scope creep and thereby allow for reduced costs and timelier implementation of equipment upgrades, traffic signal re-timings, and minor alterations.

Once the project objectives are clearly defined and the overall project level is determined, traffic control signal designers and reviewers should be aware of the effects of revisions or comments that are preferential and may influence or change the project level and required effort and cost to execute and implement the primary project objective. The scope should remain commensurate with the project level and primary type of work being implemented (project objective).

Level 0 & Level 1 Projects

Level 0 and Level 1 projects can typically be implemented relatively quickly and inexpensively and may or may not require data collection and field work including:

- ✓ Conduit condition and space
- ✓ Controller cabinet space
- ✓ Visible wiring condition (in cabinet, junction boxes, and pole bases)
- ✓ Verification of existing equipment and its functional capabilities
- ✓ Traffic volumes and turning movement counts.

Level 0 and Level 1 projects do not require modification to existing roadway infrastructure, and do not affect the traffic control signal condition diagram (other than possibly the Movement, Sequence, and Timing chart). As such, additional scoped work which would affect or necessitate a change to the Traffic Signal Permit Condition plan or require roadway construction should not be added to the project without consideration of the affect it would have on project cost and time for implementation. Items should not be added to a Level 0 or Level 1 project which would result in the project being reclassified as a Level 2 or higher project.

Level 2 & Level 3 Projects

Level 2 and 3 projects involve installation of some new equipment while retaining other existing equipment and the scope of the project must be carefully developed to ensure all necessary upgrades are included within the project funding while balancing the overall compliance of the signal with the current standards required in this Publication.

For Level 2 and Level 3 projects, existing field conditions must be reviewed, including:

- ✓ Conduit condition and space
- ✓ Controller cabinet space
- ✓ Visible wiring condition (in cabinet, junction boxes, and pole bases)
- ✓ Verification of existing equipment and its functional capabilities

In some cases, it is economical and efficient to complete additional upgrades to bring the intersection into compliance with current standards in conjunction with other work which is already part of the project scope.

The following guidelines should be followed when scoping upgrades for Level 2 and Level 3 projects:

- ✓ For projects where signal upgrades are required as mitigation identified in the Transportation Impact Study (TIS) for a PennDOT Highway Occupancy Permit (HOP), all the signal work required should be identified during the TIS review stage and included in the list of required mitigation in the TIS.
- ✓ For grant-funded projects, such as ARLE or Green Light-Go, all the signal work required should be identified during the pre-application scoping process to be included in the grant cost estimate.
- ✓ For other PennDOT projects, all the signal work required should be identified at the E&E Scoping phase prior to the beginning of preliminary engineering.
- ✓ The following upgrades should be considered for Level 2 and 3 projects:
  - Upgrading pedestrian signal heads to include pedestrian countdown timers.
  - Eliminating “blind clearance” left-turn phasing (no yellow arrow)
  - Modifying protected/permitted left-turn phasing to incorporate Flashing Yellow Arrow (FYA)
  - Adding backplates with retroreflective borders
  - Upgrading signals head to all 12-inch indications
  - Adding overhead street name signs
- ✓ Other items which don’t comply with current standards in this publication.
- ✓ Existing non-compliant equipment or operation may remain in place if the upgrades to achieve compliance would require replacing a traffic signal support which would not otherwise be replaced.
- ✓ The need for pedestrian accessibility upgrades shall comply with ADA/PROWAG (see **Chapter 8**).

Level 4 Projects

Level 4 projects involve installation of all new traffic signal equipment either as a full replacement for an existing traffic control signal or as a new traffic control signal in a previously unsignalized location. Scoping considerations for new signals should be based on current and future signal operation needs and design considerations coupled with an awareness of how best to provide an optimal design within the funding anticipated or available. All new traffic installations (Level 4 projects) must, at a minimum, be scoped to meet all current MUTCD and PennDOT Publication 148 standards.

6.3 Design Documentation

The elements of a traffic signal design should be documented within a Traffic Signal Design Report which should be included with traffic signal design submissions and retained in the intersection file in the Traffic Signal Asset Management System (TSAMS). Documenting and retaining this information assists with future modifications of the intersection to understand the rationale behind the existing operation.

At a minimum, the Traffic Signal Design Report should include the information shown in **Exhibit 6-4** based on the Project Scope (see **Section 6.2**).

Exhibit 6-4 Traffic Signal Design Report Elements

Design Report Element	Project Level				
	0	1	2	3	4
Project Description: Provide a thorough description of the project so the reviewer can have a full understanding of the overall project intent and purpose, owner, location, scope, history and background, expected outcome, land uses in the vicinity, and any other relevant information to help the reviewer fully understand the project		X	X	X	X
Vulnerable Road Users Engineering Study: See **Sections 8.2** and **9.2**				X	X
Roadway and Traffic Data					
Traffic Volumes: Provide traffic volume data as necessary to show that the signal is warranted and for developing the timings to be used. Opening year traffic volumes should be used for proposed traffic signals and modifications to existing signals.		X	X**	X	X
Turn Lane Warrant Analysis: See Publication 46, Chapter 11					X
Railroad Grade Crossing*: See **Section 2.7**		X	X	X	X
Timing and Phasing					
Change and Clearance Intervals: See **Section 10.4.1**		X		X	X
Left Turn Phasing: See **Section 10.3.3**				X	X
Pedestrian Timing: See **Section 10.4.3**		X		X	X
Volume-Density and/or Indecision Zone Protection: See **Section 10.4.2**		X		X	X
Capacity Analysis and Level of Service, including queuing analysis: See Publication 46, Chapter 10		X		X	X
No Turn on Red Engineering Study: See **Section 3.2.1**		X		X	X
Progression Analysis*: Provide a brief discussion on progression analysis that was completed for the project including existing (if applicable) versus proposed green band efficiency (calculated as bandwidth divided by cycle length)		X		X	X
Systems Engineering*: See **Section 18.2**				X	X
Transit Signal Priority*: See **Section 11.6**		X	X	X	X

*When applicable
**When timing changes are included in the project scope

7. UTILITIES

7.1 General

Existing utilities located within the project work area will impact traffic control signal designs in terms of what designers must do both procedurally, and design consideration-wise, to avoid and/or minimize conflicts and impacts with these utilities.

Procedural Actions:

- ✓ Identify all existing utilities and their locations that are within the project work area **(Section 7.2)**.
- ✓ Show all identified existing utilities on the traffic control signal construction plans **(Section 7.3).**
- ✓ Follow and obtain the necessary utility coordination, clearances, and/or relocations **(Section 7.4 and 7.5)**.
- ✓ Identify and meet the minimum clearances (lateral & vertical) from the utility lines to any traffic control signal equipment **(Section 7.6)**.
- ✓ Show necessary communication service information on the traffic signal construction plans **(Section 7.8.2)**.

Design Considerations:

- ✓ Avoid or minimize conflicts/impacts with existing utilities by assessing various potential design options for the various traffic control signal components **(Section 7.7)**.
- ✓ Identify optimal location for new electric power service and controller cabinet **(Section 7.8.1)**.

For addition information, see the following sections in this chapter and PennDOT's Utility Coordination/Relocation Web Page.

7.2 Identifying Utility Locations

During design, it is important to know where all the existing utilities are located for the following reasons:

- ✓ To design around the existing utility locations and avoid the need for utility relocations, which can be expensive and time-consuming.
- ✓ To eliminate unexpected damage to utilities during the construction and installation of the traffic control signal. Examples include damage to water lines, cutting of fiber optic lines, etc.
- ✓ To eliminate the need for unplanned construction/design changes to avoid utilities.
- ✓ To identify the electric power source for the traffic signal. (See **Chapter 15** for more information)
- ✓ To identify the backhaul communications source, if applicable. (See **Chapter 1** for more information)

7.2.1 Pennsylvania ONE-CALL System

PA Act 287 of 1974 as amended, known as the Underground Utility Line Protection Law, requires designers to contact the PA One Call System whenever excavation is expected. The signal designer must follow the PA One Call System regulations and policies. For design purposes, design notification to obtain utility plans can be initiated via online request through Pennsylvania One Call System. The system's User's Guide states "The designer shall make a reasonable effort to prepare the construction drawings to avoid damage to and minimize interference with a facility owner's facilities in a proposed construction area." Consult the system's User's Guide and other information related to designer responsibilities at www.pa1call.org.

When utilities are marked in the field, they should follow ANSI Standard Z535.1 (Common Ground Alliance Best Practices for Temporary Marking). The colors and designations of the markings are as shown in **Exhibit 7-1**.

Exhibit 7-1 Utility Colors and Designation

Color	Designation(s)
White	Proposed excavation
Pink	Temporary survey markings
Red	Electric power lines, cables, conduit, and lighting cables
Yellow	Gas, oil, steam, petroleum, or gaseous materials
Orange	Communication, alarm or signal lines, cables or conduit and traffic loops
Blue	Potable water
Purple	Reclaimed water, irrigation, and slurry lines
Green	Sewer and drain lines

Source: Pennsylvania One Call Website, https://ams.pa1call.org/pa811/Public/POCS_Content/About_Us/FAQS/Color_Code.aspx

7.2.2 PennDOT-owned Utility Facilities

PennDOT is normally not considered a facility owner within the state right-of-way under the Underground Utility Line Protection Law. Therefore, PennDOT-owned utility facilities will not be identified through the PA One Call System. Designers must obtain as-built plans from PennDOT to determine if any PennDOT-owned underground facilities are present. PennDOT facilities may include drainage pipes and highway lighting wires.

7.2.3 PennDOT Utility Contacts

Each PennDOT District has a Utility Coordinator who can assist with utility coordination, see District Utility Contacts.

7.3 Plans Utility Information

A traffic control signal design needs to address existing utility facilities at the physical intersection location. Designers shall include utility locations (aerial and underground) on traffic control signal construction plans so that designs can avoid potential damage and/or interference to the existing utilities. It is important to identify the following attributes for each utility:

- ✓ Lateral location
- ✓ Height or depth
- ✓ Size

The presentation format shall follow Publication 14M (DM-3). See **Chapter 33** for additional information on Plans.

7.3.1 Aerial

Overhead (aerial) utilities, such as electric, and communication cables are typically carried on wooden utility poles, which are owned and maintained by utility companies. Luminaires for street lighting which are not attached to traffic signal support structures are also considered aerial utilities for the purposes of signal design. Utility pole locations should be surveyed and shown on construction plans.

7.3.2 Underground

Several types of utilities, such as electric, gas, potable water, storm sewer, and sanitary sewer, can be carried through conduit and pipes underground. For projects involving excavation, the location of all underground utilities must be determined, and a PA One Call is required. The depths of each utility will vary. PA One Call requires hand digging within 18” of a marked underground line.

Some projects may require Subsurface Utility Engineering (SUE).

7.4 Utility Clearance for ECMS Projects

Utility Clearances are required on all projects let through ECMS. The District Utility Relocation Units are responsible for the clearance of utility facilities. The role of the signal designer in the Utility Clearance process will be determined by the District Utility Coordinator.

Utility Clearances inform all concerned parties the necessary arrangements for utility relocations have been made with utility companies to allow the project to proceed to letting. The Utility Clearances should be issued prior to the commitment and commencement of construction and can be in the form of the Utility Clearance Form D-419, one of the Department's Standard Special Provisions, or a Modified D-419.

Refer to Publication 16 (DM 5 – Utility Relocation) for information on Utility Clearance procedures, including utility relocations. If traffic signal work is incorporated into a larger roadway project, the utility clearance process is typically handled by the roadway designer.

7.4.1 Utility Coordination

Utility coordination involves identification and potential relocation of existing facilities that may conflict with the proposed project.

Each utility with facilities in the project limits should complete the Utility Relocation Questionnaire and Permit Application, Form D-4181 to identify whether their facilities are impacted using a copy of the preliminary design plans.

7.4.2 Utility Relocations

If a utility identifies an impact on Form D-4181 and needs to be relocated, one of the six types of relocation work is designated as indicated in DM-5:

- ✓ Prior Work
- ✓ Restrictive Work
- ✓ Concurrent Work
- ✓ Coordinated Work
- ✓ Incorporated Work
- ✓ Not Affected

For those projects that will require utility relocation, it is strongly recommended that the new utility locations be identified during the design phase.

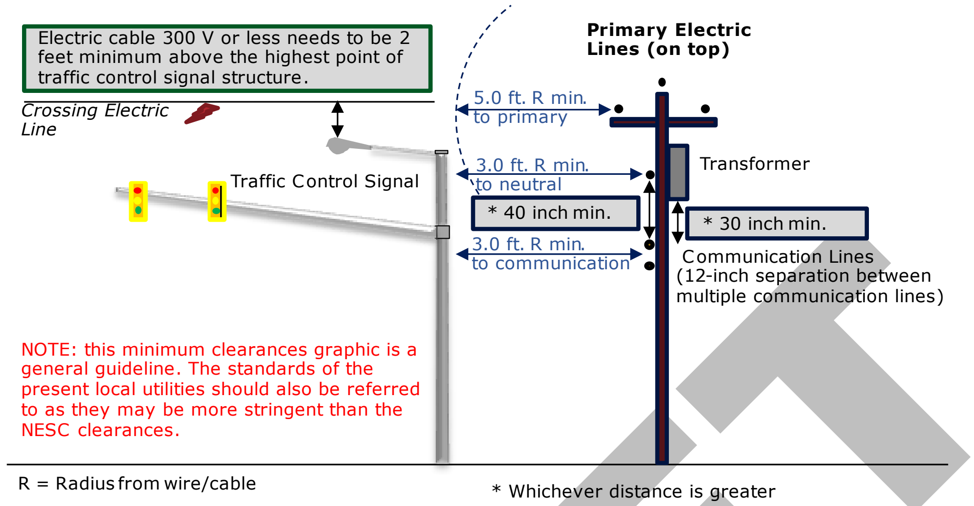
7.5 Utility Coordination for Non-ECMS Projects

Although a formal Utility Clearance is not required for projects which are not let through ECMS, the same principles apply, and the designer should ensure all utilities are either not impacted or the necessary relocation is coordinated with the project.

7.6 Overhead Clearance Dimensions

Refer to the National Electrical Safety Code (NESC), dated 2007 or as amended, for national clearance and installation standards. The standards of the present local utilities should also be referred to as they may be more stringent than the NESC clearances. The lateral clearances from the utility lines to any traffic control signal equipment must be met as well as vertical clearances between utility lines and mast arms and luminaries. See **Exhibit 7-2** for NESC minimum utility clearances.

Exhibit 7-2 NESC Minimum Utility Clearances



7.7 Design Considerations/Utility Impacts

Existing utilities within the intersection requires a designer to assess various potential design impacts, including the following:

- ✓ Designing the physical layout of the traffic control signal to avoid conflicts with existing utilities, and/or the need to relocate existing utilities.
- ✓ Designing signal pole/mast arm locations to avoid aerial utility lines during installation.
- ✓ Designing signal head placement to avoid, or limit, visibility restrictions caused by crossing aerial utility lines.
- ✓ Designing traffic control signal equipment to achieve the needed clearances (lateral & vertical) to aerial utility lines.
- ✓ Designing locations/depths of signal pole foundations to avoid underground utilities during excavation and installation.
- ✓ Designing pedestrian ADA ramp design/location and placement of pedestrian push buttons to avoid underground utilities during excavation and installation. Valves and manhole covers may be located within sidewalks, but grade breaks for ADA ramps must be located to avoid valves and manhole covers.
- ✓ Designing signal conduit and junction box locations/depths to avoid underground utilities during excavation and installation.
- ✓ Defining alternate construction techniques where underground utilities prevent standard excavation or boring practices. As an example, hand trenching may be required.
- ✓ After assessing various design options, some projects may require the need for certain utilities to be relocated to make the signal design/installation work.
- ✓ Contact the PA Public Utilities Commission (PUC) any time traffic control signal equipment crosses a railroad right-of-way or railroad pre-emption is required. See **Chapter 11** for additional information regarding railroad preemption.

7.8 Utility Service

Utilities provide electric service to every traffic control signal. Utilities may also provide communications service for connections between traffic signals and/or to the Commonwealth network.

7.8.1 Electric Service

The utility pole carrying electrical service closest to the chosen controller cabinet location should be selected for the electrical service point. Where feasible for the specific project circumstances (intersection geometrics, signal visibility, safety, etc.), designers should choose the controller cabinet location to be on the same corner as the existing electric so that electric doesn't have to cross over/under the street to get to the controller cabinet.

7.8.2 Communications Service

When providing hard-wired communications, commonly fiber, to a traffic control signal; there are two methods of providing the communications services as follows:

1. Department or municipal owned pathways, either aerial or underground. Provision using this method will require utility clearances as described in earlier in this chapter.
2. Use of external utility pathways, either aerial or underground. Provisions using this method will be described in this section.

When attaching to an aerial utility there are several factors to consider as follows:

- ✓ Attachment Agreement – Verification if an existing attachment agreement exists or if a new attachment agreement is required. New aerial attachments where a previous attachment agreement is not in place will require a legal attachment agreement with the pole owner. As these agreements can take time to process, early coordination should occur. There also may be more than one pole owner for any aerial run, and an attachment agreement would be required for each pole owner.
- ✓ Make Ready Work – Coordination with the utility owner(s) will also require the identification of the nature of the proposed attachment to include function, materials, and a guying plan. The pole owner(s) will then identify the location on the pole that is desired and will identify any make ready work to include utility pole replacement, line adjustments, and adjustments to other attachments. The utility pole owner(s) will often provide a listing of other utilities that will require facility adjustments. Coordination with each utility that requires adjustment will be require. Each utility will provide a cost for their make ready work.
- ✓ If an existing Department or Municipal owned aerial line is present under an existing attachment agreement, placement of a new aerial communication run on the existing aerial attachment, or overlashing, may be used. Coordination with the utility pole owner(s) will still be required as revisions to the existing attachment may be needed.
- ✓ When proposing an aerial attachment to an external utility pole owner, not only should initial capital costs for required make ready work be considered, but ongoing monthly or annual attachment costs should be anticipated as well.

Use of an underground utility duct for communications will have many of the same factors to consider as an aerial attachment as follows:

- ✓ Occupancy Agreement – Verification if an existing occupancy agreement exists or if a new occupancy agreement is required. As these agreements can take time to process, early coordination should occur.
- ✓ When proposing use of an external utility owner's duct, not only should initial capital costs be considered, but ongoing monthly or annual occupancy costs should be considered as well.
- ✓ When using an external utility duct for communications, the utility owner may require being present to provide access to the ducts or require presence when the project contractor is working within the utility owned duct. Language should be included in the project contract to convey to the contractor these requirements.

8. PEDESTRIANS

8.1 General

Every traffic control signal shall safely and efficiently serve all users who may legally cross or pass through the intersection. Pedestrians are vulnerable road users without the protection of a vehicle, and pedestrians require careful consideration as part of the traffic control signal design to reduce the risk and severity of vehicle-pedestrian crashes.

Pedestrian amenities at traffic control signals include:

- ✓ Pedestrian signal heads
- ✓ Pedestrian detectors
- ✓ Accessible Pedestrian Signals (APS)
- ✓ Pedestrian pavement markings (crosswalks)
- ✓ Curb ramps
- ✓ Sidewalk

This chapter presents further information in the following areas:

- ✓ Pedestrian study considerations
- ✓ ADA related information and references

For addition information, see the following references:

- ✓ Publication 10 (DM-1 series)
  - DM-1X, Bike/Ped Checklist (Appendix S)
- ✓ Publication 13M (DM-2) (Chapter 6)
  - Technically Infeasible Form (Chapter 6, Appendix A)
  - Pedestrian Study Determination (Chapter 6, Appendix E)
- ✓ Publication 72M (RC Standards)
  - Curb Ramps (RC-67M)
- ✓ Publication 111
  - Pavement Markings (TC-8600 & TC-8604)
  - Signs (TC-8700C & TC-8702 series)
- ✓ Publication 148 (TC-8800 Series)
  - Miscellaneous – Pedestrian Pushbutton Mounting Details and Typical Pedestrian Pushbutton Locations (TC-8803)
  - Signal Heads (TC-8805)
- ✓ Publication 212
- ✓ Publication 236
- ✓ MUTCD
  - Chapter 3B, Pavement and Curb Markings
  - Section 4C.05, Warrant 4, Pedestrian Volume
  - Section 4D.02, Provisions for Pedestrians
  - Chapter 4I, Pedestrian Control Features
  - Chapter 4K, Accessible Pedestrian Signals and Detectors
- ✓ Americans with Disabilities Act
  - 2010 ADA Standards for Accessible Design
  - 2023 Public Right-of-Way Accessibility Guidelines (PROWAG)
- ✓ FHWA Crosswalk Marking Selection Guide
- ✓ **Section 10.4.3** for pedestrian interval timing
- ✓ **Chapter 1** for signal heads

- ✓ **Section 17.3** for pedestrian detection
- ✓ **Chapter 19** for pavement markings and signs

8.2 Pedestrian Study

A Vulnerable Road User Accommodation at Traffic Control Signals Engineering Study (Form TE-XXX) shall be conducted prior to beginning traffic control signal design for Level 3 and 4 signal projects (see **Section 6.2**). The study will evaluate the need for pedestrian amenities and ADA compliance at the project's signalized intersection(s) along with the related design and operational features.

New Form TE-XXX will replace Form TE-672 to determine the appropriate pedestrian amenities at signalized intersections.

The pedestrian study shall be approved by the District Traffic Engineer.
If pedestrian restrictions are recommended for one or more crossings at an intersection, the Assistant District Executive Design, Maintenance, or Operations shall also approve the pedestrian study.

8.2.1 Study Input – Outreach Efforts

Outreach efforts should occur with the following stakeholders, as applicable:

- ✓ Municipality(s)
- ✓ Transit organization(s)
- ✓ School district(s)
- ✓ Emergency services
- ✓ Advocacy groups (blind, elderly, wheelchair users, etc.)

Pedestrian amenities should be discussed if a public meeting is held for the project.

Documentation of outreach efforts should be included on Form TE-XXX. Documentation shall include any noted issues, concerns, and recommendations from the stakeholders.

8.2.2 Pedestrian Crossings

Unless there are geometric limitations which necessitate prohibiting a pedestrian crossing, a pedestrian crossing using appropriate pedestrian amenities should be provided across all legs if any of the following apply:

- ✓ There is evidence of pedestrian activity. Evidence of pedestrian activity includes one or more pedestrians in a traffic count or physical evidence such as a worn path.
- ✓ A legal pedestrian crossing exists, as indicated by the presence of a marked or unmarked crosswalk as defined in §102 of the Vehicle Code. A crosswalk exists if either:
  - ▪ A sidewalk[1] exists on one or both sides of the roadway on any approach to the intersection, or
  - ▪ An existing pedestrian crossing is distinctly marked by lines or markings.
- ✓ There is presumed pedestrian activity. Although no pedestrian activity was observed, pedestrian activity is presumed to be possible if either:
- ✓ The intersection is located inside of the urbanized boundary as indicated on PennDOT Functional Classification maps, or
- ✓ There are existing or proposed transit facilities (i.e. bus stops) and/or pedestrian generators within ½ mile of the intersection. Pedestrian generators include any land use with residents, employees, or

[1] A sidewalk is that portion of a street between the curb line, or the lateral line of a roadway, and the adjacent property line or on easements of private property that is paved or improved and intended for use by pedestrians.

guests who could travel as a pedestrian and pedestrian transportation facilities such as sidewalks, paths, and trails.

A pedestrian crossing may be prohibited if there are geometric constraints that limit safe pedestrian movements at one or both ends of a crossing area. Examples of geometric constraints include, but are not limited to:

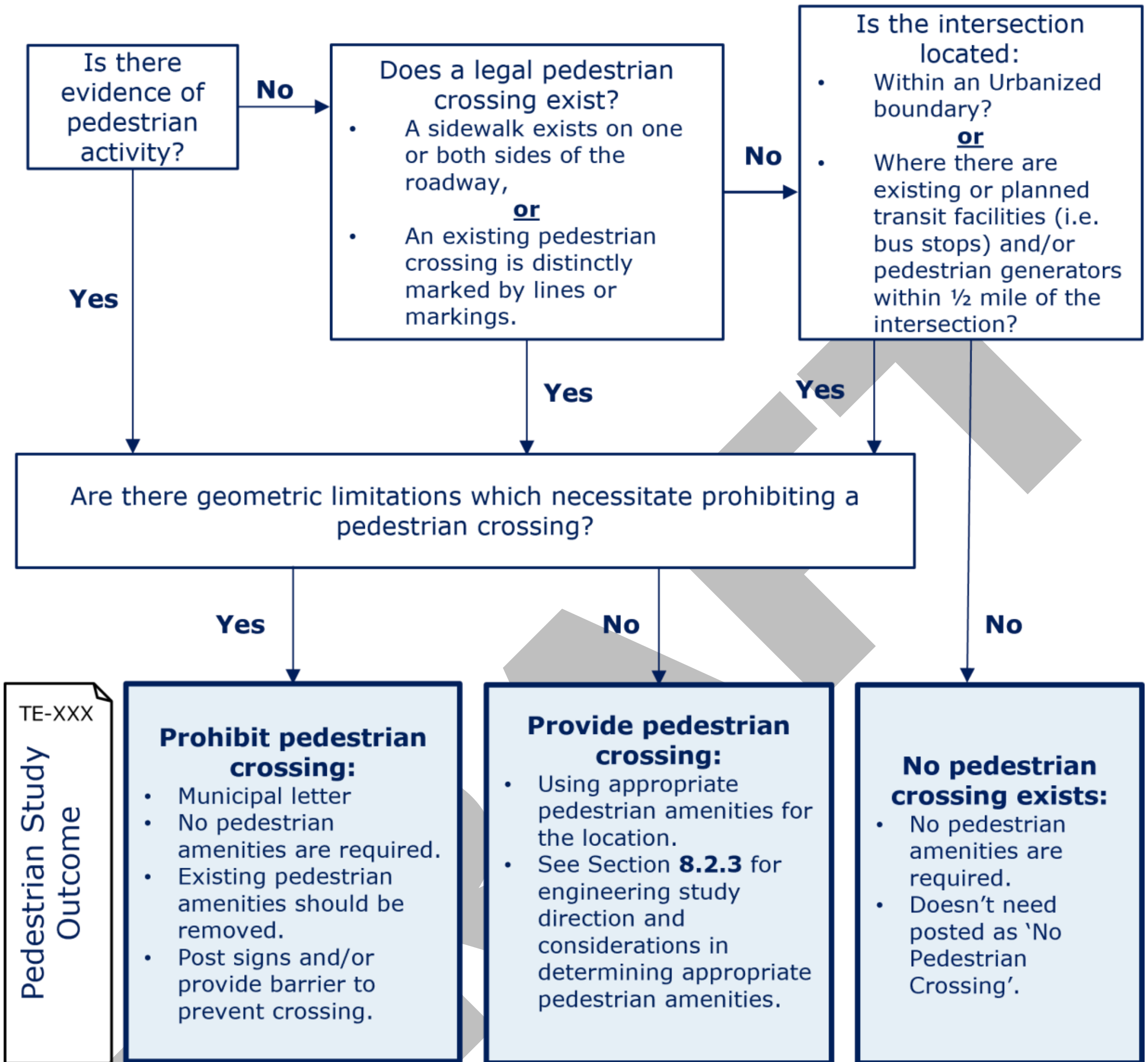
- ✓ Underground structures
- ✓ Elevation differences requiring structures such as bridges or retaining walls.
- ✓ Lack of shoulder with a physical barrier (guiderail, concrete barrier, etc.)

Lack of ADA compliance shall not be justification to prohibit pedestrian crossings; the geometric constraints must be so severe as to preclude a safe pedestrian crossing for all pedestrians.

When the geometric constraints necessitate prohibiting a pedestrian crossing adjacent to a Pedestrian Access Route, a detectable physical barrier shall be used to preclude the pedestrian movement along with the NO PEDESTRIAN CROSSING (R9-3) signs at each end of the crossing location. The physical barrier should be a detectable feature, such as grass strips, landscaping, planters, fencing, railings, or other barriers. If a physical barrier is infeasible, documentation shall be contained in the engineering study and Technically Infeasible Form. The NO PEDESTRIAN CROSSING (R9-3) sign shall not be used alone without a physical barrier.

Exhibit 8-1 summarizes the procedure for determining pedestrian crossings described in this section.

Exhibit 8-1 Pedestrian Crossing Outcomes from Pedestrian Study



See **Section 19.3.3** for signs related to prohibited pedestrian crossings.

8.2.3 Pedestrian Amenities

The Vulnerable Road User Accommodation at Traffic Control Signals Engineering Study (Form TE-XXX) should determine the need for pedestrian amenities within the context of the following:

- ✓ MUTCD standards and guidance,
- ✓ ADA and PROWAG, and
- ✓ Pennsylvania-specific study requirements in this **Section 8.2**.

The pedestrian amenities are not mutually exclusive, and some combinations of amenities shall be required together, such as a crosswalk and sidewalk require a curb ramp to connect them. The following considerations provide a framework as part of the engineering study and judgement process:

Pedestrian Signal Heads

In addition to the requirements for pedestrian signal heads in MUTCD Section 4D.02, pedestrian signal heads are required at traffic control signals in Pennsylvania for pedestrian crossings under any the following conditions:

- ✓ At established school crossings. An official school crossing exists if any one of the following exists:
- ✓ The intersection is adjacent to school property which meets the definition of a school zone in Title 67 Pa. Code Chapter 212.
- ✓ The school crossing is an official school crossing designated by school and/or traffic officials responsible for school safety.
- ✓ When the normal vehicle clearance time (yellow + all red) may not provide sufficient time for a pedestrian who leaves the curb at the onset of yellow to get far enough to avoid an unreasonable conflict with vehicles on a conflicting approach.

If pedestrian signal heads are installed for one or more crosswalks at an intersection, pedestrian signal heads should typically be installed at all crosswalks within the intersection. There may be certain situations where vehicle signals for pedestrians may be appropriate, such as one leg of an intersection that crosses a minor driveway.

All new and replaced pedestrian signal heads shall contain a pedestrian change interval countdown timer and provide Accessible Pedestrian Signals (APS), see **Accessible Pedestrian Signals (APS)**.

If pedestrian signal heads are not recommended, a vehicular signal head must be visible to a pedestrian within the crosswalk.

Pedestrian signal heads shall not be used across "yield" movements, such as right-turn channelized lanes.

See **Section 16.3** for design requirements for pedestrian signal heads.

Accessible Pedestrian Signals (APS)

Accessible Pedestrian Signals (APS) shall be provided where pedestrian signal heads are provided.

See **Section 17.3** for design requirements for APS.

Pedestrian Detectors

Pedestrian detectors may be active or passive detection devices. When pedestrian signal heads are provided and the walk indication is not provided every cycle, pedestrian detectors shall be used to actuate pedestrian intervals. Active pedestrian detectors incorporated into APS may be used to actuate pedestrian intervals. See **Section 10.4.3** for calculation of pedestrian intervals. Pedestrian push buttons shall be accompanied by traffic control signal pedestrian actuation series signs (R10-2 through R10-4) as described in **Section 19.3.3**.

If a median is provided, determine whether pedestrian crossings will be for the entire roadway, or a multi-stage crossing will be provided. If a multi-stage crossing is proposed, pedestrian detection shall be provided within each pedestrian refuge island (median waiting area) if pedestrian actuation is required for the crossing. The pedestrian refuge island must be of sufficient width (measured from curb to curb in the direction of pedestrian travel) to be ADA compliant (typically six (6) feet minimum, see PROWAG R302.2.1). Multi-stage crossings shall not be used when the pedestrian refuge island is less than six (6) feet in width.

See **Section 17.3** for design requirements for pedestrian detectors.

Pedestrian Pavement Markings (Crosswalks)

Crosswalks shall be marked at those crossings where pedestrian signal heads are utilized. Crosswalks shall be designed in accordance with Publication 111, TC-8600, Sheets 5 and 6 as follows:

- ✓ Type A (parallel) crosswalks should be used unless the study identifies the need for Type C (perpendicular) crosswalks to provide additional emphasis to the crossing.
- ✓ Type B crosswalks are not recommended for signalized intersections.
- ✓ Type C crosswalks may be used where the municipality systematically uses Type C crosswalks.
- ✓ Decorative crosswalks (Type D, Type E, or Type F) should only be used when requested by the municipality and accompanied by a signed maintenance agreement by the municipality indicating they will maintain the decorative crosswalks.
- ✓ The intersection crosswalk shall be the same Type crosswalk design for all legs of the intersection. Mixing of different crosswalk Types is not allowed at an intersection.

At signalized intersections where a right turn "yield" movement is allowed, the following should be considered:

- ✓ If the approach is to have crosswalks installed, crosswalks should be used across the right turn "yield" movement.
- ✓ Crosswalks across the "yield" movement should be located to provide the optimum sight distance for both the pedestrian and the motorist involved and include all appropriate advance yield pavement markings and signs.

See **Section 19.2** for design requirements for pedestrian crosswalks.

Curb Ramps/Blended Transitions

Curb ramps provide an accessible route between the roadway crosswalk and a landing or sidewalk. Typically, curb ramps connect a sidewalk at the top of curb elevation down to the crossing roadway surface through a cut in the curb.

A blended transition is a wraparound connection at a corner, or a flush connection where there is no curb to cut through, other than a curb ramp. A blended transition is permitted in lieu of a curb ramp where a pedestrian access route crosses a curb, and where there is a flush connection between the sidewalk or shared use path and a crosswalk, such as at a raised crossing.

Curb ramps or blended transitions are required whenever there is a marked crosswalk to provide a space outside the roadway for pedestrians to wait before the signal phase designated for crossing. Curb ramps or blended transitions are not required where there is no sidewalk, pedestrian signals, or pedestrian pushbuttons.

Curb ramps and blended transitions shall be designed in accordance with Publication 72M (RC-67M) and PROWAG.

Sidewalk

Paved sidewalks should be considered where a Pedestrian Access Route (PAR) does not otherwise exist to connect the intersection to nearby pedestrian generators.

8.2.4 Study Outcome

If the approved pedestrian study recommends pedestrian amenities, the pedestrian amenities should be designed and installed in accordance with applicable standards (see references in **Section 8.1**).

If the approved pedestrian study concludes that pedestrian accommodation is not needed, the municipality shall be advised of the findings as specified in an example municipal letter in **Exhibit 8-2**.

- ✓ The Department will not provide new pedestrian accommodations at the intersection based on the approved documentation.
- ✓ Existing intersection pedestrian features, which are not required for pedestrian accommodation may be removed by the municipality, or they may remain in-place and be maintained until they are no longer functional, at which point they must be removed.

Exhibit 8-2 Example Municipal Letter

OS-2A (12-15)

pennsylvania
DEPARTMENT OF TRANSPORTATION

Date

Municipal Official
Municipality
Address
City, PA 12345

VIA CERTIFIED MAIL

Dear Municipal Official:

This letter is regarding a Pedestrian Study Notice for [PROVIDE LOCATION]. An engineering study approved by the Pennsylvania Department of Transportation evaluated the need for pedestrian accommodations at the signalized intersection(s) of [PROVIDE LOCATION].

The study has determined that there is no need to provide pedestrian accommodations at this intersection at this time. Therefore, the Department will not provide pedestrian accommodations at this intersection in conjunction with the [NAME OF PROJECT], and the traffic signal permit for this intersection will be modified accordingly.

In light of the study findings, the following pedestrian features are no longer needed at this intersection:

- [LIST OF UNNEEDED PEDESTRIAN FEATURES]

The Department recommends, but does not require, the removal of these features. As an alternative, these features may remain in-place and be maintained until they are no longer functional, at which point they must promptly be removed.

Thank you for your attention to this matter. If you have any questions, please contact [DEPARTMENT CONTACT NAME] at [PHONE NUMBER].

Sincerely,

[NAME]
District Executive
Engineering District [__]-0

Bureau or Office Name
Address | City, PA zip code | phone number | www.penndot.gov

8.3 Americans with Disability Act (ADA)

8.3.1 ADA Law and Regulation

The Americans with Disabilities Act (ADA) of 1990 is a federal civil rights statute that prohibits discrimination against people with disabilities. The Summary of ADA Title II (28 CFR PART 35) requirements are stated at ADA Regulation. Pedestrian amenities at traffic control signals may not prohibit use by people with disabilities. When it is determined that pedestrians are present, then proper access shall be provided for pedestrians, including those with disabilities, in accordance with ADA Regulation (28 CFR Part 35). ADA requirements and the cost of providing ADA-compliant accommodations shall not be used as the basis to restrict pedestrians.

8.3.2 ADA Accommodation Guidance for Signalized Intersections

Where the engineering study (see **Section 8.2**) identifies the need for pedestrian amenities at intersections with traffic control signals, the pedestrian amenities shall meet ADA requirements. The applicability of ADA requirements includes:

- ✓ New construction must be accessible and usable by persons with disabilities. Technical infeasibility shall not be a factor in design. See **Section 8.3.3**.
- ✓ Alterations within existing developed right-of-way must provide usability to the maximum extent feasible. See **Section 8.3.4**.
- ✓ Existing facilities that have not been altered shall not deny access to persons with disabilities. See **Section 8.3.5**.

ADA requirements relevant to traffic control signal design include:

- ✓ Curb ramps connect sidewalks with crosswalks.
- ✓ Curb ramps and landings/turning areas provide access to pedestrian-actuated controls.
- ✓ Curb ramp design criteria includes requirements to facilitate use by pedestrians in wheelchairs and visually impaired pedestrians.
- ✓ At intersections with non-complex signal phasing where pedestrian timing corresponds with the vehicular signal, visually impaired pedestrians may use the sound of traffic to determine when to cross.
- ✓ At intersections with pedestrian signal heads, accessible pedestrian signals (APS) shall be used (per PROWAG) to provide indication of pedestrian timing in non-visual formats (such as audible tones and/or speech messages, and vibrating surfaces).
- ✓ Pedestrian-actuated crossing controls should meet the requirements in PennDOT Publication 13M (DM-2), Chapter 6, Section 6.13, PennDOT Publication 72M, RC-67M, Sheet 8, and PROWAG.

8.3.3 New Construction Projects

New construction projects are held to the highest standards regarding pedestrian usability and ADA compliance. These projects involve construction in a previously undeveloped right-of-way (greenfield).

These projects must evaluate the need for a complete pedestrian route between logical termini.

A Technically Infeasible Form will be required for any reconstructed element that does not meet PennDOT's standards. Technically Infeasible justification may only be applied to New Construction in extremely limited circumstances.

For additional information not provided in this chapter, consult Publication 13M (DM-2), Chapter 6, Section 6.3.

8.3.4 Alteration Projects

Alteration Projects are projects that include a change to or an addition of a pedestrian facility in an existing, developed public right-of-way that affects or could affect pedestrian access, circulation, or usability. Most projects will be alterations. Note, resurfacing is considered an alteration.

When an existing pedestrian feature will be altered or replaced as part of an alteration project's work scope, this pedestrian feature must be addressed in one of two ways:

- ✓ Be brought into compliance with current PennDOT standards (see **Section 8.3.2**), or
- ✓ A Technically Infeasible Form will be required for any reconstructed element that does not meet PennDOT's standards.

Although an alteration project does not require any additional work beyond the altered pedestrian facilities, it may be beneficial to upgrade other unaltered pedestrian facilities as part of the project to improve access.

For additional information not provided in this chapter, consult the Publication 13M (DM-2), Chapter 6, Section 6.3.

8.3.5 Non-Alteration Projects

Non-Alteration Projects include routine maintenance and repair work that usually does not impact, disturb, or modify pedestrian facilities.

Therefore, these types of work do not trigger the need for ADA compliance upgrades at an intersection and may be completed without requiring other simultaneous modifications to ensure full ADA compliance. Note: resurfacing projects are not considered routine maintenance.

For additional information not provided in this chapter, consult the Publication 13M (DM-2), Chapter 6, Section 6.3.

Exhibit 8-3 provides examples of non-alteration activities which do not typically trigger ADA compliance upgrades.

Exhibit 8-3 Non-Alteration Activities at Traffic Control Signals

Project Types	Activity Types				
	Maintenance	Repair	Modification	Replacement	Relocation
Traffic control signal poles				X*	
Traffic control signal wiring	X	X	X	X	
Traffic control signal conduit outside of the pedestrian accessible route	X	X	X	X	
Traffic control signal conduit within the pedestrian accessible route	X	X**			
Traffic control signal timing and phasing	X		X		
Electrical service equipment	X	X	X		
Traffic control signal coordination equipment	X	X	X	X	
Traffic control signal controllers, controller cabinet assemblies, and related electronic equipment	X	X	X	X	
Pavement markings on roadways	X	X		X	
Pedestrian pushbuttons	X	X**			
Accessible pedestrian signals (APS)	X	X**			
Circular LED vehicle traffic control signal modules	X	X	X	X	X
LED pedestrian signal head modules or LED countdown pedestrian signal head modules.	X	X**		X***	
LED modules to replace incandescent or other light sources				X***	
Vehicular detectors	X	X	X	X	X
Traffic control signage	X	X	X	X	
Roadway lighting	X	X	X	X	
Video surveillance equipment	X	X	X	X	X
Emergency vehicle preemption systems	X	X	X	X	X
Junction boxes. (Including junction boxes outside the pedestrian accessible route).	X	X	X	X	
Conduit and utility repairs that result in small portion < 100 feet and < 500 square feet) of accessible route being removed and replaced would require only repair in kind and would not trigger any new installation or upgrades to existing sidewalk or curb ramps	X	X		X	X
Traffic control signal preventative maintenance activities (see Pub 191)	X	X	X	X	
Note: Emergency traffic control signal pole replacements and other emergency repairs to an existing traffic control signal installation are acceptable					

*The replacement of a signal pole using the same foundation is not an alteration to the sidewalk or street; however, PennDOT may not deny access to the push button and must provide access to the push button.
**Minor Repair Only
***Module display and operation replaced in-kind only. Otherwise, replacement is an alteration.

9. BICYCLES

9.1 General

This is a new chapter which provides information & guidance on addressing bicyclists as users of signalized intersections.

Requirements in the MUTCD are referenced in the Chapter.

Bicycle signal faces are adopted for use according to MUTCD, PART9.

Traffic signal designers must assess bicyclist needs and provide proper accommodations for bicyclists using bicycle facilities at intersections with traffic control signals. This Chapter addresses bicycle accommodations within the project scope of traffic control signal designs (see to DM-2 Chapter 14 for the complete design of bicycle facilities).

On-road bicycle facilities are bicycle routes that use part of the roadway, either in a shared or dedicated space. These on-road bicycle facilities often cross at signalized intersections. As indicated in DM-2 Chapter 14, PennDOT recognizes four types of on-road bicycle facilities, which are listed below, from least separated to most separated from motor vehicle traffic:

- ✓ Shared Roads
- ✓ Visually Separated (by signs/markings only) Bike Lanes
- ✓ Physically Separated Bike Lanes
- ✓ Shared-Use Path/Bikeways Crossings

Cyclists using on-road facilities are considered vehicles and must obey all traffic rules.

This chapter addresses several types of bicycle accommodations as follows:

- ✓ Signalized intersection amenities
- ✓ Bicycle signals at signalized intersections
- ✓ Signalized crossings (shared-use pathways)

The design of bicycle requirements shall adhere to the guidelines presented in the following references:

- ✓ MUTCD, PART 9
- ✓ Publication 10 (DM-1 series)
- ✓ Publication 13 (DM-2), *Contextual Roadway Design*, Chapter 14 Bicycle Facilities

9.2 Bicycle Study

Like in Chapter 8 Pedestrians, Form TE-XXX is also used to determine the appropriate bicyclist amenities at signalized intersections.

A Vulnerable Road User Accommodation at Traffic Control Signals Engineering Study (Form TE-XXX) shall be conducted prior to beginning design for Level 3 and 4 traffic control signal projects (see **Section 6.2**). This study will evaluate the appropriate and reasonable bicycle amenities for the signalized intersection(s) within the project scope.

The bicycle study shall be approved by the District Traffic Engineer and the District Bicycle/Pedestrian Coordinator.

9.2.1 Study Input

As identified on TE-XXX, the designer should ask these important context questions:

- ✓ What are the current or expected bicycle volumes?

Outreach efforts should occur with the following stakeholders, as applicable:

- ✓ MPO(s)
- ✓ Municipality(s)
- ✓ School district(s)
- ✓ Emergency services
- ✓ Advocacy groups (bicycle groups)

Bicycle amenities should be discussed if a public meeting is held for the project.

Documentation of outreach efforts should be included on TE-XXX. Documentation shall include any noted issues, concerns, and recommendations from the stakeholders.

9.2.2 Study Output - Bicycle Accommodations (Amenities)

Bicycles operating on Pennsylvania roadways are considered vehicles (see **Section 4.2.3**) and should be expected at all signalized intersections. Therefore, the design criteria and treatment guidance provided in this chapter is intended to support the operation of bicycles as vehicles. The design of all signalized intersections, except those at intersections of roadways where bicycles are prohibited, shall include appropriate and reasonable accommodations for bicyclists.

Using the study inputs on TE-XXX, the designer shall use engineering judgment to determine appropriate and reasonable accommodations for bicyclists as part of the traffic control signal project design.

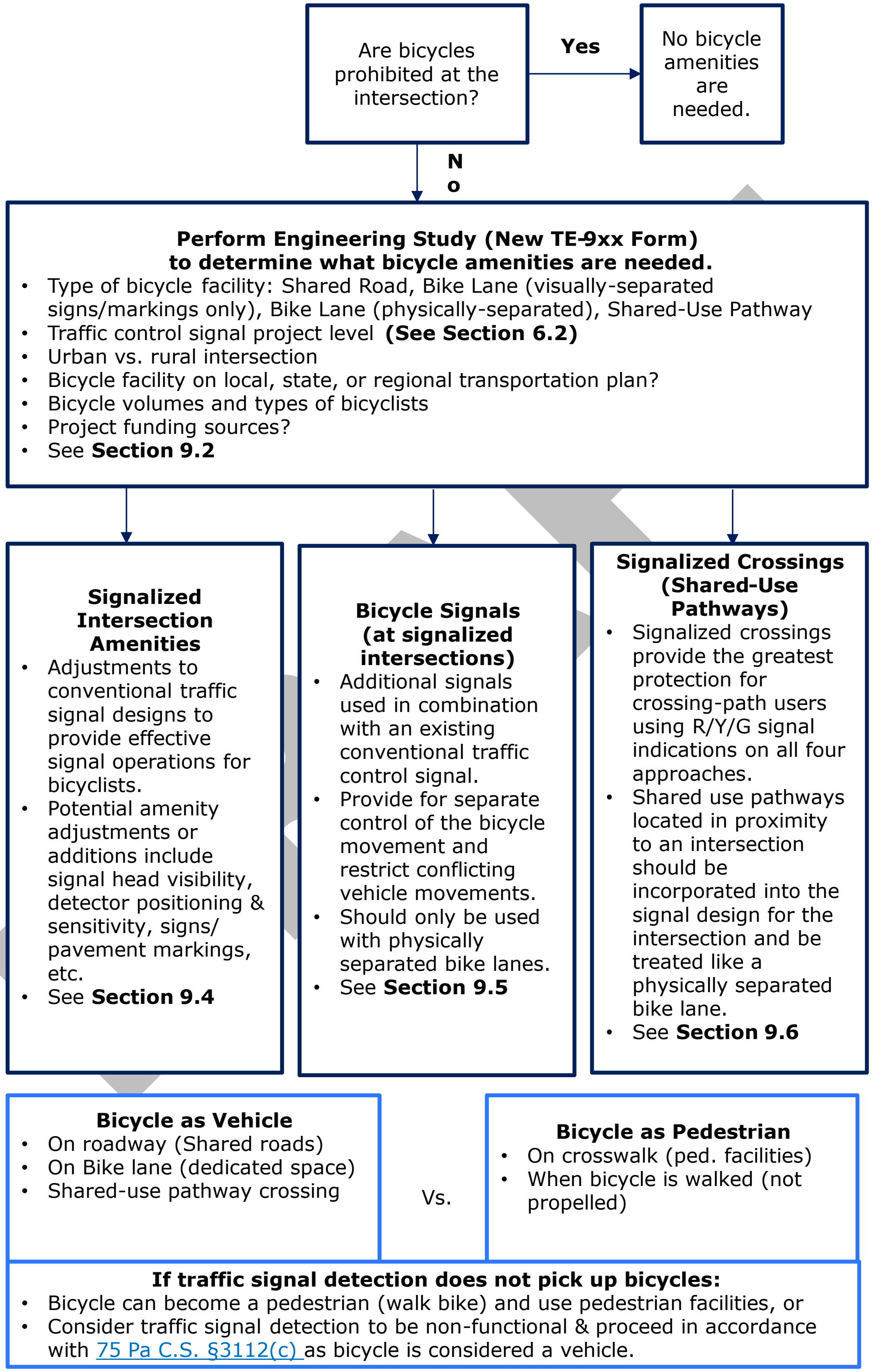
These signalized intersection accommodations (amenities) often require adjustments to conventional traffic signal designs to provide for safe and effective signalized intersection operations for both bicyclists and motorized vehicles.

As provided in the following sections of this Chapter, these appropriate and reasonable accommodations will fall into four areas:

- ✓ Bicycles prohibited at intersection (See **Section 9.3**)
- ✓ Signalized intersection amenities (See **Section 9.4**)
- ✓ Bicycle signals at signalized intersections (See **Section 9.5**)
- ✓ Signalized crossings (Shared-Use Pathways) (See **Section 9.6**)

See **Exhibit 9-1** for a depiction of the process for determining appropriate and reasonable bicycle accommodations for a traffic signal design.

Exhibit 9-1 Determination of Bicycle Accommodations (Amenities)



9.3 Bicycles Prohibited at Intersection

If bicycles are legally prohibited at an intersection, provision of bicycle amenities is not needed.

9.4 Signalized Intersection Amenities

Existing or new traffic control signal intersection project designs require the consideration of potential bicycle amenities which will provide for safe and efficient operation of bicyclists and reduce conflicts with motorized vehicles as well. The following signalized intersection amenities may be used to accommodate bicyclists:

Signal Heads

- ✓ Signal Head Visibility
  - Ensure that all existing vehicular signal heads intended for bicyclist use are adequately visible for the bicyclist. If not adjust the signal heads appropriately.
  - At installations where visibility-limited signal faces are used, signal faces shall be adjusted so bicyclists for whom the indications are also intended can see the signal indications. If the visibility-limited signal faces cannot be aimed to serve the bicyclist, then separate signal faces shall be provided for the bicyclist. (MUTCD 9F.03)
- ✓ Bicycle Signal Heads – see **Section 9.5** for the specific requirements for using these dedicated bicycle signal heads.

Detection

- ✓ Bicycle Detection Positioning (MUTCD 9B.20 & 9E.15)
- ✓ Bicycle Signal Actuation (R10-22) sign (MUTCD Figure 9B-1) may be installed at signalized intersections where markings are used to indicate the location where a bicyclist is to be positioned to actuate the signal.
- ✓ A symbol (MUTCD Figure 9E-16) may be placed on the pavement indicating the optimum position for a bicyclist to actuate the signal.
- ✓ Detection Sensitivity for Bicycles
  - Adjust sensitivity of imbedded loop sensor systems to detect bicycles.
- ✓ If existing loop detection sensors aren't capable of detecting bicycles, consider other type detection technologies that will.
  - For new signalized intersections, consider detection technologies that will detect bicycles.

Controller Signal Timing

- ✓ Longer minimum green times may be necessary to allow bicyclists to cross signalized intersection and avoid being trapped (see Section **10.4.2**).

Intersection Treatments

Publication 13 (DM-2), Chapter 14.4 provides various intersection treatment considerations of which the following apply to signalized intersections. The below referenced DM-2 sections need considered as part of the signal design to provide safe & efficient interaction of motorized vehicle and bicycles.

- ✓ Bicycle Boxes - A bicycle box is a designated area located at the head of a traffic lane at a signalized intersection. It provides bicyclists with a safe and visible space to get in front of queuing motorized traffic during the red signal phase. Motor vehicles must queue behind the white stop line at the rear of the bicycle box. (See DM-2 Section 14.4.1).
- ✓ Bike Lanes at Right-Turn Only Lane – Consider potential methods to providing lane configuration accommodations for bicyclists at intersections with turn lanes to minimize conflicts. (See DM-2 Sections 14.4.2 and 14.4.3).

- ✓ Colored Bike Lanes in Conflict Areas - Colored pavement within a bicycle lane increases the visibility of the facility and reinforces bicyclist priority in conflict areas. (See DM-2 Section 14.4.4)
- ✓ Combined Bike Lanes/Turn Lanes - The combined bike lane/turn lane places a standard-width bike lane on the left side of a dedicated right-turn lane. (See DM-2 Section 14.4.5)

Shared-Use Pathway Crossings

- ✓ Path/trail crossings within the functional area of a signalized intersection are typically diverted to the signalized intersection to avoid traffic operation problems. For this restriction to be effective, barriers and signing may be needed to direct path users to the signalized crossing.
- ✓ Refer to Publication 13 (DM-2), Chapter 14.5.2 for additional information on routing users to signalized crossings.

9.5 Bicycle Signal Faces at Signalized Intersections

Bicycle signal faces are additional signals used in combination with an existing conventional traffic control signal to provide for separate control of the bicycle movement and restrict conflicting vehicle movements. Bicycle signal heads are like conventional traffic control signals, but use red, yellow, and green lenses incorporating a stenciled bicycle icon. Bicycle signal faces shall comply with MUTCD Chapter 4H.

See **Section 9.4** for other potential signalized intersection amenities which may be used in combination with bicycle signals.

Refer to Publication 13 (DM-2), Chapter 14.7.4.d for additional information on bicycle signals at signalized intersections.

9.6 Signalized Crossings (Shared-use pathways)

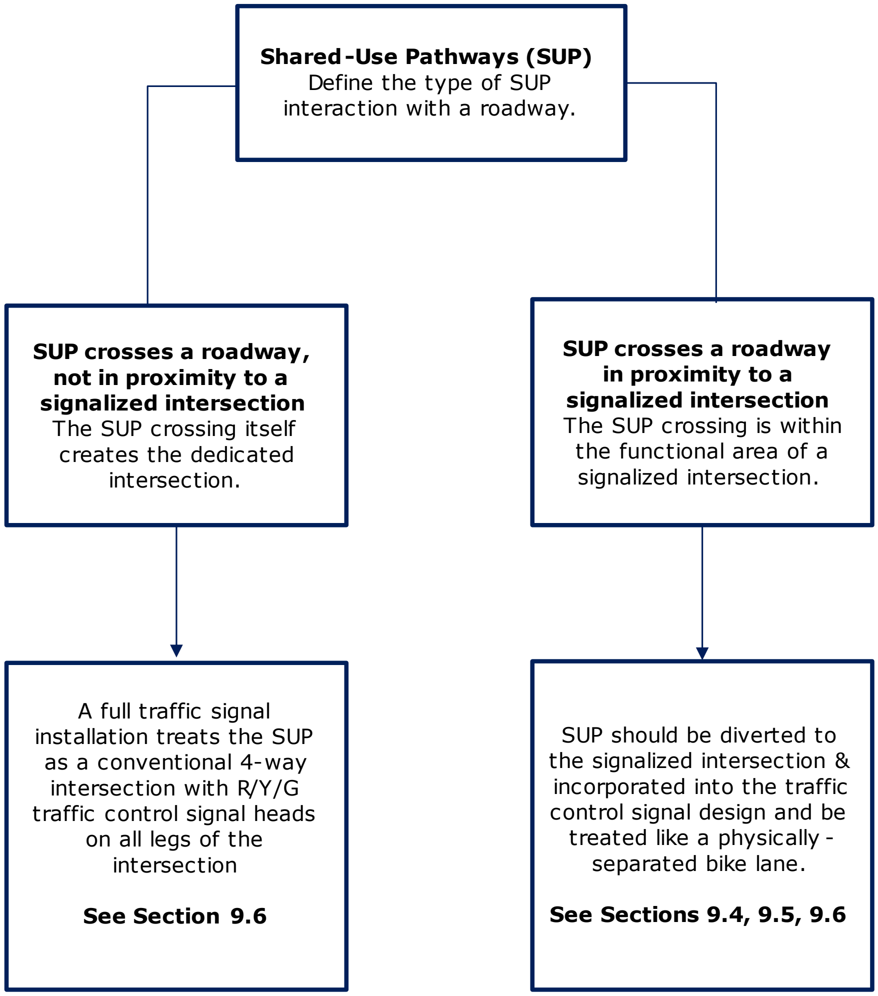
Traffic-control signalized crossings are traffic signal installations for bicycle and pedestrian crossings (typically shared-use paths intersecting with a roadway).

- ✓ A full traffic signal installation treats the path crossing as a conventional four-way intersection and provides standard red, yellow, and green traffic signal heads for all legs of the intersection.
- ✓ Shared-use path signals are normally activated by push buttons but may also be triggered by embedded loop, infrared, microwave, or video detectors.
- ✓ Refer to Publication 13 (DM-2), Chapter 14.5.3 for additional information on traffic controlled signalized crossings.

Shared-use pathway crossings should not be provided within the functional area of an existing signalized intersection. Rather, they should be routed directly to the signal and incorporated into the signal design for the intersection and be treated like a physically separated bike lane. See **Sections 9.4 & 9.5.**

See **Exhibit 9-2** for a depiction of how Shared-Use Pathways crossings are to be addressed depending upon their proximity to a signalized intersection.

Exhibit 9-2 Shared-Use Pathways



10. OPERATIONS

10.1 General

As previously indicated in **Section 1.4.2**, designers shall use the guidance in the STM2 for the design of operational aspects (signal timing, phasing, sequencing, etc.) of traffic control signals in Pennsylvania. A traffic signal designer should have a thorough understanding of the concepts (fundamental and advanced) presented in the STM2 before being responsible for traffic signal operational designs.

Exhibit 10-1 presents the detailed organization of the STM2 chapter/section of operational topics. If there is any Pennsylvania supplemental information to be provided for an STM2 section topic, it is presented in following **Sections 10.2, 10.3, and 10.4**.

Section 10.5 provides information on flashing operation of traffic signals.

This chapter covers timing settings at the intersection level. For coordination and system timing information, refer to **Chapter 1**.

Exhibit 10-1 Signal Timing Manual, Second Edition Organization (STM2)

Chapter		Sections
1	**Introduction**	1.1 Focus for 2nd Edition 1.2 STM2 Organization 1.3 References
2	**Signal Timing Program**	2.1 Elements of Successful Signal Timing Programs 2.2 Benefits of Regional Signal Timing Programs 2.3 References
3	**Signal Timing Concepts**	3.1 Traffic Signal Basics 3.2 Initial Signal Timing Considerations 3.3 Data Collection 3.4 Operational Objectives and Performance Measures 3.5 References
4	**Signal Design**	4.1 Detection 4.2 Signal Cabinet Equipment 4.3 Displays 4.4 Signalized System Design 4.5 Comprehensive Design Considerations 4.6 References
5	**Introduction to Timing Plans**	5.1 Basic Signal Timing Concepts 5.2 Critical Movement Analysis 5.3 Role of Software in Signal Timing 5.4 References
6	**Intersection/ Uncoordinated Timing**	6.1 Basic Signal Timing Parameters 6.2 Detector Configurations 6.3 Time-of-Day Plans 6.4 References
7	**System/ Coordinated Timing**	7.1 Application of a Coordinated System 7.2 Coordination Planning Using a Time-Space Diagram 7.3 Introduction to Coordination Parameters

Chapter		Sections
		7.4 Coordination Parameter Guidance 7.5 Other Considerations for Coordination 7.6 Complexities 7.7 References
8	**Implementation & Maintenance**	8.1 Transfer Plans from Office to Field 8.2 Field Observations and Adjustments 8.3 After Implementation 8.4 Staffing Needs 8.5 References
9	**Advanced Signal Systems**	9.1 Systems Engineering 9.2 Advanced Coordination Features 9.3 Traffic Responsive Plan Selection Systems 9.4 Adaptive Signal Control Technology Systems 9.5 References
10	**Preferential Treatment**	10.1 Types of Preferential Treatment 10.2 Introduction to Preferential Treatment 10.3 Preferential Treatment Advancements 10.4 Preemption and Priority 10.5 Preemption Considerations for Rail 10.6 Preferential Treatment Considerations for Emergency Vehicles 10.7 Preferential Treatment Considerations for Transit 10.8 Preferential Treatment Considerations for Trucks 10.9 References
11	**Special Conditions**	11.1 Weather Events 11.2 Traffic Incidents 11.3 Planned Special Events 11.4 References
12	**Oversaturated Conditions**	12.1 Symptoms of Oversaturation 12.2 Operational Objectives for Oversaturated Conditions 12.3 Mitigation Strategies for Oversaturated Conditions 12.4 References

10.2 Signal Timing Concepts – Supplemental Information

The information in this section refers to information found in Chapter 3 of the STM2.

STM2 provides an overview of the signal timing outcome-based approach. This process encourages practitioners to consider all system users (e.g., pedestrians, bicycles, motor vehicles, emergency vehicles, transit, and rail) and to establish user priorities by movement for each signalized intersection location.

10.2.1 Traffic Signal Basics

Refer to Section 3.1 of the STM2, and Appendix A (for Glossary of Terms) of the STM2.

Intersection Operation Types

An actuated signal can adjust operations using external information about user demand (i.e., requests for service). Detectors are used to place requests for service on actuated phases. A traffic signal which has actuations for all phases is fully-actuated. A signal which has actuation for some, but not all, phases is semi-actuated. A signal with no actuation is pretimed.

The type of operation used can have a profound effect on the operational efficiency of any signal and, if incorrectly chosen, can defeat the purpose for which the signals were installed. The selection of the best form of operation for any location can be made only with a full knowledge of local conditions.

Exhibit 10-2 provides guidance for selecting an appropriate type of signal operation for various intersection types (isolated or coordinated) based on various local conditions as shown in the exhibit.

Exhibit 10-2 Signal Operation Applicability/Selection Guidance

	Pretimed Operation		Actuated Operation			
	Isolated	Coordinated	Isolated (Semi-Actuated)	Isolated (Fully-Actuated)	Coordinated	Adaptive
Fixed Cycle Length	Yes	Yes	No	No	Yes	Varies by vendor
Conditions Where Applicable	Where traffic is consistent, including cross street traffic	Where traffic is consistent, including cross street traffic, and intersections are closely spaced	Where defaulting to one movement is desirable, major road is posted <40 mph and crossroad carries light traffic demand	Where detection is provided on all approaches, isolated locations where posted speed is >40 mph	Arterial where traffic is heavy and adjacent intersections are nearby	Volumes fluctuate from day to day

Adapted from FHWA *Signal Timing Manual*

Exhibit 10-3 may be used as a guide for selecting the appropriate type of signal operation (pre-timed, fully-actuated, or volume-density operations) for an isolated intersection, subject to variations in local conditions.

Exhibit 10-3 Signal Operation Selection Guidance, Isolated Intersections

Factor	Pretimed Operation	Fully-Actuated Operation	Volume-Density Operation
Main street average[1] to peak value traffic volume	Any	More than 20%	More than 30%
Main street average hour variation of traffic volume[2]	Less than 20%	More than 20%	More than 30%
Cross street average hour variation of traffic volume[2]	Less than 20%	More than 20%	More than 30%
Cross street volume relative to main street volume	More than 25%	Any	More than 30%

[1]Average refers to the average hourly volume over the day.
[2]Variation between morning and afternoon average hourly volumes

In **Exhibit 10-3**, a 20% variation is taken as the critical value since this variation would require a change in cycle length with average volumes that requires changing the type of control.

Multiple timing patterns should be used when there are directional shifts or volume variations in traffic during different portions of the day.

Often, it is found that certain movements (such as left turns or movements from a minor approach) cannot be accommodated adequately without the provision of special phases such as advance or exclusive phases. The demand for such special phases varies from cycle to cycle. These special phases should be actuated to be extended, skipped, or maintained as demand warrants without causing unnecessary delays to the major movements.

10.2.2 Data Collection

Refer to Section 3.3 of the STM2 for information on Data Collection. In addition, Chapter 10 of Publication 46 includes a summary of data collection requirements.

10.3 Introduction to Timing Plans – Supplemental Information

The information in this section refers to information found in Section 5.1 and Section 5.3 of STM2.

There are many signal timing parameters that must be defined for every user group (e.g., vehicles, pedestrians, etc.) at an intersection for every time period throughout the day. To keep the parameters organized, practitioners have developed conventions for how movements are referenced, how phases are numbered, how overlaps work, and how those movements, phases, and overlaps correspond to detectors, signal cabinet equipment, and displays.

10.3.1 Movement and Phase Numbering

Refer to Section 5.1.1 of the STM2.

For new and reconstructed signals, the typical movement and phase numbering shown in STM2 Exhibits 5-1 and 5-2 should be utilized. For east-west main streets, phase 2 should be the eastbound direction, and for north-south main streets, phase 2 should be the northbound direction.

For projects which modify existing signals, the cabinet wiring should be reviewed to ensure the design is consistent with the existing phase numbering scheme. The capabilities of the existing cabinet (number of load switches) may require deviating from NEMA phasing.

A load switch and the signal indications wired to it are controlled by timing associated with a vehicle phase, a pedestrian phase, an overlap (see **Section 10.3.4**), or a pedestrian overlap.

10.3.2 Ring and Barrier Concept

Refer to Section 5.1.2 of the STM2.

10.3.3 Left Turn Phasing

Left Turn Phase Modes

Left turning traffic on an approach is controlled by one of the following modes. **Exhibit 16-9** illustrates how each of these modes function. Also, refer to **Section 16.2.7** for typical signal head layouts for the various left-turn movements/phase modes.

- ✓ **Permissive Only Mode -** Turns made on a circular green signal indication or a flashing left-turn yellow arrow signal indication after yielding to pedestrians, if any, and/or opposing traffic, if any.
- ✓ **Protected Only Mode -** Turns made only when a left-turn green arrow signal indication is displayed. Protected only mode may be one of the following:
    - ▪ **Protected-Prohibited -** A protected only mode left turn movement that does not begin and terminate at the same time as the adjacent through movement. Protected-prohibited phasing can only be used when all left turn movements are made from an exclusive left-turn lane.
    - ▪ **Split Phasing -** A protected only mode left turn movement that always begins and terminates at the same time as the adjacent through movement.
- ✓ **Protected/Permissive Mode -** Both protected and permissive modes can occur on an approach during the same cycle.
- ✓ **Variable Left-Turn Mode -** On an approach, the operating mode changes among the permissive only mode and/or the protected only mode and/or the protected/permissive mode during different periods of the day or as traffic conditions change.
- ✓ **Prohibited -** Left turn movements are not allowed from the approach.

Left turn phasing should be evaluated for Level 3 and 4 projects (see **Exhibit 6-1**). Refer to:

- ✓ Section 4.3.1.2 of the STM2.
- ✓ Section 5.1.3 of the STM2.
- ✓ **Section 16.2.7** for signal head layouts for left-turn movements/phase modes.

Safety and operations at signalized intersections can be improved by restricting turning maneuvers, particularly left turns, during certain periods of the day or by prohibiting certain turning movements altogether. Signing or channelization can be implemented to restrict or prohibit turns at intersections.

Left Turn Phasing Mode Selection

Permissive left turns are desirable because motorists can use available gaps to turn left, unless conditions exist which make permissive left turns inappropriate.

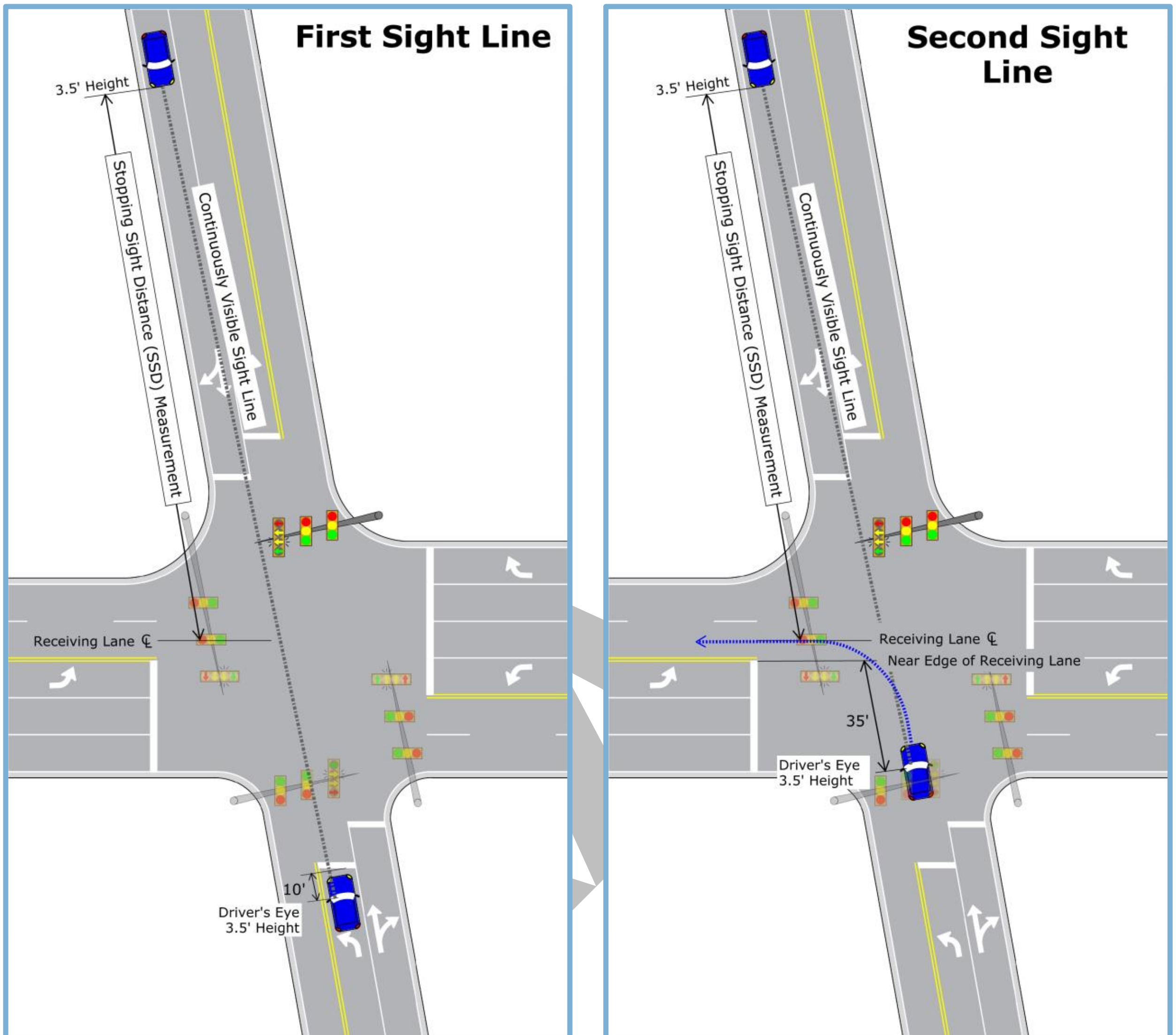
Protected-only mode is less efficient because green time allocated to left turn movements reduces the time available for other movements. Protected-only mode should only be used where permissive left turns are always inappropriate, including the following:

- ✓ Left turns can be made from more than one lane.
- ✓ Three or more opposing through lanes.
- ✓ Multi-legged intersections with more than four approaches.
- ✓ Approaches with significant non-correctable sight distance deficiencies, including deficiencies created by stopped opposing left-turn vehicles.

Sight distance for left turns at signalized intersections should be measured as follows:

- ✓ Sight Line Determination:
  - **The first sight line** should be determined from a point 10 feet upstream of the stop line, representing the location where a driver's eye would be positioned when the vehicle is stopped at the stop line.
  - **The second sight line** should be determined at a point 35 feet upstream from the near edge of the receiving lane (typically the centerline except when a median exists), representing the location of a driver's eye at a point where the vehicle may be positioned to wait for a gap in traffic to make a permissive left turn movement assuming a 25' turning radius.
- ✓ The stopping distance should be measured from center of the receiving lane to the point where an oncoming vehicle would first be visible and remain continuously visible from each of the points above.
- ✓ The height of both the driver's eye and the approaching vehicle should be assumed to be 3.5 feet above the road surface.
- ✓ A permissive left turn movement should not be included in the signal phasing if either of the sight distance measurements above is less than the minimum stopping sight distance as defined in the Publication 212 Appendix.
- ✓ See **Exhibit 10-4** for a graphic depiction of how to apply these criteria for measuring sight distance for left turns at signalized intersections.

Exhibit 10-4 Measuring Sight Distance for Left Turns at Signalized Intersections



Variable-mode left turn phasing should be considered when permissive left turns are inappropriate during only certain times of day, including the following:

- ✓ Approaches that have experienced five or more crashes (including non-reportable) of a type that would be susceptible to correction by protected-prohibited phasing within a continuous 12-month period over the most recent 3 years. (Non-reportable crashes must be police-verified and documented to enable consideration.) Engineering judgment should be used to determine whether to consider crash data impacted by temporary or abnormal conditions.

> The conflict factor (CF) is one factor to consider for left turn phasing. The type of left turn phasing selected should be the most safe and efficient operation for the location and time of day period.
>
> - ✓ If CF threshold is exceeded, then Protective-Permissive left turn phasing may be appropriate.
> - ✓ If one or more of the other listed criteria are met, then Protected Only left turn phasing must be used.

- ✓ The conflict factor (CF) is the product of the volume of left turns and the opposing through traffic.
  - Conflict factors should be calculated using current or opening-day traffic volumes.
  - Opposing right turn movements may be added to the opposing through movement when appropriate and/or specified by the District Traffic Engineer or designee.
  - Protected/permissive left turn phasing should be considered for the hours when the CF is greater than 50,000 with one opposing lane or greater than 100,000 with two opposing lanes if there is a minimum of two left turn vehicles per signal cycle.
- ✓ The opposing speed limit is greater than 45 mph and there are more than three left-turning vehicles per cycle.

Other factors to be considered in the evaluation of left turn phasing at an intersection should include the following:

- ✓ **Vehicle Characteristics:** The number and type of vehicles using the intersection and their effect on its operation may be considered. (Specifically, review the effect of trucks and buses on the traffic flow because of their braking and acceleration characteristics and their size.)
- ✓ **Adjacent Traffic Control Signals:** Consideration should be given to the traffic control signals (type and phasing) which are operating at adjacent intersections. Also, the effect that a newly installed left turn phase would have on the signal operation at adjacent intersections may be considered, such as impacting the cycle length for coordinated signals.
- ✓ **Delay:** If a left-turn phase will reduce delay and improve the overall level of service. In general, avoid a solution that lowers an intersection into Level of Service E.
- ✓ **Induced Demand:** A signalized intersection without a left-turn phase may have less turning traffic than adjoining or nearby signalized intersections with left-turn phases. A portion of the driving public may migrate to an intersection with a left-turn phase for safety and security reasons (i.e., they may find it easier to make the turn there). Therefore, installing a left-turn phase may increase the turning traffic at that intersection and reduce left-turn traffic at adjoining or nearby signalized intersections with existing left-turn phases.
- ✓ **Left-Turn Storage:** Is there enough storage within the left-turn lane to accommodate the queue for a protected-only left turn phase?
- ✓ **Intersection Geometry:** Does the intersection geometry result in overlapping left turns paths, which would prohibit having opposing left turn movements operate concurrently?
- ✓ **Pedestrian Conflicts:** Are there frequent vehicle-pedestrian conflicts when left turns are made as a permitted movement, or are drivers seeking a gap in opposing traffic to make a permitted left turn unlikely to also ensure the crosswalk is clear before turning? If variable-mode left turn phasing is used, consider omitting the permitted left turn interval during cycles when the conflicting pedestrian phase is active.

Left Turn Phase Sequence

Left-turn sequence refers to when left-turn phases occur in the cycle relative to the opposing through phase, including the following:

- ✓ **Lead/Lead Sequence:** The opposing protected left-turn phases occur prior to the through phases (as shown by Phases X and X in Exhibit X)
- ✓ **Lag/Lag Sequence:** The opposing protected left-turn phases occur after the through phases.

- ✓ **Lead/Lag Sequence:** The opposing left turns begin and end at separate times relative to the through phases (as shown by Phases X and X in Exhibit X)
- ✓ **Split Phasing:** The right-of-way is assigned to all movements on an approach, followed by all the movements on the opposing approach. The left-turn movement is protected only and operates concurrently with the adjacent through movement.

Additional information on left-turn sequence, including advantages and disadvantages of each type of sequence, is contained in Sections 5.1.3.4 and 5.1.3.6 of the STM2.

Yellow Trap (Left-Turn Trap)

The combination of a permissive left-turns with lagging protected left-turns creates a situation commonly called the "yellow trap" or "left-turn trap." The yellow trap is a condition where a left-turning user interprets the onset of a steady circular yellow indication and incorrectly assumes opposing through traffic sees the same steady circular yellow indication. This can be problematic if the left-turning user attempts to proceed through the intersection on yellow when oncoming traffic still sees a green indication.

Lagging left turn phasing should not be used unless one of the following conditions exist:

- ✓ A flashing yellow arrow display is used.
- ✓ There is no left turn movement on the opposing approach (such as a T-intersection)
- ✓ The phasing provides lagging permissive-protected phasing for both approaches at the same time (with the through traffic phase terminating for both directions at the same time)
- ✓ The lagging left turn phasing only occurs during preemption sequences.

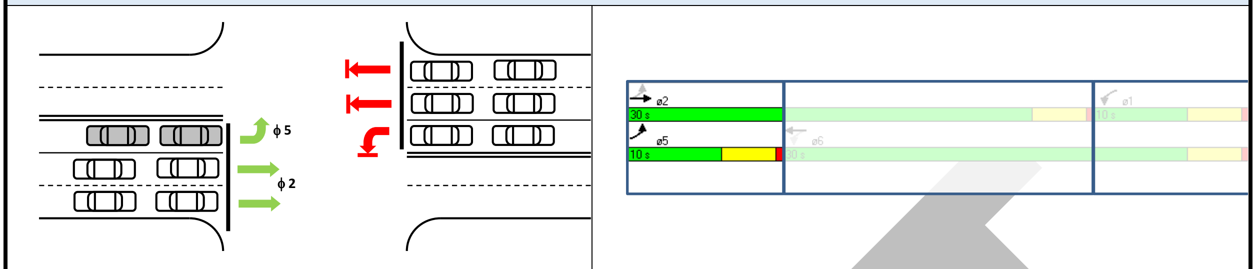
⇐ Click icon to play a video of a Lead-Lag left turn trap.

⇐ Click icon to play a video of a Lag-Lag left turn trap.

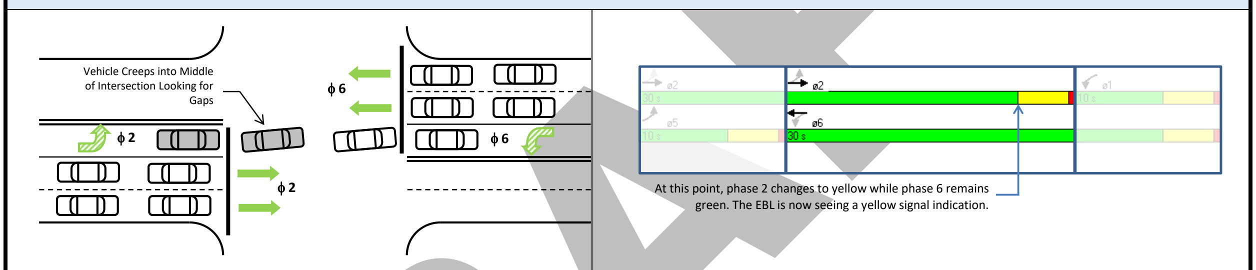
As a demonstration of the left-turn trap, consider the lead/lag scenario depicted in **Exhibit 10-5.** An animation of the lead/lag left-turn trap is also available on the Flashing Yellow Arrow Resource Page.

Exhibit 10-5 Lead/Lag Left-Turn Trap

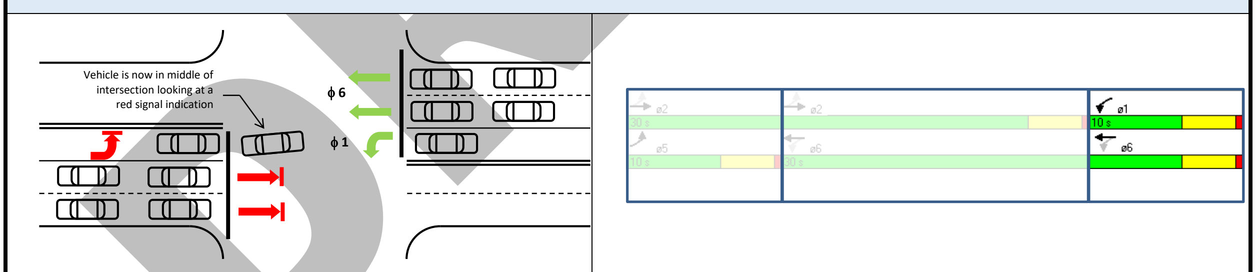
Stage 1: Phase 5 EBL shows a protected left-turn arrow while Phase 2 EBT shows a circular green. The opposing WB movements are stopped. *No issues during this stage; the left-turn vehicles have a protected movement.*



Stage 2: The EBL and WBL movements operate as permissive lefts (circular green indication). During this stage, the EBL may enter the intersection looking for gaps in the opposing traffic. Note that the EBL is actually operating as Phase 2 permissive. *At the end of this stage is when the left-turn trap occurs. Phase 2 indications will change to yellow. The EBL vehicle now must consider how to clear the intersection and may falsely assume the opposing through is seeing a yellow indication and is about to stop. In fact, the WBT remains green since Phase 1 WBL is up next.*



Stage 3: Phase 1 WBL shows a green arrow (protected) operation while Phase 6 WBT remains green. *EBL motorists may assume the WBT movements is stopping, and EBL motorists will either get trapped in the intersection or attempt to turn left through the intersection creating a crash situation.*



Conditional Service

Conditional service allows a left-turn phase, which is normally set as a leading phase, to re-service as a lagging phase if the opposing through phase has gapped out and sufficient time is available for a minimum green plus vehicular clearance interval. Note that the through movements must be actuated. The phasing and signal displays must be designed to prevent the yellow trap if conditional service is allowed.

Permissive Operation Delay

When a Flashing Yellow Arrow display is used, the permissive (flashing yellow) indication may be delayed relative to the opposing through receiving a green indication. This allows the opposing through to start moving and occupy the intersection so it is clear the left-turns must yield to the oncoming traffic. If used, the permissive operation delay should be 2 to 3 seconds.

10.3.4 Overlaps

An overlap allows traffic movement during the green indications of, and clearance indications between, two or more phases. Overlaps are typically wired to their own load switch to control the signal indications. The overlap output is determined by included phase(s) (also referred to as a parent phase) and may sometimes be determined by modifier phase(s). The meaning of the included (parent) and modifier phase depends on the overlap type as described later in this section.

The most common type of overlap is providing a protected right-turn arrow, which is displayed when a corresponding protected left-turn phase is active.

Modern controllers supporting NTCIP 1202 v03A (or later) are required to support the following overlap types, which operate as indicate in **Exhibit 10-6**:

- ✓ **Normal:** The overlap output is controlled by included phases. Modifier phases are not used.
- ✓ **Minus Green Yellow Alternate:** The overlap output is controlled by the included phases and the modifier phases.
- ✓ **Pedestrian Normal:** The overlap output is controlled by the included phases.
- ✓ **FYA Four Section:** The overlap output is controlled by the included phases and the modifier phases. It is used with the 4-section signal head where the overlap drives the flashing yellow arrow, yellow and red. The permissive through phase opposing the left-turn signal is the included phase and the associated left-turn protected phase is the modifier phase. This overlap type may also be used with a three-section head which contains red arrow, yellow arrow, and flashing yellow arrow indications for permissive-only left turn phasing.
- ✓ **FYA Three Section:** Applies to three-section heads for FYA with a shared yellow/flashing yellow arrow indication.
- ✓ **FRA Three Section and FRA Four Section *(not currently used in Pennsylvania)*:** Applies to flashing red arrow.
- ✓ **Transit-2**: Used to control a 2-section bar signal for transit vehicles. See NTCIP 1202 Section 5.10.2.2 for more information.

Exhibit 10-6 Overlap Output Indications

<table>
<tr><th rowspan="2">Overlap Type</th><th colspan="4">Overlap Outputs</th></tr>
<tr><th colspan="2">Green</th><th>Yellow</th><th>Red</th></tr>
<tr><td>Normal</td><td colspan="2">▪ An included phase is green
▪ An included phase is yellow (or red clearance), and an included phase is next</td><td>▪ An included phase is yellow, and an included phase is not next</td><td>▪ Whenever the overlap green and yellow are not on</td></tr>
<tr><td>Minus Green Yellow Alternate</td><td colspan="2">▪ An included phase is green, and a modifier phase is NOT green
▪ An included phase is yellow (or red clearance), and an included phase is next, and a modifier phase is NOT green</td><td>▪ An included phase is yellow, and a modifier phase is NOT yellow, and an included phase is not next</td><td>▪ Whenever the overlap green and yellow are not on</td></tr>
<tr><th rowspan="2">Overlap Type</th><th colspan="4">Overlap Outputs</th></tr>
<tr><th>Dark</th><th>FYA</th><th>Yellow</th><th>Red</th></tr>
<tr><td>FYA Three Section / FYA Four Section</td><td>▪ An overlap modifier phase is green</td><td>▪ An included phase is green, and a modifier phase is NOT green
▪ An included phase is yellow (or red clearance), an included phase or a modifier phase is next, and a modifier phase is NOT green</td><td>▪ An included phase is yellow, an included phase is not next, and a modifier phase is NOT green
▪ A modifier phase is yellow</td><td>▪ An included phase is red, a modifier phase is NOT green, and a modifier phase is NOT yellow
▪ A modifier phase is timing a red clearance interval</td></tr>
<tr><th rowspan="2">Overlap Type</th><th colspan="4">Overlap Outputs</th></tr>
<tr><th colspan="2">Walk</th><th>Pedestrian Clearance</th><th>Don’t Walk</th></tr>
<tr><td>Pedestrian Normal</td><td colspan="2">▪ An included phase is green
▪ An included phase is yellow (or red clearance), and an included phase is next
▪ An included phase is walk
▪ An included phase is in ped clear interval, and an included phase is next</td><td>Upon clearance of the Walk interval</td><td>▪ When the programmed pedestrian clearance time expires
▪ Whenever the overlap Walk and ped clear are not on</td></tr>
</table>

Overlaps generally follow the timing of the included phases, but an overlap may be programmed to extend beyond when the overlap would normally terminate (sometimes called a Trailing Overlap) by setting Overlap Trailing Green, Overlap Trailing Yellow Change, and Overlap Red Clearance. Trailing Overlaps are commonly used at closely spaced intersections such as two closely spaced T-intersections or for advance warning flashers.

Pedestrian Overlaps must have the Overlap Walk and Overlap Pedestrian Clearance parameters set. Upon completion of the Walk interval, the overlap enters the pedestrian change interval.

Conflicting pedestrian phases can be set for an overlap, which prevent the overlap from displaying green when the pedestrian phase is active (in the walk or clearance interval). The overlap is allowed to proceed upon completion of the active pedestrian phase and buffer interval.

Individual controller software may offer additional proprietary overlap types. The use of proprietary overlap types should be avoided where possible to allow competitive bidding of controllers unless multiple controller vendors offer the feature with similar settings.

To distinguish from phases, overlaps are typically referred to by letters. Internally, controller databases store overlaps with numbers (Overlap A=1, Overlap B=2, etc.).

Overlapping of non-conflicting phases may be a desirable option at some signalized intersections. Certain considerations (e.g., prohibition of U-turns from the complementary left turn, pedestrian clearance, and physical vehicular conflict) must be examined to ensure that an overlap phase is appropriate for an intersection. When a right-turn overlap is opposite a permitted left turn, the right turn green arrow should not be displayed during the yellow change or red clearance interval when the overlap included phase is next to prevent a yellow trap situation.

Refer to Section 5.1.4 of the STM2 for more information about overlaps.

10.3.5 Traffic Signal Analysis Software

Various software packages are available to analyze, optimize, and simulate traffic flow at signalized intersections or along signalized corridors or networks. For more information reference Publication 46 Chapter 12, Traffic Engineering Software.

Refer to Section 5.3 of the STM2.

10.4 Intersection/Uncoordinated Timing – Supplemental Information

The information in this section refers to information found in Section 6.1 of the STM2. A summary basic signal parameters is identified in **Exhibit 10-7** including a cross reference to additional information found in this publication and STM2.

Exhibit 10-7 Basic Signal Timing Parameters

Timing Parameter	STM2 Section	Pub 149 Supplemental Information
Yellow Change	6.1.1	10.4.1
Red Clearance	6.1.2	10.4.1
Minimum Green	6.1.3	10.4.2
Maximum Green	6.1.4	10.4.2
Passage Time (Unit Extension or Gap Time)	6.1.5	10.4.2
Walk	6.1.6	10.4.3
Flashing Don't Walk	6.1.6	10.4.3

10.4.1 Vehicle Change and Clearance Intervals

Use the engineering practices contained in this section, along with engineering judgment, to determine the vehicle change and clearance intervals for each approach to a signalized intersection. Traffic signal change and clearance intervals shall be calculated using the workbook provided on the Traffic Signal Portal. Any engineering judgment used to override the calculated values shall be documented on the calculation worksheets and in the traffic signal file in TSAMS.

Yellow Change Interval

Refer to Section 6.1.1 of the STM2. Pennsylvania's Vehicle Code is a permissive yellow law, and vehicles may legally enter an intersection up to the point when the signal indication changes from yellow to red.

In compliance with the requirement to determine the yellow change interval using engineering practices in Section 4F.17 of the MUTCD, the yellow change interval should be calculated using Equation 6.1 of the STM2 with a perception-reaction time of 1 second and a deceleration rate of 10 ft/s^2. The approach speed should be the posted or statutory speed limit. The grade measurement should be taken approximately 5 seconds upstream from the stop line based on the approach speed representing the upstream point of the dilemma zone. The calculated yellow change interval shall not be rounded down. The designer should ensure the yellow change interval timing parameter is compatible with the controller equipment:

- ✓ Modern controllers allow the yellow change interval to be set in 0.1 second increments.
- ✓ Electromechanical controllers typically operate in 1% increments of the cycle length dial.
- ✓ The yellow change interval shall be at least 3 seconds in accordance with the MUTCD.

Yellow Change Interval for Left Turns

When determining the yellow change interval for left turn phases, use 25 mph for the speed. If timing a single point urban interchange (SPUI) or an intersection with a wide, sweeping radius, assume a speed of 35 mph.

Red Clearance Interval

The yellow change interval should be followed by a red clearance interval to provide additional time before conflicting traffic movements, including pedestrians, are released. Refer to Section 6.1.2 of the STM2. For intersections with sight distance problems, use site-specific observations and engineering judgment as necessary to adjust the interval duration and it should not exceed 6 seconds.

The red clearance interval should be calculated using the following equation from NCHRP Report 731, *Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections* (2012):

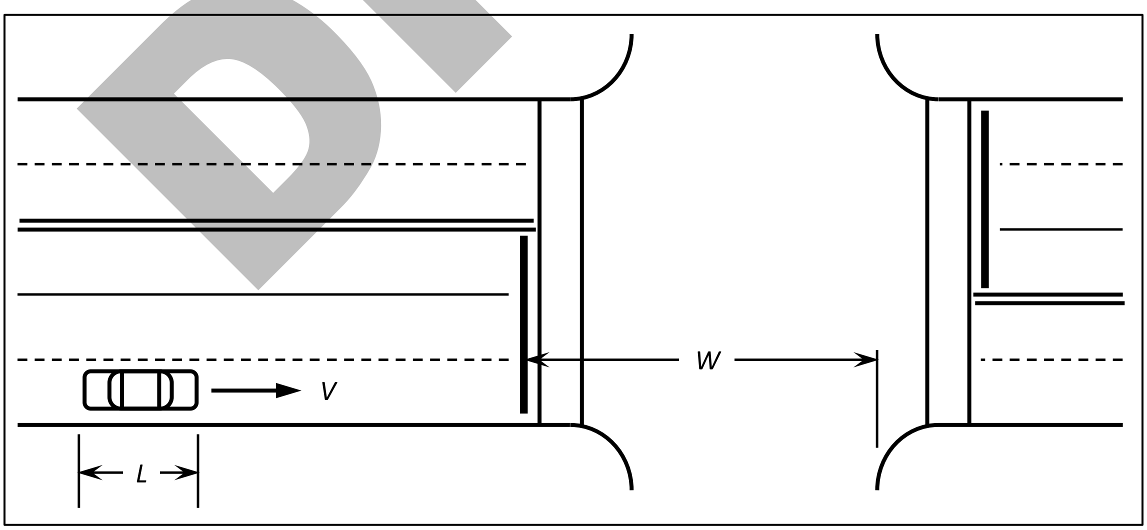
$$R = \frac{W + L}{1.47V} - 1$$

Where:

R = Red clearance interval; s
V = Approach speed of the roadway; mph
W = Width of intersection; ft (from the stop line to the end of the farthest traveled lane)
L = Length of vehicle; ft (typically 20 ft)

Refer to **Exhibit 10-8** for a graphical definition of the terms used in the red interval calculation.

Exhibit 10-8 Definition of Terms for Red Clearance Intervals



Red Clearance Interval for Left Turns

For left turn phases, use a speed of 25 mph. If timing a single point urban interchange (SPUI) or an intersection with a wide, sweeping radius, assume a speed of 35 mph.

The width of the intersection, W, for a left turn phase is commonly determined from a scaled intersection drawing. This distance (W) is measured along the path of the left turn vehicle from the stop to the end of the farthest conflicting lane.

Flashing Yellow Arrow (FYA) Displays

For FYA signal head displays (see **Sections 16.2.2, 16.2.7, and 16.2.8**), the following also apply for change and clearance intervals:

- ✓ When used for permissive left-turn phasing, the FYA signal display shall be tied to the opposing through green indication/display.
- ✓ Steady yellow arrow time for clearing the green arrow for leading or lagging left-turns should be the same as the current yellow change interval for protected left-turn operation.
- ✓ Steady yellow arrow time for clearing the FYA should be the same as the opposing through circular yellow change interval, as the FYA is driven by an overlap with the opposing through phase.
- ✓ All new and retrofit FYA installations shall include a red clearance interval, with a steady red arrow shown, when transitioning from a protected left-turn to a permissive left-turn in protected/permissive operations. The all-red interval shall be calculated in accordance with **Red Clearance Interval for Left Turns above,** as a protected left-turn phase.

10.4.2 Vehicle Green Intervals

Green intervals including green parameters, applicable controller function types, and related STM2 references are shown in **Exhibit 10-9.**

Exhibit 10-9 Green Intervals

Green Parameter	STM2 Reference	Applicable Function Types	Video Links
Minimum Green	6.1.3	Actuated, Variable Initial	Minimum green
Added Initial[1]	6.1.3.3	Variable Initial	Variable initial
Maximum Initial	6.1.3.3	Variable Initial	
Passage[2]	6.1.5	Actuated, Gap Reduction	Passage Time
Time Before Reduction (TBR)	See Note 3	Gap Reduction	
Time To Reduce (TTR)	See Note 3	Gap Reduction	
Minimum Gap	See Note 3	Gap Reduction	
Maximum Green[4, 5]	6.1.4	Actuated, Gap Reduction	Maximum Green

[1]Added Initial is also known as Seconds/Actuation (see **Exhibit 10-12.**)
[2]Passage is also known as Vehicle Extension, Unit Extension, or Gap Time
[3]See **Exhibit 10-11** for guidance.
[4]Controllers typically provide for two maximum green settings which can be selected by time of day (MAX 1 and MAX 2)
[5]The maximum time when the gap reduction function is used should be set no lower than the TBR plus TTR (see Exhibit 6-13 of the STM2). If the maximum time is set less than this sum, the controller will not have the ability to properly perform the gap reduction function.

The three controller function types shown above in **Exhibit 10-9** are described below:

- ✓ **Actuated -** Actual green time is based on vehicle detection utilizing minimum green and maximum green time parameters.
- ✓ **Variable Initial -** The adjustment of the amount of initial green time given to a phase based on queue length (when stop line detection is not used). This green interval times concurrently with the

minimum green interval and increases by each vehicle actuation received during the initial period. This time cannot exceed the maximum variable initial. Refer to **Exhibit 10-10** for a schematic of variable initial function.

- ✓ **Gap Reduction –** A higher passage time is used initially to prevent premature gap outs when vehicles are slowly clearing the intersection. After a specified time (“time before reduction”), the passage time is reduced to a minimum gap value using a gradual reduction over a specified time (“time to reduce”) as vehicular flow decreases. The gap reduction function decreases the likelihood of “trapping” a vehicle within the decision zone (also called the indecision zone, or Type II dilemma zone) and makes the operation more efficient by exiting the phase as platoon headways become greater. The decision zone is a defined area in front of a stop line where drivers must choose between stopping and proceeding through the intersection upon the change from a green to yellow indication. Detection setback designs can be used to reduce the probability of drivers having to make this type of decision within the decision zone area on high-speed approaches. Refer to **Exhibit 10-11** for a schematic of volume-density operation.

Exhibit 10-10 Variable Initial Function

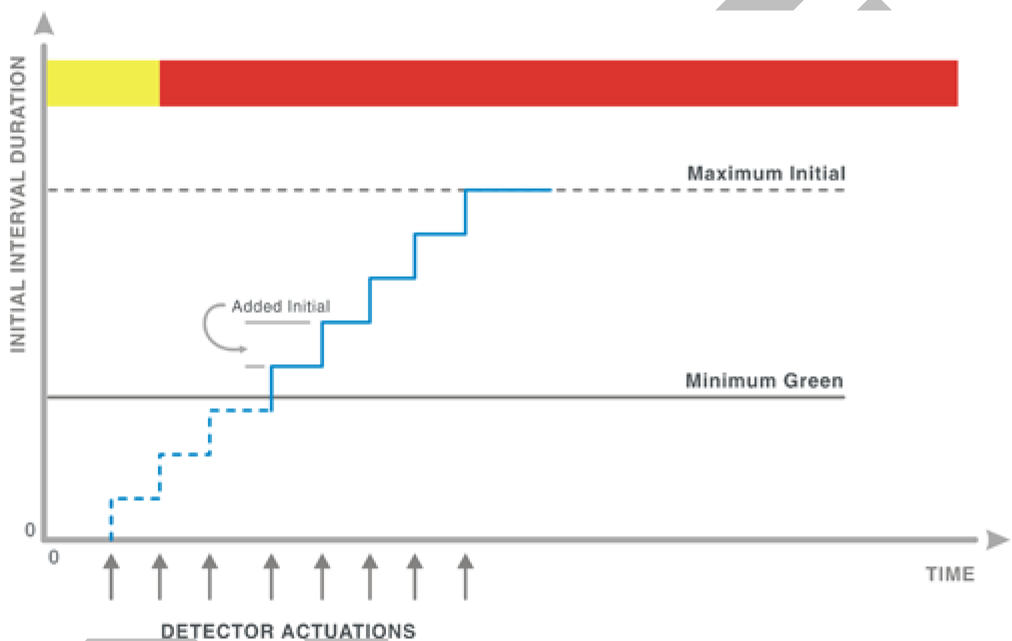
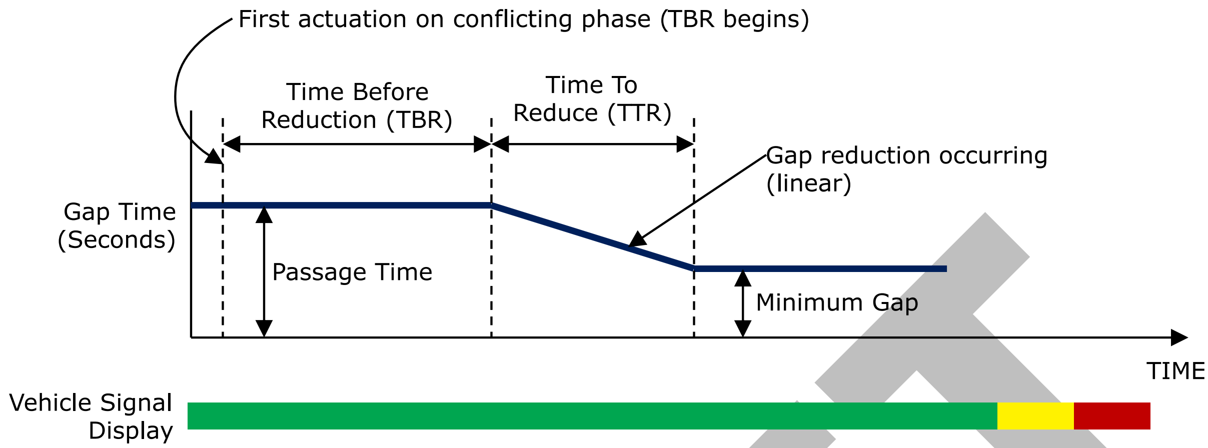


Exhibit 10-11 Gap Reduction Function



Volume-Density Operation

Volume-density operation is a controller feature with two, separate functions: variable initial function and gap reduction function.

For the gap reduction function, the passage time is decreased from its original value to a point called the minimum gap. This reduction occurs after the time before reduction (TBR) and takes place over a period called the time to reduce (TTR).

Typical values for Volume Density Operation are shown in **Exhibit 10-12**.

Exhibit 10-12 Volume Density Chart

Speed (mph)	Loop Setback (ft)	Max. Initial (s)	Added Initial (s)		Passage (s)	Min. Gap (s)	TBR (s)[1]	TTR (s)[2]	Max 1 (s)[3]
			1 lane	2 lanes					
35	230	24	2	1.5	4.5	2.7	24	10	≥34
40	275	30	2	1.5	4.8	2.7	30	15	≥40
45	330	35	2	1.5	5.0	2.7	35	15	≥47
50	365	37	2	1.5	5.0	2.5	37	15	≥52
55	400	42	2	1.5	5.0	2.3	42	20	≥62

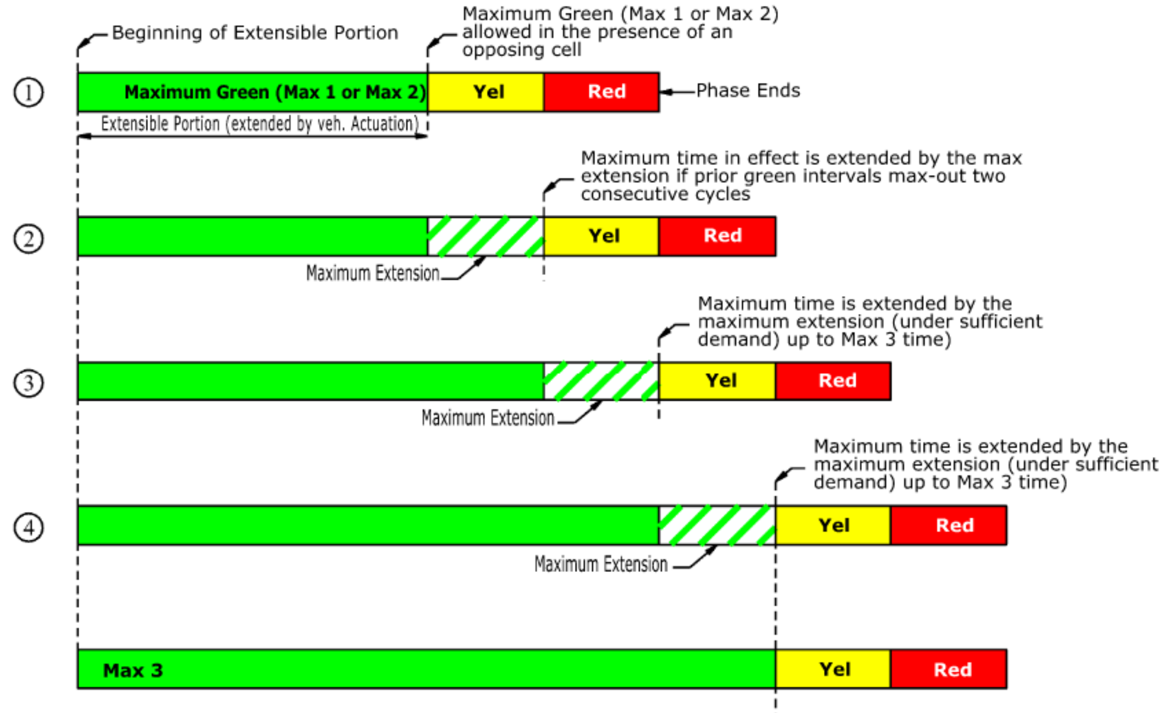
[1]TBR generally set the same as Max. Initial by assuming that a serviceable conflicting call was placed at the start of the initial green timing.
[2]Generally, TTR is approximately ½ of TBR.
[3]Maximum green ≥ (TBR + TTR) to reach the minimum gap.

Dynamic Maximum or Max 3

Many modern controllers also provide a feature that allows the maximum green time to be increased to a defined threshold after maxing out a phase a certain number of consecutive times (or alternatively to select among two or three maximum green values). The maximum green time may then be automatically decreased back to the original value after the phase has gapped out a certain number of times. The exact methods and user settable parameters for this feature vary by manufacturer.

Exhibit 10-13 illustrates an example of a Dynamic Maximum. In this example, the original maximum time is the Maximum 1 or Maximum 2 which is determined based on the time of day (TOD) and shown as (1) in the exhibit. With two consecutive max-outs, the maximum green will be extended by the Maximum Extension time as shown in (2) and (3) in the exhibit. The extension of the maximum green is limited by the Maximum 3 value as shown in (4) in the exhibit.

Exhibit 10-13 Dynamic Maximum Example



Notes:

1. Under normal conditions, phase will max-out with sufficient demand under prevailing Max 1 or Max 2.
2. If condition 1 terminates due to max-out for two consecutive cycles, the maximum time in effect will extend by one maximum extension.
3. If the new maximum established in condition 2 terminates due to max-out, the maximum will be extended by an additional maximum extension.
4. The maximum will continue to extend by the maximum extension if the prior phase maxed-out until the Max 3 settings has been reached.

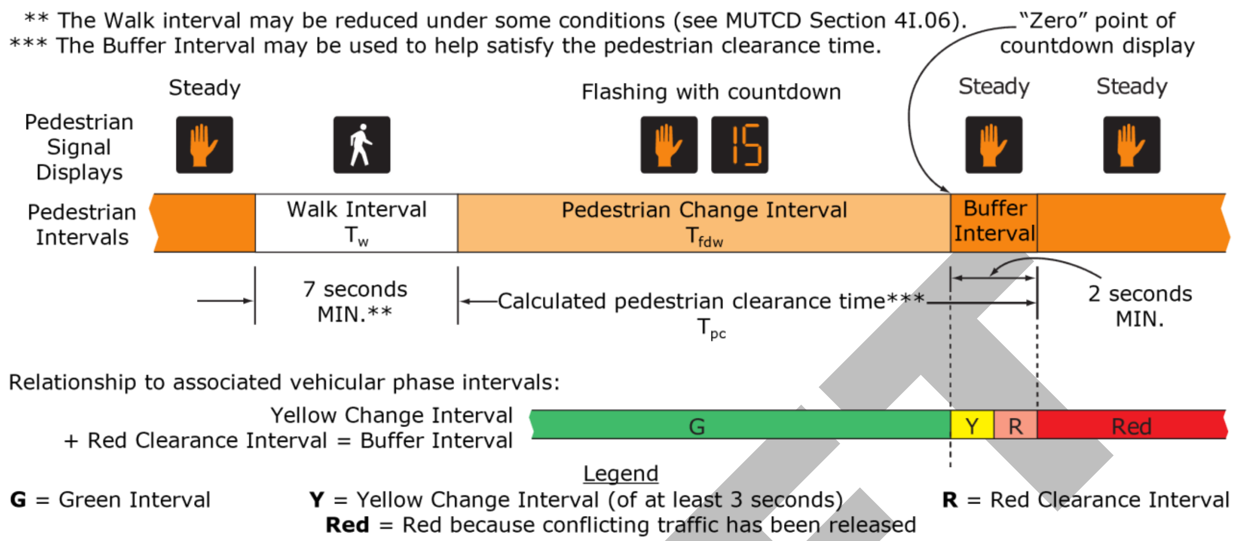
10.4.3 Pedestrian Intervals

Refer to MUTCD Section 4I.06 Pedestrian Intervals and Signal Phases and Section 4I.04 Countdown Pedestrian Signals.

When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder.

A pedestrian clearance time shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication. The first portion of the pedestrian clearance time shall consist of a pedestrian change interval during which a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed. The remaining portions shall consist of the yellow change interval and any all-red clearance interval (prior to a conflicting green being displayed), during which a flashing or steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed.

Exhibit 10-14 Pedestrian Intervals



Adapted from MUTCD Figure 4I-4

The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 ft per second, to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait. The distance is typically measured in the middle of the crosswalk. Where pedestrians who walk slower than 3.5 ft per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of 3 ft per second should be considered in determining the pedestrian clearance time. A slower walking speed should be considered when near elementary schools and elderly facilities.

Use the following equation to calculate the length of the pedestrian clearance time:

$$T_{pc} = \frac{L}{S_w}$$

T_{pc} = Pedestrian clearance time; s

L = Pedestrian walking distance from the curb or edge of shoulder to the far edge of the traveled way; ft

S_w = Walking speed; s [typically 3.5 ft/s]

When countdown pedestrian signals are used, the numeric countdown signal indication shall be displayed only during the pedestrian change interval (flashing don't walk interval) and no numeric indication shall be visible during a steady upraised hand indication or walking person indication.

When the signalized intersection is operating in coordination with other adjacent signals, the pedestrian phase time should be incorporated into the background cycle if the pedestrian phase is expected to be served 25% or more of the cycles on average while the coordinated timing pattern is in effect.

When pedestrian actuation is rare (less than 25% of the cycles), the split time may be set below the necessary pedestrian time, and the signal may go into “free” operation to serve the pedestrian phase and then transition back to coordination.

Refer to Section 6.1.6 of the STM2.

> When pedestrian times are not accommodated within the split time during coordination, each cycle when pedestrians are served will cause the signal coordination to go into transition.
>
> - ✓ The transition typically takes 3-4 cycles to return to synchronized coordination.
> - ✓ Therefore, if pedestrians are served more than 1 in every 4 (25%) of cycles, the signal will effectively be in transition all the time and the benefits of coordination will not be achieved.

WALK Interval

The WALK interval allows pedestrians to access the intersection and provides enough time for pedestrians to enter the crosswalk before the pedestrian change interval (flashing DONT Walk interval) commences. The walk interval shall be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. Longer walk intervals are often used when the duration of the vehicular green phase associated with the pedestrian crossing is long enough to allow them.

Pedestrian Change Interval (FLASHING DONT WALK)

The pedestrian change interval (flashing DONT WALK) allows pedestrians to clear the intersection approach, alerts pedestrians of an upcoming changing phase, and provides time for pedestrians to cross the intersection approach upon termination of the WALK interval prior to the release of conflicting traffic.

Use the following formula to calculate the minimum duration of the pedestrian change (FLASHING DON’T WALK) interval:

$$T_{fdw} = T_{pc} - Y - R$$

T_{fdw} = pedestrian change (FLASHING DON’T WALK) interval, s

T_{pc} = pedestrian clearance time, s (see above)

Y = yellow change interval, s

R = red clearance interval, s

Engineering judgement should be used to determine when it is appropriate to subtract the yellow change interval and red clearance interval from the calculated pedestrian clearance time. For example, a permissive left turn may result in vehicles turning during the yellow interval when a pedestrian is still in the crosswalk.

Minimum Green Interval Without Pedestrian Signal Use

When pedestrian signal indications are not provided but pedestrian requirements are to be considered in the signal timing plan, the length of the green interval should, as a minimum, include sufficient time (T_p) to allow pedestrians to cross the roadway at a walking speed of 3.5 ft. per second, plus additional time (3 seconds) for starting at the beginning of the green.

$$T_p = \frac{L}{S_w} + 3$$

T_p = Minimum green interval without pedestrian signals; s

L = Pedestrian walking distance from the curb or edge of shoulder to the far edge of the traveled way; (ft)

S_w = Walking speed; s [typically 3.5 ft/s]

Leading Pedestrian Interval (LPI)

Leading Pedestrian Interval (LPI) is also known as "pedestrian head start" or "delayed vehicle green" that gives pedestrians an advance walk signal indication before a concurrent green signal is provided to vehicles. This allows pedestrians to establish a presence in the crosswalk, thereby increasing their visibility to drivers and potentially reducing conflicts with turning vehicles.

LPI has been recommended as an FHWA "Proven Safety Countermeasure" to reduce pedestrian–vehicle crashes at signalized intersections. According to the Crash Modification Factor (CMF) Clearinghouse, the estimated LPI crash reduction factor for vehicle-pedestrian crashes in suburban and urban areas is 19%.

LPI Implementation

The decision process for LPI implementation should be documented using Form TE-XXX, Vulnerable Road User Accommodation at Traffic Control Signals Engineering Study.

Prior to implementing a new exclusive pedestrian phase, LPI should be implemented and evaluated for effectiveness.

The decision to implement LPI should be based on engineering judgement. The following are some of the considerations that may influence an engineering judgement decision:

- ✓ **Local Experiences:** Citizen complaints about turning vehicles not yielding to pedestrians.
- ✓ **Crash Data/Conditions:** Historical crashes between vehicles turning on green and pedestrians in the crosswalk with the pedestrian walk signal indication illuminated (or the presence of conditions that could potentially lead to such crashes - including, but not limited to, those described in sub-sections 3(c), 3(d), and 3(e)).
- ✓ **Land-Use Context:** LPI can be particularly useful in pedestrian generator locations such as playgrounds, parks, schools, recreation centers, urban areas, hospitals, retirement/assisted-living communities, transit stops, etc.
- ✓ **Intersection Type and Operation:** Intersections with a high proportion of vehicle turning movements that conflict with pedestrians, such as T-intersections or one-way streets.
- ✓ **Visibility Issues:** Concerns for reduced pedestrian visibility by drivers, due to obstructions or poor sight distance. At a minimum, the following should be considered: sun angle, lighting, and intersection geometry.
- ✓ **Controller Capabilities:** Prior to recommending LPI, confirm that the controller can support LPI programming.

LPI can unnecessarily increase vehicle delay when there is no pedestrian actuation (i.e., when pedestrian recall is present), since the LPI is called every signal cycle, even when pedestrians are not actively crossing. When pedestrian actuation with LPI is present and utilized, the LPI is called as needed without unnecessarily delaying other modes of traffic.

LPI Design Considerations

LPI Duration is a 3-second minimum per MUTCD, however:

- ✓ Typically, a 3 to 6-second range is used.
- ✓ LPI timing should also take into consideration the following scenarios:
  - Approaches with sizable portions of users with slower crossing speeds (children, older adults, persons with physical disabilities).
  - Approaches where the pedestrian detector location is not immediately adjacent to the curb (or, if no pedestrian detector is present, allocation of 6-feet from the face of the curb or from the edge of the pavement may be considered for calculating extended LPI).

LPI signal applications shall comply with Section 4F.01, Par.03, F "Application of Steady Signal Indications" and Section 4I.06 "Pedestrian Intervals and Signal Phases" of the MUTCD.

LPI timing should allow pedestrians to clear at least the width of one lane of traffic, in addition to the width of a parking and/or bicycle lane, or in the case of a large corner radius, to travel far enough for the pedestrian to establish their position ahead of the turning traffic before the turning traffic is provided a green indication.

A minimum of 3-second LPI duration is required by the MUTCD and LPI durations fall within a 3 to 6-second range.

Consider whether the all-red clearance interval for the phase preceding the LPI provides sufficient time for a vehicle to advance through the far side of the associated crosswalk prior to the LPI walk indication being displayed.

At locations where LPI is used, the walk indication should be displayed for at least the LPI duration plus 7 seconds.

If LPI is used, consideration should be given to turning movements across the crosswalk during the LPI.

- ✓ **Protected/Prohibited Left Turn**
  The LPIs shall not be timed with the opposing protected left-turn interval. For opposing leading left-turn movement, the LPIs shall be timed prior to the green interval for through vehicle movements and after the opposing protected left-turn movement.

  For opposing lagging left-turn movement, the LPI shall also be timed prior to the green interval for through vehicle movements.

- ✓ **Protected/Permissive Left Turn**
  Under situations with protected/permissive left turns, LPIs should not be considered without mitigation of the conflicts with the advanced left turns, particularly under non-concurrent terminations of the left-turn phases. Some potential mitigation efforts for when the left turns don't end concurrently include replacement of five-section shared signal heads with Flashing Yellow Arrow (FYA) signal heads, signage (such as the left "TURNING VEHICLES YIELD TO PEDESTRIANS" sign (R10-15L)), etc.

Example signal timings for the use of LPI with left turns are illustrated in **Exhibit 10-15** and **Exhibit 10-16.** *Please note, these example signal timings are illustrative only – the exact timings will vary based on site conditions.*

Exhibit 10-15 Schematic Diagram for Example Signal Timing with LPI (Lead/Lead Left Turn)

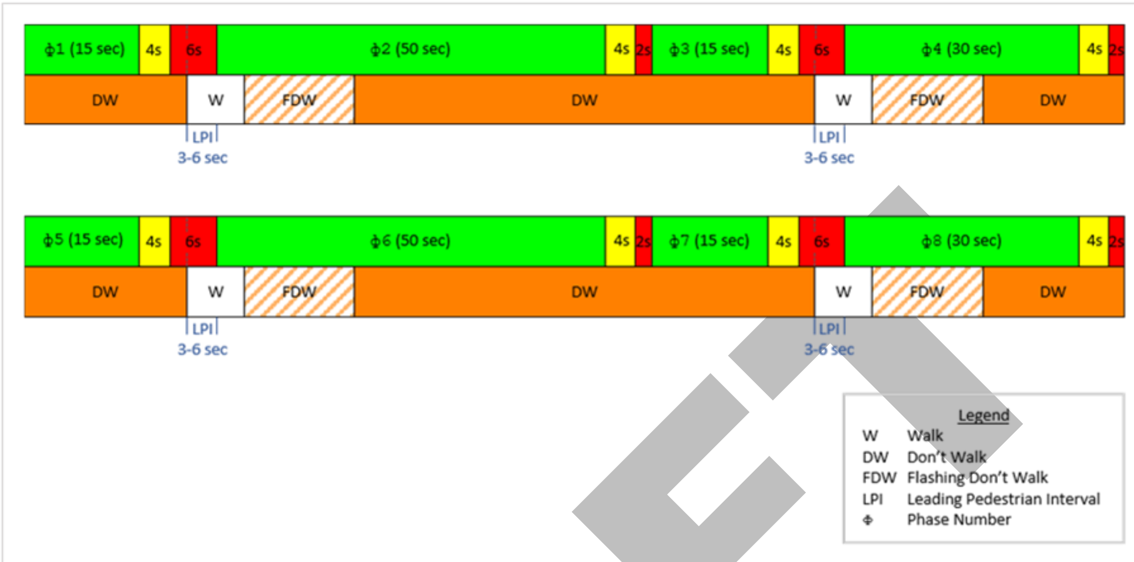
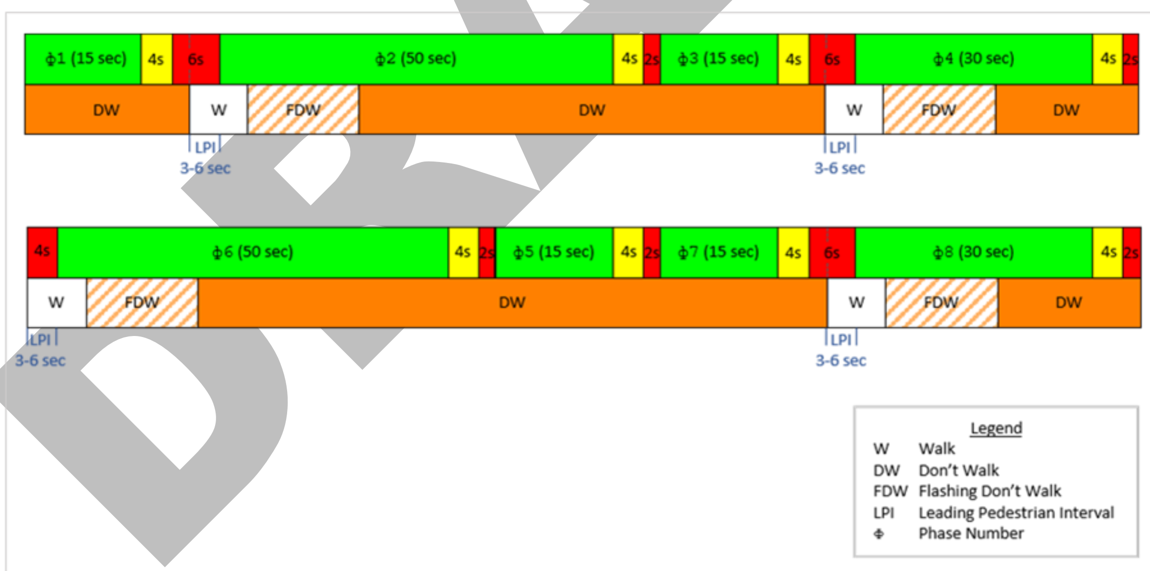


Exhibit 10-16 Schematic Diagram for Example Signal Timing with LPI (Lead/Lag Left Turn)



✓ **Right Turns on Red**
Prohibition of right turns on red may be considered to enhance LPI implementation compliance. Prohibition of right turns on red can be accomplished using a static or electronic blank-out "NO TURN ON RED" sign (R10-11). Implementation of the prohibition of rights on red shall comply with PennDOT Publication 212, Section 116. Consider the use of the electronic blank-out signs that are illuminated during the pedestrian intervals at locations with inconsistent pedestrian volumes, low/non-illuminated crosswalks, locations with high volumes that could see capacity issues with continual right-turn prohibitions, etc.

If right turns on red are not prohibited, the installation of supplementary "TURNING VEHICLES YIELD TO PEDESTRIANS" sign (R10-15R) should be considered.

Exclusive Pedestrian Phase

Prior to implementing a new exclusive pedestrian phase, LPI should be installed and evaluated for its effectiveness. An exclusive pedestrian phase shall only be provided if the pedestrian study (see **Section 8.2**) determines there would be significant conflicts between turning vehicles and pedestrians during the WALK interval with both concurrent walk or leading pedestrian interval and a capacity analysis demonstrates satisfactory level of service with implementation of the exclusive pedestrian phase. If used, an exclusive pedestrian phase shall be pedestrian-actuated.

All exclusive pedestrian phases shall be submitted to the Bureau of Operations for review and approval prior to including an exclusive pedestrian phase on a new or revised permit.

10.4.4 Recalls and Memory Modes

Refer to Section 6.1.8 of the STM2.

Recall

Recall is a feature which automatically places a call for service for a phase without considering detection. Determination of the phase recall is especially important because it allows the intersection to operate more efficiently during non-peak traffic periods. Recalls should be indicated on the traffic signal permit plan. The types of recall include:

Minimum recall places a call on a phase whenever the phase is inactive. The call is dropped when the phase turns green, which results in the phase being served for at least the minimum green interval. The green interval may be extended if vehicle actuation occurs prior to termination of the passage time. Minimum recall will serve the phase every cycle with the controller never displaying green for shorter than the minimum green. Minimum recall shall be used for phases with advance detection and no stop bar detection to ensure the phase is served for any vehicles stopped between the advance detector and the stop line. The minimum green cannot be truncated by preemption. Ensure coordinated split times are longer than the minimum green setting.

Soft recall is like minimum recall, but the phase call is dropped when there is a call on other conflicting phases based on vehicle demand. Soft recall may skip the phase during some cycles but will result in the signal dwelling in green for the phase in the absence of any demand at the intersection.

Maximum recall places a continuous call on a phase, which results in the phase being served for the maximum green time. Maximum recall is used when there is no functioning vehicle detection for a phase. Maximum recall can result in inefficient operation during light volume conditions such as during night times and weekends.

Pedestrian recall places a call for pedestrian service on a phase and will serve the pedestrian walk and pedestrian change intervals every cycle. Vehicle actuation may extend the green interval after the termination of the pedestrian change interval. Pedestrian recall may be appropriate in high pedestrian demand locations such as downtown environments and intersections near schools. Pedestrian recall is also used when there is no functioning pedestrian detection for a phase and a pedestrian crossing exists.

Exhibit 10-17 Phase Recall Settings

Recall Mode	Detection Location	Memory Mode
Minimum Recall	Stop line	Non-Locking
	Setback	Non-Locking
Maximum Recall	No Detectors	Not Applicable
Pedestrian Recall	Not Applicable	Not Applicable
Soft Recall	Stop line	Non-Locking
	Setback	Locking

Locking Memory

The ability of the traffic control signal controller to remember a detector actuation is referred to as controller memory mode. It dictates whether an actuation received during the red interval (and optionally, the yellow interval) is retained until the assigned phase is served by the controller. Phases and detectors may operate in locking or non-locking mode. Controllers also allow all the detectors tied to a particular phase to be locking or non-locking. Locking only occurs when the phase called by a detector is not green.

Locking mode is when a detector call remains active even if the detector is no longer detecting demand. In the locking mode, the first actuation received by the controller on a specified channel during the red interval is used by the controller to trigger a continuous call for service. This call is retained until the assigned phase is serviced, regardless of whether any vehicles or pedestrians are waiting to be served. This mode is typically used for the major road through movement phases associated with a low percentage of turning vehicles (as may be found in rural areas). One advantage of using this mode is that it can eliminate the need for stop line detection if advance detection is provided and that it is designed to ensure efficient queue service. Pedestrian pushbuttons always operate in locking mode since the presence is not continually monitored.

Non-locking mode only places calls when there is active demand on the detector input. In the non-locking mode, an actuation received from a detector is not retained by the controller after the actuation is dropped by the detection unit. The controller recognizes the actuation only during the time that it is held present by the detection unit. In this manner, the actuation indicates to the controller that a vehicle is present in the detection zone and the controller converts this actuation into a call for service. This mode is typically used for phases that are served by stop line detection. It allows permissive movements (such as right-turn-on-red) to be completed without invoking a phase change. In doing so, it improves efficiency by minimizing the cycle time needed to serve minor movement phases. Non-locking mode is not typically used with pulse detection due to an inability to detect vehicle presence after the pulse duration elapses.

10.5 Flashing Operation of Traffic Control Signals

10.5.1 General

For additional information not provided in this chapter, consult the MUTCD Sections 4G.01, 4G.02, 4G.03, and 4G.04. The meaning of flashing signals in Pennsylvania is defined in the Vehicle Code, 75 Pa.C.S. §3114.

The following shall apply whenever signals are placed in flashing operation:

- ✓ If the signals on an approach are flashing yellow, a circular yellow shall be flashed instead of any yellow arrow which may be included in that signal face.

- ✓ No steady circular green or green arrow or flashing yellow shall be terminated and immediately followed by a steady red or flashing red without the display of the steady yellow indication; however, transition may be made directly from a steady circular green or green arrow to a flashing yellow.
- ✓ Stop signs shall not be used with traffic control signals which are not flashing red at all times in accordance with MUTCD Section 4A.08.

10.5.2 Turn-On Flash

When a new traffic signal is initially turned on at a location which was previous unsignalized, the traffic signal is typically operated in flashing mode for a period of 3 to 7 days before full operation in accordance with specifications in Publication 408, Section 950.

During the initial turn-on flashing operation, the signal should flash yellow for approaches which are uncontrolled prior to the signal being activated, and should flash red for approaches which have stop signs prior to the signal being activated.

10.5.3 Emergency Flash

Emergency flash is initiated by the conflict monitor, malfunction management unit or a manual switch.

Under emergency flash, flashing red indications should be used for all approaches (all-red flashing), meaning the intersection would operate as all-way stop control.

Engineering judgment may be used to determine if emergency yellow/red flashing is needed at a select location for safety and operational reasons, such as a railroad crossing location where traffic needs to be cleared from the railroad tracks.

Note: Under emergency conditions if yellow/red flash is used, a 5-section head for left turns should flash the same color as the rest of the approach, while a 3-section head for left turns on the yellow flashing approach should go dark.

> Signals where emergency yellow flashing on the mainline approaches was approved prior to the effective date of this publication should be changed to all-red flashing with the next permit update.

10.5.4 Scheduled Flash

Scheduled flash has been used during low volume periods (typically late night) to minimize delay and reduce energy consumption, primarily at pretimed signals. Scheduled flash is unnecessary with actuated signals since the signal can operate with low delay for all movements during low volume periods while still retaining the safety benefits of normal signal operation.

Recent studies have shown a significant reduction in nighttime crashes when late-night flash is removed. Therefore, use of scheduled flash is not recommended.

> Signals where scheduled flash was approved prior to the effective date of this publication should be evaluated for removal of scheduled flash during the next permit update.

11. PREEMPTION AND PRIORITY CONTROL

11.1 General

Preferential treatment, using preemption and/or priority controls, is an application that can be used at signalized intersections to adjust operations in favor of a particular user.

Traffic control signals may be designed and operated to respond to certain classes of approaching vehicles by altering the normal signal timing and phasing plan(s) during the approach and passage of those vehicles. The alternative plan(s) may be as simple as extending a currently displayed green interval or as complex as replacing the full set of signal phases and timing.

A traffic control signal design needs to carefully evaluate the need for preemption or priority controls as this will have impacts on the physical layout, equipment required and signal operational programming/phasing.

Preemption is the transfer of normal operation of a traffic control signal to a special control mode of operation, and is typically given to special classes of vehicles, such as

- ✓ Trains
- ✓ Boats
- ✓ Emergency Vehicles
- ✓ Light rail transit

Coordination is not maintained during preemption, and several cycles of transition may be necessary to return to coordinated operation after the preemption sequence is served.

Priority Control is a means by which the assignment of right-of-way is obtained or modified, and is typically given to certain non-emergency vehicles, such as

- ✓ Light-rail transit vehicles operating in a mixed-use alignment.
- ✓ Buses

Priority control typically tries to serve the preferential vehicle within defined windows that don't break the coordination at the intersection.

This chapter presents information on the following preferential treatment types:

- ✓ **Emergency Vehicle Preemption** (see **Section 11.3**)
- ✓ **Railroad Preemption (Highway-Rail Grade Crossing)** (see **Section 11.4**)
- ✓ **Queue Preemption** (see **Section 11.5**)
- ✓ **Transit Priority** (see **Section 11.6**)

Preemption or priority control of traffic control signals may also be a means of assigning priority right-of-way to specified classes of vehicles at certain non-intersection locations, such as approaches to:

- ✓ One-lane bridges and tunnels (see **Chapter 26**)
- ✓ Movable bridges (see **Chapter 29**)
- ✓ Highway maintenance and construction activities
- ✓ Metered freeway entrance ramps (see **Chapter 1**)
- ✓ Transit operations

For addition information, see the following references:

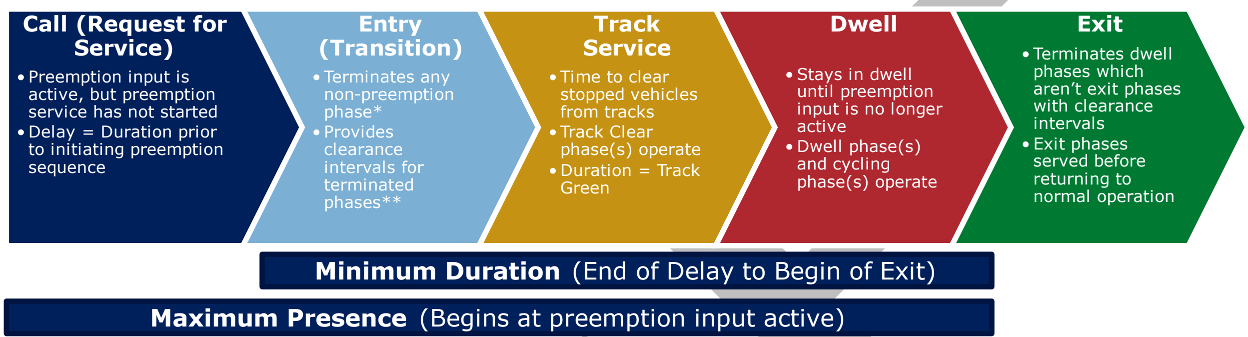
- ✓ MUTCD Sections 4F.18, 4F.19, 4F.20, 8D.08, and 8D.14.
- ✓ Traffic Signal Preemption for Emergency Vehicles (A Cross-Cutting Study), FHWA (2006)
- ✓ Publication 46 (Chapter 4)
- ✓ Publication 148 (TC-8807)

- ✓ Publication 408 (Section 956)
- ✓ ECMS Master Items (0956)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

11.2 Controller Preemption Operation

Preemption service consists of up to five states, as shown in **Exhibit 11-1**.

Exhibit 11-1 Preemption States



*Phase cannot be terminated until completion of minimum green interval.
**Includes pedestrian clearance interval (if pedestrian phase active), yellow change interval, and red clearance interval

Call (Request for Service)

Preemption begins when the preemption input is active, meaning the preferred vehicle has sent the system a "request" for preferential treatment. The type of input and detection is described in the following sections depending on the type of preferential treatment.

Controllers prioritize preemption based on the preemptor number, such that a call on a lower preemptor number (higher priority) will terminate preemption service on a higher preemptor number. Railroad preemption shall always have the highest priority (preemptor #1). Queue preemption should have the next highest priority (typically preemptor #2). Emergency vehicle preemption shall have the lowest priority (typically preemptors #3 through #6).

When emergency vehicle preemption is provided for multiple approaches, the system shall provide service on a first-come, first-serve basis. Once the first priority vehicle calls the system, it shall prevent other preemptive vehicles from entering calls until the first emergency vehicle releases control and clears the intersection. This can be achieved with the Preempt Override parameter, so the lower numbered preemptors don't override the higher numbered preemptors.

If the preemption is programmed with a delay, the entry (transition) state does not begin until the delay time has expired. If the preemptor is non-locking, preemption service will not occur if the preemption input is no longer active before the end of the delay period. The delay parameter is most frequently used with queue preemption.

Entry (Transition)

A call for preemption may occur during any interval of the normal controller operation. During the entry (transition) to preemption, the controller unit may stay in a normal sequence phase if that phase is also defined as a preemption phase. Other phases must be terminated to provide service only to the preemption phase(s). For example, if the signal is in phase 2+6 green when a preemption call is received which is only to serve phase 2, the signal should terminate green for phase 6 but remain green for phase 2. Care should be taken to avoid yellow traps, if practical.

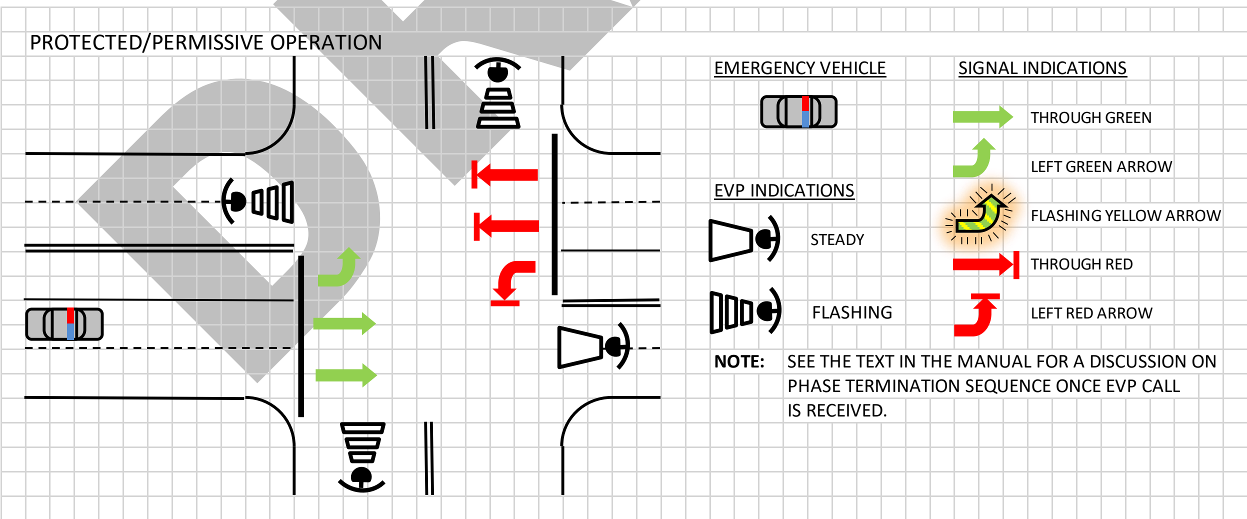
There are cases where the transition to preemption can create a left-turn trap when left turns are permitted by a circular green indication, if the through phase in one direction stays green to serve preemption but the opposing phase changes to yellow because it is not a preemption dwell phase. To avoid this left-turn trap situation, one of the following must be implemented:

- ✓ Use a separate flashing yellow arrow (FYA) signal head for the left turn movement (see the Flashing Yellow Arrow Resource Page of the Traffic Signal Portal for more information).
- ✓ Require the signal to terminate all green indications and go to an all-red interval during the preemption entry state prior to going to the dwell state.
- ✓ Add an OPPOSING TRAFFIC MAY HAVE EXTENDED GREEN (W25-2) sign facing each approach that might have a left-turn trap during the preemption sequence.

The transition selection for intersections with flashing yellow arrow signal indications should be as follows: (refer to **Exhibit 11-2)**:

- ✓ If the through phase in the direction of the EV and opposing through phase are green and lefts are in FYA, preemption terminates both through phases, and brings the through and left green arrow for the direction of the EV (FYA off for opposing left turn).
- ✓ If the left green arrow and through phase in the direction of the EV are green, preempt the left green arrow and through phase and then brings up this same green arrow and through phase (FYA off for opposing left turn).
- ✓ If the left green arrow and through phase in the opposing direction of the EV are green, preemption terminates the left green arrow and through phase and brings up the opposing (EV direction) left green arrow and through phase (FYA off for opposing left turn).
- ✓ If the side street is green, a preemption on the main street terminates the side street phases and brings up the left green arrow and through in the direction of the EV (FYA off for opposing left turn).

Exhibit 11-2 Emergency Vehicle Preemption: Protected/Permissive Operation



The right-of-way transfer procedure is executed during the entry stage. The signal controller safely transitions (or terminates if necessary) all phases in conflict with the preemption phases.

The transition into and out of preemption because of a preemptive call being received during any interval of traffic control signal operation shall be clearly defined in the Movement, Phasing, and Sequence Chart; Phasing Diagram; and associated notes in Publication 148, TC-8807 or on the traffic signal permit.

Track Clearance

If configured, the track clearance phase(s) is served for a specified amount of time before the dwell phase(s) begins timing. This is typically used with railroad preemption to clear any queued traffic from the railroad tracks before the railroad active traffic control system is activated, including gate systems and flashing-light signals.

If not configured, the sequence proceeds directly from the entry (transition) state to the dwell (limited service) state.

Dwell (Limited Service)

The dwell phases are served directly following the track clearance state, if configured; otherwise, the dwell phases are served directly following the entry (transition) state. For railroad preemption when preemption is anticipated to run for a longer time, the signal may be operated with limited service for non-conflicting movements during the dwell state (cycling phases). Traffic control signals operating during preemption conditions should be operated in a manner designed to keep traffic moving to the maximum extent feasible. The stopping of all traffic by the display of a steady red for all signals is prohibited, except during clearance intervals or where railroad tracks pass through the intersection in a manner that doesn't permit any non-conflicting movements to operate.

The controller remains in the dwell state until either the preemption call is dropped, or the maximum preemption time has been reached. The controller will not move past the dwell stage until the minimum dwell time has been served, if configured.

In most cases for emergency vehicle preemption, traffic signals should be designed and programmed to provide green indications for the direction of the approaching emergency vehicle, and red indications for all other approaches. During preemption, the traffic signal operates with split phasing, even if concurrent phasing is used during non-preemption operation. Emergency vehicle preemption only uses dwell phases and not cycling phases.

Exit (Recovery)

The exit (recovery) state begins immediately after the preemption dwell state ends. Four options are available within most controllers in determining what happens when exiting preemption. After serving the phase(s) defined by the exit type, the controller resumes the normal sequence from that point.

- ✓ **Exit Phases:** The controller will serve the designated exit phase(s) first.
- ✓ **Queue Delay Recovery:** The controller serves the phase with the highest demand or longest wait time first.
- ✓ **Short Service:** The controller serves the first phase which was shortened during preemption entry.
- ✓ **Exit to Coordination:** The controller returns to the place in the coordinated cycle where it would have been if there was no preemption.

Additional vendor-specific options may include:

- ✓ **Exit Timing Plan:** The exit sequence is defined by a separate timing plan.
- ✓ **Free:** The controller runs one cycle in free operation before returning to normal operations.
- ✓ **Skipped Phase:** The controller serves the first phase with demand, was next in sequence, but was not served during preemption.
- ✓ **Go to Next Demand:** The post preemption phase may be the phase immediately after the preemption phase during normal operation.
- ✓ **Resume Interrupted Sequence:** The post preemption phase will be the phase that occurred before the preemption phase.

In many cases, Phases 2 and 6 are programmed as the Exit Phases based on an assumption these phases have the most vehicle demand and would have been impacted most by the preemption.

11.3 Emergency Vehicle Preemption

Emergency vehicle preemption shall only be included as part of the traffic signal operation if justified by a request from the appropriate municipal organization(s) including the following:

- ✓ The approach(es) for which preemption is requested is along an emergency vehicle response route. An emergency vehicle response route may be routes leading away from a fire or ambulance station or routes leading toward an emergency medical facility.
- ✓ Documentation that emergency vehicles using the emergency vehicle response route are equipped with the necessary in-vehicle equipment to activate the preemption or will be equipped prior to signal installation.
- ✓ Verification the emergency vehicle preemption system type (see **Section 11.3.1**) that is proposed achieves the desired operation given the geometric and adjacent land use approaching the intersection.
- ✓ Evaluation of the estimated benefits to emergency vehicle response times.
- ✓ Other information which demonstrates the need for emergency vehicle preemption at the subject intersection.

Note: If emergency vehicle preemption is justified as indicated above, the following funding protocols apply:

- ✓ Preemption equipment that is installed on signal mast arms (or span wires) is eligible for State or Federal project funding.
- ✓ In-vehicle preemption equipment (emitters and such) is not eligible for State or Federal project funding and must be purchased locally.

If preemption is determined to be placed at a signalized location, proper placement and capabilities should be determined prior to the device location finalization.

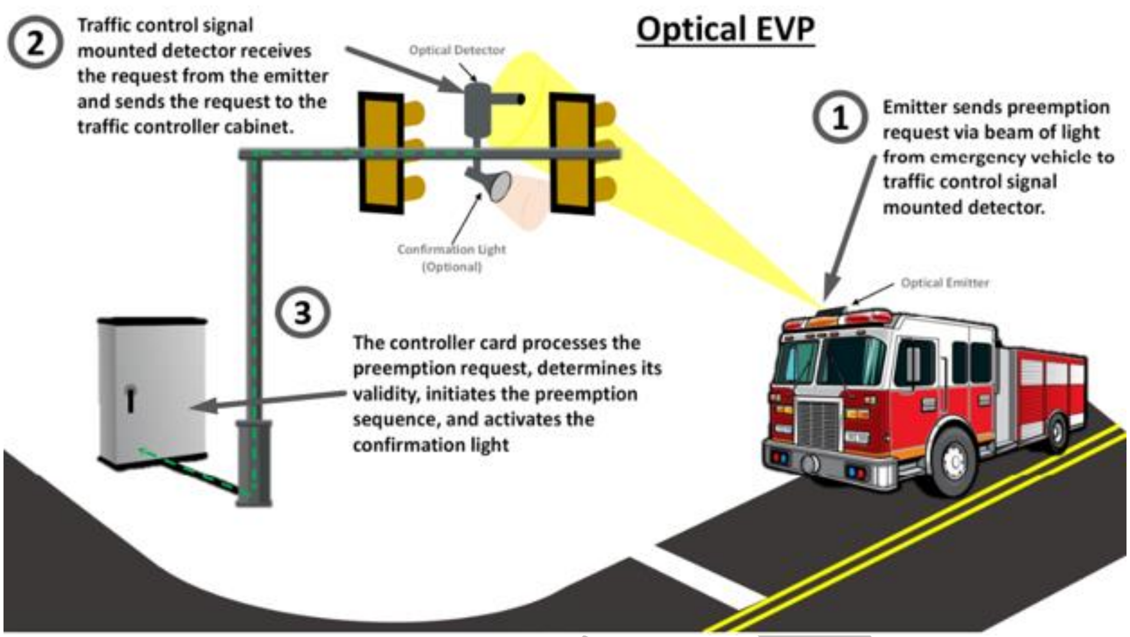
11.3.1 System Types

Emergency vehicle preemption (EVP) systems may use either optical, acoustic, or radio with global positioning system (GPS) technologies. Each technology is described in this section, along with considerations for designers to achieve the desired operation.

Optical Preemption System

Optical preemption systems work as shown in the **Exhibit 11-3** illustration:

Exhibit 11-3 Optical EVP Illustration



Optical preemption systems have the following design considerations:

- ✓ Traffic control signal mounted detectors must be installed on an approach basis.
- ✓ See **Section 11.3.2** for information on fail-safe confirmation light indications that are required for optical preemption systems.
- ✓ An emitter must be installed in each emergency vehicle to be served by preemption.
- ✓ If the emitter is not isolated, such as wired in series with the emergency lights, any traffic control signal within range might be preempted during an emergency response or a traffic stop when the emergency vehicle is stationary.
- ✓ Traffic control signals within range of the emitter may be preempted even if an emergency vehicle turns prior to reaching the traffic control signal(s).
- ✓ Most optical systems estimate distance based on light-source intensity and are analog in nature. Light intensity is inversely proportional to the square of the distance from the light source. This relationship is described under ideal circumstances; field conditions may make consistent point of detection calibration more difficult.
- ✓ Manufactures of the optical systems recommend that customers clean and inspect detectors as often as determined necessary by observation but no less than every 12 months.
- ✓ Claims of optical system detection ranges vary between 2,500 and 4,000 ft. Limited empirical data is available to validate these claims; however, there is substantial anecdotal testimony from first responders that the performance claimed by optical EVP systems may not be regularly reproduced in field applications. Studies show that the optical EVP system's detection performance fell far short of the advertised 2,500-ft. range with anecdotal evidence supporting range less than 1,000-ft. being typical. Reasons for this may include:
    - **Actual field conditions** have an impact on the line-of-sight between the optical emergency vehicle emitters and detectors. Obstructions or limited line-of-sight examples include, tree canopies, buildings, overhead bridges, overhead utilities, horizontal & vertical geometry of roadway, large trucks between emergency vehicle and traffic control signal, etc.

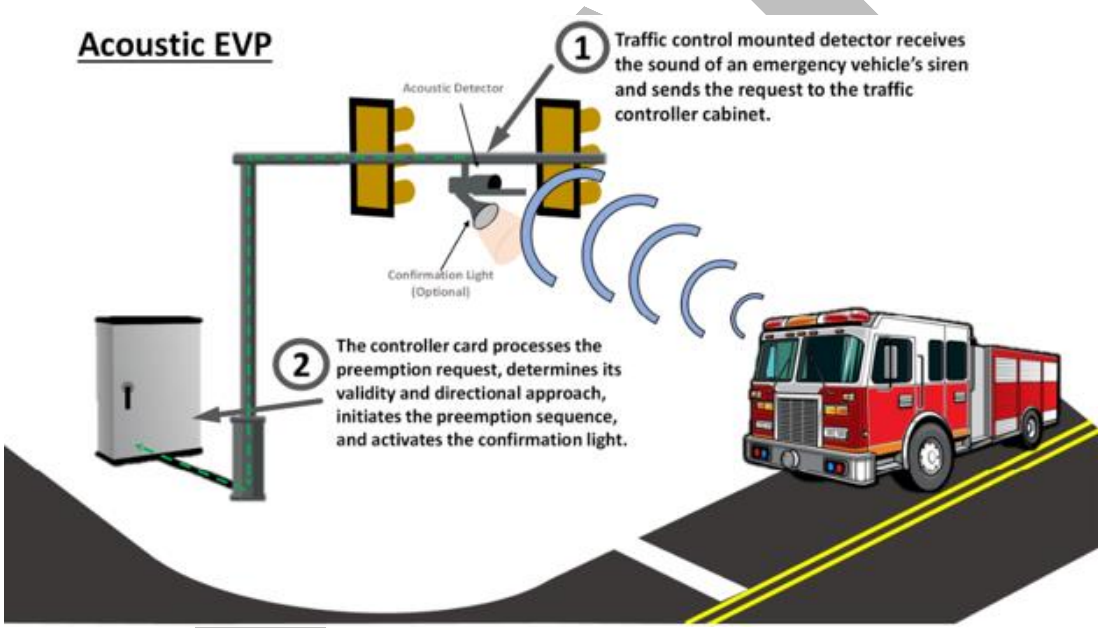
- **Actual lighting and atmospheric conditions** may also impact performance. Direct sunlight into a receiver may prevent it from detecting an emitter, and severe atmospheric conditions, such as heavy rain or snow, may reduce the distance at which a line-of-sight system will function.
- **Equipment conditions** including dirty lenses or reduced light source intensity may also impact performance.

✓ In additional to subpar detection range, first responders also report lack of detection consistency with optical systems.
✓ Modifying the position of the receiver or even locating it separate from the traffic signal equipment can sometimes correct line-of-sight field issues.
✓ For a given roadway and speed limit, a more limited detection range may increase the likelihood that an approaching emergency vehicle will reach the back of a traffic queue or a traffic signal prior to the appearance of a preemption green light. Appropriate signal timing adjustments may be needed to offset these detection range limitations.

Acoustic Preemption System

Acoustic preemption systems work as shown in the **Exhibit 11-4** illustration.

Exhibit 11-4 Acoustic EVP Illustration



Acoustic preemption systems do not require an emitter on the emergency vehicle, but it is desirable that all the types of sirens used by emergency vehicles be evaluated and the system be calibrated to help ensure that the desired performance is achieved.

Acoustic preemption systems have the following design considerations:

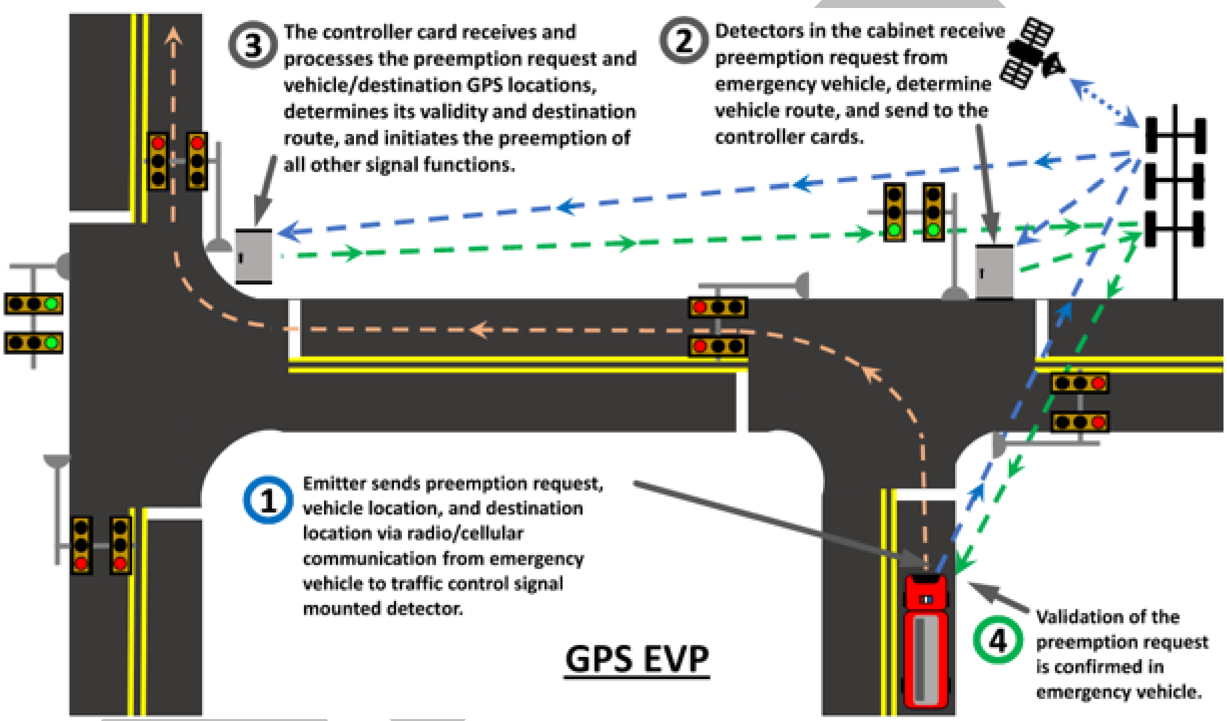
✓ Traffic control signal mounted detectors must be installed on an approach basis.
✓ See **Section 11.3.2** for information on fail-safe confirmation light indications that are required for acoustic preemption systems.
✓ The ability to use siren equipment already installed in emergency vehicles dispenses the need for separate vehicle mounted equipment.

- ✓ Sound waves are easily reflected by buildings or other large vehicles present at or near an intersection, causing the "reflected" wave to trigger a preemption event in the wrong direction. Reflected waves can also create unnecessary collateral preemption events alongside streets near the emergency vehicle's route.
- ✓ Acoustic sensors can sometimes be sensitive enough to activate the preemption in response to a siren from too far away, or from an unauthorized vehicle with a horn exceeding 120 dB (many truck and bus horns exceed this threshold at close range).

Wireless Global Position System (GPS) Preemption Systems

GPS preemption systems work as shown in the **Exhibit 11-5** illustration.

Exhibit 11-5 GPS EVP Illustration



The GPS feature monitors the movement of the approaching emergency vehicle and initiates the preemption phasing accordingly. Each intersection is setup to identify a trigger point on each approach. The emergency vehicle uses the GPS to set the route to the destination, and as the emergency vehicle travels the route, each traffic control signal has preemption call placed when the vehicle crosses the trigger point. Since the emergency vehicle preemption is route based, only signals on the route are preempted.

GPS preemption systems have the following design considerations:

- ✓ Traffic control signal mounted detectors must be installed on an intersection basis.
- ✓ Installation of a separate confirmation light to validate the preemption is not required on the traffic control signal as validation is confirmed inside the vehicle (see **Section 11.3.2).**
- ✓ Offer unmatched precision and management capabilities over older preemption technologies alone.
- ✓ Provides graphical user interface with real-time vehicle locations and signal preemption status.
- ✓ In dense cities with tall buildings, GPS receivers may have difficulty obtaining the three required GPS satellite signals, required for triangulation to determine location.
- ✓ Extremely heavy cloud cover or severe weather can also adversely impact the ability of the GPS receiver from obtaining the three required satellites.

11.3.2 Confirmation (Fail-Safe) Indications

Systems in which traffic control signals are preempted by approaching emergency vehicles shall be designed and installed to provide a confirmation indication to validate to the driver of the approaching emergency vehicle when the equipment has preempted the traffic control signal at that intersection. In the past, this was also referred to as a fail-safe indication.

For Wireless GPS systems, the confirmation indication is provided inside the vehicle via a graphical display on the GPS system's computer screen. Installation of a separate confirmation light on the traffic control signal is not required.

For Optical & Acoustic systems, the confirmation indication is provided by a separate white confirmation light installed on the traffic control signal for each intersection approach served by the preemption system. These approach confirmation lights can operate in either a dark mode, flashing mode, or a steady mode, and shall be designed to operate as follows:

- ✓ **Dark mode:** When the confirmation light is dark, this is considered the normal status of the light. The confirmation light will be in this mode most of the time as the preemption system is in the listening mode for a preemption activation. The traffic control signal indications will operate in normal programmed phases and timings.
- ✓ **Flashing mode**: The confirmation indication shall be a flashing white light on the intersection approach that the emergency vehicle is using as it moves toward the traffic control signal. The traffic control signal indication will be green for this intersection approach.

11.4 Railroad Preemption

Where the distance between a traffic control signal and a highway-rail grade crossing is less than 300 feet, rail preemption should be utilized to help avoid a potential collision between a vehicle which is queued on the tracks and the rail utility. An interconnection between the rail utility and the controller cabinet will be necessary. Rail preemption shall supersede emergency preemption.

Coordination with the PUC and railroad is required during the design of all railroad preemption systems.

When the grade crossing is equipped with an active traffic control system, the normal sequence of highway intersection signal indications should be preempted upon approach of trains to avoid entrapment of vehicles on the crossing by conflicting aspects of the highway traffic signals and the grade crossing signals. The preemption feature requires an electrical circuit between the control relay of the grade crossing warning system and the traffic signal controller. The circuit shall be of the closed circuit principle; that is, the traffic signal controller is normally energized and the circuit is wired through a closed contact of the energized control relay of the grade crossing warning system. This is to establish and maintain the preemption condition during the time that the grade crossing signals are in operation. There multiple or successive preemption may occur from differing modes, train actuation should receive first priority and emergency vehicles second priority.

Where a signalized highway intersection is adjacent to a grade crossing not provided with an active traffic control system, the possibility of vehicles being trapped on the crossing remains and preemption of the signal controller is usually required. However, at some locations, the characteristics of the crossing and intersection area along with favorable speeds of both vehicular and train traffic may permit alternate methods of warning traffic. Where preemption of the traffic signal is determined to be desirable, consideration should be given to the installation of active traffic control devices at the grade crossing, since the cost of the grade crossing devices would usually represent a minor addition to the cost of the railroad circuits required for the preemption function.

The preemption sequence initiated when the train first enters the approach circuit shall at once bring into effect a highway signal display which will permit traffic to clear the tracks before the train reaches the crossing. The preemption shall not cause any short vehicular clearances, and all necessary vehicular clearances shall be provided. However, because of the relative hazards involved, pedestrian clearances may be abbreviated in order to provide the track clearance display as early as possible.

To avoid any misinterpretation during the time the clear-out signals are green, consideration should be given to the use of 12-inch red lenses in the signals which govern highway traffic movement over the crossing with adequately screened or louvered green lenses in the clear-out signals beyond the crossing.

After the track clearance phase, the highway intersection traffic control signals should be operated to permit vehicle movements that do not cross the tracks, but shall not provide a through circular green or arrow indication for movement over the tracks. This does not prohibit green indications for highway traffic movements on a roadway paralleling the tracks.

Design of the rail preemption system involves determining the amount of time a queue of vehicles needs to clear the tracks before transferring right-of-way to the rail. The "Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings," is adopted by PennDOT from the Texas Department of Transportation and should be utilized to calculate the proper clearances and to provide the rail utility with the correct distance for placing its actuators on its tracks. Typically, while the signalized intersection is preempted by the railroad, a non-conflicting phase is active.

Refer to Publication 46, Chapter 4.6 (Traffic Signals near Grade Crossings) and MUTCD, PART 8.

11.4.1 Pre-Signal

Pre-signals are traffic control signal faces that control traffic approaching a grade crossing in conjunction with the traffic control signal faces that control traffic approaching a highway-highway intersection beyond the tracks. Supplemental near-side traffic control signal faces for the highway-highway intersection are not considered pre-signals.

MUTCD Section 8D.11 (paragraphs 01 & 02) provides the following guidance for use of pre-signals at or near grade crossings.

- ✓ If a grade crossing is near an intersection controlled by a traffic control signal and the Clear Storage Distance[2] is less than the design vehicle length, the use of pre-signals to control traffic approaching the grade crossing in the direction toward the intersection should be considered.
- ✓ If a grade crossing equipped with flashing-light signals, but without automatic gates, is located within 200 feet of an intersection controlled by a traffic control signal, a pre-signal should be provided.

Pre-signal operates continuously in coordination with downstream traffic control signal and should include green offset where the downstream signal remains green longer than the pre-signal to clear all vehicles from the crossing through the downstream intersection.

11.4.2 Queue Cutter Signal

A traffic control signal that is intended to prevent vehicular queuing across tracks at a grade crossing where traffic queuing occurs and is activated for one direction of travel by an approaching train, actuation from a downstream queue detection system, by time of day or a combination of any of these. Queue cutter signal is designed to detect the buildup of a queue of vehicles before the queue reaches to the Minimum Track

2 The distance available for vehicle storage measured between 6 feet from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway.

Clearance Distance[3] (MTCD). Queue cutter signal is interconnected with the railroad warning system allowing time for the queue cutter to change to red before the railroad flashing lights are activated.

If clear storage distance is more than 450 feet, the use of queue cutter signal should be considered. A queue cutter signal is not operated as a part of a downstream intersection traffic control signal but is an independently controlled traffic control signal. A queue cutter signal can be an effective means of traffic control to reduce the likelihood of vehicles stopping within the minimum track clearance distance. Queue cutter signals must use downstream queue detection. Self-checking loop processor system must be used and in case of a system failure, queue cutter signal must flash red. A STOP HERE ON RED sign must be installed near the queue cutter signal or stop line.

11.5 Queue Preemption

Where queue spillback is a concern and deemed necessary to address with signal operations, queue preemption may be utilized. Use cases for queue preemption include:

- ✓ At the end of limited access ramp sections to prevent queues vehicles from affecting the limited access facility mainline.
- ✓ At the end of turn lanes to prevent the turning queue from extending into through vehicle lanes
- ✓ To clear out spillback congestion emanating from downstream intersections

Queue preemption should only be used to prevent occasional queuing issues and should not be used for recurring queue issues on every cycle. Alternative timing solutions should be used to address recurring queue issues.

Queue preemption operates with a detection zone located where the queue will begin to impact safety or traffic flow upstream of the intersection. If the detector is continuously occupied for a predetermined amount of time, the signal may be preempted, and the phase of concern will be activated. The detection zone location and occupancy actuation time should be approximated by factoring in the estimated queue discharge rate, vehicle headways, and average vehicle arrival rate to avoid the back of queue reaching the point of conflict.

11.6 Transit Signal Priority

Transit signal priority (TSP) may be used to improve transit performance and reliability for buses or light-rail services. Traffic signal timings can be modified through TSP in the following ways:

- ✓ Green/Phase Extension
- ✓ Red Truncation/Early Green
- ✓ Phase Insertion
- ✓ Sequence Change
- ✓ Phase Skipping

Transit priority shall not supersede emergency preemption. Like emergency preemption, TSP requires emitters located within the transit vehicles to communicate with the traffic signal controller. The effectiveness of TSP should be evaluated and recommended in an engineering study and approved by the appropriate District Traffic Engineer prior to considering deployment.

Refer to STM2, Chapter 10 for more information on the application of TSP.

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3 The length along a highway at one or more railroad or light rail transit tracks, measured from the highway stop line, warning device, or 12 feet perpendicular to the track center line, to 6 feet beyond the track(s) measured perpendicular to the far rail, along the center line or edge line of the highway to obtain the longer distance.

12. SUPPORTS

12.1 General

Overhead-mounted vehicular traffic signals are attached to mast arms or suspended from span wire between strain poles. Post-mounted vehicular traffic signals and all pedestrian signals are mounted to the mast arm pole, strain pole, or pedestal poles. Pedestrian stub poles can be used for mounting pedestrian push buttons.

While the main component of a traffic signal support is the pole structure itself, there are also other necessary components that make a complete support installation (including the foundation, pole/base connections, welded/bolted support connections, span/tether wire, bolts/washers/nuts, and support paint/coating).

It is important that a traffic signal design accomplish the following:

- ✓ Locate signal supports for operational and safety effectiveness (see **Section 12.2**)
- ✓ Ensure signal supports are designed to support the necessary loading (see **Section 12.2.3**). The use of standard support designs and materials (pole, mast arm, foundation designs, etc.) simplifies the checks necessary for the structural design and reduces the procurement timeline.

See **Chapter 1** for items which are physically attached to traffic signal support structures, but do not directly pertain to the operation or function of the traffic signal.

For addition information related to Supports, see the following references:

- ✓ Traffic Signal Portal – Manufacture Structure Drawings
- ✓ Publication 46 (Chapter 4)
- ✓ Publication 148 (TC-8801, TC-8803)
- ✓ Publication 408 (Section 951)
- ✓ ECMS Master Items (0951)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

12.2 Location of Supports

The location of fixed traffic signal supports should consider the below items; justification for designs which cannot comply with the criteria below shall be documented.

- ✓ Locating within available right-of-way or easements.
- ✓ Locating to minimize risk of supports being struck by errant vehicles (see **Section 12.2.1**).
- ✓ Ensuring the signal heads attached to the support meet all location requirements (see **Chapter 16**).
- ✓ Avoiding conflicts between the signal support foundation and underground utilities.
- ✓ Maintaining the pedestrian accessible route along sidewalks and ensuring pedestrian push buttons are in accordance with MUTCD and PROWAG requirements. Except when also used to mount pedestrian detectors, supports for overhead signals should be located behind the sidewalk area to minimize obstructions to pedestrians and vehicular traffic.
- ✓ Minimizing arm or span length.
- ✓ Utilizing standard pole, arm, and/or foundation designs.
- ✓ Minimizing the number of poles required for placement of vehicular signal faces, pedestrian signal faces, vehicular detection sensors, and pedestrian push buttons.

The potential hazard of fallen traffic signals, cables, or mast arms in the traveled roadway may present a safety problem equal to that of non-yielding roadside obstructions. Accordingly, supports for overhead signals should not be breakaway. Moreover, fixed overhead signal supports, base-mounted controller cabinets, and other rigidly supported appurtenances should be located outside the pedestrian accessible route.

Traffic signal pedestals or poles of yielding or breakaway design may be used as supports for non-overhead signals and appurtenances.

Where new traffic signal supports are being installed to replace existing supports, designers should consider how traffic control will be maintained when the new supports are erected prior to the old signal faces being deenergized. Usually, the new signal support should be placed behind the existing support to avoid obstructing the existing signal faces.

12.2.1 Support Setback Requirements

The scenarios discussed on the following Exhibits below should be followed for placement of traffic signal supports, except the exhibits do not apply to pedestrian stub poles which must be located so the pushbutton placement complies with ADA requirements (see MUTCD Chapter 4I and Publication 111 (TC-8803)). These scenarios are not all inclusive. Use engineering judgment to determine placement in extenuating circumstances.

Please refer to Publication 148 (TC-8800 Series) for other types of support placements that are not mentioned in this section.

Exhibit 12-1	Curbed Roadway and Speeds of 35 mph or less
Exhibit 12-2	Curbed Roadway and Speeds Greater Than 35 mph
Exhibit 12-3	No Curbs and Shoulder 0’ to 8’
Exhibit 12-4	No Curbs and Shoulder Greater Than 8’

Exhibit 12-1 Curbed Roadway and Speeds of 35 mph or Less

A minimum clearance of 2 feet should be maintained between the face of full height barrier curb and the support itself or any signal equipment to be installed on the signal support, whichever is closer to the curb.

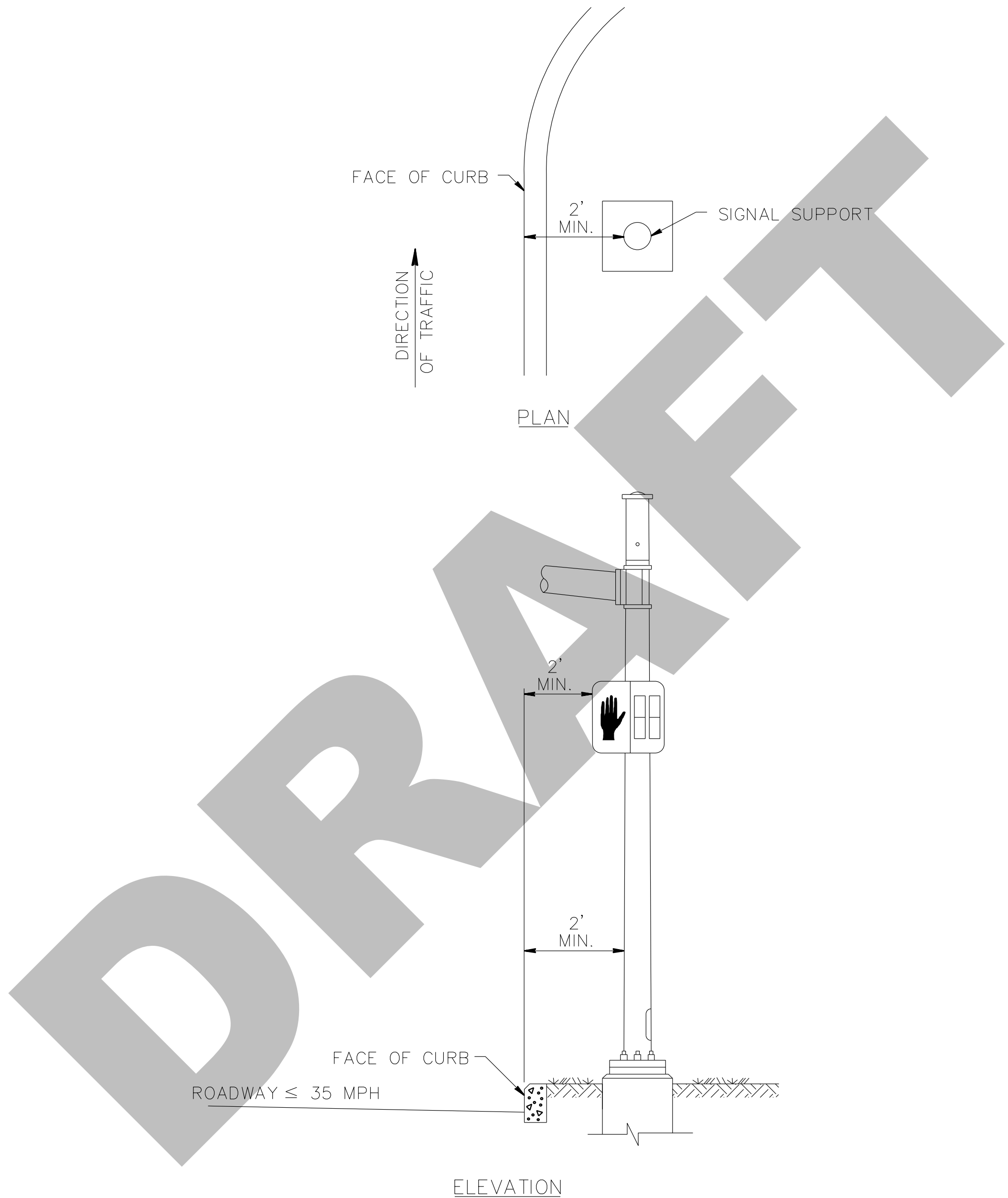
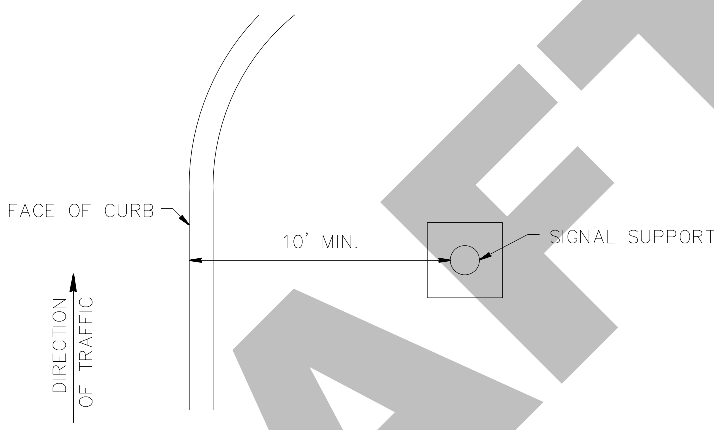


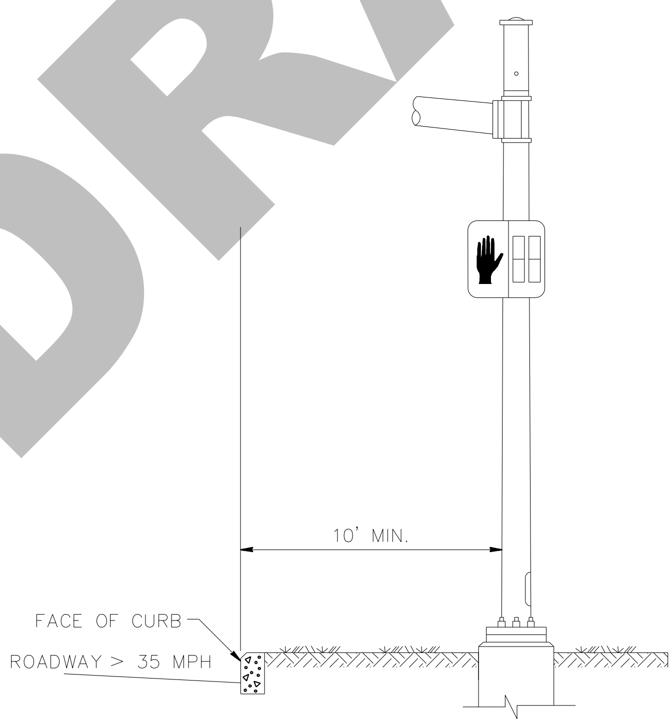
Exhibit 12-2 Curbed Roadway and Speeds Greater Than 35 mph

The signal support should have a minimum clearance of 10 feet from the face of curb.

- ✓ On **rural** highways, every effort should be made to attain the clear roadside concept that will not compromise vehicular safety.
- ✓ On **urban** streets, every effort should be made to obtain the 10 feet clearance, unless engineering judgment, other requirements (e.g., ADA, Right-of-Way, etc.), or documented extenuating circumstances dictate otherwise.
- ✓ For a roadway cross-section that includes curbed shoulder and speeds greater than 35 mph, the signal support should have a minimum clearance of 10 feet from the travel lane and 2 feet from the face of curb.



PLAN



ELEVATION

Exhibit 12-3 No Curbs and Shoulder 0' to 8'

The signal support shall have a minimum clearance of 10 feet from the travel lane. On rural highways, every effort shall be made to attain the clear roadside concept that will not compromise vehicular safety.

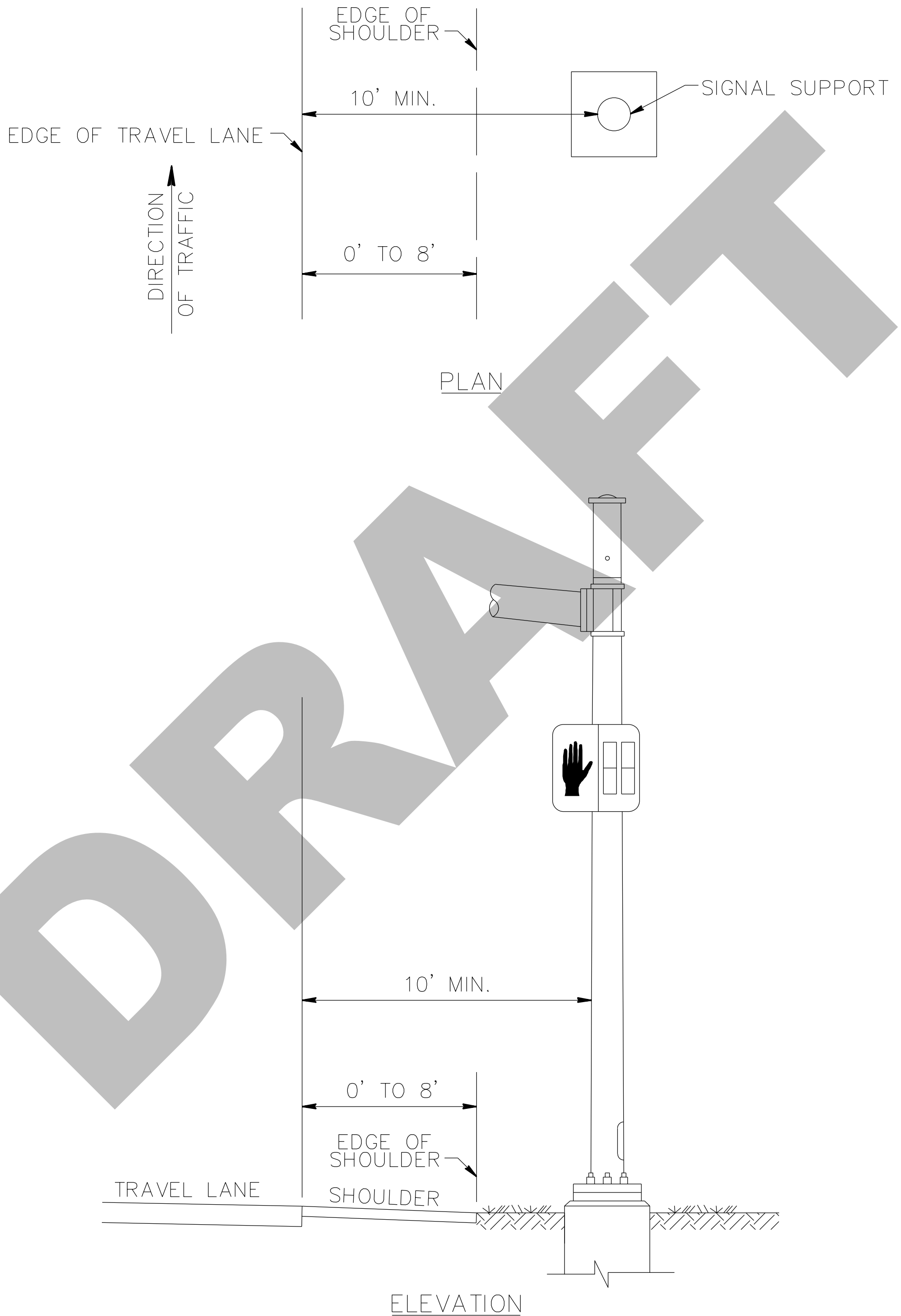
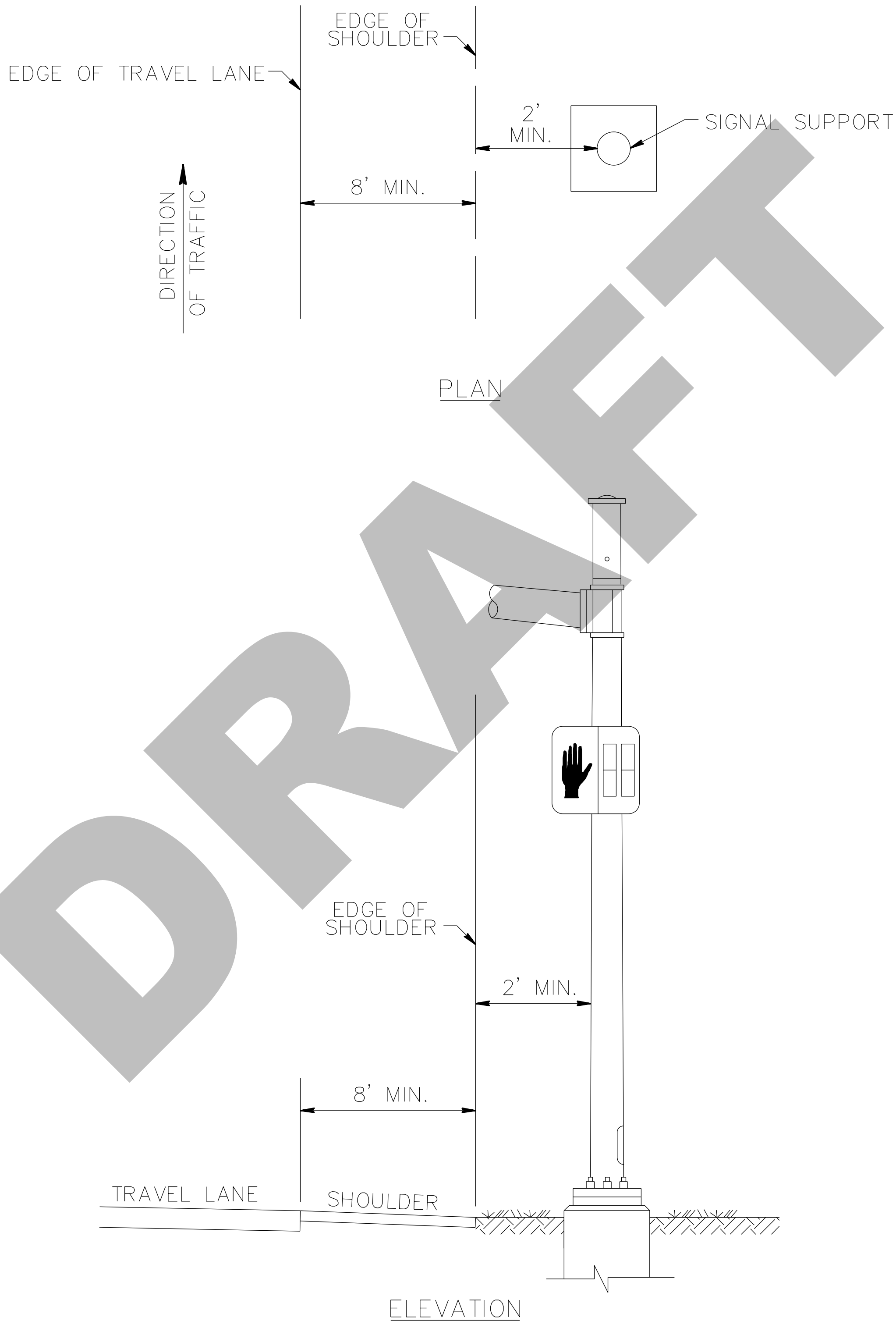


Exhibit 12-4 No Curbs and Shoulder Greater Than 8’

The signal support shall have a minimum clearance of 2 feet from the shoulder. On rural highways, every effort shall be made to attain the clear roadside concept that will not compromise vehicular safety.



12.2.2 Islands and Medians

The installation of fixed supports for overhead traffic signals and pedestrian poles in islands and medians should be avoided, if possible. However, fixed supports or any signal equipment to be installed on the signal support, whichever is closer to the curb, may be located in islands or medians when necessary to maintain the effectiveness of the signal display provided the designer can provide a set-back as indicated in **Exhibit 12-5**. For more information refer to the AASHTO Green Book.

Exhibit 12-5 Traffic Signal Support Setback in Islands and Medians

Roadway Speed Limit	Traffic Signal Support Setback in Islands or Medians	
	Curbed Island[2]	Uncurbed Island[3]
35 mph or less[1]	2 feet from face of curb	10 feet from edge of travel lane
Greater than 35 mph	10 feet from edge of travel lane	

[1]Speeds less than 35 mph also need to consider vehicle turning patterns and roadway geometry.
[2]Applies where the curb for the island or median is 4 inches or greater.
[3]Applies to uncurbed islands, islands with mountable curb, and islands where vertical curb is less than 4 inches.

12.2.3 Placement Behind Guide Rail

If a traffic signal support is placed behind guide rail, refer to Chapter 12 of Design Manual 2 (Publication 13M) to ensure the traffic signal support does not impact the deflection and performance of the guide rail.

12.3 Design Criteria for Fabrication

The criteria stated herein shall be utilized in the design of galvanized steel structures used for the support of traffic signals for fabrication. This section is intended to define standard structural loadings for typical signal supports using standard design items. If a traffic signal support will exceed the loadings in this chapter or include other features such as decorative elements, a specialized design supported by structural calculations is required.

12.3.1 Design Criteria for All Support Structures

See **Section 12.3.2** "Design Criteria for Strain Poles," for additional requirements for strain poles.

Vertical poles and mast arms shall be designed and constructed in accordance with the 2001 AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals" including interim specifications (2002, 2003, and 2006), hereafter referred to as the "AASHTO Specifications." In this part, the AASHTO Specifications article numbering system is followed. Where new sections, articles, equations, figures, or tables have been added, the suffix P is used to designate "Pennsylvania Article." All references to the AASHTO Specifications sections, articles, equations, figures, or tables carry the prefix A, except where noted. References to the AASHTO Specifications commentary carry the prefix AC, except where noted.

> The design criteria for traffic signal supports is currently based on the 2001 AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals" with the 2002, 2003, and 2006 interim updates.
>
> PennDOT is developing alternative design standards using the AASHTO "LRFD Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals." When the LRFD design criteria are established, Chapter 12 of Pub 149 will be updated along with Publication 148, TC-8800 Series.

- ✓ Provide base and connection plates as indicated in Publication 148, TC-8801 sheet 10 of 10.
- ✓ Provide a complete joint penetration weld for the connection of the column or shaft to the base plate and

the connection of the arm to the flange plate for mast arm and strain pole structures only (this is not a requirement for pedestal poles).

- ✓ Attach a back-up ring as specified in the AASHTO Specifications (Table 11-2, Detail 11). The back-up ring shall be attached to the plate with a full-penetration weld or with a continuous fillet weld around the interior face of the back-up ring.
- ✓ For pole diameters 18 inch and larger, seal the top of the backing ring with a continuous 1/8- inch fillet weld to seal off the area between the ring and the pole. For pole diameters less than 18 inch, seal the top of the backing ring with a continuous bead of caulk after galvanizing to seal off the area between the ring and the pole.
- ✓ Provide 6-inch complete penetration longitudinal shaft welds at the base plate connection.
- ✓ The use of mast arm plate socket connections with fillet welds are prohibited.
- ✓ Provide welded connections as shown in Publication 148, TC-8801 sheet 10 of 10.
- ✓ The minimum thickness for the main column and mast arms shall be 3/16 inch (7 gauge). When the main column and mast arms are less than 5/16 inch, submit a non-destructive testing plan where UT testing is required to be performed to the Structural Materials Division, Bureau of Bridge.
- ✓ Provide a built-up box on columns with mating splice plate for mast arm connection as shown in Example 8 of Figure 11-1(c) in AASHTO Specifications. With prior Department approval, alternate mast arm connections as shown in the AASHTO Specifications (Example 16 of Figure 11-1(c)) are permitted.

Introduction

Applicable Specifications

The following shall replace the first sentence of A1.3.

The following specification documents shall be referenced for additional information on design, materials, fabrication, and construction:

The following shall supplement A1.3.

PennDOT Publication 408.

General Features of Design

Roadside Requirements for Structural Supports

Breakaway Supports

The following shall supplement A2.5.2.

Breakaway supports or yielding-type supports shall not be used for traffic signal support structures, except when permitted by this Handbook and specified in the plans and/or specifications for the project.

Loads

Dead Load

The following shall supplement A3.5.

Dead loads for signs, traffic signals, backplates, brackets, and all appurtenances shall be as given in this Handbook.

Live Load

Delete A3.6.

Wind Load

The following shall replace A3.8.

Wind load shall be the pressure of the wind acting horizontally on the supports, signs, luminaires, traffic signals, and other attachments computed in accordance with this Handbook and AASHTO Appendix C.

Steel Design

Details of Design

Slip Type Field Splice

The following shall replace A5.14.3.

Telescoping (slip-fit) splices for mast arms, which rely solely on friction between the members for their connection, will not be permitted. A thru-bolt must be provided for a positive connection when such slip fit connections are used.

Welded Connections

The following shall supplement A5.15.

Transverse welds shall not be used to splice pole sections.

Anchor Bolts

Design Basis

The following shall supplement A5.17.3.

A minimum of six (6) anchor bolts shall be required.

Bending Stress in Anchor Bolts

The following shall replace A5.17.6.4.

The clearance between the bottom of the leveling nuts and the top of the concrete foundation shall not be greater than one bolt diameter.

Minimum Protection for Structural Steel

General

The following shall replace the first sentence of A5.18.1.

Steel structures shall be protected from the effects of corrosion including those manufactured of high strength steel, by means of galvanizing in accordance with ASTM A 123 (AASHTO M 111). Accessories and hardware shall also be protected from the effects of corrosion by means of galvanizing in accordance with ASTM A 153 (AASHTO M 232).

Fatigue Design

Fatigue Importance Factors

The following shall supplement A11.6.

Traffic signal structures with mast arms less than or equal to 60 feet shall be designed for Fatigue Category II. Traffic signal structures with mast arms greater than 60 feet shall be designed for Fatigue Category I. Strain poles should be considered as an alternative to traffic signal structures with mast arms greater than 60 feet.

Fatigue Design Loads

Galloping

The following shall replace A11.7.1.

The dead load and wind surface area of a standard mitigation device shall be considered in the design of cantilevered traffic signal support structures in accordance with the standard drawings. The mitigation device should be installed only within the 180-day monitoring period in accordance with the standard drawings.

Truck-Induced Gust

Delete A11.7.4.

Design Aids

This section shall supplement AASHTO Appendix B.

Stresses for Tubular Sections

The following shall supplement **Exhibit 12-6**:

Maximum shear stress due to torsion (f_{vt}) for round stepped tubes (hot-swaged shrink fit) shall be computed using the following formula:

$$f_{vt} = \frac{M_z k_t}{6.28R^2 t}$$

Where:

f_{vt} = Maximum shear stress due to torsion, lb/in2

M_z = Total torsional moment, in-lb

R = Radius at mid-thickness of smaller diameter tube wall, in

t = Thickness of smaller diameter tube wall, in

k_t = Stress concentration factor due to change in tube diameter (use kt = 1.20)

Alternate Method for Wind Pressures

This section shall supplement AASHTO Appendix C.

Wind Load

The following shall replace the second sentence of the first paragraph of C.2:

The design wind pressures shall be computed using the wind pressure formula, Eq. C-1, for a fastest-mile wind speed (Vfm) of 80 MPH as shown in Figure C-3.

12.3.2 Design Criteria for Strain Poles

See Section **12.3.1** for requirements that apply to all support structures.

Allowable Unit Stresses

The design and construction of strain pole structures shall conform to the allowable unit stresses provided in Section 5 – Steel Design in the 2001 AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals," hereafter referred to as the "AASHTO specifications."

Refer to the Traffic Signal Portal for **Analysis and Design Workbooks**.

Span and Tether Wires

Span wire shall conform to ASTM A 475, Class A, Siemens-Martin Grade, or ASTM B 416. Tether wire shall conform to ASTM A 475, Class A, Common Grade.

Strain poles shall be designed for a sag of 5% of the span distance between poles under dead load. In computing dead load, the mass of the span and tether wire shall be based on a value of 1 lb/ft [load=1 lb/ft].

Strain Pole Deflection

The maximum horizontal deflection of strain poles, at the span wire connection, due to dead loads only, shall be 2.5% of the distance measured from the base of the strain pole to the span wire connection point.

When strain poles support more than one span, the resultant horizontal deflection, due to the combined action of all span wire loadings, shall not exceed the above.

Stringing Tension

To determine the stringing tension in the span wire system between the two strain poles, due to the dead loads of traffic signals, traffic signs, signal wire, and other attachments, the following procedure shall be used:

- ✓ Determine the effective load of each item on the span wire (traffic signal, traffic sign, signal wire, and/or other attachment) by adding to the load of each item, the load of the span wire for a length equal to half the distance in each direction to the next adjacent item or strain pole.
- ✓ Determine the vertical reaction at each strain pole structure by summing the moments (due to the effective load of each item and the vertical reaction at the strain pole) about the other strain pole structure. As a check, the sum of the vertical reactions of the two strain pole structures should be equivalent to the sum of the effective loads of each item.
- ✓ Determine the lowest point due to sag in the span wire by finding the point at which the slope of the span wire changes sign (which will be at the location of one of the load items, most probably a traffic signal). Beginning with the vertical reaction at one of the strain pole structures, determine the vertical shear acting on the span wire by successively and algebraically adding the effective load of each item in moving across to, and ending with the vertical reaction of, the other strain pole structure. The low point in the span wire is the point at which the sign of the vertical shear changes (which indicates that the slope of the span wire has changed). If the vertical shear happens to be zero at any point between the strain pole structures, this indicates that two load items are at the same elevation and share the low point of the span wire. As a check, the vertical shear must begin and end at zero at the constituent strain pole structures.
- ✓ Determine the stringing tension by evaluating the summation of moments about the low point in the span wire. Since the span wire cannot resist bending moment, set the sum of the moments about the low point of all forces acting on the span wire between the low point and either of the strain pole structures equal to zero, where the horizontal pull acting on that strain pole structure is an unknown force acting at a distance equal to the maximum allowable sag (5% of the span distance) above the low point of the span wire. The stringing tension in the span wire can then be determined by solving the summation for the unknown horizontal force acting on each of the strain pole structures.
- ✓ In the case where a strain pole structure supports wires and loading from more than one span, determine the stringing tension of each span wire that it supports, and combine these separate stringing tensions to produce the maximum resultant stringing tension acting on the given strain pole structure to evaluate the required design and construction considerations.

Sag

To determine the sag at any load item on the span wire, assume that the span wire follows a straight line between adjacent load items which slopes at a rate equal to the vertical shear at the given load item divided by the horizontal stringing tension. The change in elevation between successive load items is then equivalent to the slope of the span wire between these two load items multiplied by the distance between them. As a check, the elevation of the span wire connection at the second strain pole structure must be obtained by beginning with the connection at the first strain pole structure and successively adding the respective elevation increments in moving across the span wire.

Application of Wind Load (see Figure B-1)

W_h for strain pole structures may be applied as a series of concentrated loads along the span wire normal to the span, and W_p (normal to sign faces) shall be applied normal to the span. Strain poles (assuming a single span wire is attached to the support) shall be designed for wind loads W_h and W_p, (normal to the sign faces) applied normal to the span. Only the wind load, W_v, shall account for wind from any direction. The basic load, BL (see Section 3.9.3 of the AASHTO specifications) normal to the span shall be the effect from the wind load W_v, applied at the center of pressure of the support. The full transverse component shall be applied to the support.

Design Tension

For a strain pole structure with the ends of the span wire at the same elevation, the following approximate method may be used to determine the force component in the span wire parallel to the span for a wind loading normal to the span.

The span wire loadings (dead load, wind, and ice) are applied as a series of concentrated loads along the wire to represent the actual uniform loadings with a minimum of five equal concentrated loads recommended. The tension forces throughout the wire now become a series of vectors with the vector component in the direction of the span of equal magnitude for each vector. Knowing that the ratio of the vector length over the vector force is proportional to the ratio of the vector component length over a component force, the length of each vector may be expressed by the following equation:

$$\sqrt{(F_x^2 + F_y^2 + F_z^2)}\frac{d_x}{F_x}$$

Where:

$\sqrt{(F_x^2 + F_y^2 + F_z^2}$ = Resultant Vector

F_x = Vector force component in direction of span

F_y = Vector force component in vertical direction

F_z = Vector force component in direction of wind

d_x = Vector length component in direction of span*

(* If sag is small in relation to span length, neglect any displacements in direction of span.)

F_y and F_z for each vector (between concentrated loads of wire, signals, signs, etc.) may be found by the equations of equilibrium for a body in space. The total length of the span wire may be found for a given sag for a loading of dead load alone. The sum of all the vector lengths is equated to the total length of the span wire. F_x may be solved for since it is the only unknown in the equation. Several trials may be necessary to closely approximate the actual value.

The following illustrates a procedure for determining the vector components F_x and F_y:

In **Exhibit 12-6**:

$F_{z1} = R_{z(L)}$

$F_{z2} = R_{z(L)} – W_A$

$F_{z3} = R_{z(L)} – W_A – W_B$

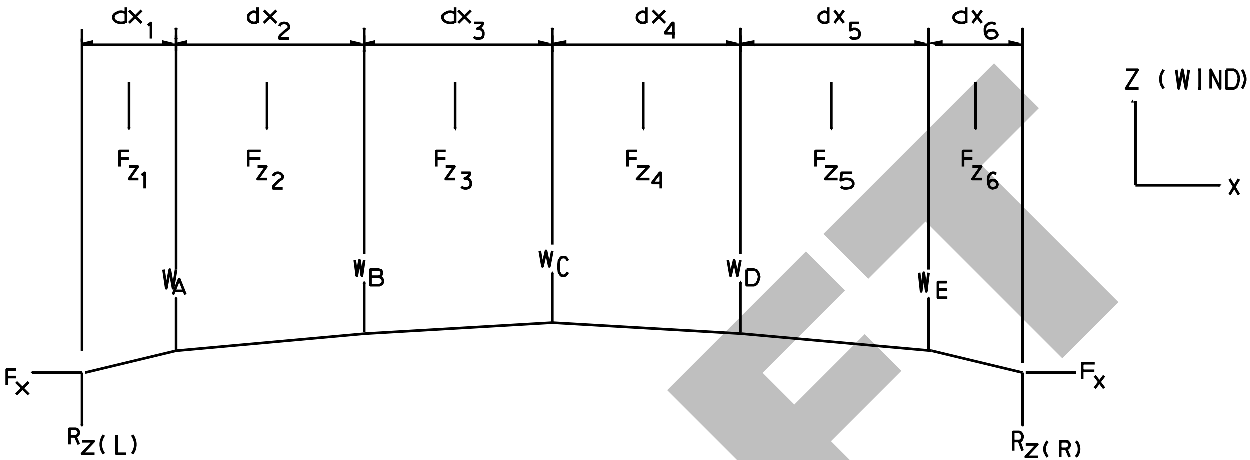
$F_{z4} = R_{z(R)} – W_E – W_D$

$F_{z5} = R_{z(R)} – W_E$

$F_{z6} = R_{z(R)}$

The total length of span wire = $\sqrt{F_x^2 + F_{y1}^2 + F_{z1}^2}\,\frac{d_{x1}}{F_x} + \sqrt{F_x^2 + F_{y2}^2 + F_{z2}^2}\,\frac{d_{x2}}{F_x} + \cdots$

Exhibit 12-6 Force Diagram



The reactions $R_{z(L)}$ and $R_{z(R)}$ may be determined by summing moments about a vertical line at the right end and left end of the span wire, respectively. A similar procedure is used in determining F_y components. The reactions in the vertical direction ($R_{y(L)}$ and $R_{y(R)}$) may be determined by summing moments about a horizontal line to the ends of the span wire.

The above procedure neglects the effect of the strain pole deflection. This results in excessively conservative values for the wire's force component in the direction of the span (F_x). The effects of the strain pole deflections on the span wire's force component should be considered by calculating the deflections of the strain pole at the span wire connection, in the direction of the span, and recomputing the wire's force component, as above, after adjusting to the span to account for the strain pole deflections. The reduction in tension does not apply to dead load tension. Given the wire is installed with the specified sag after the pole dead load deflection already has occurred, the wire tension is not reduced.

Design Stresses

Strain pole structures shall be designed and constructed to withstand maximum stresses based on Group I, Group II, and Group III loadings (whichever controls), as defined in the AASHTO specifications. In the case of strain poles which support more than one span, the resultant of the respective tensions for each span shall be used in combination with the wind applied in the direction which produces maximum stress.

12.3.3 LRFD Design Criteria for All Support Structures

This LRFD section will be incorporated into a future edition of the publication. The content is being developed under a separate effort which isn't complete yet.

12.3.4 Acceptance of Structural Designs

The manufacturer shall submit design calculations and detailed structural drawings for those signal supports that are proposed to be supplied in Pennsylvania. In addition, the manufacturer must provide PennDOT with certification, from a professional engineer registered in Pennsylvania, indicating that the designs comply with PennDOT's criteria and are adequate to support the loads specified therein.

After acceptance by PennDOT, the manufacturer will not be required to submit design calculations or structural drawings on a project-by-project basis, except for signal supports which exceed the standard structure loadings indicated herein. For these special designs, a submission of design calculations, structural drawings and the professional engineer's certification must be made for each different support.

Shop drawings will be required for all traffic signal supports on each project (PennDOT Approved Shop Drawings).

For structural design computations, use PennDOT's signal analysis spreadsheets which include:

- ✓ Mast Arm Analysis provides a tool to evaluate whether a traffic signal complies to loading requirements specified within this Chapter and TC-8801. If the loading is exceeded within this spreadsheet, then a special traffic signal structural support and foundation design would be needed.
- ✓ Span Wire Analysis provides a tool to determine the appropriate span wire tension by providing geometric specific information. This will ensure that appropriate design tensions are used for span wires.
- ✓ Strain Pole Analysis provides a tool to evaluate whether a traffic signal complies to loading requirements specified within this Chapter and TC-8801. If the loading is exceeded within this spreadsheet, then a special traffic signal structural support and foundation design would be needed.

12.4 Standard Structural Loading

Exhibit 12-7 depicts the typical loading configurations for strain pole structures. **Exhibit 12-8** depicts the typical loadings for mast arm structures, with the specific loads shown in **Exhibit 12-9**, **Exhibit 12-10**, and **Exhibit 12-11**.

Exhibit 12-7 Strain Pole Structure

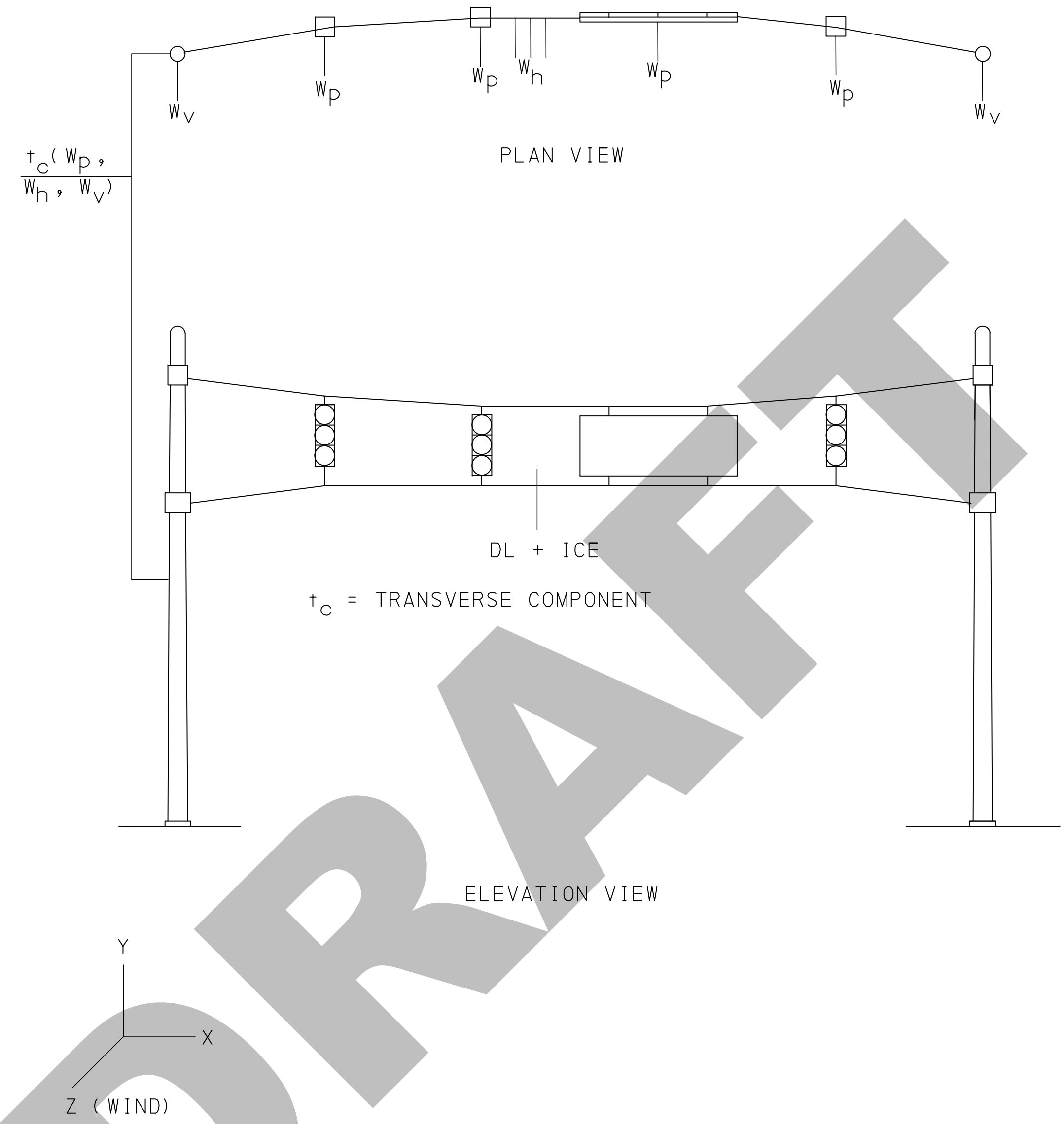
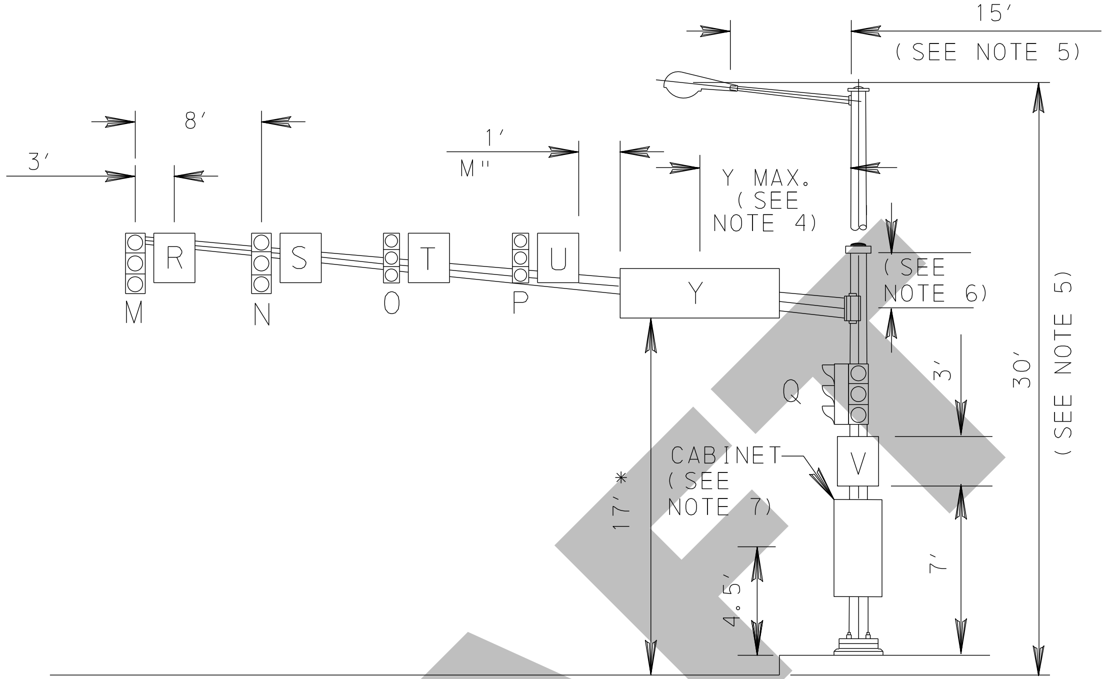


Exhibit 12-8 Mast Arm – Standard Structure Loading



* CLEARANCE BETWEEN ROADWAY AND LOWEST SIGN OR SIGNAL HEAD

NOTES :

1. THIS DRAWING IS FOR ILLUSTRATIVE PURPOSES ONLY IN ORDER TO SHOW HORIZONTAL AND VERTICAL DIMENSIONS. SEE MAST ARM IN STANDARD STRUCTURE LOADING TABLE FOR AREAS AND LOADS TO BE USED FOR EACH ITEM UNDER STANDARD STRUCTURE LOADING. SIGNAL HEADS DEPICTED ON THIS DRAWING MAY DIFFER FROM THE SIGNAL HEADS SHOWN IN THE STANDARD STRUCTURE LOADING TABLE. (FOR EXAMPLE, THIS DRAWING MAY DEPICT A 3-SECTION HEAD WHERE A 5-SECTION HEAD IS USED IN THE TABLE.)

2. ASSUME ALL OVERHEAD SIGNALS HAVE 12" LENSES WITH BACKPLATES 5" BORDER.

3. ASSUME SIGNS R, S, T, U AND V ARE 30" BY 36". FOR MASTARM LENGTHS OF 10′ OR LESS, SIGN Y IS ASSUMED TO BE 72" BY 21". FOR ALL OTHER MAST ARM LENGTHS, SIGN Y IS ASSUMED TO BE 96" BY 32".

4. Y MAX. IS THE MAXIMUM ALLOWABLE DISTANCE FROM THE SHAFT TO THE CENTROID OF SIGN Y.

5. FOUNDATION DESIGN IN PUBLICATION 148M ASSUMES LUMINAIRES, WHEN USED, HAVE A 30′ MOUNTING HEIGHT AND A 15′ ARM LENGTH.

6. WHEN THE SHAFT OF THE SUPPORT IS EXTENDED IN LENGTH BY 36" MINIMUM TO ALLOW A FUTURE LUMINAIRE VIA AN OVERLAP SLIP JOINT, PROVIDE APPROPRIATE FOUNDATION AND SUPPORT DESIGN.

7. FOUNDATION DESIGN IN PUBLICATION 148 ASSUMES A CABINET, WHEN USED, HAS A 4′-3" HEIGHT, 2′-6" WIDTH, 1′-10" DEPTH AND DEAD LOAD OF 281 lbs..

Note: For standard structure loading, place indicated signals and signs beginning at the furthermost point on the arm and then proceeding toward the shaft in accordance with the dimensions shown on **Exhibit 12-8** and Publication 148, TC-8801.

Exhibit 12-9 Mast Arm – Structural Loading Tables

Arm Length (feet)		Signals					Signs						Y max (ft)
		M	N	O	P	Q	R	S	T	U	V	Y	
0-10	W	70				123					39	87	5.2
	A	8.76				8.82					7.48	10.5	
>10-15	W	70				123	39				39	106	6.6
	A	8.76				8.82	7.48				7.48	21.33	
	W	70				123					39	106	9.5
	A	8.76				8.82					7.48	21.33	
>15-20	W	97	70			123	39				39	106	6.6
	A	13.89	8.76			8.82	7.48				7.48	21.33	
>20-25	W	97	70			123	39	39			39	106	8.5
	A	13.89	8.76			8.82	7.48	7.48			7.48	21.33	
>25-30	W	97	70	97		123	39	39			39	106	8.5
	A	13.89	8.76	13.89		8.82	7.48	7.48			7.48	21.33	
	W	97	70			123	39	39			39	106	13.5
	A	13.89	8.76			8.82	7.48	7.48			7.48	21.33	
>30-35	W	97	70	97		123	39	39	39		39	106	10.8
	A	13.89	8.76	13.89		8.82	7.48	7.48	7.48		7.48	21.33	
>35-40	W	97	70	70	97	123	39	39		39	39	106	7.9
	A	13.89	8.76	8.76	13.89	8.82	7.48	7.48		7.48	7.48	21.33	
	W	97	70	70	70	123	39	39			39	106	10.8
	A	13.89	8.76	8.76	8.76	8.82	7.48	7.48			7.48	21.33	
	W	97	70	97		123	39	39	39		39	106	15.7
	A	13.89	8.76	13.89		8.82	7.48	7.48	7.48		7.48	21.33	
>40-45	W	97	70	70	97	123	39	39		39	39	106	12.8
	A	13.89	8.76	8.76	13.89	8.82	7.48	7.48		7.48	7.48	21.33	
	W	97	70	70	70	123	39	39			39	106	15.7
	A	13.89	8.76	8.76	8.76	8.82	7.48	7.48			7.48	21.33	
	W	97	70	97		123	39	39	39		39	106	20.7
	A	13.89	8.76	13.89		8.82	7.48	7.48	7.48		7.48	21.33	
>45-50	W	97	70	70	97	123	39	39		39	39	106	17.7
	A	13.89	8.76	8.76	13.89	8.82	7.48	7.48		7.48	7.48	21.33	
	W	97	70	70	70	123	39	39			39	106	20.7
	A	13.89	8.76	8.76	8.76	8.82	7.48	7.48			7.48	21.33	
	W	97	70	97		123	39	39			39	106	28.5
	A	13.89	8.76	13.89		8.82	7.48	7.48			7.48	21.33	
>50-60	W	97	70	70	97	123	39	39		39	39	106	27.9
	A	13.89	8.76	8.76	13.89	8.82	7.48	7.48		7.48	7.48	21.33	
	W	97	70	70	70	123	39	39			39	106	30.8
	A	13.89	8.76	8.76	8.76	8.82	7.48	7.48			7.48	21.33	
	W	97	70	97		123	39	39			39	106	38.7
	A	13.89	8.76	13.89		8.82	7.48	7.48			7.48	21.33	

Notes: Where multiple configurations are shown within a range of arm lengths
W = Load (pounds) – assumes aluminum signal housing
A = Wind Area (ft^2)

Exhibit 12-10 Loads and Projected Wind Areas for Traffic Signal Heads

Lens Size– in All Sections	Signal Configuration (1)	Signal Sections Each Direction	Directions	Load - Pound (lb) With Backplate (2)	Wind Area - Square feet (ft^2) With Backplate (3)	Wind Area - Square feet (ft^2) With Backplate (3)
8	A	5	1	69	N/A	12.46
8	B	3	2	88	N/A	8.79
8	C	3	2	90	N/A	11.51
8	B	4	2	109	N/A	10.69
8	C	4	2	111	N/A	14.32
8	B	5	2	131	N/A	12.46
8	D	3	3	129	N/A	11.51
8	E	3	3	129	N/A	14.23
8	D	4	3	159	N/A	14.32
8	E	4	3	159	N/A	17.95
8	F	3	4	168	N/A	14.23
8	F	4	4	209	N/A	17.95
12	A	3	1	70	8.76	N/A
12	A	4	1	89	11.04	N/A
12	A	5	1	97	13.89	N/A
12	B	3	2	129	8.76	N/A
12	C	3	2	131	13.41	N/A
12	B	4	2	165	11.04	N/A
12	C	4	2	167	17.24	N/A
12	B	5	2	189	13.89	N/A
12	D	3	3	190	13.41	N/A
12	E	3	3	190	18.06	N/A
12	D	4	3	242	17.24	N/A
12	E	4	3	242	23.44	N/A
12	F	3	4	249	18.06	N/A
12	F	4	4	318	23.44	N/A
12PED	A	2	1	-	-	-
12PED	C	2	2	-	-	-
18PED	A	1	1	-	-	-
18PED	C	1	2	-	-	-

Notes:

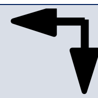
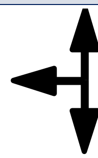
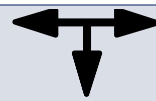
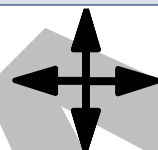
(1) Refer to **Exhibit 12-11**, Traffic Signal Configurations and Designations.

(2) A one-way 8-inch lens section is 9 pounds without attachment hardware and backplate. A one-way 12-inch lens section is 15 pounds without attachment hardware and backplate.

(3) The area for an 8-inch lens section without backplate is based on a 10-inch height by a 11.5-inch width, and the area for a 12-inch lens section without backplate is based on a 13.5-inch height by a 14.8-inch width. A 5-inch backplate border is used with 12-inch lens sections; and an 8-inch backplate border is used with 8-inch lenses.

(4) The area for a 2-section pedestrian signal assumes a 14.1-inch height and a 14.1-inch width for each section. The area of a 1-section pedestrian signal assumes an 18.9-inch height and an 18.9-inch width.

Exhibit 12-11 Traffic Signal Configurations and Designations

Designation	Traffic Signal Configuration	Directions
A		1
B		2
C		2
D		3
E		3
F		4

Direction of wind in all configurations

13. CONTROLLER ASSEMBLY

13.1 General

The controller assembly consists of a cabinet enclosure and its electrical and electronic subassemblies for controlling signal operation, including:

- ✓ Controller Unit (Timer)
- ✓ Signal Monitor (Conflict/Malfunction/Cabinet)
- ✓ Flasher Units and Flash Transfer Relay
- ✓ Load Switches or Switch Packs
- ✓ Power Supply and Circuit Breakers
- ✓ Bus or Serial Interface Units to provide serial communications.

The following subassembly features are defined by the applicable standard:

- ✓ Mounting: shelf and/or rack
- ✓ Cabinet communications: direct wire or serial bus

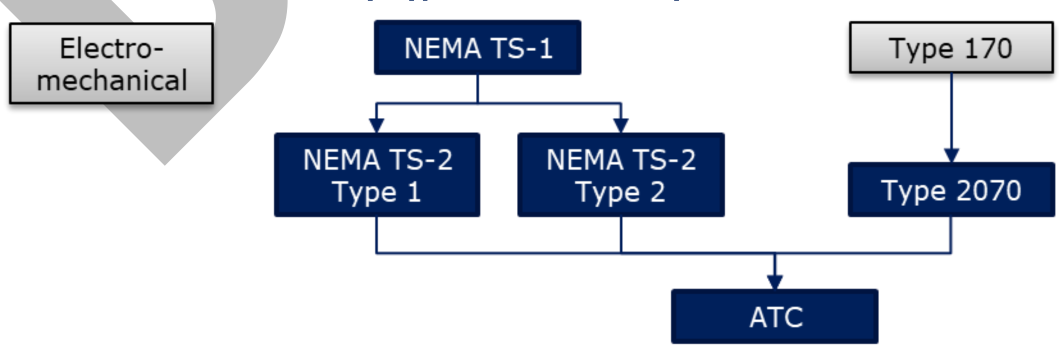
Other equipment may be located within the cabinet, but is tabulated and paid under separate bid items, such as:

- ✓ Backup power systems (see **Section 15.7**)
- ✓ Detector card racks (see **Chapter 17**)
- ✓ Preemption systems (see **Chapter 11**)
- ✓ Communication systems and peripherals (such as modems, switches, patch panels, see **Chapter 14**)

Historically, there have been two primary families of specifications for controller assemblies: NEMA and Model 170. Aspects of both standards are incorporated into the Advanced Transportation Controller (ATC) or Intelligent Transportation System (ITS) cabinet standard. Each standard includes a minimum number of inputs (detectors) and outputs (different signal indications which can be displayed at the same time).

Several types of traffic control signal controller assemblies are used in Pennsylvania, as shown in **Exhibit 13-1**. While the controller types shown in gray in **Exhibit 13-1** are no longer installed, many existing installations exist. When an existing controller assembly will be retained, the signal designer must consider compatibility for any new equipment being installed. Some newer controller assembly types provide backward compatibility with older types from the same family.

Exhibit 13-1 Controller Assembly Types used in Pennsylvania

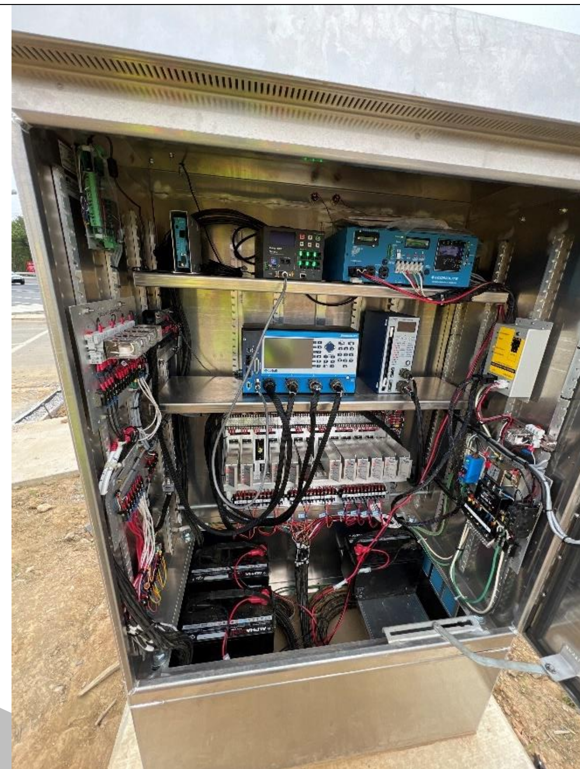


The controller unit is the heart of the controller assembly which selects and times signal displays. A controller unit might be compatible with one or more types of controller assemblies, such as an ATC controller unit which has A, B, and C connectors which is also compatible with a NEMA TS-1 or NEMA TS-2 Type 2 controller assembly. NEMA controllers include the application software to operate the intersection.

NEMA TS 1

Use function-based standards that allow for interchangeability between manufacturers.

Components are shelf-mounted within the cabinet.



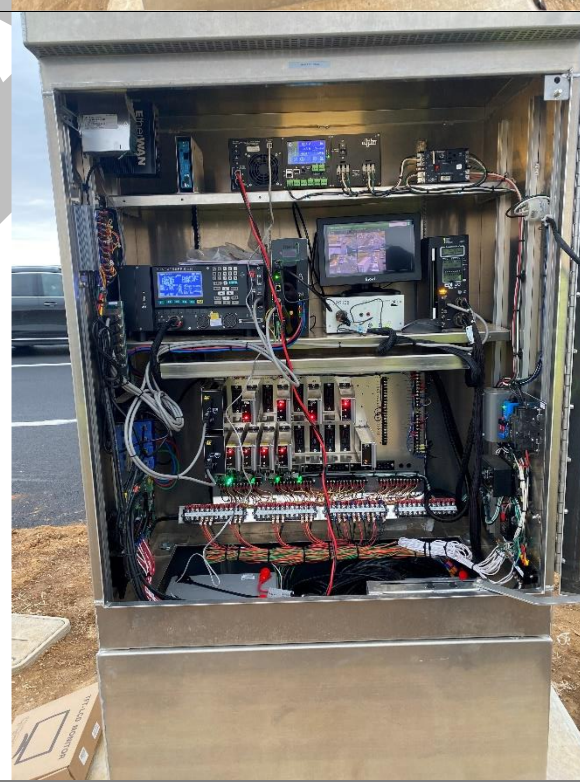
NEMA TS 2

NEMA TS2 was developed with two approaches to overcome the limitations of NEMA TS 1.

- ✓ TS 2 Type 1 units utilize a high-speed communications channel (SDLC) between all major equipment.
- ✓ TS 2 Type 2 units also have the SDLC data connector but also retain the TS1 type connectors for data exchange with the rear panel, allowing for a degree of downward compatibility.

TS 2 Type 2 controller units can be installed in a TS 1 controller assembly.

Both TS 2 Type 1 and TS 2 Type 2 use a Malfunction Management Unit (MMU) instead of a Conflict Monitor Unit (CMU), which provides advanced cabinet monitoring and diagnostics.



Type 170
The Type 170 controller standard differs from NEMA standards because it is a hardware standard only. The software to run the controller is supplied by separate, independent vendors. Additional standards were developed for ancillary equipment in the cabinet, and the cabinet itself. The Type 170 specification requires hardware to be interchangeable among manufacturers.

Type 170 controllers that were most often used in the City of Pittsburgh and Philadelphia. While no new installations are permitted by current specifications, many existing installations exist and must be maintained.

Type 2070
The Type 2070 controller standard was developed in response to rapid advances in computer technology. The hardware specifications were updated, but it maintains general compatibility with the Type 170 standard. The Type 2070 contains additional ports and more processing power than the Type 2070.

Advanced Transportation Controller (ATC)
The Advanced Transportation Controller (ATC) is developed by a joint working group to combine the best attributes of NEMA, Type 170, and Type 2070 standards, as well as incorporating emerging ideas and technology.

The ATC standard provides an open architecture that can support a wide variety of Intelligent Transportation Systems (ITS) applications including traffic management, safety, security, and other applications.

The ATC overcomes the Type 170 and Type 2070 hardware limitations by providing flexibility to evolve with technology, while still retaining interchangeability between manufacturers including connectors, user interface, software, communications, internal networks, and computer and modem modules.

For addition information related to Controller Assemblies, see the following references:

- ✓ Publication 148 (TC-8802)
- ✓ Publication 408 (Section 952)
- ✓ ECMS Master Items (0952)
- ✓ Publication 35 (Bulletin 15)

13.2 Controller Type Selection

When an existing controller assembly is not being replaced as part of a project, all new equipment specified and being installed must be compatible with the existing controller assembly type. If the existing controller assembly cannot accommodate the new equipment, the entire controller assembly may need to be replaced.

If a new controller assembly will be installed, the signal designer should determine the appropriate type of controller assembly considering the following:

- ✓ **System Communications -** if the traffic signal is part of a system, the controller assembly may need to communicate with and be compatible with controller assemblies at other intersections.
- ✓ **Maintenance -** the maintenance capabilities of the signal owner, including other types of controller assemblies they maintain, may be a crucial factor.
- ✓ **Future Expansion -** to allow for future expansion, the controller assembly should be capable of providing additional phases of operation and timing patterns regardless of the number of phases and timing patterns required in the initial design. Publication 408 requires back panels, wiring, and terminals to accommodate at a minimum 8 phases actuated, with a minimum of 12 to 16 load switch sockets and a minimum of 2 unused sockets per unit.

See **Section 10.2.1** for more information about controller operation types.

13.3 Controller Assembly Location

Of prime importance to controller location/placement is the prevention of potential damage or knockdown of controller assemblies by vehicular traffic. Designers need to consider the following items when determining potential controller locations:

- ✓ Controller assembly should not be located near a curb return or on channelization island.
- ✓ Controller assembly door should not open into traffic.
- ✓ Controller assembly should be accessible without having to climb over obstacles such as guiderail, barrier, etc.
- ✓ Visibility of signal operations from the controller assembly. Ideally, maintenance personnel should be able to view at least one of the traffic control signal indications for all operating phases while setting the timing or performing other tasks in the controller assembly.
- ✓ The controller assembly should not limit visibility between vehicles and pedestrians, or limit sight distance for vehicles seeking to turn right on red.
- ✓ Pole mounted cabinets should be placed such that a level surface exists in front of the cabinet for ease of technician access.
- ✓ To minimize wiring needs, the controller assembly should be near the intersection, but it should not be located where it is likely to be struck by an errant vehicle. See **Section 15.2** for information relating to coordinating the controller assembly location with the electrical service.

13.4 Controller Assembly Mounting Type

Controller assemblies may be pole-mounted (Type II) or base-mounted (Type I). Base-mounted (Type I) cabinets are preferred. An auxiliary cabinet may be required when the required equipment cannot fit within the desired controller assembly type, such as when backup power systems are used with a Type II controller assembly.

When the controller assembly is pole-mounted (Type II), the cabinet should not be mounted over a sidewalk since the desired mounting height places the cabinet above the cane range of a vision impaired pedestrian. This results in the cabinet placement creating an undetected obstruction, and hence a hazard for the pedestrian. Where it is not possible to avoid placing the pole-mounted cabinet over the walkway, the bottom of the cabinet should be located no more than 27 inches above the sidewalk surface, thus enabling detection within the cane range.

14. SYSTEMS AND COMMUNICATIONS

14.1 General

The system concept as related to traffic control signals includes the methods, equipment, and techniques required to interconnect signals along a corridor (or within a network area) for the purpose of providing smooth, coordinated traffic flows. Coordinated timing is typically applied on corridors with closely spaced intersections (¼ mile or less).

This system work involves the selection and design of the following system components:

- ✓ Coordination Methods (see **Section 14.2**)
- ✓ Communications Systems (**see Section 14.4**)
- ✓ System/Coordinated Timing Plans (**see Section 14.3**)

Communications infrastructure ownership should be verified before starting design. PennDOT may own communications systems to facilitate signal operation across jurisdictional boundaries.

Coordinated signal systems shall also meet the requirements as provided in the following sections:

- ✓ **Section 5.8.3,** Unified Command and Control
- ✓ **Section 14.4.2**, Backhaul/Remote Communications

For additional information related to Systems and Communications, see the following references:

- ✓ Signal Timing Manual – Second Edition (STM2) (Chapter 7)
- ✓ Publication 46 (Chapter 4)
- ✓ Publication 408 (Section 953 & 957)
- ✓ ECMS Master Items (0953 & 0957)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

14.2 Coordination Methods

Various methods are typically used to provide coordinated traffic signal timings among multiple intersections. Coordination requires a consistent cycle length for the corridor, as well as splits and offsets for each timing plan. Splits control the amount of time given to each phase in a cycle, and offsets control the time relationship between intersections.

Coordination requires the clocks at each intersection to be synchronized to a consistent time source (referred to as the master clock), and a method to choose which timing pattern to operate at any given time.

Controllers will select the timing pattern based on the following hierarchy:

- ✓ **Manual Command**

  A manual command to a particular timing pattern takes priority over all other sources.

- ✓ **Remote System Command/Closed Loop**

  A pattern command can be issued from a remote system, such as a server or on-street master controller. Communication is needed between the local controllers and the central system (see **Section 14.4**). The remote system may use various methods to select the timing pattern, including a manual command, time of day schedule, or traffic responsive algorithm.

- ✓ **Time Based Coordination (TBC) System**

  The simplest form of coordination is the use of time-based coordination. The controller at each traffic signal must be equipped with an internal or external time clock to provide a point of reference. The primary disadvantage of TBC is that the time clocks may "drift" if not properly maintained. Over time minor changes at each controller accumulate. Periodic resynchronization will be necessary. GPS time clocks can be connected to each controller to provide a consistent time source and automatically resynchronize the clocks to the same satellite.

Several factors should be considered when determining which type of control system to use, including but not limited to:

- ✓ Cost
- ✓ Desired Functions
- ✓ Operations and Maintenance - Buy-in and a financial commitment of operations and maintenance from the lead municipality must be obtained before proposing any type of system that requires periodic operations and maintenance.
- ✓ Corridor Classification

14.3 System/Coordination Timing

In the system concept, a timing plan is defined by a combination of control parameters for one or more intersections based upon an analysis of demand. A system timing plan provides the appropriate and necessary timing plans for each intersection in terms of individual needs as well as the combined needs of a series of intersections. Timing plans can be provided as a function of equipment at the local intersection, the central control point, or both. Timing plans consist of:

- ✓ **A System Cycle**. A specific cycle length is imposed throughout the system covered by the timing plan.
- ✓ **Split**. All intersections in the system have defined splits which are the apportionment of the cycle to the various phases present at that intersection.
- ✓ **Offset**. Each intersection has a unique offset. The offset is the relationship of a defined point in the cycle (typically beginning of green or beginning of yellow) at this intersection to a master system clock time. Offsets are expressed in seconds. Properly established offsets along a street can potentially provide for smooth traffic flow.

Each combination of cycle length, offset, and split is referred to as a coordination pattern or plan. The selection a coordination pattern in effect at any given time may be determined by:

- ✓ **Typical Data:** information compiled from traffic counts to reflect traffic volumes for specified time of day (morning peak, midday, afternoon peak, etc.) and day of week which represents typical demand for the time period.
- ✓ **Current Real Time Data:** on-street volumes from traffic detection equipment.
- ✓ **Special Events Data:** emergency route assignment, special right-of-way preemption (fire equipment, ambulances, buses, etc.)

A designer shall use the guidance in the STM2 for the design of system/coordinated timing aspects.

Exhibit 14-1 provides the applicable STM2 chapters/sections that are to be referenced & used for this section.

Section 14.3.1 provides Pennsylvania supplemental information for cycle lengths.

Exhibit 14-1 System/Coordinated Timing, Signal Timing Manual, Second Edition

Chapter		Sections
7	**System/ Coordinated Timing**	7.1 Application of a Coordinated System 7.2 Coordination Planning Using a Time-Space Diagram 7.3 Introduction to Coordination Parameters 7.3.1 Coordinated Phases 7.3.2 Cycle Length 7.3.3 Splits 7.3.4 Force-offs 7.3.5 Permissive 7.3.6 Yield Points 7.3.7 Pattern Sync Reference 7.3.8 Offset Reference points 7.3.9 Offsets 7.4 Coordination Parameter Guidance 7.5 Other Considerations for Coordination 7.6 Complexities
9	**Advanced Signal Systems**	9.2 Advanced Coordination Features 9.2.1 Actuating the Coordinated Phase 9.2.2 Dynamic Phase Length 9.2.3 Phase Re-Service 9.3 Traffic Responsive Plan Selection Systems 9.3.1 Traffic Responsive Algorithms 9.3.2 Traffic Responsive Detection

14.3.1 Cycle Length

In addition to the details provided in Section 7.3.2 of the STM2 the following information is provided:

- ✓ The cycle length of a traffic control signal is the time required for one complete sequence of signal indications at an intersection.
- ✓ For pretimed signals, the cycle length is predetermined and consistent. Typical pretimed signal cycle lengths are from 60 to 120 seconds. Traffic-actuated signals (fully-actuated and semi-actuated) do not have a constant time cycle because it varies with the changing demands of traffic. The true cycle length will only be achieved when the intersection is using maximum timings for all the critical phases. Cycle lengths for actuated signals may vary from 45 seconds to 180 seconds. Cycle lengths over 120 seconds should only be considered for exceptional circumstances.
- ✓ Long cycle lengths reduce the relative amount of lost time taken by the change and clearance intervals and may minimize the number of times that the major street traffic is stopped each hour, but longer cycle lengths can increase queues as well. Under all but most congested traffic conditions, moderate cycle lengths may prove to be more efficient in moving traffic with the least delay on the approaches.
- ✓ One of the difficulties in the determination of cycle lengths comes from the need to accommodate two or more radically different volume patterns at various times during the period of operation. This may be addressed by multi-cycle, multi-split pretimed control implemented by time-of-day schedule or other method, or by providing traffic actuation at the intersection.
- ✓ The optimum division of the cycle length, or split as it is sometimes called, or splits, ordinarily is as important in securing signal efficiency as the selection of the appropriate cycle length and

relationship (offset) between adjacent signalized locations. The reason is the direct relationship between the green time-to-cycle time ratio (G/C ratio) and intersection capacity.

- ✓ The cycle length should normally be as short as practical to handle the traffic demand of individual intersections. To maximize progression in multiple directions, selection of the cycle length is subject to the spacing of the coordinated signalized intersections and the prevailing speed along the corridor. Therefore, it will be assumed that the value of the cycle length has been specified based on these factors, and that the task is to divide it equitably. This task includes three parts:
  - Computation of vehicle change and clearance times at each coordinated intersection.
- ✓ Selection of a minimum green interval time
  - Proportioning of the green intervals to correspond with traffic flow and efficiency of movement.
- ✓ The distribution of split times within the cycle should be aligned with the timing objectives (see **Section 2.2**.

14.4 Communications Systems

Communications systems provide a mechanism for data transmissions between traffic signals and other traffic signals, a master controller, or a central system. Common use cases for a communications system include:

- ✓ Clock synchronization to maintain coordination between intersections.
- ✓ Device management, such as upload and download of controller timing databases.
- ✓ Traffic signal command and control to select and implement timing plans, such as time-of-day, traffic responsive, and manual patterns to manage a special event or incident.
- ✓ Data collection for performance measurement and reporting
- ✓ Equipment health monitoring to detect malfunctions and perform troubleshooting.
- ✓ Adaptive Signal Control Technology (see **Chapter 18**)
- ✓ Connected/automated vehicle applications.
- ✓ Traffic surveillance (CCTV)

Within a traffic signal cabinet, several types of equipment can be connected to the communications system, such as the traffic signal controller, detection systems, and MMUs.

Communication systems include a transmission medium and transmission system (protocol). Some transmission systems will only work with a specific medium, such as a spread spectrum radio (transmission system/protocol) will only work with radio frequency (transmission medium).

Historically, traffic signal systems were deployed with proprietary communication protocols and data definitions. Modern traffic signal systems should follow the National Transportation Communications for ITS (Intelligent Transportation Systems) Protocol (NTCIP) to provide interoperability and interchangeability.

Various methods of communications are typically used to interconnect signals within a system and/or provide remote communications as shown below. Refer to Publication 408 Section 953 for specifics on the materials and construction methods.

> Refer to the Section 3.2 in Publication 852, TSMO Guidebook: Part II – Design for more information on communication system design.

14.4.1 Transmission Media

Each transmission medium has advantages and disadvantages, which are described this section.

Recommended Communication Media

- ✓ **Fiber Optic Cable**

Fiber optic cable can be installed aerially or in conduit between intersections. Care must be taken during design to specify the correct accompanying equipment as distinct types of fiber optic cable are available, i.e., single mode vs. multi-mode, loose tube vs. tight buffered.

Advantages: Non-conductive (not susceptible to lightning strike travel), able to carry substantial amounts of data.

Disadvantages: Cable difficult and expensive to repair, accompanying equipment, and installation more expensive.

- ✓ **Wireless Broadband Radio**

  Communications between intersections is provided by an integrated broadband radio system capable of a 5.8 gigahertz (GHz) frequency and a minimum of 54 Mbps for communication between the local traffic control signal controllers.

  Radios are configurable and monitored using network monitoring software. Software includes a complete toolset to assist in advanced network monitoring and radio configuration. Provide certification that system equipment is licensed by the Federal Communications Commission (FCC) to meet the FCC regulations on wireless operation according to Parts 15.247 and 15.249 of the Code of Federal Regulations and has been approved for indoor and outdoor applications.

  Advantages: No physical connection between intersections.

  Disadvantages: Line of sight required between intersections, or additional repeater sites are required; some frequencies (2.4 Ghz and 5 GHz) may have interferences from public wi-fi in urbanized areas.

- ✓ **Cellular**

  Communications between intersections is provided by a cellular communication system consisting of a cellular modem and antennas.

  Advantages: No physical connection between intersections.

  Disadvantages: Monthly fees for cellular service.

Legacy Communication Media

While not used for new communication systems, the following legacy transmission media may still be in use and may need to be adapted to meet communication requirements to achieve the operational objectives:

- ✓ **Hard-Wire Interconnect (Cable)**

  Twisted-pair cable is installed in conduit or attached to utility poles between intersections.

  Advantages: Least expensive method of physical interconnection, no additional equipment is required beyond the controller unit.

  Disadvantages: Conducts electricity which may cause lightning or power surge damage at multiple signal controllers.

- ✓ **Leased Lines**

  Instead of running separate cable to connect signals, lines may be leased from a communication provider.

  Advantages: Lower installation cost.

  Disadvantages: Recurring monthly lease fee.

- ✓ **Spread Spectrum Radio (SSR)**

Communications between intersections is provided by a wide bandwidth frequency signal. Two frequency ranges are allowed, 902-928 MHz and 2.4 GHz, which do not require FCC licensing. An implementation survey will be required during design to determine if obstructions and/or roadway curvatures would require repeaters.

Advantages: No physical connection between intersections, lower cost.

Disadvantages: Limited bandwidth compared to fiber; repeaters may be necessary.

14.4.2 Circuit Types

Common types of communication connections for traffic signals are:

- ✓ Point-to-Point: a direct communications connection between two devices
- ✓ Point-to-Multipoint: a communication circuit connects multiple devices to a controller.
- ✓ Multipoint-to-Multipoint: a communication circuit allowing many devices to connect to many devices through a switch or router.

Point-to-Point and Point-to-Multipoint connections typically use serial communication, which is limited in the distance it can travel and the number of devices supported. Historically, a closed-loop system with a central computer which connected to a field master controller through a dial-up modem was a type of Point-to-Multipoint connection.

Multipoint-to-Multipoint networks allow multiple devices to share a connection and requires each device to have a unique, individual address. The internet is an example of a Multipoint-to-Multipoint network. Ethernet provides the ability to connect subnetworks through the internet.

New traffic signal networks shall be Multipoint-to-Multipoint networks using the Internet Protocol (IP), to provide flexibility for expanding the network to cover other devices. Section 3.2 of Publication 852 contains more information on network topology.

14.4.3 Backhaul/Remote Communications

Advancements in technology have made it possible to communicate with traffic control signal systems remotely from a central location. A central location could be a municipal office, PennDOT Engineering District office, PennDOT Central Office, or any workstation/laptop with access to an internet connection.

The private Commonwealth communication network (Commonwealth Network) shall be used for all centralized remote communication to traffic control signal system field networks. Connections to the Commonwealth network shall follow all PennDOT and Office of Administration IT Policies to maintain security of the network. Commonwealth IT maintains the connection of centralized traffic control signal management software to the Commonwealth network. Section 3.2 of Publication 852 contains more information on network requirements.

15. ELECTRICAL DISTRIBUTION

15.1 General

Electrical distribution consists of all the electrical components that power and operate a traffic control signal. Without a properly designed and installed electrical distribution the most state-of-the-art traffic control signal would operate ineffectively.

A traffic control signal design needs to include the following elements:

- ✓ Controller placement
- ✓ Conduit & Method of installation
- ✓ Junction boxes
- ✓ Wire and Cable
- ✓ Electrical Service
- ✓ Uninterruptible Power Supply (UPS)
- ✓ Generator Adapter Kit
- ✓ Surge Protection
- ✓ Bonding & Grounding

  and others

For addition information related to Electrical Distribution, see the following references:

- ✓ Publication 46 (Chapter 4)
- ✓ Publication 148 (TC-8801, TC-8804, TC-8806)
- ✓ Publication 408 (Section 954, 956)
- ✓ ECMS Master Items (0954, 0956)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-673 and TE-974

In addition to the information below, also refer to the Section 4.1 of the Signal Timing Manual – Second Edition (STM2) for additional details.

15.2 Controller Assembly Location/Placement

In addition to the controller assembly location factors described in **Section 13.3**, another key factor to consider when determining a potential controller location is the electrical service itself. Contact the utility company to determine how electric service will be provided, and field verify to determine the design aspects of the electric service and controller placement at the intersection location. If third party communication services will be used as part of the signal design, the design aspects of these communication services need considered as well regarding controller placement at the intersection.

Controller configuration shall be in compliance with Publication 408 and the Publication 148.

15.3 Conduit

A traffic control signal design needs to address the following elements related to conduit which is used to route various signal cables and wiring.

- ✓ Locations and layout of the conduit
- ✓ Size requirements for the conduit
- ✓ Method of conduit installation

15.3.1 Conduit Layout

The conduit layout should be designed to minimize difficulty in construction as well as maintenance of the traffic control signal. Conduit runs should be as straight as possible to minimize material and construction costs and to ease pulling the cables. The runs should also be routed around utilities. Since portions of the roadway may need to be closed during trenching for the conduit, major streets should be crossed by conduit only once, when possible.

A conduit shall be provided from each pole or pedestal foundation to another foundation or junction box. Conduits passing beneath the roadway shall have a junction box at each terminus. Conduits may run from foundation to foundation without a junction box when the foundations are located on the same corner and the conduit does not go beneath the roadway.

For detector leads, provide a conduit from the nearest junction box to the curb face.

The conduit shall be laid out so that the traffic control signal controller is located at or near the center of the conduit layout. This enables the creation of two separate wiring systems, each handling about half of the signals at the intersection.

Separate Conduit

The following cable types shall each be installed in their own separate conduit:

- ✓ Electrical service cable
- ✓ Street lighting (luminaire) cable

15.3.2 Size

The required conduit size is determined by the number and sizes of cable to be contained in the conduit. In no case during the traffic control signal design should a conduit be filled to more than 40 percent. The fill areas are determined by adding the cross-sectional areas of all cables to be contained in the conduit and comparing it to the 40 percent fill areas of the conduit.

In general, conduit sizes of 2-inch or 3-inch diameter are to be used for purposes of signalization or interconnection. Conduits with a diameter larger than 3 inches should not be used for traffic signals. Multiple conduit runs should be used instead.

Use of 1-inch diameter conduits will be allowed for the following situations:

- ✓ Routing of detector leads through the curb into a junction box.
- ✓ Routing of detector lead-in runs of two or less to the controller cabinet.
- ✓ Routing of service leads

When conduit is to be placed beneath the roadway, consider the following to better allow potential future signal expansion:

- ✓ Use a conduit size that is larger in diameter than required by the 40 percent fill requirement, or
- ✓ Place a spare conduit for any future expansion.

See **Exhibit 15-1** and **Exhibit 15-2** below for information on conduit fill areas and cable areas.

Exhibit 15-1 Conduit Fill Areas

	Conduit --- 40% fill areas, in^2		
Type (Diameter)	1 in	2 in	3 in
Non-metallic *	0.29	1.18	2.64
Metallic *	0.34	1.34	2.95

Note: * use these values for design purposes

Exhibit 15-2 Cable Areas

Number of Cables	Signal Cable Areas, in^2							
	#12 AWG				#14 AWG			
	3/c	5/c	7/c		3/c	5/c	7/c	Lead-in
1	0.139	0.201	0.266		0.101	0.144	0.170	0.091
2	0.278	0.402	0.532		0.202	0.288	0.340	0.182
3	0.417	0.603	0.798		0.303	0.432	0.510	0.273
4	0.556	0.804	1.064		0.404	0.576	0.680	0.364
5	0.695	1.005	1.330		0.505	0.720	0.850	0.455
Bare Copper Ground Wire - #8 AWG 1/c = 0.017 in^2								
Luminaire Cable #8 AWG 1/c = 0.058 in^2								
Coaxial Communication Cable (RG-59/U) = 0.046 in^2								
Video Camera Power Cable - #16 AWG 3/c = 0.083 in^2								

15.3.3 Method of Installation

One of the installation methods in **Exhibit 15-3** should be selected as part of the design.

Exhibit 15-3 Method of Installation

Method	Type Area	Description
Trench and Backfill	Developed	▪ Trench shall be deep enough to provide a minimum depth of cover of 24 inches. ▪ A minimum depth of cover of 36 inches is recommended if conduit carries communications cable. ▪ Trenching shall meet the provisions in Publication 148 and Publication 408 (Section 954).
Boring	Developed Under New Pavements Under Major Highways	▪ Alternative to "Trench and Backfill." ▪ Boring depths should be below the existing roadway subgrade, and not cause any deformation of the roadway. ▪ See Publication 408 (Section 954).
Jacking	Highly Developed Under New Pavements Under Major Highways	▪ Where the interruption of traffic is a critical concern, a jacking method may be considered for the installation of conduit. ▪ This method will need discussions with and preapproval by appropriate Department staff. ▪ This method is not a standard ECMS Master Item of work.

15.4 Junction Boxes

A traffic control signal design needs to address the following elements related to junction boxes:

- ✓ Need for and location of junction boxes.
- ✓ Type of junction boxes

All junction box installations consist of three basic components:

- ✓ Box

- ✓ Cover
- ✓ Coarse aggregate drain

The finished grade of a junction box cover depends upon where it is located, as follows:

- ✓ In paved areas, the cover shall be set flush with the finished grade of the sidewalk.
- ✓ In earth areas, the cover should be 1-inch above the surrounding grade.

15.4.1 Location

A junction box should be provided at the following locations:

- ✓ On intersection corners where traffic control signal poles are to be situated and underground cable runs continue to other supports.
- ✓ Where detector sensors are spliced to lead-in wire.
- ✓ In extremely long conduit runs, greater than 330 feet.

When locating junction boxes, consider future maintenance needs regarding ease and safety. Thus, placement of junction boxes in roadway and driveway areas should be avoided. Also, junction boxes should not be placed in curb ramps.

15.4.2 Types

Several types/sizes of junction boxes are available. These junction boxes may also be available in various materials per the Publication 408 and ECMS Master Item choices (precast, steel, cast-iron, reinforced plastic, etc.).

The total cross-sectional area of conduit entering a junction box should not exceed 15% of the area of the junction box. When this amount is exceeded, a larger box or additional boxes should be considered.

Junction box selection details and guidance are provided below in **Exhibit 15-4**.

Exhibit 15-4 Junction Box Details

Standards	Type Traffic Allowed	Type/Size Junction Box	Inside JB Dimensions	Purpose
Publication 148 **Traffic Standards**	**Pedestrian (Non-Vehicular)**	JB-26	12" x 12" x 12" D Min.	Only used for detector lead-in wiring.
		JB-27	12" x 18" x 24" D Min.	Traffic control signal system distribution cables & wiring
		JB-30	17" x 30" x 24"D Min	
Publication 72M **Roadway Standards**	**Pedestrian (Non-Vehicular)**	JB-1	15" x 15" x 24" D	For highway lighting wiring, but may be used for traffic control signal system distribution cables & wiring
		JB-2	24" x 24" x 36" D	
	Vehicular[1]	JB-11	30" x 30" x 26" D	
		JB-12	18" x 30" x 26" D	

[1]Vehicular-rated junction boxes should be specified in traffic islands and when located on a radius where vehicles routinely track outside the pavement in the area where the junction box is located.

15.5 Cable and Wiring

A traffic control signal design needs to address the following elements related to signal cable and wiring:

- ✓ Signal cable & wiring requirements
- ✓ Detector wiring
- ✓ Wiring method and diagram

15.5.1 Signal Cable Requirements

Cable - AWG Gauge Size

The required gauge size of cable is dependent upon the type of cable application as shown in **Exhibit 15-5** below. Specialized types of components should include wiring based on the manufacturer's specifications, and the wiring is incidental to the pay item for the component.

Exhibit 15-5 Cable AWG Size Requirements

Cable Type	AWG Size
Signal Cable	14 AWG (minimum) 12 AWG
Detector Lead-In	14 AWG (minimum)
Ground Wire (Bare Copper)	8 AWG
Electric Service Wire	8 AWG
Luminaire Cable	8 AWG

Cable – Number of Conductors

The number of conductors to be used for signal head wiring is determined by the specific application and the number of indications to be displayed by the signal.

Each signal housing requires conductors as follows:

- ✓ An ungrounded conductor for each signal indication, and
- ✓ One grounded conductor (neutral), with the neutral conductors for each indication spliced together.

The minimum number of conductors required equals the number of signal indications (sections) plus one. For example, a three-section signal head requires a minimum of four conductors (4/c).

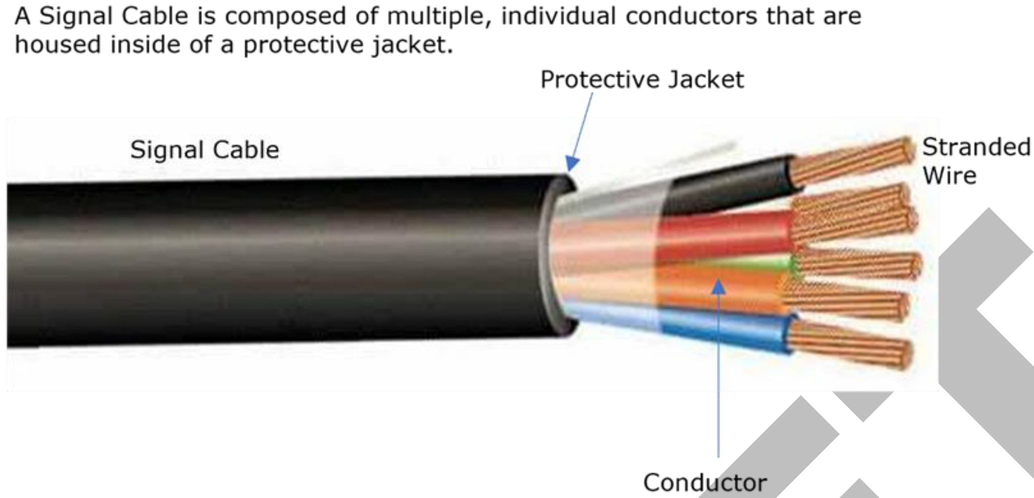
Cable sizes have been standardized to:

- ✓ Reduce the number of various size cables to be purchased, which should result in reduced construction cost.
- ✓ Allow the spare conductor to be used if another conductor is broken to maintain the operation without pulling a new cable.

For anticipating future expansion of signal operations at growing intersections, consider using a signal cable with larger number of conductors to those signal heads that may need to be upgraded in the future with a signal head having more indications. For example, the left-most signal head on a mast arm may require a five-section signal head if a left-turn phase is anticipated in the future; therefore, seven-conductor (7/C) cable may be used at the design onset.

See **Exhibit 15-6** for a diagram of a signal cable.

Exhibit 15-6 Signal Cable Diagram



See **Exhibit 15-7** below for the number of conductor requirements by specific application of the signal cable.

Exhibit 15-7 Signal Cable Number of Conductors, by Application

Application	Number of Conductors
Preemption Detector	3/c
Preemption Confirmation Light	3/c
Pedestrian Pushbutton	3/c
Pedestrian Signal	5/c
Three-Section Traffic Control Signal	5/c
Four-Section Traffic Control Signal	7/c
Five-Section Traffic Control Signal	7/c

Cable – Conductor Color Coding

The individual conductors in a signal cable shall be color coded. These codes, for up to a seven-conductor cable, shall be as shown in **Exhibit 15-8.**

Exhibit 15-8 Signal Conductor Color Coding Chart

Conductor	Color	Ped Button 3C	Ped Signal 5C	Ped Signal 7C	Veh Signal 5C	Veh Signal 7C
1	Black	Spare	Walking Person (Walk)	Walking Person (Walk 1)	Green Ball/ Arrow	Green Ball
2	White	Logic Ground	Neutral	Neutral	Neutral	Neutral
3	Red	Ped Call Detector	Upraised Hand (Don't Walk)	Upraised Hand (Don't Walk 1)	Red Ball/ Arrow	Red Ball/Arrow
4	Green	---	Reserved	Reserved	Reserved	Reserved
5	Orange	---	Spare	Walking Person (Walk 2)	Yellow Ball/ Arrow	Yellow Ball/ Arrow
6	Blue	---	---	Upraised Hand (Don't Walk 2)	---	Green Arrow
7	White/Tracer	---	---	Spare	---	Yellow Arrow/ Flashing Yellow Arrow or Spare

15.5.2 Detector Wiring

Loop detectors are wired using two cables – a loop sensor and a lead-in cable.

The loop sensor is installed in pavement surfaces through a saw-cut and covered with a sealant. The sensor must also lead to the junction box via a trench through a 1-inch conduit. The size of the loop detector determines the number of turns in the pavement.

The lead-in cable is spliced to the leads of the loop sensor in a junction box and routed, via conduit, to the controller cabinet. Three splicing alternatives are approved by the Department.

- ✓ **Alternative A:** The sensor cables and the lead-in cable are soldered together then covered first with wire nuts then immersed in an epoxy sealant.
- ✓ **Alternative B:** The sensor cables and the lead-in cable are connected via insulated compression connectors then covered in two alternating layers of electrical tape and sealant.
- ✓ **Alternative C:** The sensor cables and the lead-in cable are connected via insulated compression connectors then covered in a moisture-proof splicing kit.

Refer to Publication 111 (TC-8806) for standard Detector drawings.

For video or other methods of detection, follow the manufacturer's recommended installation procedures.

15.5.3 Wiring for Special Phasing

A five-section signal head for the protected/permissive left-turn mode is wired as follows:

- ✓ The three circular indications run off the output for the adjacent through phase, and
- ✓ The two arrow indications run off the output for the left turn phase.

In a four-section Flashing Yellow Arrow (FYA) signal head, the protected/permissive left-turn mode is wired as follows:

- ✓ The steady red arrow, steady yellow arrow, and steady green arrow can be wired the same as a traditional three-section protected/prohibited display.
- ✓ The fourth output, a flashing yellow arrow (FYA) indication, cannot be run from the output for a steady indication, and thus introduces the requirement to output and monitor as an additional signal indication.
- ✓ In order for the conflict monitor to prohibit conflicting indications in accordance with Section 4F.01 of the MUTCD, the flashing yellow arrow indication should be wired so it is monitored by a separate channel from the steady red arrow, steady yellow arrow, and steady green arrow indications in the FYA head.
- ✓ Typically, the FYA indication is wired to an overlap or the unused third output of a pedestrian load switch.
- ✓ The wiring for a four-section FYA signal head should not share conductors with wiring for other signal heads.

If an existing five-section protected/permissive signal head is replaced with a four-section FYA signal head, the existing wiring can be re-used if:

- ✓ The existing wiring was not “daisy chained’ with adjacent signal heads, and
- ✓ The existing wiring between the signal head and cabinet can be connected to different outputs for the steady indications and FYA indications, as shown above.

15.5.4 Wiring Method and Diagram

Method

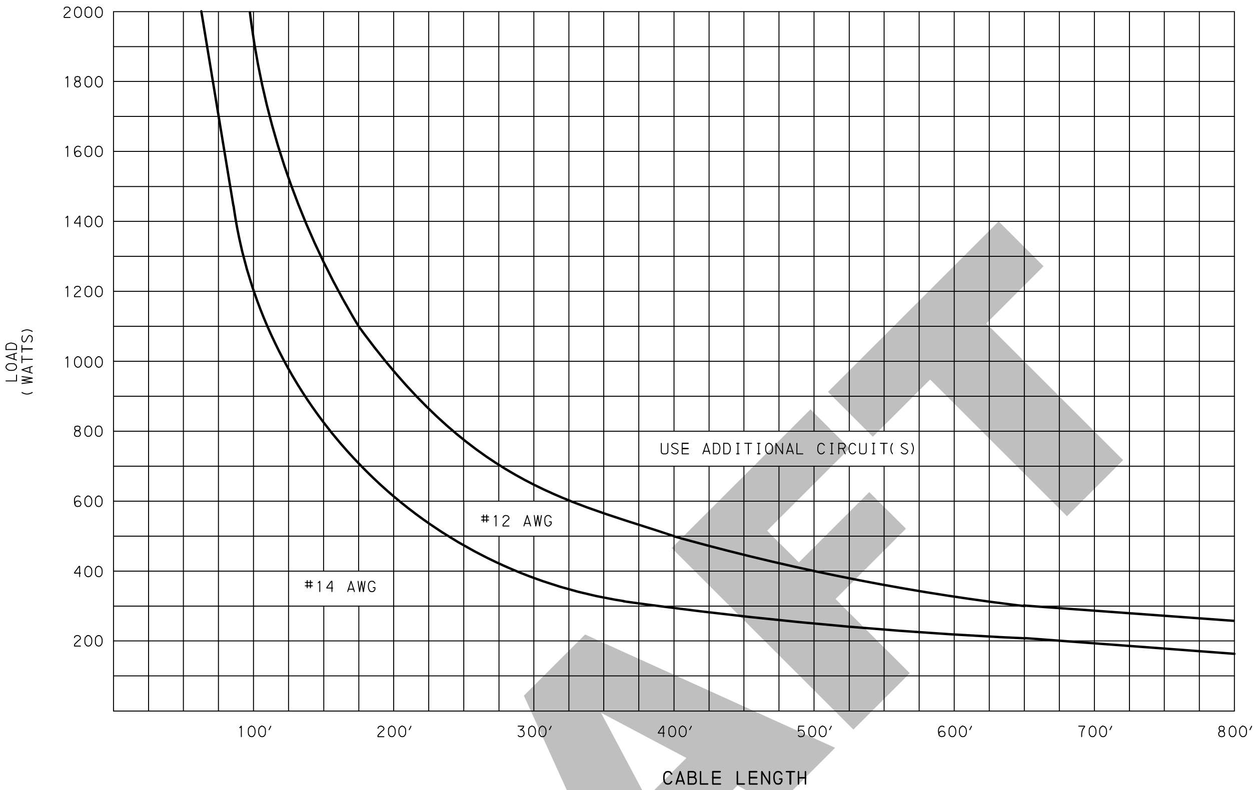
Prior to determining the wiring required for a traffic control signal design, all the following must be prepared and completed:

- ✓ Traffic control signal layout with all signal heads numbered.
- ✓ Traffic control signal operation chart
- ✓ Conduit and junction box layout

The following rules shall be adhered to when determining the required wiring:

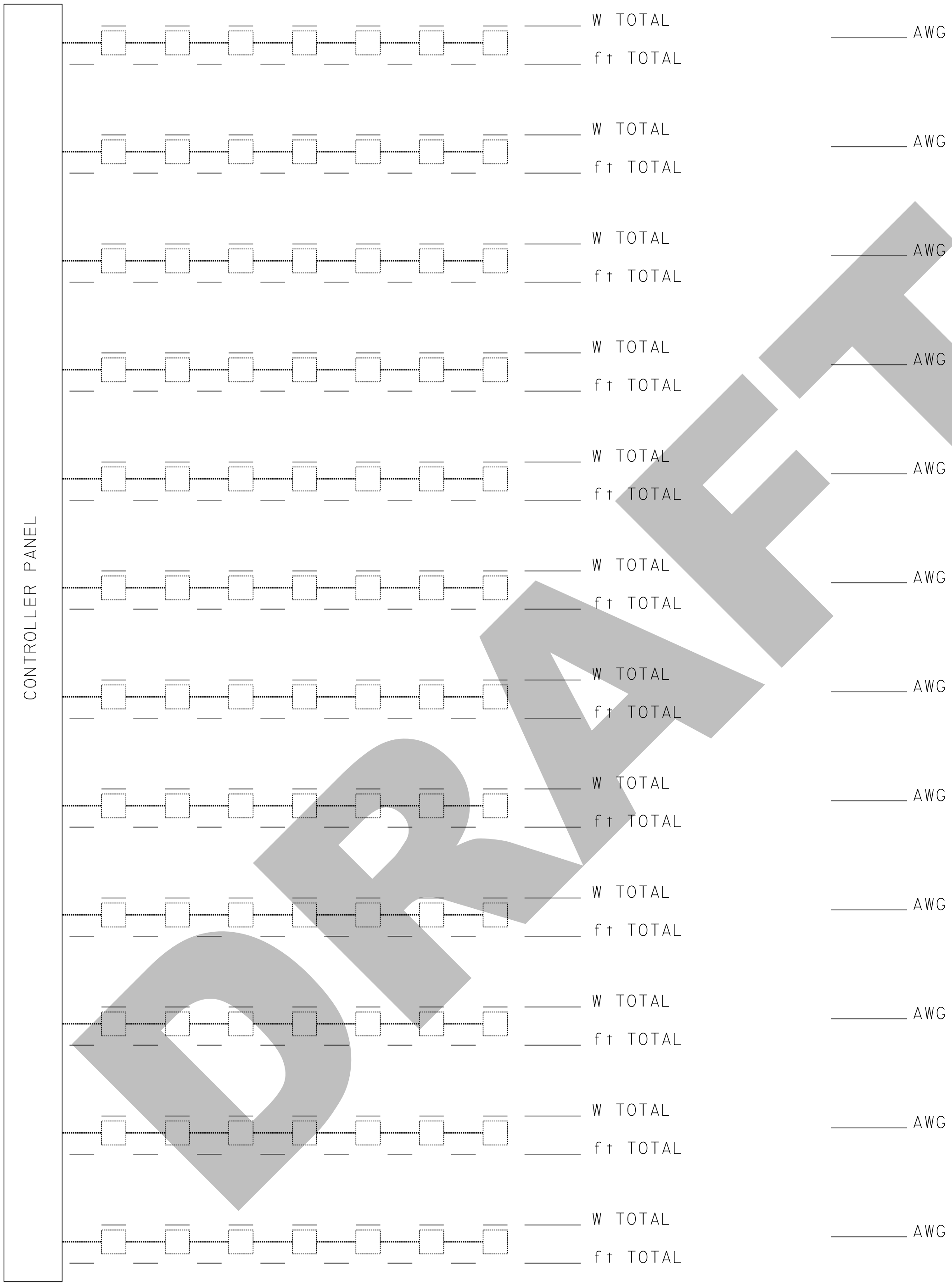
- ✓ Phase neutrals shall not be mixed
- ✓ Only those signals that display identical indications throughout the sequence of operations may have their conductors spliced together to be wired in series (also referred to as daisy-chained)
- ✓ When calculating cable length, include all vertical dimensions (e.g., inside support shafts and signal heads), drip loops, slack in junction boxes and controller cabinet.

Exhibit 15-9 Conductor Size Graph



See **Exhibit 15-10** below, which shows a worksheet (TE-673) for determining signal wiring needs. Complete this worksheet after finishing all the prerequisite items listed above.

Exhibit 15-10 Conductor Size Worksheet



○ - Signal Head

□ - Junction Box

⬡ - Detector

△ - Signal Support

8" Signal = 100 W

12" Signal = 150 W

All Pedestrian Signals = 100 W

NOTE: When calculating cable length, include all vertical dimensions (e.g. inside support shafts and signal heads, drip loops, slack in junction boxes and controller cabinet).

Wiring Diagram

See **Section 33.4.2** for information on signal wiring diagrams.

15.6 Electric Service

There are three standard methods of providing electricity from the local utility provider to the traffic signal identified in Publication 148 (TC-8804). The types are differentiated based on the point where responsibility transfers from the utility to the signal owner: on a service (utility) pole, on a signal pole, or attached to the signal cabinet. This point may vary depending on the electric utility but is typically where the electric meter is located. The traffic control signal design will necessitate which method is appropriate.

- ✓ **Type A.** Service is initially provided to a service (utility) pole. From the service pole, the service cable is routed through a 2-inch (minimum) conduit to the controller cabinet.
- ✓ **Type B.** Service is provided to a traffic control support from an overhead service drop. From the signal support, the service cable is routed through a 2-inch (minimum) conduit to the controller cabinet. Type B service can be used for either pole mounted or base mounted cabinets.
- ✓ **Type C.** Service is provided directly from an underground service connection to the controller cabinet via a 2-inch (minimum) conduit.

Design considerations in the Electrical Service Type determination should include such factors as,

- ✓ Area (urban, suburban, rural)
- ✓ Project Right-of-way
- ✓ Proximity of controller cabinet to the utility

Also, verify with the electric utility company whether the intersection needs to be metered or unmetered.

Refer to the following for additional information on electrical distribution and service:

- ✓ Publication 148 (TC-8804) for standard Electrical Distribution drawings.
- ✓ **Chapter 1** for information on utility coordination as electric service will need coordinated with the applicable utility provider.

15.7 Backup/Emergency Power

Backup/emergency power are alternate methods to power the traffic signal indications when electric utility power is lost. The need for backup/emergency power should be identified as part of the traffic control signal design. Backup/emergency power methods have become more viable as traffic signals indications switched from incandescent bulbs to LEDs which consume less power.

15.7.1 Generator Adaptor Kit

The simplest method of backup/emergency power is to connect an electric generator to temporarily power the traffic signal. A generator adaptor kit is required to facilitate the connection to a 110 V AC electric generator.

A generator adaptor kit provided on a new controller assembly installation is incidental to the controller assembly item. Modifications of an existing controller assembly to add a generator adaptor kit require the use of ECMS Master Item, “Generator Adaptor Kit Retrofit”.

15.7.2 Uninterrupted Power Supply (UPS)

A UPS system includes a separate source to maintain a continuous supply of electric power to connected equipment whenever utility power is not available and includes an automatic transfer mechanism to transfer power to the secondary source when utility power is lost.

Traffic control signals with railroad preemption or coordinated with flashing-light signal systems should be provided with a back-up power supply in accordance with MUTCD Sections 4F.18, 4F.19 and 4F.20. At other locations, the need for UPS should be discussed with the municipality and consider the following factors:

- ✓ Electric utility power reliability/anticipated frequency of outages
- ✓ Difficulty maintaining traffic control with police officers.
- ✓ Electric load to determine the anticipated runtime.
- ✓ Municipal budget for traffic signal maintenance, including regular battery replacement.

Since flashing operation uses less electricity than full traffic signal operation, a UPS system may be programmed to operate in flashing operation to extend the runtime on battery power. Some systems also will transition to flashing operation when the battery power drops below a specified level. A modification to the standard item may be used if a different runtime or minimum wattage is required.

Signal designers need to account for space needed for the UPS system, including batteries, within the controller assembly. The standard specifications for Type 1 (base-mounted) controller assemblies require a size large enough to accommodate a UPS system (cabinet size 7: 44" W x 72" H x 24" D). When a Type 2 (pole-mounted) or an existing Type 1 controller assembly is used, an auxiliary cabinet should be specified when a UPS system is being added.

15.8 Luminaires

Luminaires attached to traffic signals have special electrical requirements:

- ✓ Luminaire/street lighting wiring must be in separate conduits from the traffic signal wiring, but the conduits may use the same junction boxes with the traffic signals.
- ✓ Luminaires are typically provided with a separate electric service and disconnect from the traffic signal. Depending on the utility provider, the street lighting service may be metered or unmetered (flat rate).
- ✓ Coordination with the utility provider is needed to determine what components of the luminaire are provided by the utility (if any) and what components of the luminaire are to be procured and installed by the signal contractor.

15.9 Solar Power

While solar power is not allowed for use with traffic control signals, use of solar power is an available option for certain Flashing Beacons (Flashing Warning Devices), which are discussed in **Chapter 30**.

Publication 408, Sections 935 & 936 specifications allow solar power for the following flashing warning signs, with solar power requirements identified in the indicated subsection of 1103:

- ✓ School Zone Speed Limit Flashing Warning Sign: **Section 1103.03(h)**
- ✓ Flashing Warning Sign: **Section 1103.03(i)**
- ✓ LED Border Lit Sign: **Section 1103.03(k)**
- ✓ Permanent Speed Display Sign: **Section 1103.03(m)**
- ✓ Temporary Speed Display Sign: **Section 1103.03(n)**
- ✓ RRFB Assembly: **Section 1103.03(o)**

16. SIGNAL HEADS

16.1 General

As previously indicated in **Section 1.4.1**, all traffic signal designs must comply with the MUTCD, except where modified by Pennsylvania regulation. This chapter provides Pennsylvania-specific guidance on the application of the MUTCD to traffic control signals in Pennsylvania, including situations where applications permitted in the MUTCD are not used in Pennsylvania.

Traffic control signal indications provide the driver or pedestrian with a visual sign as to when they can safely proceed through an intersection. The proper meaning and application of these traffic control signal indications play a key role in every traffic control signal design.

Vehicular signal indications (MUTCD 4D) include red, yellow, green circular or arrow indications.

Pedestrian signal indications (MUTCD 4E) include a Portland orange "hand" symbol and a white "person" symbol as well as a numeric countdown.

A complete signal head assembly includes the following components:

- ✓ Housing / Reflectors / Backplates / Visors / Louvers
- ✓ LED Signal Modules (older signals may still use incandescent bulbs), or Optically Programmed Signal Heads for special-use situations.
- ✓ Mounting Assembly Hardware

Another type of signal head is the LED Lane-Use Traffic Control Signal. These lane-use signals are special overhead signals that permit or prohibit the use of specific lanes on a highway. Lane-use signals are typically used for reversible-lane control (see **Chapter 27,** and MUTCD Section 4M).

For addition information related to Signal Heads, see the following references:

- ✓ MUTCD (Chapters 4D, 4E, 4M)
- ✓ Publication 46 (Chapter 4)
- ✓ Publication 148 (TC-8801, TC-8803, TC-8805)
- ✓ Publication 408 (Section 955)
- ✓ ECMS Master Items (0955)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

16.2 Vehicular Signals

Vehicular signal requirements are included in MUTCD Chapters 4D, 4E, 4F and 4G.

Any supplemental information for a specific feature is provided in the following Chapter 16 sections.

Flashing red arrows shall not be used in Pennsylvania, and all references in the MUTCD to flashing red arrows are not applicable in Pennsylvania.

Chapter 16 provides the following types of signal head information:

- ✓ Allowed signal head configurations for use in PA.
- ✓ Modification of certain MUTCD figures for use in PA.
- ✓ Not allowing certain MUTCD figures for use in PA.
- ✓ Additional PA requirements.

16.2.1 Signal Indication Features (MUTCD)

Exhibit 16-1 provides an overview of the various signal head indication features, relating the specific Chapter 16 section to its corresponding MUTCD Section(s).

Exhibit 16-1 Signal Indication Features

Signal Indications	Pub 149 Section	MUTCD
Meaning of Vehicular Signal Indications	**---**	4A.03 and 4A.04
Application of Steady Signal Indications	**---**	4F.01
Signal Indications - Design, Illumination, Color & Shape	**16.2.2**	4E.01
Size of Vehicular Signal Indications	**16.2.3**	4E.02
Positions of Signal Indications	**16.2.4**	4E.03
		4E.04
		4E.05
Location of Vehicular Signal Faces	**16.2.5**	4D.05
		4D.07
		4D.08
		4D.09
		4D.10
Visibility, Aiming & Shielding of Signal Faces	**16.2.6**	4D.06
Signal Indications for Left-Turn Movements	**16.2.7**	4F.02, 4F.03, 4F.04, 4F.05, 4F.06, 4F.07, and 4F.08
Signal Indications for Right-Turn Movements	**16.2.8**	4F.09, 4F.10, 4F.11, 4F.12, 4F.13, 4F.14, and 4F.15
Signal Indications for Approaches with Shared Left-Turn/Right-Turn Lanes (no through movement)	**16.2.9**	4F.16

16.2.2 Signal Indications-Design, Illumination, Color & Shape

This section supplements MUTCD Section 4E.01 for traffic control signals in Pennsylvania.

- ✓ Each arrow signal indication shall emit a single color: red, yellow, or green. The exception in MUTCD Section 4E.01, Par.07 for the alternate display (dual-arrow signal section) of a GREEN ARROW and a YELLOW ARROW signal indication shall not be used in Pennsylvania.
- ✓ The intensity and distribution of light from each illuminated signal lens shall comply with Publication 408 (Section 955).

White Strobe Lights within or adjacent to Red Traffic Signal Indication

In compliance with Section 4E.01 paragraph 03 of the MUTCD, the Department will not allow any new strobes to be installed within or adjacent to any red signal indications.

In the past, PennDOT did allow some municipalities to install white strobe lights within or adjacent to red traffic control signal indications, which would flash whenever the signal was red. The intent was to "wake up" inattentive drivers and thereby improve safety, but research has indicated that these strobe lights are not beneficial.

> If an Engineering District is aware of any active strobe lights, they shall contact the local officials and advise them that these strobes need to be removed.
>
> A double-red signal indication is an appropriate alternative countermeasure that may be considered for select locations where strobes were previously used or requested by municipalities.

16.2.3 Size of Vehicular Signal Indications

The following shall be used in place of MUTCD Section 4E.02, Par.04 and Par.05 for traffic control signals in Pennsylvania:

Except as provided below, 12-inch signal indications shall be used for all signal sections in all new signal faces:

- ✓ The flashing yellow signal indications in an emergency-vehicle traffic control signal.
- ✓ The circular indications in signal faces controlling the approach to the downstream location where two adjacent signalized locations are close to each other and it is not practical because of factors such as high approach speeds, horizontal or vertical curves, or other geometric factors to install visibility-limited signal faces for the downstream approach.
- ✓ The circular indications in a post-mounted signal face located at an intersection with speed limits of 25 mph or less.
- ✓ The circular indications in a supplemental signal face installed for the sole purpose of controlling pedestrian movements (see Section 4E.02) rather than vehicular movements.
- ✓ The circular indications in a signal face installed for the sole purpose of controlling a bikeway or a bicycle movement.

Existing 8-inch circular signal indications that are not included in the list above may be retained for the remainder of their useful service life, but consideration should be taken to replace with 12-inch circular indications when maintenance or retrofit work is done.

16.2.4 Position of Signal Indications within a Signal Faces

This section supplements MUTCD Sections 4E.03, 4E.04, and 4E.05 for traffic control signals in Pennsylvania.

In general, all signal indications shall be arranged vertically unless there are obstructions that can be overcome with a horizontal arrangement.

Positions of Signal Indications within a Vertical Signal Face

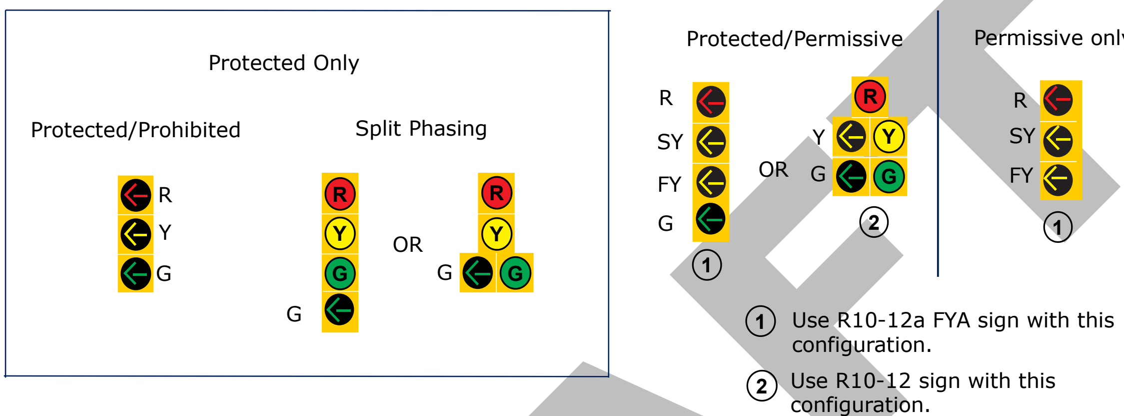
This section supplements MUTCD, Section 4E.04 for traffic control signals in Pennsylvania.

All vertically-arranged signals in Pennsylvania should use a configuration shown in **Exhibit 16-2**.

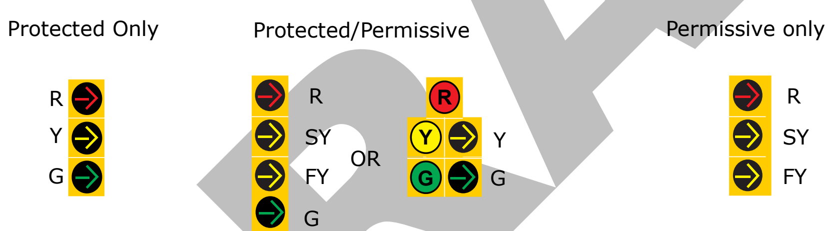
Exhibit 16-2 PA Typical Arrangements of Vertical Signal Faces

A- Standard Vehicular Signal

B - Left Turn Vehicular Signal



C- Right Turn Vehicular Signal



D – 'U-Turn' Signal Face
See MUTCD **Figure 4E-1**.

E – Single Section Continuous Movement Signal Face
See MUTCD **Figure 4E-2(C)**.

When traffic control signals are modified, traffic control signal heads which do not comply with **Exhibit 16-1** should be brought into compliance. Existing non-compliant signal heads may be retained if bringing the signal heads into compliance would result in replacement of a traffic control signal support which is not proposed to be replaced as part of the project scope.

Positions of Signal Indications within a Horizontal Signal Face

All horizontal signals in Pennsylvania shall adhere to MUTCD, Section 4E.05 and MUTCD Figure 4E-2 for traffic control signals in Pennsylvania.

16.2.5 Location of Vehicular Signal Faces

This section supplements MUTCD Sections 4D.05, 4D.07, 4D.08, 4D.09, and 4D.10 for traffic control signals in Pennsylvania.

A primary signal face is a required signal face for a given approach or separate turning movement. The number and location of primary signal faces on an approach must meet the requirements in this section and the MUTCD sections referenced in this section. One or more supplemental signal faces may be provided to enhance visibility or conspicuity.

Mounting Type

There are two types of mounting for vehicular signals:

- ✓ **Overhead signals** are mounted at least 15 feet above the roadway surface. A signal is considered overhead if it is suspended in a manner which would allow a vehicle to travel below it, even if such a travel path would not be on a roadway. Typical installations include signals placed on mast arms or span wires.
- ✓ **Post-mounted signals** are attached to a pedestal, strain pole, or the vertical support of a mast arm structure located outside the roadway or shoulder.

For approaches with a through movement, the minimum number of overhead primary through signal faces shall be in accordance with **Exhibit 16-3**. All primary overhead signal faces shall be 12" diameter.

Number of Signal Faces

This section supplements MUTCD Section 4D.05. See MUTCD Section 4F.16 for approaches with no through movement.

For new or reconstructed signal installations (see **Section 6.2** for project level definitions), the minimum number and location of primary (non-supplemental) signal faces for through traffic shall be in accordance with **Exhibit 16-3**, which replaces MUTCD Table 4D-1 for signals in Pennsylvania.

Exhibit 16-3 Minimum Number of Primary Signal Faces for Through Traffic

Number of Through Lanes on Approach	Total Number of Primary Through Signal Faces for Approach[1]	Minimum Number of Overhead-Mounted Primary Through Signal Faces Per Approach
1	2	1[4]
2	2	1
3	3[3]	2[2]
4 or more	4 or more	3[2]

[1]A minimum of 2 through signal faces is always required (see MUTCD Section 4D.05). These recommended numbers of through signal faces may be exceeded. Also, see cone of vision requirements otherwise indicated in MUTCD Section 4D.07.
[2]If practical, all the required number of primary through signal faces should be located overhead.
[3]Two primary signal faces may be used for approaches with a speed limit of 35 mph or lower.
[4]All signal faces may be post-mounted when there is one through lane and the posted speed limit is 25 mph or lower.

For approaches with more than one lane and no through movement, a minimum of two primary signal faces shall be provided for the signalized turning movement that is the major movement from the approach.

A shared signal face controlling both a left or right turn movement and the adjacent movement (usually a through movement) can serve as one of the required primary signal faces for the adjacent movement since a shared signal face always displays the same color of circular indication that is displayed by the signal face or faces for the adjacent movement.

A separate signal face controlling only a left or right turn movement cannot serve as one of the required primary signal faces for the adjacent movement (usually a through movement) because it displays signal indications that are applicable only to the turn movement.

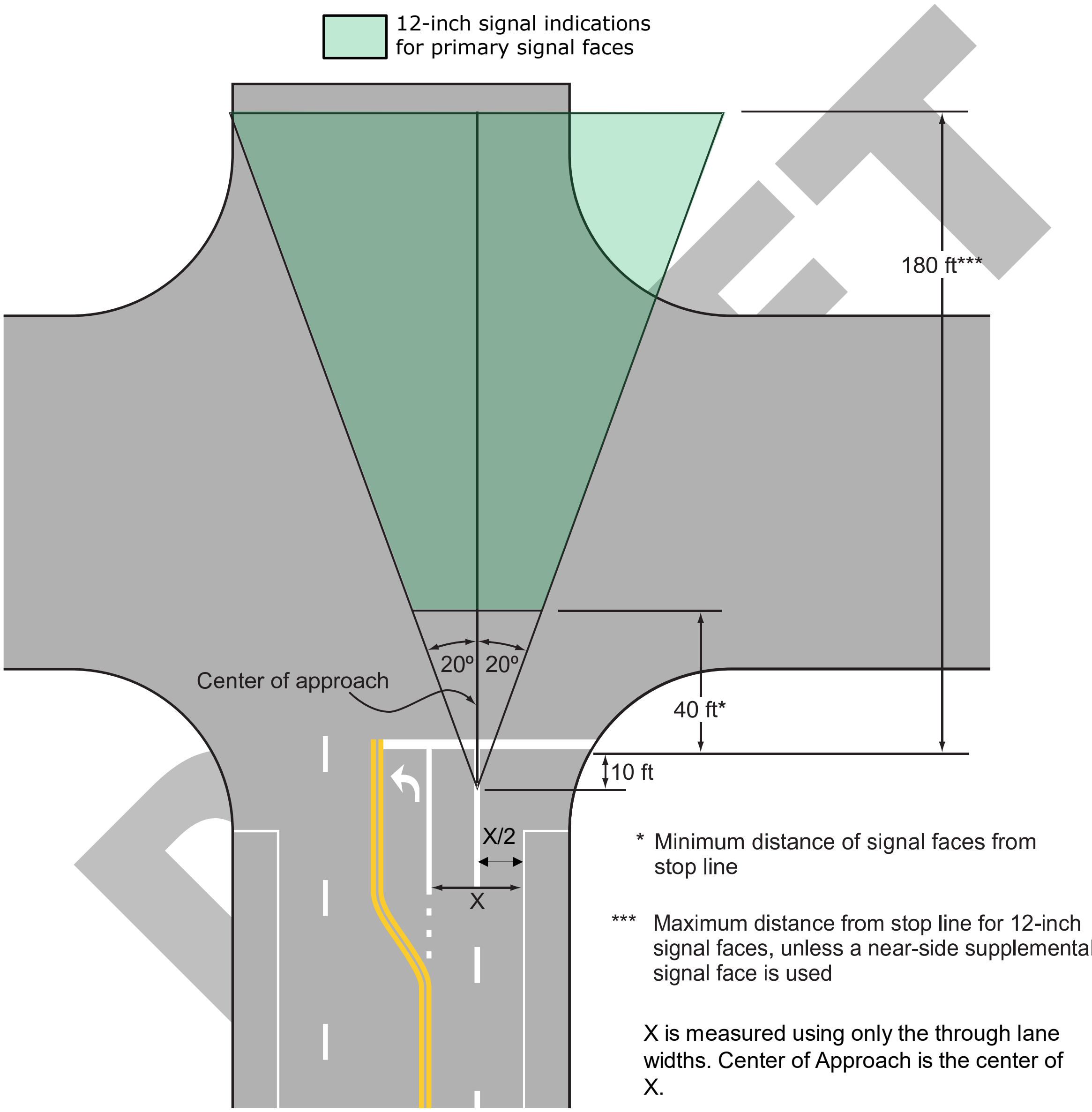
Lateral and Longitudinal Positioning

This section supplements MUTCD Sections 4D.07 and 4D.08.

At least one, and preferably both, of the minimum two primary signal faces for through movements shall be located within the green shaded area shown in **Exhibit 16-4**. **Exhibit 16-4** replaces MUTCD Figure 4D-2.

Also, the primary signal faces for left-turn and right-turn movements shall meet the lateral and longitudinal positioning distances in **Exhibit 16-4**. Refer to **Sections 16.2.7** and **16.2.8** for additional information on lane alignment for turn movement overhead signal indications.

Exhibit 16-4 Lateral and Longitudinal Location of Primary Signal Faces



Lateral Signal Face Spacing and Positioning

Overhead signal faces should be located to the left of the edge of pavement or curb line to discourage vehicles from drifting off the roadway. Where the roadway geometry changes from the approach to departure sides of the intersection, the designer should carefully consider the placement of signal heads. The right approach signal may be post mounted if a lower mounting height would provide positive guidance regarding the alignment change.

At least one overhead signal face, and preferably all primary overhead signal faces, shall be located beyond the center of the intersection.

The preferred distance between signal faces is 12 feet, measured horizontally perpendicular to the approach between the centers of the signal faces. The minimum distance between primary signal faces shall be as indicated in the MUTCD Section 4D.07. A signal face for a through movement and a signal face for an exclusive turn lane shall be located not less than 3 feet apart measured horizontally perpendicular to the approach between the centers of the signal faces.

When a single signal face is serving one approach lane, such as when there are multiple lanes for a movement, the signal face should be centered within the lane. When two signal faces are provided for a single lane, the signal faces should be located on or near the lane lines. These locations may be adjusted when necessary to satisfy the minimum horizontal spacing described in the previous paragraph.

Mounting Heights

This section supplements MUTCD Section 4D.09.

The mounting height for post-mounted signals shall be in accordance with Publication 148. Refer to PennDOT TC-8801 standard drawings. The MUTCD exception for near-side signals in a center median island is not applicable in Pennsylvania.

Lateral Offset (clearance)

This section supplements MUTCD Section 4D.10.

Refer to PennDOT TC-8801 standard drawings.

16.2.6 Visibility, Aiming, and Shielding of Signal Faces

This section supplements MUTCD Section 4D.06 for traffic control signals in Pennsylvania.

Mast arms, span wire, or pedestals (see **Chapter 12**) shall be installed as necessary to provide for proper location of the signals to make sure the signals fall within the motorist's cone of vision.

Minimum Visibility

If approaching traffic does not have a continuous view of at least two signal faces for at least the minimum distance shown in MUTCD Table 4D-2, a Signal Ahead (W3-3) shall be installed to warn approaching traffic of the traffic control signal. Any of the following countermeasures may be used to warn approaching traffic and/or increase visibility:

- ✓ Adding a warning beacon to the Signal Ahead (W3-3) sign.
- ✓ Installing an advance warning flasher (AWF) or internally illuminated warning sign (IIWS) which is interconnected with the traffic signal to flash during the period when road users passing the AWF or IIWS might encounter a red signal indication (or a queue resulting from the display of the red signal indication) upon arrival at the signalized location. See **Chapter 22** for criteria indicating when these signs are required and installation guidelines. When an AWF or IIWS is used, alternate signage is used in place of the Signal Ahead (W3-3) sign.
- ✓ Installing one or more supplemental signal faces in addition to a Signal Ahead (W3-3) sign, AWF, or IIWS.

When the location to be signalized involves horizontal or vertical curve approaches, there are three design issues that require special consideration:

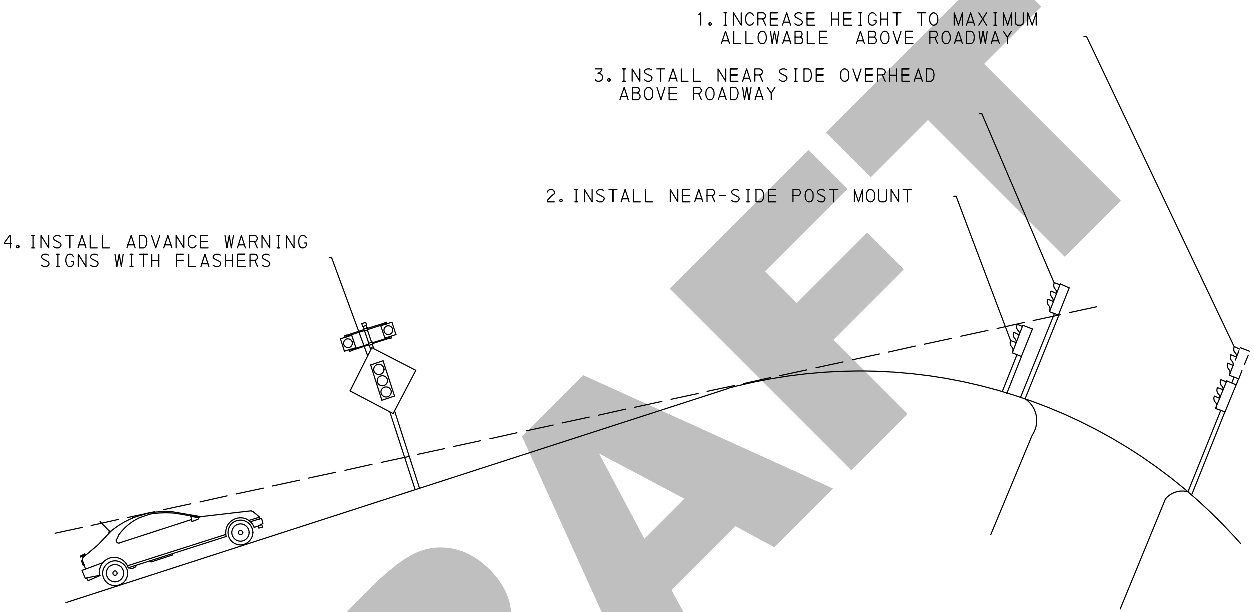
- ✓ The first issue relates to the minimum visibility distances specified in the MUTCD, Section 4D.06 ,
- ✓ The second issue involves driver expectancy regarding the lateral placement of the signal displays, and

- ✓ The third issue involves accounting for the back of the queue length in case a curve obstructs sight distance to stopped vehicles. Refer to Table 4D-2 of the MUTCD.

Vertical Curve Approaches

To resolve the minimum visibility issue on vertical curves, several techniques may be applied, as shown in **Exhibit 16-5**. In addition to the countermeasures described above, signal faces may be raised to their maximum heights.

Exhibit 16-5 Addressing Signal Visibility at Vertical Curves



Horizontal Curve Approaches

Supplemental signal faces can also be applied to horizontal curve approaches.

- ✓ Supplemental near-side signal indications may be placed on the left for right-hand curves or on the right for left-hand curves.
- ✓ These supplemental displays may be post-mounted or overhead as needed to provide adequate visibility.

Driver expectancy of the signal location is particularly critical at horizontal curve approaches. At unlighted locations at night, the driver may not always perceive the proper travel path to the intersection.

- ✓ Shifting a primary signal face, and/or
- ✓ Installing supplemental faces to guide the driver into the intersection may be considered.

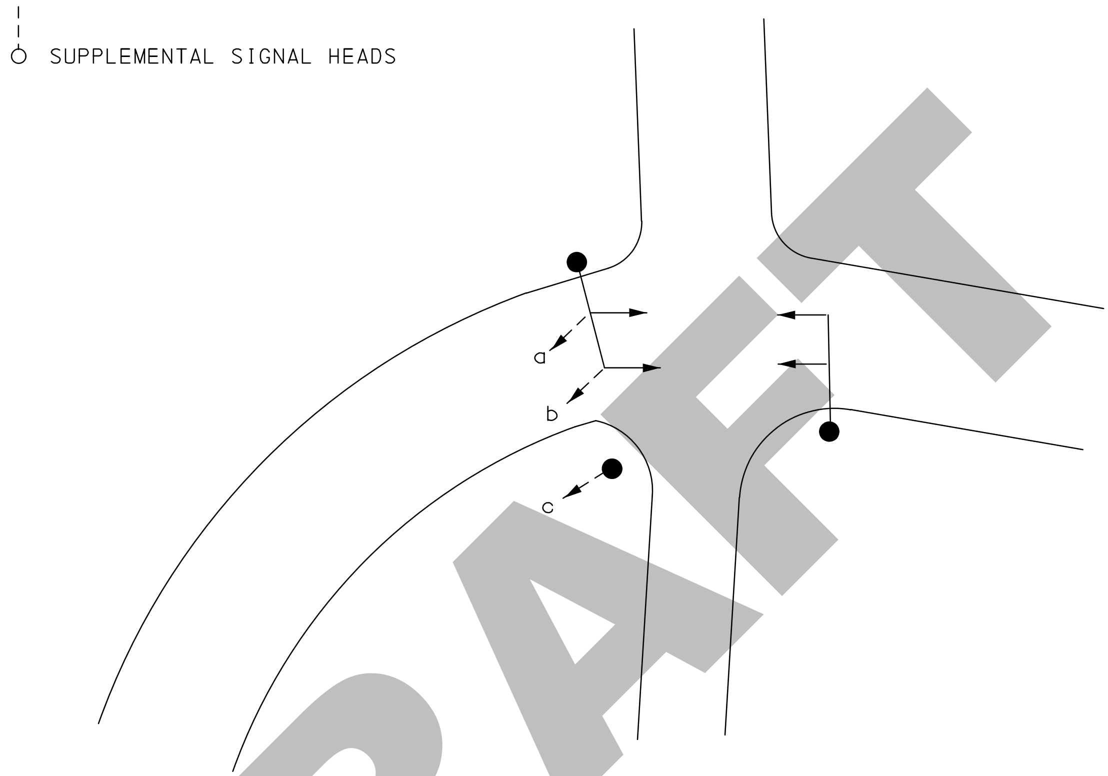
There are no formal guidelines for locating signals in such diverse situations.

- ✓ One method for determining the most effective layout is to drive the approaches at night to identify the exact point where driver confusion may arise.
- ✓ A plan view of the intersection is then drafted showing the lines of sight in relation to alternate signal head placement.
- ✓ A design layout is then developed using the "best" alternative and is reviewed in the field.

Exhibit 16-6 illustrates a layout with three possible supplemental signal locations. In this illustration, a and b represent additional signal head locations on a mast arm and c is a post-mounted near-right signal.

- ✓ Although positions a and b are the most conspicuous, they might tend to draw the driver toward the left of the curve, since drivers are accustomed to seeing the first signal (primary signal) on the right.
- ✓ Position c might be preferable in that it would tend to lead the driver around the curve.

Exhibit 16-6 Supplemental Signal Placements for Horizontal Curves



Visors

Visors shall be used on all vehicular signal faces.

There are two types of visors shown in Publication 148, TC-8805: cut-away and tunnel. Cut-away visors should be used, unless one or more of the following conditions exist, where tunnel visors should be used instead of cut-away visors:

- ✓ Where irregular street design necessitates placing signal faces for different street approaches with a comparatively small angle between their respective signal indications
- ✓ Signal indications with louvers

The standard specifications in Publication 408 include cut-away visors. If tunnel visors are to be used, they must be indicated on the traffic signal plan.

Backplates

In Pennsylvania, backplates are required on all new traffic control signals, and modifications to existing traffic control signals. Backplates shall be added to all signals at intersections as part of Level 2, 3, or 4 projects (see **Section 6.2**).

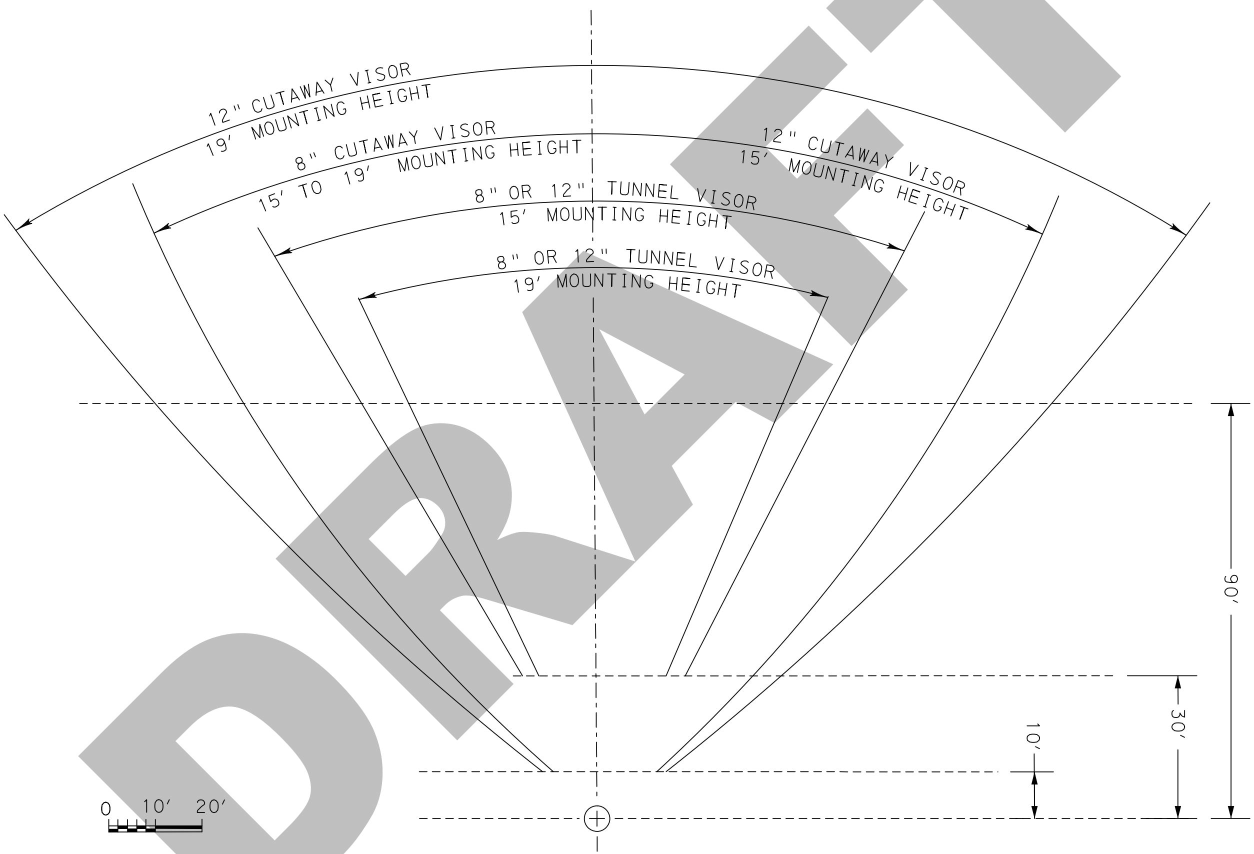
NOTE: Backplates have been part of the structural analysis for poles since at least the late 1980s (1988 edition of Pub 149); therefore, it can be assumed that all TC-7800 poles were designed for backplates. Structural analysis may be required for older poles.

See Publication 408, Section 955, and Publication 148 (TC-8805) for additional backplate requirements.

Vehicular Signal Visibility for Pedestrians

- ✓ At intersections where pedestrian signals are not used and pedestrians may be present, the designer must verify that the pedestrian has adequate visibility of the vehicular signals. See **Chapter 8** for determining whether pedestrian signals are needed.
- ✓ The pedestrian must be able to continuously see an indication while walking from the beginning of the crossing to a point 10 feet from the end of the crossing during the vehicular change and clearance intervals at a walking speed of 3.5 ft/s.
- ✓ Use **Exhibit 16-7** to determine if a supplemental signal head is needed for adequate visibility. Place the overlay such that the + point is directly over the location of the signal head nearest the crosswalk under consideration.

Exhibit 16-7 Signal Visibility for Pedestrians



Aiming

The construction specifications in Publication 408 require signal heads to be aimed toward a point approximately 150 feet in advance of the stop line and in the center of the traveled traffic approach. If an alternate aiming is desired, the designer must indicate it on the plan.

Louvers

Louvers are full-circle inserts with one or more built-in fins or vanes that restrict the viewing angle of the signal indication; and are used to decrease the possibility of motorists seeing signal indications which are not intended for them, especially at locations where roads intersect at acute angles.

- ✓ Louvers shall be considered for other special applications such as vehicular signals installed for pedestrians when their indication conflicts with other vehicular signals.

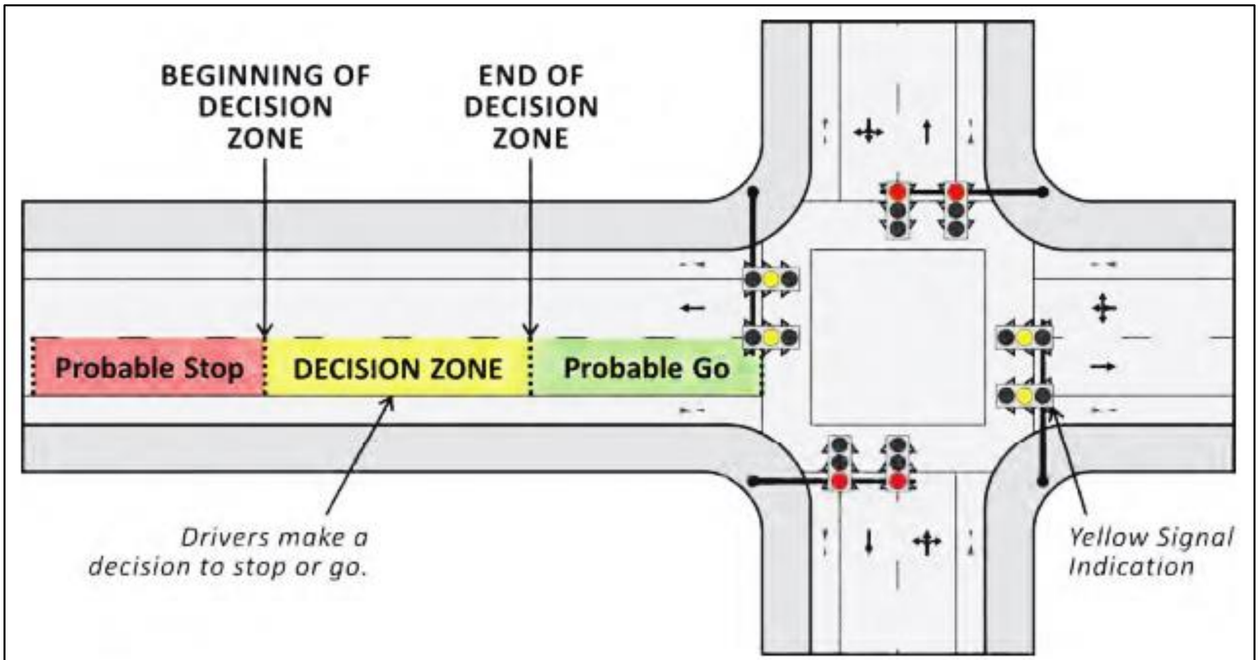
- ✓ For the louvered signal, as viewed by the intended user, indicate the degree of cut-off and which side the cut-off is to occur, right or left.
- ✓ When used, louvers should be installed with tunnel or full-circle visors.

Optically Programmed Signal Heads

Optically programmed signals are designed for applications where visibility of proper, non-conflicting signal indications is critical. The most common uses for optically programmed signals are for closely spaced intersections, offset intersections, sharply skewed intersections, or for internal clearances.

- ✓ An overhead programmed signal/louver shall be rigidly mounted to retain the signal's effectiveness and desired area of visibility and non-visibility.
- ✓ When intersections are less than 200 feet apart or very closely spaced, motorists may see upstream signal indications and become confused as to which signals control the intersection. This confusion may be greatest during the clearance interval of the intersection. Oftentimes, this results in motorists becoming trapped within the intersection area, thus potentially creating delays and hazards to other motorists. The potential for such occurrences can be drastically reduced by using optically programmed signals/louvers and "distance limiting" their area of visibility.
- ✓ Distance limiting is the programming of the signal so that motorists cannot see the signal display until they are beyond the point at which they have decided to proceed through the first set of signals.
  - The second set of signal indications should be visible as far in advance as possible, but not prior to the "Probable Go" point as shown in **Exhibit 16-8**.
- ✓ The distance limit point shown on the signal plan should generally correspond to the distance from the stop line to the End of Decision Zone (typically about 2.5 seconds of travel time) from the stop line (as per the Signal Timing Manual – Second Edition (STM2) and can be calculated using prevailing vehicular speeds.
- ✓ Besides closely spaced intersections as described above, the use of programmed signals should be considered at
  - Skewed intersections when the angle between two approaches is 35 degrees or less.
  - At intersections where the cross streets are offset, or where a railroad is downstream of the cross street.
- ✓ See the following Internal Clearance sub-section for additional information.
- ✓ See Publication 408, Section 955, and Publication 148 (TC-8805) for additional requirements.

Exhibit 16-8 Decision Zone Boundaries on a Typical Intersection Approach



Source: *Traffic Signal Timing Manual*, 2nd Edition

⇐ Click icon to play a video illustrating the Decision Zone.

Closely-Spaced Intersections

When far side signals are of such a distance from the stop line that the signals may draw and stop motorists within the intersection area, or across railroad tracks, during the clearance interval, the provision of an "internal clearance" can help eliminate this situation.

- ✓ To provide an internal clearance on an approach, it is necessary to furnish two separate, yet interrelated, signal installations.
- ✓ The first consists of an installation of standard signals placed in accordance with usual design practice.
  - The second consists of optically programmed signals placed at the far side of the intersection. These signals shall be distance limited as per the procedure described above in the 'Optically Programmed Signal Head' sub-section.
- ✓ The internal clearance is provided in the controller phasing and is controlled by the overlap settings (see **Section 10.3.4**).
- ✓ The beginning of the green interval for both signals occurs simultaneously.
  - The clearance interval of the programmed signals is delayed long enough to allow a vehicle which enters the intersection during the yellow interval of the standard signals to clear the intersection.
- ✓ The internal clearance allows motorists entering the intersection during the normal yellow interval to see the green indication of the programmed signal once they cross the stop line. Thus, the motorists are informed that they have the right-of-way to complete the movement.

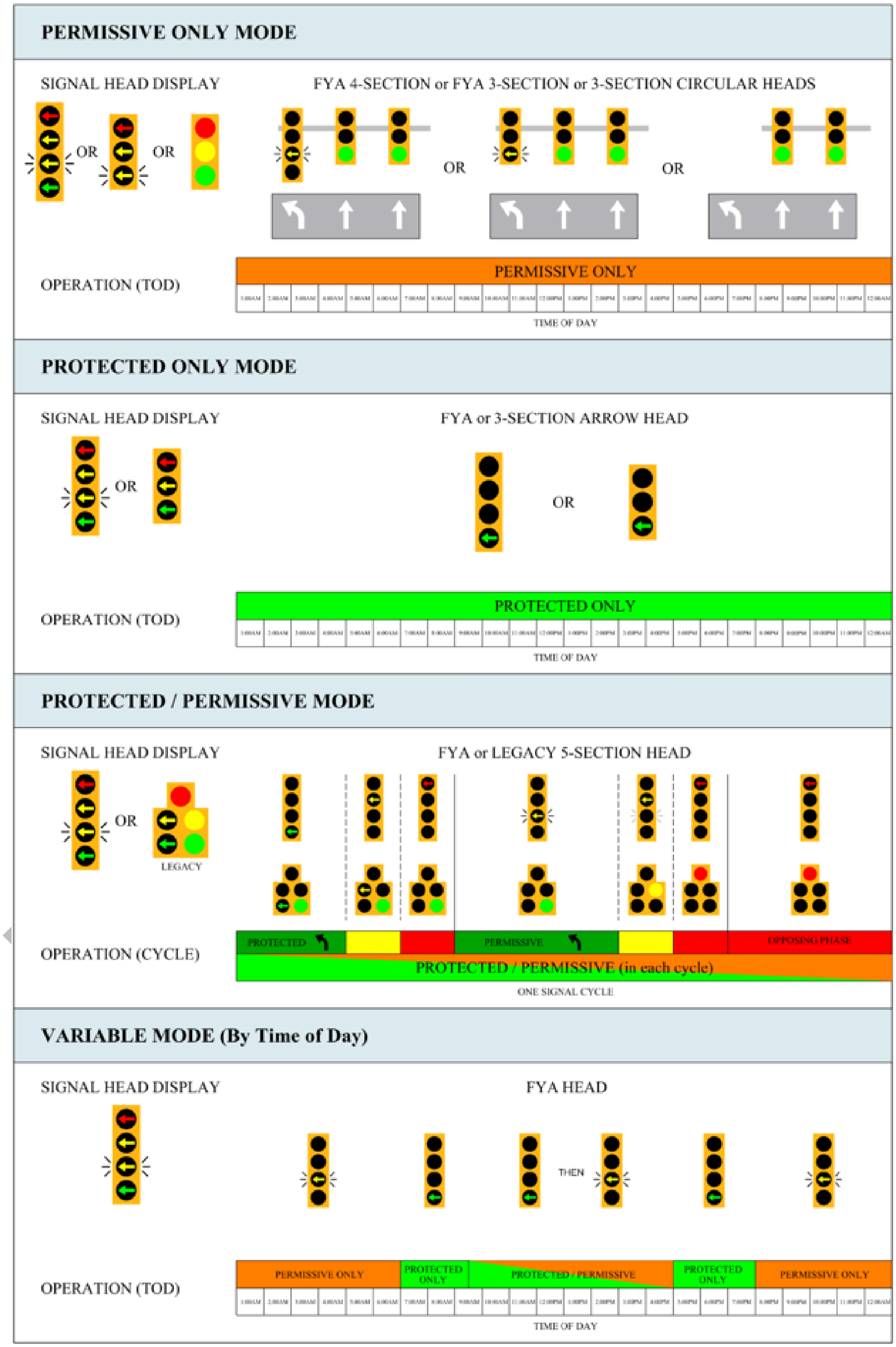
16.2.7 Signal Indications for Left-Turn Movements

This section supplements MUTCD Sections 4F.02, 4F.03, 4F.04, 4F.05, 4F.06, 4F.07 and 4F.08 for traffic control signals in Pennsylvania. Also, refer to **Section 10.3.3** for additional detailed information on left turn phasing.

Left turning traffic on an approach is controlled by one of the following modes, see **Exhibit 16-9** for an illustration example of how each of these modes function:

- ✓ **Permissive Only Mode -** Turns made on a circular green signal indication or a flashing left-turn yellow arrow signal indication after yielding to pedestrians, if any, and/or opposing traffic, if any.
- ✓ **Protected Only Mode -** Turns made only when a left-turn green arrow signal indication is displayed. Protected only mode may be one of the following:
  - **Protected-Prohibited -** A protected only mode left turn movement that does not begin and terminate at the same time as the adjacent through movement. Protected-prohibited phasing can only be used when all left turn movements are made from an exclusive left-turn lane.
  - **Split Phasing -** A protected only mode left turn movement that always begins and terminates at the same time as the adjacent through movement.
- ✓ **Protected/Permissive Mode -** Both protected and permissive modes can occur on an approach during the same cycle.
- ✓ **Variable Left-Turn Mode -** On an approach, the operating mode changes among the permissive only mode and/or the protected only mode and/or the protected-permissive mode during different periods of the day or as traffic conditions change.
- ✓ **Prohibited -** Left turn movements are not allowed from the approach.

Exhibit 16-9 Left-Turn Phasing Modes Illustration



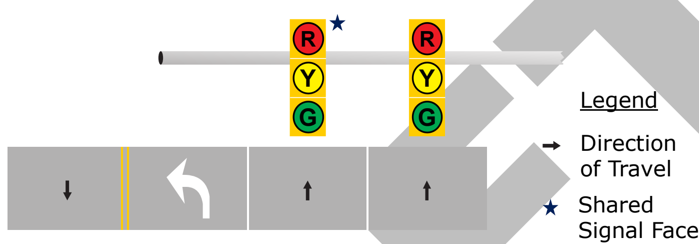
Permissive Only Mode Left-Turn Movements

This section supplements MUTCD Sections 4F.03 and 4F.04.

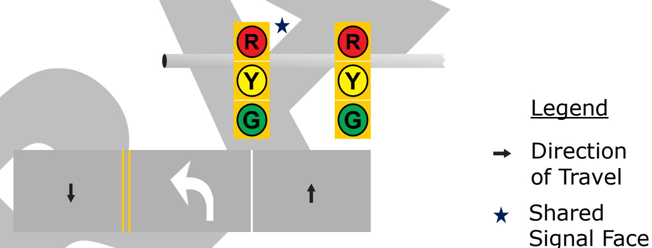
- ✓ MUTCD Figure 4F-3 (Flashing Red Arrow) is not allowed in Pennsylvania.
- ✓ **Exhibit 16-10** and **Exhibit 16-11** shows figures that shall be used in Pennsylvania for acceptable permissive only signal face types and positions.

Exhibit 16-10 PA Typical Position of Shared Signal Faces for Permissive Only Mode Left Turns

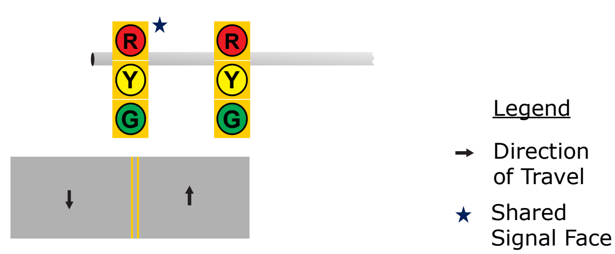
A – Exclusive Left Turn Lane with Shared Signal Face (Multiple Other Lanes)



B – Exclusive Left Turn Lane with Shared Signal Face (Single Other Lane)



C – Single Lane Approach

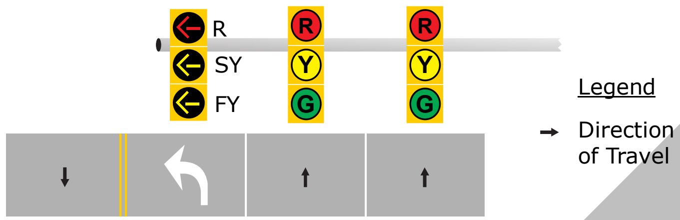


Adapted from MUTCD Figure 4F-1.

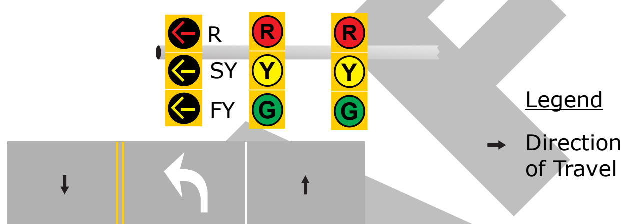
See **Section 16.2.5** for requirements for lateral spacing between signal faces.

Exhibit 16-11 PA Typical Position of Separate Signal Faces for Permissive Only Mode Left Turns

A – Exclusive Left Turn Lane with Separate Signal Face (Multiple Other Lanes)



B – Exclusive Left Turn Lane with Separate Signal Face (Single Other Lane)



Adapted from MUTCD Figure 4F-2.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

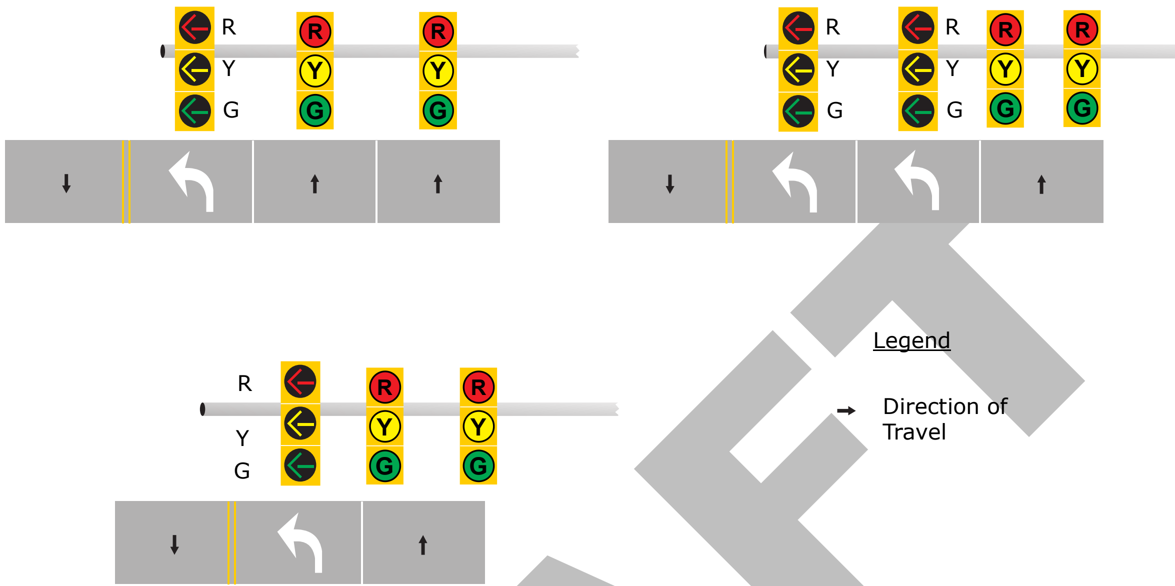
Protected Only Mode Left-Turn Movements

This section supplements MUTCD Sections 4F.05 and 4F.06.

Exhibit 16-12 and **Exhibit 16-13** shows figures that shall be used in Pennsylvania for acceptable protected only signal face types and positions.

Exhibit 16-12 PA Typical Position of Signal Faces for Protected Only Mode Left Turns (Separate Left Turn Signal Face)

Separate Left Turn Signal Face **(Protected-Prohibited Phasing or Split Phasing)**



Adapted from MUTCD Figure 4F-5.

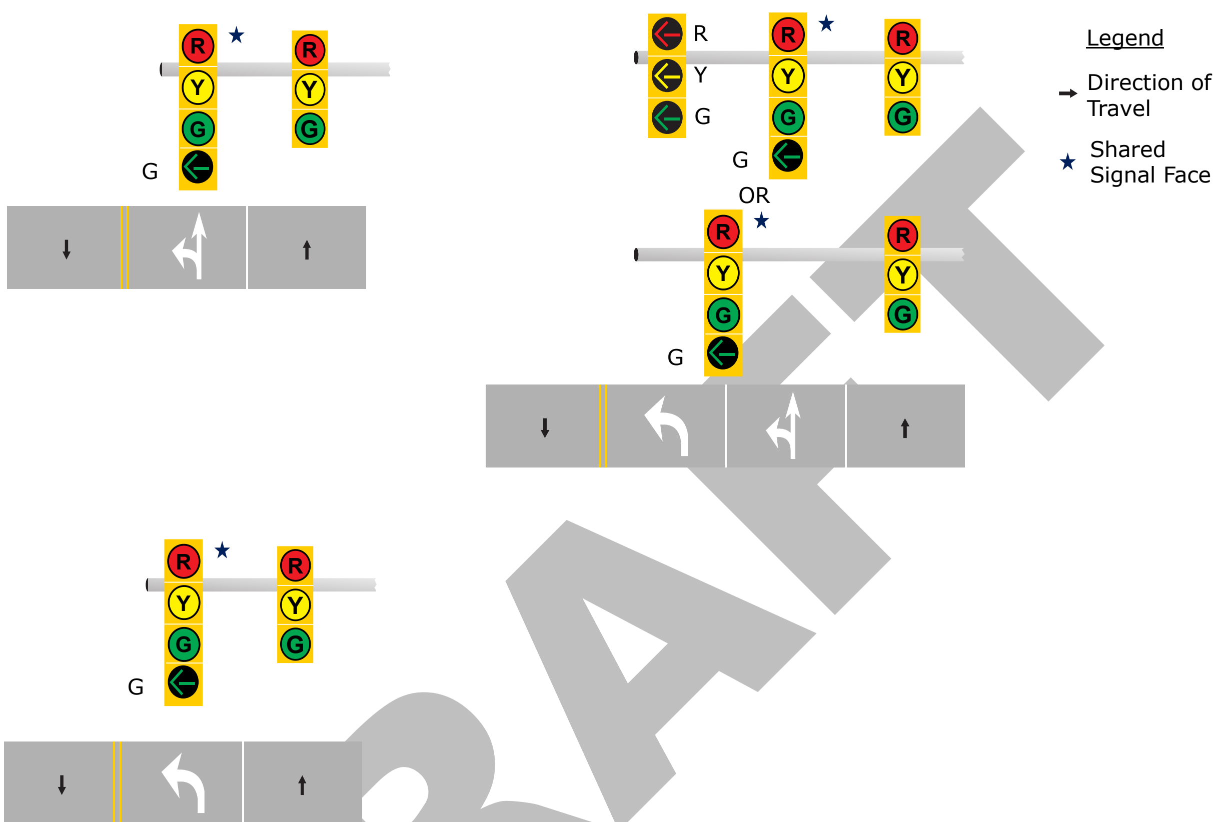
See **Section 16.2.5** for requirements for lateral spacing between signal faces.

With multiple left turn lanes, provide one signal face for each turn lane.

Protected-prohibited left turn phasing shall only be used on an approach with an exclusive left-turn lane; and signal faces for protected-prohibited phasing should be capable of displaying only one of the three indications at any given time (steady red arrow, steady yellow arrow, and steady green arrow).

Exhibit 16-13 PA Typical Position of Signal Faces for Protected Only Mode Left Turns (Shared Left Turn Signal Face)

Shared Left Turn Signal Face **(Split Phasing)**



Adapted from MUTCD Figure 4F-4.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

For split phasing, the four-section signal face shall display the circular green and green arrow indications simultaneously.

Older Displays for Protected/Prohibited Left-Turn Movements

Prior to 2013, the standard vehicular signal configuration in Publication 149 for protected/prohibited left-turns included a circular red indication, which also required use of the LEFT TURN SIGNAL (R10-10L) sign. Although this practice was discontinued in the 2009 Edition of the MUTCD and was removed in the 2013 edition of Publication 149, many signals with this configuration still exist.

To facilitate MUTCD compliance, circular red indications in separate left-turn signal faces for protected/prohibited phasing shall be replaced with a red arrow indication whenever signal permits are modified. The LEFT TURN SIGNAL (R10-10L) sign may be removed when the circular red indication is replaced with a red arrow signal indication.

A traffic signal permittee should replace the circular red indication with a red arrow indication as part of preventative maintenance activities. The District Traffic Signal Unit should be notified when the change is made, but a permit revision is not required if this is the only change made.

Protected/Permissive Mode Left-Turn Movements

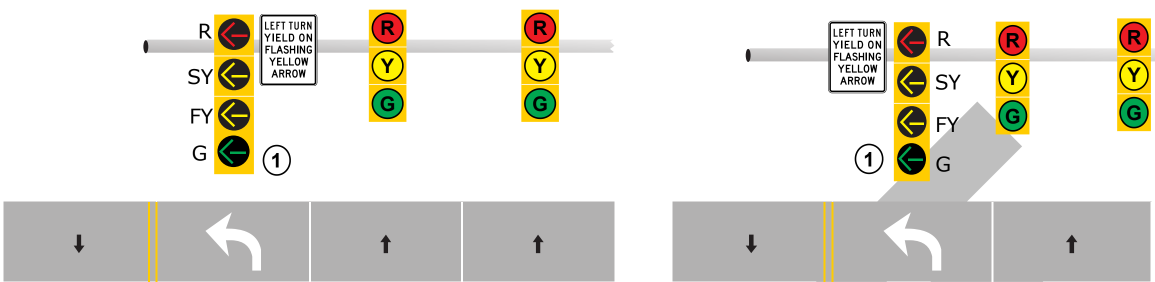
This section supplements MUTCD Sections 4F.07 and 4F.08.

Exhibit 16-14 shows figures that shall be used in Pennsylvania for acceptable protected/permissive signal face types and positions, unless one of the following exceptions applies:

- ✓ If a protected/permissive phase is added on an approach with an exclusive left-turn lane and the project scope does not include replacing the mast arm, a five-section shared signal face may be used if the mast arm is not long enough to locate a separate four-section signal face over the exclusive left-turn lane. The five-section shared signal face shall be located over an extension of the lane line between the exclusive left turn lane and the adjacent approach lane.

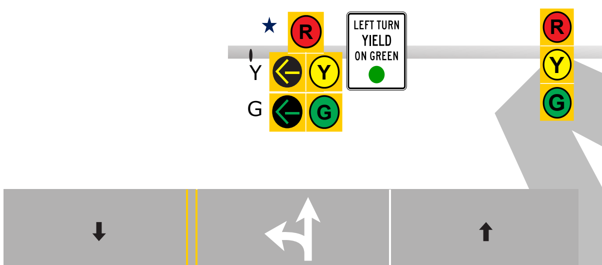
Exhibit 16-14 PA Typical Position of Signal Faces for Protected/Permissive Mode Left Turns

A – Exclusive Left Turn Lane Protected/Permissive Left Turn Leading or Lagging



① Separate left turn signal face shall be located within the left turn lane.

B – Shared Left Turn Lane Protected Left Turn Leading Only

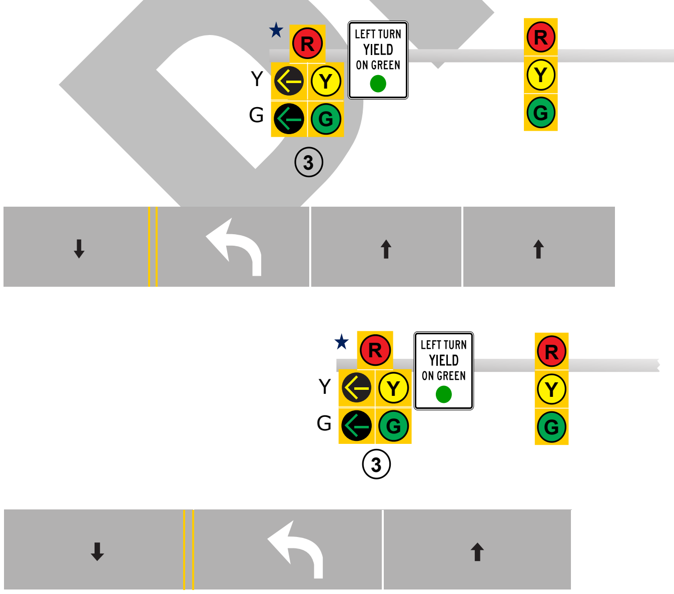


Legend

→ Direction of Travel

★ Shared Signal Face

C – Retrofits Only: Exclusive Left Turn Lane Protected/Permissive Left Turn Leading Only②



② Shared faces may only be used with an exclusive left turn lane for retrofits where the project scope does not include signal support replacement and the existing support is unable to support a separate left turn signal face within the left turn lane

③ Shared left turn signal face shall be located over an extension of the lane line between the exclusive left turn lane and the adjacent approach lane.

Adapted from MUTCD Figure 4F-6 & Figure 4F-7.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

The FYA face may be pedestal-mounted within a median if existing overhead supports are inadequate to ensure the proper alignment between the FYA and the associated turn lane.

A supplement FYA signal face should be installed if the primary FYA face is mounted at a height that is obscured by large vehicles.

FYA Retrofits

The use of Flashing Yellow Arrow for protected-permissive phasing was first introduced in Pennsylvania in 2016. Prior to that time, the 5-section signal face was used for protected-permissive phasing. Engineering judgement considering the following criteria should be used when determining candidate retrofit locations:

- ✓ Type of cabinet and controller
- ✓ Vehicle detection
- ✓ Mast arm orientation and length
- ✓ Structure integrity of the existing signal support and mast arm
- ✓ Availability of a post mounted alternative if needed.
- ✓ Vertical clearance constraints
- ✓ Presence of conflicting left-turn paths

Candidate retrofit locations should be prioritized based on the following:

- ✓ Corridors where changing to lead/lag rather than lead/lead left-turn phasing would improve progression but implementation without FYA would result in a yellow-trap situation.
- ✓ Locations where left-turn demand is low during off-peak periods and variable modes of left-turn phasing would be beneficial.
- ✓ Locations where crash patterns involve left-turning vehicles and could be attributed to driver misunderstanding of shared signal indications.
- ✓ Locations with frequent railroad or emergency vehicle preemption which currently results in a left-turn trap.
- ✓ Locations undergoing signal upgrades.

Variable Mode Left-Turn Movements

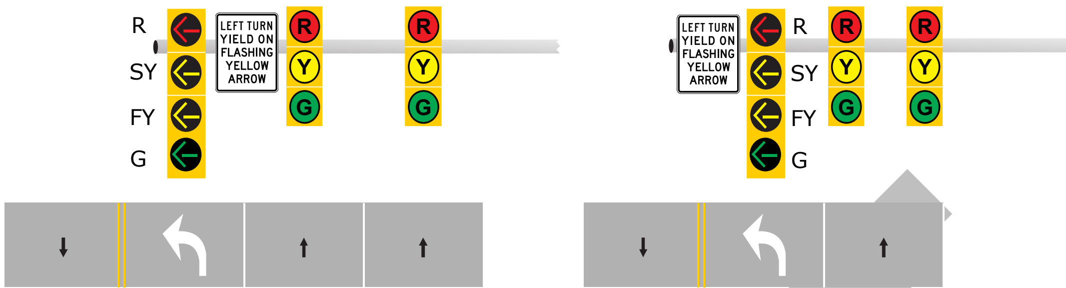
With the use of the four-section FYA signal display, the FYA signal head indications can adapt in response to the following three left-turn modes of operation, providing additional operational flexibility.

- ✓ Permissive-only,
- ✓ Protected/permissive, and
- ✓ Protected/prohibited.

Exhibit 16-15 shows figures that shall be used in Pennsylvania for acceptable variable mode left turn signal face types and positions.

Exhibit 16-15 PA Typical Position of Signal Faces for Variable Mode Left Turn Phasing

A – Exclusive Left Turn Lane Variable Mode Left Turn



The green arrow indication is not used when operating in the permissive only mode.

The flashing yellow arrow indication is not used when operating in the protected only mode.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

16.2.8 Signal Indications for Right-Turn Movements

This section supplements MUTCD Sections 4F.09, 4F.10, 4F.11, 4F.12, 4F.13, 4F.14, and 4F.15 for traffic control signals in Pennsylvania.

Right-turning traffic is controlled by one of four modes as follows:

- ✓ **Permissive Only Mode -** turns made on a CIRCULAR GREEN signal indication or a flashing right-turn YELLOW ARROW signal indication after yielding to pedestrians, if any.
- ✓ **Protected Only Mode -** turns made only when a right-turn GREEN ARROW signal indication is displayed.
- ✓ **Protected/Permissive Mode -** both modes occur on an approach during the same cycle.
- ✓ **Variable Right-Turn Mode** – the operating mode changes among the protected only mode and/or the protected/permissive mode and/or the permissive only mode during different periods of the day or as traffic conditions change.

Although the MUTCD states that a steady right-turn red arrow signal indication shall be displayed if it is intended to <u>not</u> permit right turns on red, or a circular red signal indication shall be displayed if it is intended to permit right turns on red, the Pennsylvania Vehicle Code §3112(a)(3)(ii) does not differentiate between an arrow or circular indication when establishing the legality of a right turn on red movement. Therefore, in Pennsylvania:

- ✓ A right turn on red is permitted after stopping with either a steady circular red or a steady right red arrow indication unless a No Turn on Red sign is installed.
- ✓ A steady red right-turn arrow may be used without impacting whether right-turn on red is permitted on the approach.

Channelized Right-Turn Movements

If a single-lane right-turn movement is channelized and separated from other movements on the approach by an island, the right-turn movement may be excluded from the traffic control signal operation. If excluded from the traffic control signal operation, a channelized right-turn movement shall be YIELD-controlled, unless an acceleration lane is provided. STOP-control should not be used for a channelized right turn movement when the other movements on the approach are part of the traffic control signal operation.

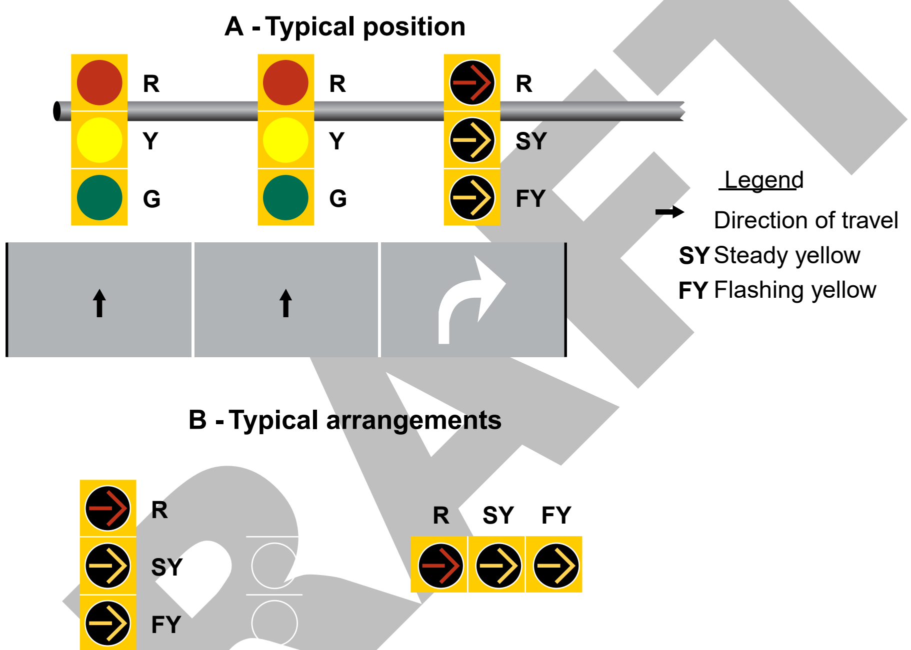
If a channelized right-turn movement is included with the traffic control signal operation, separate right-turn signal face(s) shall be provided with all right-arrow indications which operates using one of the four modes described above.

Permissive Only Mode Right-Turn Movements

This section supplements Sections 4F.10 and 4F.11 of the MUTCD .

- ✓ MUTCD Figure 4F-8 (Shared Signal Faces) may be used as shown in the MUTCD.
- ✓ MUTCD Figure 4F-9 (Separate Signal Faces w/ FYA) is modified as shown in **Exhibit 16-16**, which shows figures that shall be used in Pennsylvania for acceptable permissive only signal face types and positions for separate faces with FYA.
- ✓ MUTCD Figure 4F-10 (Flashing Red Arrow) is not allowed in Pennsylvania.

Exhibit 16-16 PA Typical Position of Separate Signal Faces with FYA for Permissive Only Mode Right Turns



Adapted from MUTCD Figure 4F-9.

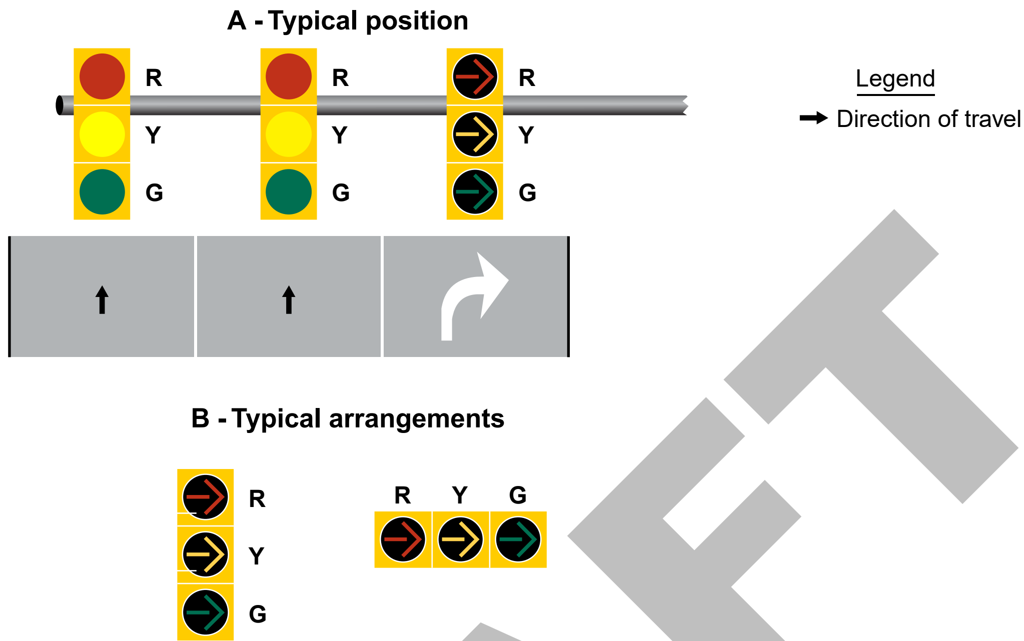
See **Section 16.2.5** for requirements for lateral spacing between signal faces.

Protected Only Mode Right-Turn Movements

This section supplements Sections 4F.12 and 4F.13 of the MUTCD.

- ✓ MUTCD Figure 4F-11 (Shared Signal Faces) may be used as shown in the MUTCD.
- ✓ MUTCD Figure 4F-12 (Separate Signal Faces) is modified as shown in **Exhibit 16-17**, which shows figures that shall be used in Pennsylvania for acceptable protected only separate signal face types and positions.

Exhibit 16-17 PA Typical Position of Signal Faces for Protected Only Mode Right Turns



Adapted from MUTCD Figure 4F-12.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

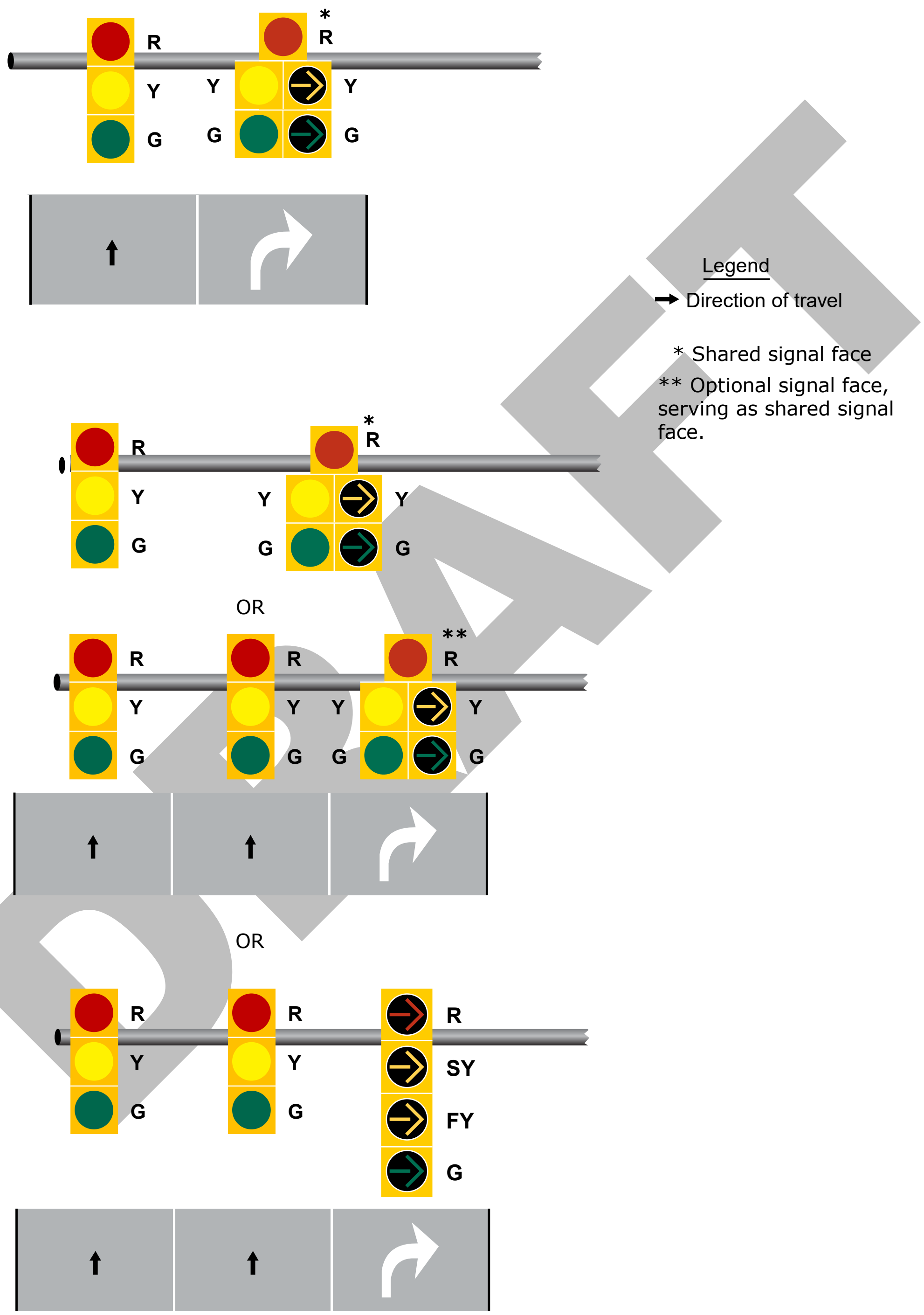
Protected/Permissive Mode Right-Turn Movements

This section supplements Sections 4F.14 and 4F.15 of the MUTCD.

Exhibit 16-18 shows figures that shall be used in Pennsylvania for acceptable protected/permissive signal face types and positions.

Exhibit 16-18 PA Typical Position of Signal Faces for Protected/Permissive Mode Right Turns

Typical Positions



Typical arrangements see **Exhibit 16-2.**

Adapted from MUTCD Figure 4F-13 & 4F-14.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

Variable Mode Right-Turn Movements

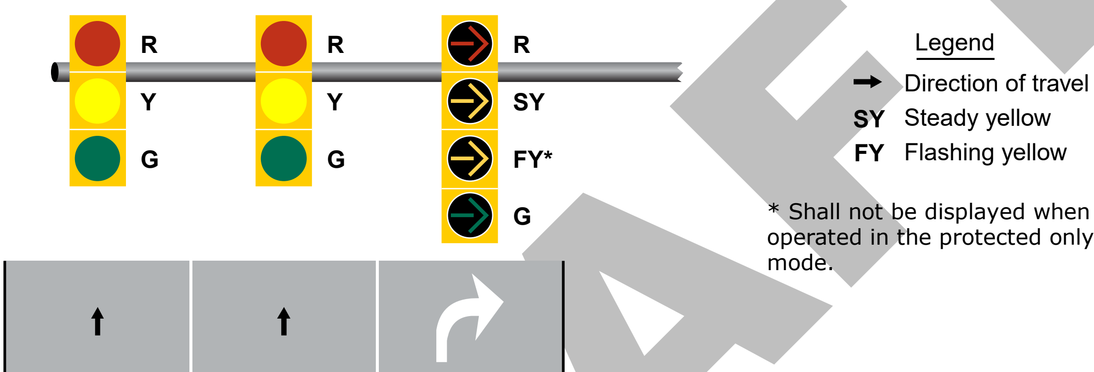
With the use of the four-section FYA signal display, the FYA signal head indications can adapt in response to the following three right-turn modes of operation, providing additional operational flexibility.

- ✓ Permissive-only,
- ✓ Protected/permissive, and
- ✓ Protected/prohibited.

Exhibit 16-19 shows figures that shall be used in Pennsylvania for acceptable variable mode right turn signal face types and positions.

Exhibit 16-19 PA Typical Position of Signal Faces for Variable Mode Right Turn Phasing

Typical Position



Adapted from MUTCD Figure 4F-14.

See **Section 16.2.5** for requirements for lateral spacing between signal faces.

16.2.9 Signal Indications for Approaches with no Through Movement

This section supplements MUTCD Section 4F.16 for approaches with no through movement in Pennsylvania.

The most common application of MUTCD Section 4F.16 is for the approach on the stem of a T-intersection, and three-section signal faces with circular red, circular yellow, and circular green indications are typically used for that application.

16.3 Pedestrian Signals

This section supplements MUTCD Chapter 4I for pedestrian signals in Pennsylvania.

The design and operation of traffic control signals shall take into consideration the needs of pedestrian as well as vehicular traffic. See **Chapter 8** on Pedestrian Accommodations and the process by which to determine if pedestrian signals are needed.

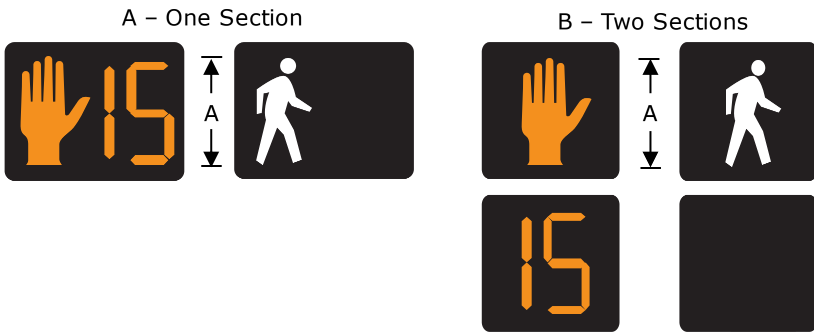
Pedestrian signal heads provide special types of traffic control signal indications exclusively intended for controlling pedestrian traffic.

Exhibit 16-20 shows acceptable pedestrian signals that shall be used in Pennsylvania. These signal indications consist of the following illuminated symbols:

- ✓ WALKING PERSON (symbolizing WALK),

- ✓ UPRAISED HAND (symbolizing DONT WALK), and
- ✓ Countdown timer (displayed during flashing upraised hand interval).

Exhibit 16-20 Pedestrian Signals



For crosswalks where the pedestrian enters the crosswalk more than 100 feet from the pedestrian signal head indications, Dimension "A" should be at least 9 inches high.

MUTCD Chapter 4I requires that all pedestrian signal heads used at crosswalks include a pedestrian change interval countdown display.

The 2023 PROWAG requires that at intersections with pedestrian signal heads, accessible pedestrian signals (APS) shall be used to provide indication of pedestrian timing in non-visual formats (such as audible tones and/or speech messages, and vibrating surfaces).

Since pedestrian change interval displays and APS are required everywhere that pedestrian signal heads are used, the following changes can be made to the pedestrian signals even if the traffic signal permit does not show these changes. The municipality should notify their PennDOT District Traffic Unit when such a change is made and shall update the traffic signal component information in TSAMS.

- ✓ Replacement of existing pedestrian signals heads (without pedestrian change interval countdown display) with new pedestrian signal heads that include a pedestrian change interval countdown display.
- ✓ Addition of APS to the intersection.

Pedestrian Countdown Interval Displays are required at all pedestrian signal heads used at crosswalks per MUTCD.

APS is required where pedestrian signal heads are provided per 2023 PROWAG.

Permit revisions are not required for updating pedestrian signal heads to include countdown timers, or to add APS, but information needs updated in TSAMS.

16.4 Lane-Use Signal Heads

See **Chapter 27** and MUTCD Chapter 4T for information on lane-use signal heads.

17. DETECTORS

17.1 General

Actuated traffic control signal depends on the ability to sense traffic demand for local intersection control. Sensors may also be used as system detectors for traffic responsive operation. Detector data is also fundamental to developing automated traffic signal performance measures. Therefore, the proper design and installation of a traffic control signal's detection system is critical to an intersection's safe and efficient operation.

Designers have various options available regarding detection system type and functionality. The designer should be careful to consider all manufacturer recommendations for detection equipment to ensure that the specified equipment can accommodate the full function of the design and operational intent in all roadside environments.

This chapter presents information related to vehicular detection and pedestrian detection types relevant to traffic signal designers.

For Preemption Detectors (emergency vehicles) and Specialized Preemption Detectors (railroad, transit, etc.), see **Chapter 11**.

For additional information on signal timing settings related to detection, see **Chapter 10**.

For addition information related to detectors, see the following references:

- ✓ Publication 46 (Chapter 4)
- ✓ Publication 148 (TC-8803; TC-8806)
- ✓ Publication 408 (Section 956)
- ✓ ECMS Master Items (0956)
- ✓ Publication 35 (Bulletin 15)
- ✓ FHWA *Traffic Detector Handbook: Third Edition* – Volume I and Volume II

17.2 Vehicular Detection

Vehicular detectors are devices that sense the presence of vehicles in designated zones within the roadway and provide information an on or off indication to the controller. The controller can use detection for information such as the presence, occupancy, volume, and speed of vehicles. This section provides various technical information and guidance related to vehicular detection, as follows:

- ✓ Detector types
- ✓ Detection zone function and location (modes, sizes & types)
- ✓ Controller assembly interface
- ✓ Detector technology selection guidance
- ✓ Design guidance (in-pavement detectors & over-roadway detectors)

The following terminology is used in this section:

- ✓ **Detection Area** refers to a contiguous area detected by a sensor. For inductive loops, each loop sensor is one detection area. For over-roadway detection, a sensor may have multiple detection areas.
- ✓ **Amplifier Channel** is only used with inductive loops to identify the loop sensors which are wired together in series or parallel to a single lead-in cable to an amplifier.
- ✓ **Detection Zone** refers to the area which provides actuation. A detection zone may be comprised of a single detection area or multiple detection areas. For inductive loops, a detection zone may be comprised of a single amplifier channel or multiple amplifier channels.

- ✓ **Controller Input** refers to detection zones which provide an actuation input to the controller through the same input channel.

17.2.1 Detector Types

Vehicle detectors can be broadly grouped into two major categories:

- ✓ **In-pavement detectors** require construction and closing the lane with a temporary traffic control pattern to repair the detector or change the detection zone location.
- ✓ **Over-roadway detectors** are typically configured through software, either in the cabinet or remotely. This allows detection zones to be created and moved without a technician being in the roadway. A lane closure may be required when working on the sensor if the sensor is located over the lane to facilitate safe access with a bucket truck.

The various detector types available for traffic control signals are shown in **Exhibit 17-1**, with more information about each detection technology following.

Exhibit 17-1 Typical Vehicle Detector Types

In-Pavement Vehicle Detectors	Over-Roadway Vehicle Detectors
✓ Inductive loops	✓ Video detector ✓ Omni-view video detector system ✓ Thermal imaging ✓ Radar ✓ Radar and video detection system

Inductive Loops

Inductive loop detection involves the placement of a continuous length of wire in the pavement, a lead-in cable, and an amplifier to provide an input to the controller.

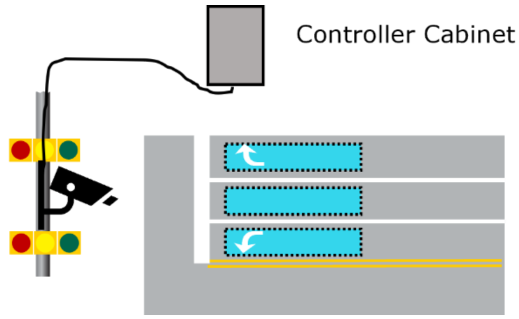
The loop wire in the pavement is a large inductor creating a magnetic field around it. When a ferrous object, such as a car, passes over the loop, eddy currents, induced in the frame of the vehicle, causes a decrease in the inductance of the loop. The detector amplifier senses this decrease and translates it to a vehicle demand.

Loop detectors cannot determine the direction by which a vehicle crosses over it. Therefore, a delay can be used to avoid false calls from turning vehicles which may cross a loop intended for traffic traveling the opposite direction.

Avoid locating detectors where vehicles may park over them or near driveways to avoid false detections. Manholes or other subsurface structures which may affect the operation of the detectors must not be within the area of a loop detector. A series of smaller detection areas may be used to avoid subsurface structures and to provide the required area of detection.

Video Detector

A video detection system uses one or more video cameras rigidly mounted on traffic supports and a processor with software to digitize and analyze the imagery to detect vehicles. One video camera can provide detection to several lanes of traffic for one approach and of providing demand and volume, simultaneously. Video detection systems use video detection cards or other cabinet equipment for processing the image into detector calls. Video detectors are required to determine the direction by which a vehicle crosses over it.



Accurate detection requires that the system be able to operate successfully in all kinds of weather and under a variety of ambient light conditions. Although the capabilities of these systems have increased, certain conditions such as heavy fog and washout caused from the sun aligned directly with the approach may still produce detection problems. Proper configurations shall and should be drawn through the video detection software to establish the detection zones. These detection zones may be removed, replaced, or redrawn using the video detection software on a laptop computer. Video detection can be used successfully for actuation detection on any approach if the camera can be located to meet the following criteria:

- ✓ The camera is mounted at a height of approximately 30 feet; a lower height where the camera is mounted on a mast arm is acceptable for stop line detection, and up to 100 feet upstream detection for approaches of 30 MPH or less.
- ✓ At a mounting height of 30 feet, a detection zone may be placed as far as 300 feet from the camera. This horizontal to vertical ratio of 10 to 1 defines the maximum limit for reliable detection at lower mounting heights. Vertical curvature of the approach should also be considered. Note: Trucks may block vehicles causing inefficiency in working as volume-density detector.
- ✓ The camera is mounted such that the zone of detection is in view and the horizon is NOT in the view.
- ✓ The camera is aligned with the lanes that are being detected with a head-on view of traffic as much as practical.
- ✓ The selected zone of detection is not affected by occlusion.
- ✓ The intersection should have adequate street lighting levels to assure that whole vehicles, not just their headlights, are detected at night.

Video Omni-View Detectors

Omni-view video detection systems utilize a 360-degree lens to track, detect, classify, and count pedestrians, bicycles, and motor vehicles for the entire intersection as indicated.

Thermal Imaging

Thermal camera also known as infrared camera detects heat (infrared energy) given off by objects and produces it as a thermal image where other typical video detection systems depends on amount of available light. Unlike other video detection systems, thermal cameras can detect motorized vehicles, cyclists, and pedestrians in both day and night. Thermal imaging cameras have no imaging challenges such as sun glare, shadows, snow, and fog which are typically known problems of traditional visible light imaging technologies. Thermal imaging detection systems use video detection cards or other cabinet equipment for processing the image into detector calls. This system may be used in vehicle presence detection at traffic control signals, queue detection, speed, and vehicle classification.

Radar

Radar systems use sensors rigidly mounted on traffic supports to detect approaching vehicles based on the frequency of emitted microwaves. When a vehicle passes through the beam of energy, a portion of the energy is reflected to the sensor and detection is made. Radar sensors can detect vehicles in pulse and presence mode. Radar systems require interface boards/modules in lieu of loop amplifiers. This type of detection may be used to track vehicles approaching the intersection. Radar systems allow for continuous tracking of vehicles at an intersection and perform well under all weather and light conditions.

Radar & Video Detectors

These detection systems are a combination of radar and video detection. Typically, the radar is used for advance detection and video is used for stop-bar detection.

Emerging Technology

Detection technology continues to evolve. New technologies must be approved by PennDOT prior to implementation at traffic signals for detection.

17.2.2 Detection Zone Function and Location

Operating Modes

The detection operating mode refers to the way the detection unit measures activity and is set in the detection unit. It also affects the duration of the actuation submitted to the controller by the detection unit. There are two detector operating modes: presence and pulse.

- ✓ **Presence Mode**: Presence mode (area or presence detection) is used to measure occupancy and the actuation starts with the arrival of the vehicle to the detection zone and ends when the vehicle leaves the detection zone. The time duration of the actuation depends on the vehicle length, detection zone length, and vehicle speed. Presence mode is typically the default mode.
- ✓ **Pulse Mode**: Pulse mode (point or passage detection) is used to count vehicles by motion only. The actuation starts with the arrival of the vehicle (pulse activation occurs usually 0.10 to 0.15 seconds) to the detection zone and ends after the pulse duration. This mode is typically used when the detectors are located upstream of the stop line and associated detector channel operates in the locking mode.

Detectors may be configured to provide a delay or extension. These parameters can also be programmed into most controller units directly, which is recommended. Programming a delay or extension within the detector itself should only be used when the controller is not capable of configuring these parameters. See **Chapter 10** for more information on controller programming for delay and/or extension parameters.

Detection Zone Size

Detection zone sizes are broadly grouped into two categories, short zones, and long zones:

- ✓ **Short Zone:** A detection zone that is less than 20 feet in length in the direction of travel.
- ✓ **Long Zone:** A detection zone that is 20 feet or greater in length in the direction of travel and primarily used for presence mode detection. Long zones may be comprised of a single detection area or multiple (sequential) short detection areas functioning as a single detection zone.

The specific size of the zone is dependent upon the detection technology used and/or vendor-specific processing algorithms.

Detection Zone Types

The following detection zone types may be used in Pennsylvania:

- ✓ **Stop Line Presence Zone (long zone, presence mode):** A detection zone located at the stop line which is used to call the phase and may be used to extend the phase. The size of the zone should account for the range of probable vehicle stopping positions to minimize the likelihood of missed detection to call a phase based on where the vehicle is stopped. Additional zone(s) may be required at locations where the stop line is set back from the intersection to detect vehicles which stop between the stop line and the intersection. Since stop line presence zones typically use long zones, multiple vehicles may occupy the zone at the same time, and the zones should not be used for counts.

- ✓ **Advance Zone (short zone, presence, or pulse mode):** A detection zone located upstream from the stop line which may be used for volume density operation and/or used to determine estimated arrival time of the vehicle at the intersection and whether the vehicle arrives on red or green. A short zone shall be used to ensure each individual vehicle is detected separately. When an advance zone is used for variable initial operation (see Section 10.4.2), the detector needs to be in locking mode to count vehicles arriving on red.
- ✓ **Stop Line Lane-by-Lane Count Zone (short zone, pulse mode):** A detection zone located at or in front of the stop line to be used for lane-by-lane count data collection. A short zone shall be used to ensure each individual vehicle is detected separately. These detection zones are not used for signal actuation.
- ✓ **System Zone (short zone, pulse mode):** A detection zone typically located in the departure lanes of the intersection to measure traffic volumes for system operation. A short zone shall be used to ensure each individual vehicle is detected separately. These detection zones are not used for signal actuation.
- ✓ **Queue Detection Zone (short or long zone, presence mode):** A detection zone location at the point where a queue is of concern, such as on freeway off-ramps or left turn lanes. The detection zone is used in presence mode to measure occupancy.
- ✓ **Dilemma Zone (short or long zone, presence mode):** A detection zone or combination of multiple zones within the range where an approaching driver is indecisive regarding stopping prior to the stop line or proceeding into or through the intersection when the signal changes from green to yellow, usually 2.5 to 5.5 seconds upstream of the stop line.

Acceptable Detector Use (by Operating Mode & Zone Type)

Exhibit 17-2 Acceptable Detector Use (by Operating Mode and Zone Type)

Detector Type[1]	Operating Mode		Zone Types					
	Presence	Pulse	Stop Line Presence	Advance Zone[6]	Stop Line Lane-by-Lane Count	System Zone	Queue Detection Zone	Dilemma Zone
In Pavement Detectors								
Inductive Loops	A	A	A	A	P[2]	A	A	N/A
Over-Roadway Detectors								
Video	A	A	A	N/A	P[4]	P[3]	P[3]	N/A
Video Omni-View	A	A	A	N/A	A	P[3]	P[3]	N/A
Thermal Imaging	A	A	A	N/A	P[4]	P[3]	P[3]	N/A
Radar	A	A	A[5]	A	A[5]	A	A	A
Radar & Video	A	A	A	A	A	A	A	A

A – Acceptable
P – Potentially Acceptable if conditions are met
N/A – Not Applicable
[1]See **Section 17.2.1** for definitions of each detector technology.
[2]Requires inductive loops using separate lead ins wired to separate amplifier channels and broken out by separate detector inputs at the controller.

[3]Dependent on mounting height and zone distance from detector.
[4]Dependent on manufacturer and model.
[5]Dependent on manufacturer may require separate models installed.
[6]Includes volume density zones.

Detection Zone Locations for Automated Traffic Signal Performance Measures (ATSPM)

As defined by FHWA, Automated Traffic Signal Performance Measures (ATSPM) is a suite of performance measures, data collection, and data analysis tools to support objectives and performance based approaches to traffic signal operations, maintenance, management, and design to improve the safety, mobility, and efficiency of signalized intersections for all users. See Exhibit 3-2 in NCHRP Report 954, *Performance-Based Management of Traffic Signals*, for information on the applicability of various detection zone types to use different performance measures available with ATSPM.

17.2.3 Controller Assembly Interface

The number of detection channels available from a particular detector depends on the cabinet interface. The signal designer must consider the detection technology in use or proposed along with the cabinet interface to determine how many detection channels are available and to assign the channels for the desired operation.

Loop detectors may have either shelf-mounted amplifiers or detector cards within a card rack. An amplifier may have 1, 2, or 4 channels.

NEMA TS-1

In a NEMA TS-1 cabinet, the detector inputs to the controller are typically limited to one per phase, with a detector channel typically configured to call the corresponding phase. If there is more than one detector or detection zone for a phase, the detectors are wired together on the detector panel. Each detector has a point-to-point wire connection to a pin on the A, B, or C connectors. Detector actuations are accomplished via contact closure.

NEMA TS-2

In a NEMA TS-2 cabinet, detector inputs are over the SDLC bus, with 4 BIUs or “racks” of 16 channels each, for a total of 64 channels. Each detector cabinet interface can be assigned to use one or more of the four BIUs, but the same BIU should not be assigned to more than one detector cabinet interface. For example, if video detection is using 24 channels and advance radar detection is using 6 channels, the video detection system would need to use 2 BIUs (32 channels), and the radar detection system would need to use 1 BIU (16 channels).

Caltrans 332/336

Cabinets in a Caltrans configuration (332 or 336) use rack-mounted detector cards. The card rack is hard wired to provide 18 detector channels to the controller unit.

ATC

An ATC cabinet provides detector inputs using a Serial Interface Unit (SIU), which can provide up to 128 detection channels to the controller.

17.2.4 Detector Technology Selection Guidance

There is no single detection technology that universally performs better than all other systems, and the performance may vary depending on time of day, weather conditions, types of vehicles, and/or pavement condition. Traffic signal designers must consider these factors when determining the most effective detection to be used at a particular intersection.

Factors to consider when comparing detection technologies include:

- ✓ Likelihood and impacts of false detections.
- ✓ Likelihood and impacts of missed detections.
- ✓ Device placement and potential for occlusion
- ✓ Infrastructure condition (pavement, signal supports, bridge decks, etc.)
- ✓ Municipal maintenance capabilities
- ✓ Initial installation cost vs. ongoing maintenance costs
- ✓ Ability to relocate detection zones for anticipated future lane changes or temporary conditions.
- ✓ Private driveway approaches to traffic signals located outside the legal right-of-way.
- ✓ Visual obstructions (overhead wires, trees, shadows, etc.)
- ✓ Detection zone location (stop line vs. advance detection)
- ✓ Directionality (where vehicles may cross the detection zone in directions other than the direction to be detected)
- ✓ Data collection requirements

The selection of vehicular detector type needs to consider the intended application, ease of installation and maintenance, and design requirements. Tables 1-1 and 1-2 in the FHWA *Traffic Detector Handbook: Third Edition – Volume 1* provide strengths and weaknesses of commercially available detection technologies and the types of data available from each technology. The Idaho Transportation Department research report titled "Evaluation of Vehicle Detection Systems for Traffic Signal Operations" (2016) provides additional information on performance of various detection technologies.

17.2.5 Design Guidance – In Pavement Detectors

Before design of in-pavement sensors, a field investigation should be made to determine the condition of the roadway pavement. If the pavement is damaged (rutted, cracked, broken, etc.), the pavement should be reconstructed prior to installing in-pavement sensors.

Inductive Loop Detectors

The following bid items are applicable to signal designs using loop detectors:

- ✓ Loop Sensor (0956-0101 & 0956-0102 includes backer rod), which includes the loop wire, sawcut, sealant, backer rod in the pavement and to the first junction box where a splice is made to the detector lead-in cable.
- ✓ Detector Lead-in Cable (0956-001) from the loop splice junction box back to the controller cabinet
- ✓ Conduit connecting from the edge of pavement at each loop to the splice junction box and then back to the controller cabinet (see **Chapter 15** for electrical distribution)
- ✓ Loop Amplifiers Shelf-Mounted with various items (0956-0111, 0956-112, 0956-121, 0956-122, 0956 124, and 0956-0125) dependent on #channels and timer or count output parameters.
- ✓ Loop Amplifiers Rack-Mounted with various items (0956-0131, 0956-0132, 0956-0141, 0956-0142, 0956-0143, 0956-0144) dependent on #channels and timer or count output parameters.
- ✓ Detector Card Rack (0956-0011) (if not using shelf-mounted detectors).

In-pavement loop sensors should have a junction box located in its immediate vicinity out of the roadway area. Each loop sensor shall be provided with its own length of 1-inch diameter rigid conduit from the junction box or pole base just beyond the curb or edge of roadway under the finished pavement. The conduit carries the sensitive sensor wires from the saw slot slit in the roadway to the junction box or pole base, where the sensor wires are spliced to the lead-in wire. Refer to TC-8806 (Detectors) for more details on junction box and conduit use with in-pavement detectors.

The complexity of the intersection operation (traffic volumes, # of loops, movements, phases, etc.) may influence design choices regarding desirable amplifier channel size, loop wiring, and number of needed amplifiers.

Avoid locating loop sensors where vehicles may park over them or near driveways to avoid false detections. Manholes or other subsurface structures which may affect the operation of the detectors must not be within the area of a loop detector. A series of smaller detection areas may be used to avoid subsurface structures and to provide the required area of detection.

Use of Single vs. Multiple Channel Amplifiers:

Loop amplifiers may provide 1, 2, or 4 channels. Each channel provides an independent connection to a loop sensor (or series of loop sensors tied together as one). A simple example of a signal design with 4 loop sensors may use one 4-channel amplifier, two 2-channel amplifiers, or four 1-channel amplifiers. Each signal design is unique and should consider the following items when determining which channel size amplifiers (or combination of amplifiers) to use:

- ✓ For existing controller cabinets, the available space and shelf mounting/card rack may dictate what channel size/quantity of amplifiers fit best.
- ✓ Multi-channel amplifiers are typically more cost effective since a lesser quantity of amplifiers can be used to provide the same total number of channels within the controller assembly; and multi-channel amplifiers also use less space within the cabinet.
- ✓ If a loop amplifier goes bad, all its channels will be inoperable. In the case of the larger 4-channel amplifier, more loop sensors will be inoperable versus a 2-channel or 1-channel amplifier.

Use of Shelf-Mounted Loop Amplifiers vs. located within a Detector Card Rack:

- ✓ NEMA TS-2 Type 1, and Type 170 or 2070 controller assemblies must use rack-mounted detectors. NEMA TS-1 and TS-2 Type 2 controller assemblies may use either shelf-mounted or rack-mounted detectors.
- ✓ The desired number of channels per amplifier may dictate the mounting type.
  - Shelf-mounted loop amplifiers come in either 1-channel or 2-channel versions with **no** 4-channel availability.
  - Rack-mounted loop amplifiers come in either 2-channel or 4-channel versions with **no** 1-channel availability.
- ✓ Shelf-mounted may provide ease of maintenance by being able to observe traffic in the lane while holding the detector outside of the cabinet.
- ✓ Card rack may provide an opportunity to do a TS-2 connection to the controller even in a TS-1 cabinet, which would allow more than 8 outputs to the controller to be used.

Use of Single vs. Multiple loop sensors per amplifier channel (Loop Wiring):

Each detection channel which is passed to the controller unit for actuation may be comprised of a single loop sensor or multiple loop sensors wired together in series or parallel with one lead-in cable, as shown in **Exhibit 17-3** and **Exhibit 17-4**. Intersection configuration and signal operations play a key role in determining which method is preferable for safe and efficient operations. Some considerations are as follows:

- ✓ If multiple loop sensors are joined together with one lead-in cable, the loops must be of identical size to be tuned correctly. Otherwise, separate amplifier channels and lead-in cables are needed.
- ✓ Cases where multiple loop sensors may be joined together with one lead-in cable on the same amplifier channel include the following:
  - Multiple short loop sensors in the same approach lane which are intended to function as a single detection zone.
  - Multiple loop sensors in adjacent lanes which call the same phase (either for the same movement or for compatible movements served by the same phase)
  - A combination of the above
- ✓ Each loop sensor should have an independent lead-in cable and amplifier channel where data collection for Automated Traffic Signal Performance Measures is desired.
- ✓ Methods for joining multiple loop sensors together:

- ✓ **Series connection -** if one loop goes bad all detection capabilities of the joined loops are lost and a constant call (fail safe) is in effect.
    - **Parallel connection –** the amplifier will lose detection from the broken loop but will still have detection of the good loop as it tunes itself to the good loop. Depending upon the broken loop location, it may involve losing a different lane's detection.
- ✓ When loops are connected in series the inductance of the assembly increases whereas the inductance decreases if the loops are connected in parallel. These effects must be considered when calculating the total inductance of a multi-loop assembly.

Exhibit 17-3 Loop Wiring Options

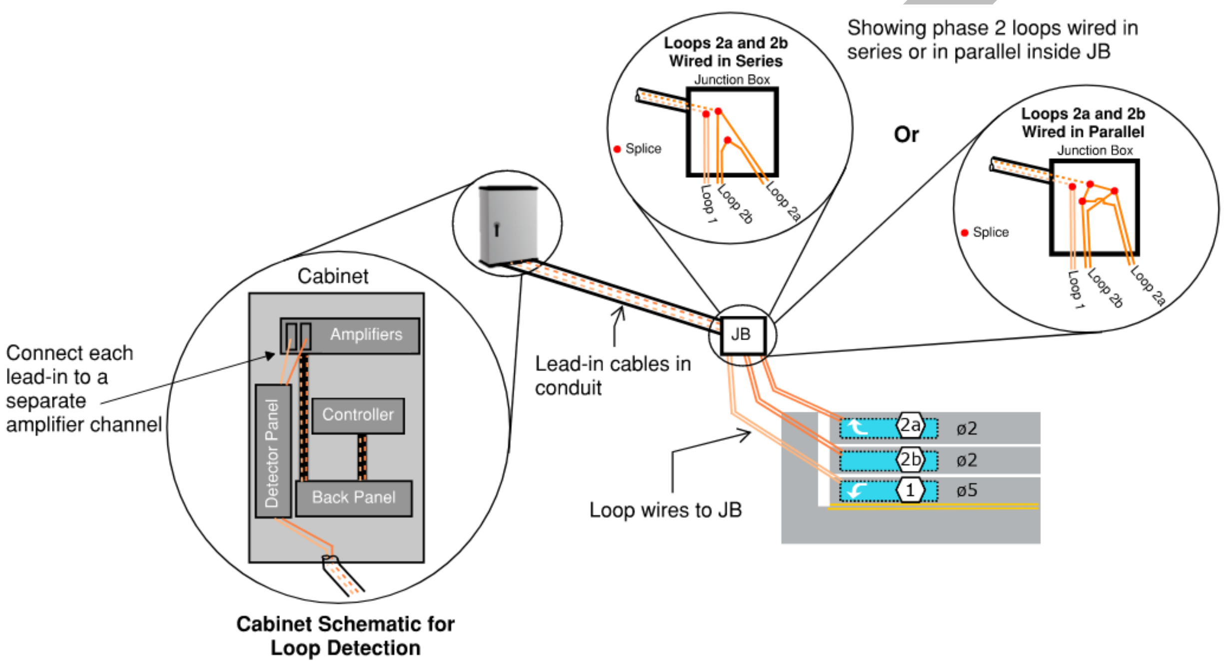
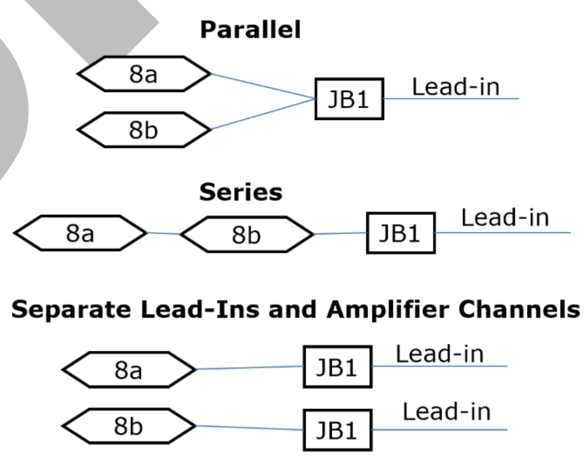


Exhibit 17-4 Loop Wiring Example Diagram



Zone Type/Configuration

Refer to **Exhibit 17-2** for applicable uses of inductive loop sensors.

There are several basic loop configurations which may be used. Refer to TC-8806 in Publication 148 for inductive loop layout details and installation.

As defined at the beginning of **Section 17.2**, a detection area is the area detected by one loop sensor. Following are typical configurations of loop sensors:

- ✓ **Short Loop Sensors and Sequential Short Loop Sensors**

  The short loop may be installed either alone to create a short detection zone, or sequentially in conjunction with other short loop to create a long detection zone. Sizing and layout criteria are as follows:

  - The length shall be 6 feet.
  - The minimum width shall be 5 feet.
  - The sides of the zone should be 2 feet from either edge of the travel lane, which would provide 4 feet between zones in adjacent lanes.
- ✓ For detection in advance of the stop line, the location from the stop line is determined by the speed of approaching vehicles.
- ✓ A long detection zone shall be comprised of four sequential short loops. The first loop should be placed so that it extends 3 feet beyond the stop line. The spacing between the second, third, and fourth sequential loops shall be 10 feet, 15 feet, and 20 feet, respectively (see **Exhibit 17-5** and Publication 148, TC-8806).
- ✓ **Long Loop Sensors**

  The long loop is used to provide a long detection zone with one loop. Each detected lane of an approach shall have a separate zone (see **Exhibit 17-5** and Publication 148, TC-8806). Sizing and layout criteria are as follows:

  - The maximum length shall be 50 feet. If a detection zone longer than 50 feet is needed, sequential short loops shall be used (see above).
  - The maximum width shall be 8 feet and the minimum 5 feet. If a wider detection zone is needed, sequential short loops shall be used (see above).
  - The sides of the zone should be a minimum of 2 feet from either edge of the travel lane, which would provide 4 feet between zones in adjacent lanes.
  - The front edge of the zone may extend 3 feet beyond the stop line.
- ✓ Long loops shall operate in the presence mode only.
- ✓ **Modified Long Loop Sensors**

  The modified long inductive loop was devised to address the problem of adjacent lane detection in extremely high sensitivity inductive loop systems. The outer configuration of the loop is identical to conventional loops, but has a saw cut down the center. The loop consists of wire laid in a figure eight pattern in the saw cut, thus creating two narrow loops laid side by side (see **Exhibit 17-5** and Publication 148, TC-8806). This winding pattern creates fields that cancel outside the perimeter of the loop and are enhanced within it. Modified long loops are more effective than conventional loops in the detection of small vehicles such as bicycles and small motorcycles. The procedures for sizing and layout shall be identical to those for both short and long conventional loops.

  Refer to TC-8806 (Detectors) in Publication 148 for additional loop patterns for small vehicles. The loop sensor quantity must consider any extra turns or other wiring configurations.

Layout Option Typicals

Exhibit 17-5 illustrates four options for loop layouts. Details on dimensions for each type are loop are indicated in Publication 148, TC-8806.

Exhibit 17-5 Loop Detection Options

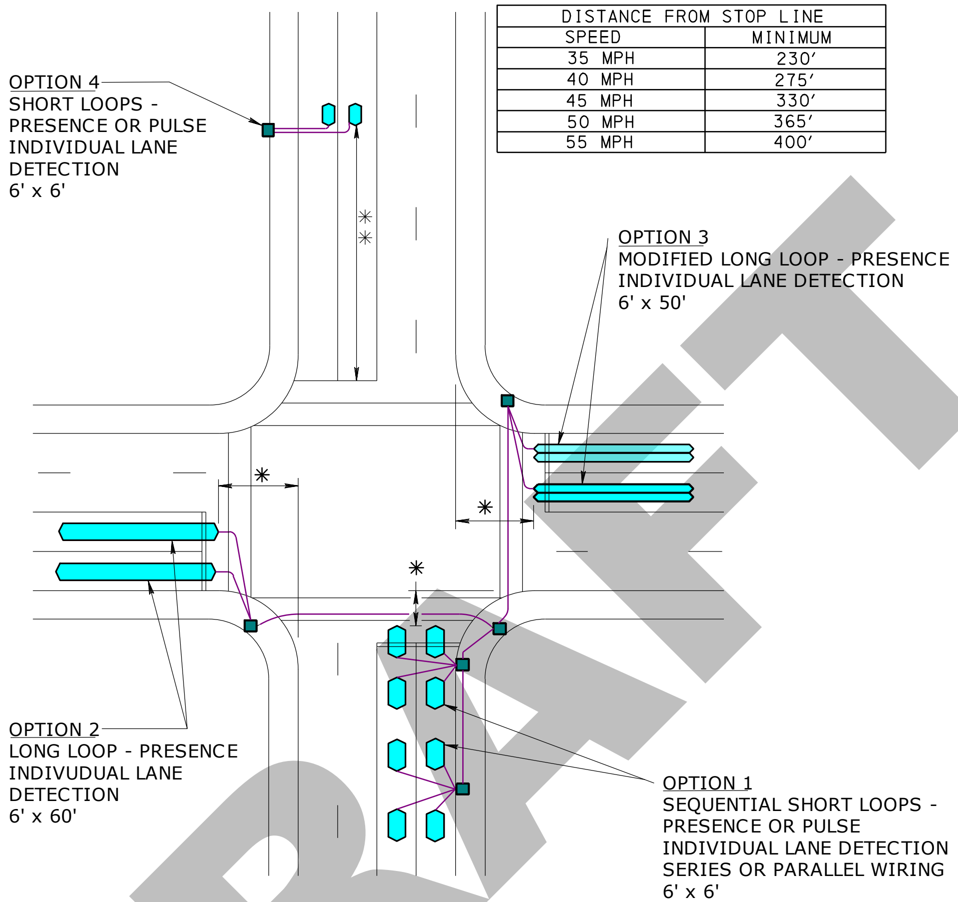


CHART A
OPTION 4

DISTANCE FROM STOP LINE	
SPEED	MINIMUM
35 MPH	230′
40 MPH	275′
45 MPH	330′
50 MPH	365′
55 MPH	400′

✳ DIMENSION VARIES WITH INTERSECTION GEOMETRY AND TYPE OF DETECTION

✳✳ VARIES WITH SPEED, SEE CHART A

Option 1 performs best when alternate loops are paired and wired in parallel to separate input channels. Option 1 also has the benefit that detection is completely lost if one loop fails. Although the initial installation cost is higher, maintenance is easier since only a small loop needs to be replaced if damaged.

Option 2 has the lowest construction cost because it has less lead wire and fewer junction boxes.

Short loops are more sensitive and better suited for sensing small vehicles. Long loops are less sensitive, and increasing sensitivity makes loop loops more susceptible to detecting vehicles in adjacent lanes. The long loops in Option 3 are sensitive enough to detect bicycles and small motorcycles without detecting vehicles in adjacent lanes.

Exhibit 17-6 shows the following detection zone types which can be achieved with each loop layout option.

Exhibit 17-6 Loop Layout Options with Applicability

Detection Zone Type	Option 1: Sequential Short Loops	Option 2: Long Loop	Option 3: Modified Long Loop	Option 4: Short Loop
Stop Line Presence Zone	X	X	X	-
Advance Zone	-	-	-	X
Stop Line Lane-by-Lane Count Zone	X[1]	-	-	-
System Zone	-	-	-	X
Queue Detection Zone	X	X	X	X
Dilemma Zone	X[1]	-	-	X

X: Acceptable
–: Not Applicable
[1]Requires inductive loops using separate lead-ins wired to separate amplifier channels and broken out by separate detector inputs at the controller.

17.2.6 Design Guidance – Over-Roadway Detectors

Since over-roadway detectors are highly dependent upon proprietary and/or patented manufacturer designs and procured as an off-the-shelf system, the designer should be careful to consider all manufacturer capabilities for these types of detection equipment. Ensure that the specified equipment type can accommodate the full function of the design and operational intent in all roadside environments.

Detection area sizes should not be dimensioned on the plan for over-roadway detectors. The detection area should be sized in the field by the manufacturer's representative to obtain optimal operation. The following factors should be considered when sizing detection areas for over-roadway detectors and verifying the manufacturer's capabilities:

- ✓ Detection area width should be sized to limit the impacts of angle occlusion where the projection of a vehicle in adjacent lanes is within the sensor's view of the lane to be detected.
- ✓ The passage (vehicle extension) interval may need to be revised based on the field-installed detection area size (see **Section 10.4.2**).
- ✓ The detector should be rigidly mounted to provide stability with respect to wind and vibration. Over-roadway detectors shall not be mounted on span wire. Placing detectors near the end of long mast arms should be avoided due to oscillation.

For information on specifying detection areas on traffic control signal plans, see **Chapter 33**.

Occlusion

Over-roadway detectors rely on an unobstructed straight line between the detector and the area being detected. Occlusion refers to situations where an over-roadway detector is unable to accurately sense vehicles on the roadway. Occlusion can occur for multiple reasons as shown in **Exhibit 17-7** and **Exhibit 17-8**.

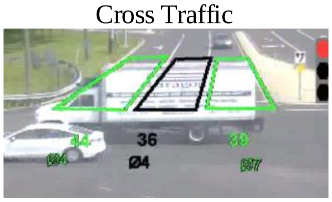
A traffic signal designer must understand how the detection will be used to determine whether any potential occlusion is a concern or can be tolerated. For example, stop bar presence detection used to call a phase can typically operate at an acceptable level even with some occlusion, but an advance zone for volume density operation needs to be able to differentiate individual vehicles to accurately count the arrivals on red.

Exhibit 17-7 Types of Occlusion

Occlusion Type	Description	False Positive	False Negative
Cross Traffic	Vehicle crossing perpendicular to the zone within the intersection blocks the sensor's view of the detection zone		X
Turning Traffic	Vehicle path crosses through the zone in the wrong direction		X
Angle	The view of distant lanes is blocked by tall vehicles in lanes closer to the sensor. This may cause missed detection in distant lanes when the view is obstructed or may cause false detection in distant lanes when the tall vehicle's image is projected into the distant lanes.	X	X
Distance	Individual vehicles can't be detected due to the distance between the sensor and the detection zone		X

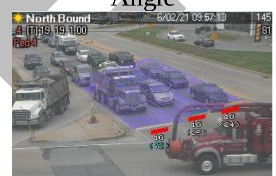
Exhibit 17-8 Occlusion Examples

Cross Traffic



Turning Traffic

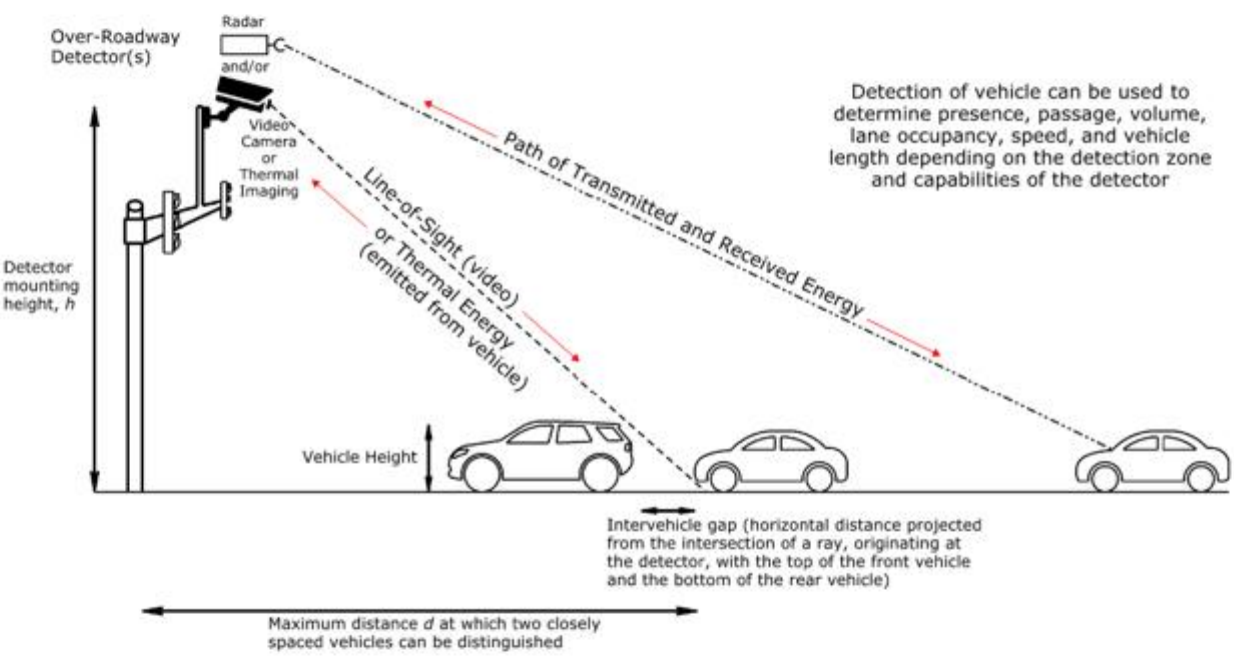
Angle



Distance

Based on, line-of-sight considerations, the maximum distance that an over-roadway detector can differentiate two closely spaced vehicles is a function of detector height, inter-vehicle distance or gap, and vehicle height as shown below in **Exhibit 17-9**.

Exhibit 17-9 Detector Line-of-Sight Geometry



Video Detectors

The following bid items are applicable to signal designs using video detectors:

- ✓ Video detector (0956-0700).
- ✓ Video detector with internal heater (0956-0701).
- ✓ Video detection system (0956-0711).
- ✓ Omni-view video detection system (0956-0712)
- ✓ Omni-view video detection system with Wi-Fi travel time processor (0956-0713).
- ✓ Detector card (0956-0750).
- ✓ Detector card rack assembly (0956-0011).
- ✓ Monitor and keyboard/mouse for video detection (0956-0751).

In most cases, the system items should be used, which encompass all the equipment necessary for all video detection zones shown on the signal plan to provide actuation at an intersection. One each quantity of the detection system item should be tabulated per controller assembly (typically one per intersection).

The video detector item may be used where only a single detector is being installed or replaced. The tabulated quantity of video detectors is the number of cameras.

Video detection systems typically consist of one or more cameras, a microprocessor-based computer to process the video image, and software to interpret images and convert them into traffic flow data. Traditional video detection systems have one or more cameras aimed at each approach. An omni-view video detection system has a fish-eye lens which can see 360 degrees, capturing multiple approaches.

In addition to determining a mounting location to minimize occlusion, as described earlier in this section, video detector placement must also consider lighting and weather impacts, especially the sun angle during sunrise and sunset.

Zone Type/Configuration

Refer to **Exhibit 17-2** for applicable uses of video detectors.

Layout Typicals

Refer to Publication 148, TC-8806 for example zone placement.

Thermal Imaging

The following bid items are applicable to signal designs using thermal imaging detectors:

- ✓ Thermal Video detector (0956-0702).
- ✓ Video detection system (0956-0711).
- ✓ Detector card (0956-0750).
- ✓ Detector card rack assembly (0956-0011).
- ✓ Monitor and keyboard/mouse for video detection (0956-0751).

In most cases, the system item should be used, which encompass all the equipment necessary for all thermal imaging detection zones shown on the signal plan to provide actuation at an intersection. One each quantity of the detection system item should be tabulated per controller assembly (typically one per intersection).

The thermal video detector item may be used where only a single detector is being installed or replaced. The tabulated quantity of thermal video detectors is the number of cameras.

Thermal video detection systems typically consist of one or more thermal imaging cameras, a microprocessor-based computer to process the thermal image, and software to interpret images and convert them into traffic flow data. Traditional thermal imaging detection systems have one or more cameras aimed at each approach.

Thermal imaging video detector placement must consider a mounting location to minimize occlusion as described earlier in this section.

Zone Type/Configuration

Refer to **Exhibit 17-2** for applicable uses of thermal imaging detectors.

Layout Typicals

Refer to Publication 148, TC-8806 for example zone placement.

Radar Detectors

The following bid items are applicable to signal designs using radar detectors:

- ✓ Radar detector (0956-0601).
- ✓ Radar detection system (0956-0771).
- ✓ Radar detection system (0956-0772).
- ✓ Radar detection system (0956-0773).
- ✓ Detector card (0956-0750).
- ✓ Detector card rack assembly (0956-0011).

In most cases, the system items should be used, which encompass all the equipment necessary for all radar detection zones shown on the signal plan to provide actuation at an intersection. One each quantity of the detection system item should be tabulated per controller assembly (typically one per intersection).

The radar detector item may be used where only a single detector is being installed or replaced. The tabulated quantity of radar detectors is the number of detectors.

Radar detection systems typically consist of one or more detectors, a microprocessor-based computer to process and interpret the radar energy profile and software to convert this radar profile into traffic flow data. Traditional radar detection systems have one or more detectors aimed at each approach.

Radar detector placement must consider a mounting location to minimize occlusion as described earlier in this section.

Zone Type/Configuration

Refer to **Exhibit 17-2** for applicable uses of radar detectors.

Layout Typicals

Refer to Publication 148, TC-8806 for example zone placement.

Radar and Video Detectors

The following bid items are applicable to signal designs using radar and video detectors:

- ✓ Video detector (0956-0700).
- ✓ Video detector with internal heater (0956-0701).
- ✓ Radar detector (0956-0601).
- ✓ Radar and Video detection system (0956-0611).
- ✓ Detector card (0956-0750).
- ✓ Detector card rack assembly (0956-0011).
- ✓ Monitor and keyboard/mouse for video detection (0956-0751).

In most cases, the system items should be used, which encompass all the equipment necessary for all radar & video detection zones shown on the signal plan to provide actuation at an intersection. One each quantity of the detection system item should be tabulated per controller assembly (typically one per intersection).

The radar detector item and video detector item may be used where only a single detector is being installed or replaced. The tabulated quantity of radar and video detectors is the number of detectors.

Radar & video detection systems typically consist of one or more detectors, a microprocessor-based computer to process the radar profile and video image, and software to interpret and convert them into traffic flow data. Traditional radar & video detection systems have one or more detectors aimed at each approach.

Radar & video detector placement must consider a mounting location to minimize occlusion as described earlier in this section. Video cameras must also consider lighting and weather impacts, especially the sun angle during sunrise and sunset.

Zone Type/Configuration

Refer to **Exhibit 17-2** for applicable uses of radar and video detectors.

Layout Typicals

Refer to Publication 148, TC-8806 for example zone placement.

17.3 Pedestrian Detection

Pedestrian detection is necessary to actuate the pedestrian signal phases at all locations where the pedestrian phase is not on recall and served every cycle.

Pedestrian detection may be active or passive. With active detection, the pedestrian is required to do something to actuate the pedestrian phase (typically pushing a button). Passive pedestrian detection actuates the pedestrian phase based on the presence of pedestrians in a specific location, such as the sidewalk near the beginning of the crosswalk.

17.3.1 Active Pedestrian Detection

Accessible Pedestrian Signals (APS) are push buttons that incorporate additional features to assist visually impaired pedestrians with locating the button and understanding the current state of the pedestrian signals. Accessible Pedestrian Signals (APS) shall be provided where pedestrian signal heads are provided per **Section 8.2.3**.

APS must include locator tones, audible walk indications (either percussive tones or spoken WALK messages), and push buttons with vibrotactile arrow indications to assist the impaired pedestrians in safely traversing the intersection and actuating the pedestrian phase. The vibrotactile arrow must be aligned parallel to the direction of travel on the associated crosswalk.

APS should be located horizontally and vertically in accordance with the MUTCD Chapter 4I, and Publication 111 (TC-8803). APS should be located on the traffic signal supports for vehicular and pedestrian signals where possible. If the PROWAG, MUTCD, and TC-8803 location requirements cannot be met using those supports, supplemental pedestrian stub poles should be used.

Consult the MUTCD sections 4K.01, 4K.02, 4K.03, 4K.04, and 4K.05 for guidance on APS.

17.3.2 Passive Pedestrian Detection

Detection systems that passively sense the presence and walking speed of pedestrians may be considered. Passive pedestrian detection systems must be approved by the Bureau of Operations prior to use. If APS is required, push buttons are required to provide the vibrotactile function.

18. ADAPTIVE SIGNAL CONTROL TECHNOLOGY (ASCT) SYSTEMS

18.1 General

Adaptive signal control technology (ASCT) adjusts traffic signal timings to match current traffic conditions along a corridor rather than using pre-programmed, daily signal timing schedules. Various methods can be used to adjust traffic signal timings under the umbrella of adaptive signal control technology, but they can be grouped into the following two methods:

- ✓ **Pattern-based:** The controller operates in coordination (see **Chapter 1**) using cycle, offset, and split parameters, but the ASCT downloads new cycle, offset, and/or split settings for the active timing plan based on current traffic conditions.
- ✓ **Non-pattern-based:** The controller operates "free," and the ASCT uses phase calls, detector calls, and/or phase holds to provide time to the desired phases, effectively overriding the timings programmed in the local controller.

There are three typical data sources used for ASCT to understand current traffic conditions:

- ✓ **Binned detector data** from the controller: Controller collects and stores detector volume and occupancy in bins of a defined time interval.
- ✓ **High-resolution event log data** from the controller: Controller collects and stores timestamped event data at 0.1 second resolution.
- ✓ **Direct detection data** collected by the ASCT: The detection system communicates directly with the ASCT.

The ASCT algorithm to optimize traffic signal timing may operate in one of the following manners:

- ✓ **Software-based**
  - ▪ ASCT operates as a software module in the traffic signal controller unit.
- ✓ ASCT operates on a central server which communicates with each local controller unit. The central server may be a physical or virtual server located in an agency facility (on-premises) or may be cloud-hosted.
- ✓ **Hardware-based**
- ✓ ASCT software operates on separate hardware installed in the controller cabinet and hardwired to the local controller unit.

For addition information related to Adaptive Signal Control, see the following references:

- ✓ Signal Timing Manual – Second Edition (STM2) (Section 9.4)
- ✓ NCHRP Synthesis Report 403
- ✓ Publication 46 (Chapter 4)
- ✓ Publication 408 (Section 957)
- ✓ ECMS Master Items (0957)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-153
- ✓ Form TE-974

18.2 ASCT Systems Engineering Process

23 CFR 940.11 requires a systems engineering analysis for all ITS projects using federal highway trust funds, which includes deployment of ASCT. The systems engineering process is used to identify the objectives for the system and minimize the risk of the project not meeting those objectives. For ASCT projects, the process

typically involves the evaluation of commercial, off-the-shelf (COTS) systems to determine whether the capabilities of those systems will meet the objectives.

Form TE-153 (Pennsylvania Traffic Signal Systems Solutions Toolbox) assists designers when evaluating Adaptive Signal Control Technology Systems by providing Pennsylvania-specific information that identifies appropriate needs and requirements.

For additional direction on ASCT selection guidelines, including use of Form TE-153, please reference Publication 46, Section 4.6.

18.3 ASCT Measurement & Payment

The bid items and specifications for an ASCT system will be determined by the outcome of the systems engineering process. Most projects with an ASCT system will require special provisions to modify the ECMS master items or a non-standard (9000) item.

See Publication 408 and corresponding ECMS Master Items (0957) for the specifics on how this work is measured and paid, for design plan preparation purposes:

- ✓ Section 957.4(a) Hardware Adaptive Signal System
- ✓ Section 957.4(b) Software Adaptive Signal System
- ✓ Section 957.4(c) Intersection Adaptive System Detection System

19. PAVEMENT MARKINGS AND SIGNS

19.1 General

A traffic control signal design shall include the necessary pavement markings and signs as may be required to properly direct and control the flow of vehicular and pedestrian traffic through the signalized intersection.

Pavement markings and signing shall meet the provisions listed in the following references:

- ✓ *MUTCD*
  - Pavement Markings (PART 3 Markings)
  - Signs (PART 2 Signs)
- ✓ Publication 46
  - Pavement Markings (Chapter 3)
  - Signs (Chapter 2)
- ✓ Publication 111
  - Pavement Markings (TC-8600)
  - Signs (TC-8700C, TC-8701D & TC-8702 series)
- ✓ Publication 148
  - Signs on signal supports (TC-8801)
  - Ped signs on pedestal supports (TC-8803)
- ✓ Publication 212 (Official Traffic Control Devices)
- ✓ Publication 236 (Sign Handbook)
  Note, that the series numbers in Publication 236 supersede those of the MUTCD.
- ✓ Publication 408
  - Pavement Markings (Sections: 901, 960-965, 1103)
  - Signs (931, 935, 936, 971, 975, 976, & 1103)
- ✓ ECMS Master Items
  - Pavement Markings (0901, 0960, 0961, 0962, 0963, 0964, & 0965)
  - Signs (0931, 0935, 0936, 0971, 0975, & 0976)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

19.2 Typical Pavement Markings-Signalized Intersection

Pavement markings provide the motorist with guidance so that they remain in the appropriate lane as they approach and travel through an intersection.

The designer should consider the agency responsible for maintaining pavement markings as part of the signal design to avoid including optional markings which are unlikely to be maintained based on the agency's resources or logistics of refreshing the markings.

Traffic signal plans shall include the required pavement markings needed for the signalized intersection design and be shown for at least 150 feet from the stop line. Additional area should be included where auxiliary lanes for the signalized intersection extend further from the intersection.

> Section 19.2 clarifies the application of pavement markings at signalized intersections when using the standards from Publication 111, TC-8600.

The typical pavement markings utilized at signalized intersections includes the following:

- ✓ Lane lines (lane, edge, and centerlines)
- ✓ Stop lines
- ✓ Dotted extension lines

- ✓ Crosswalk lines/markings
- ✓ Pavement legends (word & symbol markings)
- ✓ Median & gore transverse markings (when applicable)

The following two Exhibits show typical pavement marking configurations encountered at signalized intersections. **Exhibit 19-1** shows typical configurations for one approach lane and **Exhibit 19-2** shows typical configurations for two approach lanes.

Exhibit 19-1 Pavement Markings for Signalized Intersection One Approach Lane – Typical Configurations Encountered

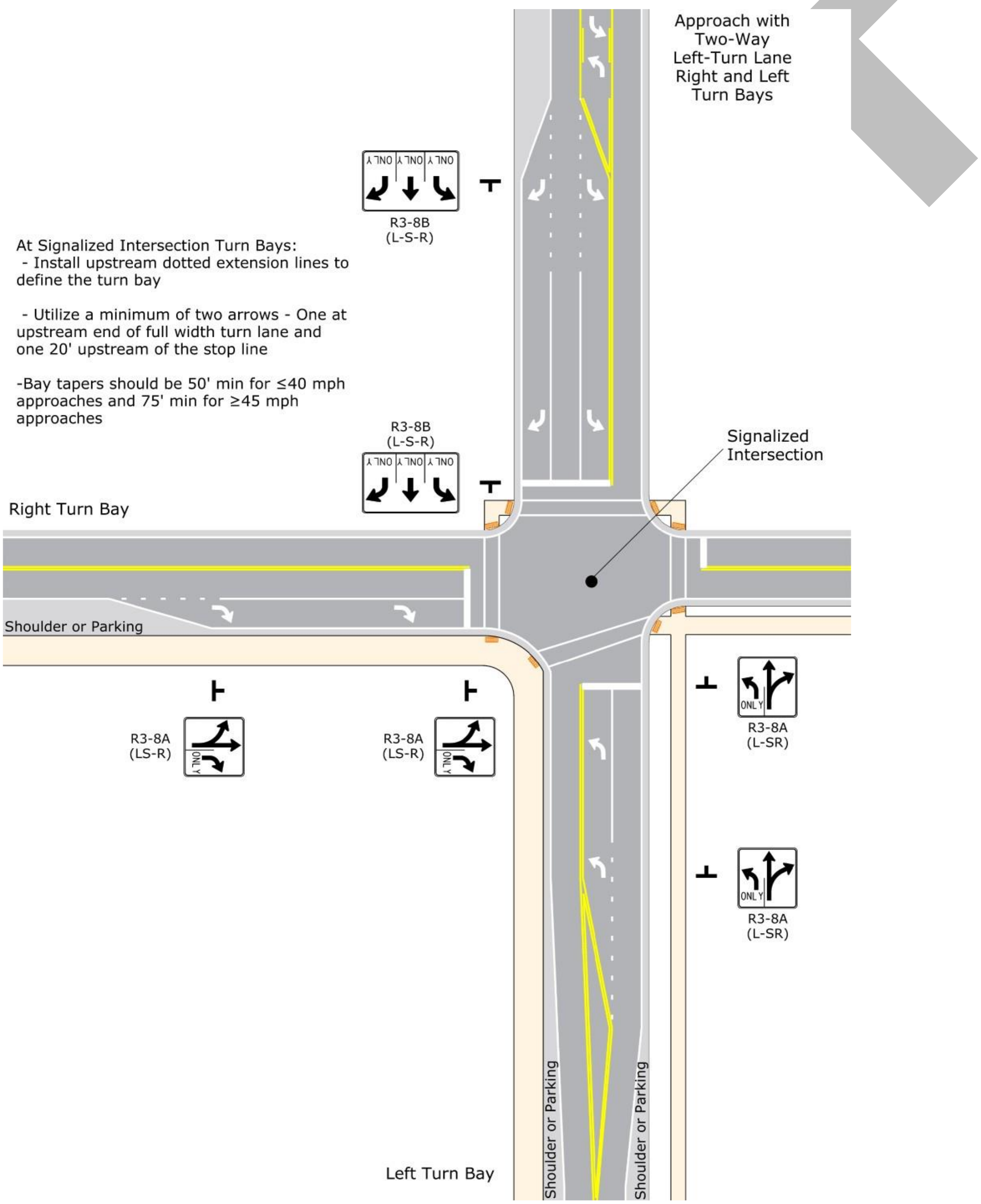
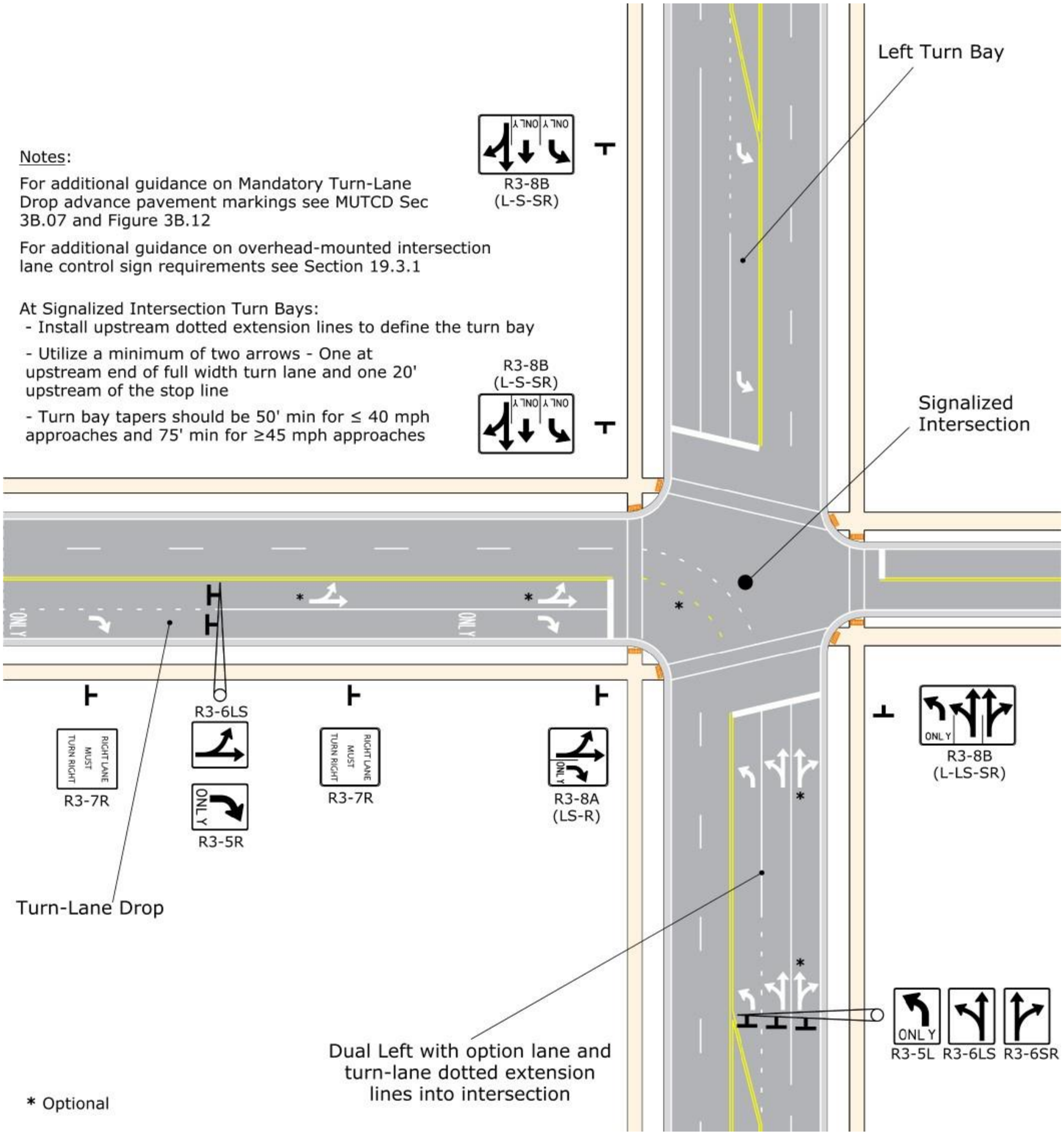


Exhibit 19-2 Pavement Markings for Signalized Intersection Two Approach Lanes – Typical Configurations Encountered



Also, Publication 111 (TC-8600 series) provides standard drawings, details, and notes for various types of pavement markings. Pavement markings applicable to traffic signals are in the following titled TC-8600 sheets:

- ✓ Conventional Highways (Sheets 3 & 4)
- ✓ Crosswalks (Sheets 5 & 6)
- ✓ Legends & Symbols (Sheets 8, 9, 10, & 13)

19.2.1 Pavement Marking Materials

Section 3.2 of Publication 46 provides a brief description of the various marking materials that are approved and available for use in Pennsylvania. The Materials and Testing Division conduct the testing of these materials on the Department's test deck and in the laboratory, with the assistance of the Highway Safety and Traffic Operations Division (HSTOD).

A list of prequalified pavement marking materials, eligible for use on Department construction projects, are in Bulletin 15 (PennDOT Publication 35).

Since stop lines, crosswalk lines, and pavement legends within lanes are regularly driven over, these markings should be of a durable material other than waterborne paint (see Publication 46, Exhibit 3-3).

The traffic signal permit plan should not identify material type to allow the permittee flexibility on what type of material to use for refreshing markings as maintenance.

The traffic signal construction plan will need to identify the material type in the tabulations. See **Chapter 33** for more information.

19.2.2 Lines

The following line types are defined for use at signalized intersections in Pennsylvania:

Exhibit 19-3 Pavement Lines

Line			References	
Type	**Color**	**Minimum Width (in.)**	**Pub 111**	**MUTCD[1]**
Longitudinal Markings[2]				
Edge Line	White	4	TC-8600 Sheets 3 & 4	3B.09, 3B.12
Edge Line	Yellow	4		
Solid Lane Line	White	6		3B.06
Broken Lane Line	White	6		3B.06
Auxiliary Lane Line (Wide dotted lane line)	White	6		3B.07
Transverse Markings[3]				
Stop Line	White	24	TC-8600 Sheets 3 & 4	3B.19
Dotted Extension Line	White	4		3B.11
Dotted Extension Line	Yellow	4		
Centerline (Two-way barrier lines)	Yellow	4		3B.01

[1]MUTCD 3A.04 provides general information on the functions, widths and patterns of longitudinal pavement marking lines.
[2]Longitudinal markings run in the direction of travel.
[3]Transverse markings are those which run perpendicular to direction of travel. Dotted extension lines connecting lanes through the intersection are considered transverse markings since they are crossed by vehicles.

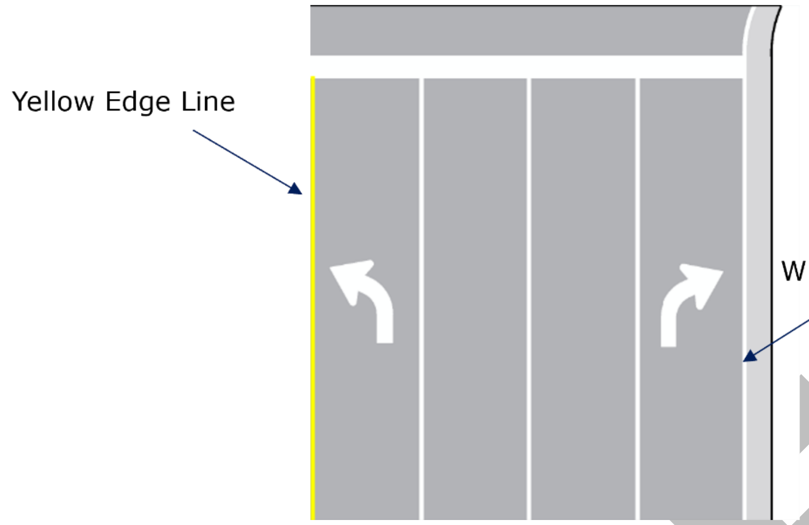
See the following sub-sections for further information on each line type.

Edge Lines

There are two color types of edge lines:

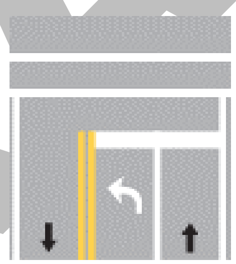
- ✓ A white edge line that delineates the right edge of the traveled way, and
- ✓ A yellow edge line that delineates the left edge of the traveled way when adjacent to a median that separates opposing directions of vehicular traffic flow.

The minimum width of an edge line is 4-inches, but a 6-inch width edge line may be used for enhanced safety per MUTCD Section 3A.04.



Stop Lines

Stop lines which are 24 inches wide shall be used to indicate the point behind which vehicles are required to stop in compliance with a traffic control signal. A stop line shall extend over the entire width of each lane on an approach.



Stop lines when used on a multi-lane approach to a signalized intersection may be staggered to assist turning vehicles and to improve sight distance for motorist desiring to make a turn on red.

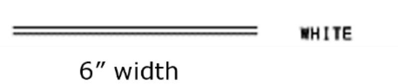
The stop line shall be no less than 4 feet from the nearest edge of the intersecting roadway and any crosswalk markings.

If the right turn on red movement is allowed, the stop line should be no more than 30 feet from the nearest edge of the intersecting roadway to ensure maximum sight distance.

Stop lines should be placed considering turning paths of the largest expected design vehicle. The stop line may be located further from the intersecting roadway when necessary to accommodate large vehicle turning movements.

Lane Lines

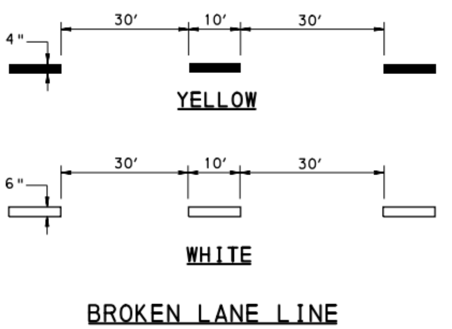
Lane lines on an approach to a signalized intersection shall be solid white for 150 feet measured from the stop line.



Lane lines that delineate the edge of a turning lane from other lanes on the approach are to be solid white lines with a length in accordance with Pub 111 TC 8600 (Sheet 3 of 13, Note 3).

Broken Lane Lines

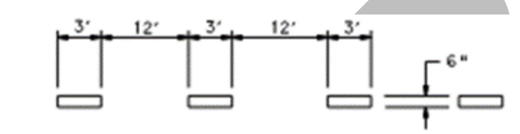
Broken lane lines indicate a permissive condition where vehicles may cross the line to change lanes. Yellow broken lines for passing in the opposite direction travel lane or two-way left-turn lanes are not used at signalized intersections, but the transition from those pavement markings may be shown on a signal plan.



Auxiliary Lane Lines

Auxiliary lane lines are referred to as wide dotted white lane lines in the MUTCD. Auxiliary lane lines shall be used:

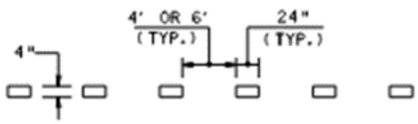
- ✓ In advance of lane drops at intersections to distinguish a lane drop from an intersection through lane (MUTCD Section 3B.07, Par.07, E), and
- ✓ To separate a through lane that continues beyond an intersection from an adjacent auxiliary lane between two intersections (MUTCD Section 3B.07, Par.07, F).



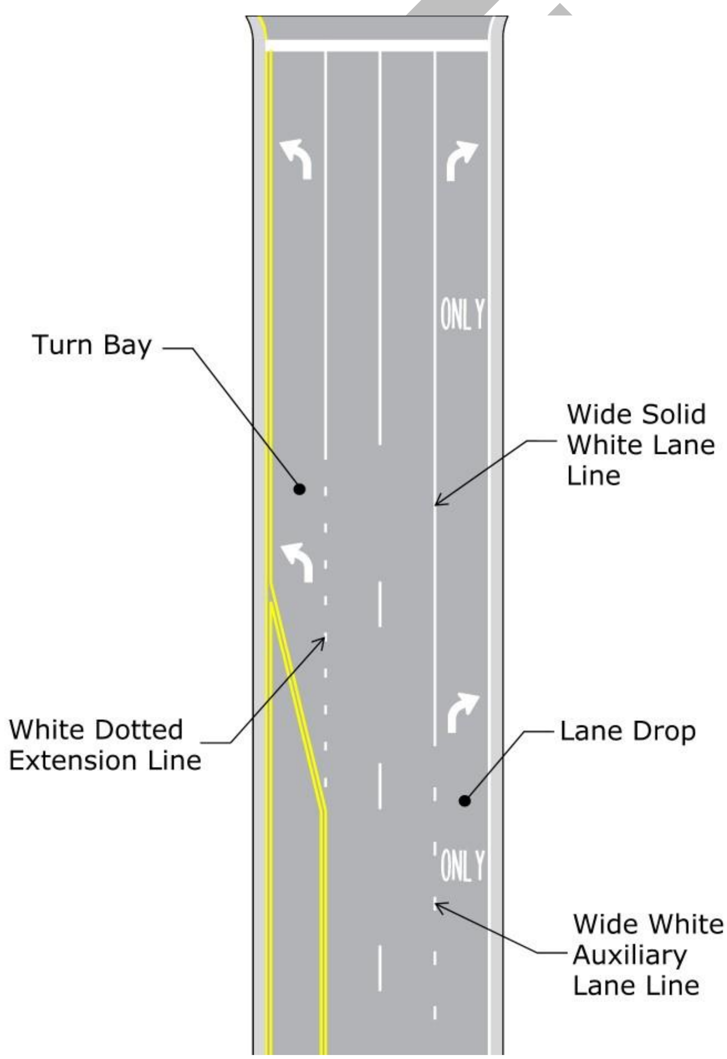
- ✓ MUTCD Section 3B.07, Par.10
- ✓ MUTCD Section 3B.07, Par.11

Dotted Extension Lines

Dotted extension lines may be used to delineate travel paths for turning or through traffic movements at offset, skewed, or complex intersections and for multiple turn lanes. Extensions of lane lines through intersections shall be the same color as the line markings they extend and shall never connect to a lane line of a different color. Extensions of double yellow center lines through intersections, when used, should provide positive guidance through the intersection, and be comprised of a single yellow line of equal width to one of the double lines. (MUTCD Section 3B.11)



Dotted extension lines should be used in the taper of turn bays to provide positive guidance and to discourage use of the turn bay by through vehicles. Dotted extension lines should also be used in the taper where an auxiliary lane begins where the roadway alignment may cause vehicles to drift into the auxiliary lane unintentionally.

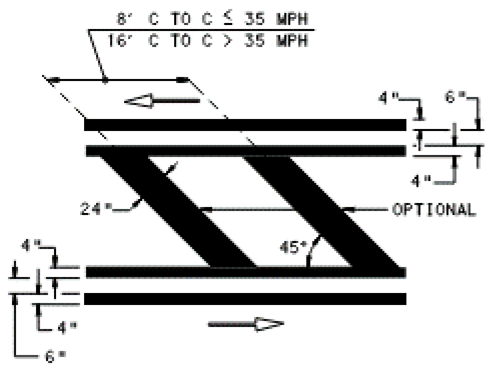


Centerlines

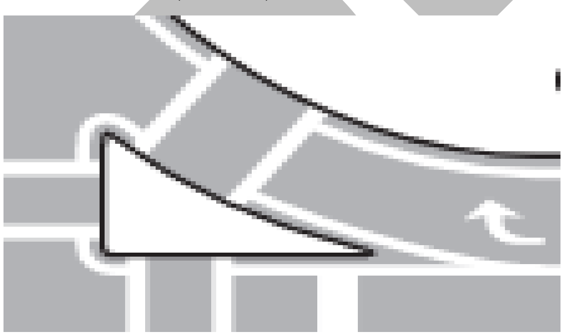
Publication 111, TC-8600 (Sheet 3) refers to these centerlines as two-way barrier lines. For signalized intersections not separated by a median, a centerline shall precede the signalized intersection by the minimum distance noted in Table A of the above Publication 111 reference.

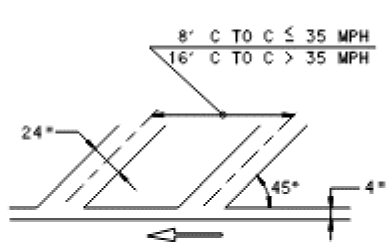
19.2.3 Median and Gore Markings

Transverse median markings are 24" wide yellow lines spaced as indicated in Publication 111, TC-8600 (Sheet 4), within two sets of Two-Way Barrier lines (Centerlines). Use transverse lines only when required to provide emphasis if the sight distance or visibility is restricted.

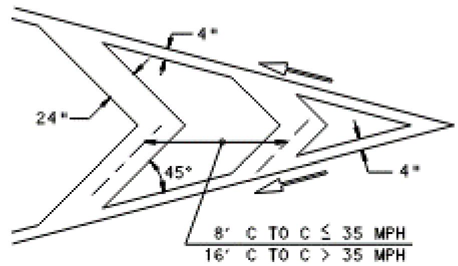


Gore markings use edge lines that are 4" solid white lines. Use of transverse or diagonal lines only when required to provide additional emphasis if the sight distance or visibility of gore is restricted, see Publication 111, TC-8600 (Sheet 4).





ONE-WAY BARRIER GORE MARKING
(OPTIONAL)



CHEVRON GORE MARKING
(OPTIONAL)

19.2.4 Pavement Legends

For general information on pavement legends (word and symbol), refer to (Publication 111,TC-8600 Sheet 3, Notes 14 & 15). These notes provide guidance on maximum lines of information, placing of legends in multiple line message so it reads in the direction of travel, and legend spacings & alignment.

Lane Use Arrows and ONLY Word Markings

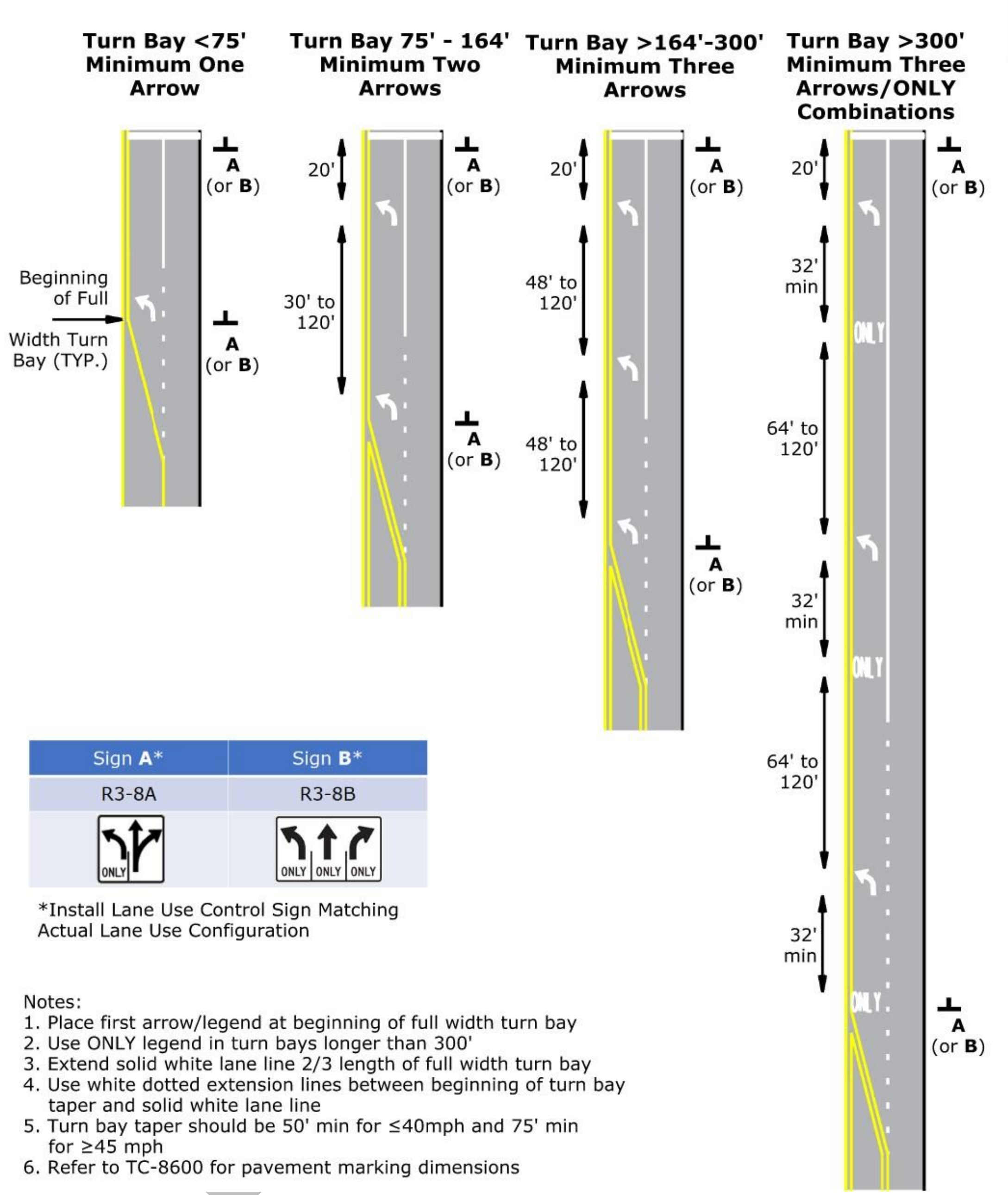
Pavement legends approaching signalized intersections include lane-use arrow markings and ONLY word markings. In general, the number of markings should be the minimum necessary to provide positive guidance for lane control due to ongoing maintenance costs for the signal owner.

At exclusive turn lanes (bays), lane-use arrow markings shall be used and shall be accompanied by intersection lane control signs (see **Section 19.3.1**). See **Exhibit 19-4** for figures showing the minimum number of required lane-use arrows and distances for various turn bay lengths.

The ONLY word pavement marking shall be used for turn bays longer than 300 feet and for lane drops (see **Section 19.4.4**). The ONLY word pavement marking shall be located upstream of a lane-use arrow marking.

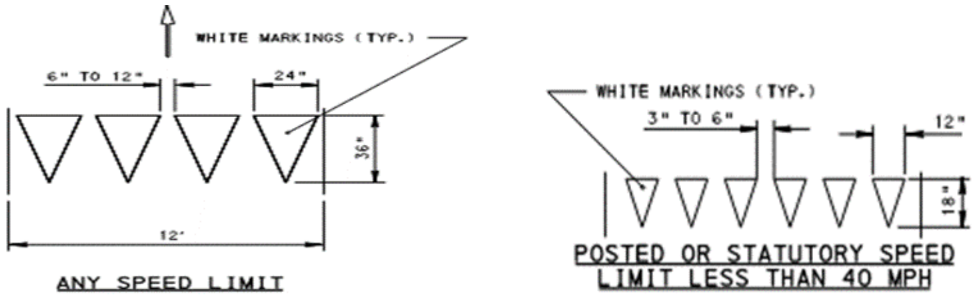
While use of lane-use arrow markings for straight through lanes is optional, they should be considered for through lanes adjacent to lane drops or other geometric conditions where additional direction may be beneficial to the driver. See **Section 19.4.4** for application of pavement markings at lane drops.

Exhibit 19-4 Minimum Lane-Use Arrows for Various Turn Bay Lengths



Yield Lines

Channelized right turn movements may use yield markings to indicate the point behind which vehicles are required to yield in compliance with Yield sign.



19.2.5 Crosswalks

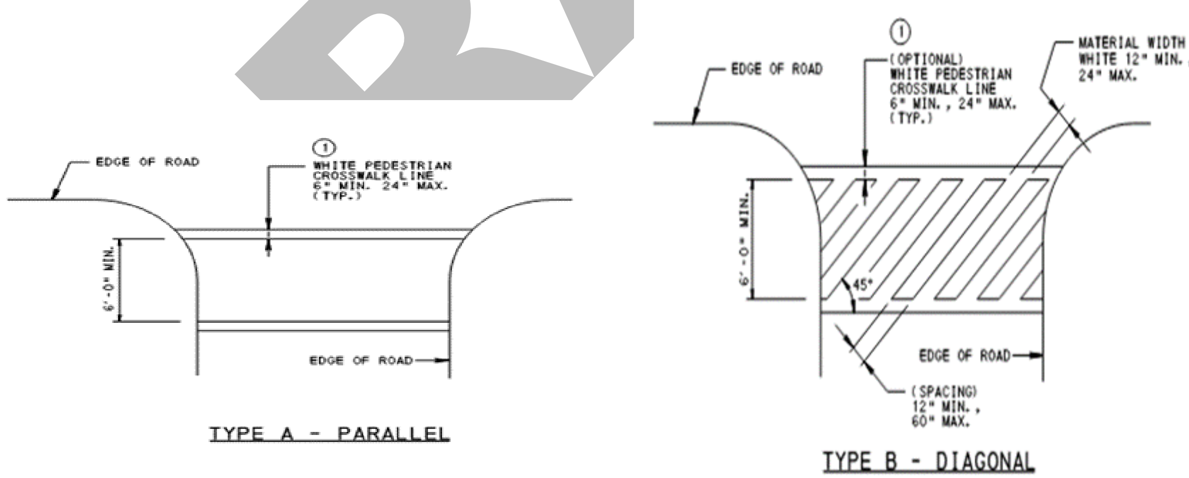
Crosswalks shall be designed in accordance with Publication 111, TC-8600 (Sheets 5 & 6) and Publication 72M, RC-67M. The type of crosswalk should be identified in the engineering study (see **Section 8.2.3**). **Exhibit 19-5** shows the various crosswalk types.

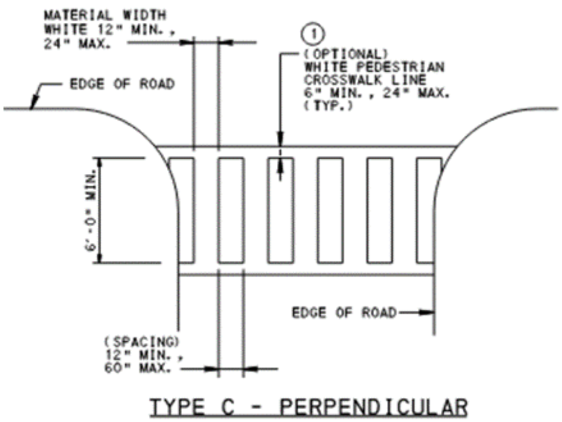
Layout of crosswalks and curb ramps should be developed in concert with one another so that the curb ramps are located within the extension of the crosswalk markings, and safe and efficient movement of pedestrians and vehicles is provided through the intersection. The pedestrian accessible route should not be obstructed by poles, hydrants, or other street hardware.

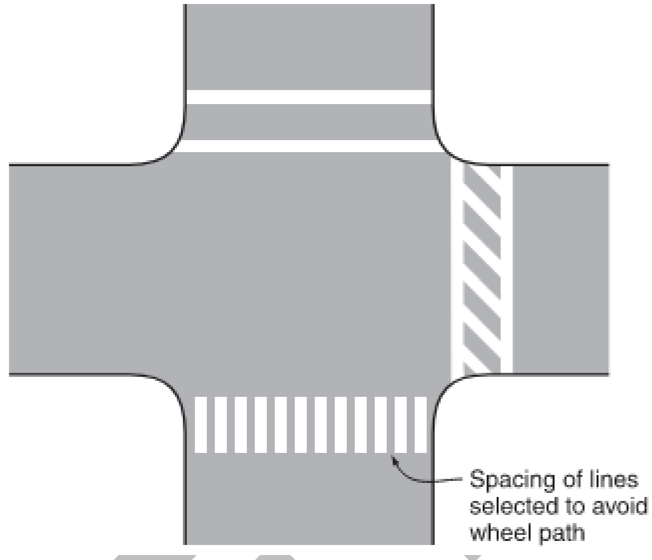
The crosswalk should be a minimum of 2 feet from adjacent parallel travel lanes.

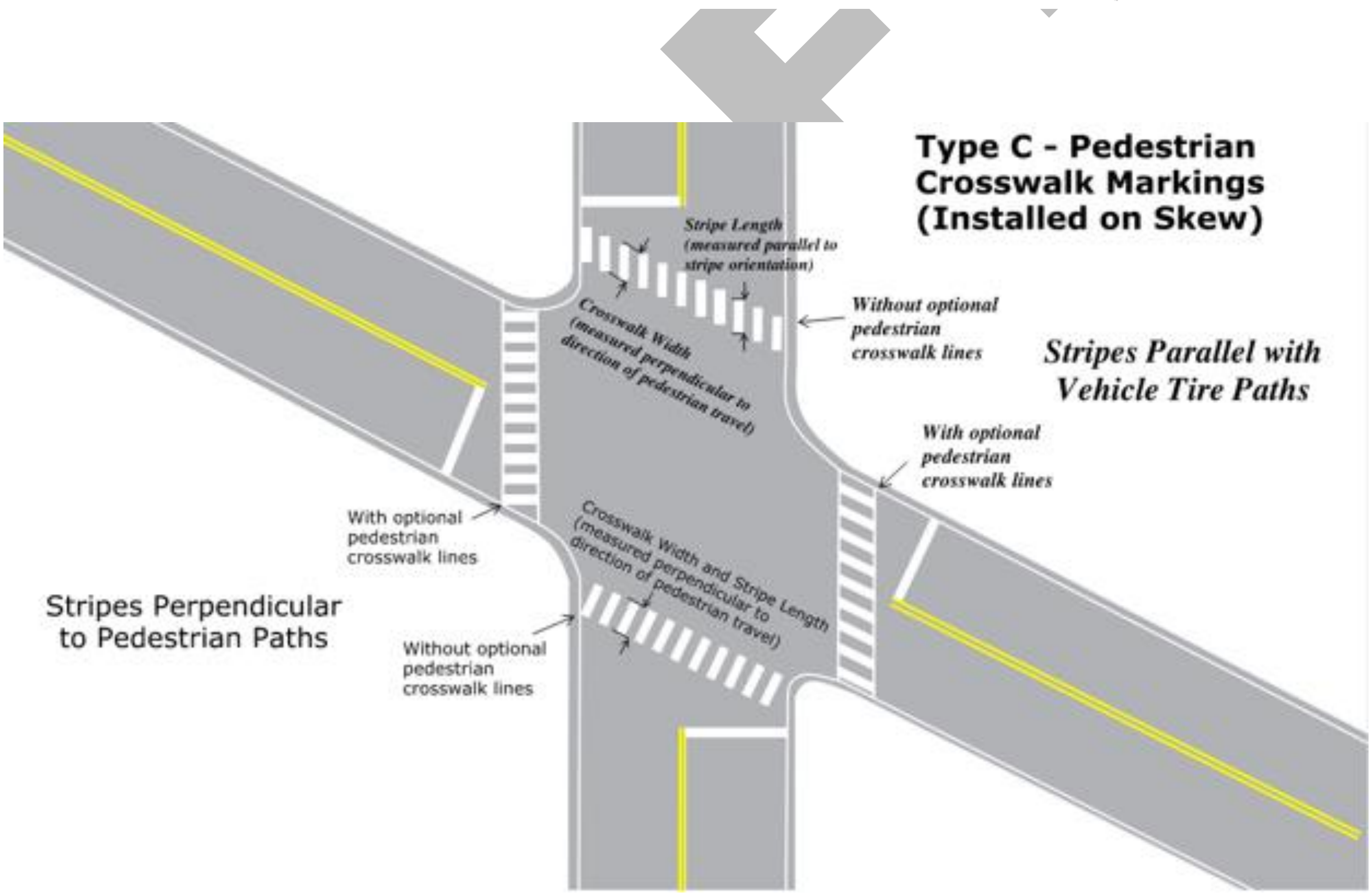
The FHWA Crosswalk Marking Selection Guide is also a good reference as a decision support tool for selecting crosswalk marking designs. It provides information about selecting crosswalk marking designs based on overall effectiveness and considerations of materials, maintenance, and cost. The Guide also covers Title VI and other sociodemographic effects and considerations relative to crosswalk markings.

Exhibit 19-5 Crosswalk Types









19.2.6 Bicycle Markings

Green-colored pavement may be used within a bicycle box and the bicycle-approach lane in accordance with Publication 13, Chapter 14.

19.3 Typical Signs-Signalized Intersection

Traffic control signal plans shall include the required signs needed for the signalized intersection design, which typically include the following (as described in the following sub-sections):

> Section 19.3 clarifies the application of signs at signalized intersections when using the standards from Publication 236, Handbook of Approved Signs.

- ✓ Movement Prohibition & Intersection Lane Control Signs
- ✓ Traffic Signal Pedestrian and Bicycle Actuation
- ✓ Traffic Signal Signs *(Signs used to supplement traffic signal control)*
- ✓ No Turn on Red Signs
- ✓ Traffic Signal Warning Signs
- ✓ Pedestrian Signs
- ✓ Street Name Signs
- ✓ Advance Street Name Signs
- ✓ Illuminated Signs *(if needed, this is a special application which applies to one of the above typical signs)*
- ✓ Warning Signs

The signs should be the same on the traffic signal construction plan and traffic signal permit plan. Except for projects where the traffic signal is the primary work and no other plan sets are being prepared, other signs should be indicated on a signing and pavement marking plan and tabulated separately. Notes may be included to cross-reference other plan sets including signs in the vicinity of signalized intersections. See **Chapter 33** for more information on traffic signal plan requirements.

Signs at traffic control signals should be official traffic signs listed in Publication 236.

- ✓ The MUTCD contains additional signs which are not approved for use in Pennsylvania.
- ✓ In accordance with 67 Pa. Code §212.101, any custom sign message must be approved by the Chief of the Traffic Engineering & Permits Section in the Bureau of Operations. Custom signs may only include custom messages and may not create custom symbols.

19.3.1 Movement Prohibition & Intersection Lane Control Signs

Movement Prohibition Signs

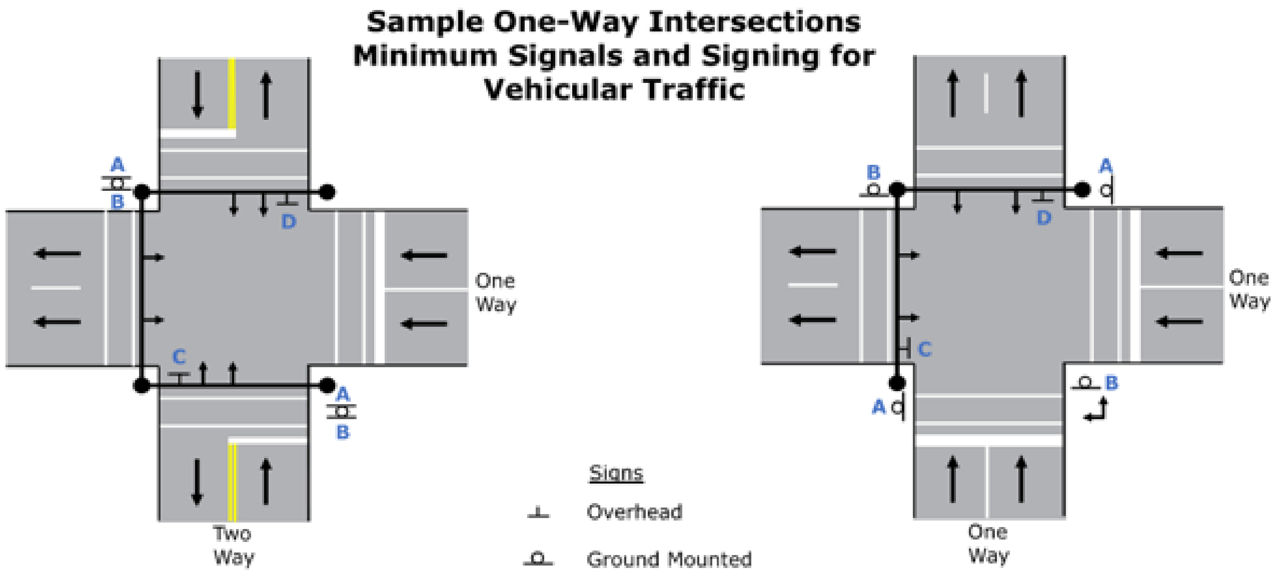
Where specific movements are prohibited, Movement Prohibition signs shall be installed, except No Left Turn and No Right Turn signs may be omitted where ONE WAY signs are mounted overhead near the appropriate signal faces.

When used with overhead traffic signals, No Right Turn (R3-1), No Left Turn (R3-2), and No U-Turn (R3-4) signs, should be installed adjacent to the overhead signal face closest to the direction of the prohibited movement. A second No Right Turn (R3-1) or No Left Turn (R3-2) sign shall also be installed (post mounted) at the near right-hand corner of the intersection. Additional post-mounted signs may be installed to reinforce the movement prohibition.

An auxiliary sign with the same turn prohibition message may be used in advance of the intersection.

See **Exhibit 19-6** for sample one-way intersections with minimum number of signals and signing for vehicular traffic.

Exhibit 19-6 Sample One-Way Intersections Minimum Signals & Signing for Vehicular Traffic



Sign A	Sign B	Sign C	Sign D
R6-1R or R6-2R	R6-1L or R6-2L	R6-2R	R6-2L
ONE WAY or ONE WAY	ONE WAY or ONE WAY	ONE WAY	ONE WAY

Intersection Lane Control Signs

Intersection lane control signs should be used on every signalized approach to an intersection with one or more mandatory turn lanes. Pavement markings and physical channelization supplement the regulatory intersection lane control signs, and intersection lane control signs should not be omitted due to the presence of pavement markings or physical channelization.

Lane control signing should not be installed past the stop line.

Post-Mounted Intersection Lane Control Signs

For approaches with two or three lanes (including turn lanes), Lane Use Control signs (R3-8A or R3-8B) shall be installed post-mounted if overhead lane control signal signs are not used on the approach. R3-8A signs are used for a two-lane approach to an intersection, and R3-8B signs are used for a three-lane approach to an intersection. These signs may also be used to supplement overhead lane control signs.

For each sign used, at least two post-mounted intersection lane control signs should be installed on the approach to an intersection. The first sign should be located where at the upstream end of the lane(s) to which the sign applies, and the second sign should be located near the stop line.

The mandatory and optional movement lane control signs listed in the **Overhead-Mounted Intersection Lane Control Signs** section shall not be post-mounted.

The following signs in **Exhibit 19-7** may be installed as post-mounted intersection lane control signs.

Exhibit 19-7 Post-Mounted Intersection Lane Control Signs

R3-8A (L-S) | R3-8A (S-R) | R3-8A (L-R) | R3-8A (L-LS) | R3-8A (L-SR) | R3-8A (S-SR) | R3-8A (LS-R)

* R3-8B (L-S-R)

* See Pub. 236 for all available symbol combinations for R3-8B series sign.

Alternative Post-Mounted Intersection Lane Control Signs

When overhead lane control signal signs are not used on the approach, R3-7 series word message signs (see **Exhibit 19-8**) may be used as an alternative to the R3-8 series lane control sign in the following situations:

- ✓ Approach lane configuration:

  Where placement of an R3-8 series advance intersection lane control sign may be confusing, such as where left and right turn bays begin at different locations longitudinally, the R3-7L or R3-7R sign may be considered for installation at the appropriate location.

- ✓ Physical width restriction (on three-lane approach):

  Where physical width constraints restrict the installation of an R3-8B (48” x 30”) sign, the R3-7L (36” x 36”) or R3-7R (36” x 36”) sign may be considered for installation.

- ✓ Physical width restriction (on two lane approach):

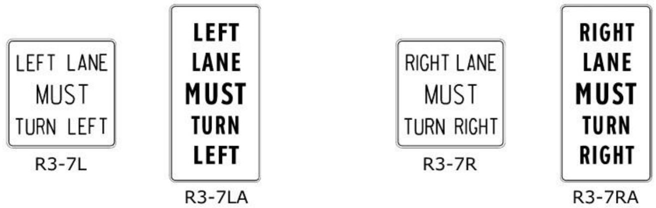
  Where physical width constraints restrict the installation of an R3-8A (30” x 30”) sign, the R3-7LA (24” x 48”) or R3-7RA (24” x 48”) sign may be considered for installation.

At least two post-mounted intersection lane control signs should be installed on the approach to an intersection for each turn lane. The first sign should be located at the upstream end of the lane(s) to which the sign applies, and the second sign should be located near the stop line. If an alternate R3-7 series sign is used for one of these two signs, it does not preclude the use of the conventional R3-8 series sign for the other post-mounted sign if field situations allow. Mixing and matching of the R3-7 series and R3-8 series signs is permitted.

- ✓ Lane Drops (MUTCD Section 2B.27, Par.05, A):

  At locations where through lanes become mandatory turn lanes (i.e. lane drops) and where overhead mounting on the approach is impracticable for the Advance and/or Intersection lane Control signs, a Mandatory Movement Lane Control (R3-7) sign should be post-mounted on the left-hand side of the roadway where a through lane is becoming a mandatory left-turn lane on a one-way street or where a median of sufficient width for the signs is available, or on the right-hand side of the roadway where a through lane is becoming a mandatory right-turn lane.

Exhibit 19-8 Alternate Post-Mounted Intersection Lane Control Signs



Overhead-Mounted Intersection Lane Control Signs

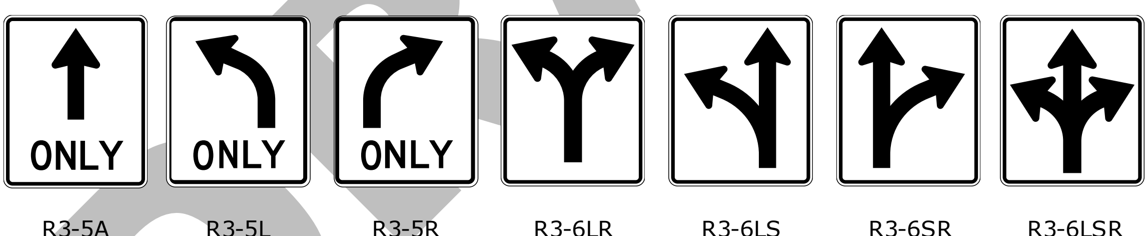
Except where placement of overhead lane control signs is infeasible, overhead lane control signs should be installed over the appropriate lanes for the following conditions per MUTCD Section 2B.27, Par.04:

- ✓ Where through lanes become mandatory turn lanes.
- ✓ On approaches with multiple-lane turns that include shared lanes for through and turning movements.

  NOTE: Multiple-lane turns means a specific turn movement that has more than one approach lane allowing that turn movement. In the condition above, one of the lanes for the specific turn movement involves a shared lane that allows for two movements (i.e. straight and turn).
- ✓ On approaches with three or more though lanes which also have turn lanes.
- ✓ Where other lane-use regulations are present that would be unexpected by unfamiliar road users, such as auxiliary lanes which do not have a bay taper or on wide approaches where post-mounted signs may not be readily visible from lanes in the center of the roadway.

The following signs shown in **Exhibit 19-9** may be installed as overhead lane control signs:

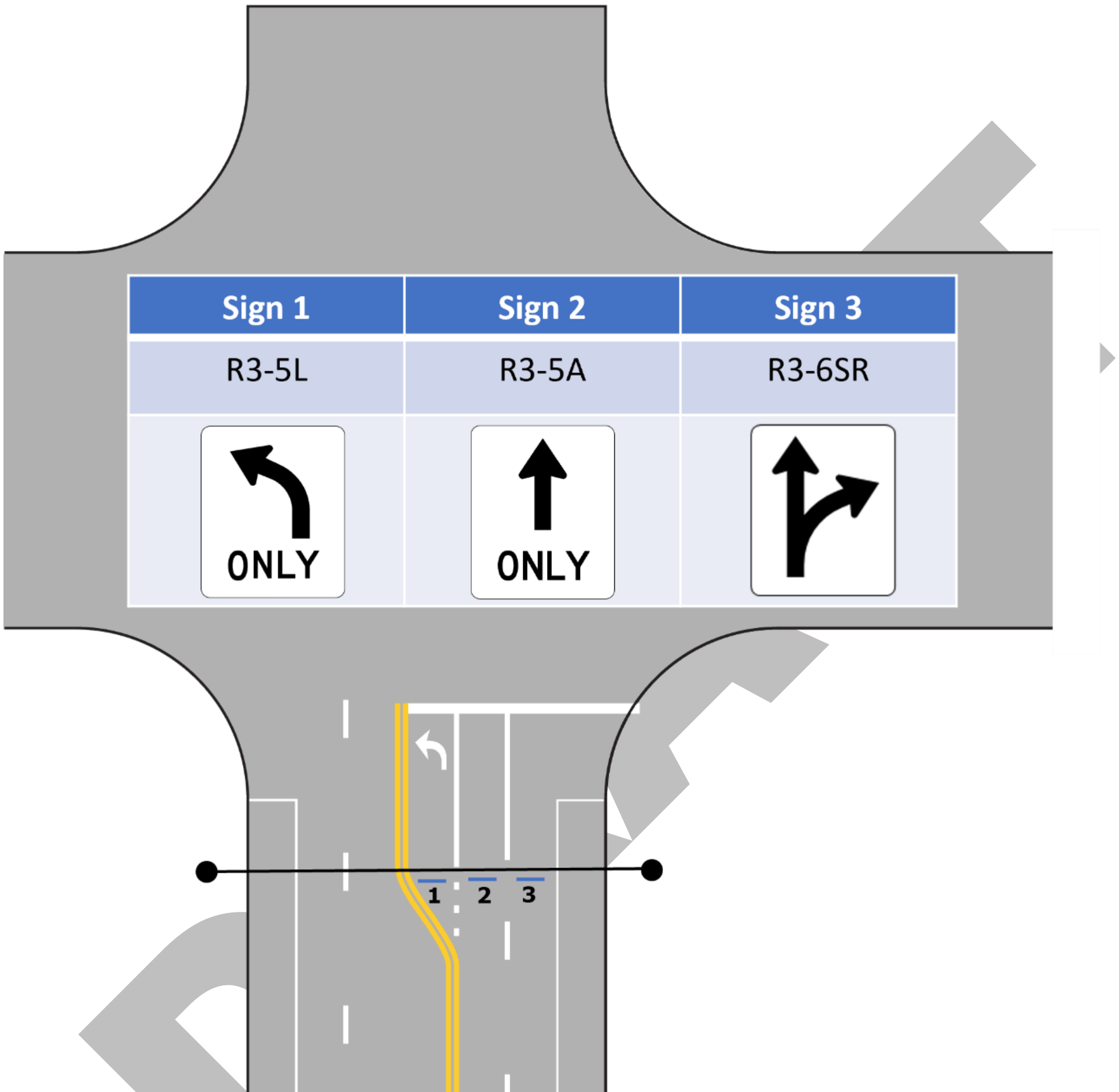
Exhibit 19-9 Overhead Mounted Intersection Lane Control Signs



- ✓ Straight-Through (R3-5A) sign, over a lane where only straight-through movements are permitted.
- ✓ Left Turn (R3-5L) sign, over a mandatory left turn lane.
- ✓ Right Turn (R3-5R) sign, over a mandatory right turn lane.
- ✓ Optional Left or Right Turn (R3-6LR) sign, over a shared lane from which traffic must turn either left or right.
- ✓ Optional Left Turn (R3-6LS) sign, over a shared lane from which traffic must either turn left or process straight through the intersection.
- ✓ Optional Left, Straight, and Right Turn (R3-6LSR) sign, over a shared lane where left turns, straight through movements, and right turns are permitted and there is an adjacent lane from which traffic is required to turn left or right.
- ✓ Optional Right Turn (R3-6SR) sign, over a shared lane from which traffic must either turn right or process straight through the intersection.

If overhead lane control signs are provided on an approach, a sign should be installed over the center of each lane in advance of the intersection, desirably near the upstream end of the turn lane which begins closest to the intersection. See **Exhibit 19-10** for an example intersection approach layout of overhead lane control signs.

Exhibit 19-10 Overhead Lane Control Signs – Intersection Approach Example Layout



Route markers or guide signs may be used to supplement or take the place of overhead lane control signs. If the size of the signs exceeds the standard loading for a traffic signal support structure (see **Chapter 12**), a sign structure is required.

Overhead lane control signs are typically mounted to standard traffic control signal support structures (see **Chapter 12**) but may be mounted to other structures provided the signs are located in advance of the intersection and centered over the lane to which each sign applies. Due to the higher costs for installation and ongoing maintenance of structures, designers must carefully consider the need for overhead lane control signs and limit their use to locations where the need is justified.

Railroad Grade Crossings

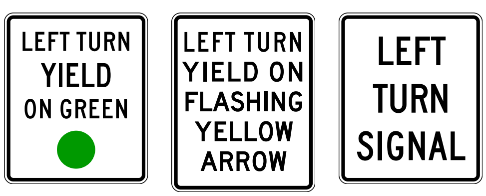
Two R8-8 "Do Not Stop on Tracks" signs should be considered for each direction at each track crossing location. One should be placed before the crossing (or gates if present), and one after.

19.3.2 Traffic Signal Signs

Turn-Related Signs

The following turn-related signal signs in **Exhibit 19-11** may be installed as indicated in this section.

Exhibit 19-11 Turn-Related Signal Signs



R10-12 R10-12A R10-10L

A Left Turn Yield On Green (R10-12) sign shall be installed adjacent to a shared signal face used for protected/permissive left turn phase operation where permissive left-turn movements occur during the display of a circular green (see **Exhibit 16-14** B).

A Left Turn Yield on Flashing Yellow Arrow (R10-12A) sign shall be installed adjacent to a signal face which includes a flashing yellow arrow (FYA) display (see **Exhibit 16-14A**). No variations to the R10-12A sign to include the use of symbols is allowable. See Publication 236 for the R10-12A sign specification.

The Left Turn Signal (R10-10L) sign should not be used when the separate left-turn signal face contains all left arrow indications.

Prior to the 2009 MUTCD, a circular red indication was allowed for separate left-turn signal faces. These installations should be upgraded to comply with the current MUTCD by replacing the circular red indication with a red arrow indication. Where the circular red indication from a pre-2009 installation remains in use in a separate left-turn signal face, the Left Turn Signal (R10-10L) sign shall be used on approaches where other signal faces may display green or yellow indications while the circular red indication is illuminated for the left turning movement.

The Right Turn Signal (R10-10R) sign shall not be used. Existing Right Turn Signal signs should be removed whenever signal permits are revised. The Right Turn Signal sign is only used in cases where the right turn signal face would display a circular red at the same time when the adjacent through signal faces would not display circular red. A red arrow indication should be used instead. It is noted that right turn on red is allowed in Pennsylvania when a red arrow indication is used.

No Turn on Red (NTOR) Signs

Right turn on red (or left turn on red from a one-way street to a one-way street) is permitted in Pennsylvania unless signing is in place prohibiting the turn (see **Section 16.2.8**). Therefore, MUTCD Section 2B.60, Paragraph 1, is replaced with the following for Pennsylvania:

> **Where a right turn on a red signal indication (or a left turn on a red signal indication from a one-way street to a one-way street is prohibited), a NO TURN ON RED (R10-11, R10-11b) word message sign shall be used.**

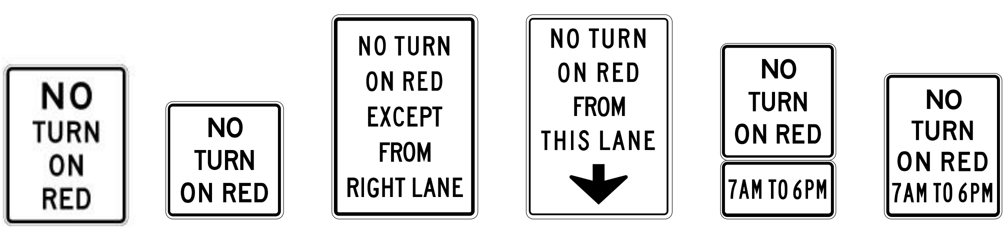
The above standard modification is necessary due to the requirements of 75 Pa.C.S. §3312(a)(3)(ii), which was in effect prior to January 16, 2007 and is an exception to the substantial conformance requirements in 23 CFR §655.603(b)(1).

The following supplements MUTCD Section 2B.60 for use of No Turn on Red signs in Pennsylvania:

When an engineering study (see **Section 3.2.1**) indicates a restriction of right turn on red (or left turn on red from a one-way street to a one-way street) is warranted, the NO TURN ON RED word message (R10-11) sign shall be installed near the appropriate signal head (see **Exhibit 19-13** for a NTOR sign placement example). A supplemental NO TURN ON RED sign may be post-mounted near the stop line. The NO TURN ON RED Square-Shaped Sign (R10-11B) may be used as an alternate to the No Turn On Red (R10-11) sign when the R10-11 sign cannot be installed due to field conditions such as vertical clearance restrictions.

The signs in **Exhibit 19-12** are approved in Pennsylvania when no turn on red is prohibited:

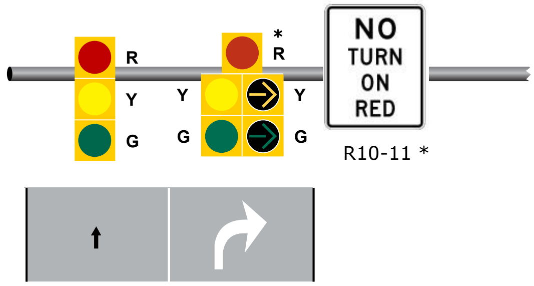
Exhibit 19-12 No Turn on Red Signs



R10-11 R10-11B R10-11C R10-11D R10-20AP R10-101

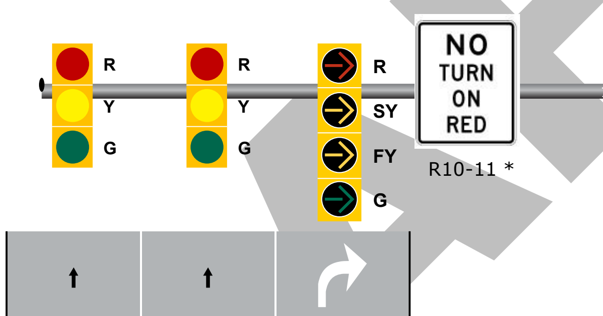
Exhibit 19-13 No Turn on Red Sign Placement Example

A - Circular Red Indication (right-turn lane)



* The No Turn On Red Square-Shaped Sign (R10-11B) may be used as an alternate to the R10-11 sign when the R10-11 sign cannot be installed due to field conditions such as vertical clearance restrictions.

B - Red Arrow Indication (right-turn lane)



A Restricted Hours Plaque (R10-20AP) may be used in conjunction with the R10-11 or R10-11B sign or a No Turn on Red with One-Line Restriction (R10-101) sign may be used when the turn on red restriction is warranted but only at a specific time.

Alternatively, a blank-out sign may be used instead of a static No Turn on Red sign when the turn prohibition applies only at certain times during the day or during one or more portion(s) of a particular cycle of the traffic signal.

On signalized approaches with more than one right-turn lane, a No Turn On Red Except From Right Lane (R10-11C) sign may be post-mounted at the intersection or a No Turn On Red From This Lane (with down arrow) (R10-11D) sign may be mounted directly over the center of the lane from which turns on red are prohibited.

Although MUTCD Section 4A.03 makes a distinction between circular red and red arrow indications relative to turning right on red, §3112(a)(3)(ii) of the Pennsylvania Vehicle Code does not make a distinction. Therefore, in Pennsylvania, right turn on red is permitted from both circular red and red arrow indications. A No Turn on Red sign must be used to prohibit right turn on red for both circular red and red arrow indications. When turning on red is prohibited on a red arrow indication, the No Turn on Red Squared-Shaped Sign (R10-11B) shall be used.

Stop Here on Red Signs

The Stop Here on Red (R10-6AL and R10-6AR) sign should be used when the stopping location must be placed further than normal from the intersection to indicate the stopping point for vehicles. The sign should be placed in line with the extension of the stop line. The Left Lane Plaque (R10-6-1) should be used when the stop line for the left turn lane is at a different location than the stop line for other lanes.

Turning Traffic Conflict Signs (R10-15, R10-16, R10-30)

The Turning Traffic Must Yield to Pedestrians (R10-15L and R10-15R) sign may be installed to remind drivers who are making turns to yield to pedestrians, especially at intersections where turn on red is permitted and pedestrian crosswalks are marked. The R10-15L and R10-15R signs shall be post-mounted near the stop line.

The U-Turn Yield To Right Turn (R10-16) sign may be installed near the left-turn signal face if U-Turns are allowed on a protected left-turn movement on an approach from which a Right-Turn Green Arrow signal indication is simultaneously being displayed to drivers making a right turn from the conflicting approach to their left.

The Right Turn on Red Must Yield to U-turn (R10-30) sign may be installed to remind road users that they must yield to conflicting U-turn traffic on the street or highway onto which they are turning right on a red signal after stopping.

Do Not Block Intersection Signs

The Do Not Block Intersection (R10-7) sign may be used in advance of a street or other crossing which must be kept open where stopped traffic frequently blocks an intersection or driveway.

19.3.3 Pedestrian Signs

Pedestrian Crossing Signs (R9-2, R9-3)

The following shall apply to use of pedestrian crossing signs in Pennsylvania and supersede MUTCD Section 2B.57:

Where crosswalks are clearly defined, the Cross Only at Crosswalks (R9-2) sign may be used to prohibit pedestrians from crossing at locations away from crosswalks.

The No Pedestrian Crossing (R9-3) sign shall be used when pedestrian need is determined (see **Section 8.2**) and accessible route is restricted. The sign may supplement a physical barrier, but the sign alone does not communicate the crossing prohibition to pedestrians for vision disabilities. When used, the R9-3 sign shall be positioned on the far side of the roadway facing pedestrians that would desire to cross the roadway.

The appropriate Use Crosswalk Plaque (R9-3BPL or R9-3BPR) should be used beneath the R9-3 sign to provide adequate pedestrian guidance to the appropriate crossing when a clearly marked, safe alternate pedestrian crossing point is provided within 300 feet away.

Traffic Signal Pedestrian Actuation Signs (R10-3 through R10-4)

The following shall apply to use of pedestrian crossing signs in Pennsylvania and supersede MUTCD Section 2B.58:

Where manual actuation of a traffic signal is required for pedestrians to call a signal phase to cross the roadway, traffic signal signs applicable to pedestrian actuation (R10-3 through R10-4) shall be mounted immediately above or incorporated into the pushbutton detector units.

The Educational Push Button for Walk Signal with Countdown Timer (R10-3E) sign should be the standard sign used for new pedestrian-actuated crossings since countdown timers are required for all new pedestrian signals (see **Section 8.2.3** and **Section 16.3**). Where older symbol message pedestrian signals without countdown timers are being retained for the remainder of their useful life, the Educational Push Button for Walking Person Signal (R10-3B) sign should be used. The non-educational pushbutton signs (R10-2 and R10-3) should not be used.

Where separate pedestrian signals are not provided and pedestrians cross following vehicular signals, the Push Button for Green Signal (R10-4) sign should be used.

Where manual actuation of a flashing beacon is required to turn on the warning lights, the Push Button to Turn on Warning Lights (R10-25) sign shall be mounted immediately above or incorporated into the pushbutton detector units.

In-Street Pedestrian Crossing (R1-6) and Overhead Pedestrian Crossing Signs (R1-9)

The In-Street Pedestrian Crossing Sign (R1-6) and the Overhead Pedestrian Crossing Sign (R1-9) shall not be used at signalized intersections.

19.3.4 Street Name Signs

Overhead Street Name Signs

Street name signs at traffic control signals should be overhead mounted. Post-mounted street name signs (D3-1) may be used to supplement overhead-mounted signs.

Overhead street name (OSN) signs include the following signs listed in Publication 236, which take the place of the D3-1 sign for overhead applications in Pennsylvania:

- ✓ D3-4 (single line overhead street name sign), and
- ✓ D3-5 (double-line overhead street name sign)

Publication 236 allows reducing inter-letter spacing and letter height where the legend would otherwise exceed the maximum width which can be structurally or physically accommodated. **Exhibit 12-8** indicates the assumed maximum width for overhead street name signs is 96 inches.

Street name signs are invaluable to unfamiliar drivers, and OSN signs that are near traffic control signals are especially valuable because drivers should already be looking in that general area.

When roads have generally accepted street names as determined by the local authorities, OSN signs should be included in the traffic signal design for Level 3 and Level 4 projects (see **Chapter 6**).

The additional wind loading created by installing an OSN sign to an existing mast arm support does necessitate a structural review.

The minimum mounting height to the bottom of the sign is 17 feet.

When attached to traffic control signal mast arms, OSN signs should be located as follows:

- ✓ Vertically - centered vertically at the same height as the mast arm; except when OSN signs are installed on existing mast arms, the signs may be designed to rotate and spill the wind to reduce the wind loading.
- ✓ Horizontally - the preferred horizontal location is to the right of the right overhead signal, centered over the right edge of the right approach lane.

Sign colors (Publication 236 for D3-4 and D3-5 signs):

- ✓ Preferred color of OSN signs is white on green.
- ✓ When requested by local authorities, the District Traffic Unit may authorize white-on-blue, white-on-brown, or black-on-white colors. No other color combinations are permitted by the MUTCD.

Sign legends (Publication 236 for D3-4 and D3-5 signs)

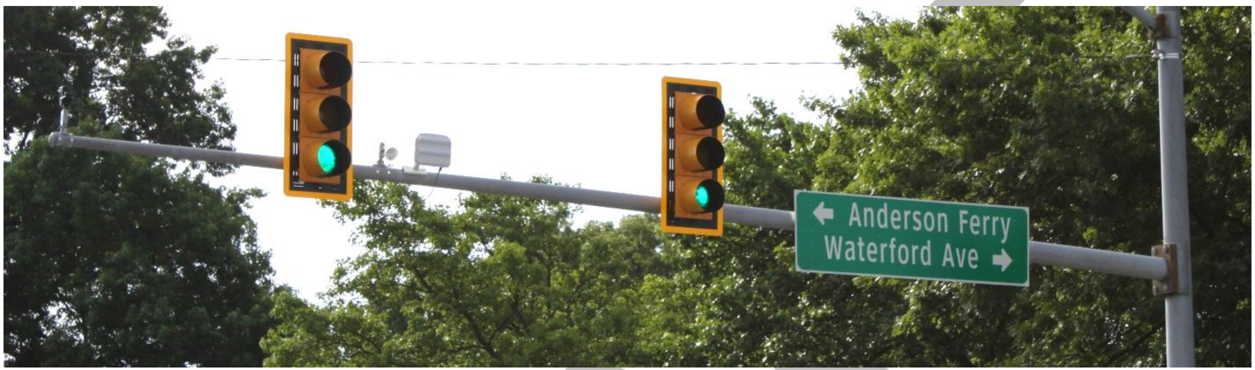
- ✓ Use of upper- and lower-case legend.
- ✓ Use of the currently approved standard legend type for all new OSN signs

To maximize legibility, do not use left or right arrows on a D3-4 sign unless the sign is used at a crossroad where one of the legs is not a public road.

Suffixes such as "Rd" and "St" may be omitted if the use of the suffixes would exceed the maximum allowable sign width. Suffixes should not be omitted in the following cases:

- ✓ For alphabetic or numeric street names (e.g., K St and 13th St)
- ✓ To distinguish between other nearby roads with the same base name (e.g., Schuylkill Dr and Schuylkill Ave)
- ✓ When the name of the roadway is a cardinal direction (e.g., East Ave and North St)
- ✓ Anytime that the lack of the suffixes could be confusing.

Exhibit 19-14 Overhead Street Name Signs



Advance Street Name Signs

Advance street name signs include the following signs listed in Publication 236:

- ✓ D3-2 (single line advance street name sign), and
- ✓ D3-3 (double-line advance street name sign)

Advance Street Name Signs are desirable especially on multilane approaches where the driver might be required to make multiple lane changes. See MUTCD Figure 2D-14 for examples Advance Street Name Signs. These signs are discussed in more detail in Publication 46, Chapter 2.

19.3.5 Illuminated Signs

Illuminated signs may be used where an engineering study shows that reflectorized signs will not provide effective performance or where extraneous light makes it difficult to read reflectorized signs. Therefore, an illuminated sign is a special application to a typically required sign at a signalized intersection.

The sign display message character color, dimensions, and layout must be in accordance with Publication 236 and the MUTCD.

The traffic control signal shall be given dominant position and brightness to assure its target priority in the overall display.

Internally Illuminated signs are referenced in Publication 408, Section 1103.02(g).

Exhibit 19-15 Illuminated Street Name Sign

19.3.6 Blank Out Signs

A "blank-out" sign is a sign that displays a single predetermined message only when activated. When not activated, the sign legend is not visible.

As such, the size of a blank-out sign's legend elements, overall sign size, and sign placement should comply with the applicable provisions for the conventional version of the sign in Publication 236 and the MUTCD.

Blank-out signs used as part of a traffic signal design must operate in coordination with the signal controller so that the sign is only ON (illuminated) when the specific condition for the sign message applies.

Examples of where blank-out signs may be applicable and beneficial with respect to traffic signals are:

- ✓ Light Rail Transit Approaching (W-10-7 activated blank-out sign) (MUTCD Section 8B.17).
- ✓ Preemption of highway traffic signals at or near grade crossings (MUTCD Section 8D.09).
- ✓ Movement prohibitions during preemption (R3-1a & R3-2a activated blank-out signs) (MUTCD Section 8D.10).
- ✓ Movement prohibitions during specific traffic signal phases (MUTCD Sections 2B.26 & 2B.60).
- ✓ Traffic signal signs (MUTCD Sections 2B.59 & 2C.44)
- ✓ Advance warning on approaches to traffic signals with restricted line-of-sight, sight distance (MUTCD Section 2C.35). See **Section 19.3.7** and **Chapter 1**.

For addition information, see the following references:

- ✓ Publication 35 (Bulletin 15), Section 1103
- ✓ Publication 236
- ✓ Publication 408, Sections 935, 936, 953, and 1103.03(j)
- ✓ MUTCD PART 2, and Sections 2L.01, 8B.17, 8D.09, and 8D.10

19.3.7 Warning Signs

The SIGNAL AHEAD (W3-3) sign shall be installed in advance of any signalized location when physical conditions prevent the motorist from having a continuous view of at least two signal indications for the following distances as specified in **Exhibit 19-16** and in accordance with PennDOT Publication 236, and MUTCD 2C.35.

Exhibit 19-16 Minimum Sight Distance for Signal Visibility

85th Percentile Speed MPH	Distance Feet
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

Table is from Publication 236 and MUTCD, Table 4D-2.

A BE PREPARED TO STOP (W3-4) sign may be used to warn of stopped traffic caused by a traffic control signal or in advance of a section of roadway that regularly experiences traffic congestion. When a BE PREPARED TO STOP sign is used in advance of a traffic control signal, it shall be used in addition to a Signal Ahead sign and shall be placed downstream from the SIGNAL AHEAD (W3-3) sign.

Where additional emphasis for a warning sign is determined to be needed, a flashing warning beacon may be installed to supplement the sign (see **Chapter 30**).

See **Chapter 21** for information on the application of advance red signal indication ahead warnings.

19.4 Typical Applications – Signing & Pavement Marking at Signalized Intersections

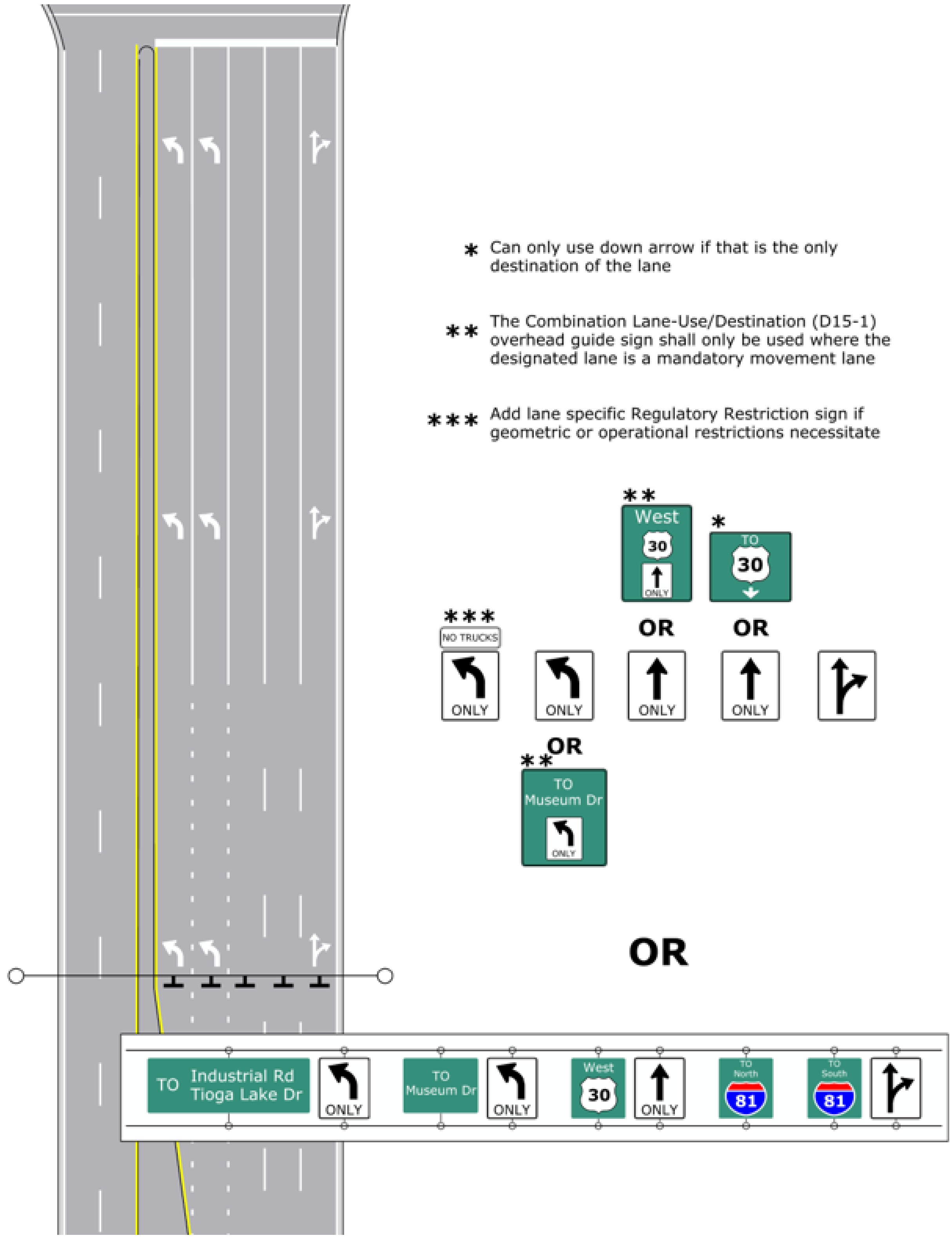
The following sub-sections provide exhibits that show typical applications for signing & pavement markings at various signalized intersection approach configurations.

19.4.1 Turn Lanes

See previous **Exhibit 19-4** for typical applications of signing & pavement markings at a left-turn bay. In this typical application, the solid white line is used for 2X/3 of full width left-turn lane, then the dotted extension line is used for remaining portion.

Exhibit 19-17 provides typical applications for overhead lane control sign options.

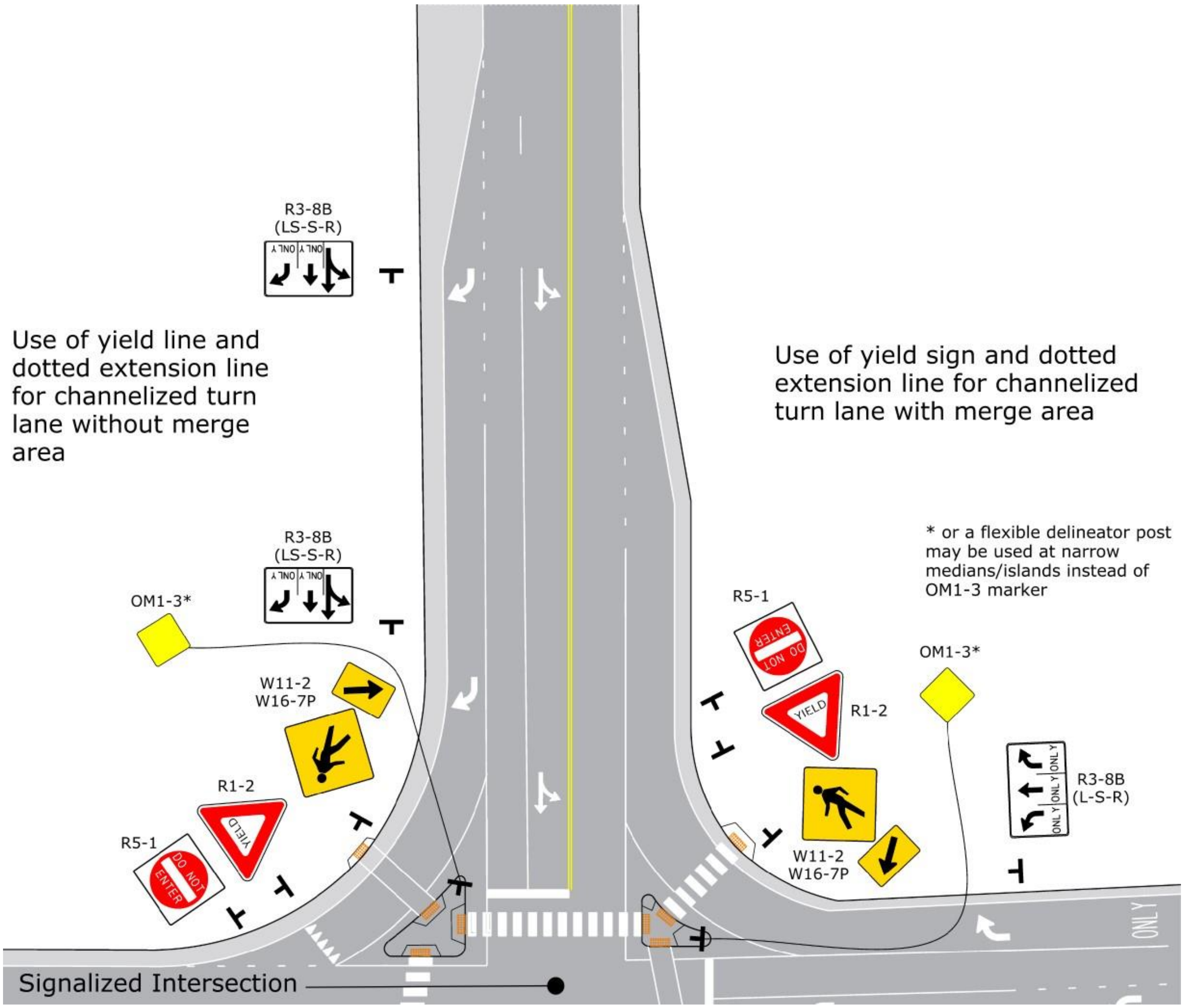
Exhibit 19-17 Overhead Lane Control Sign Options & Typical Applications



19.4.2 Channelized Turn Lanes

Exhibit 19-18 shows two typical applications for signing & pavement markings at channelized right-turn yield applications, one for a channelized turn lane without a merge area and the other for a channelized turn lane with a merge area.

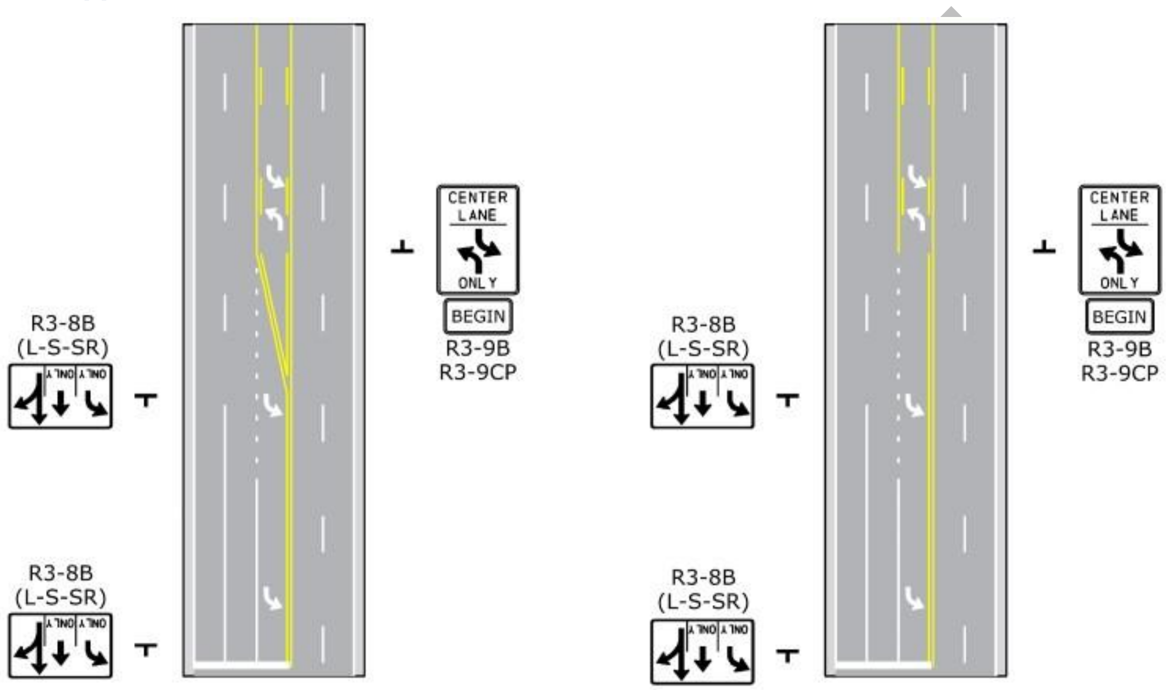
Exhibit 19-18 Channelized Right-Turn Yield Typical Applications



19.4.3 Transition from Two-Way Center Left Turn Lane to Exclusive Turn Lane

Exhibit 19-19 shows two typical applications for signing & pavement markings at a transition from a two-way center left turn lane to an exclusive turn lane.

Exhibit 19-19 Transition from Two-Way Center Left Turn Lane to Exclusive Turn Lane Typical Applications

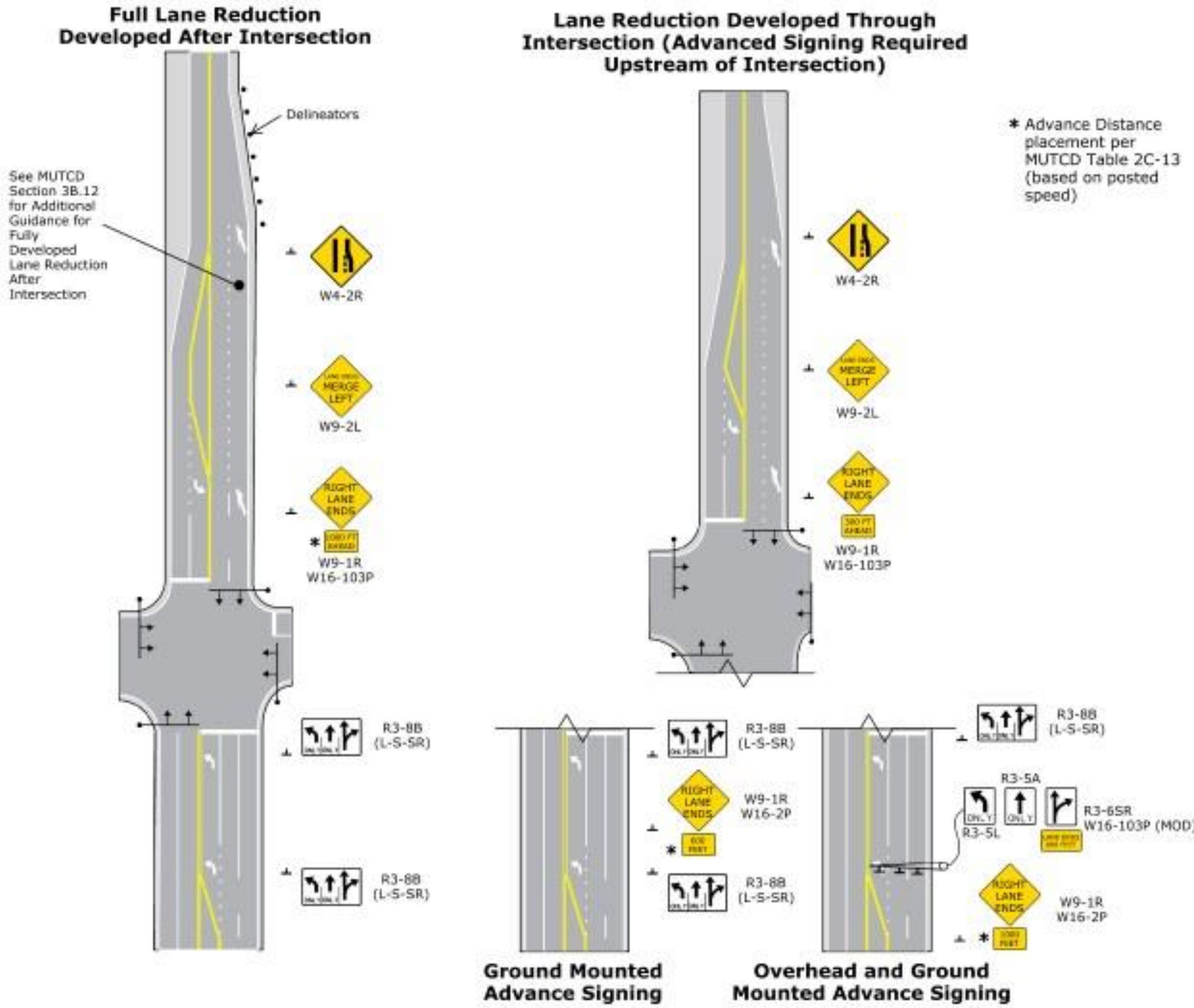


19.4.4 Lane Drops

At lane drops, where through lanes approaching an intersection become mandatory turn lanes, lane-use arrow markings and ONLY word pavement markings shall be used and shall be accompanied by standard signs; see MUTCD 3B.21.04, 3B.23.08, 2B.28.06, and Pub 111 TC 8600 (sheet 3 of 13). As discussed in Section **19.3.1,** overhead lane designation signs should be used when a through lane becomes a mandatory turn lane.

For lane reductions, where a through lane approaching an intersection is eliminated beyond the intersection, advance signing in advance of the intersection is necessary if the lane reduction is not fully developed beyond the intersection; see MUTCD Section 3B.12, 2C.47, and Figures 2C-13. See **Exhibit 19-20** for typical applications of lane reductions.

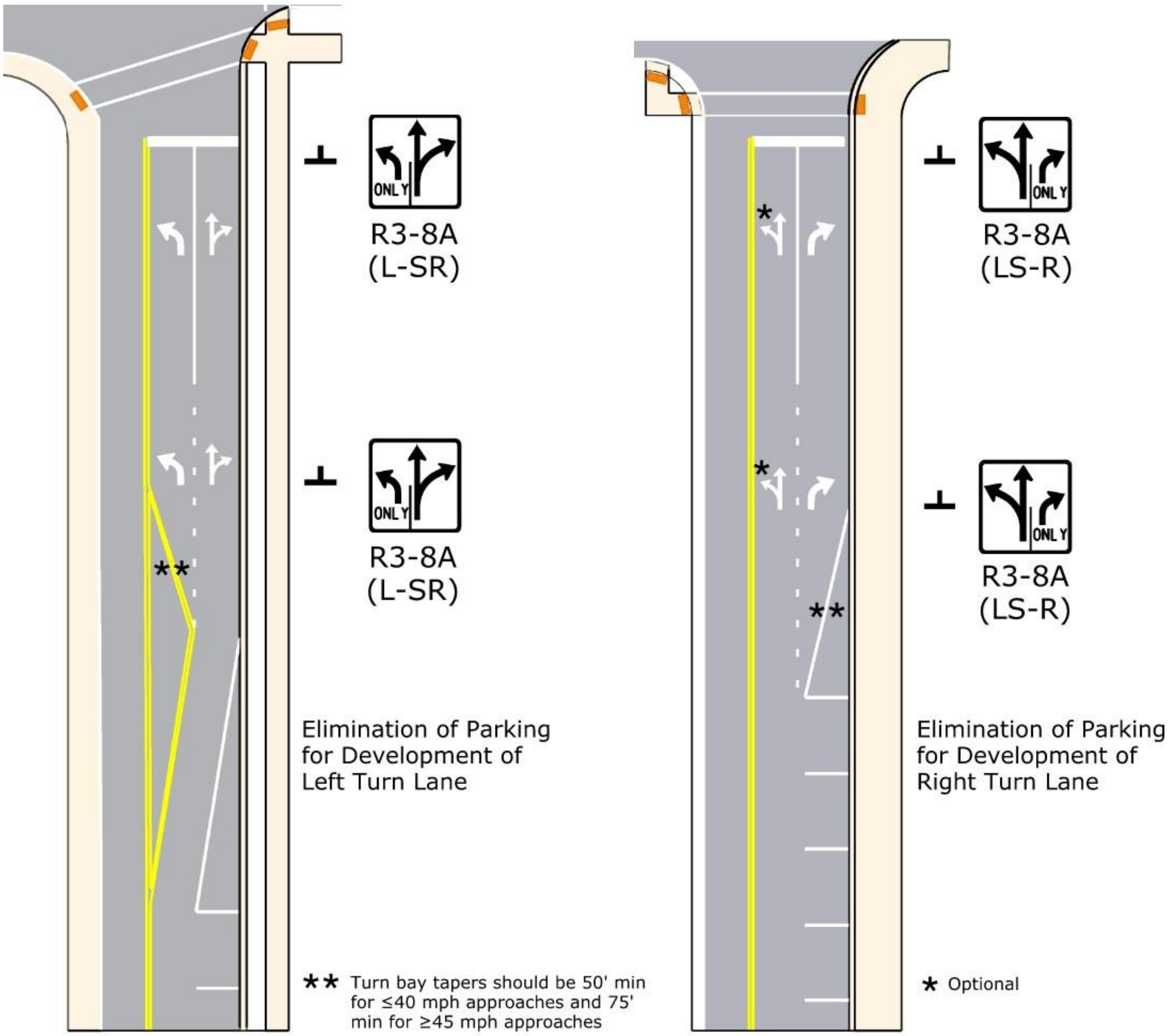
Exhibit 19-20 Lane Reductions Typical Applications



19.4.5 Parking

Exhibit 19-21 shows two typical applications for signing & pavement markings at approaches where parking needs eliminated for development of either a left turn lane or right turn lane.

Exhibit 19-21 Parking Typical Applications



20. INTERSECTION LIGHTING

The purpose of this Chapter is to provide guidance as appropriate for intersection lighting when installing traffic signals.

Each proposed signalized intersection should be evaluated to determine whether intersection lighting is needed. If roadway lighting is provided along the intersection approaches, the roadway lighting may satisfy the need for intersection lighting. Intersection lighting should be considered for the following situations:

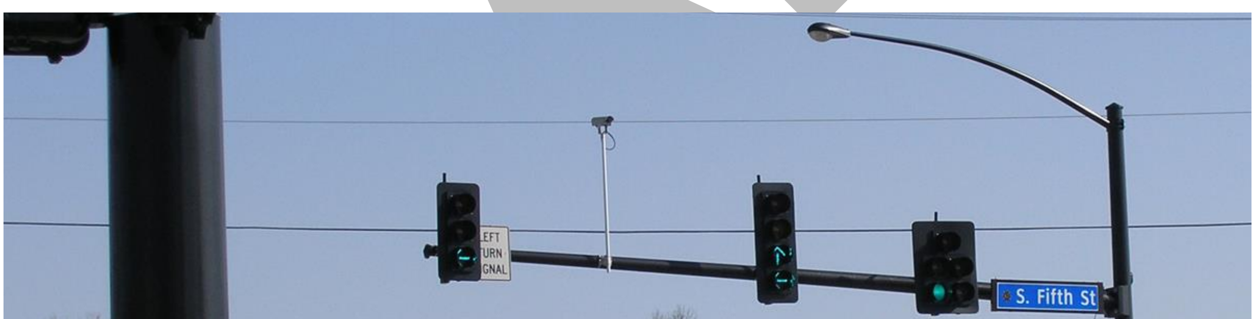
- ✓ To illuminate key decision points and conflict points, including crosswalks
- ✓ To provide contrast to increase visibility of pedestrians.
- ✓ To improve performance of video detection systems

Once a determination to install intersection lighting has been made, the appropriate lighting level should be established by referring to the design value tables in the latest AASHTO Roadway Lighting Design Guide. The design value should be the sum of the recommended values for the two intersecting roadways.

Additionally, Publication 13M (DM 2), Chapter 5, Lighting, should be evaluated appropriately.

For complicated intersections, a qualified lighting engineer should design and/or review the intersection lighting to ensure adequate lighting levels are provided.

If intersection lighting is proposed to be attached to the traffic signal on luminaire arms, the intersection lighting should be incorporated into the traffic signal design. Refer to **Section 15.8** for electrical requirements.



21. OTHER ATTACHMENTS TO TRAFFIC SIGNALS

21.1 General

Traffic signal permittees may receive requests to install other equipment to traffic signal structures which is not directly associated to the operational function of the traffic signal.

This chapter lists common items which may be physically attached to traffic signal support structures (**Chapter 12**) but do not directly pertain to the operation or function of the traffic signal. An existing traffic signal undergoing a retrofit project design may already include some of these types of other equipment/attachments.

The equipment described in this chapter is not included in the typical loading calculations in **Chapter 12**. Therefore, the specific pole loading should be analyzed to determine if a special pole design is needed.

21.2 Traffic-Related Equipment (non-Traffic signal)

This equipment category is traffic-related but is not part of the specific equipment needed for the installation and operation of the traffic signal.

21.2.1 Closed-Circuit Television Cameras

Closed-circuit television (CCTV) video cameras provide supplemental surveillance for overall traffic or incident monitoring purposes as part of PennDOT's RTMC functions. Cameras primarily used for law enforcement or security surveillance are not traffic-related equipment and should follow **Section 21.3**.

CCTV video cameras are not a type of traffic control signal detection system as they don't serve any input function regarding vehicle detection for controller operations.

For information on attaching a CCTV video camera to a traffic signal support structure, refer to the following references:

- ✓ Publication 408, Sections 1210.2(b), and 1210.2(c)
- ✓ Publication 647, ITS Standard Drawings (ITS-1210, sheet 6 of 6)

21.2.2 Connected Vehicle Equipment

Connected vehicle equipment installed at traffic signals enables equipped vehicles (cars, transit, emergency responders, freight) to receive information about the signal phasing and timing (SPaT) of the traffic signal, enabling various application use cases, such as red-light violation warning. This exchange of information between a vehicle and the infrastructure, called vehicle-to-infrastructure (V2I) communication, can also enable many different application use cases, such as emergency vehicle preemption, transit signal priority, and the warning of vulnerable road-users in crosswalks.

The FCC has allocated a portion of the 5.9 GHz band for vehicle-to-infrastructure communication. For a connected vehicle deployment, the connected vehicle equipment includes roadside unit (RSU) mounted on the signal structure, typically on the mast arm or signal pole with clear line-of-sight along all approaches to the intersection. The RSU maximum mounting height is 26 feet, but the minimum mounting height may depend on manufacturer requirements and site conditions.

The RSU typically requires network connectivity and is powered via ethernet. The RSU is responsible for broadcasting and receiving messages to and from equipped vehicles in a standardized format established by SAE International. Most modern ATC controllers can provide the proper NTCIP messaging required to enable connected vehicle messages. The RSU typically converts the NTCIP SPaT message to SAE J2735 format. The RSU may need to be accompanied by additional processors located in the traffic signal cabinet if the signal controller is not compliant with the NTCIP SPaT message format, or to perform other processing required by a V2I application which can't be handled by the RSU.

To enable V2I communication within the 5.9 GHz band, vehicles must be equipped with ether an aftermarket or original equipment on-board unit (OBU). RSU and OBU use a communications standard called C-V2X, which is a standard developed by the 3rd Generation Partnership Project (3GPP). Other technologies for V2I communications are still emerging using 4G/5G communication, GPS, or localized communication mediums. These additional technologies may compliment the direct C-V2X communication in the future.

For industry and national guidance on connected vehicle equipment, refer to the following references:

- ✓ Connected Transportation Interoperability (CTI) standards:
  - CTI 4501 v01.01 – Connected Intersections Implementation Guide
  - CTI 4001 v01 – Roadside Unit (RSU) Standard
  - CTI 4402 v01.00 – Connected Intersections Validation Report
- ✓ SAE International
  - SAE J2735 - V2X Communications Message Set Dictionary
  - SAE J2945/4 – Road Safety Applications
- ✓ 5GAA – United States Vehicle-to-Infrastructure Communications Day One Deployment Guide
- ✓ United States Department of Transportation – Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment

When considering connected vehicle equipment at traffic signals, systems engineering, an organized approach to developing and implementing the system, should be conducted to ensure that the technology effectively supports the management and operations of the transportation system. A systems engineering analysis is required for projects using Federal funds per Title 23 CFR 940.11.

If connected vehicle equipment is being proposed, contact the Department's Transformational Technology Division for further guidance, standards, and requirements for the deployment.

21.3 Third-Party Equipment and Attachments

For traffic signals, third-party equipment refers to any equipment attached to traffic signal support structures which is unrelated to the installation and operation of the traffic signal and does not serve a traffic purpose. The equipment may be owned by the traffic signal permittee or may be owned by another entity with permission from the traffic signal permittee to attach to the structure.

PennDOT will not fund the purchase, installation, relocation, or replacement of third-party equipment as it is not transportation infrastructure or a traffic control device; municipal and/or private funding must be used. If a municipality desires to have third-party equipment procured, installed, replaced, or relocated as part of a PennDOT project, a Contribution Agreement must be prepared by the Office of Chief Counsel and fully executed, and the Contribution Agreement must be included and required on the Project Development Checklist in ECMS (see Publication 51).

If purchase, installation, relocation, or replacement of third-party equipment is included in the project scope, the policy procedure requirements provided in Publication 191, Traffic Signal Maintenance Manual, Section 7.3 must be followed to ensure the following:

- ✓ Additional equipment does not exceed the structural capacity of the traffic signal structures.
- ✓ Additional equipment does not interfere with the traffic signal operation or create a distraction for drivers.

21.3.1 Automated License Plate Readers (ALPRs)

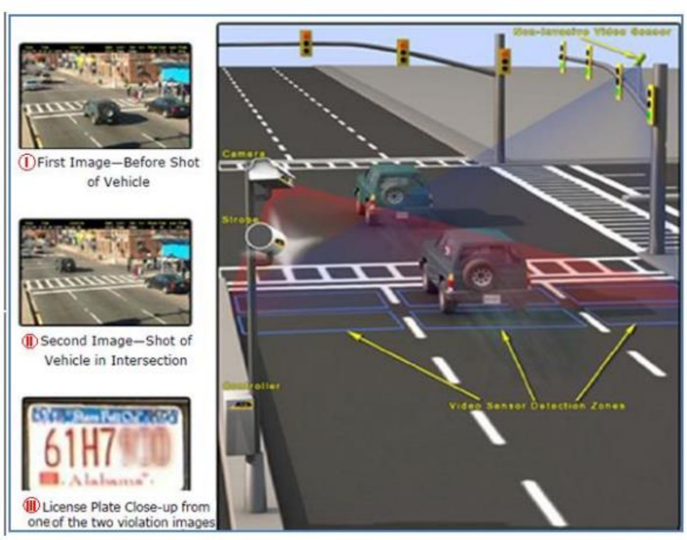
Law enforcement agencies use ALPRS (cameras and computer software) to scan the license plates of passing vehicles for various enforcement functions. This retrieved data can instantly be compared against designated lists such as vehicle registration, stolen vehicles, Amber Alerts, unpaid parking tickets, etc.

Law enforcement may request that ALPR cameras be installed at a fixed location, such as permanently attaching the cameras to a traffic signal support. Below is an example photo of an ALPR attached to a traffic signal support.

21.3.2 Automated Red Light Enforcement (ARLE) Equipment

Automated Enforcement refers to the use of camera technology to enforce existing traffic safety laws. A common type of automated enforcement program is for red light violations, known as Automated Red Light enforcement (ARLE). ARLE Systems are at signalized intersections where red light running has been an issue. Pennsylvania law identifies eligibility requirements for the use of ARLE Systems. For additional information on ARLE, see Traffic Signal Portal (ARLE).

Some equipment components of the ARLE system may be requested to be attached to a traffic signal support.



21.3.3 Communication Network Equipment

Various private communication equipment from cellular and internet companies is often attached to existing infrastructure in the public right-of-way like utility poles, streetlights, and/or traffic signals. This makes them more discreet, while also bringing them closer to smartphones and other devices improving the provided communications coverage.

Antennas and "small cells" are two typical types of communications network equipment attached to traffic signal supports. A small cell installation consists of small radio equipment and antennas that are about the size of a pizza box or backpack and are used for transmitting data to and from a wireless device.

Below are some example photos of communications network equipment attached to traffic signal supports.

21.3.4 Security Cameras

Municipalities may utilize security surveillance cameras as part of their law enforcement function. These cameras are different than CCTV cameras as they are not used for traffic-related purposes but rather security and law enforcement surveillance. The security cameras may be attached to various public infrastructure including traffic signal supports. Below is an example photo of a security camera attached to a traffic signal support.

21.3.5 Banners and Civic Displays

Municipalities often decorate their downtown areas or main highway corridors with various types of banners or civic displays throughout the year. Banners may be attached to utility poles, street lighting supports, or traffic signal supports. If banners are attached to a traffic signal support, they must be attached to the vertical support pole. Civic display may include holiday decorations, flowerpots, and other ornamental attachments. In addition to following the requirements of this Chapter for attachment to traffic signal poles, Banners and Civic Displays must also comply with the requirements in Publication 46, Chapter 2.

Below are two example banners that municipalities often display, Hometown Heroes and Holiday banners.


PITTSBURG
HOMETOWN HEROES
WE SALUTE YOU


Seasons
Greetings

22. ADVANCE RED SIGNAL WARNINGS

22.1 General

Advanced Warning Flasher (AWF) or Internally Illuminated Warning Sign (IIWS) may be used to alert drivers regarding a red signal indication ahead, see **Exhibit 22-1**. Other advance warning applications include the SIGNAL AHEAD (W3-3) sign (see **Section 19.3.7**) or supplementing the SIGNAL AHEAD sign with a warning beacon (see **Section 30.3**).

Prior to considering and installing AWF or IIWS, consideration should be given to other countermeasures, including but not limited to:

- ✓ Adjustment of timing parameters, which may include increasing yellow and/or all red intervals.
- ✓ Improving vehicular detection in advance of the signalized intersection
- ✓ Modification of the signal system such as installing additional signal heads
- ✓ Lowering approach speed limits

Exhibit 22-1 Advanced Warning Flasher and Internally Illuminated Warning Sign

Advanced Warning Flasher (AWF)

Internally Illuminated Warning Sign (IIWS)

For addition information, see the following references:

- ✓ MUTCD (PART 2 Signs)
- ✓ Publication 111 (TC-8700C & TC-8702 series)
- ✓ Publication 212 (Official Traffic Control Devices)
- ✓ Publication 236 (Sign Handbook)
- ✓ Publication 408 (935, 936, 975, 976, & 1103)
- ✓ ECMS Master Items (0935, 0936, 0975, & 0976)
- ✓ Publication 35 (Bulletin 15)

- ✓ Form TE-974

22.2 Criteria

Due to the complex nature of traffic flow characteristics, the criteria in **Exhibit 22-2** should be applied along with engineering judgment for each prospective installation of an AWF or IIWS. Combinations of these criteria or other considerations may justify the installation of AWF or IIWS.

Exhibit 22-2 AWF and IIWS Criteria

CATEGORY	CRITERIA	COMMENT
Isolated or Unexpected signalized intersection	Where there is a long distance from the last intersection at which the mainline is controlled, or the intersection is otherwise unexpected on a roadway with a speed limit of 45 mph or higher.	This guideline may be applicable where the distance from the last intersection is greater than 10 miles, or at a freeway terminus, or at other locations where the intersection is unexpected.
Limited sight distance	Where the distance to the stop line, D, with two signal heads visible is insufficient: $D \leq 1.467vt + \frac{v^2}{0.93(a+32.2s)}$ Where: D = distance to stop line feet; V = posted speed in mph; t = reaction time, 2.5 seconds; a = deceleration rate: 8 ft/s^2 (trucks), 10 ft/s^2 (all traffic); s = decimal gradient	See Graphs of Limited Sight Distance, **Exhibit 22-3 & Exhibit 22-4**. A sight distance falling below the lines for the given speed and grade indicates the possible need for AWF or IIWS.
Dilemma Zone	Where a dilemma zone exists for all traffic or for heavy vehicles. A dilemma zone exists if: $Y \leq t + \frac{1.467v}{2(a+32.2s)}$ Where: Y = yellow interval in seconds; v = Posted speed in mph; t = 1 second; a = deceleration rate: 8 ft/s^2 (trucks), 10 ft/s^2 (all traffic); s = decimal gradient	See Graphs on Minimum Yellow Intervals, **Exhibit 22-5 & Exhibit 22-6**. If the yellow interval is less than indicated, AWF or IIWS may be considered (longer yellow should be considered first).
Crashes	If an approach has a crash problem, the intersection should be examined for existence of dilemma zone, sight distance restriction, or excessive queuing.	If no sight distance or dilemma zone problems exist, AWF or IIWS may not be an appropriate countermeasure to crash problems.
Heavy Truck Volume	Where the roadway has a grade of 3% or greater and truck volume exceeds 15%.	
Engineering Judgment	Engineering judgment should be based on additional data such as complaints, violations, conformity of practice, and traffic conflicts.	

Exhibit 22-3 and **Exhibit 22-4** below provides criteria on limited sight distance and the possible need for AWF or ILWS.

Exhibit 22-3 AWF or IIWS Limited Sight Distance (> 15% Trucks)

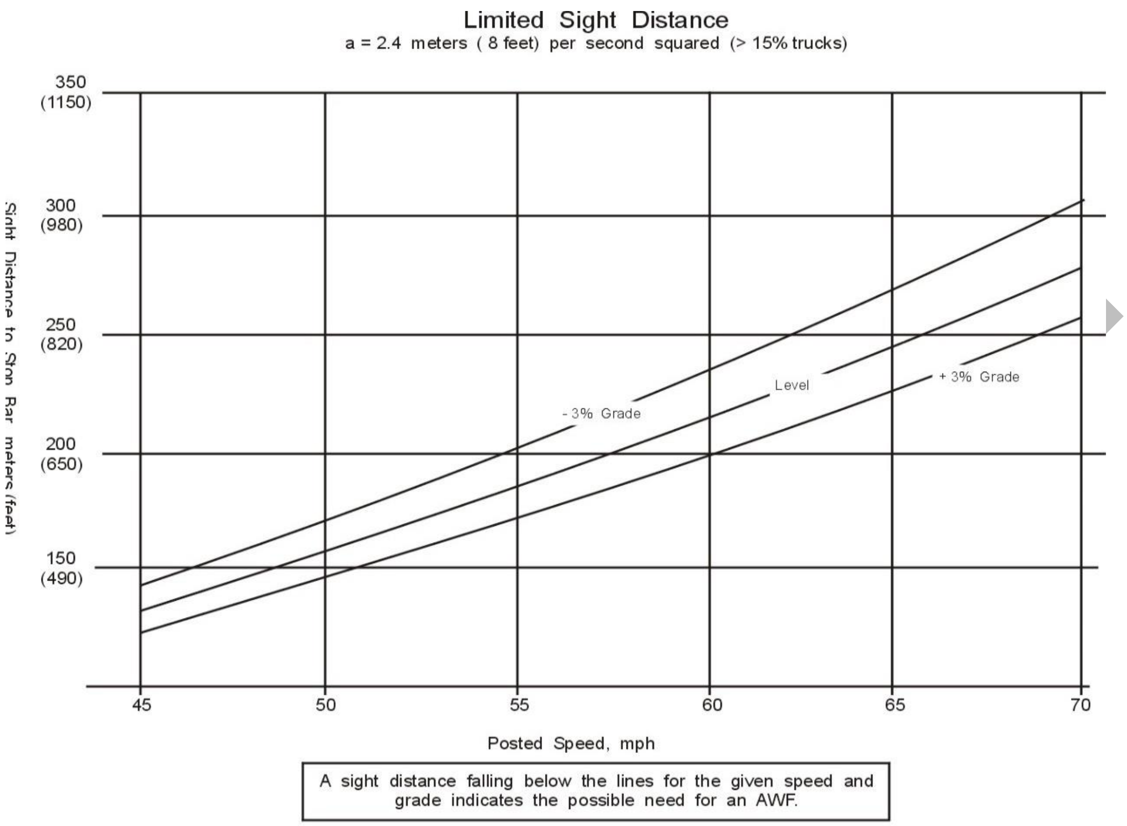


Exhibit 22-4 AWF or IIWS Limited Sight Distance (≤ 15% Trucks)

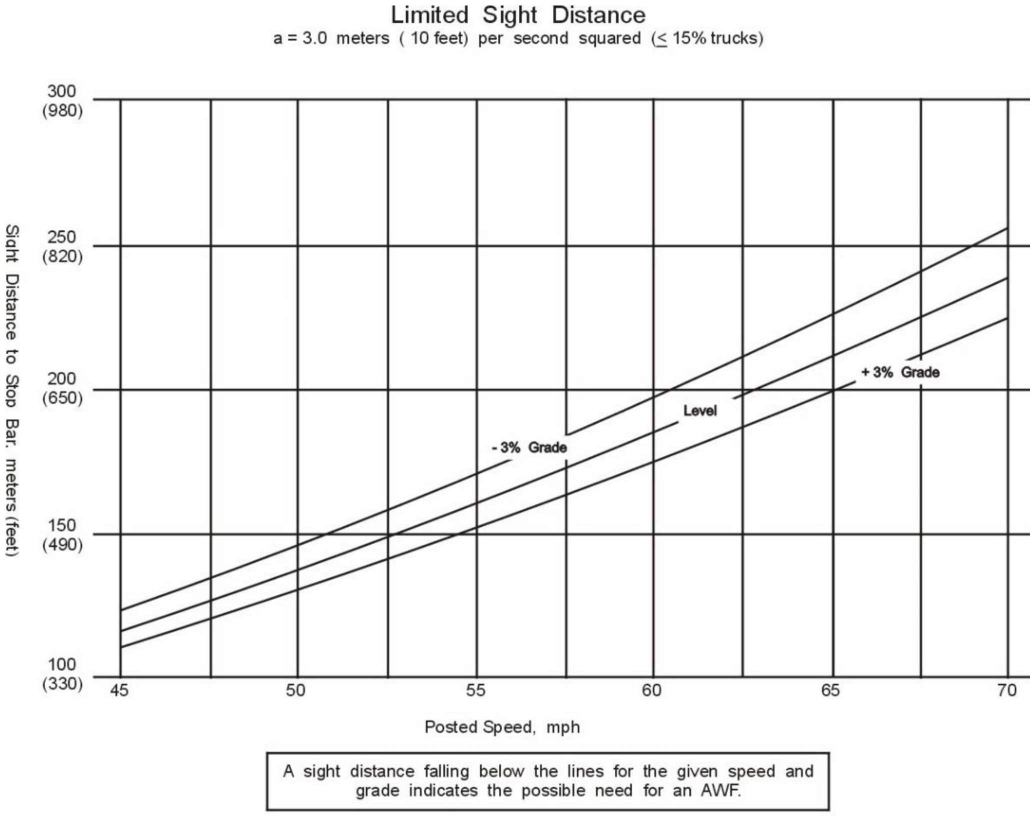


Exhibit 22-5 and **Exhibit 22-6** below provides criteria on recommended yellow clearance intervals and the possible need for AWF or ILWS.

Exhibit 22-5 AWF or IIWS Recommended Yellow Intervals (> 15% Trucks)

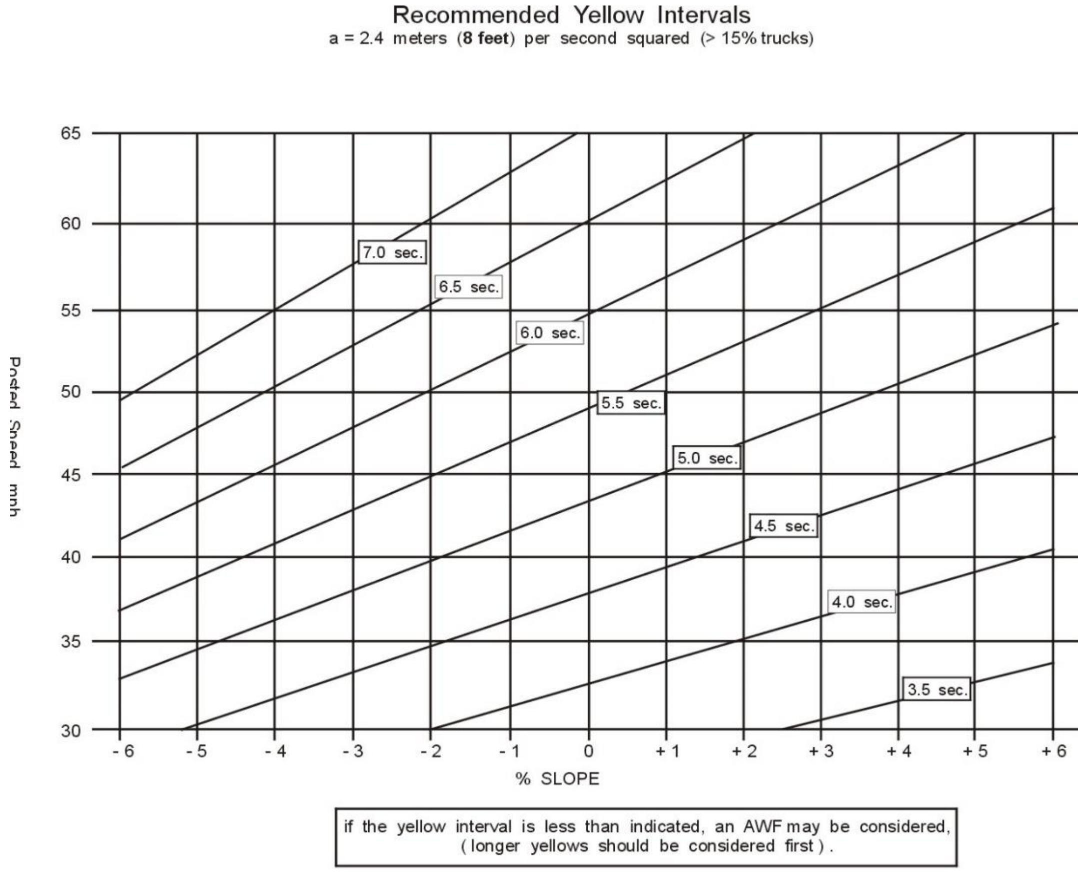
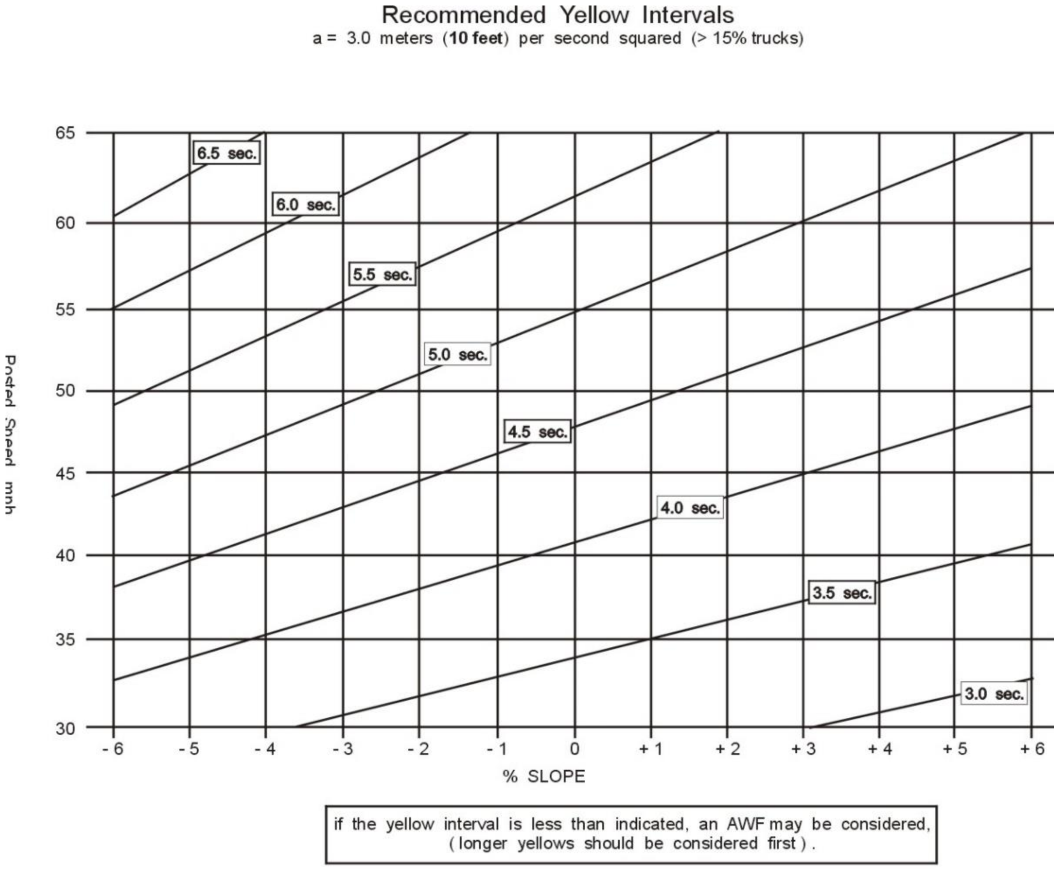


Exhibit 22-6 AWF or IIWS Recommended Yellow Intervals (≤ 15% Trucks)



22.3 Installation Guidelines

22.3.1 Active Flashing Periods

Power shall be supplied to the AWF or IIWS from the signal control cabinet.

The advanced warning flasher (AWF) shall flash yellow in a (inside-outside) wig-wag manner for the following periods:

- ✓ Prior to the termination of the green interval (Leading Flash)
- ✓ During the yellow and red signal intervals
- ✓ If the signal goes into flashing operation.

The Leading Flash is the amount of time, prior to the signal turning yellow, that the AWF flashes (or IIWS displays). The AWF shall flash (or IIWS should be illuminated) during the Leading Flash Period and continue flashing (illumination) through the signal's yellow clearance interval and the red. The Leading Flash time is shown in **Exhibit 22-7** below.

For existing systems where the placement is other than what is listed in **Exhibit 22-7**, the Leading Flash Time can be computed by the following formula:

Where: $$F = \frac{0.68D}{v} - 1.5$$

F = Leading Flash Time, seconds

D = Travel distance from AWF/IIWS to stop line, feet

v = posted speeds, mph

22.3.2 AWF/IIWS Sign Placement

The AWF or IIWS should be set back from the intersection in accordance with **Exhibit 22-7** below. At locations on four lane divided roadway, the AWF shall be placed on both sides of the approach.

The intersection detection shall be determined without regard to the AWF placement.

Exhibit 22-7 AWF or IIWS Location Placement

Posted Speed Limit (mph)	AWF or IIWS Placement	Leading Flash (seconds)
40	560 ft	8.0
45	560 ft	7.0
50	700 ft	8.0
55	700 ft	7.0

PART IV SPECIAL-USE TRAFFIC SIGNALS

23. TEMPORARY TRAFFIC CONTROL SIGNALS

23.1 General

During stationary construction or maintenance operations, temporary traffic control signal equipment and materials may be required as part of a temporary traffic control plan (TCP) design. Applications of temporary traffic signals include the following:

- ✓ Controlling alternating two-way traffic in a single lane rather than using flaggers.
- ✓ Providing traffic signal control at an intersection not normally signalized due to changed traffic patterns or other obstructions which make unsignalized operation impractical.
- ✓ Providing traffic signal control at an intersection along a detour route.
- ✓ Modifying existing traffic signal timing or phasing along a detour route.
- ✓ Changes to an existing traffic control signal due to lane closures or shifts, intersection modification requiring removal of traffic signal supports, etc.

Temporary Traffic Control (TTC) Signal design and usage must conform to the following:

- ✓ Publication 213 (PATA 700 series; Appendix D)
    - Appendix D includes "Guidelines for the Selection of Temporary Traffic Control Signals in Work Zones" and "Design Guidelines for Long-Term Temporary Signal Control in Work Zones."
- ✓ Publication 408 (Sections 950 & 958)
- ✓ ECMS Master Items (0958)
- ✓ Publication 35 (Bulletin 15)
- ✓ MUTCD (Part 4 Signals)
- ✓ Manufacturer's recommendations for portable signal installation & use

It is important that the designer is knowledgeable of the Publication 408 specifications and ECMS Master Items for these TTC signals and how the measurement of payment and pay items are defined. This will ensure that the project PS&E are properly developed.

For existing two-lane/two-way highways operating temporarily with one-lane/two-way traffic flow, various types of temporary signal configurations and equipment may be specified as shown below in **Exhibit 23-1**.

Exhibit 23-1 PATA Drawing Reference Guide for Temporary Traffic Control Signals

Type of Highway	Type of Application	Type of TTC Signal Support		
		Pedestal-Mounted Portable	Trailer-Mounted Portable	Overhead Span Wire Fixed Supports
Existing Two-Lane/Two-Way Highway Operates with Temporary One-Lane/Two-Way Traffic Flow	Short-Term Non-Complex Condition Auto or Manual Control	PATA 701	PATA 702	N/A
	Short-Term Complex Condition Auto or Manual Control	PATA 703	PATA 704	N/A
	Long-Term Complex or Non-Complex Condition Auto or Manual Control	N/A	PATA 706	PATA 705

Refer to Publication 213, Appendix D for more information.

Short-term temporary traffic control, including use of a flagger and placing a traffic signal into flashing mode, is typically implemented using Pennsylvania typical applications (PATA) in Publication 213 without requiring input from the traffic signal designer.

Automated Flagger Assistance Devices (AFAD) are remotely controlled by an on-site flagger who is located out of the lane of traffic. AFADs are not traffic control signals, and they should not be used as a substitute for or replacement for a continuously operating temporary traffic control signal. The use of AFADs for a short-term operation (see Publication 213) does not require a traffic signal permit.

23.2 Pedestal-Mounted Portable

Pedestal-mounted portable traffic control signals shall not be used for long-term stationary operations, see **Exhibit 23-1**.

When utilized as part of a TCP design, use the following requirements:

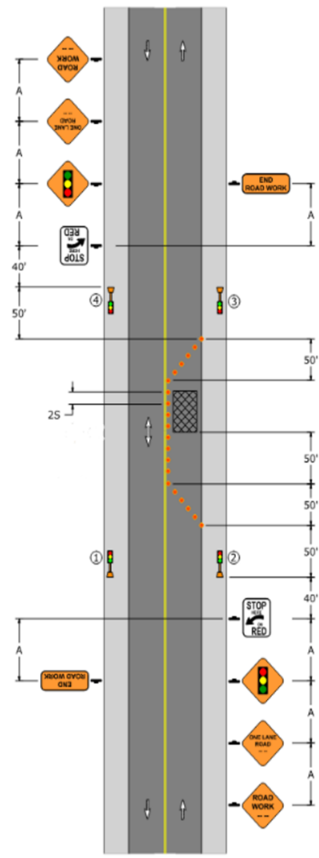
- ✓ Manufacturer's requirements for the pedestal-mounted portable signal.
- ✓ Applicable requirements of the Department's certificate of approval issued to the manufacturer.
- ✓ Publication 213
- ✓ Publication 408 (Sections 950 & 958)
- ✓ ECMS Master Items (0958 Pedestal-Mounted Portable Device)

Exhibit 23-2 provides an example of pedestal-mounted, portable TTC signals used for short-term stationary operations with non-complex conditions using PATA 701 in Publication 213, and provides additional designer information related to use of pedestal-mounted portable TTC devices.

Exhibit 23-2 Pedestal-Mounted Portable Signal Example using PATA 701

Tabulation of Pay Items

Item #	Item Description	Unit	Qty	Notes for Designer
0958-0061	Temporary Traffic Control Signals, Pedestal-Mounted Portable Device	Each	4	✓ Pedestal-mounted portable signal devices include all the subcomponents for operation of each installation (one signal head, controller, power source, communication to other pedestal-mounted portable signal devices operating together as a system, etc.). ✓ Incidental to this pay item is operation, maintenance, repair, replacement, controller timing programming and all timing changes and adjustments, and removal of the temporary pedestal-mounted portable signal device after completion of all construction phases/stages requiring the device.
0958-0241	Temporary Traffic Control Signals, Pedestal-Mounted Portable Device, Reset	Each	Varies	✓ Only include this Item if the project requires the reset of the pedestal-mounted portable signal device. Reset quantity would vary based on how the setup might change over time in the traffic control scheme. The reset quantity would be for the total number of pedestals that are reset (or relocated) in subsequent MPT phases. ✓ Incidental to this pay item is operation, maintenance, repair, replacement, controller timing programming and all timing changes and adjustments.
0901-0001	Maintenance and Protection of Traffic During Construction	LS	LS (entire project)	✓ The advance signing, channelizing devices, warning lights, etc.) used in this example would be covered under the project 0901 MPT Lump Sum item. ✓ If the designer needs to provide additional detailed project guidance and direction, this information can be included within the 0901-0001 special provision and the plans sheets, as applicable.



23.3 Trailer-Mounted Portable

Trailer-mounted portable traffic control signals may be used for both short-term and long-term stationary operations, see **Exhibit 23-1**.

When utilized as part of a TCP design, use the following requirements:

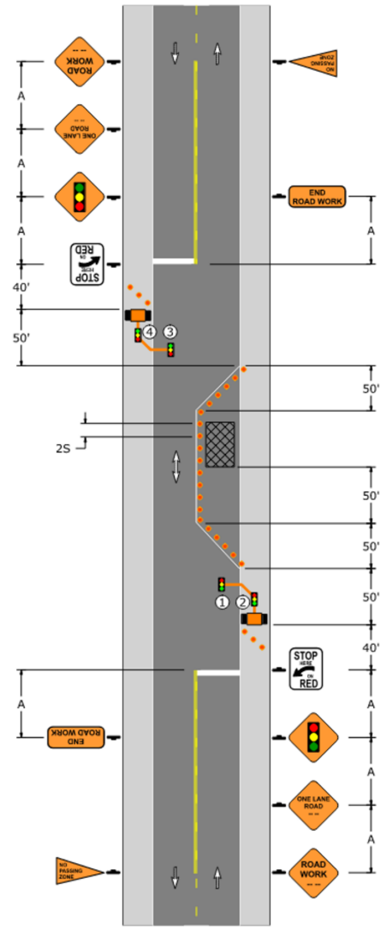
- ✓ Manufacturer's requirements for the trailer-mounted portable signal.
- ✓ Applicable requirements of the Department's certificate of approval issued to the manufacturer.
- ✓ Publication 213
- ✓ Publication 408 (Sections 950 & 958)
- ✓ ECMS Master Items (0958 Trailer-Mounted Portable Device)

Exhibit 23-3 provides an example of trailer-mounted, portable TTC signals used for long-term stationary operations with complex or non-complex conditions using PATA 706 in Publication 213, and provides additional designer information related to use of trailer-mounted portable TTC devices.

Exhibit 23-3 Trailer-Mounted Portable Signal Example using PATA 706

Tabulation of Pay Items

Item #	Item Description	Unit	Qty	Notes for Designer
0958-0081	Temporary Traffic Control Signals, Trailer-Mounted Portable Device (one overhead signal, 1-vertical pole signal)	Each	2	✓ Additional, separate unique pay item choices (0958-xxxx) are provided that define the configuration of the trailer-mounted portable device (arrangement of signal heads, and with/without work zone luminaires). See ECMS. ✓ Trailer-mounted portable signal devices include all the subcomponents for operation of each installation (signal heads, controller, power source, communication to other trailer-mounted portable signal devices operating together as a system, etc.). ✓ Incidental to this pay item is operation, maintenance, repair, replacement, controller timing programming and all timing changes and adjustments, and removal of the temporary trailer-mounted portable signal device after completion of all construction phases/stages requiring the device.
0958-0261	Temporary Traffic Control Signals, Trailer-Mounted Portable Device, Reset	Each	Varies	✓ Only include this Item if the project requires the reset of the trailer-mounted portable signal device. Reset quantity would vary based on how the setup might change over time in the traffic control scheme. The reset quantity would be for the total number of trailers that are reset (or relocated) in subsequent MPT phases. ✓ Incidental to this pay item is operation, maintenance, repair, replacement, controller timing programming and all timing changes and adjustments. ✓ May also need to account for removal of pavement markings and addition of revised markings using pavement marking items for any reset scenarios.
0901-0001	Maintenance and Protection of Traffic During Construction	LS	LS (entire project)	✓ The advance signing, channelizing devices, warning lights, etc.) used in this example would be covered under the project 0901 MPT Lump Sum item. Note: If barrier is used in place of channelizing devices, it is also a separate pay item per Section 901 of Pub 408. ✓ If the designer needs to provide additional detailed project guidance and direction, this information can be included within the 0901-0001 special provision and the plans sheets, as applicable.
0901-0320	4" Standard Pavement Markings, Paint & Beads, Yellow	LF	6,000	(PATA 706 Note 5b) yields (TTX Zone)X 4 (DY for two approaches) = 3(A)X4 = appx. 6000
0901-0330	4" Standard Pavement Markings, Paint & Beads, White	LF	450	150+(Work Area) = appx. 450
0901-0324	24" Standard Pavement Markings, Paint & Beads, White	LF	24	For two Stop Lines.
0963-0001	Pavement Marking Removal	SF	630	Remove existing DY from between stop bars (assume DY at 6") (overlap from multiple applications).



23.4 Fixed Supports

Fixed support traffic control signals shall not be used for short-term stationary operations, see **Exhibit 23-1**.

When utilized as part of a TCP design, use the following requirements:

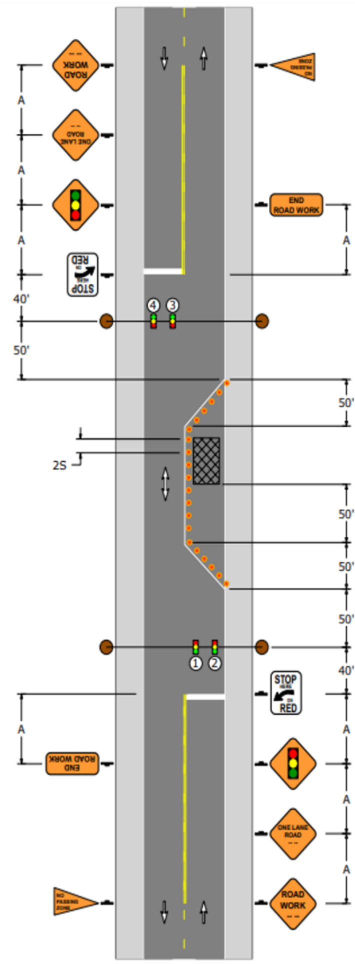
- ✓ Publication 213
- ✓ Publication 408 (Sections 950 & 958)
- ✓ ECMS Master Items (0958 Fixed Supports)

Exhibit 23-4 Temporary Traffic Control Signal on Fixed Supports Example using PATA 705 provides an example of Temporary Traffic Control Signals On Fixed Supports used for long-term stationary operations with complex or non-complex conditions using PATA 705 in Publication 213, and provides additional designer information related to use of TTC signals on fixed supports.

Exhibit 23-4 Temporary Traffic Control Signal on Fixed Supports Example using PATA 705

Tabulation of Pay Items

Item #	Item Description	Unit	Qty	Notes for Designer
0958-0001	Temporary Traffic Control Signals On Fixed Supports (2 Approaches)	Each	1	This pay item is used for the complete setup of a temporary traffic control signals on fixed supports (2 Approaches), including all required materials and work. ✓ Temporary fixed support signals are comprised of the same traffic control signal components (equipment and materials) that are used on permanent signals; however, temporary fixed support signals are bid as a complete setup without identifying each individual signal component as done with conventional traffic signals. ✓ Additional, separate unique pay item choices (0958-xxxx) are provided that define the number of approaches *(2 approaches, 3 approaches, or 4 or more approaches)* covered by the complete setup. See ECMS. ✓ Incidental to this pay item is operation, maintenance, repair, replacement, electrical service agreement fees, energy supply costs, controller timing programming and all timing changes and adjustments, and removal of the temporary fixed support signal system after completion of all construction phases/stages requiring the temporary signal system. ✓ Incidental to this pay item are all necessary signs, pavement markings, channelizing devices, warning lights, etc.
0958-0181	Temporary Traffic Control Signals On Fixed Supports, Reset (2 Approaches)	Each	Varies	This pay item is used for the reset of a temporary traffic control signals on fixed supports (2 Approaches), including all required materials and work. ✓ Only include this Item if the project requires the reset of temporary traffic control signals on fixed supports (2 approaches). Reset quantity would vary based upon the number of times the setup has to be modified in subsequent MPT phases. ✓ Additional, separate unique pay item choices (0958-xxxx) are provided that define the number of approaches *(1 approach, 2 approaches, 3 approaches, or 4 or more approaches)* covered by the complete reset setup. See ECMS. ✓ Incidental to this pay item is operation, maintenance, repair, replacement, electrical service agreement fees, energy supply costs, controller timing programming and all timing changes and adjustments. ✓ Incidental to this pay item are all necessary signs, pavement markings, channelizing devices, warning lights, etc.
0901-0001	Maintenance and Protection of Traffic During Construction	LS	LS (entire project)	✓ This Item is still needed for the project, but it doesn't include anything related to the complete setup of the temporary traffic control signal on fixed supports, which is covered by Item 0958-0001. ✓ If the designer needs to provide additional detailed project guidance and direction, this information can be included within the 0901-0001 special provision and the plans sheets, as applicable.



23.5 Existing Signalized Intersections/Corridors

Existing signalized intersections and coordinated signal systems may be impacted by a project's proposed traffic control phase regarding operational changes in traffic volumes, traffic direction patterns, vehicle types, geometric needs, etc. These operational changes may necessitate revisions to existing signals and signal systems as part of the project temporary traffic control, such as:

- ✓ Phasing and timing revisions
- ✓ Coordination revisions
- ✓ Geometric changes

Publication 408, Section 958 contains specifications for the following work on existing permanent signals that may be needed as part of TTC design. This work is further described in **Section 23.5.1** and **23.5.2**.

- ✓ Temporary timing adjustments (and restoration) to existing permanent traffic control signal controller.
- ✓ Temporary modifications (and restoration) to existing permanent traffic control signal.

23.5.1 Temporary Timing Adjustments to Existing Permanent Traffic Signal Controller

Where traffic congestion is anticipated along detour routes or non-detour routes near a construction project, the timing of existing traffic control signals may be modified while the construction project is anticipated to impact traffic. Timings may be determined based on projected traffic volumes during the design phase and included in the bid package, or timing may be developed while the project is in construction.

The Temporary Timing Adjustments to Existing Permanent Traffic Signal Controller pay Item# 0958-0281 may be used for either case. When the timings are not provided as part of the bid package, the MPT item should describe the intended use of the temporary timing adjustment item.

The Temporary Timing Adjustments to Existing Permanent Traffic Signal Controller item only includes timing changes which can be accomplished with the existing controller unit. The item includes restoring the timing to the original preconstruction conditions. If other physical modifications are required, see **Section 23.5.2**.

23.5.2 Temporary Modifications to Existing Permanent Traffic Signal

Temporary modifications to an existing traffic control signal may include, but are not limited to, the following:

- ✓ Relocation of signal heads because of lane shifts, lane closures, or other lane configuration changes
- ✓ Phasing modifications, including associated timing modifications
- ✓ Detection zone modifications due to lane configuration changes
- ✓ Pavement marking modifications (if not otherwise included in the MPT item)
- ✓ Pedestrian crossing modifications or restrictions

The Temporary Modifications to Existing Permanent Traffic Signal pay item include the restoration to original preconstruction conditions after completion of all construction phases/stages requiring the signal modifications. Separate unique item choices (0958-xxxx) are provided in ECMS that define the number of approaches covered by the Temporary Modifications to Existing Permanent Traffic Signal item (Each).

The Temporary Modifications to Existing Permanent Traffic Signals, Reset item is used for additional changes between construction phases and/or stages. Separate unique pay item choices (0958-xxxx) are provided in ECMS that define the number of approaches covered by the Temporary Modifications to Existing Permanent Traffic Signal, Reset item (Each).

24. EMERGENCY VEHICLE ACCESS, TRAFFIC CONTROL SIGNAL

An emergency-vehicle traffic control signal is a special traffic control signal that directs all conflicting traffic to stop to permit the driver of an authorized emergency vehicle to proceed into the roadway, directly from the driveway for an emergency facility or at an intersection.

An emergency-vehicle traffic control signal may be installed at a location that does not meet other traffic control signal warrants such as at an intersection or other location to permit direct access from a building housing the emergency vehicle.

For additional information related to Emergency Vehicle Access, traffic control signals, see MUTCD, Section 4G.

Note, hybrid beacons for emergency vehicle access are Not Permitted for use in Pennsylvania. (see Chapter 31)

25. FREEWAY ENTRANCE RAMP, TRAFFIC CONTROL SIGNAL (RAMP METERING)

Ramp control signals are traffic control signals that control the flow of traffic entering the freeway facility. This is often referred to as "ramp metering."

For additional information related to Ramp Metering, see MUTCD, Chapter 4P and PennDOT Publication 852, TSMO Guidebook, Part II: Design.

26. ONE-LANE, TWO-WAY FACILITIES, TRAFFIC CONTROL SIGNAL

A traffic control signal at a narrow bridge, tunnel, or roadway section is a special signal that alternates which direction of vehicles passing over a bridge or through a tunnel or roadway section that is not of sufficient width for two opposing vehicles to pass is directed to stop and which direction is permitted to proceed.

Since there is typically not a dominant movement and the transition time between phases is longer than typical due to the extended red clearance interval, traffic control signals for one-lane, two-way facilities should rest in red in the absence of demand on any approach.

For additional information related to One-Lane, Two-Way Facilities, traffic control signals, see MUTCD, Chapter 4O.

For additional information on temporary traffic control signals for one lane, two-way facilities, see **Chapter 23**.

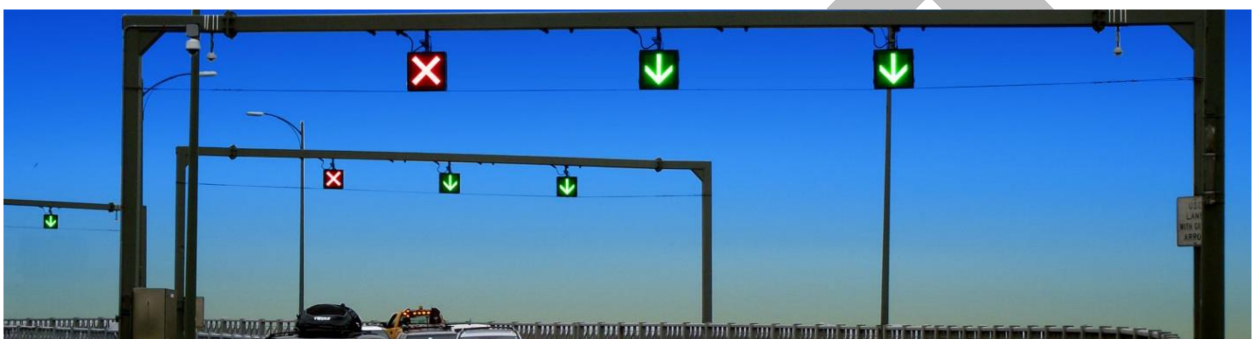
27. LANE-USE CONTROL SIGNALS

Lane-use control signals are special overhead signals that permit or prohibit the use of specific lanes of a street or highway or that indicate the impending prohibition of their use. An engineering study should be conducted to determine whether static signs may be used or if lane-use control signals are necessary.

Lane-use control signals are distinguished by placement of special signal faces over a certain lane or lanes of the roadway and by their distinctive shapes and symbols. Supplementary signs are sometimes used to explain their meaning and intent.

Lane-use control signals are most used for reversible-lane control but are also used in certain non-reversible lane applications and for toll plaza lanes.

For additional information related to Lane-Use control signals, see MUTCD, Chapter 4T.



28. TOLL PLAZA, TRAFFIC SIGNALS

All toll plazas in Pennsylvania are maintained by the tolling authority, and the appropriate tolling authority's publications and policies should be referenced for traffic signals within the toll plaza. For additional information on traffic signals at or near Toll Plazas, including traffic control signals, lane-use control signals, and warning beacons, see MUTCD, Chapter 4R.

Traffic control signals or devices that closely resemble traffic control signals that use red or green circular indications shall not be used at toll plazas to indicate the open or closed status of the toll plaza lanes.

29. MOVABLE BRIDGE, TRAFFIC SIGNALS

Traffic signals for movable bridges are a special type of highway traffic signal installed at movable bridges to notify road users to stop because of a road closure rather than alternately controlling the flow of conflicting traffic movements. The signals are operated in coordination with the opening and closing of the movable bridge, and with the operation of movable bridge warning and resistance gates, or other devices and features used to warn, control, and stop traffic.

For additional information related to Movable Bridge, traffic signals, see to MUTCD, Chapter 4Q.

At the time of this publication, there are no movable bridges in Pennsylvania outside of Philadelphia.

Movable bridge signals may also be used at other structures to stop traffic when the roadway traversing the structure is closed, such as a tunnel closure.

PART V OTHER MISCELLANEOUS, TRAFFIC SIGNALS

30. FLASHING BEACONS (FLASHING WARNING DEVICES)

30.1 General

A Flashing Beacon is a highway traffic signal with one or more signal sections that operates in a flashing mode. It can provide traffic control when used as an intersection control beacon or it can provide warning when used in other applications.

This chapter addresses the following types of beacons:

- ✓ Intersection Control Beacons
- ✓ Warning Beacons
- ✓ Speed Limit Sign Beacons (including School Zones)
- ✓ Stop Beacons
- ✓ Rectangular Rapid Flashing Beacons (RRFB)
- ✓ Flashing LED Border Sign

Flashing warning devices that are designated to only be activated during certain time periods (time, day, calendar dates) shall include a controller with time clock. It is important that these devices are designed properly to allow the programming that is necessary to operate in accordance with the approved Traffic Signal Permit. For example, school zone speed limit sign flashers are only activated during specific times when school is in session.

For addition information related to Flashing Warning Devices, see the following references:

- ✓ MUTCD, Chapters 2A & 4S
- ✓ Publication 46, Chapter 4
- ✓ Publication 148 (TC-8800 Series)
- ✓ Publication 236
- ✓ Publication 408 (Section 1103)
- ✓ ECMS Master Items (0935 & 0936)
- ✓ Publication 35 (Bulletin 15)
- ✓ Form TE-974

Design considerations include:

- ✓ Solar components (if applicable), see **Section 15.9**
- ✓ Detector (if applicable), see **Chapter 17**
- ✓ Controller communication (if applicable), see **Chapter 1**

When flashing beacons are pedestrian-actuated, see **Section 17.3** for information on pedestrian detection and see **Section 19.3.3** for signs to be used with pedestrian detectors.

30.2 Intersection Control Beacon

Intersection Control Beacons may be used at intersections where traffic or physical conditions do not justify conventional traffic control signals, but crash rates indicate the possibility of a special need. Prior to developing the design for an Intersection Control Beacon, the District Traffic Engineer must determine if an Intersection Control Beacon is appropriate based on the warrants provided in Publication 46, Chapter 4.

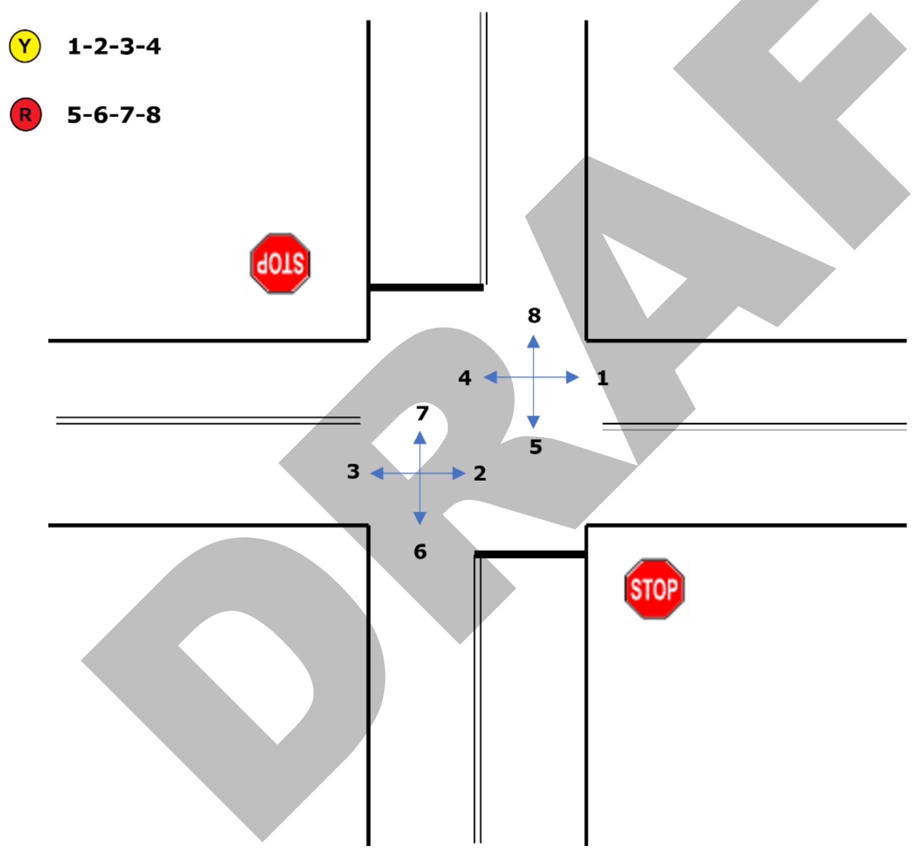
An Intersection Control Beacon consists of one or more signal faces directed toward each approach to an intersection. Each signal face consists of one or more signal sections of a standard traffic signal face, with flashing CIRCULAR YELLOW or CIRCULAR RED signal indications in each signal face. They shall be installed and used only at an intersection to control two or more directions of travel. The major street approaches flash yellow and other approaches flash red, unless a multi-way stop is used. See **Exhibit 30-1**.

An Intersection Control Beacon should be mounted overhead, either over the center of the intersection or with separate mounting on the far side of the intersection facing each approach. If an Intersection Control Beacon is used at an intersection which is expected to require a full traffic control signal in the future, the mounting should be designed to allow the signal faces to be replaced on the same supports for stop-and-go operation.

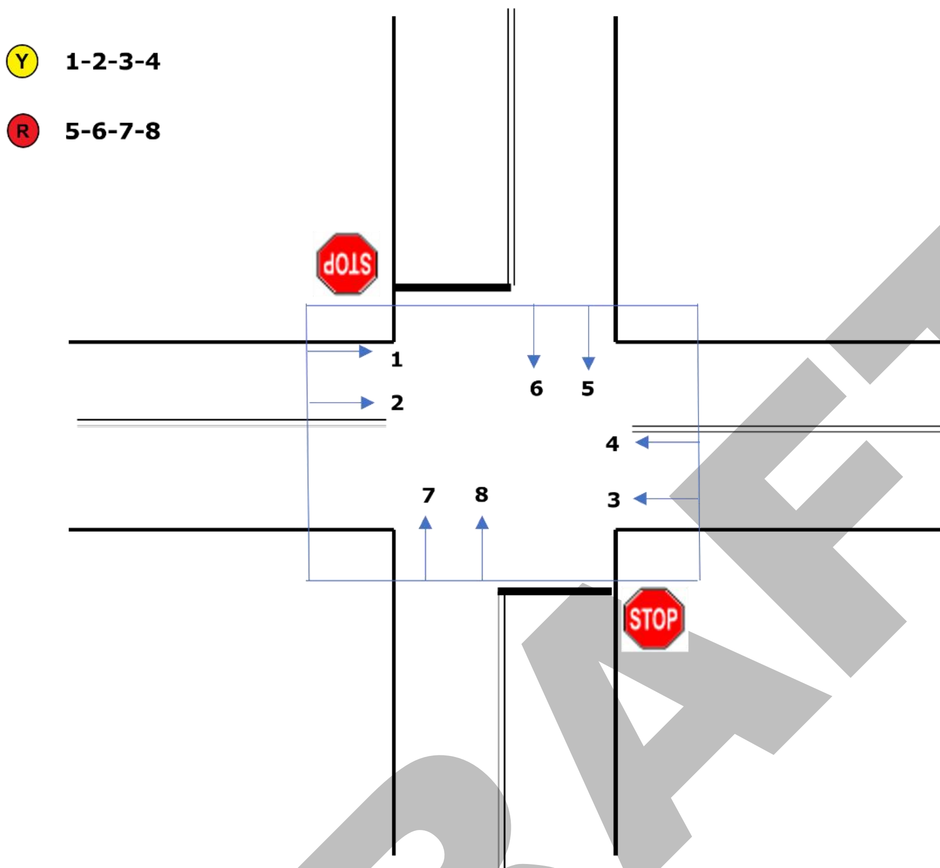
A Stop Beacon may be used instead of an Intersection Control Beacon (see **Section 30.4**).

Exhibit 30-1 Intersection Control Beacon

A - Signal Heads in Center of Intersection



B - Signal Heads on Far-Side Box Span



30.3 Warning Beacon

Warning beacons may be used for several types of applications, typical applications include:

- ✓ At obstructions in or immediately adjacent to the roadway,
- ✓ As supplemental emphasis to warning signs:
  - When a warning beacon is added to a SIGNAL AHEAD (W3-3) sign, it should be included on the signal permit and not a separate flashing warning device permit.
  - When warning beacons are used with INTERSECTION AHEAD symbols signs (yellow), this special case of warning beacon is used instead of an intersection control beacon in **Section 30.2**.
- ✓ As emphasis for midblock crosswalks,
- ✓ As supplemental emphasis to regulatory signs, except STOP, DO NOT ENTER, WRONG WAY, and SPEED LIMIT signs; and
- ✓ In conjunction with a regulatory or warning sign that includes the phrase WHEN FLASHING in its legend to indicate that the regulation is in effect or that the condition is present only at certain times.

Warning beacons shall use flashing CIRCULAR YELLOW signal indications. Warning beacons may have one or two indications. If two indications are used, they should be flashed alternately.

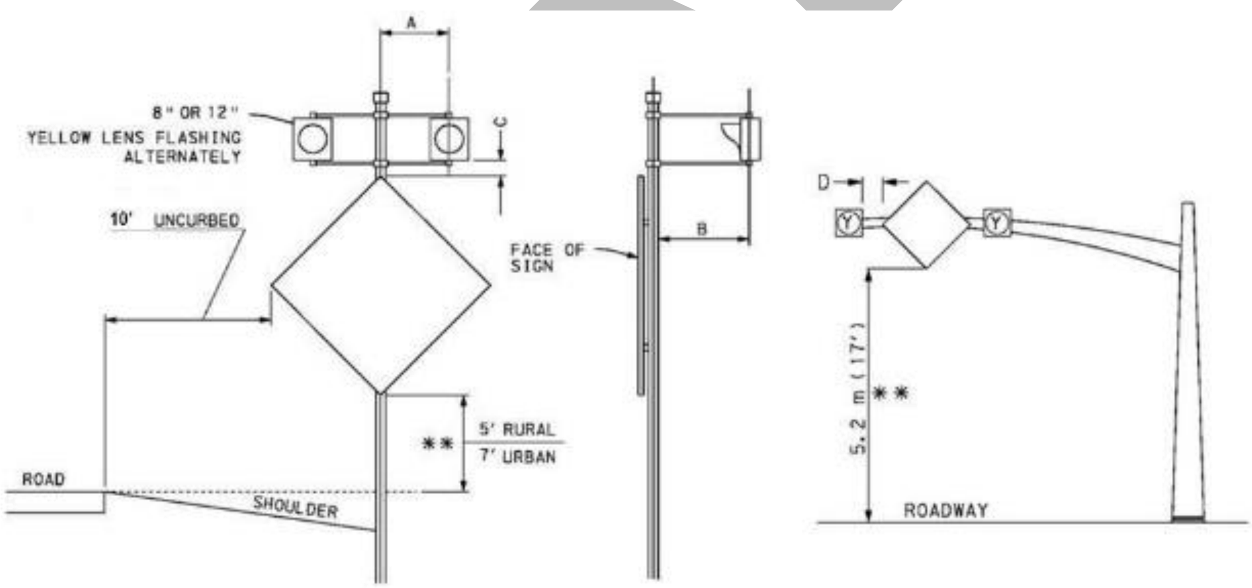
For additional information related to Sign Warning beacons, see MUTCD Section 4S.03.

Exhibit 30-2 is a picture of a Curve Ahead warning system.

Exhibit 30-2   Curve Ahead Warning System

Exhibit 30-3 shows a flashing warning device detail for two signal indications, and **Exhibit 30-4** shows a detail for a one signal indication. These indications may also be actuated to only flash when conflicting activity (pedestrians, bicycles, etc.) is present.

Exhibit 30-3   Flashing Warning Device Detail – Two Signal Indications



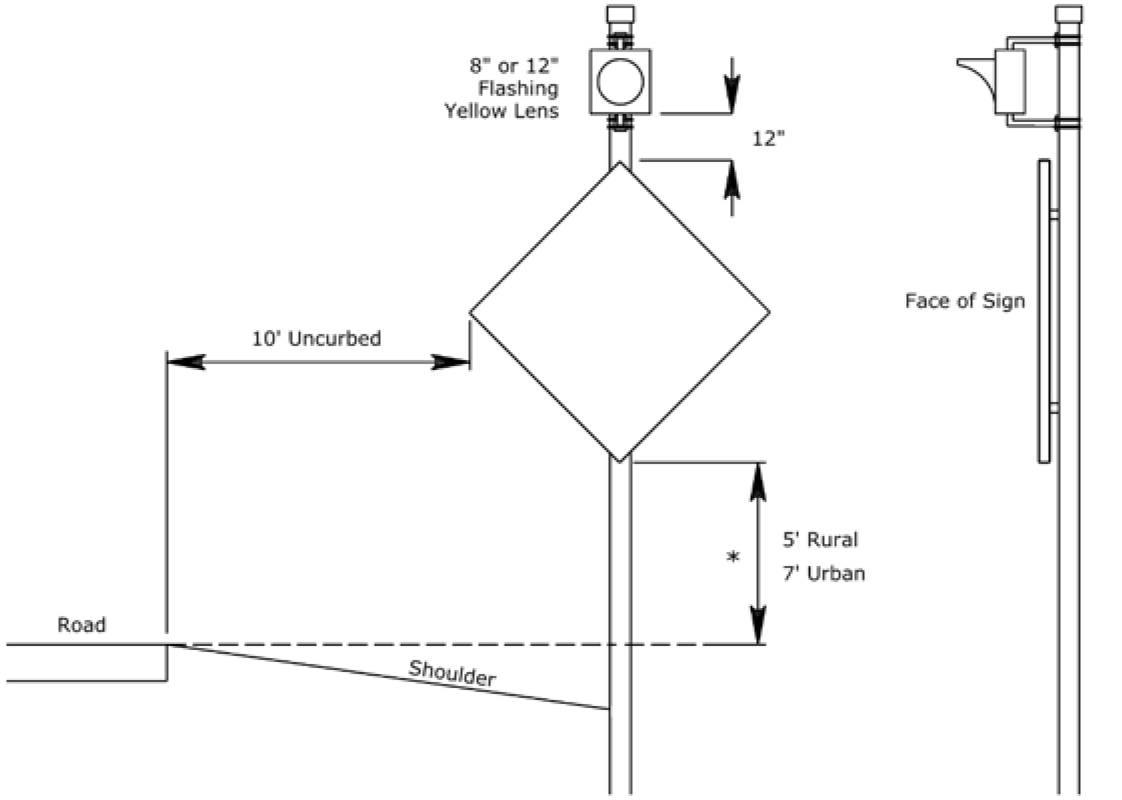
SIGN SIZE	A	B	C	D
30" x 30"	16"	15"	6"	12"
36" x 36"	* 20"	15"	6"	12"
48" x 48"	28"	15"	6"	12"
60" x 60"	37"	15"	6"	12"

* DIMENSION A FOR S1-1 SIGNS IS 16" AND THE 36" x 36" IS THE MINIMUM SIZE SIGN USED.

** CLEARANCE BETWEEN ROADWAY AND LOWEST SIGN OR SIGNAL HEAD.

Note: Foundations are required for all Flashing Warning Device structures, in compliance with Publication 148.

Exhibit 30-4 Flashing Warning Device Detail – One Signal Indication



* Clearance between roadway and lowest sign or signal head

Note: Foundations are required for all Flashing Warning Device structures, in compliance with Publication 148

30.4 Stop Beacon

A Stop Beacon shall be used only to supplement a STOP sign, a DO NOT ENTER sign, or a WRONG WAY sign. A Stop Beacon is an alternative to an Intersection Control Beacon (see **Section 30.2**).

Stop beacons shall use flashing CIRCULAR RED signal indications.

For additional information related to Stop beacons, see MUTCD Section 4S.05. Prior to developing the design for a Stop Beacon, the District Traffic Engineer must determine if a Stop Beacon is appropriate based on the Intersection Control Beacon warrants provided in Publication 46, Chapter 4.

30.5 Speed Limit Sign Beacon

A Speed Limit Sign Beacon may only be used to supplement a Speed Limit sign. These beacons are typically installed with regulatory speed limit signs or school zone signs to command added attention.

Speed Limit beacons shall use flashing CIRCULAR YELLOW signal indications.

For additional information related to Speed Limit Sign beacons, see MUTCD, Section 4S.04.

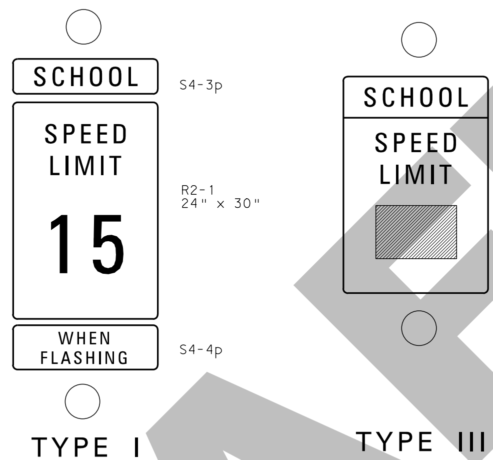
30.5.1 School Zones

School zone speed limits must be established in accordance with 75 PA C.S. §3365(b) and 67 Pa. Code §212.501. A school zone speed limit flashing warning sign may be used to provide a flashing beacon to indicate when the school zone speed limit active, and the 15mph speed limit may be a blank out.

For Speed Limit Sign beacons in proximity to school zones:

- ✓ Also see MUTCD, Section 7B.05, School Speed Limit Assembly (S4-1P, S4-2P, S4-3P, S4-4P, S4-6P, S5-1) and END SCHOOL SPEED LIMIT Sign (S5-3).
- ✓ The beacons shall consist of two one section signal heads with yellow circular indications aligned vertically on a speed limit sign and shall flash alternately.
- ✓ See **Exhibit 30-5** for the three options allowable for School Zone Speed Limit signs.

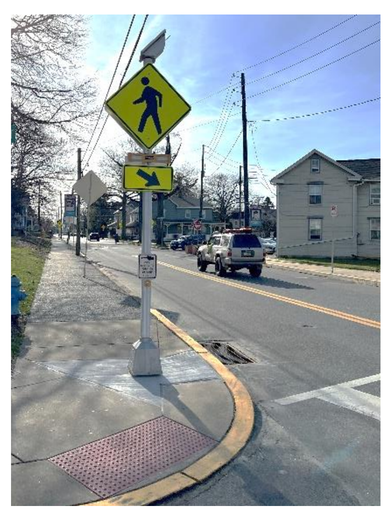
Exhibit 30-5 School Zone Speed Limit Signs Options



Notes:

1. Either of the illustrated types of signs may be installed at the locations indicated on the Permit diagram.
2. Type I is comprised of standard signs having the PennDOT designation numbers indicated. It shall have 8" diameter signals mounted externally.
3. Type III must have a PennDOT certificate of approval. The sign shall be the changeable message type with minimum dimensions of 24" x 38" and 8" diameter signals mounted externally.
4. When the signals are flashed in Type III, the speed message "15" shall be visible.
5. Types I and III shall be installed with the closest part of the signal housing 12" from the edge of the sign.

30.6 Rectangular Rapid Flashing Beacon (RRFB)



Rectangular Rapid Flashing Beacon (RRFB) is a special type of traffic device that uses a pair of rectangular yellow LED-array-based light source beacons, which are flashed in a stutter pattern like that used on emergency vehicles.

RRFBs are available for optional use to provide supplemental emphasis to pedestrian, school crossing or trail crossing signs at uncontrolled marked intersections. See MUTCD Chapter 4L for information on application, design, and operation of RRFBs.

30.7 Flashing LED Border Sign System

LED Border Lit Signs are considered a type of Flashing Warning Device, and Flashing Warning Devices are a type of traffic signal. Therefore, approval authority, installation, maintenance, and operation are subject to the requirements for traffic signals in Title 67 Pa. Code Chapter 212.

Applications for LED Border Lit Signs shall be submitted using Form TE-160, and permits shall be issued using Form TE-670.

Prior to installing a permanent LED Border Lit Sign, the following countermeasures should be considered, as applicable:

- ✓ Clearing vegetation
- ✓ Double placement of signs
- ✓ Conspicuity plaques (W16-102P) placed on signs.
- ✓ Transverse rumble strips (should not be permitted in areas with residences and nearby businesses)
- ✓ Increasing sign size.
- ✓ Placing and installing a retroreflective material to the sign support in compliance with the provisions of Section 2A.11 of the MUTCD.

Installation of a LED Border Sign shall only occur when warranted by a study which uses sound engineering judgment and data to substantiate the need for the LED Border Lit Sign. The following guidelines should be considered as part of an engineering and traffic study:

- ✓ Documented safety concerns – a minimum of one year of crash data, near-miss data, volume data, or other traffic data for a traffic safety evaluation.
- ✓ Demonstrated and documented crash problem.
  - For STOP and STOP AHEAD signs, consider installing a LED Border Lit Sign only if there were at least two documented crashes from failure to stop (running the stop sign) during a 12-month period.
- ✓ Visibility Restrictions
- ✓ Unusual Geometrics
- ✓ Poor conspicuity (i.e., sign blending in with the environment)
- ✓ Engineering judgment

Although no quantitative warrants are established for use of LED Border Lit Signs, their use should be considered as an alternative to a flashing beacon supplementing the sign (see **Section 30.3**), and the use of the LED Border Lit Signs should be limited to locations where a flashing beacon would also be appropriate. Examples of where these signs may be considered include:

- ✓ Pedestrian crosswalks
- ✓ School zones
- ✓ STOP signs
- ✓ YIELD signs
- ✓ Curves and traffic changes ahead

All LED Border Lit Signs shall comply with the specifications in Publication 408 and use a product listed on Bulletin 15. The specifications for LED Border Lit Signs are in Section 1103.03(k) of Publication 408 and are incorporated into sign specifications in Sections 935 and 936. Approved products are listed in Section 1103.03(g) to (n)-Electrically Power Traffic Signs in Bulletin 15. All LED Border Lit Signs shall also comply with all standards in the MUTCD. The sign size and layout shall be consistent with requirements in Publication 236, Handbook of Approved Signs.

Flashing LED Border Signs contain LEDs modules placed around the perimeter outer edge of the sign. These sign systems must meet the requirements of MUTCD Section 2A.21.

When LEDs are flashed, all LEDs must flash simultaneously and have a flash rate of more than 50 and less than 60 times per minute.

For additional information related to Flashing LED Border Signs, see the following references:

- ✓ MUTCD Section 2A.21

- ✓ Publication 408 (935, 936 & 1103)

30.8 Speed Display Signs

Speed Display signs utilize an internal speed detection device to capture the approach speed of an approaching vehicle and then display this speed information to the driver via the Speed Display sign. The goal is for drivers to reduce their speeds once they realize they are traveling too fast.

Speed Display signs can be used in permanent installations or temporary installations. Examples of where these signs may be appropriate to help with addressing speeding related issues:

- ✓ Problem highway areas (curves, congested areas, etc.)
- ✓ School zones
- ✓ Work zones
- ✓ Residential roads in conjunction with traffic calming measures

Prior to installing a permanent Speed Display sign system, a flashing warning device permit issued by the local Engineering District is required. When requesting a flashing warning device permit, submit the application, detailed location information (photos and description), proposed permanent Speed Display sign system, and discussion of the other alternatives that were considered prior to requesting a permanent Speed Display sign system.

If a temporary Speed Display system is placed along a state highway, the District Traffic Engineer shall be notified approximately 3 days prior to deployment. The temporary Speed Display system should be in place for a maximum of two weeks. The temporary Speed Display system should not be used for enforcement purposes as outlined in the Vehicle Code (75 Pa.C.S. §3368). An enforcement component is essential after deployment of the temporary Speed Display system. The temporary Speed Display sign system shall be placed behind curb or in another location that presents the least practicable obstruction to the motoring public. The temporary Speed Display sign system shall be placed in a way as to not restrict sight distance or block other regulatory, warning, or guide signage. The temporary Speed Display sign system should not block existing driveway entrances or intersections.

Speed Display signs must meet the requirements of:

- ✓ MUTCD Section 2B.21 & 2C.13
- ✓ Publication 408 (935 & 1103)

> MUTCD Section 2C.13, Par.04 states that…
>
> The Vehicle Speed Feedback sign and plaque shall not flash, strobe, change color, or use other animated elements integrated into the changeable legend display.
>
> When no vehicles are approaching, the changeable display shall not display a legend.

Speed display sign system installations may be post or structure mounted. The Speed Display sign assembly includes specified post or structural support with foundation, and all hardware to provide a functional assembly including mounting hardware, wiring, controller assembly with programmable schedule option, light sensor, dynamic display panel, "Your Speed" sign (if applicable), and solar components (if applicable). Speed display sign systems must use an approved product listed in Bulletin 15, Section 1103.03(g) to (n) – Electrically Powered Traffic Signs.

Approval of Speed Display signs installed in work zones in accordance with Act 229 is handled as part of the overall approval of the traffic control plan and do not require a separate permit. One of the specific requirements of Act 229 is that on Interstate highway work zones with a project cost exceeding $300,000, a speed display sign shall be installed on each mainline approach to the work zone to inform motorists of their speed.

Exhibit 30-6 Speed Display Sign

31. HYBRID BEACONS

Hybrid Beacons (sometimes referred to as HAWK signals) are not permitted in Pennsylvania.

Chapter 4J the MUTCD (Pedestrian Hybrid Beacons) is not applicable and shall not be used in Pennsylvania. For midblock, or trail crossing, locations with pedestrian safety concerns, refer to Publication 46, Section 4.3, Warrant PA-2, Optional Traffic Signal Warrant for Midblock Crossings and Trail Crossings. This warrant evaluates and provides an alternative for handling these challenging unique situations.

Chapter 4N of the MUTCD (Emergency-Vehicle Hybrid Beacons) is not applicable and shall not be used in Pennsylvania.

32. IN-ROADWAY WARNING LIGHTS

In-roadway warning lights (IRWL) are a special type of highway traffic signal installed in the roadway surface to warn road users that they are approaching a condition on, or adjacent to, the roadway that might not be readily apparent; and might require the road users to slow down and possibly come to a stop.

In Pennsylvania where pavement freeze/thaw damage is common, IRWLs may not be a practical choice and should be considered with caution.

IRWL shall comply with Chapter 4U of the MUTCD.

PART VI PLANS, SPECIFICATIONS, AND ESTIMATES (PS&E) PACKAGE/BID PACKAGE

33. TRAFFIC CONTROL SIGNAL PLANS

33.1 General

Design Manual, Part 3, Publication 14M (DM-3, Plans Presentation) provides PennDOT policy on the development and preparation of Plans. The objective of DM-3 is to promote uniformity in the preparation of plans by establishing the general format and presenting the required detailed information for each type of plan sheet required in the maintenance and construction of highway facilities.

Exhibit 33-1 shows various DM-3 chapters that apply in the development of traffic signal construction plans.

Exhibit 33-1 DM-3 Chapters

DM-3	Title	Traffic Signal Applicability
Chapter 1 [1]	General Procedures	
Chapter 2 [2]	Construction Plans	All Construction Plans shall be completed using the presented methods, procedures, and examples to promote order & consistency. Note: As presented, Construction Plans may include a few Supplemental Plans as part of the overall Plan: ✓ Traffic Control Plan ✓ Traffic Signal Plan ✓ Signing & Pavement Marking Plan ✓ Utility Relocation Plan ✓ Etc.
Chapter 4	Traffic Control Plans (TCP)	If temporary traffic signals (see **Chapter 23**) are used as part of the project design, the temporary traffic signal plan is incorporated into the traffic control plan.
Chapter 10 [2]	Traffic Signal Plans	The Traffic Signal Plans presented may be included as: ✓ Part of the Construction Plans as a 'Supplemental Plan' (sometimes referred to as an "ALSO" plan), or ✓ As a separate plan. When they are a separate plan and not included with the Construction Plans, they shall be an entity in themselves and shall constitute a complete set of plans.
Chapter 12 [1]	CADD Procedures & Configuration	All plans shall be completed using industry standard computer aided drafting software and the presented protocols.
Chapter 13 [1]	Engineering Graphics Standards	All plans shall be prepared by using the presented drawing practices.
Chapter 14 [1]	Standard Drafting Abbreviations	All plans shall be prepared using the presented terminology and associated abbreviations for uniformity in plans development and presentation.
Chapter 15 [1]	Plates	The various plates represent example sketches and general format that are provided as guidance in the preparation of highway plans.

[1] Provides general information that apply to the development of all types of Plans.
[2] Provides specific information related to the development of Construction Plans (including Supplemental Traffic Signal Plans) and Separate (stand-alone) Traffic Signal Plans.

The following information in this chapter builds upon the uniformity & preparation requirements presented in DM-3, and provides additional detailed guidance and requirements specific to the development of traffic signal construction plans. This chapter is not intended to provide details on every aspect in the preparation of a complete project plan set. The designer must utilize the pertinent requirements found in DM-1, DM-2 (13M), DM-2 (13), DM-3, and DM-5 for determining what is required for a complete project plan set, based upon the particular project factors.

33.2 Traffic Signal Plan – Types (Construction & Permit)

Traffic signal design is unique by requiring the preparation of both a Construction Plan and Permit Plan for each location. While similar, these plans serve different purposes as described below:

- ✓ **Traffic Signal Construction Plans *(used by contractors to install traffic signals)* -** the final product of pre-construction activities in traffic signal design is the Traffic Signal Construction Plan. The construction plan and tabulation sheet are primarily used as a tool for contractors to know what equipment and items are to be installed new and which items are preexisting that shall remain. Supporting the plans and Special Provisions are the standard design practices, standard details, other applicable national and local standards, and any necessary agreements.

  As-built construction plans, which document all field changes made during construction, are required when a construction plan is produced, and the project is required to follow Publication 408 specifications. See Publication 408, Section 950 for as-built plan requirements.

- ✓ **Traffic Signal Permit Plan *(used by Permittee to operate and maintain traffic signals)* -** the permit plan is part of the overall approved Traffic Signal Permit that is utilized by the Permittee (owner) of the traffic signal. In general, the permit plan is used to show operational information and traffic control signal equipment, signs, and pavement markings related to the operational and safety aspects of the intersection. The roadway geometrics and all traffic control equipment should be presented on the permit plan as if they were existing features.

  As-built permit plans are required when something shown on the existing permit plan is modified during construction. See Publication 46 Section 4.9 for as-built permit plan requirements.

33.2.1 Construction Plan vs. Permit Plan Information

Typical information found in a Traffic Signal Construction Plan and a Traffic Signal Permit Plan is shown in **Exhibit 33-2**.

Much of the information is the same between these two plan types, with differences noted in the exhibit. Use the information in this exhibit along with the overall guidance in this chapter to help ensure that the Construction and Permit plans are complete and concise for their intended purposes as provided above.

Exhibit 33-2 Traffic Signal Construction Plan vs. Traffic Signal Permit Plan

Plan Item	Plan Type		Details
	Const.	Permit	
PLAN SHEET			
Legend	X	X	**Locate at bottom right of plan sheet.** ✓ Indicate all symbols here which appear on the intersection representation that need explanation. ✓ After each symbol, give a definition of what it represents. ✓ Use hollow symbols and slanted text for existing equipment and items on traffic signal construction plans. ✓ Use filled symbols and vertical text for proposed equipment and items on traffic signal construction plans and for all items on traffic signal permit plans.
Title Block	X	X	**Locate at bottom right corner of plan sheet.** ✓ Locate in the top quarter of the box the following categories: ▪ **County:** insert respective county ▪ **Municipality:** insert respective municipality ✓ **Intersection of:** insert street names and SR number, where applicable ✓ Locate in the second quarter, the following: ▪ **Approved By**: ______________ Municipal Official Date ✓ Locate in the third quarter, the following: ▪ **Recommended:** _____________ District Traffic Engineer Date ✓ Locate at bottom quarter of box, the following: ✓ Scale: insert bar scale (see DM-3 Section 2.1F for style) For all the above, the respective information must be filled in for each project
Construction Plan Upper Title Block	X	---	**Locate at the top right corner of the plan sheet.** ✓ District - indicate number ✓ County-indicate County name ✓ Route - indicate the routes involved ✓ Section - indicate section number (for PennDOT construction projects, otherwise leave blank) ✓ Sheet - indicate sheet number of contract plan set
Permit Plan Upper Title Block	---	X	**Locate at the top right corner of the plan sheet.** ✓ Permit No. - indicate number ✓ Date Issued - Date original permit was issued ✓ Sheet ____of____- this is for this sheet number and for total number of sheets in permit *(Note, Form TE-964 is always Sheet 1 and is included in the total sheet count)*

Plan Item	Plan Type		Details
	Const.	Permit	
PLAN SHEET			
Revision Block	X	---	**Locate below the upper title block.** ✓ Once plans have been approved, and changes are made, they should be indicated as follows: ✓ Revision number - indicate number (1, 2, 3, etc.) ✓ Revision - indicate revision ✓ Date - indicate date revision was made. ✓ By - indicate who made revision ✓ For construction plans, revisions are only noted for bid addendums.
General Notes	---	X	**Locate on right hand side of plan sheet. (Permit Plans only)**
Sign Tabulation	X	X	**Locate on lower left of plan sheet.** See **Section 33.4.7**
Signal Head Identification	X	X	**Locate at bottom middle of plan sheet.** See **Section 33.4.8**
Movement & Sequence Chart	X	X	**Locate on upper left of plan sheet.** See **Section 33.4.1**
Timing Chart	X	X	**Locate next to movement & sequence chart.** See **Section 33.4.2**
Signal Wiring Diagram	X	---	**Locate where able to on plan sheet or place on additional sheet.** See **Section 33.4.6**
Intersection Layout	X	X	See **Section 33.2.2** *Note: some layout differences exist between the construction & permit signal plans*
TABULATION SHEET			
Traffic Signal Support Items	X	---	See **Section 33.5.1**
Electrical Distribution Items	X	---	See **Section 33.5.2**
Detector Items	X	---	See **Section 33.5.3**
Miscellaneous Items	X	---	See **Section 33.5.4**
Pavement Marking Items	X	---	See **Section 33.5.5**
Sign Items	X	---	See **Section 33.5.6**

33.2.2 Traffic Signal Plan Symbols

The symbols in **Exhibit 33-3** should be used when preparing traffic signal plans in addition to those found in DM-3. The existing and proposed styles should be used on traffic signal construction plans. All features on traffic signal permit plans should be shown with existing styles since the permit plan represents an as-built condition.

Exhibit 33-3 Plan Symbols

	Equipment		Call Out	
	Existing	Proposed	Existing	Proposed
Traffic Signal Supports				
Mast Arm			?	?
Strain Pole				
Pedestal				
Pedestrian Stub Pole			?	?
Controller Assembly				
Auxiliary Cabinet				
Controller Assembly-Ground			CC	CC
Controller Assembly-Pole				
Phase Number			?	?
Traffic Signal Systems and Communication				
Antenna			A1	
CCTV Camera			V1	V1
Electrical Distribution				
Junction Box JB-1			JB#	JB#
Junction Box JB-2				
Junction Box JB-11				
Junction Box JB-12				
Junction Box JB-25				
Junction Box JB-26				
Junction Box JB-27				
Junction Box JB-30				
Conduit			C/#	C/#
Luminaire			L#	L#

	Equipment		Call Out	
	Existing	**Proposed**	**Existing**	**Proposed**
Signal Heads				
Vehicular Signal Head 8"			?	?
Vehicular Signal Head 12"				
Programmable Louvered Vehicular Signal Head 8"				
Programmable Louvered Vehicular Signal Head 12"				
Pedestrian Signal Head				
Blank-Out Sign Head				
Detectors				
Radar Detector-Advance			R1	R1
Radar Detector-Stop Bar				
Video Detector			V1	V1
Omnidirectional Video Detector				
Detection Zone			?	?
Accessible Pedestrian Signal			?	?
Pushbutton			??	??
Preemption Detector Acoustic			A1	A1
Preemption Detector GPS				
Preemption Detector Optical				
Preemption Confirmation Light			A	A
Signs				
Structure-Mounted Sign	or	or	?	?
Post-Mounted Sign				

33.2.3 Digital Model

[Reserved]

PennDOT is developing updates to signal plan presentation using digital models as the design of record for traffic signals under a separate effort. The digital model requirements will be incorporated into Section 33.2.3 at the conclusion of that effort. The plan presentation styles developed under that effort are included in Section 33.2.2 of this edition.

33.3 Traffic Signal Plan Sheet – Intersection Layout

Although it may not be possible to totally comply with the intersection layout sequence indicated in this section, this guidance procedure provides a systematic method for use in preparing a traffic control signal plan. The preparation guide is a tool and should not supersede design features developed as part of the traffic control signal design.

This procedure, when used in conjunction with the guidance in this chapter, helps ensure that the final product is a complete and concise plan for the installation of traffic control signals. Designs should follow the general plan presentation requirements in Publication 14M (DM-3) when a new drawing is prepared (see **Exhibit 6-1** to determine when a new Permit drawing is required).

Traffic signal plans should be drawn at a scale of 1”=20’ or 1”=25’ when plotted on a 22”x34” sheet. The bounds of the intersection layout should be established to include the following for each approach:

- ✓ All detection zones.
- ✓ All traffic signal-related signs (see **Chapter 19**)
- ✓ The full length of any turn bays and the associated tapers

Additional sheets and/or match lines are to be used when the intersection layout does not fit within a single sheet at the required scale. Additional sheets may also be required to accommodate notes, tables, and other information required to be shown on the plan in this chapter.

Exhibit 33-4 shows the required ‘Intersection Layout’ information by each Plan type (Signal Construction Plan and a Signal Permit Plan). Note, that while much of the information is the same, there are differences between the requirements.

Exhibit 33-4 Intersection Layout (Construction vs. Permit Signal Plan)

Intersection Layout	Signal Construction Plan	Signal Permit Plan
Right-of-way width dimensions & easements	X	X
SR, segment, and offset	X	X
Construction baseline with stationing	X	---
Phasing symbols of each approach	X	X
Lane widths	X	X
Speed limit of each approach	X	X
Average grades of each approach	X	X
Nearest signal in each direction (or “no signal within one mile”)	X	X
Municipal border if appropriate	X	X

Intersection Layout	Signal Construction Plan	Signal Permit Plan
Existing roadway data per Publication 14M (DM-3) and **Section 33.3.1** of this publication.	X	---
Curbs	X	X
ADA Curb Ramps	X	X
Pavement markings	---	X
Pavement markings *(indicate existing versus new proposed for contractor)*	X	---
Supports with pole #s	X	X
Vehicular signal heads with #s	X	X
Pedestrian signal heads with #s, and pedestrian pushbuttons with #s	X	X
Signs with letter designation	X	X
Controller	X	X
Loop detectors with dimensions and #s	X	X
Detectors for over-roadway detectors with #s	X	X
Detection zones for over-roadway detectors	X	X
Junction boxes with #s	X	---
Conduit and its size	X	---
Electrical service location and type	X	---
Wiring diagram	X	---
Utilities	X	---
Contractor notes	X	---
Any other items specifically needed to relay the full intent of the construction scope of work to a contractor	X	---

33.3.1 Base Plan

The development of an accurate base plan should include a field survey performed by a surveyor so the most accurate design can be made. LiDAR point cloud data can also be used to develop the base plan. The base plan should include:

- ✓ Baseline
- ✓ Roadway grade
- ✓ Edges of pavement and shoulder
- ✓ Curbing
- ✓ Curb ramps
- ✓ Sidewalks
- ✓ Islands
- ✓ Pavement markings
- ✓ Inlets
- ✓ Underground utilities
- ✓ Utility poles and overhead wires
- ✓ Existing signal equipment (if applicable)
- ✓ Legal right-of-way and easements

- ✓ Pertinent topography
- ✓ Bar Scale
- ✓ North Arrow

Field verification of the site is necessary prior to continuing the design. If the project involves roadway construction, ensure the geometrics match the final constructed condition shown on the roadway plan.

33.3.2 Pavement Marking Layout

The roadway geometrics and lane configurations will either be based on existing conditions or proposed improvements that are based on previously completed capacity analysis and roadway design.

See the following chapters of this publication for information on pedestrians and pavement markings:

- ✓ **Chapter 8** (pedestrians)
- ✓ **Chapter 19** (pavement markings/signs)

Pavement markings should be labeled with a letter indicating the color and the width, with the labels defined in the plan legend. Examples are shown below:

W/4"	SOLID WHITE LINE/WIDTH
Y/4"	SOLID YELLOW LINE/WIDTH
DY/4"	SOLID DOUBLE YELLOW LINE/WIDTH
AW/4"	AUXILIARY WHITE LINE/WIDTH
BW/4"	BROKEN WHITE LINE/WIDTH
BY/4"	BROKEN YELLOW LINE/WIDTH
DEW/4"	DOTTED EXTENSION WHITE LINE/WIDTH

33.3.3 Location of Traffic Control Signal Supports

Follow the provisions of **Chapter 12** this publication while designing the location of supports.

33.3.4 Signal Heads and Pedestrian Accommodations

Locate the required positions of traffic control signals in conformance with the provisions of the MUTCD and **Chapter 16** of this publication.

33.3.5 Location of the Traffic Control Signal Controller

See Section 13.3 for information on controller assembly location & placement.

33.3.6 Location of Detection Areas

If the traffic control signal installation under design is to be actuated, add detection of the sizes and types as required by the design.

See **Chapter 17** and Publication 148, TC-8806 for details on detection.

33.3.7 Electrical Distribution

See **Chapter 15** of this publication for details regarding the location of junction boxes, conduit, and electrical service conduit.

33.3.8 Sign Placement

Add all regulatory and warning signs necessary to complete the design. See **Chapter 19** for sign details.

33.4 Traffic Signal Plan Sheet – Charts & Diagrams

33.4.1 Movement and Sequence Chart

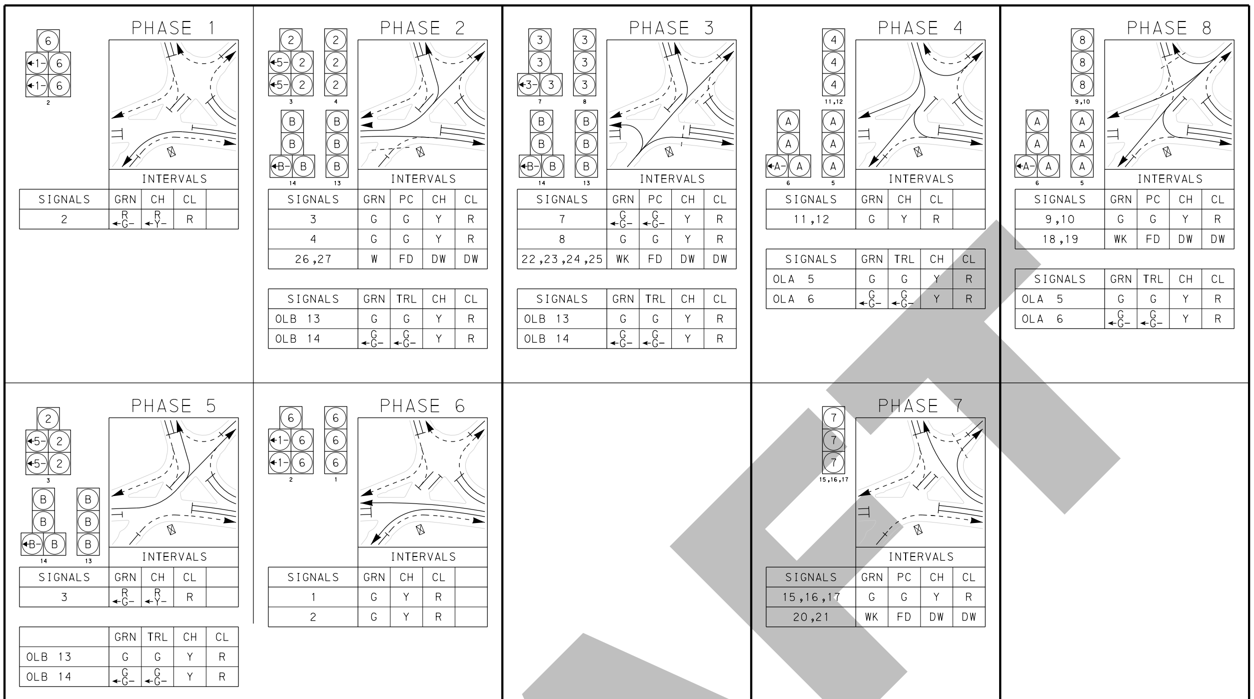
> The previous Movement, Sequence, and Timing Chart has been split into a:
> - ✓ Movement and Sequence Chart, and
> - ✓ Several tables of phase timing, overlaps, preemption, and coordination.

The Movement and Sequence Chart displays a visual indication of which movements occur during the phases of operation. See **Chapter 10** to determine the appropriate timing parameters and phasing. The following guidelines apply to how the Movement and Sequence Chart is shown on the plan:

- ✓ Locate on upper left of sheet.
- ✓ Designate the phases using NEMA phasing. See **Chapter 10** of this publication. Use multiple rows to indicate each ring. Use thicker vertical lines to indicate barriers.
- ✓ Diagrammatic representation of movements for respective phase (including movements permitted or protected by overlap during the phase), including pedestrian movements with dashed line.
- ✓ Horizontally list the intervals for each phase or overlap
  - LPI – Leading pedestrian interval (also referred to as Advance Walk)
  - GRN – Green interval
  - TRL – Trailing green interval (only used for overlaps) (also referred to as lagging green)
  - PC – Pedestrian clearance interval
  - CH – Vehicular change interval (yellow)
  - CL – Vehicular clearance interval (red)
- ✓ Vertically list the signal head numbers as shown on the plans. Indicate the phase and/or overlap which run each signal head.
- ✓ For each interval, show the signal head display by indicating:
  - G for Green Ball indication
  - R for Red Ball indication
  - Y for Yellow Ball indication
  - W for "WALKING PERSON" indication or "WALK" indication
  - FD for Flashing "HAND" indication or Flashing "DONT WALK" indication.
  - DW for "UPRAISED HAND" indication or "DONT WALK."
  - ←G— for Green Arrow indication
  - ←Y— for Yellow Arrow indication
  - ←FY— for Flashing Yellow Arrow indication.
  - ←R— for Red Arrow indication
- ✓ Indicate whether signals will flash red, yellow, or be off during emergency flashing operation. Typically, pedestrian signals will be off and all vehicular signals will flash red.
- ✓ Show the required operational notes for controller operation.

An example Movement and Sequence Chart is shown in **Exhibit 33-5**.

Exhibit 33-5 Example Movement and Sequence Chart



33.4.2 Phase Timing Chart

A Timing Chart is required on every traffic control signal plan. See **Chapter 10** to determine the appropriate timing parameters and phasing. The following guidelines apply to the Timing Chart:

- ✓ Indicate the time settings for each phase, using the method indicated in **Exhibit 33-6.**
- ✓ The terminology for common controller software and NTCIP 1202 v03, *Object Definitions for Actuated Traffic Signal Controller (ASC) Units* is available from the Traffic Signal Portal.

Exhibit 33-6 Example Timing Chart

PHASE TIMING

	1	2	3	4	5	6	7	8
MIN GREEN	10	10		5		10		
ADVANCE WALK								
WALK		7		7		7		
DON'T WALK		15		14		15		
VEH EXT	2	2		2		2		
MAX 1	60	60		25		60		
MAX 2	60	60		25		60		
YELLOW	4.5	4.5		3		4.5		
RED	2.5	2		2		2		
ACT B4								
SEC/ACT								
MAX INT								
TIME B4								
TO REDUCE								
MIN GAP								
VEH RECALL		MN				MN		
PED RECALL		RW				RW		
MEMORY	NL	L		NL		L		

MN - MINIMUM RECALL
MX - MAXIMUM RECALL
PR - PEDESTRIAN RECALL
SR - SOFT RECALL
L - LOCKING
NL - NON-LOCKING
RW - REST IN WALK

> The rows for timing settings which are not used at a particular intersection, such as volume density settings, may be removed from the timing chart.

33.4.3 Overlap Chart

When overlaps are used, an Overlap Chart must be included on the plan to identify the overlap settings. Refer to **Section 10.3.4** for details on overlap terminology. The following guidelines apply to the Overlap Chart:

- ✓ Indicate the settings used for each overlap using the method indicated in **Exhibit 33-7**.
- ✓ The overlap type refers to one of the types indicated in **Section 10.3.4.** The following shortened terms should be used: NORMAL, -GY ALT, PED NORM, FYA-4, FYA-3, TRANSIT.
- ✓ For normal overlaps, the modifier, lag green, yellow, and red lines may be omitted when unused.

Exhibit 33-7 Example Overlap Chart

OVERLAPS

	OL-A	OL-B
SIGNALS	5-6	13-14
TYPE	NORMAL	NORMAL
INCLUDED	Ø4-Ø8	Ø2-Ø3-Ø5
MODIFIER		
LAG GREEN	5	5
YELLOW	4	4
RED	2.5	2.5

33.4.4 Preemption Chart

When preemption is used, a Preemption Chart must be included on the plan to identify the preemption settings. Refer to **Chapter 11** for details on preemption terminology. The following guidelines apply to the Preemption Chart:

- ✓ The settings which only apply to railroad preemption may be omitted when railroad preemption is not used.
- ✓ Emergency vehicle preemption settings which use the default in Publication 148, TC-8807 may be omitted and replaced with the following note: EMERGENCY PREEMPTION PARAMETERS TO BE AS INDICATED IN PUBLICATION 148, TC-8807, DATED _______, 20__ UNLESS OTHERWISE INDICATED."
- ✓ At a minimum, the following notes must be provided on the traffic signal plan for intersections with railroad preemption:
  - A note explaining which signals may remain green when going into train preemption
  - A note explaining that the regular yellow and all-red intervals should time out before going into train preemption
  - A note explaining the operation of the signal if preemption occurs during flashing operation
  - A note explaining the operation of the pedestrian intervals
  - A note explaining emergency preemption operation with train preemption

Exhibit 33-8 Example Preemption Chart

PREEMPTION

TYPE	EVP	EVP	EVP	EVP	RR	QUEUE
SIGNALS	A	B	C	D		
PHASES	Ø1,Ø6	Ø5,Ø2	Ø4	Ø8		Ø4
PREEMPT MIN	10	10	10	10		30
PREEMPT MAX	60	60	60	60		
TRACK CLEAR					Ø3,Ø8	
MIN GREEN					54	
DWELL					Ø2,Ø6	
CYCLE					Ø1,Ø2,Ø4,Ø5 Ø6	
EXIT PHASE	Ø1,Ø6	Ø5,Ø2	Ø4	Ø8	Ø2,Ø6	Ø4
[N]					ON	

33.4.5 Coordination Chart

When a traffic signal is part of a coordination system, the coordination timings may be shown either on the traffic signal plan for each intersection, or a separate plan may be developed with the coordination timings for the entire system.

If coordination timings are shown on the intersection traffic signal plan, the following guidelines for the Coordination Chart apply:

- ✓ Indicate the times for each coordination pattern and day plan in accordance with **Exhibit 33-9**
- ✓ Split and offset times should be shown in seconds unless the controller only allows entering the data in percentages of the cycle length
- ✓ Include a note indicting the reference point in the cycle (typically beginning of green or beginning of yellow for the coordinated phase)

Exhibit 33-9 Coordination Chart (Intersection)

COORDINATION PATTERNS

SPLIT PATTERN	CYCLE LENGTH	OFFSET	SPLITS 1	SPLITS 2	SPLITS 3	SPLITS 4	SPLITS 5	SPLITS 6	SPLITS 7	SPLITS 8	COORD PHASES	DWELL
1	135	0	21	53	21	40	21	53	26	35	2 6	5
2	135	25	21	53	21	40	21	53	26	35	2 6	5
3	135	0	21	53	21	40	21	53	26	35	2 6	5
4												
5												
6												
7												
8												

DAY PLAN/EVENT

DAY PLAN	1					
DAY OF WEEK						
Su	M	Tu	W	Th	F	Sa
	X	X	X	X	X	

EVENT	ACTION PLAN	START TIME
1	1	06:00
2	100	09:00
3	2	12:30
4	3	16:30
5		
6		
7		
8		

DAY PLAN/EVENT

DAY PLAN	2					
DAY OF WEEK						
Su	M	Tu	W	Th	F	Sa
X						X

EVENT	ACTION PLAN	START TIME
1	1	06:00
2	100	09:00
3	2	12:30
4	100	16:30
5		
6		
7		
8		

33.4.6 Signal Wiring Diagram

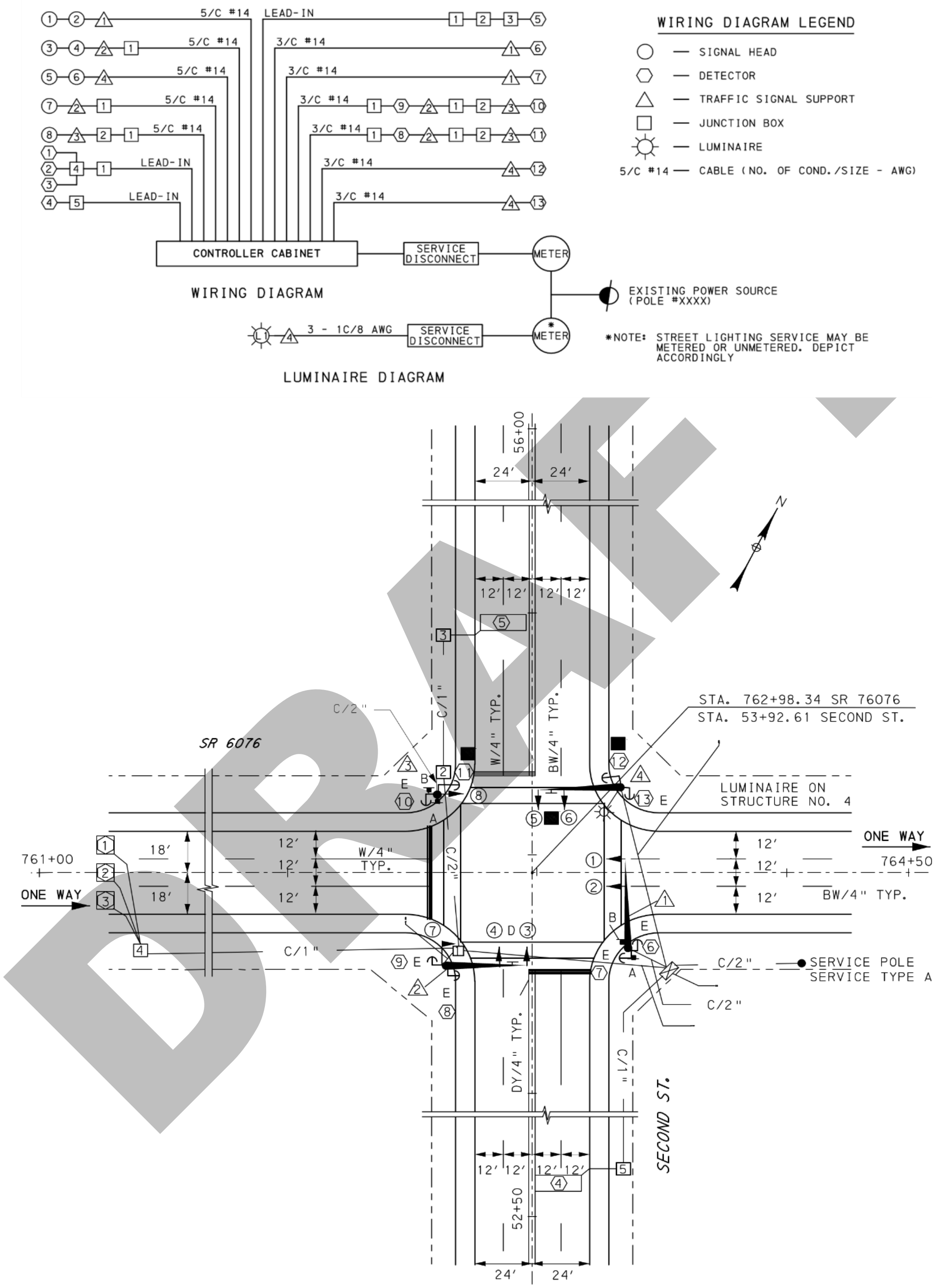
A schematic wiring diagram shall be prepared for each traffic control signalization design location. The signal wiring diagram is only required on the traffic signal construction plan and is not required on the traffic signal permit plan.

The schematic signal diagram shall provide the following items:

- ✓ Locate where able on sheet or place on additional sheet.
- ✓ Provide schematic diagram of wire routing between signal heads, luminaires (if present), detectors, push buttons, poles, junction boxes, controller assembly, and meter/service.
- ✓ Indicate location of wire splices, if applicable.
- ✓ Indicate wire conductor and size.

An example signal wiring diagram is illustrated in **Exhibit 33-10.**

Exhibit 33-10 Example Wiring Diagram



33.4.7 Sign Tabulation

Locate on lower left of the plan sheet.

- ✓ Title

- ✓ Column headings
- ✓ Plan symbol
- ✓ Description includes sign nomenclature from Publication 236 and actual legend
- ✓ Size (width X height)
- ✓ Plan callout beginning with letter "A" (do not use letters I or O)
- ✓ Description

33.4.8 Signal Head Identification

Located at bottom middle of plan sheet.

Vehicle Signals

- ✓ Diagram of signal faces
- ✓ Show signal numbers as they appear on the plans.
- ✓ Indicate colors and type.
- ✓ R for Red Ball indication
- ✓ Y for Yellow Ball indication
- ✓ G for Green Ball indication
- ✓ ←G for Green Arrow indication
- ✓ ←Y for Yellow Arrow indication
- ✓ ←SY for Steady Yellow Arrow indication
- ✓ ←FY for Flashing Yellow Arrow indication
- ✓ ←R for Red Arrow indication
- ✓ Indicate size of signal
    - 8-inch signal
    - 12-inch signal
    - Indicate type of visors.
    - Indicate if backplates are to be installed
- ✓ Indicate louvers (if required)

Pedestrian Signals

- ✓ Diagram of signal faces
- ✓ Indicate type per Pub 148, TC-8805 (Type A6 or Type A9)
- ✓ Show signal numbers as they appear on the plans
- ✓ Indicate messages and location
- ✓ Upraised hand indication
- ✓ Walking person indication
- ✓ Countdown digits indication
- ✓ Indicate size of message
- ✓ Indicate visor type

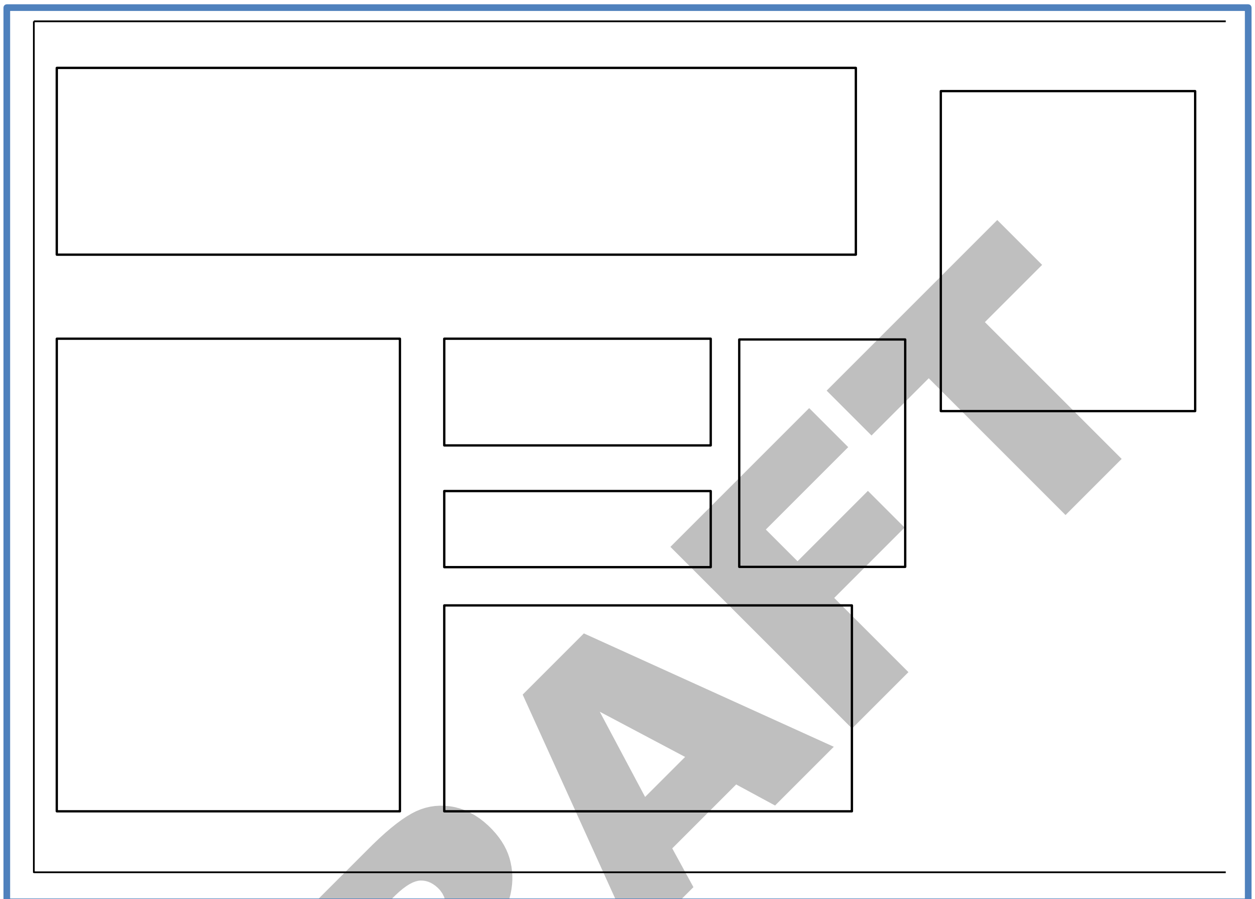
33.5 Traffic Signal Tabulation Sheet

Complete the various tables on the tabulation sheet in conformance with the guidelines set forth in Publication 14M (DM-3) to provide a complete and accurate listing of all construction items composing the traffic control signal design. Complete the tabulation of the electrical distribution items from the wiring diagram.

Finally, check both the plan sheet and tabulation sheet to ensure completeness and accuracy.

Exhibit 33-11 shows an example development of a tabulation sheet layout. Following this exhibit are sections with the six categories of items tables that need completed on the tabulation sheet as set forth in Publication 14M (DM-3).

Exhibit 33-11 Development of a Tabulation Sheet



33.5.1 Traffic Control Signal Support Items

- ✓ Item numbers
- ✓ Location
- ✓ Mast arms
- ✓ Strain poles
- ✓ Sign and signal locations
- ✓ Luminaires

33.5.2 Electrical Distribution Items

- ✓ Item numbers
- ✓ Location
- ✓ Conduit
- ✓ Trench
- ✓ Signal cable
- ✓ Junction box
- ✓ Electrical service
- ✓ Detector items

33.5.3 Detector Items

- ✓ Amplifier
  - Item numbers

- Description
- Quantity
- Location
- Operation

✓ Sensors

- Item numbers
- Quantity
- Size
- Description
- Location

DETECTION ZONE INFORMATION

DETECTOR	DETECTION ZONE(S)	MODE	TYPE	ROUTE	PHASE	LOCATION
2	11 12 6' X50'	PRESENCE	VIDEO	MACLAY ST	4	4
2	13 14 6' X50'	PRESENCE	VIDEO	MACLAY ST	7	4
2	1 2 6' X50'	PRESENCE	VIDEO	CAMERON ST	6	4
2	3 4 6' X50'	PRESENCE	VIDEO	CAMERON ST	1	4
1	5 6 6' X50'	PRESENCE	VIDEO	ARSENAL BLVD	8	2
1	7 6' X50'	PRESENCE	VIDEO	ARSENAL BLVD	3	2
1	8 9 6' X50'	PRESENCE	VIDEO	CAMERON ST	2	2
1	10 6' X50'	PRESENCE	VIDEO	CAMERON ST	5	2
1	21 (SEE NOTE 2)	PRESENCE	RADAR (DILEMMA)	CAMERON ST	2	2
2	22 (SEE NOTE 2)	PRESENCE	RADAR (DILEMMA)	CAMERON ST	6	3

33.5.4 Miscellaneous Items (Controller Assemblies, Systems and Communication Equipment, Signal Heads)

✓ Item numbers
✓ Controller assembly
✓ Vehicle signal heads
✓ Pedestrian signal heads
✓ Systems
✓ Communications
✓ Preemption

33.5.5 Pavement Marking Items

✓ Item numbers
✓ Quantity
✓ Description

33.5.6 Sign Items

✓ Item numbers
✓ Description
✓ Size
✓ Square feet
✓ Sign Type/Mount

- Type B

- Type F
- Structure-Mounted

34. OTHER TRAFFIC SIGNAL PLANS

Chapter 33 provides details for preparing construction plans for traffic control signals (R-Y-G operation).

This chapter provides details related to the preparation of other traffic signals plans.

As defined in **Section 1.1**, other traffic signals include:

- ✓ Flashing beacons (also known as flashing warning devices)
- ✓ Emergency vehicle access signals
- ✓ Ramp metering signals
- ✓ Lane-use control signals
- ✓ Toll plaza signals
- ✓ In-roadway lights

While not every plan preparation item covered in **Chapter 33** will apply to a particular 'other traffic signal' plan, the concepts and details of **Chapter 33** do apply.

Therefore, when preparing signal plans for any of the 'other traffic signals' types, follow the guidance and details presented in **Chapter 33** and develop plans that meet the intent of Publication 14M (DM-3) and the pertinent parts of **Chapter 33** for your signal device.

35. BID PROPOSAL (PACKAGE)

The PS&E package is the set of documents which contains the Plans, Specifications, Estimate, and other project documents.

The Bid proposal (package) is a set of documents which contains project requirements and other information and is used by a contractor to prepare and submit a bid for constructing the project. The Bid proposal (package) excludes the Estimate and some project documents internal to the project owner and not appropriate for the contractor to use for bidding.

Both the PS&E package and Bid package are prepared by the project owner. Publication 51 details the requirements and process of developing a PS&E package and then converting it into a Bid package.

The Bid proposal (package) includes the following:

- ✓ Plans (see **Chapter 33**),
- ✓ Specifications (see **Section 35.1** in this Chapter),
- ✓ Special Provisions (see **Section 35.3** in this Chapter),
- ✓ Design Items (also known as Pay Items or Contract Items in Publication 408) (see **Exhibit 36-1** and **Exhibit 36-2**),
- ✓ Referenced Standard Drawings (see **Section 35.2** in this Chapter),
- ✓ Addenda, and
- ✓ All other documents referred to therein (see **Section 35.2** in this Chapter).

The proposal is typically incorporated into the construction contract, which is the legal agreement between the project owner and the contractor for construction of the project.

Specifications refer to the written documentation incorporated into a construction contract describing the scope of work, materials to be used, methods of installation, and expected work quality. Specifications for traffic signals occur in different formats, including one or more of the following:

- ✓ Incorporating PennDOT standard specifications in Publication 408 by reference
- ✓ Using standard special provisions maintained in ECMS.
- ✓ Writing and including project-specific special provisions
- ✓ Special Provisions referenced within Publication 408 or bound with the proposal.
- ✓ Written agreements furnished under the contract.

As indicated in **Section 5.1**, traffic signals should be:

- ✓ Designed using the Department's standard construction specifications, standard drawings, and available ECMS Master Items. Designs should only deviate from standard specifications and items in unusual cases where the standards cannot be used due to unique project-related situations as indicated in **Section 5.8.2.**
- ✓ Constructed using the Department's qualified products and materials listed in Publication 35 (Bulletin 15), see **Section 5.5.2** and **Section 5.6.1,** except for unique project-related situations as indicated in **Section 5.8.2.**

35.1 Standard Specifications

Standard specifications are those specifications found in Publication 408.

Exhibit 35-1 shows primary standard specifications for traffic control signals, and **Exhibit 35-2** shows primary standard specifications for flashing warning devices. Standard specifications from other areas of Publication 408 may be applicable to traffic signal projects for ancillary work such as signs, pavement markings, and curb ramps.

Exhibit 35-1 Traffic Control Signals Primary Specifications

Publication 408			Pub 149 Reference
Section	**Title**	**Purpose**	
950	Traffic Signals - General	▪ Contains general specifications applicable to all types of traffic signal components in Sections 951 thru 958. ▪ Contains general specifications applicable to any work at traffic signals which isn't specific to components covered in Sections 951 thru 958, including standard construction practices, testing and compliance procedures, warranties/guarantees, maintenance, asset management, documentation submittals, and materials acceptance.	**Chp 6.1**
951	Traffic Signal Supports	▪ Specifications for traffic control signal supports and pedestrian stub pole supports.	**Chp 12**
952	Controller Assembly	▪ Specifications for the various components & configurations that make-up a controller assembly (cabinet, controller unit, and the various electric & electronic hardware inside the cabinet for controlling the signal operation), and the installation thereof (foundation, hardware, etc.).	**Chp 13**
953	Systems & Communications	▪ Specifications for the various available system and communication types & components when signal coordination or signal communication linkage is required.	**Chp 1**
954	Electrical Distribution	▪ Specifications for the electrical distribution for the control & illumination of traffic control signals. ▪ Electrical distribution consists of all the electrical components that power, distribute, and operate a traffic control signal (electrical service, cable, conduit, junction boxes, back-up power, etc.).	**Chp 15**
955	Signal Heads	▪ Specifications for signal head assemblies (indication modules, reflectors, backplates, housing & mounting hardware, etc.). ▪ Includes specifications for vehicular, pedestrian, and lane-use signal head assemblies.	**Chp 1**
956	Detectors	▪ Specifications for the various available detection types & components used for the detection of vehicles or pedestrians at signalized locations.	**Chp 17**
957	Advanced Traffic Signal Technology	▪ Specifications for adaptive signal control technology systems that provide responsive, real-time signal timings to match current traffic conditions along a corridor. ▪ Includes specifications for hardware, software, and detection system components for the adaptive system.	**Chp 18**
958	Temporary Traffic Control Signals	▪ Specifications for temporary traffic control signals on fixed-supports. ▪ Specifications for temporary, portable traffic control signals (pedestal & trailer-mounted). ▪ Specifications for existing permanent traffic control signals needing temporary timing adjustments and/or temporary modifications.	**Chp 23**

Exhibit 35-2 Flashing Warning Devices Primary Specifications

Publication 408			Pub 149 Reference
Section	**Title**	**Purpose**	
935	Post Mounted Signs, Type F	▪ Specifications for various flashing warning devices (post mounted, internally illuminated, LED blank-out, LED border lit, flashing warning, speed display, RRFBs). ▪ Use Section 935 when attaching flashing warning devices to existing poles. ▪ Use Section 936 when installing a new support pole for the flashing warning device	**Chp. 19 & 1**
936	Structure Mounted Signs		
975	Remove Post Mounted Signs, Type F	▪ Specifications for removal of the various Type F signs.	**---**
976	Remove Structure Mounted Sign	▪ Specifications for removal of the various structure mounted signs.	**---**
1103	Traffic Signing and Marking	▪ Material specifications for flashing warning devices referenced by Sections 935 and 936.	**Chp. 19 & 1**

35.2 Publications/Bulletins

As specifications include publications/bulletins referenced within Publication 408, or bound with the proposal, it is important that traffic signal designs follow and utilize the requirements, standards, and guidance within these applicable publications.

The following are references within this publication for accessing key publications needed for traffic signal design:

- ✓ **Exhibit 1-3** shows the applicable laws, regulations and primary publications for the design, construction, and maintenance of traffic control signals. While **Exhibit 1-1** lists various Department publications under Planning & Programming, Design, Construction and Maintenance bins, the design of traffic signals will involve some of these publications, regardless of the area they are assigned. In fact, there are references throughout this publication to Publications 35, 111, 148, 408, etc.
- ✓ **Section 5.6.2** and **Section 5.6.3** details Publication 148 and Publication 111.
- ✓ **Exhibit 23-1** shows the various Publication 213 PATA drawings for temporary traffic control signals for existing two-lane/two-way highways operating temporarily with one-lane/two-way traffic flow.

35.3 Special Provisions

Special Provisions are additions and revisions to the Standard Specifications, which include the following types:

- ✓ Standard Special Provisions are maintained in ECMS, in the following seven indices:
  - ▪ Changes to Specifications (C)

- Design Build (D)
- General Provision (G)
- Item-Related (I)
- Non-Pay Item (N)
- Provisional Specification (P)
- Section-Related (S)

✓ Project-specific Special Provisions are written specifically for the project being bid and typically are used to develop specifications for modified or non-standard pay items.

The majority of traffic signals should be able to be designed (and constructed) using the Department's standard construction specifications, standard drawings, and available ECMS Master Items.

Designs should only deviate from standard specifications and items in unusual cases where the standards cannot be used due to unique project-related situations (see **Section 5.1**). See **Section 5.8.2** for requesting the use of 1) proprietary specifications, and/or 2) patented/proprietary materials, products, or processes that may necessary.

For PennDOT-let projects, all project-specific special provisions relating to traffic signals must be reviewed and approved by the Chief of the TSMO Arterials and Planning Section prior to advertisement in ECMS.

✓ Standard specifications for traffic signals in Publication 408 were significantly updated in October 2021.

✓ Bidding projects using standard items reducing risk for contractors, which will lead to more competitive bidding and better prices.

✓ Use of standard items provides for better cost estimates since ECMS Item Price History can be used to compare the same items.

✓ Review time for source of supply will be reduced since Bulletin 15 approval means a detailed review of the product against the specifications is not required for each project.

36. COST ESTIMATES

Cost estimates are part of the PS&E package but are not part of the Bid package.

When preparing traffic signal cost estimates, use the standard Master items and price history in ECMS for the various related signal items that are needed to construct the traffic signal.

Exhibit 36-1 shows the ECMS Master item series that corresponds to each Publication 408 section for key traffic signal-related specifications.

Exhibit 36-2 shows the ECMS Master item series that corresponds to each Publication 408 section for other related specifications often used with traffic signals.

Bulletin 15 qualified product/material listings are also organized by their corresponding Publication 408 specification section for which they are qualified for use.

The Green Light-Go estimating guide is a good source of information that explains how to prepare a cost estimate.

Exhibit 36-1 Primary ECMS Traffic Signal Master Items

Pub 408 Section	Title	Master Items
950	Traffic Signals -General	0950 Series
951	Traffic Signal Supports	0951 Series
952	Controller Assembly	0952 Series
953	Systems & Communications	0953 Series
954	Electrical Distribution	0954 Series
955	Signal Heads	0955 Series
956	Detectors	0956 Series
957	Advanced Traffic Signal Technology	0957 Series
958	Temporary Traffic Control Signals	0958 Series

Exhibit 36-2 Other ECMS Master Items Related to Traffic Signals

Pub 408 Section	Title	Master Items
630	Plain Cement Concrete Curb	0630 Series
676	Cement Concrete Sidewalks	0676 Series
695	Detectable Warning Surface	0695 Series
931	Post Mounted Signs, Type B	0931 Series
935	Post Mounted Signs, Type F	0935 Series
936	Structure Mounted Signs	0936 Series
960	Hot Thermoplastic Pavement Markings	0960 Series
961	Cold Plastic Pavement Markings or Legends	0961 Series
962	Waterborne Pavement Markings	0962 Series
963	Pavement Marking Removal	0963 Series
964	Epoxy Pavement Markings	0964 Series
965	Preformed Thermoplastic Pavement Markings	0965 Series
975	Remove Post Mounted Signs, Type F	0975 Series
976	Remove Structure Mounted Sign	0976 Series

APPENDIX A. GLOSSARY

Consult the 11th Edition of the MUTCD for definitions of key words and terms used in this publication. In addition, the following words, and terms, when used in this Handbook, shall have the meanings indicated, unless the context clearly indicates otherwise:

AASHTO – The American Association of State Highway and Transportation Officials.

AASHTO "Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" – Provides guidance for the design and use of traffic signal supports. This document should be used in conjunction with **Chapter 12** of this publication.

Accessible route – A continuous, unobstructed path connecting all accessible elements and spaces of a building or facility.

Actuated operation – A type of traffic control signal operation in which some or all signal phases are operated based on actuation (vehicle detection, pushbutton, etc.).

ADA – Americans with Disabilities Act (1990).

Adaptive signal system – A technology using detection data and algorithms to adjust signal timing parameters for current conditions. Adaptive signal systems still rely on local controllers for many timing parameters and share many features of traditional systems, but they have more flexibility in how they adjust timing parameters.

Added initial – An increment of time added to the minimum initial portion in response to vehicle actuation.

All-red clearance interval – An interval that follows a yellow change interval and precedes the next conflicting green interval.

Alteration project – A highway alteration project is a change to any portion of an existing facility (space, site, structure, or improvement of a pedestrian or vehicular route) located in the public right-of-way that affects or could affect access, circulation, or use of the facility. Alterations could also affect the structure, grade, function, and use of the roadway.

As-built plans – A modified traffic signal plan showing the roadway geometrics and the traffic signals after completion of the construction project, showing any field adjustments due to structural shifts of signal supports, unanticipated corner radius changes, etc.

Breakaway (yielding) – Crashworthy; a characteristic of a roadside appurtenance that has been successfully crash tested in accordance with a national standard such as AASHTO's Manual for Assessing Safety Hardware (MASH).

Capacity – The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour.

Change and clearance interval – Sum of the yellow change and all-red clearance intervals. Refer to **Chapter 10** of the publication for additional information.

Coordinated traffic control (coordination) – The establishment of a definite timing relationship between adjacent controller units.

Conflict Factor (CF) – The product of the left turn volume and the opposing through traffic volume for any one-hour period of a normal weekday.

Conflict monitor - A device housed in the controller cabinet which continuously checks for the presence of conflicting signal indications such as simultaneous green signal indications on both the mainline and side road approaches. If a conflict is detected, the monitor places the signals into a flashing operation.

Controller – The electronic device that controls the sequence and duration of traffic signal indications.

Countdown pedestrian signal – A pedestrian signal head that displays the number of seconds remaining in the pedestrian change interval.

Curb ramp – A short pedestrian ramp cutting through a curb or built up to a curb from a lower level.

Detector – A device for indicating the presence of a vehicle or pedestrian.

Detector amplifier – A device capable of intensifying the electrical energy produced by a sensor.

Emergency vehicle preemption – The transfer of normal operation of a traffic control signal to a special control mode of operation for emergency vehicles. Refer to **Chapter 11** of this publication for additional information.

Emitter – A device located in each emergency vehicle to allow activation of emergency vehicle preemption equipment at the intersection, if provided. Refer to **Chapter 11** of this publication or additional information.

FHWA – The Federal Highway Administration of the United States Department of Transportation.

Fixed supports – Permanent or temporary mounting mechanisms that are not portable and are not designed so that they are easily transported and reused at other locations. Trailers or pedestals that are portable are not fixed supports.

Global Positioning System (GPS) – Technology that uses satellites to obtain key location information to be used at a signalized intersection. Refer to **Chapter 11** of this publication for additional information.

Green interval timings – The amount of time given for a particular green interval in a phase. Refer to **Chapter 10** of this publication for additional information.

Green time-to-cycle time ratio (G/C ratio) – The ratio of the green time to the cycle length.

Highway Capacity Manual (HCM) – Published by the Transportation Research Board, National Research Council.

Incandescent indications – Vehicular or pedestrian signals, or a blank-out sign, which are illuminated with a traditional light bulb having a thin tungsten filament.

Initial (minimum) interval – The shortest green time of a phase. Refer to **Chapter 10** of this publication for additional information.

Intersection – The area embraced between the prolongation and connection of the lateral curb lines, or if none, the lateral boundary lines of the roadways (i.e., the traveled portion) of two or more streets or highways.

Isolated intersection – A signalized intersection that is located far enough from other signalized intersections so that the signal timing at the other intersections does not influence the traffic flow at this intersection.

Lead/lag left turn phasing – Allows left turn traffic to get a green arrow before or after opposing traffic gets a circular green depending on traffic demand.

Lead/lead left turn phasing – Allows left turn traffic to get an exclusive left turn arrow before the opposing through traffic gets a circular green. Typically, simultaneous left turn arrow indications may be present for non-conflicting left turn movements. Refer to **Chapter 10** of this publication for additional information.

Local authorities –

i. County, municipal and other local boards or bodies having authority to enact regulations relating to traffic.

ii. The term also includes airport authorities except where those authorities are within counties of the first class or counties of the second class.

iii. The term also includes State agencies, boards, and commissions other than the Department, and governing bodies of colleges, universities, public and private schools, public and historical parks.

Local controller – The controller located at an intersection, and which operates the traffic signals only at that intersection and does not control or directly influence any other intersection.

Locking mode – When a particular phase receives a call, and that call will remain until the phase has been serviced.

MUTCD – The Manual on Uniform Traffic Control Devices, as adopted by the Federal Highway Administration (FHWA), and available on the FHWA website.

Mast arm support – A support consisting of an arm in an approximate horizontal position and a vertical pole that together are designed to hold signal heads, small signs, luminaires, and related appurtenances.

Master controller – The controller that supervises and directs the timing patterns for all local controllers within a traffic control signal system for the purpose of coordinating the operation of the signal system to improve traffic flow and safety.

Maximum green – The maximum time which a phase may retain the right-of-way. Maximum green starts timing at the beginning of the green period if there is a call on the opposite phase or whenever a call arrives on the opposite phase after the green period has started.

Maximum initial – Used primarily in volume-density operation, it establishes the upper limit of the variable initial period and provides sufficient time to clear the number of vehicles that can be stored between the detector and the stop line. Refer to **Chapter 10** of this publication for additional information.

Maximum recall – Places a call on a phase and then keeps the phase green for a time equal to the maximum setting. Refer to **Chapter 10** of this publication for additional information.

Minimum gap – The minimum value the extension will be allowed to shrink between actuations for a phase with a green indication. **Chapter 10** of this publication for additional information.

Minimum green – The minimum amount of green time allocated to a particular movement or phase at an intersection.

Minimum recall – Places a call on a phase and then keeps the phase green for at least as long as the initial (minimum) setting. Refer to **Chapter 10** of this publication for additional information.

NEMA – The National Electrical Manufacturers Association.

Non-locking mode – Allows particular phase calls to be processed, but if that call is dropped during a conflicting phase, the original phase call will be removed from memory.

Operations – As it relates to traffic, this is the day-to-day control of traffic systems, including the analysis of the systems, detection of problems and deficiencies, setting of priorities, assignment of resources and development of improvements through geometric design, traffic control, or other means. Frequently referred to as "traffic operations."

Optically programmed signals – A type of signal face or signal section designed (or shielded, hooded, or louvered) to restrict the visibility of a signal indication from the side to certain lane or lanes, or to a certain distance from the stop line. Also known as programmed visibility signals or visibility-limited signal faces or signal sections.

Overlap – A vehicle movement, usually a right turn, which is allowed to run concurrently with two standard phases. Refer to **Chapter 10** of this publication for additional information.

Passage time – Provides an additional time increment upon completion of the initial (minimum) interval for each vehicle as it passes the detector. It also determines the length of gap which, if exceeded, permits the right-of-way to be transferred to another phase. Refer to **Chapter 10** of this publication for additional information.

Peak-hour traffic volume – The highest number of vehicles passing over a section of a lane or a roadway during 60 consecutive minutes of a normal day. The term "peak hours" refers to the peak-hour traffic volume for the morning and the peak-hour traffic volume in the afternoon.

Pedestrian detection – Hardware used to notify the traffic controller of the presence of a pedestrian, typically via a pushbutton.

Pedestrian need – Based upon a study, the determination of the accommodations needed for pedestrians considering whether pedestrians are or will be present, pedestrian volumes, types of pedestrians, and other relevant factors.

PennDOT – The Pennsylvania Department of Transportation; the Department of Transportation of the Commonwealth of Pennsylvania.

Pennsylvania Vehicle Code – Title 75, Pennsylvania Consolidated Statutes having the citation 75 Pa.C.S.

Permitted left turn phasing – Allows a left turn to be made on a circular green indication when there is a sufficient gap in opposing traffic. Refer to **Chapter 10** of this publication for additional information.

Physical barrier – A physical obstruction (i.e., fence, planter, guiderail, etc.) which prohibits a pedestrian movement. Placement of an intentional physical barrier to deter pedestrian movements must be outside the vehicular line of sight and clear zone.

Presence mode – Provides one output pulse for each vehicle passing over the detection area, or an output for each vehicle stopped over the detection area. Does not provide a locking call. Refer to **Chapter 17** of this publication for additional information.

Pretimed operation – A non-actuated traffic control signal where right-of-way at the intersection is assigned according to one or more predetermined schedules and is therefore not influenced by the presence or absence of traffic. Pretimed operation may also be referred to as fixed-time operation.

Prevailing Vehicular Speed – The speed at which the majority of the traffic is traveling at or below (normally the 85th percentile speed).

Protected/permitted left turn phasing – Allows vehicles to make left turns on a protected left turn arrow indication. Upon completion of that phase, if a sufficient gap in opposing traffic is available, a left turn can be made on a circular green indication. Refer to **Chapter 10** of this publication for additional information.

Protected/prohibited left turn phasing – Motorists can only turn left on the green arrow. Refer to **Chapter 10** of this publication for additional information.

PROWAG – Public Rights of Way Accessibility Guidelines.

Publications (PennDOT):

Publication 13 – Design Manual Part 2: Contextual Roadway Design

Publication 13M – Design Manual Part 2: Highway Design

Publication 35 – Approved Construction Materials (Bulletin 15).

Publication 46 – Traffic Engineering Manual

Publication 72M – Roadway Construction Standards

Publication 111 – Traffic Control Pavement Markings and Signing Standards, TC-8600 and TC-8700 Series.

Publication 148 – Traffic Standards Signals, TC-8800 Series.

Publication 191 – Traffic Signal Maintenance Manual

Publication 212 – Official Traffic Control Devices.

Publication 213 – Temporary Traffic Control Guidelines.

Publication 236 – Handbook of Approved Signs.

Publication 408 – Highway Construction Specifications.

Pulse mode – When detection occurs, provides a locking call on the controller until serviced. Refer to **Chapter 17** of this publication for additional information.

Push button detection – A mechanical switch that when pushed or activate, it tells the controller of the presence of a pedestrian.

Recall – An operational mode of an actuated controller whereby a phase, either vehicle or pedestrian, is displayed each cycle whether demand exists or not.

Signal Timing Manual - Second Edition (STM2) - TRB's National Cooperative Highway Research Program (NCHRP) Report 812: Signal Timing Manual - Second Edition, covers fundamentals and advanced concepts related to signal timing. The report addresses ways to develop a signal timing program based on the operating environment, users, user priorities by movement, and local operational objectives. Refer to **Chapter 10** of this publication for additional information.

Soft recall – Similar to minimum recall, but phase will discontinue its call for the green interval if there are conflicting phase calls at the intersection by the actual vehicle demand.

Span wire – A cable extended between strain poles used as a horizontal support for signal heads and small signs.

Split phasing – Where two opposing approaches flow in totally separate phases that time consecutively rather than concurrently. Refer to **Chapter 10** of this publication for additional information.

Strain pole – A vertical support for span wire and related appurtenances.

Surge Protection Devices (SPDs) – Devices designed to protect electronic systems against damages caused by lightning or other electrical disturbances. When used on traffic signal equipment, these devices should conform to the National Fire Protection Association's NFPA 780 (installation of Lightning Protection Systems) standard. In accordance with the new guidelines, critical applications include inductive loops, video cameras, pedestrian pushbutton loops, service loops for controls or signals that exit or enter the cabinet, and the AC that supplies the power.

Traffic control signal -- The specific type of traffic signal that provides alternating stop and go traffic control with red-yellow-green (R-Y-G) signal indications.

Traffic signal – The broad category of highway lights including traffic control signals (provide alternating stop and go), pedestrian signals, flashing beacons, lane-use control signals, ramp metering, and in-roadway lights.

Traffic signal housing – The outer part of a traffic signal section that protects a light and other required components from the elements.

Traffic signal permit – The document approved by the Department to authorize the installation and operation of the traffic signal. The traffic signal permit is for a traffic signal at a specific intersection, and it includes the Traffic Engineering Form TE-964, and traffic signal plans showing the intersection plan sheets with the locations of the traffic signals, traffic signal supports, controller cabinet, junction boxes, detectors, stop lines, street names, approach grades, distance to nearest signals, etc., plus the traffic signal phasing diagram.

Traffic signal support – The physical means whereby signal heads, signs, and luminaires are supported in a particular location. Structural supports are to be designed to carry the loads induced by attached signal heads, small signs, luminaires, and related appurtenances.

Traffic signal system – Two or more traffic control signals operating in coordination with each other.

Traffic signal timing – The analysis of intersection geometrics, speeds, and historical traffic volumes used to identify the specific duration in seconds for the green, yellow, red, Walk, and Don't Walk intervals of each phase. For traffic actuated signals, the traffic signal timing also includes information on the incremental extensions of the green intervals due to the continued presence of approaching vehicles.

Uninterrupted power supply (UPS) – A battery backup system designed to instantly provide electrical power for the operation of the controller and traffic signals during a power outage. UPS became viable with the conversion to LED signals.