

CHAPTER 4

TRAFFIC SIGNAL DESIGN

4.0 General – “Highway traffic signal” is a generic term that applies to intersection stop-and-go signals, flashing beacons, lane use control signals, ramp entrance signals and other types of devices. A traffic control signal (traffic signal) shall be defined as any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed. Traffic is defined as pedestrians, bicyclists, vehicles, and other conveyances using any highway for purposes of travel. This Chapter the design of traffic control signals.

In this Manual, the term “**traffic signal**” applies to a **traffic control signal** unless otherwise noted.

Standards for traffic control signals are important because they need to attract the attention of a variety of road users, including those who are older, those with impaired vision, as well as those who are fatigued or distracted, or who are not expecting to encounter a signal at a particular location.¹

The selection and use of traffic signals should be based on an engineering study of roadway, pedestrian, bicyclist and other conditions.

The designer responsible for any type of traffic signal design project, including traffic control signals, should be aware that the design must comply with various standards. In addition to Department Standard Specifications, the following standards shall be consulted:

- Manual on Uniform Traffic Control Devices (MUTCD) – The MUTCD is the basic guide for signing and marking. The requirements of the MUTCD must be met, as a minimum, on all roads in Tennessee.
- Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, AASHTO – This document provides structural design criteria.
- The National Electrical Code, National Fire Protection Association (NFPA) – This code contains provisions that are considered necessary for the practical safeguarding of persons and property from hazards arising from the use of electricity.
- National Electrical Manufacturer’s Association (NEMA) Standards for Traffic-actuated Controllers – This publication describes the physical and functional requirements of signal controllers. Two standards, TS-1 and TS-2, are defined. TS-1 dates back to the 1970s but still applies to most of the equipment in current use. TS-2 is an emerging standard that incorporates contemporary computer and communications technology.
- TDOT Design Standards – These standards are composed of a number of standard drawings that address specific situations that occur on a large majority of construction projects.

4.1 Traffic Signal Design – A traffic signal shall be designed for both safe and efficient traffic operations. To accomplish this, the design should incorporate the fewest number of signal phases and the shortest cycle lengths that can efficiently

¹ MUTCD, FHWA, 2003, p. 4B-1.

move traffic without compromising safety. The design and operation of traffic signals shall take into consideration the needs of pedestrians as well as vehicular traffic.² The following design criteria set forth TDOT's application of the traffic signal design standards given in the MUTCD.

The key decisions affecting a traffic signal system design include:

- Intersection geometrics (lanes, sight distance, grade, etc.)
- Determination of traffic signal operational mode
- Selection of left turn treatments
- Selection of the traffic signal phasing plan
- Determination of detection needs
- Development of traffic signal timing parameters
- Development of the timing plan(s) for arterial coordination
- Determination of preemption needs
- Location and configuration of all traffic signal displays
- Location and configuration of the controller and cabinet
- Selection of type and location of traffic signal support poles
- Determination of necessary traffic signing
- Location of stop lines and crosswalks
- Determination of wiring, conduit and pull box needs

Future Intersection Expansion – Any planned or anticipated intersection improvements or future phasing needs should be considered. The traffic signal controller type, cabinet type, pole design and traffic signal cable are examples of design features that may be affected by future improvements.

4.1.1 Intersection Geometrics – Intersection geometrics play a pivotal role in designing a traffic signal. In particular, geometrics play just as important a role as traffic volumes in evaluating turn phasing. For example, left turns may be made from shared lanes yielding to the opposing thru traffic; however, the capacity of a shared lane is somewhat limited. The Highway Capacity Manual provides a procedure for assessing the capacity of both shared and exclusive lanes under traffic signal control. The operational advantage of an exclusive lane should be clear from a capacity perspective. Exclusive left turn lanes are normally required when protected left turn movements are provided in the traffic signal phasing.

When left turning volumes are high, multiple exclusive left turn lanes may be required to provide adequate capacity. Dual left turn lanes should be considered when a capacity analysis suggests that overall intersection performance could be improved. Proper attention must be paid to accommodating traffic in multiple left turn lanes as it leaves the intersection. The exit roadway must have enough lanes to accommodate the left turns and pedestrian crosswalks should be clearly marked. Pedestrian signals should always be used for any crosswalk in which pedestrians will encounter protected left turns.

4.1.2 Traffic Signal Movements – A typical four-leg intersection can have up to eight separate movements requiring traffic signal phases (four thru and four left turns). If right turn movements are signalized separately, they are usually operated in conjunction with a protected side street left turn

² MUTCD, FHWA, 2003, p. 4D-2.

movement and operated as an overlap (concurrently with another phase). Four-leg intersections can be operated with between two and eight phases. Two phase operation would only provide phases for the two crossing movements, while the eight phase operation would provide separate phases for each movement. An intersection with two to four vehicle phases should use a four phase cabinet facility. An intersection with five to eight vehicle phases should use an eight phase cabinet facility. Newer controllers allow up to 16 phases, but more than eight phases are only used in unusual situations, such as running two intersections from one controller or complex interchanges.

Four phase cabinets should be used for intersections with 2 to 4 phases and eight phase cabinets should be used for those with 5 to 8.

4.1.3 Traffic Signal Mode of Operation – A traffic signal may operate under two basic modes of operation. It may operate as a fixed time signal, in which basic timing intervals are constant, or as an actuated signal, where many of the timing intervals are variable based on demand.

Traffic signals may be operated as independent (or isolated intersections) or as part of a coordinated signal system. Coordinated traffic signal systems are designed to minimize delay. An individual intersection operates most efficiently when it is allowed to respond to traffic demand in

Traffic signals can operate as an independent intersection or as part of a coordinated system. The traffic signals can be set up to operate in the fully or semi-actuated mode, in fixed time mode, or in a flashing mode of operation. How a signal is operated determines its effectiveness in reducing delay and increasing safety. Signal operation also influences public acceptance.

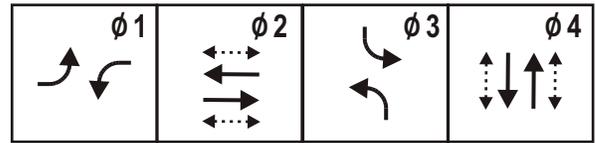
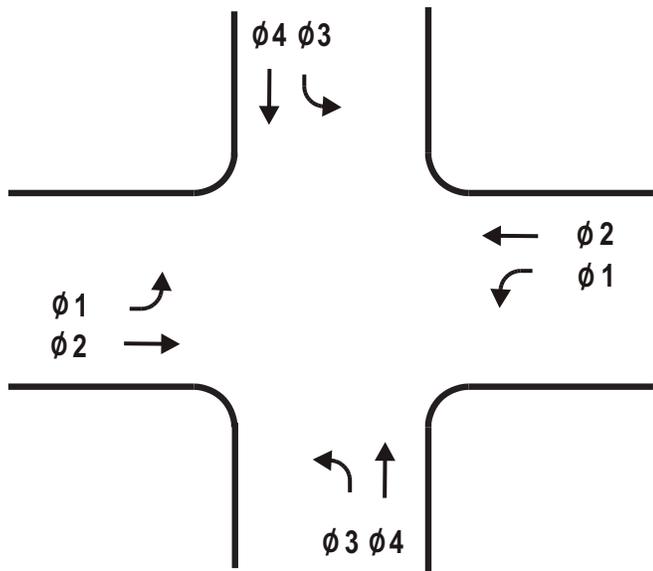
an actuated mode. Actuated operation allows the traffic signal to adjust the cycle length and phase split times on a cycle-by-cycle basis. At all intersections, vehicles tend to group into "platoons." Once a platoon is established, delay can be reduced by keeping the platoon moving through adjacent signals. The coordination of traffic signals (operating more than one signal in a system) can provide smooth progression along an arterial. Operating traffic signals in a coordinated mode does have some drawbacks. The coordination of the system may further delay some minor traffic movements.

4.1.4 Pre-Timed (Fixed Time) Operation – Pre-timed operation is an infrequently used mode of operation (except in downtown areas) in which a traffic signal operates in a non-actuated mode (no vehicle detectors) and in which both the timing and phasing do not vary from cycle to cycle (see Figure 4.1).

Pre-timed two-phase operation is often used in a central business district, but is infrequently used on major streets.

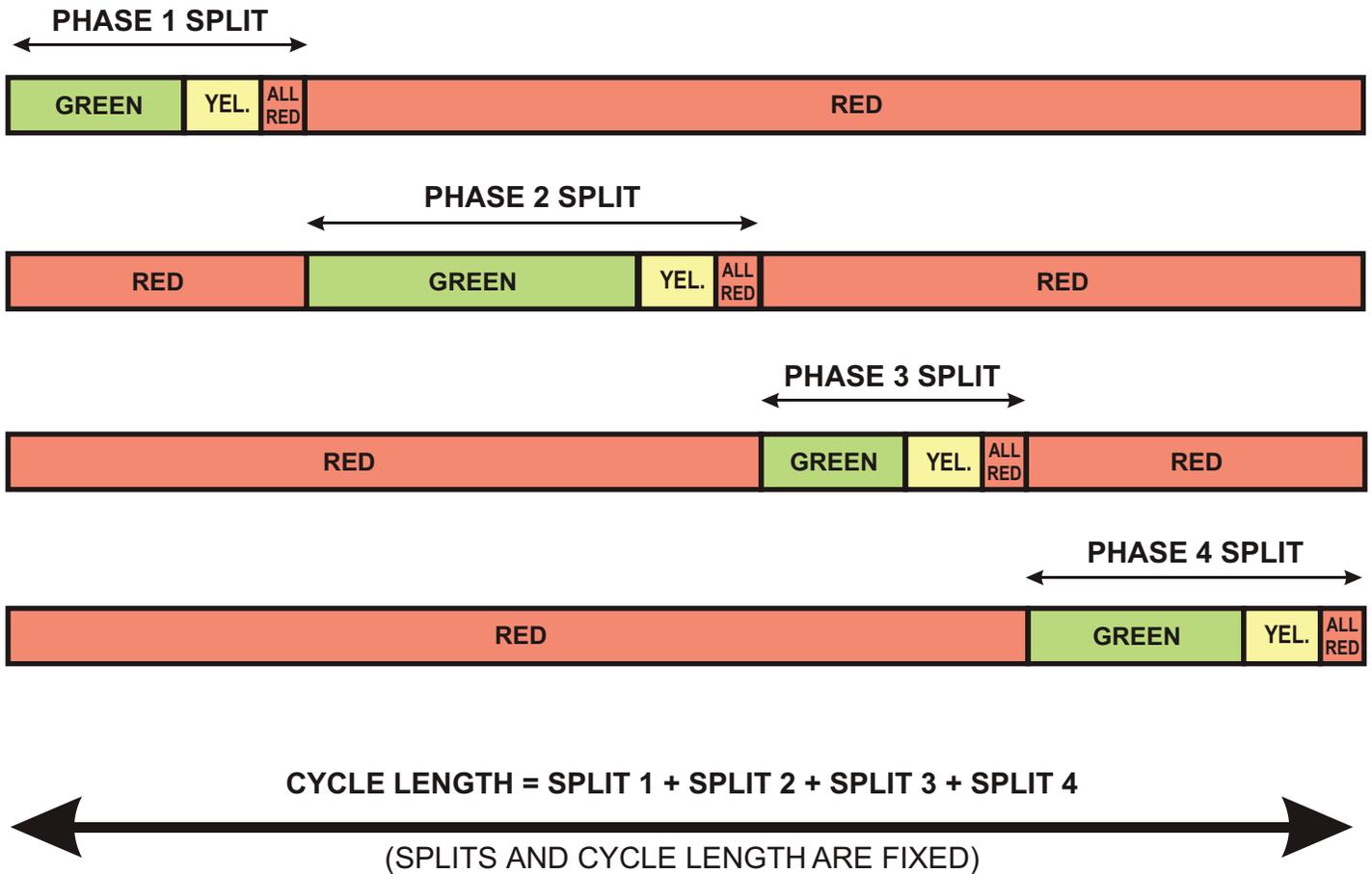
Advantages to pre-timed operation include:

1. Simplicity of equipment
2. Easy to coordinate along a route or in a grid (like a CBD)



LEGEND: → VEHICLE MOVEMENT
 ←····· PEDESTRIAN MOVEMENT

FOUR-PHASE



Disadvantages to pre-timed operation include:

1. Can't recognize or adjust to short term fluctuations in traffic
2. Can cause excessive delays to vehicles and pedestrians during off-peak periods

Pre-timed operation is best suited for the following conditions:

- **Uniform Traffic Demand** – where traffic variations and timing requirements are predictable or do not vary significantly.
- **Signal Coordination** – at intersections in which the major street continuously operates in coordinated mode and fluctuations in volumes along the minor street are negligible.
- **Closely Spaced Signalized Intersections** – at intersections where coordination between adjacent intersections is needed to provide consistent interval timing and offsets.
- **CBD Signals and One-Way Streets** – where two-phase operation is utilized to provide a measure of coordination and speed control.
- **Maintenance** – where ease of maintenance is a concern (no vehicle detectors to maintain).

4.1.5 Traffic Actuated Operation – Traffic-actuated operation of isolated intersections attempts to adjust green time on one or more approaches continuously. These adjustments occur based on real-time traffic measures of traffic demand from vehicle detectors placed on one or more approaches to the intersection.

Advantages to actuated operation include:

1. Reduced Delay (if properly timed)
2. Adaptable to short-term fluctuations in traffic flow
3. Increased capacity
4. More effective at multiple phase intersections

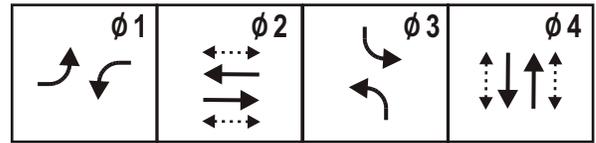
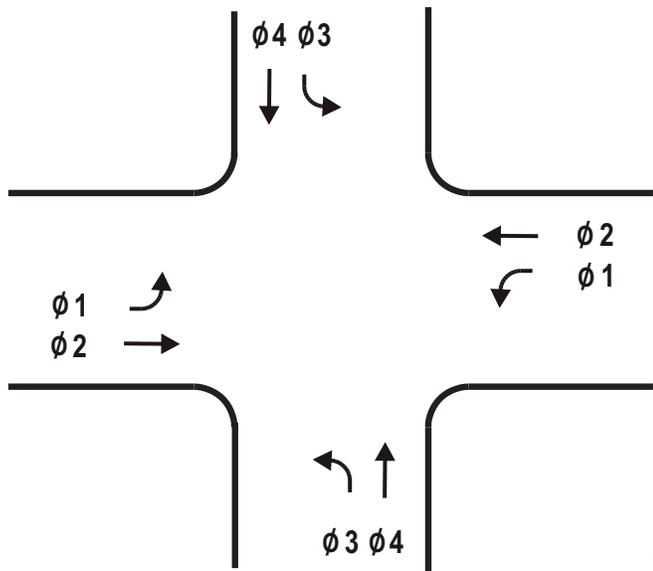
Disadvantages to actuated operation include:

1. Higher cost than pre-timed
2. Long term maintenance of detectors

Traffic actuated signal control can be broken into two types of operation (fully-actuated and semi-actuated, or partially activated).

4.1.6 Fully-Actuated Operation – Fully-actuated operation describes the actuated mode of operation in which a traffic signal operates with vehicle detection for all signal phases. Since the traffic signal operation is based on traffic demand, both the timing and phasing can vary from cycle to cycle (see Figure 4.2).

Fully-actuated operation should normally be used at isolated, high speed and heavy volume intersections.



LEGEND: → VEHICLE MOVEMENT
 ←····· PEDESTRIAN MOVEMENT

FOUR-PHASE

* EACH GREEN INTERVAL VARIABLE FROM:

- A. MIN GREEN TIME SETTING IF ON RECALL
- OR
- B. ZERO IF NOT ON RECALL

TO MAX GREEN TIME SETTING

VARIABLE *
 ←·····→



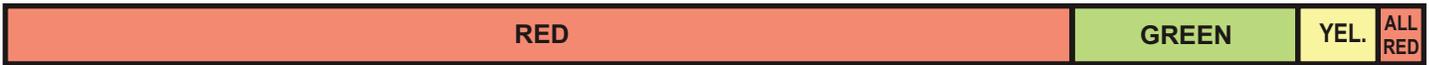
VARIABLE *
 ←·····→



VARIABLE *
 ←·····→



VARIABLE *
 ←·····→



NO TRUE CYCLE LENGTH



Fully-actuated operation should be considered under any of the following conditions:

- **Isolated Intersections** – where traffic fluctuations cannot be anticipated, fully-actuated operation provides maximum flexibility by allowing the traffic signal controller to skip those phases without traffic present.
- **High Speed Intersections** – to reduce problems caused by arbitrary stopping of the major street thru movement, regardless of demand.
- **Part Time Coordination** – when a traffic signal operates in a system part of the day, but operates in a “free” mode at other times.
- **Efficiency** – where traffic operations require maximum efficiency to adequately accommodate existing traffic volumes at the best possible level of service. Fully-actuated operation allows the traffic signal controller to tailor its timing to each individual signal phase according to its actual traffic demand on a cycle-by-cycle basis.

Volume-density operation is a more sophisticated form of fully-actuated control. It has the ability to calculate the duration of Minimum Green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from the initial Passage Time to a Minimum Gap. This reduction in allowable time between calls (or actuations) generally improves efficiency.

4.1.7 Semi-Actuated Operation – Semi-actuated operation is similar to a fully-actuated traffic signal with but not all signal phases are actuated. Some movements do not have detection and are operated as pre-timed phases. When this type of operation is chosen, it is usually the major street signal phase that is non-actuated. The timing on the phases that are actuated can variable or be entirely skipped from cycle to cycle as traffic demands.

In semi-actuated coordinated systems, the major movement is the coordinated phase. Because the major movement is the coordinated phase, it is in effect on constant recall, and no detection is needed while the system is operating. Minor movements are served only when called (or detected) and only at certain points within the system background cycle. In a system, these points ensure that the major movement will be coordinated with adjacent intersections.

In semi-actuated controlled intersections that are not in a system, the major movement is placed on Minimum Recall.

The major movement rests in green until a conflicting call (detection) is received. The Minimum Green must be long enough to ensure it is adequate for the major street movement, but not so long as to unnecessarily delay side street traffic.

Semi-actuated operation should be used when side street volumes are low and sporadic or when an intersection is operated in coordination 24 hours a day.

Semi-actuated operations can work under one of the following conditions:

- **Unpredictable Side Street Volumes** – where side street volumes are sporadic.
- **Limited Traffic Signal Need** – where a traffic signal is needed for only brief periods of the day.
- **Full Time Signal Coordination** – in signal systems that operate in a coordinated mode at all times, where the main street thru traffic phase operates without vehicle detection.

4.1.8 Mode During System Control – Many fully-actuated traffic signals that are in signal systems operate as both fully-actuated and semi-actuated traffic signals. They can be fully-actuated during off peak hours when the system may not running and all intersections to run free, but operate as semi-actuated traffic signals when the system is running.

4.1.9 Dual Ring Controller Operation – A traffic actuated controller typically employs a “dual ring concurrent” timing process. This concept is illustrated in Figure 4.3. A dual-ring controller uses eight phases, each of which controls a single traffic movement. The eight phases are required to accommodate the eight movements (four thru and four left turns) at an intersection. Any movements that do not have a separate protected movement are not assigned phases and not used. Phases 1 through 4 are included in ring 1, and phases 5 through 8 are included in ring 2. The two rings operate independently, except that their control must cross the “barrier” at the same time.

To avoid conflicts, all of the movements from one street must be assigned to one side of the barrier. Similarly, all movements from the other street must be assigned to the other side. On both sides of the barrier there are four phases (two thru and two left). One phase from ring 1 and one phase from ring 2 may operate concurrently, however the concurrent phases must be on the same side of the barrier (see Figure 4.3). Simultaneous phase operation in each ring is not permitted.

The dual-ring concurrent operation of an isolated actuated traffic signal can be the most efficient method of operation.

As an example, if phase 2 (in ring 1) is the EB thru movement, it may be displayed concurrently with either phase 5 (EB left turn) or phase 6 (WB thru), both of which are in ring 2. However, phase 2 can never be displayed concurrently with any of the phases across the barrier (phases 3, 4, 7 or 8 – all side street phases). Any allowed combination of phases may be skipped if there is no demand for that movement.

Four phase operation can be achieved using a dual ring controller by only using phases 1-4. This type of controller can be used for pre-timed, semi-actuated or fully-actuated operation. The majority of signalized intersections now employ dual-ring traffic actuated controllers conforming to NEMA standards. Eight phase dual-ring controllers are typically used in all new installations.

4.2 Traffic Signal Intervals (Phases) – A traffic signal vehicle interval, or phase, can be defined as the part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously (left turn phases, etc.). Generally, the number of traffic signal phases should be held to a minimum. When more than three phases are used to operate a traffic signal, the delay and cycle length usually increase as a result of the increase in start up delays and the increase in signal clearance intervals per signal cycle. When this occurs, the overall intersection efficiency decreases, but the use of fully-actuated traffic signal controllers can sometimes minimize these negative effects .

The number of signal phases used in a traffic signal design is basically a left turn protection issue.

If the need for left turn phasing on an intersection approach has been established, the guidelines in Section 4.2.3 should be used to select the type of left turn phasing to provide. Care should be taken to avoid a “yellow trap” which can occur in some combinations of the type and sequence of left turn movements (see Section 4.2.5).

4.2.1 Need for Left Turn Protection – The primary factors to consider in the need for protection are the left turn volume and the degree of difficulty in executing the left turn through the opposing traffic. The designer should be aware that left turn phases can sometimes significantly reduce the efficiency of an intersection. Left turn phasing should be considered on an approach with a peak hour left turn volume of at least 100 vehicles and a capacity analysis showing that the overall operations are improved by the addition of the left turn phase.

The designer’s goal should be to accommodate left turn movements adequately and safely while delaying the heavier thru traffic movements as little as possible.

In addition, the following guidelines may be used when considering the addition of separate left turn phasing at either a new or existing signalized intersection:

4.2.2 Left Turn Phase Warrants – The following warrants may be used in the analysis of the need for the installation of separate left turn phases.

1. Volume Warrant – Left turn phasing may be considered based on a cross-product threshold as defined by the product of the left turning volume and the volume of opposing traffic (opposing traffic includes both opposing thru and opposing right turning traffic). Left turn phasing should be considered on any approach that meets the following thresholds:

- **One Opposing Lane – 50,000**
- **Two Opposing Lanes – 90,000**
- **Three Opposing Lanes – 110,000**

2. **Delay Warrant** – Left turn phasing may be considered if the left turn delay is greater than or equal to 2 vehicle hours on the critical approach during the peak hour. Also, a minimum left turn volume of two vehicles per cycle must exist with the average delay per vehicle being no less than 35 seconds.³
3. **Accident Warrants** – Left turn phasing may be considered on an approach if the following left turn accident experience is documented:⁴
 - **One approach** – 4 left turn accidents in one year or 6 left turn accidents in two years.
 - **Two opposing approaches** – 6 left turn accidents in one year or 10 left turn accidents in two years.
4. **Sight Distance** – Left turn phasing allowing only protected turns should be considered at locations where vertical or horizontal curves restrict visibility and prohibit safe left turn maneuvers.
5. **High Speed, Wide Intersections** – Left turn phasing may be considered at a location in which two or more opposing lanes of traffic having a posted speed limit of 45 miles per hour or greater must be crossed in making the left turn movement.

4.2.3 Types of Left Turn Phasing – Three general types of left turn phasing are possible. Figure 4.4 displays the signal heads for various types of left turn phasing.

- A. **Permissive Only Left Turn Mode** – Left turns are allowed only concurrently with the adjacent thru movement and must yield to opposing traffic.
- B. **Protected/Permissive Left Turn Mode** – This is the most common and generally most efficient type of left turn operation. It allows left turns to be made both on the left turn GREEN ARROW (when they are protected) and on the CIRCULAR GREEN signal indication (when they are permitted, but must yield to opposing traffic). It should be considered when any of the following conditions exist:
 - **Capacity** – where intersection capacity is limited and maximum efficiency of the traffic operations is needed.
 - **Left Turn Storage** – where left turn lanes are not present or left turn lanes are of inadequate length to store the actual left turn traffic volumes.
 - **Left Turn Accidents** – where the left turn signal phase is not justified by the left turn accident warrant described in Section 4.2.2.

The preferred phasing method is protected/permissive unless one of the conditions exists requiring protected only left turn phasing. It is generally more efficient than protected only left turn phasing.

³ Manual of Traffic Signal Design, ITE, 1998, p.32

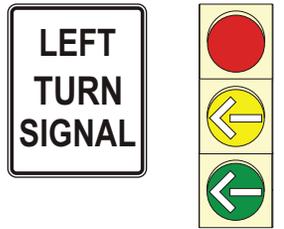
⁴ Ibid. p. 32-33

LEFT TURN SIGNAL DISPLAYS

PERMISSIVE ONLY MODE

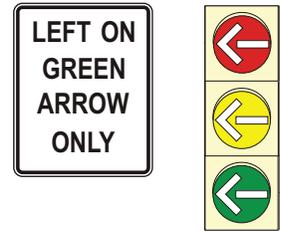
NO SEPARATE SIGNAL REQUIRED

PROTECTED ONLY MODE
(ONE PER LEFT TURN LANE)



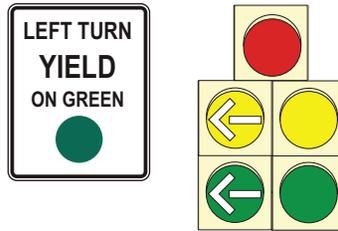
(SIGN REQUIRED)

OR



(SIGN OPTIONAL)

PROTECTED/
PERMISSIVE MODE



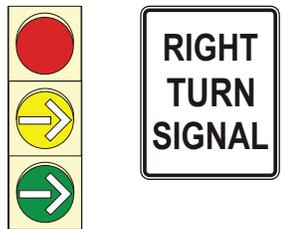
(SIGN OPTIONAL)

RIGHT TURN SIGNAL DISPLAYS

PERMISSIVE ONLY MODE

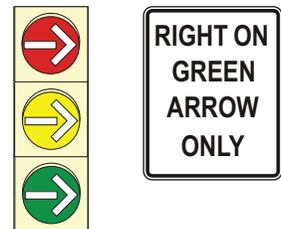
NO SEPARATE SIGNAL REQUIRED

PROTECTED ONLY MODE
(ONE PER LEFT TURN LANE)



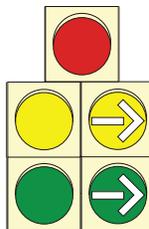
(SIGN REQUIRED)

OR



(SIGN OPTIONAL)

PROTECTED/
PERMISSIVE MODE



NO SIGN

C. Protected Only Left Turn Mode – This type of left turn operation allows left turns to be made only on a left turn GREEN ARROW display. It should be considered when any of the following conditions exist:

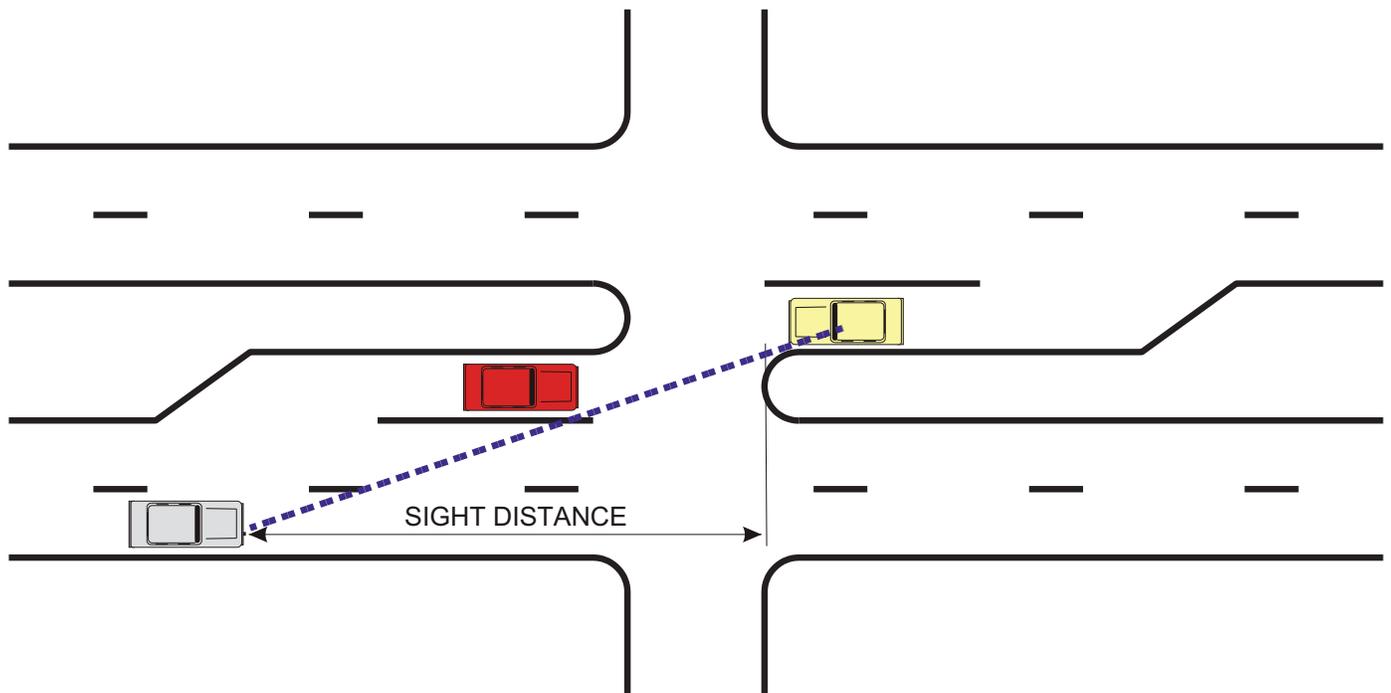
- **Limited Left Turn Sight Distance** – the view of opposing thru and opposing right turn traffic is restricted (see Figure 4.5).

Protected only left turn phasing should always be used for intersections with insufficient sight distance and high approach speeds.

- **Excessive Street Width** – left turning traffic must cross three or more lanes and the speed of the opposing traffic is 45 mph or greater.⁵
- **Inadequate Geometry** – at intersections where there is inadequate room for opposing left turn movements on the same street to move simultaneously without conflicting or crossing. Either Lead-Lag or split phasing must be used.
- **Left Turn Accidents** – where the left turn signal phase is justified by the left turn accident warrant described in Section 4.2.2 of this manual.
- **Multiple Left Turn Lanes** – on approaches where two or more side by side left turn lanes exist.⁶ Protected left turn phasing shall be provided for an approach to an intersection with two or more adjacent left turn only lanes on one approach.
- **Lead-Lag** – Protected only phasing shall be used on the approach with the leading left movement of a Lead-Lag intersection phasing sequence to avoid a “yellow trap” (see Sections 4.2.4-D and 4.2.5).

⁵ Traffic Engineering Handbook, ITE, 1999, p. 477

⁶ Ibid.



OPERATING SPEED (MPH)	SAFE SIGHT DISTANCE (FT.)		
	2-LANE	4-LANE	6-LANE
20	240	260	280
30	360	390	420
40	470	520	560
50	590	650	700
60	710	780	840

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2001.

4.2.4 Sequence of Left Turn Protection – Once the need for and type of left turn protection is determined, it must then be decided where to sequence the left turn phase in the signal cycle. Additionally, if there is more than one left turn phase to be added, it must also be decided how they will sequence in relation to one another.

A. Leading Left Turn – This defines a left turn signal phase that precedes the thru green signal phase on a particular street (see Figure 4.6 and 4.7). Left turning motorists tend to react quicker to a leading left turn than to a lagging left turn.

A leading left turn should be used in the following circumstances⁷:

- **Lack of Left Turn Lanes** – a leading left turn signal phase increases the approach capacity on approaches without separate left turn lanes. This assures that all traffic moves on the approach at the beginning of the green signal phase.
- **Signal Coordination** – where a time-space diagram indicates that a leading left turn signal phase will increase the arterial green bandwidth and improve the signal progression.
- **Minimizing Conflicts** – to minimize conflicts between left turn and opposing thru vehicles by clearing the left turns through the intersection first.

Leading left turn phasing should be used unless other sequencing is needed for more efficient operation or safety. However, caution should be exercised to avoid a “yellow trap” when using simultaneous leading protected/permissive left turns (see Section 4.2.5).

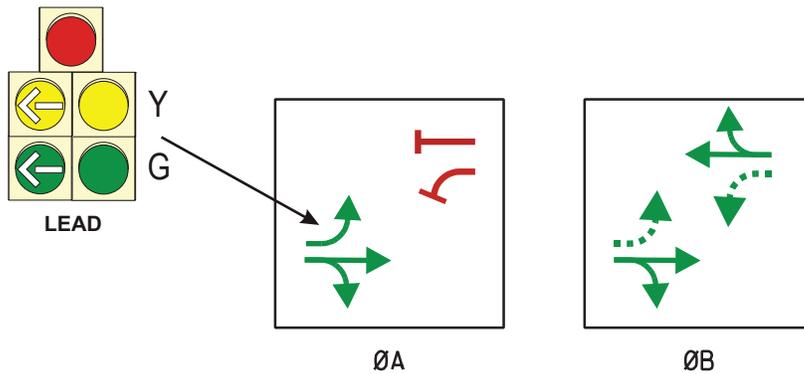
B. Split Phase – This defines the situation when each approach on the same street is serviced separately with GREEN signal indications (see Figure 4.7). Typically, it is the side street which is split phased. The major street should almost never be split phased. Split phasing could be used in the following circumstances:

- **Lack of Turn Lanes** – on an approach that lacks left turn lanes and whose left turn and thru volumes are approximately equal. This assures that all traffic moves on an approach at the beginning of the green signal phase.⁸
- **Inadequate Intersection Geometry** – at intersections where intersection turning movements dictate exclusive left turn lanes and shared thru/left turn lanes.
- **Offset Intersections** – where alignment prohibits concurrent left turn and thru movements from opposite approaches.

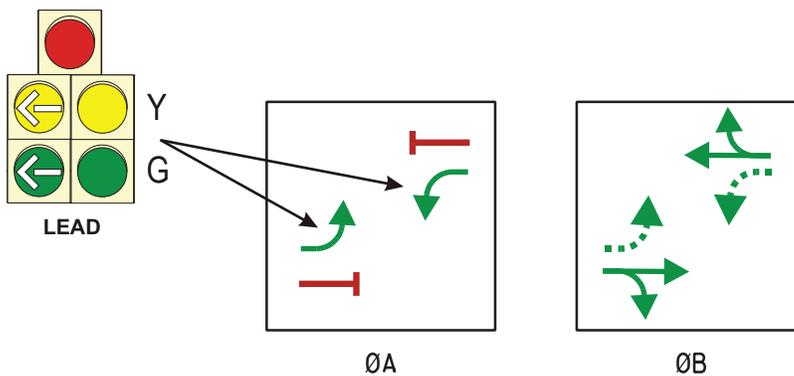
Split phasing typically creates additional overall intersection delays and should only be used in unusual circumstances.

⁷ Traffic Control Devices Handbook, ITE, 2001, p. 274

⁸ Traffic Engineering Handbook, ITE, 1999, p. 480.



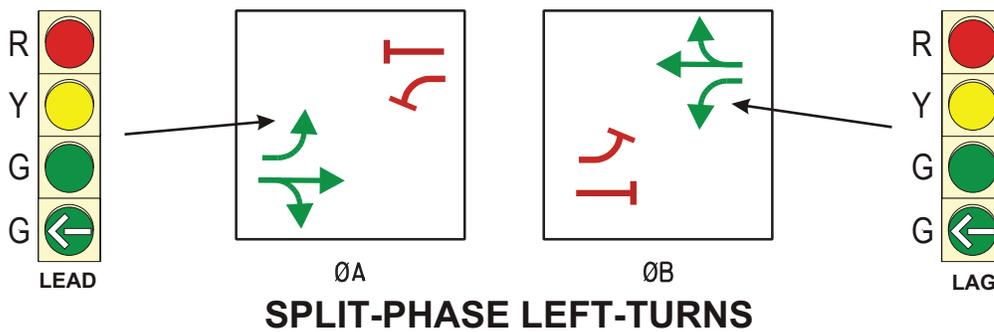
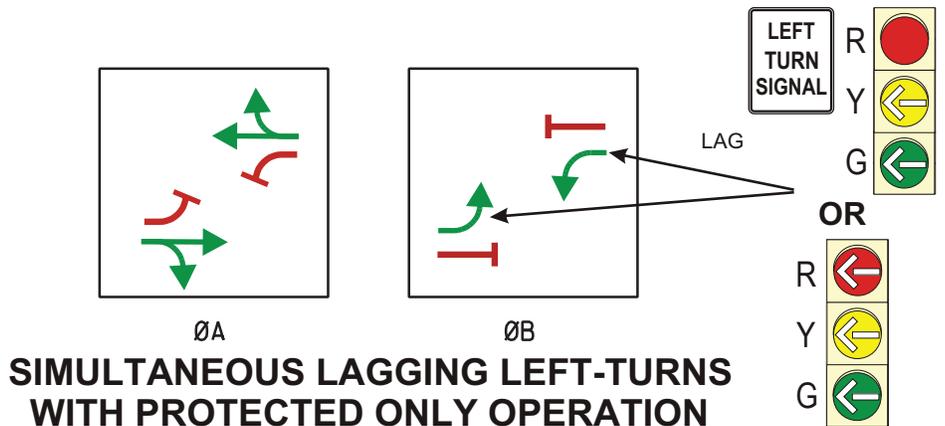
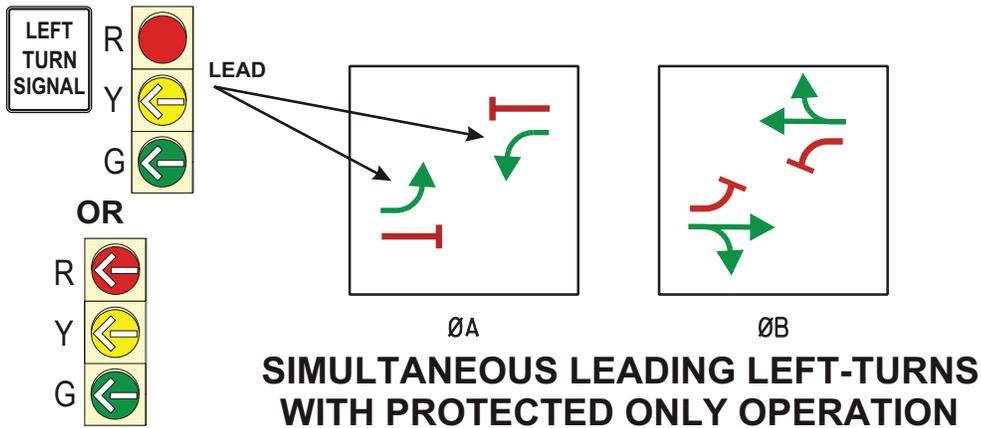
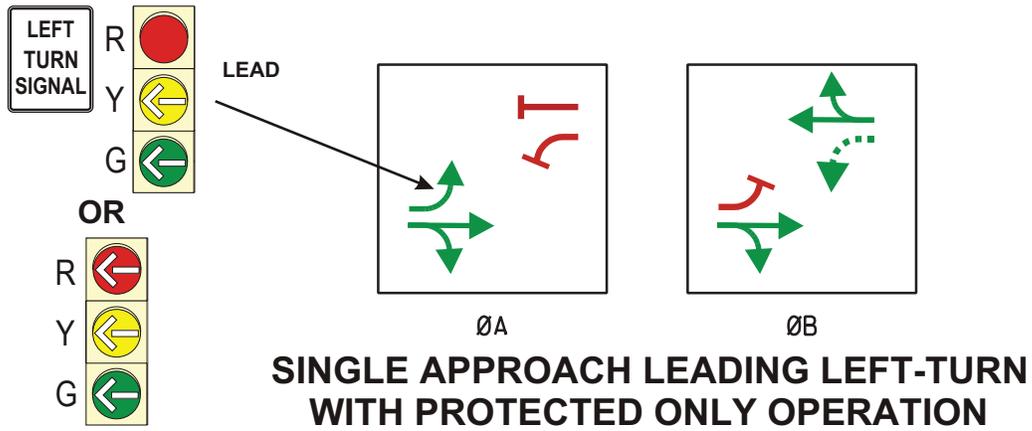
**SINGLE APPROACH LEADING LEFT-TURN
WITH PROTECTED-PERMISSIVE
OPERATION**



**SIMULTANEOUS LEADING LEFT-TURNS
WITH PROTECTED-PERMISSIVE
OPERATION**

NOTE: TO AVOID A “YELLOW TRAP”:

1. REQUIRE THE SIDE STREET TO BE SERVICED PRIOR TO RETURNING TO THE LEFT TURN PHASE
- OR 2. PHASE OMIT THE LEADING LEFT TURN PHASE WHEN THE OPPOSING THRU GREEN IS DISPLAYED



- C. **Lagging Left Turn** – This is a left turn signal phase that comes at the end of the thru green phase. This type of sequence is not normally expected by drivers.

Lagging left turn movements should be used cautiously. They are not normally expected by drivers and can lead to a “yellow trap” in certain situations.

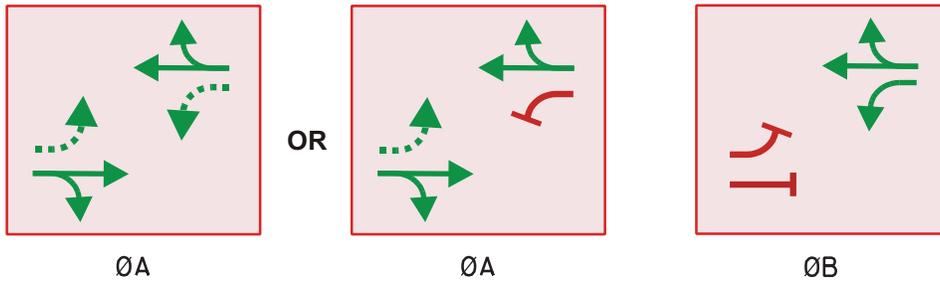
A “yellow trap” can occur when a traffic signal controller with a protected/ permissive or protected only lagging left turn initiates its lagging left turn phase (see Figure 4.8). The opposing left turn movement can experience a “yellow trap” (see Section 4.2.5). For these reasons, this phasing sequence is not recommended. Single lagging left turns should only be used if the leading left turn movement is prohibited or is at a T-intersection. Simultaneous lagging left turns should only be used if they are protected only phases (see Figure 4.7)

- D. **Lead-Lag Left Turns** – This is the combination where both a leading and lagging left turn signal phase is provided on the same street. Figure 4.8 shows this combination operating in a protected/permissive mode as previously described. It may be used in the following circumstances:

- **Lack of Left Turn Lanes** – on one and two lane approaches that lack left turn lanes.
- **Signal Coordination** – where a time-space diagram indicates that a lead-lag left turn combination in the proper direction will increase the arterial green band width and improve signal progression.
- **Unequal Left Turn Volumes** – To allow for the separate timing of each left turn phase.
- **Inadequate Intersection Geometry** – At intersections where there is inadequate room for opposing left turn movements on the same street to move simultaneously without conflicting or crossing. Protected only left turns must be used.

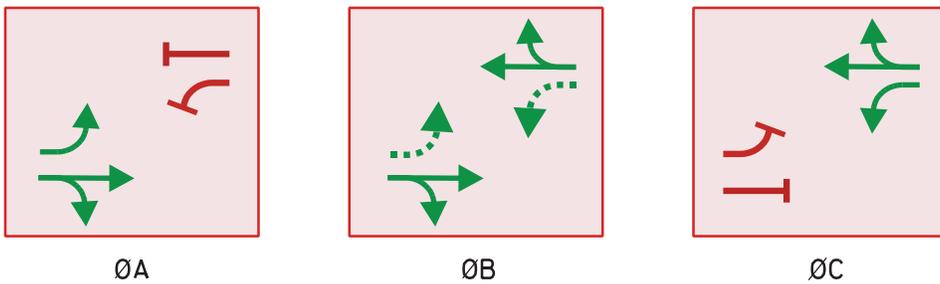
Leading left turn movements in lead-lag signal phasing shall be protected only phases to avoid a “yellow trap”.

DO NOT USE - YELLOW TRAP



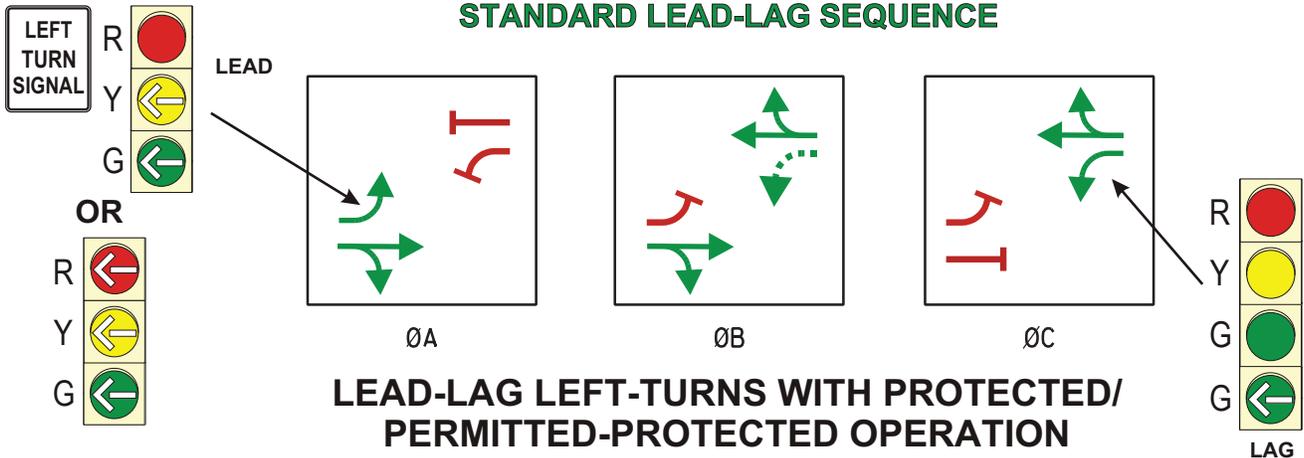
SINGLE LAGGING LEFT-TURN

(Phase A left turn experiences yellow-trap -
Do not use unless Phase A left-turns are prohibited)



**LEAD-LAG LEFT-TURNS WITH
PROTECTED-PERMITTED OPERATION**
(Phase A left turn experiences yellow trap)

STANDARD LEAD-LAG SEQUENCE



**LEAD-LAG LEFT-TURNS WITH PROTECTED/
PERMITTED-PROTECTED OPERATION**
(Use protected only phasing for leading
left-turn to avoid yellow trap)

4.2.5 Left Turn “Yellow Trap” – A “yellow trap” can occur when all movements for one approach conclude (permissive or protected-permissive left and thru movement), but the opposing approach movements continue (see Figure 4.8). A driver on the concluding approach waiting to turn left in the permissive portion of the ending movement sees all of the signal indications turn YELLOW and wrongly assumes that the opposing traffic is also receiving YELLOW signal indications (the opposing direction is about to receive a protected left turn in combination with its thru movement). The driver now believes that his left turn can be completed on yellow when, in fact, the opposing thru traffic still has a CIRCULAR GREEN thru signal indication. If the left turn is made under these conditions an accident could occur.

A “Yellow Trap” is a condition in which a permitted left turn phase ends in one direction while the opposing through movement continues through the succeeding phase. A hazard is introduced because the left turning drivers tend to perceive the end of their phase as an opportunity to clear the intersection as a “sneaker,” while the green indication in the opposing direction is displayed continuously during the transition from one phase to the next.

A “yellow trap” can occur when:

- **Simultaneous Protected/Permissive Leading Left Turns** – A fully-actuated traffic signal controller with simultaneous protected/permissive leading left turns, in the absence of side street traffic, cycles back and forth between a thru phase and a leading left turn phase.⁹ In this case, the “yellow trap” can be eliminated by using protected only left turns, by servicing the side street prior to returning to the left turn phase, “or by phase omitting the protected left turn phase when the opposing thru green is displayed”.¹⁰
- **Single Lagging Protected Only or Protected-Permissive Left Turns** – A “yellow trap” can occur when a single lagging left turn movement begins after completion of an opposing permissive left turn movement. The “Yellow Trap” can be avoided only if leading left turns are prohibited.
- **Lead-Lag Left Turns** – Similar to a single lagging left turn movement, a lead-lag “yellow trap” can occur when a single lagging left turn movement begins after completion of the permissive portion of the protected/permissive phase of the opposing movement. The “Yellow Trap” can be avoided if leading left turns in lead-lag phasing are protected only.

⁹ Traffic Engineering Handbook, ITE, 1999, p. 479

¹⁰ Ibid.

4.2.6 Right Turn Indication¹¹ – Typical right turn signal heads are shown in Figure 4.4. Separate phasing is typically not defined for right turns, but two types of indications may control right turning movements. Three parameters define the right turn treatment for each approach:

Separate right turn signal indications are typically used only when a separate right turn lane exists.

- Lane utilization (shared, exclusive or channelized)
- Right turn on red (allowed or prohibited)
- Right turn movement protection (permissive, protected or both)

It is important to ensure that the lane utilization is compatible with the signal protection and with the accommodations for pedestrians. The three types of right turn phasing are:

- A. Permissive Only Mode** – A separate signal indication is not required and right turns may be made on red unless prohibited by a traffic sign. Unless otherwise noted, this type of control is in effect.
- B. Protected Only Mode** – This indication is used when right turns are not allowed concurrently with the adjacent thru movement. The protected right turn cannot occur concurrently with an adjacent Pedestrian Walk phase. A separate right turn signal head is required.
- C. Protected/Permissive Mode** – This allows right turns to be made both on a right turn GREEN ARROW and on the CIRCULAR GREEN signal indication. Typically displayed as a phase overlap with a protected side street left turn movement, a separate signal face may be used, but is not required.

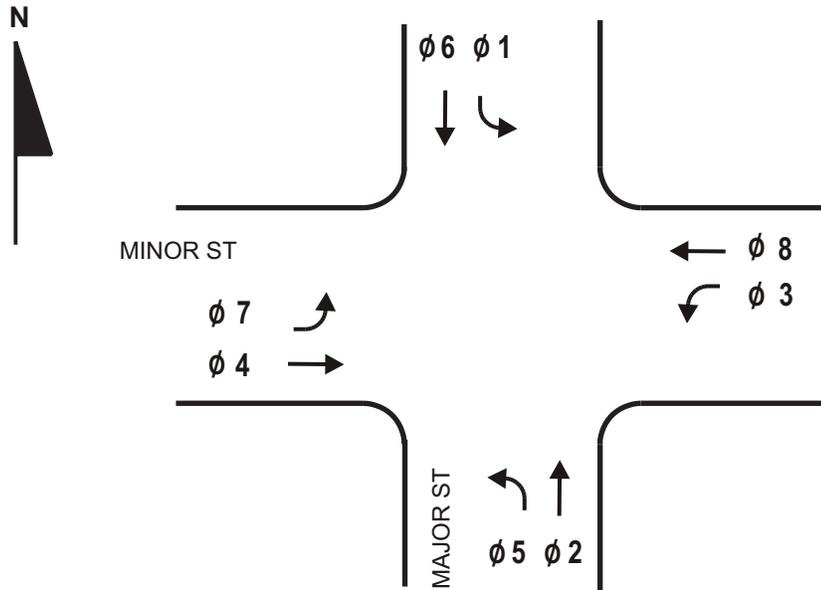
4.2.7 Phase Numbering Convention – Phases for Pre-timed, Semi-Actuated or Fully-Actuated control are numbered with a convention that provides the basis for the numbering system for signal heads and detectors. Phasing diagrams typically use the NEMA phase numbering convention. In the absence of a phase numbering convention by the local agency, the following convention should be used:

4.2.7.1 Four way Intersections (8 - Phase Traffic Signal Controllers)

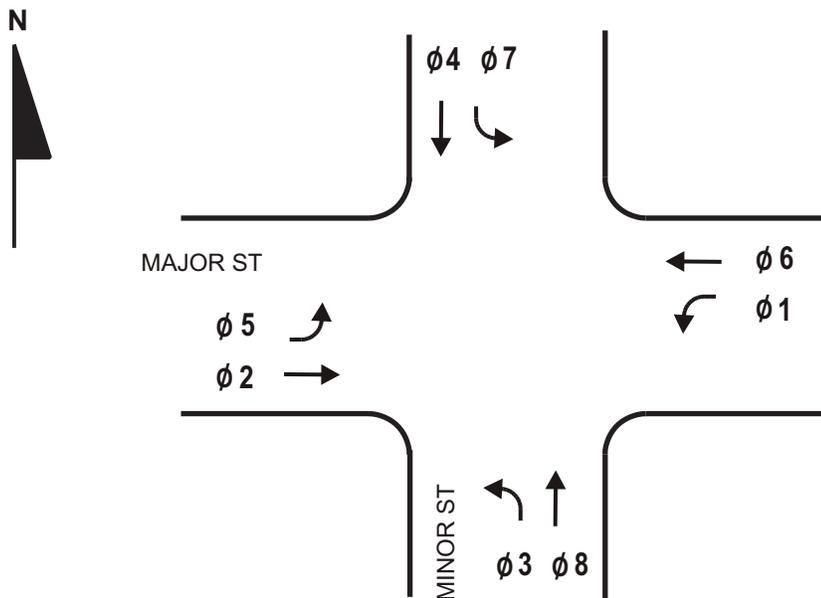
A. Major street runs North - South (see Figure 4.9)

- Phase 1 SB left turn traffic
- Phase 2 NB thru traffic
- Phase 3 WB left turn traffic
- Phase 4 EB thru traffic
- Phase 5 NB left turn traffic
- Phase 6 SB thru traffic
- Phase 7 EB left turn traffic
- Phase 8 WB thru traffic

¹¹ MUTCD, FHWA, 2003. p. 4D-7.



**NORTH-SOUTH AS
MAJOR STREET**
FOR 8-PHASE CONTROLLER



**EAST-WEST AS
MAJOR STREET**
FOR 8-PHASE CONTROLLER

B. Major street runs East - West (see Figure 4.9)

Phase 1	WB left turn traffic
Phase 2	EB thru traffic
Phase 3	NB left turn traffic
Phase 4	SB thru traffic
Phase 5	EB left turn traffic
Phase 6	WB thru traffic
Phase 7	SB left turn traffic
Phase 8	NB thru traffic

4.2.7.2 Tee-Intersections – Overlaps A through D (phases operating concurrently with other phases) are used if a four phase cabinet is used.

A. Major street runs North - South; minor street intersects from the East (see Figure 4.10)

Phase 1	SB left turn traffic
Phase 2	NB thru traffic
Phase 4	WB traffic
Phase OL	SB thru traffic

B. Major street runs North - South, minor street intersects from the West (see Figure 4.10)

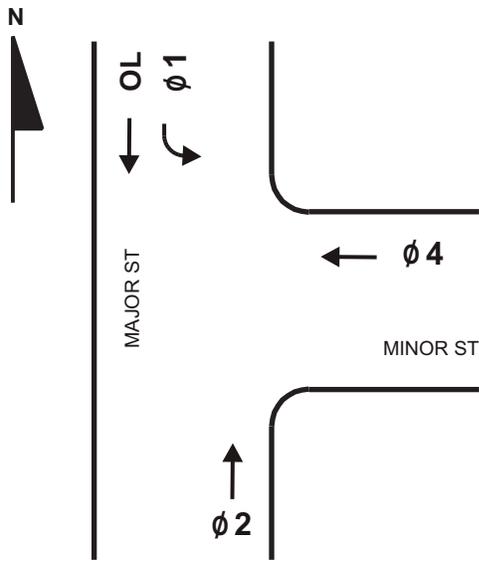
Phase 1	NB left turn traffic
Phase 2	SB thru traffic
Phase 4	EB traffic
Phase OL	NB thru traffic

C. Major street runs East - West, minor street intersects from the South (see Figure 4.10)

Phase 1	WB left turn traffic
Phase 2	EB thru traffic
Phase 4	NB traffic
Phase OL	WB thru traffic

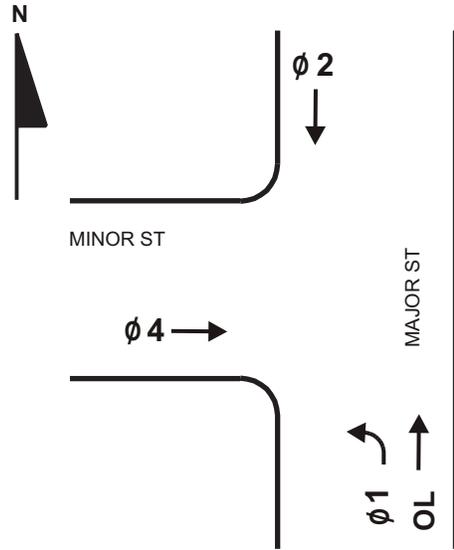
D. Major street runs East - West, minor street intersects from the North (see Figure 4.10)

Phase 1	EB left turn traffic
Phase 2	WB thru traffic
Phase 4	SB traffic
Phase OL	EB thru traffic



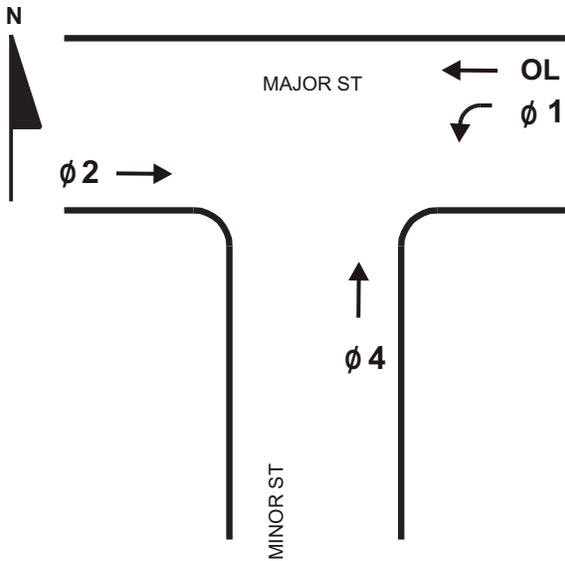
**EAST APPROACH AS
MINOR STREET**

FOR 8-PHASE CONTROLLER
IN A 4-PHASE CABINET



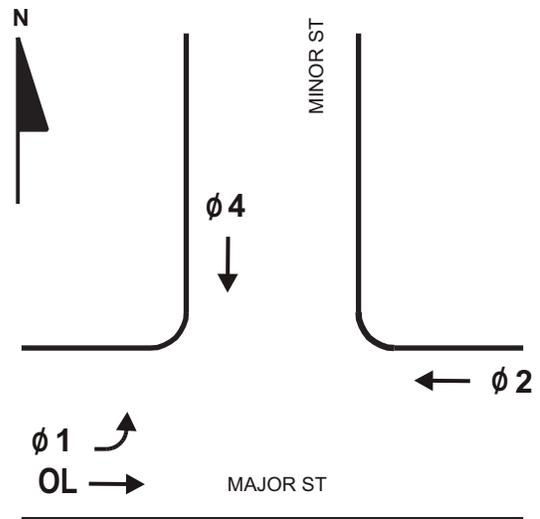
**WEST APPROACH AS
MINOR STREET**

FOR 8-PHASE CONTROLLER
IN A 4-PHASE CABINET



**SOUTH APPROACH AS
MINOR STREET**

FOR 8-PHASE CONTROLLER
IN A 4-PHASE CABINET



**NORTH APPROACH AS
MINOR STREET**

FOR 8-PHASE CONTROLLER
IN A 4-PHASE CABINET

4.3 Vehicle Detection – As described in Section 4.1.3, traffic signals are classified as pre-timed or actuated. Vehicle actuated traffic signals can be semi-actuated with detectors on some, but not all approaches, and in which right-of-way is relinquished only when a call is received for the actuated phase, or fully-actuated which requires detectors on all approaches and in which right-of-way does not automatically go to a designated phase unless it is recalled by a function on the traffic signal controller.

The type of vehicle detection system used for actuated traffic signal control depends on the operational requirements of the intersection in terms of type and use of data needed by the controller to operate efficiently and the construction and maintenance cost.

Vehicle detectors are used to detect the presence or passage of a vehicle on a portion of a roadway. They are an integral part of any traffic actuated traffic signal design as their input determines the variable timing and phasing of the traffic signal. Additionally, the proper placement of these detectors contributes significantly to the overall efficiency of the traffic operations at the intersection.

4.3.1 Locking vs. Non-Locking Memory – Traffic signal controllers have three modes for detection memory: lock, non-lock and recall.

- A. Locking Memory** – Locking memory means that a vehicle call is held by the controller (even after the vehicle has left the detection area) until the call has been satisfied. This is appropriate for left turn lanes which are controlled by a protected-only left turn phase, for some side streets and for high speed approaches that have advance loops only and no stop line loops.
- B. Non-Locking Memory** – Non-locking memory means that a waiting call is dropped (or forgotten) by the controller as soon as the vehicle leaves the detection area. This is particularly useful in lanes where a large number of vehicles turn right on red and also in left turn lanes with permissive or protected-permissive left turn phases. Most stop line loops are set as non-locking, except in unusual circumstances.

Where stop line detectors are used to detect the presence of a vehicle, they are typically located where the vehicle is anticipated to stop, and operate in the non-locking memory mode of detection. They may extend several feet beyond the stop line to ensure vehicle detection. Where advance detectors are used to detect the passage of a vehicle some distance back from the stop line, they are located in the path of the vehicle and typically operate in the locking memory mode of detection to retain the vehicle call. Table 4.1 shows the typical uses of locking and non-locking memory.

Table 4.1 Typical Uses of Locking and Non-Locking Memory

Location of Loop	Type	Memory Setting
Left Turn Lane Stop Line	Protected Only Phasing	Locking*
Left Turn Lane Stop Line	Protected/Permissive or Permissive Only Phasing	Non-Locking
Thru Lane Stop Line	Thru Phase (On Recall)	Non-Locking (typical) or Locking**
Thru Lane Advance	Thru Phase	Locking
Thru Lane Stop Line	Thru Phase (Not on Recall)	Locking**
Right Turn Lane Stop Line	Protected Only Phasing	Locking
Right Turn Lane Stop Line	Protected/Permissive or Permissive Only Phasing	Non-Locking

* Consider using delay features on loop detector units to prevent cross traffic from placing a vehicle call to the controller.

** Consider using delay features on loop detector units on side street combination thru/right turn lanes where vehicles may turn right on red.

4.3.2 Detection for Different Approach Speeds – Stop line presence detection is typically used on low speed approaches (30 mph or less). Approaches with only stop line detection and with speeds greater than 35 mph may cause problems for a driver in deciding whether or not to proceed through an intersection when faced with a Yellow Change Interval.¹² This is often referred to as a “**dilemma zone**”.

A common method of addressing the dilemma zone issue is to install advance detectors. A combination of advance detectors and stop line loops can be used on moderate speed approaches (35 to 40 mph). Advance detectors alone are typically used on high speed approaches (40 mph and higher) and often on moderate speed approaches. A combination of advance detectors and stop line loops can be used on moderate speed approaches (35 to 40 mph).

4.3.3 Stop Line Detection – Stop line detectors are located at the stop line on an intersection approach. Stop line detection is used in thru lanes on minor approaches, thru lanes on low speed approaches, and in left turn lanes (see Figure 4.11). All left turn lanes at actuated traffic signals must have stop line detection. Stop line detection is obviously needed to actuate a dedicated left turn phase that is not on recall. Approaches with left turn lanes, but without separate left turn phases, must have stop line detection so that the traffic signal controller can hold the green phase while the left turn vehicle waits for possible gaps in opposing traffic.

4.3.4 Advance Detection – Advance detectors are used on the thru lanes of moderate/high speed approaches (35 mph or greater) in advance of the approach stop line (see Figure 4.11). These detectors typically operate in a locking memory mode and detect the passage of a vehicle. Advance detectors can provide the traffic signal controller with information on vehicles approaching the intersection and, in the case of a volume density operation, can count the number of vehicles on the approach that are waiting with a RED signal indication. The location of these detectors is based on the safe stopping distance of approaching vehicles for the approach speed (see Figure 4.12).¹³

Advance detection should be used for approaches with speeds 35 mph or higher.

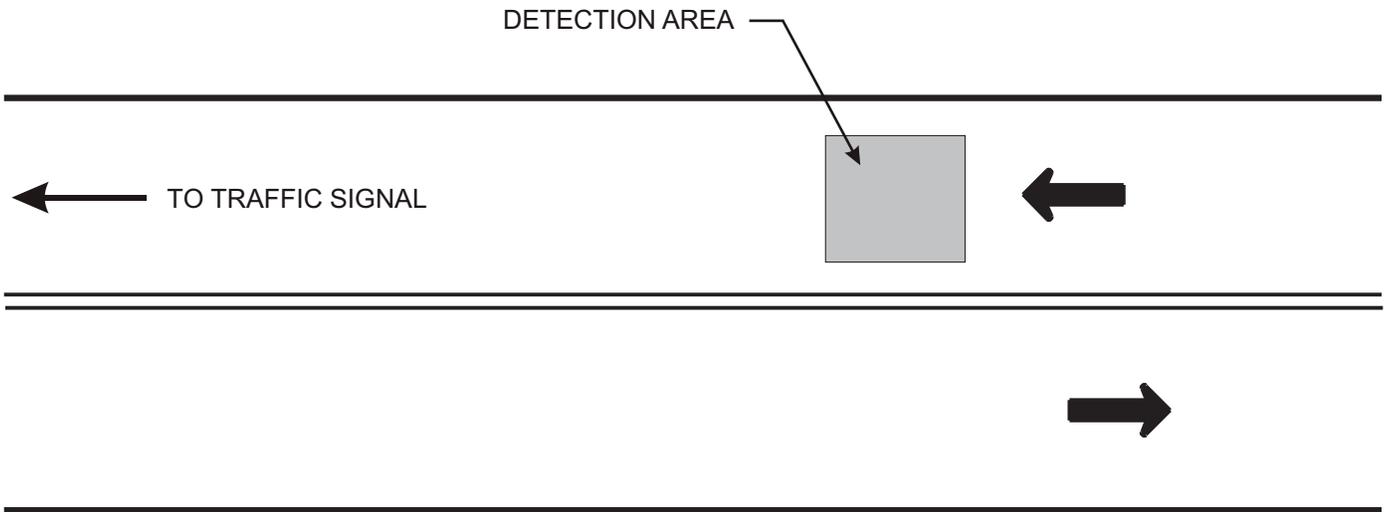
4.3.5 Methods of Detection – Many different technologies exist to enable detection of vehicles. The three types of detection typically used in Tennessee are:

- Inductive Loop (standard saw cut loops or preformed loops)
- Microwave Detection
- Video Detection

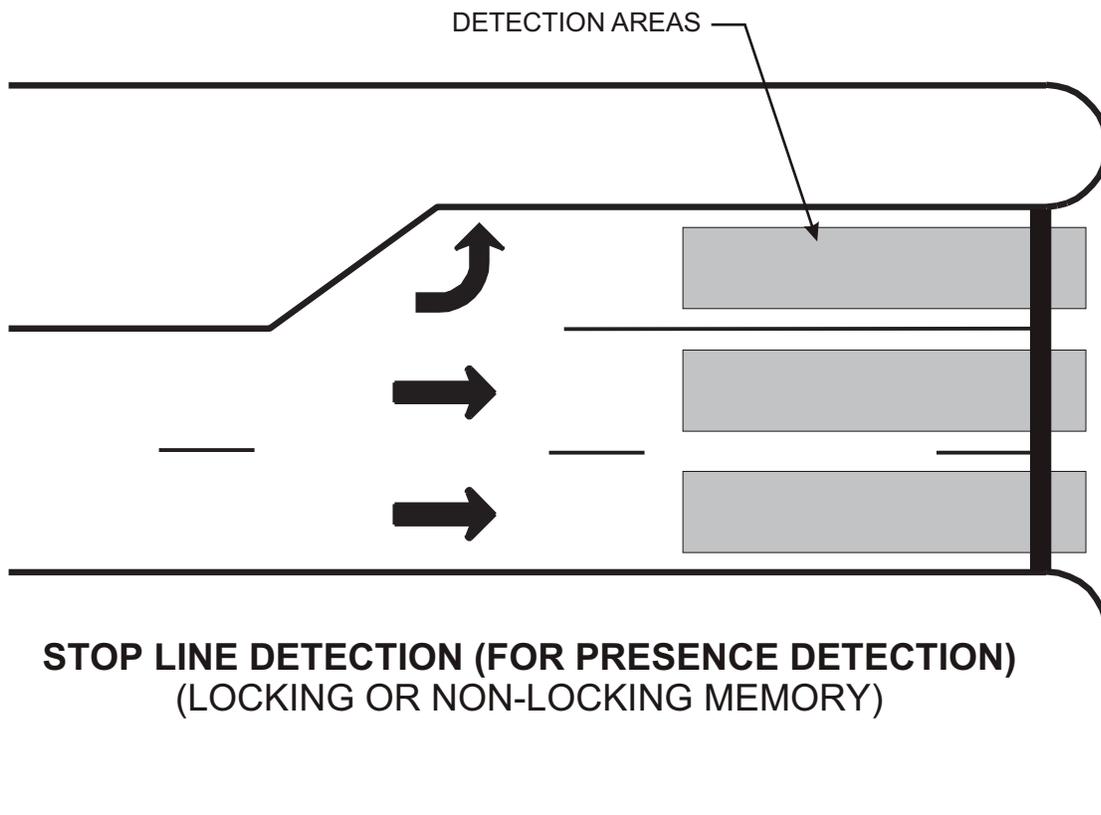
All three of these methods of detection can be used for stop line detection. However, the inductive loop is normally used for advance detection. Table 4.2 lists the advantages and disadvantages of these and other types of detection technologies.

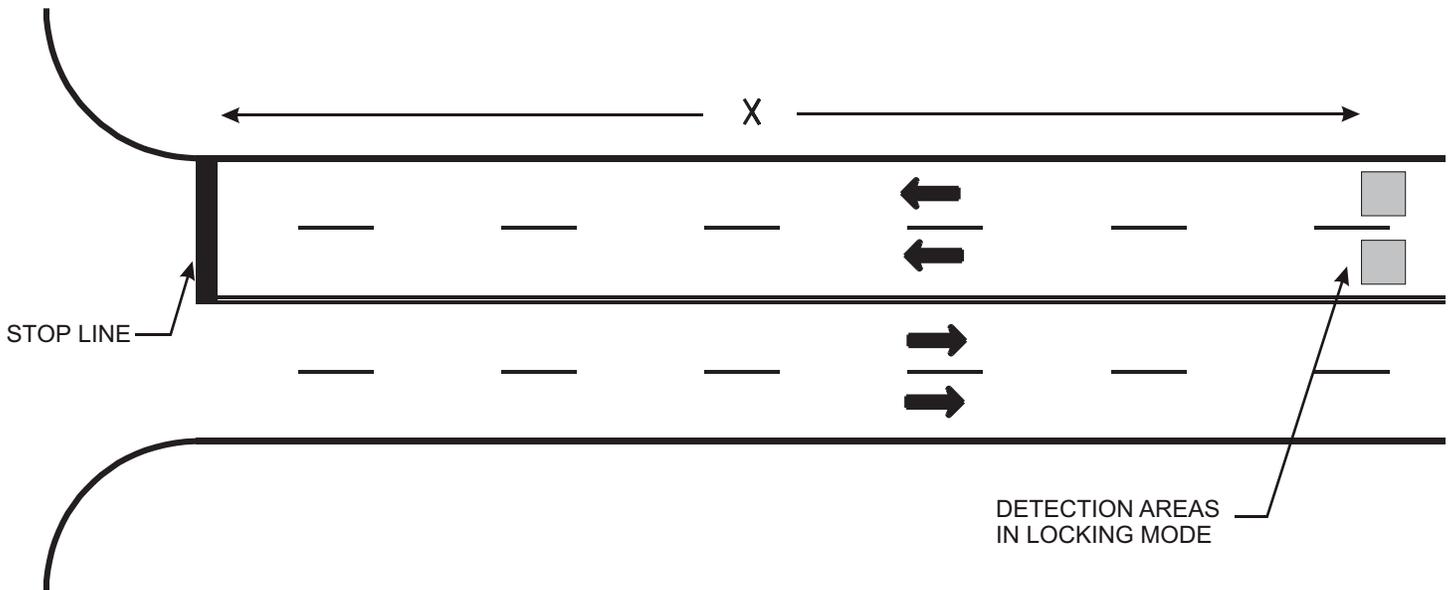
¹² Manual of Traffic Signal Design, ITE, 1998, p. 38

¹³ Ibid, p. 89



ADVANCE DETECTION (LOCKING MEMORY)





ADVANCE DETECTOR SETBACK (X)

SAFE STOPPING SIGHT DISTANCES:

$$X = SSD = rV + 0.5V^2/d$$

WHERE: SSD = STOPPING SIGHT DISTANCE (FT)
 r = REACTION TIME = 1.0 SEC
 V = APPROACH SPEED (FT/SEC)
 d = DECELERATION RATE (10 FT/SEC²)

APPROACH (MPH)	SPEED (FT/SEC)	DETECTOR SETBACK (X) (FEET)
35	51.3	185' (USE VOLUME DENSITY CONTROLLER)
40	58.7	230' (USE VOLUME DENSITY CONTROLLER)
45	66.0	285' (USE VOLUME DENSITY CONTROLLER)
50	73.3	340' (USE VOLUME DENSITY CONTROLLER)
55	80.7	405' (USE VOLUME DENSITY CONTROLLER)
60	88.0	475' (USE VOLUME DENSITY CONTROLLER)
65	95.3	550' (USE VOLUME DENSITY CONTROLLER)

Source: *Manual of Traffic Signal Design*, ITE, 1998.

Table 4.2 Comparison of Vehicle Detection Technologies

Technology	Strengths	Weaknesses
Inductive Loop	<ul style="list-style-type: none"> ■ Flexible design to satisfy large variety of applications. ■ Mature, well understood technology. ■ Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). ■ High frequency excitation models provide classification data. 	<ul style="list-style-type: none"> ■ Installation requires pavement cut. ■ Decreases pavement life. ■ Installation and maintenance require lane closure. ■ Wire loops subject to stresses of traffic and temperature. ■ Multiple detectors usually required to instrument a location.
Magnetometer	<ul style="list-style-type: none"> ■ Less susceptible than loops to stresses of traffic. ■ Some models transmit data over wireless RF link. 	<ul style="list-style-type: none"> ■ Installation requires pavement cut. ■ Decreases pavement life. ■ Installation and maintenance require lane closure. ■ Small detection zones.
Magnetic	<ul style="list-style-type: none"> ■ Can be used where loops are not feasible (e.g., bridge decks). ■ Some models installed under roadway without need for pavement cuts. ■ Less susceptible than loops to stresses of traffic. 	<ul style="list-style-type: none"> ■ Installation requires pavement cut or tunneling under roadway. ■ Cannot detect stopped vehicles.
Microwave Radar	<ul style="list-style-type: none"> ■ Generally insensitive to inclement weather. ■ Direct measurement of speed. ■ Multiple lane operation available. 	<ul style="list-style-type: none"> ■ Antenna beamwidth and transmitted waveform must be suitable for the application.
Infrared	<ul style="list-style-type: none"> ■ Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class. ■ Multizone passive sensors measure speed. ■ Multiple lane operation available. 	<ul style="list-style-type: none"> ■ Operation of active sensor may be affected by fog or blowing snow. ■ Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog.
Ultrasonic	<ul style="list-style-type: none"> ■ Multiple lane operation available. 	<ul style="list-style-type: none"> ■ Some conditions such as temperature change and extreme air turbulence can affect performance. ■ Large pulse repetition periods may degrade occupancy measurement
Acoustic	<ul style="list-style-type: none"> ■ Passive detection. ■ Insensitive to precipitation. ■ Multiple lane operation available. 	<ul style="list-style-type: none"> ■ Cold temperatures have been reported as affecting data accuracy. ■ Specific models are not recommended with slow moving vehicles in stop and go traffic.
Video Image Processor	<ul style="list-style-type: none"> ■ Monitors multiple lanes and multiple zones/lane. ■ Easy to add and modify detection zones. ■ Rich array of data available. ■ Provides wide-area detection when information gathered at one camera location can be linked to another. 	<ul style="list-style-type: none"> ■ Inclement weather, shadows, vehicle projection into adjacent lanes, occlusion, day-to-night transition, vehicle/road contrast, and water, salt grime, icicles, and cobwebs on camera lens can affect performance. ■ Requires 50- to 60-ft camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement. ■ Some models susceptible to camera motion caused by strong winds. ■ Generally cost-effective only if many detection zones are required within the field of view of the camera.

Source: A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems, FHWA, 2000.

4.3.6 Inductive Loop Detection – The inductive loop detects vehicles by sensing a change of inductance in the loop caused by the passage or presence of a vehicle over the loop. Inductive loops have historically been placed in the pavement by saw cutting a slot, installing loop wire and encapsulating the loop wire by filling the saw cut with sealant. The induction detector is made up of three components; a loop of wire saw cut into the roadway surface, a lead-in (shielded) cable and a detector processing unit in the controller cabinet. It is capable of both passage and presence detection.¹⁴

The life of a regular inductive loop which is saw cut into the pavement is dependent on the condition of pavement and it must be replaced each time a road is milled and resurfaced.

When installing inductive loop detection, the saw cut, loop wire, lead-in cable and detector units are measured separately.

A presence detector should be able to detect all licensed motor vehicles including a small motorcycle. A conventional long rectangular inductive loop may not detect a small motorcycle.¹⁵ A common inductive loop configuration that provides greater detection capabilities is the “quadrupole” loop. Quadrupole loops also provide more accuracy in vehicle detection and avoid false detections from adjacent thru lanes.

A. Placement/Pattern – A detector’s function determines its pattern and placement. The basic inductive loop detector used by TDOT is either a square or rectangle that has a length of 6 to 50 feet. Figure 4.13 displays the typical layouts of inductive loop detectors.

B. Preformed Inductive Loops – Preformed inductive loops function similarly to a regular saw cut loop; however, the conductor is encased in a heavy duty plastic housing. They are placed within concrete or in the lower lifts of asphalt prior to final paving (see Figure 4.14). Preformed loops can last longer than traditional saw cut loops and should be strongly considered on new construction projects where maintenance of saw cut loops is an issue. While they can be installed in existing pavement, it is not recommended due to the size of the saw cut required.

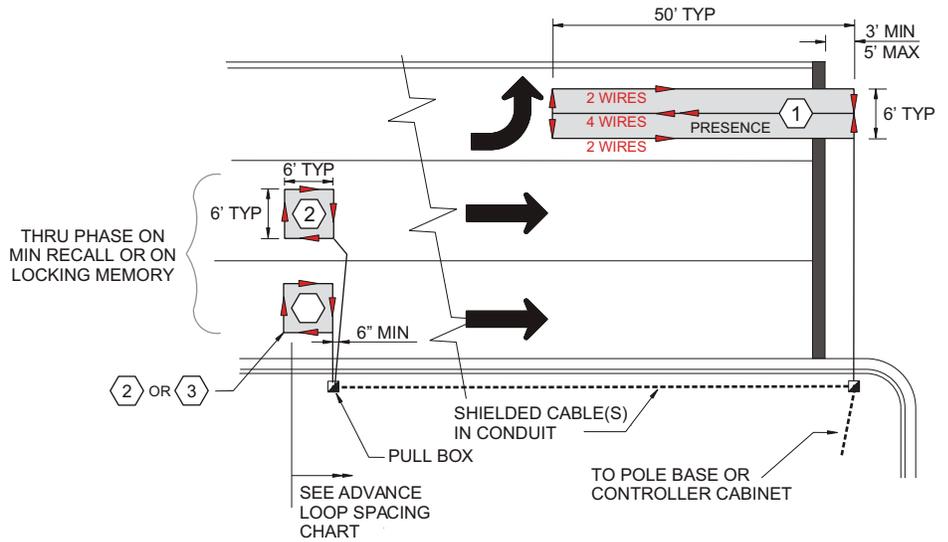
When long term maintenance is a concern, an alternative to the traditional saw cut inductive loop for new construction projects is the preformed inductive loop.

C. Loop Detector Processing Units – Detector processing units are devices in the signal controller cabinet that receive and interpret the signal from inductive loops and transmit the data to the controller. The local maintaining agency should be consulted for the type of unit desired (single channel vs. multi-channel and shelf mount vs. card rack).

¹⁴ Traffic Detector Handbook, ITE, 2nd Ed. p. 3

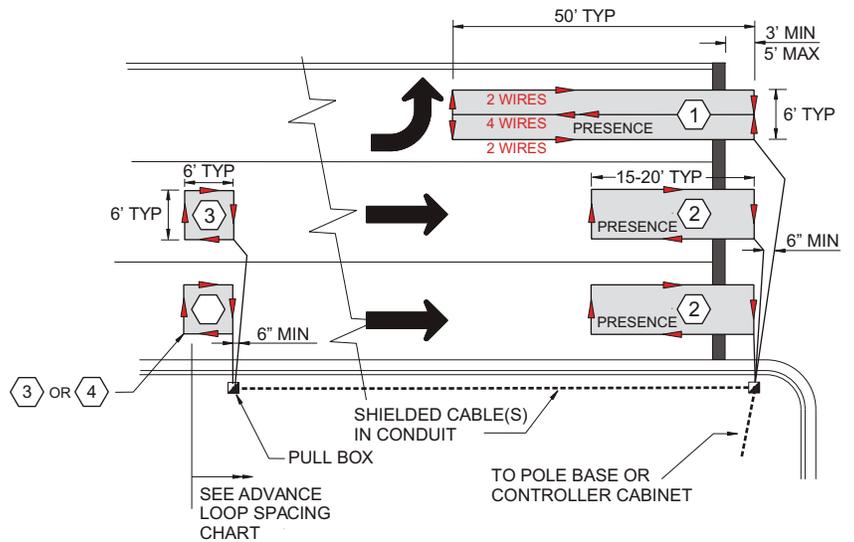
¹⁵ Manual of Traffic Signal Design, ITE, 1998, p. 87

ADVANCE LOOP SPACING	
APPROACH SPEED (MPH)	DISTANCE TO STOP LINE (FT)
35	185'
40	230'
45	285'
50	340'
55	405'
60	475'



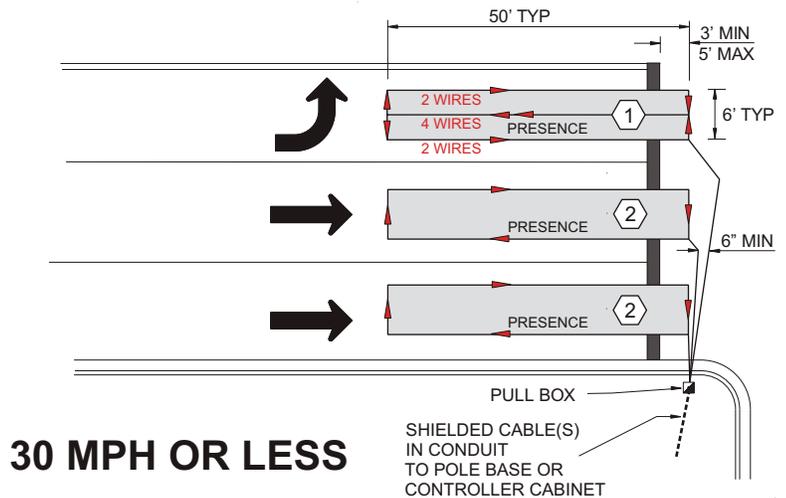
TYPICAL HIGH SPEED APPROACH

LOOP TURNS		
LOOP LENGTH	NO. TURNS IN ASPHALT	NO. TURNS IN CONCRETE
6 - 24'	3	4
24 - 50'	2	3
QUADRUPOLE	2-4-2	3-6-3

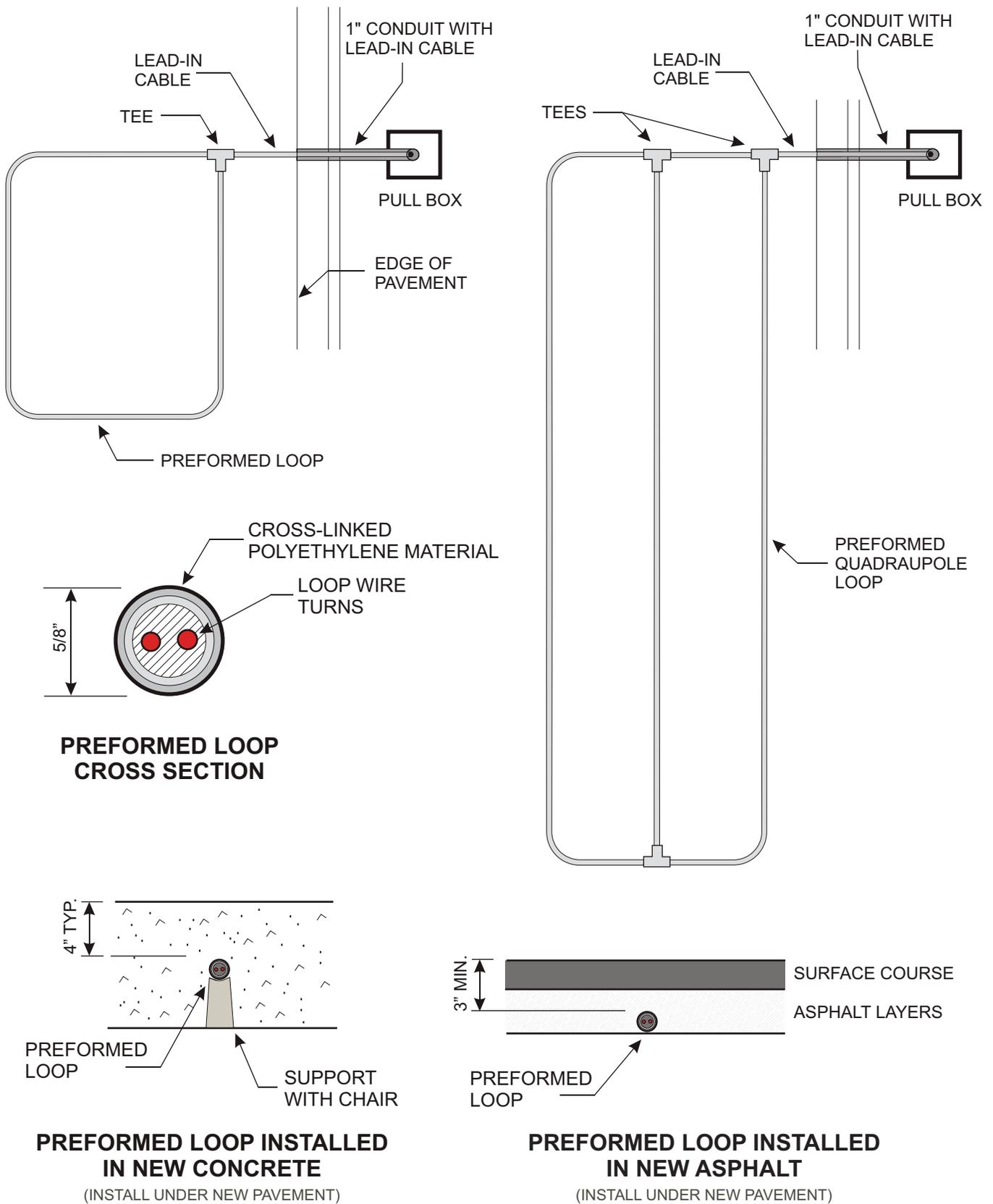


ALTERNATE HIGH SPEED APPROACH (FOR USE WHEN PRESENCE DETECTION IS REQUIRED)

- ② DETECTOR NUMBER (LOOPS WITH SAME NUMBER INDICATE WIRED IN SERIES)
- ALL LOOPS TO BE CENTERED IN TRAVEL LANE
- ALL DISTANCES FROM STOP LINE



30 MPH OR LESS



4.3.7 Microwave Detection – Sometimes referred to as radar detection, microwaves are beamed toward the roadway by a transmitter device. As a vehicle enters the influence area of this transmitter, the microwaves are reflected back to an antenna at a different frequency, allowing the presence of the vehicle to be detected (see Figure 4.15). This detection is not influenced by adjacent construction and can be implemented without lane closures associated with saw cutting loops. Microwave detectors are also immune to adverse weather such as fog and rain. One advantage that the microwave detector has over the video detector is that it can often see around tall vehicles and detect occluded (blocked) vehicles.

Older microwave detectors could not be used as presence detectors, requiring phases to be set on locking memory. Newer microwave detectors that use frequency modulated continuous wave (FMCW) can be used as a presence detector and can detect motionless vehicles. New microwave detectors can detect up to 200 feet for an area 15 feet wide and can detect eight separate detection zones within this detection area.

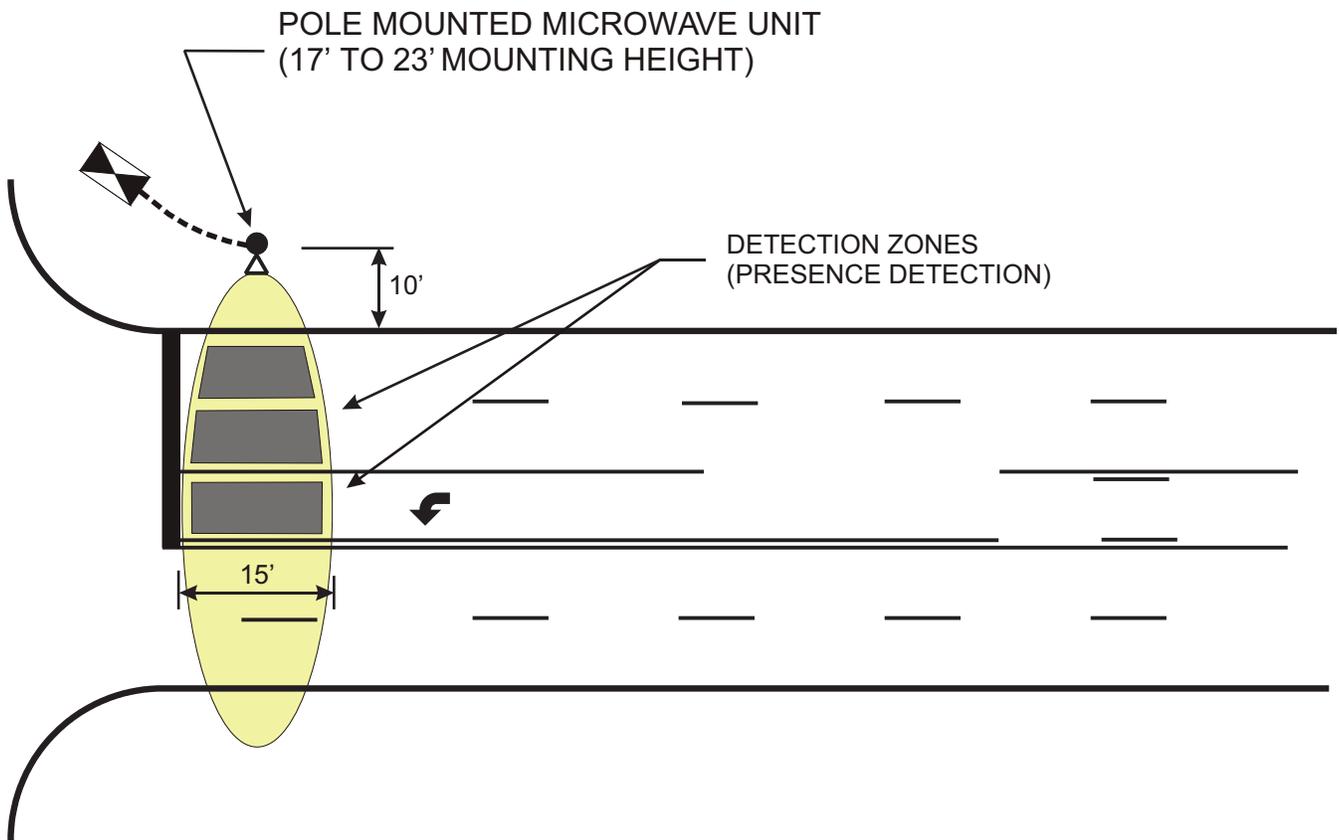
Microwave detection is typically accomplished by a side fire unit that can detect zones similar to those for stop line inductive loops. This type of detection can be considered in areas where loop installation is not possible, i.e., pavement is in poor condition, etc. The detection zones may be programmed using a laptop computer interfaced with the unit.

When installing microwave or video detection, a footnote should be added to the Plans noting the number of cameras, the number of processing units or other equipment and the estimated quantity of required cable. Each intersection is measured per each.

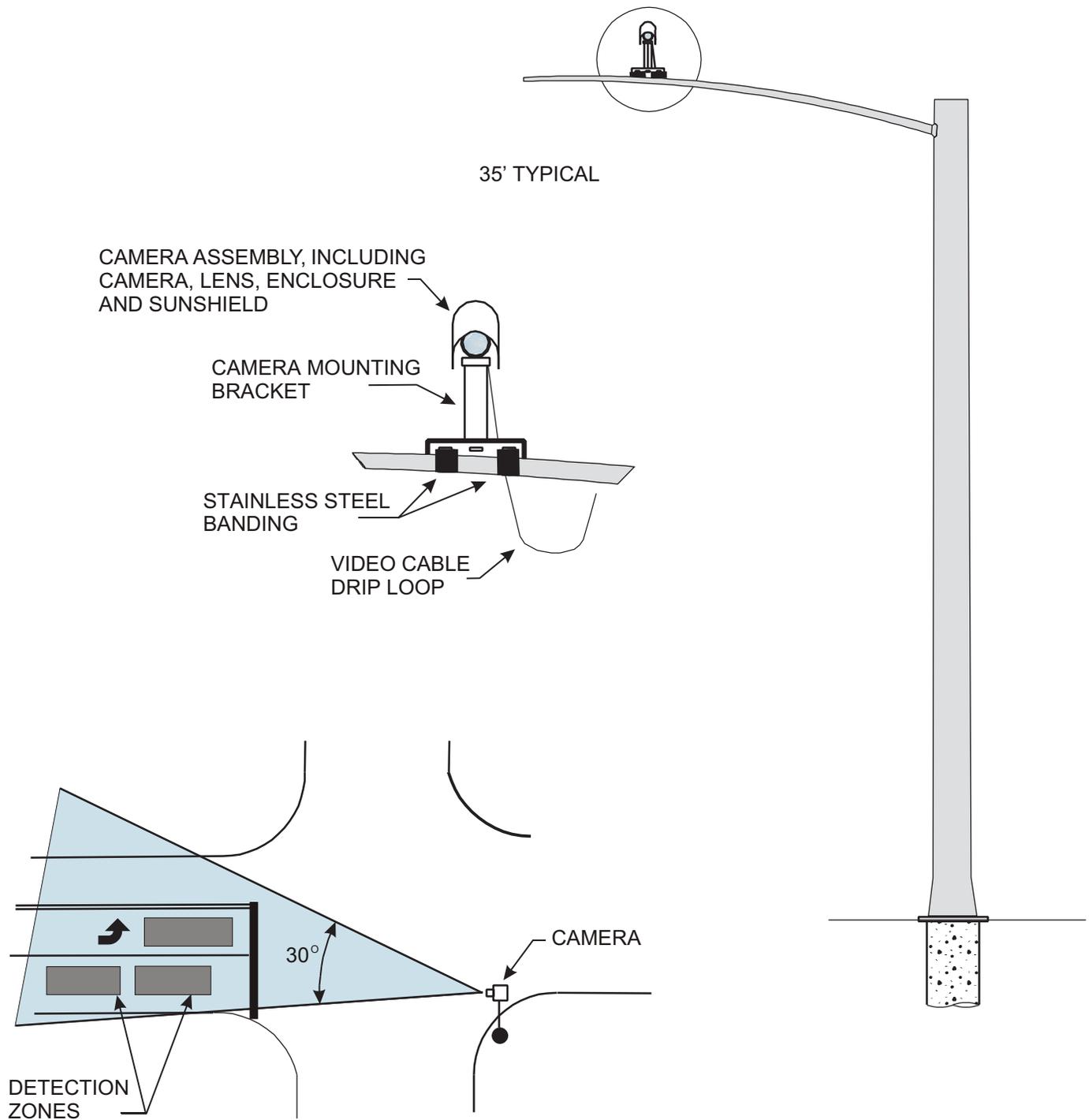
4.3.8 Video Detection – Video detection is an image processor consisting of a microprocessor-based CPU and software that analyzes video images. The detector areas are programmed through a laptop computer. Each detection zone emulates an inductive loop (see Figure 4.16). Video detection has the distinct advantage of working throughout a construction project, when inductive loops are often disturbed. This detection is not influenced by adjacent construction.

Camera systems provide many features loops cannot, such as incident monitoring and creating new detection zones anywhere in the field of view. They are non-destructive to the roadway surface. They also have shortcomings. Sun angle, shadows, rain, fog, dust, and power spikes can cause problems. Tall vehicles can obscure a lane causing missed signals.

Camera position is the primary factor for successful operation. Cameras should be mounted on the most stable fixture possible. Typical mounting is on a luminaire arm. The use of video detection requires that consideration be given to sight lines to the detection zones, which can be obstructed by large trucks or other obstacles. Video detection is a more expensive detection alternative than other methods and is typically limited to stop line detection.



Microwave Detection
(Side-Fired Radar)



VIDEO DETECTOR PLACEMENT

4.3.9 Phase Recalls – The recall feature of a traffic signal controller is a function that causes the automatic return of the right-of-way to a phase regardless of actuation on that approach. Minimum Recall returns to the selected phase for the minimum amount of green time (Minimum Green) for that phase. Maximum Recall returns to the selected phase for the maximum of green time (Maximum Green) for that phase. The Maximum Recall feature is used primarily for fixed time advances and the major street phase of traffic signals in a signal system. Minimum Recall is used primarily for the major street phase of a fully-actuated traffic signal not in a system and for the phase in which the signal is expected to rest.

- **Minimum Recall** is used for the arterial phase of full-actuated traffic signals.
- **Maximum Recall** is used primarily for fixed time (pre-timed) intersections and the coordinated phase of traffic signals in a system.
- **Minimum Recall** may be used for left turn or side street phases of traffic signals in systems when that feature is needed for the desired operation (to ensure a minimum side street call, etc).

4.4 Pedestrian Signal Interval – Pedestrian intervals are signal timing features activated by pedestrian pushbuttons or internally generated recalls which allow pedestrians to receive pedestrian signal displays and/or adequate signal time to aid in crossing the street. Pedestrian phase timing parameters are detailed in Section 4.5.7 and the pedestrian signal head requirements are discussed in Section 4.9.11. Pedestrians are better controlled by pedestrian signal faces rather than vehicular signal faces, therefore pedestrian signal heads should be installed at any new intersections where pedestrian phasing is provided.

A pedestrian signal interval is made up of two parts:

- **Walk Interval** – an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed.
- **Pedestrian Change Interval** – an interval during which the flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication is displayed.

4.4.1 Pedestrian Signal Warrants – A pedestrian signal phase with pedestrian signal heads shall be installed when any of the following occur:¹⁶

1. When Signal Warrant 4, “Pedestrian Volume” is fulfilled.
2. When Signal Warrant 5, “School Crossing” is fulfilled.
3. Obscured signal heads or confusing phasing (such as split-phasing operation) might present problems for pedestrians.
4. Where there is an established school crossing at the proposed signal location.

Pedestrian phasing needs should be considered for all new signalized intersections unless pedestrians are prohibited from using the intersection.

¹⁶ MUTCD, FHWA, 2003, p. 4E-1.

5. Where sidewalks and pedestrians are present or could be expected to be present.

4.4.2 Pedestrian Interval Sequence

- A. **Concurrent Movement** – The most common sequence is to move pedestrians concurrent with parallel vehicular traffic. Care must be taken, however, not to move pedestrians during the display of a conflicting left turn or right turn arrow for the parallel vehicular traffic.
- B. **Exclusive Movement** – This sequence moves pedestrians on a phase totally separate from any vehicular phase. When used, pedestrians cross all approaches simultaneously. This sequence shall only be used where both pedestrian volumes and conflicting vehicular turning movement volumes are high.

4.4.3 Countdown Pedestrian Signals – Technology has been developed to provide additional information to the pedestrian regarding the necessary clearance time to successfully complete the crossing of a roadway at crosswalks. A pedestrian interval countdown display may be added to a pedestrian signal head in order to inform pedestrians of the number of seconds remaining in the Pedestrian Change Interval (see Figure 4.17). The countdown indication is located adjacent to the standard pedestrian signal indication and provides a sequential countdown in seconds from the start of the flashing Pedestrian Clearance Interval (“DON’T WALK” indication) until the steady “DON’T WALK” indication is displayed.

The pedestrian countdown indication provides additional information on the time left before the pedestrian phase terminates.

The flashing “DON’T WALK” indication is intended to provide the pedestrian, who has already begun crossing, with adequate time to finish the crossing; a clearance interval. The solid “DON’T WALK” indication is intended to keep all pedestrians from being in the intersection at that time. A countdown pedestrian indication provides pedestrians with additional information, specifically a descending numerical countdown of the flashing hand clearance interval, which indicates to the pedestrian the time available for their crossing and is intended to be intuitively understood. Providing additional pedestrian clearance time information may help the pedestrian decide whether to start the crossing or wait for the next “WALK” indication.

Countdown features on pedestrian signal heads are supplemental and are not required, but may be used by a local agency.

If countdown pedestrian signals are used, a steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed during the Yellow Change Interval and any All Red Clearance Interval (prior to a conflicting green being displayed).

TYPICAL PEDESTRIAN SIGNAL HEADS

DON'T WALK INDICATION



WALK INDICATION



**COUNTDOWN
PEDESTRIAN
SIGNAL HEAD**



R10-1

**SIGN FOR INTERSECTION
WITHOUT PED SIGNALS
OR PUSHBUTTONS**



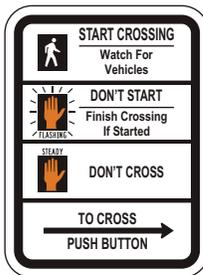
R10-3a

**SIGN FOR INTERSECTION
WITH PUSHBUTTONS BUT
NO PEDESTRIAN SIGNALS**



R10-2a

**SIGN FOR INTERSECTION
WITH PED SIGNALS BUT NO
PUSHBUTTONS (OPTIONAL)**



R10-3b

**SIGN FOR INTERSECTION
WITH PEDESTRIAN SIGNALS
AND PUSHBUTTONS**



R10-3d

INSTALL AT CORNER



R10-4b

INSTALL IN MEDIAN

PEDESTRIAN SIGNAL SIGNS FOR STREETS WITH MEDIANS

4.4.4 Pedestrian Actuation – Pedestrian detection is typically accomplished by active devices, primarily a pushbutton. While passive pedestrian detection is possible, it is rarely used. Pushbuttons shall be provided where the local governing agency requests or requires, sidewalks are present, or where appropriate.

If pedestrian phasing is utilized, but no pushbuttons are provided, any concurrent thru phases must be on recall to serve the pedestrian phase.

- A. Undivided Roadways** – When pedestrian actuated phases are provided, pedestrian pushbuttons are to be provided on the appropriate corners with a pushbutton for each crossing direction. Each pushbutton is to be supplemented by an R10-3a or R10-3b sign as appropriate with an arrow pointing in the direction of the crossing.
- B. Divided Roadways** – On divided roadways, both pedestrian pushbuttons and pedestrian signals are also to be installed in the median area if the median is of sufficient width to safely store pedestrians, and if the amount of pedestrian clearance time provided is only sufficient to reach the median area.¹⁷ The pushbuttons are to be supplemented with an R10-3d sign.
- C. Semi-Actuated Locations** – At locations that have vehicle detectors only on the minor street and pedestrians crossing the major street are a concern, pedestrian pushbuttons will be needed for the semi-actuated approaches along with an adequate Minimum Green to assure a safe crossing of the major street.
- D. Fully-Actuated Locations** – At locations that have vehicle detectors on all approaches and pedestrian crossing is allowed, pushbuttons will be needed on all non-recalled approaches.

A pedestrian pushbutton is required for any actuated phase with a concurrent pedestrian movement.

Requirements for locations with and without pedestrian signal heads and pushbuttons are listed in Table 4.3. The various signs required for the different pedestrian actuation and indication scenarios are shown in Figure 4.17.

¹⁷ MUTCD, FHWA, 2003, p. 4E-6.

Table 4.3 Pedestrian Signal Head and Pushbutton Needs

Pedestrian Signal Heads	Pedestrian Pushbuttons	Requirements	
NO	NO	Pedestrians use Vehicle Signals to cross street	NOT RECOMMENDED
		Recall for Vehicle Phases with concurrent Pedestrian Movements	
		Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance	
		CROSS ON GREEN LIGHT ONLY (R10-1) sign required	
NO	YES	Pedestrians use Vehicle Signals to cross street	NOT RECOMMENDED
		Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance	
		TO CROSS STREET PUSH BUTTON WAIT FOR GREEN LIGHT (R10-3a) sign required	
YES	NO	Good for Fixed Time Signals	RECOMMENDED FOR FIXED TIME CONTROL
		Recall for Vehicle Phases with concurrent Pedestrian Movements	
		Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance	
		No Sign Required (R10-2a Optional)	
YES	YES	Good for Actuated Signals	RECOMMENDED FOR ACTUATED CONTROL
		Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance	
		Pushbutton/Pedestrian Signal (R10-3b or (R10-3d and R10-4b)) sign required	

4.4.5 Accessible Pedestrian Signals – The Americans with Disabilities Act (ADA) requires access to the public right-of-way for people with disabilities. Access to traffic and signal information is an important feature of accessible sidewalks and street crossings for pedestrians who have vision impairments. While most intersections pose little difficulty for independent travelers who are blind or have low vision, there are some situations in which the information provided by an accessible pedestrian signal is necessary for independent and safe crossing.¹⁸

The technique used by pedestrians with visual disabilities to cross streets at traffic signals is to start crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, corresponding to the onset of the Green Interval. This is effective at many locations. The existing environment is often sufficient to provide the information that pedestrians who have visual disabilities need to operate reasonably safely at a signalized location. Therefore, many signalized locations will not require any accessible pedestrian signals.¹⁹

“Most intersections will not require accessible pedestrian signals. If a particular signalized location presents difficulties for pedestrians who have visual disabilities to cross reasonably safely and effectively, an engineering study should be conducted that considers the safety and effectiveness for pedestrians in general, as well as the information needs of pedestrians with visual disabilities” - MUTCD 2003.

An accessible pedestrian signal detector may provide assistance in locating the pushbutton as well as physical confirmation of the Walk Interval (see Section 4.5.7 for more information on a Walk Interval). The installation of accessible pedestrian signals at signalized locations should be based on an engineering study, which should consider the following factors.²⁰

1. Potential demand for accessible pedestrian signals
2. A request for accessible pedestrian signals
3. Traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high turn-on-red volumes
4. The complexity of traffic signal phasing
5. The complexity of intersection geometry

For accessible pedestrian signal locations, each crosswalk can have a signal device that includes either audible indications or vibrotactile indications of the WALK indication. In addition, these locations may contain accessible pedestrian detectors.

¹⁸ “Accessible Pedestrian Signals”, U.S. Access Board, 1998.

¹⁹ MUTCD, FHWA, 2003, p. 4E-3.

²⁰ Ibid, p. 4E-4.

4.4.5.1 Accessible WALK Indications – An accessible pedestrian signal typically includes a signal device that provides either audible indications or vibrotactile indications of the Walk Interval.

- A. Audible Confirmation** – Audible pedestrian signal devices supplement visual WALK indications and are designed to aid visually impaired pedestrians. When verbal messages are used to communicate the pedestrian interval, they provide a message that the Walk Interval is in effect, as well as to which crossing it applies. The verbal message is provided at regular intervals throughout the timing of the Walk Interval.
- B. Vibrotactile Confirmation** – A vibrotactile pedestrian device communicates information about pedestrian timing through a vibrating surface by touch. Vibrotactile pedestrian devices indicate that the Walk Interval is in effect, and for which direction it applies, through the use of a vibrating directional arrow or some other means. They are located adjacent to the pushbutton.

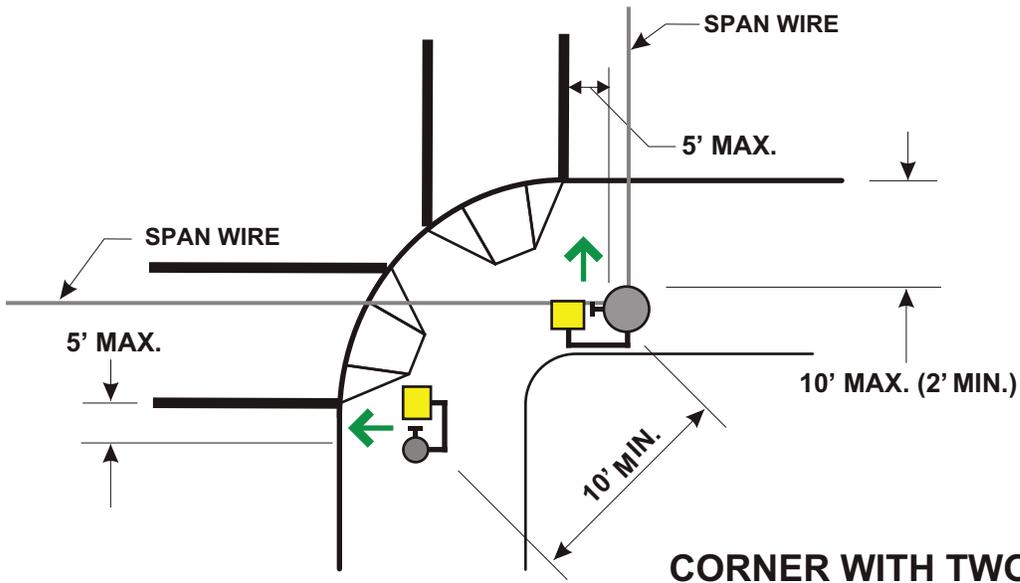
4.4.5.2 Accessible Pedestrian Signal Detector – An accessible pedestrian signal detector is a device that can assist a pedestrian with visual or physical disabilities in activating the pedestrian phase. Accessible pedestrian signal detectors may be either pushbuttons or passive detection devices. Pushbutton locator tones, which help the pedestrian find the pushbutton, may also be used with accessible pedestrian signals. A pushbutton locator tone is a repeating sound that informs approaching pedestrians that they are required to push a button to actuate pedestrian timing, and that enables visually impaired pedestrians to locate the pushbutton.

When used, accessible pedestrian pushbuttons on corners should be separated by at least 10'.

At accessible pedestrian signal locations, pushbuttons should clearly indicate which crosswalk signal is actuated by each pushbutton. At corners of signalized locations with accessible pedestrian signals where two pedestrian pushbuttons are provided, a distance of at least 10 feet should separate the pushbuttons to enable pedestrians who have visual disabilities to distinguish and locate the appropriate pushbutton.

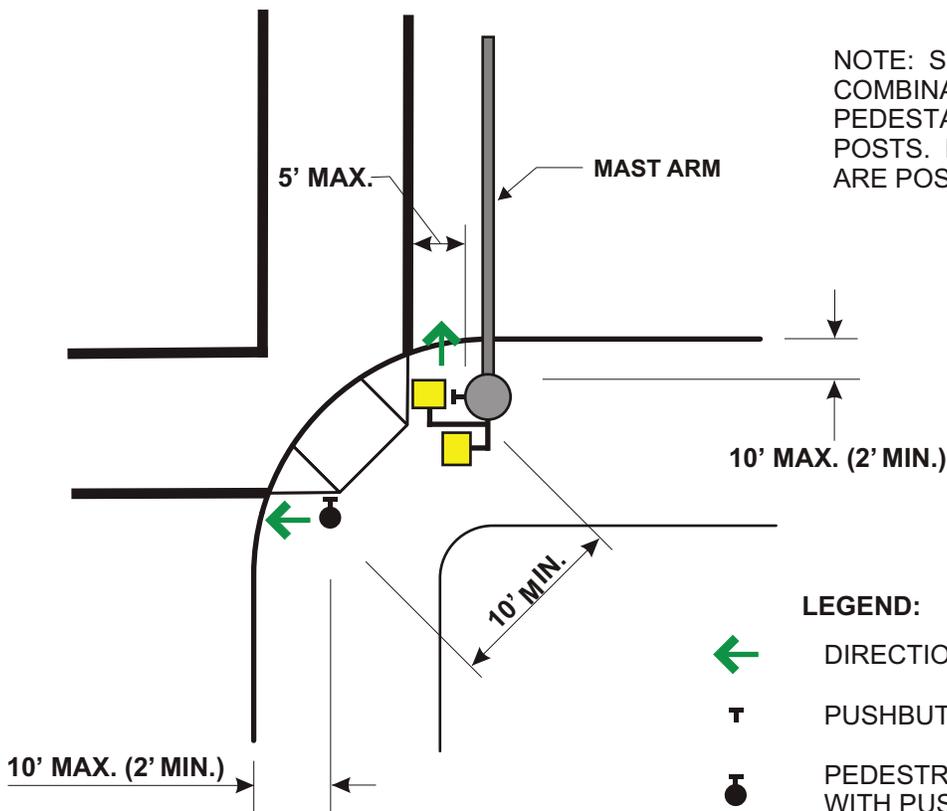
Pushbuttons for accessible pedestrian signals should be located as follows (see Figure 4.18):

- Adjacent to a level all-weather surface to provide access from a wheelchair and where there is an all-weather surface, wheelchair accessible route to the ramp
- Within 5 feet of the crosswalk extended
- Within 10 feet of the edge of the curb, shoulder or pavement
- Parallel to the crosswalk to be used



CORNER WITH TWO RAMPS

NOTE: SCHEMATICS SHOW VARIOUS COMBINATIONS OF SIGNAL POLES, PEDESTAL POLES AND PUSHBUTTON POSTS. DIFFERENT COMBINATIONS ARE POSSIBLE.



CORNER WITH SINGLE RAMP

LEGEND:



DIRECTION FOR PUSHBUTTON



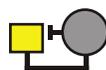
PUSHBUTTON



PEDESTRIAN PUSHBUTTON POST WITH PUSHBUTTON



PEDESTAL POLE WITH PEDESTRIAN SIGNAL AND PUSHBUTTON



SIGNAL SUPPORT POLE WITH PEDESTRIAN SIGNAL AND PUSHBUTTON

4.5 Traffic Signal Timing – Proper signal timing is essential to the efficient operation of a signalized intersection. The objective of signal timing is to determine the appropriate timing for each required signal phase so as to minimize the average delay to any single group of vehicles or pedestrians and to reduce the probability of conflicts that could cause accidents.²¹

TDOT typically provides basic signal timings on the timing detail sheet to allow a safe startup of the system while the road project is still in the construction phase. If the local agency agrees, plans can note that the local agency is to provide initial signal timings. Startup timing should emphasize safety over efficiency. These timings should be based on operational traffic volumes expected for approximately three years after completion of construction.

Regardless of how precise a theoretical method of signal timing might be, its effectiveness in actual traffic conditions must be observed in the field and appropriate timing adjustments made after implementation.

4.5.1 Types of Signal Timing Data – In general, an intersection will require one or more of the following types of signal timing data:

- **Preset Timing Intervals** – phase timing intervals that are fixed and do not change.
- **Actuated Timing Intervals** – a number of timing variables that can change including individual phase splits that can vary.
- **Fixed Time Plan** – based on a fixed cycle length (see Figure 4.1 for basic fixed time cycle schematic). Multiple timing plans may be needed for different time periods.
- **Coordinated Signal Timing Plan** – time-of-day and traffic responsive plans (splits, cycle lengths and offsets) with the intersection is part of a larger system.

4.5.2 Preset Timing Intervals – All traffic signal controllers have some preset timing intervals. In non-actuated (pre-timed) control, all intervals are preset. In semi-actuated or fully-actuated control, some intervals are also preset and some are variable. Preset intervals found in both pre-timed and actuated control include the following:

- **“Yellow Change (Clearance)” Interval** (see Section 4.5.6)
- **“Red Clearance (All Red)” Interval** (see Section 4.5.6)
- **“Walk” Interval** (see Section 4.5.7)
- **“Pedestrian Change” Interval** (see Section 4.5.7)

4.5.3 Pre-Timed Timing Intervals – As previously defined, a pre-timed traffic signal controller is one in which the timing and phasing do not vary from

²¹ Traffic Control Devices Handbook, ITE, 2001, p. 352

cycle to cycle. In addition to the intervals listed in Section 4.5.2, the basic timing parameters for a pre-timed controller are:

- **Cycle Length**
- **Green Intervals (Splits) – Maximum Green on Recall**
- **Number of Timing Plans**

If pedestrians regularly use the intersection, pedestrian timing will also have to be considered both with and without pedestrian signal indications and/or pushbuttons. The movement green required for vehicles shall be compared with the required pedestrian crossing times (see Section 4.5.7). If the pedestrian timing requirement exceeds the movement green, the pedestrian timing shall govern and the movement green lengthened.

Green movement timing for pre-timed signals shall be equal to or greater than the required pedestrian crossing time if pedestrians use the intersection.

Once the signal phasing has been decided upon using the guidelines in Section 4.2, the cycle length of the signal must then be determined. A signal's cycle length is defined as the total time in seconds required to complete a prescribed sequence of signal phases. In general, signal cycles should be as short as possible to adequately handle the traffic demand.

4.5.3.1 Cycle Length Determination – Cycle lengths should be calculated for the different time periods (AM Peak hour, the PM Peak hour and the off peak periods as a minimum). Additional cycle lengths for additional time periods may also be needed. There are several methods that can be used to calculate cycle lengths, two of which are provided below.

A. Critical Lane Volume Method – The sum of the critical lane volumes for each signal phase can be used to determine a minimum cycle length. The first step is assigning peak hour approach volumes to individual lanes as follows:

- **Exclusive Turn Lanes** – Where exclusive turn lanes are available, all turns are assigned to the appropriate turn lane. The remaining approach thru volumes are equally distributed to the approach thru lanes.
- **Shared Lanes Without Permissive Left Turns** – For shared and/or thru lanes where permissive left turns are not present, the approach volume is equally distributed amongst the approach lanes.
- **Shared Lanes With Permissive Left Turns** – Where permissive left turns are present in shared lanes, the left turn volumes must be converted to thru vehicle equivalents (TVE) (refer to Chapter 16 of the 2000

Highway Capacity Manual). They are then added to the thru and right turn volumes on the approach and equally distributed to the approach lanes.

The total TVE left turn volume is then subtracted from the inside (left) shared lane volume to determine the actual number of thru vehicles in that lane. This actual number of thru vehicles is added to the actual left turn volume and assigned to the shared inside (left) lane. The actual remaining traffic is then distributed equally to the remaining approach lanes. The highest lane volume for this approach is the critical lane volume for the approach.

- Using the assumed signal phasing, the highest lane volume moving in each phase is identified as the critical lane volume for that phase.
- The critical lane volume for all phases is totaled, determining the minimum cycle length.

Various methods of establishing cycle length exist; Webster's equation is given as Equation 4.1.

Equation 4.1²²

$$\text{Optimal Cycle Length (C)} = \frac{1.5L + 5}{1.0 - \sum Y_i}$$

Where: L = usable time per cycle (seconds)

Y_i = critical lane volume (i^{th} phase, vph)/saturation flow (vph)

- B. Signal Timing Software – WIN TEAPAC 2000 and SIGNAL 2000 software applications provide a relatively quick and easy method of determining how well a range of cycle lengths will work for a given set of conditions at an intersection.**

4.5.3.2 Cycle Lengths in Signal Systems

- A. Existing System –** Where a traffic signal is to be added to an existing signal system, it must operate on the same cycle length as the system or a multiple of it.
- B. New System –** If individual traffic signals are being timed for a new signal system, the intersection requiring the longest cycle lengths is the “critical intersection” and its cycle length will determine the cycle length for the system.

²² Northwestern University Traffic Institute, Traffic Actuated Control Workshop, November 2001.

4.5.3.3 Movement Timing – With solid state equipment the green time for each phase is set on Maximum Recall because of the lack of signal detection. This setting for each phase is based on the average needs for that particular movement as determined by traffic counts. Ideally, it should be long enough to service all the vehicles and pedestrians accumulated during the Change Interval.²³ Two methods of calculating the Maximum Green time are as follow:

A. Manual Calculation – The Green Interval timing can be calculated for each phase by Equation 4.2.

Equation 4.2²⁴

$$G = \left[\frac{V_A}{V_T} \times C \right] - CLR$$

Where: G = Green Interval for phase (sec.)

V_A = Critical lane volume for phase (veh/hr.)

V_T = Sum of critical lane volumes for all phases (veh/hr.)

C = Cycle Length

CLR = Clearance Interval for phase (sec.)

B. Signal Timing Software – WIN TEAPAC 2000 and SIGNAL 2000 are examples of software applications that provide a relatively quick and easy method to determine optimum green phase settings while minimizing the approach and overall intersection delay.

4.5.4 Basic Actuated Timing Intervals – In addition to the intervals listed in Section 4.5.2, the following timing parameters are used in a basic actuated traffic signal controller:

- **Minimum Green**
- **Passage Time**
- **Maximum Green**

4.5.4.1 Minimum Green – The Minimum Green setting is the shortest time allowed by a phase.

- **Approach with Stop Line Detection** – When detectors are located at the approach stop line, a Minimum Green of 6.0 seconds shall be used for thru movements on side streets and longer for major streets.

²³ Traffic Engineering Handbook, ITE, 1999, p. 480

²⁴ Northwestern University Traffic Institute, Traffic Actuated Control Workshop, November 2001.

- **Approach with Advance Detection Only** – When an approach has only advance detection, the Minimum Green shall be the amount of time required to clear the stored vehicles between the stop line and the detectors (see Section 4.5.3.3 for equation to determine Minimum Green for advance detection).
- **Turn Lanes** – A Minimum Green of 6.0 seconds shall be used for any turn lane.
- **Approaches with Pedestrian Phases** – The Minimum Green required for vehicles shall be compared with the required pedestrian crossing times (see Section 4.5.7). If the pedestrian timing requirement exceeds the Minimum Green, the pedestrian timing shall govern and the Minimum Green lengthened.

For approaches with pedestrian phases, the Minimum Green shall be equal to or greater than the required pedestrian crossing time.

4.5.4.2 Passage Time (Vehicle Extension or Interval) – This function extends the green for a phase beyond Minimum Green up to a preset maximum timing to accommodate additional vehicles stopped behind the stop line or vehicles approaching the stop line after the phase indication turns green. It is also the allowable gap in approaching traffic for the signal phase to lose the green.²⁵ The basic relationship between these timing parameters is shown in Figure 4.19.

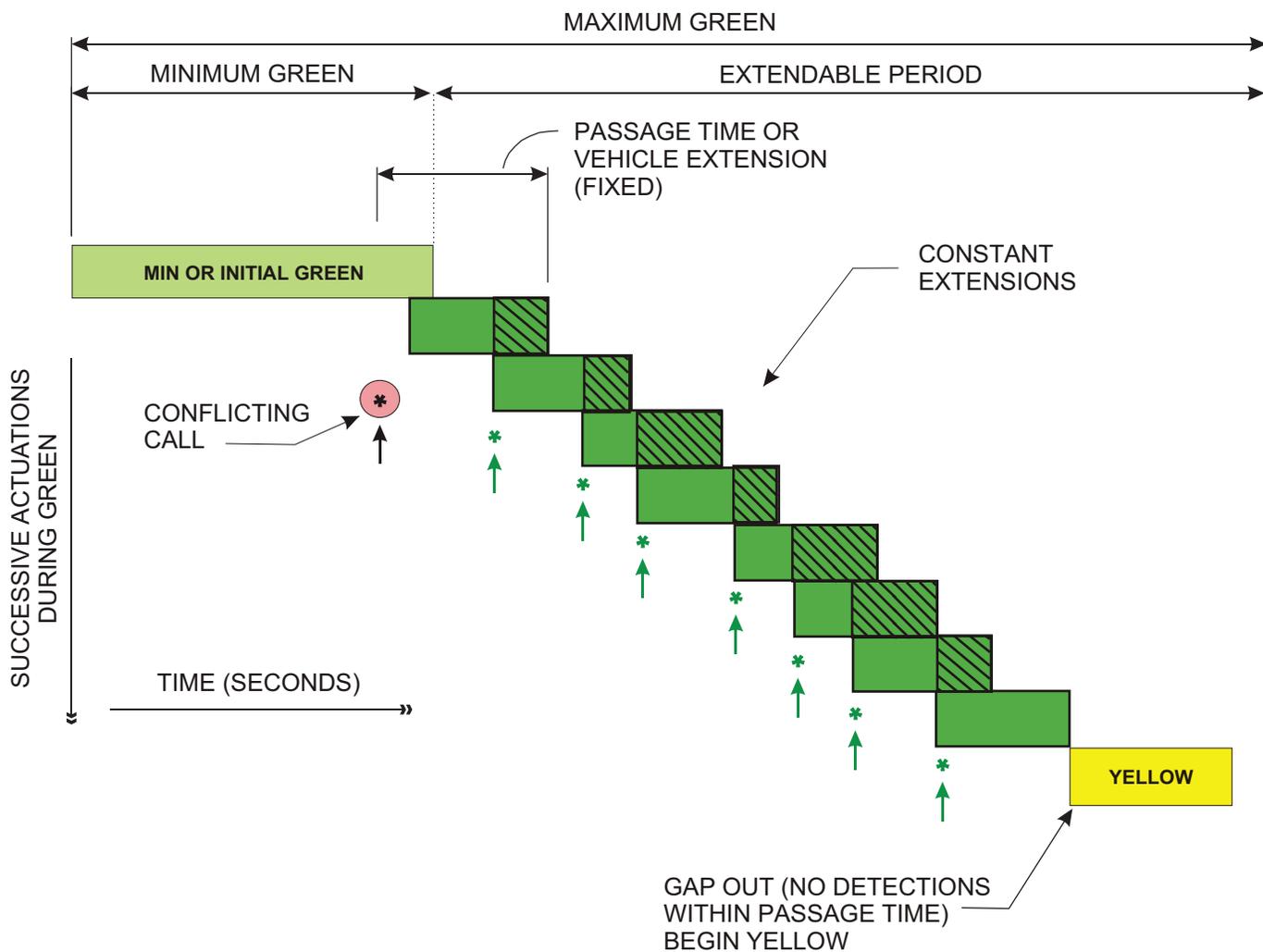
For maximum efficiency the Passage Time should be set as short as practical to retain the green as long as a consistent demand is present, but not so long that it retains vehicles straying behind. However, where detectors are located at some distance from the stop line, the Passage Time must be long enough to permit the vehicle to travel from the detector to the stop line without gapping out.

Typical Passage Times are 2.0 to 3.0 seconds for stop bar loops, with longer times for advance loops (3.5 to 6.0 seconds).

4.5.4.3 Maximum Green – The Maximum Green defines the longest green time allowed for the signal phase in the presence of a serviceable conflicting call or another phase on recall. It can be determined using the methods described for Green Interval timing for pre-timed controllers (see Section 4.5.3.3). At all but oversaturated intersections, the Maximum Green should be long enough to clear the largest platoons of traffic expected.

Major thru movements should have a Maximum Green time of between 60 and 120 seconds.

²⁵ Manual of Traffic Signal Design, ITE, 1998, p. 152



LEGEND

-  PASSAGE TIME (OR VEHICLE EXT)
-  UNEXPIRED PORTIONS OF PASSAGE TIME OR VEHICLE EXTENSION INTERVALS
-  DETECTOR ACTUATION ON CONFLICTING PHASE
-  DETECTOR ACTUATION ON A PHASE WITH RIGHT OF WAY

NOTE - IN THIS SCHEMATIC, THERE IS A DEMAND FOR ANOTHER PHASE AND THE PHASE GAPS OUT PRIOR TO REACHING MAX GREEN. IF ACTUATIONS CONTINUE TO MAX GREEN, THE GREEN WILL END AT MAX GREEN TIME AND YELLOW WILL BEGIN AT THAT POINT. IF THERE IS NO DEMAND FROM ANOTHER PHASE, THIS PHASE WILL REST IN GREEN AFTER REACHING MAX.

4.5.5 Volume Density Timing Intervals –

Even more sophisticated operation is possible with the volume density traffic actuated traffic signal controller unit. In addition to the features discussed above, volume density provides two means of modifying the basic timing intervals. These are:

- **Variable Initial** is a means of extending the initial portion of the Green Interval. This is done on the basis of the number of actuations above a preset number while the phase is displaying a YELLOW or RED indication. This extended initial provides additional green time for a queue of vehicles waiting, when the GREEN signal indication appears, to clear the intersection if the detectors are set back a distance from the stop bar and there are no vehicles following.
- **Gap Reduction** is a means of reducing the Passage Time or gap on the basis of the time that opposing vehicles have waited. In effect, it benefits the waiting vehicles by reducing the time allowed between vehicles arriving on the green phase before that phase is terminated.

Volume-density operation is a more advanced form of fully-actuated control. It has the ability to calculate the duration of Minimum Green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from Passage Time down to a Minimum Gap. Reducing the allowable time between calls below the passage time will improve efficiency by being better able to detect the end of queued flow.

In addition to the intervals listed in Section 4.5.2, the following timing parameters are used in volume density signal operation:

- **Minimum Initial (Minimum Green)**
- **Maximum Initial**
- **Added Initial**
- **Variable Initial**
- **Initial Gap (Passage Time),**
- **Time Before Reduction (TBR)**
- **Time to Reduce (TTR)**
- **Minimum Gap**
- **Maximum Green**

These features are typically used for approach speeds of greater than 30 mph and provide a Variable Initial green time as well as a variable “gap” reduction feature.

Variable Initial – This feature increases the minimum assured green time (Minimum Initial) so it will be long enough to serve the actual number of vehicles waiting for the green between the stop line and the detector. This

interval is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in unacceptably long Minimum Initial requirements). This feature allows the Minimum Initial to be set low for light volumes. Vehicles crossing the detector when the phase is red will add time to the minimum assured green, so that when the phase is served, the minimum assured green will be long enough to serve the actual number of vehicles waiting for the green (see Figure 4.20).

4.5.5.1 Minimum Initial (Minimum Green) – This setting provides the guaranteed shortest green time for the signal phase. It cannot vary. Because of the Added Initial feature, the Minimum Initial does not have to be long enough to start up and clear the intersection of all the vehicles waiting between the stop line and the detector. Instead, it is intended to allow time for the first motorist to respond to the onset of the GREEN signal indication.²⁶ If pedestrians regularly use the intersection, the Minimum Green shall also be calculated for the pedestrian crossing (see Section 4.5.7). If the pedestrian timing requirement exceeds the Minimum Green plus its Yellow Change Interval, the pedestrian timing shall govern.

For approaches with pedestrian phases, the Minimum Green shall be equal to or greater than the required pedestrian crossing time.

This value can usually be expected to range between 10-15 seconds on a moderate speed approach and 15-20 seconds for high-speed approaches.

4.5.5.2 Maximum Initial – The maximum initial setting is the longest timing to which the Variable Initial interval can be extended. It is the timing necessary to ensure that a queue of vehicles released at the beginning of green will be moving across the stop line detector before the termination of green. Assuming a start up delay of 3 seconds and a discharge rate of 2 seconds per vehicle, the maximum initial can be calculated by the following equation.

Equation 4.3

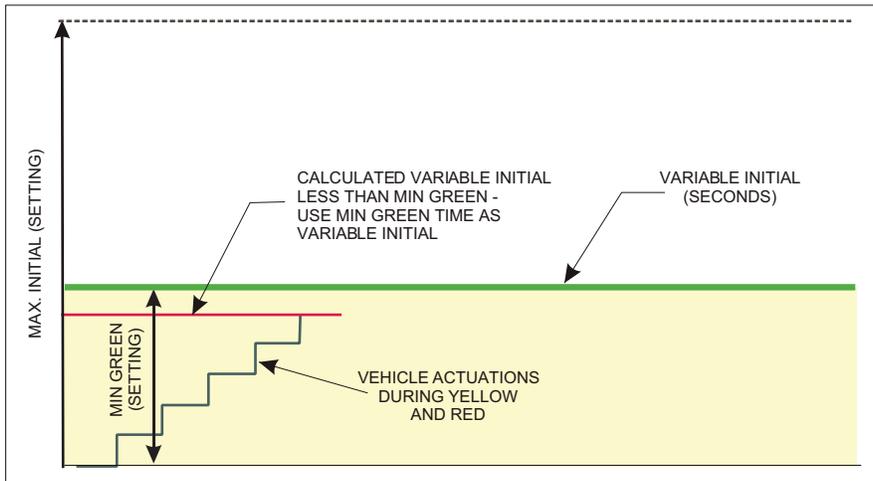
$$MI (\text{sec.}) = 3 + 2n$$

Where: MI = Maximum Initial

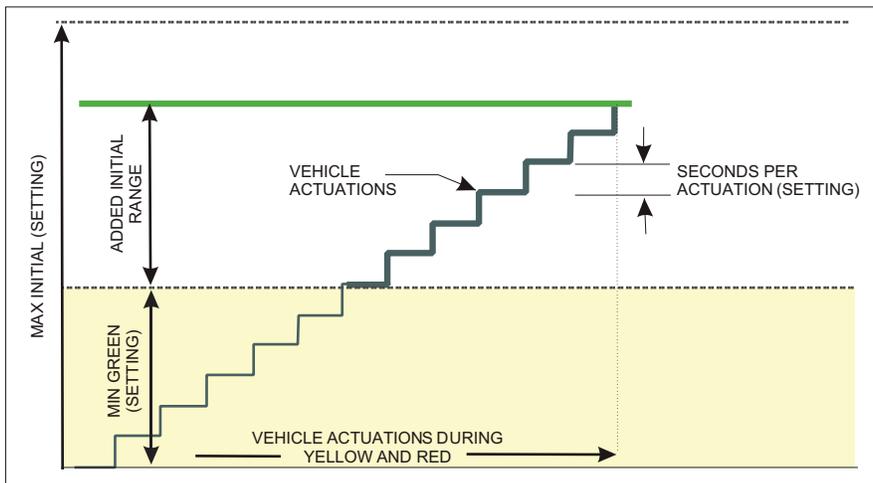
n = max number of queued vehicles per lane (from stop line to detector), calculated as the distance from stop line to detector divided by 25 ft/vehicle

The maximum initial can not exceed the Maximum Green time for the phase.

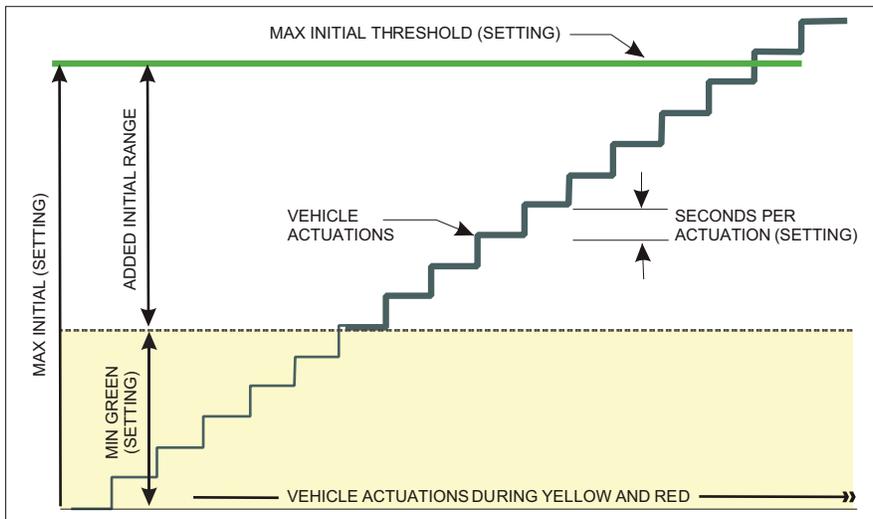
²⁶ Traffic Control Devices Handbook, ITE, 2001, p. 329



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
CALCULATED VARIABLE INITIAL LESS THAN MIN. GREEN



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
VARIABLE INITIAL BETWEEN MIN. GREEN AND MAX. INITIAL



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
CALCULATED VARIABLE INITIAL GREATER THAN MAX. INITIAL

4.5.5.3 Added Initial – Because the initial (or minimum) green is set low for volume density timing (unless pedestrian timing governs); additional time is needed to clear the queue of vehicles which have arrived during the clearance and change intervals. The Added Initial function provides the additional initial green timing to clear into the intersection all the vehicles waiting between the stop line and the detector who were not accommodated by the Minimum Initial green timing.

The Added Initial is the added interval of timing for each vehicle actuation that is received on the approach during the clearance and change intervals, but only becomes active once it exceeds the Minimum Initial setting.²⁷ The Added Initial can be calculated by Equation 4.4. The adequacy of this timing must be checked in the field.

Equation 4.4

$$\text{Added Initial (sec./act.)} = \frac{\text{MI}}{n}$$

Where: MI = Maximum Initial

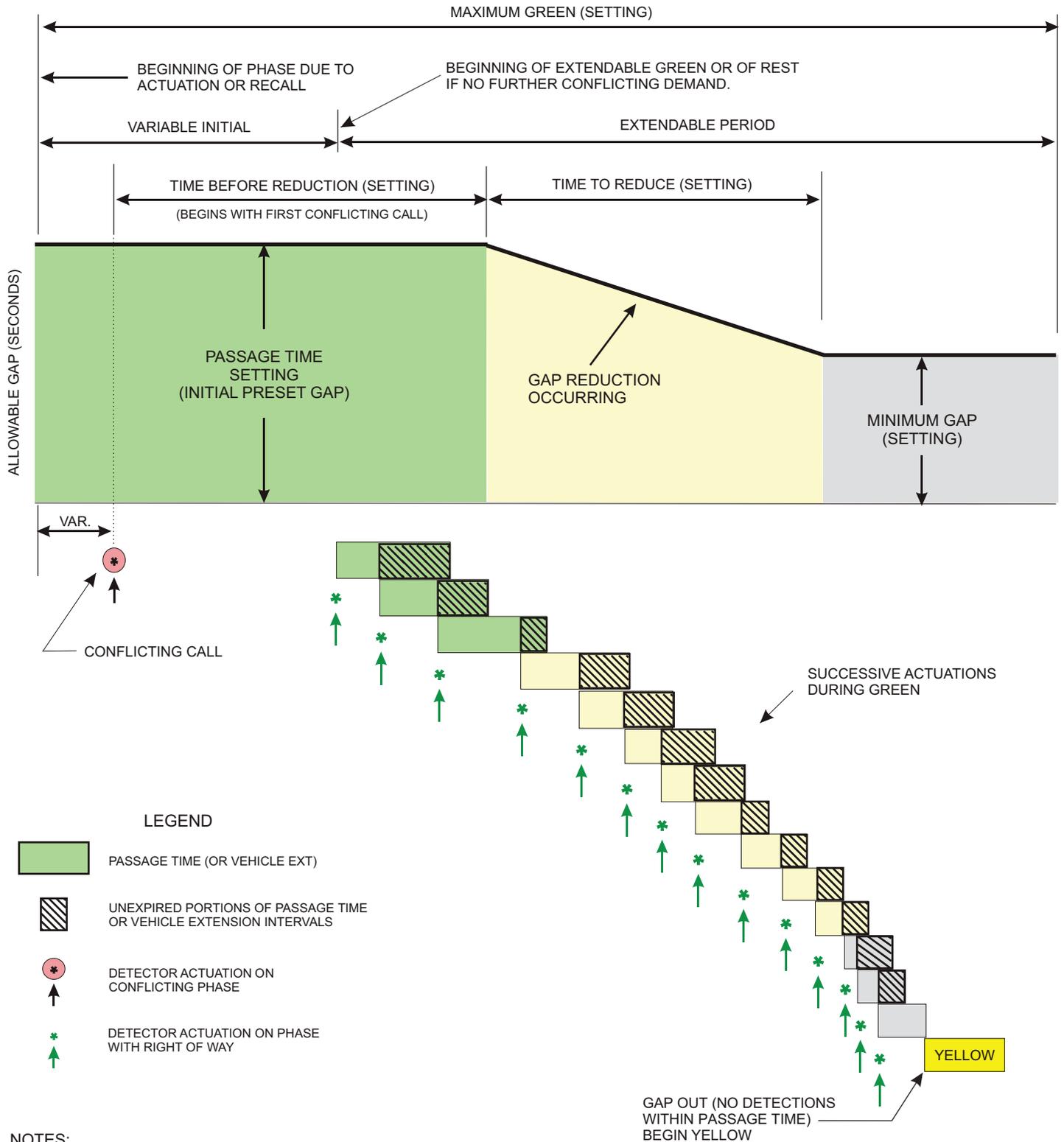
n = max number of queued vehicles per lane (from stop line to detector), calculated as the distance from stop line to detector divided by 25 ft/vehicle

Often a value of 2 or 3 seconds per vehicle seconds is used for the Added Initial.

4.5.5.4 Variable Initial – Variable Initial timing describes the initial green used in a volume density phase before the extendable portion of the phase starts. If the number of actuations during the clearance and change intervals is small and the Added Initial time calculated for these vehicles is less than the Minimum Green, the Variable Initial is the Minimum Green. With heavy traffic, the Added Initial increases the initial green beyond the Minimum Green to ensure that vehicles between the stop line and the detector can clear the intersection.

Gap Reduction – This feature reduces the Passage Time and as a result reduces the allowable time gap between actuations that will cause the green to remain on that approach (see Figure 4.21). When a phase is green, the time between vehicles to terminate that phase starts out at the amount of time set for the Passage Time. After the phase has been green for some time, it becomes desirable to terminate the phase on smaller distances between vehicles. (i.e., successive actuations must be closer together than the Passage Time to extend the green).

²⁷ Manual of Traffic Signal Design, ITE, 1998, p. 154



NOTES:

1. IN THIS SCHEMATIC, THERE IS A DEMAND FOR ANOTHER PHASE AND THE PHASE GAPS OUT PRIOR TO REACHING MAX GREEN. IF ACTUATIONS CONTINUE TO MAX GREEN, THE GREEN WILL END AT MAX GREEN TIME AND YELLOW WILL BEGIN AT THAT POINT. IF THERE IS NO DEMAND FROM ANOTHER PHASE, THIS PHASE WILL REST IN GREEN AFTER REACHING MAX.
2. SEE FIGURE 4.17 FOR VARIABLE INITIAL DETERMINATION.

4.5.5.5 Initial Gap (Passage Time) – The Initial Gap setting in a volume density controller is the beginning value of the green extension timing after the Variable Initial green timing expires. It is the same as Passage Time and is calculated as the time it takes a vehicle to travel from the detector to the stop line. This can be calculated using Equation 4.5 shown below.

Equation 4.5

$$\text{Initial Gap (Passage Time)} = \frac{D}{V}$$

Where: D = Distance from the detector to the stop line (feet)

V = 85th percentile approach speed (ft/sec.)

4.5.5.6 Time Before Reduction (TBR) – The Time Before Reduction setting sets the time before the Initial Gap setting is allowed to begin reducing towards the Minimum Gap setting. It starts as soon as a call is received on a conflicting phase. It can start at the beginning of the Minimum Green if vehicles are waiting on other approaches before the Minimum Green.

The Time Before Reduction should be set at approximately 1/3 of the Maximum Green. However, it should be observed in the field to assure that it does not cause the green to prematurely gap out.

4.5.5.7 Time to Reduce (TTR) – The Time to Reduce setting is the time over which the Initial Gap is reduced to the Minimum Gap and assures that the phase will not be held by large gaps in traffic. It begins after the Time Before Reduction is timed out. During the Time to Reduce, there is a linear reduction in the allowable gap from the Initial Gap (Passage Time) setting to the Minimum Gap setting.

The Time to Reduce should be set at approximately 1/3 of the Maximum Green.

4.5.5.8 Minimum Gap – The Minimum Gap setting establishes the minimum value for which the allowable gap between actuations can be reduced after expiration of the Time to Reduce. This is the average headway between vehicles and is approximately the time it takes a vehicle to travel from the detector through the dilemma zone. The amount of time into the green to reduce to the Minimum Gap should be set at about 2/3 of the maximum time. The allowable gap will gradually reduce in that time frame. Therefore, the last 1/3 of the Maximum Green would be extended only by tightly spaced vehicles.

A setting of 2.5 seconds is adequate for a single lane approach. Generally the Minimum Gap should not be set lower than 2 seconds.

4.5.5.9 Last Car Passage – Last Car Passage is a feature to provide full Passage Time to the last vehicle upon a gap out when the gap time has been reduced. This helps ensure that the last vehicle receives sufficient Passage Time to clear the intersection without encountering dilemma zone issues. When using volume density timing, this feature should normally be set to “on” when gap reduction features are utilized.

4.5.5.10 Listed below are some basic rules for volume density timing:

- Min Green \geq Ped Walk + Ped Clearance
- Min Green \leq Variable Initial \leq Max Initial
- Max Initial \leq Max Green
- TBR + TTR \leq Max Green
- Passage Time \geq Min Gap

Table 4.4 lists some recommended volume density timing values for different approach speeds.

Table 4.4 Recommended Volume Density Timing Values

Approach Speed (MPH)	Distance from Stop Line to Advance Detector (feet)	Minimum Green* (secs)	Maximum Initial (secs)	Added Initial (secs)	Initial Gap (Passage Time) (secs)	Time Before Reduction (secs)	Time to Reduce (secs)	Time to Reduce (secs)	Maximum Green (secs)
35	185	10	18	2.4	3.6	1/3 Max Green	1/3 Max Green	2.0	35-70
40	230	15	21	2.3	3.9	1/3 Max Green	1/3 Max Green	2.0	40-80
45	285	15	26	2.3	4.3	1/3 Max Green	1/3 Max Green	2.0	45-90
50	340	20	30	2.2	4.6	1/3 Max Green	1/3 Max Green	2.0	50-100
55	405	20	35	2.2	5.0	1/3 Max Green	1/3 Max Green	2.0	55-110
60	475	25	41	2.2	5.4	1/3 Max Green	1/3 Max Green	2.0	60-120
65	550	25	47	2.1	5.8	1/3 Max Green	1/3 Max Green	2.0	60-120

* If pedestrians are an issue for the approach, Minimum Green must be compared against pedestrian timing requirements.

4.5.6 Vehicle Clearance Intervals – Vehicle clearance intervals consist of a Yellow Change Interval and an optional All Red Clearance Interval and should provide enough time so that the motorist can either stop or proceed safely through the intersection prior to the release of opposing traffic.

A vehicle clearance interval is composed of a Yellow Change Interval and an All Red Clearance Interval.

4.5.6.1 Yellow Change Interval (Yellow Clearance Interval) Timing –

The Yellow Change Interval of a traffic signal is used to notify the motorist that the Green Interval is ending. The Yellow Change Interval normally has a range of 3.0 to 6.0 seconds. *Tennessee Code Annotated* requires a minimum three seconds yellow time, with 4.0 seconds preferred. Yellow Change Intervals in excess of 5.0 seconds may encourage motorists to “run the yellow” instead of stopping.²⁸ If a clearance interval time in excess of 5.0 seconds is required on all but very high speed approaches (greater than 55 mph), the additional time should be provided by an All Red Clearance Interval.

A. Thru Vehicle Clearances – The clearance interval time for thru vehicles is calculated by the Equation 4.6 which includes a reaction time, a deceleration time and an intersection clearance time. This equation assures that the clearance interval time is of sufficient length to eliminate the “dilemma zone” in which a motorist has difficulty in deciding whether to stop or proceed through the intersection.

Equation 4.6²⁹

$$CP = t + \frac{V}{2a} + \frac{(w + L)}{V}$$

Where: CP =non-dilemma clearance interval (yellow + All Red), (sec.)

t =Perception – Reaction Time (normally 1 sec.)

V=Approach speed (ft./sec.)

a =Deceleration rate (typically 10 ft./sec.²)

w =Intersection width, stop line to far cross street curb line (ft.)

L =Length of vehicle (typically 20 ft.)

The Yellow Change Interval is often set as the sum of the first two terms of Equation 4.6 ($t + V/2a$) rounded up to the next ½ second, and the All Red is set at the value of the third

²⁸ Traffic Engineering Handbook, ITE, 1999, p. 481

²⁹ Manual of Traffic Signal Design, ITE, 1998 p. 143

term. Table 4.5 lists calculated and recommended rounded vehicle clearance timing values for thru phases.

B. Left Turn Vehicle Clearance Interval – In determining the clearance interval for left turn phases, Equation 4.6 is also used but the turning path of the vehicle is used for “w” and the speed of the turning vehicle “V” should be 15 mph. The turning path of the vehicle is measured on an arc from the stop line in the left turn lane to the far left curb line of the street from which the turn is made.

4.5.6.2 All Red Clearance Interval – The All Red timing is an optional part of the clearance interval and immediately follows a Yellow Change Interval. It is used to provide additional timing (beyond that needed to stop) for a vehicle to clear the intersection before the display of a conflicting GREEN signal indication. It is calculated using the third term in Equation 4.6 shown above (2.5 seconds max).

Table 4.5 Recommended Yellow Change and All Red Clearance Interval Values

Approach Speed (MPH)	Calculated Yellow Interval (secs)	Calculated Minimum TOTAL Clearance Interval (seconds)*								
		Crossing Street Width (feet)								
		30	40	50	60	70	80	90	100	110
25	2.8	4.2	4.5	4.7	5.0	5.3	5.6	5.8	6.1	6.4
30	3.2	4.3	4.6	4.8	5.0	5.2	5.5	5.7	5.9	6.2
35	3.6	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1
40	3.9	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.1
45	4.3	5.1	5.2	5.4	5.5	5.7	5.8	6.0	6.1	6.3
50	4.7	5.3	5.5	5.6	5.8	5.9	6.0	6.2	6.3	6.4
55	5.0	5.7	5.8	5.9	6.0	6.1	6.3	6.4	6.5	6.6
60	5.4	6.0	6.1	6.2	6.3	6.4	6.5	6.7	6.8	6.9
65	5.8	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1

* Based on Equation 4.6

Approach Speed (MPH)	Recommended Yellow Interval (secs)	Recommended All Red Clearance Interval (seconds)								
		Crossing Street Width (feet)								
		30	40	50	60	70	80	90	100	110
25	4.0	0.5	0.5	1.0	1.5	1.5	2.0	2.0	2.5	2.5
30	4.0	0.5	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.5
35	4.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	2.0	2.0
40	4.5	1.0	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0
45	4.5	1.0	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0
50	5.0	1.0	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0
55	5.0	1.0	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0
60	5.5	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0
65	6.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0

4.5.7 Pedestrian Phase Timing

4.5.7.1 Walk Interval – Where pedestrian phases are provided, Walk Interval timing provides the time necessary for a pedestrian to leave the curb to cross the street. The typical **minimum** Walk Interval time value is 7 seconds.³⁰

Where large groups of pedestrians cross, field observation and timing should be used to see how long it takes the group to leave the curb.

To safely cross the street, pedestrians need at least 7 seconds to leave the curb (a Walk Interval) and time to cross the street (a Pedestrian Change Interval) – MUTCD 2003

4.5.7.2 Pedestrian Change (“Flashing” Don’t Walk) Interval – The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the Walk Interval signal indication to travel at a maximum walking speed of 4 feet per second, to at least the far side of the traveled way (or to a median of sufficient width for pedestrians to wait). Where pedestrians who walk slower than normal, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 4 feet per second per second should be used in determining the pedestrian clearance time (typically 3.0 feet per second).

For typical intersections, a walking speed between 3.0 and 4.0 feet per second shall be used. Where the crossing is routinely used by young children, the elderly, the physically challenged or large groups of pedestrians, a walking speed of 3.0 feet/second is recommended. The pedestrian clearance time for the Pedestrian Change Interval is calculated by Equation 4.7 shown below.

When pedestrian signals are used, the concurrent and parallel vehicular Green Interval plus its Yellow Change Interval must be checked to assure it is of adequate length to provide enough time for the pedestrians to cross the street. This must be done whether or not pedestrian signal indications are provided.

Equation 4.7

$$\text{PED CLR} = \frac{W}{V_p}$$

Where: PED CLR = Pedestrian clearance time (sec.)

W = width of the street (curb line to the far side of the traveled roadway) (ft.)

V_p = pedestrian walking speed (3.0 to 4.0 ft./sec.)

³⁰ MUTCD, FHWA, 2003, p. 4E-8

The Pedestrian Change Interval (pedestrian clearance time) may be entirely contained within the vehicular Green Interval (Equation 4.8), or may utilize the time of both the vehicular Green and Yellow Change Intervals (Equation 4.9)³¹ Figure 4.22 displays the two Pedestrian Change Interval timing alternatives.

On high speed approaches, or when the intersection operates well below capacity, the preferred method for displaying the Pedestrian Change Interval is to have the pedestrian clearance time entirely within the vehicular Green Interval.

Equation 4.8

$$\text{Minimum Green (sec.)} \geq \text{Ped. Walk (sec.)} + \text{Ped. Clr. (sec.)}$$

Where: Ped. Walk = Pedestrian Walk Interval

Ped. Clr. = Pedestrian clearance time (sec.)

Equation 4.9

$$\text{Minimum Green (sec.)} + \text{Yellow Change (sec.)} + \text{All Red (sec.)} \geq \text{Ped. Walk (sec.)} + \text{Ped. Clr. (sec.)}$$

Where: Ped. Walk = Pedestrian Walk Interval

Ped. Clr. = Pedestrian clearance time (sec.)

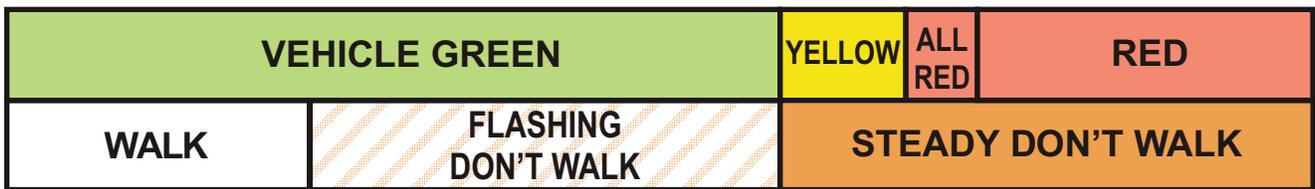
Table 4.6 Recommended Pedestrian Interval Timing Values

Walking Speed (feet/sec)	Recommended Walk Interval (secs)	Recommended Pedestrian Clearance Interval (seconds)					
		Crossing Street Width (feet)					
		30	40	50	60	70	80
3.0	7.0	10.0	13.3	16.7	20.0	23.3	26.7
3.5	7.0	8.6	11.4	14.3	17.1	20.0	22.9
4.0	7.0	7.5	10.0	12.5	15.0	17.5	20.0

4.5.8 Traffic Signal Timing Plans – A signal timing plan is a unique combination of cycle length, phasing, splits (green interval + clearance interval for each phase) and offsets (for system operation).³² Where overall intersection volumes vary significantly during the day, more than one cycle length will be needed. A change in either cycle length or phase splits will require multiple timing plans. See Section 4.6 for more detail.

³¹ MUTCD, FHWA, 2003, p. 4E-9.

³² Traffic Control Devices Handbook, ITE, 2001. p. 337



PREFERRED PEDESTRIAN TIMING SEQUENCE



ALTERNATE PEDESTRIAN TIMING SEQUENCE

4.6 Traffic Signal Coordination – Signal coordination occurs when a fixed timing relationship is established between two or more traffic signals in order to reduce overall vehicular delay. Signal systems should be designed to move platoons of the volume of traffic prevailing on any section of roadway. The development of a wide "green band" to move low volumes of traffic should not restrict the flow of other traffic. Normally systems are developed to favor the flow of the arterial street traffic. Sometimes the volume of traffic entering or leaving the system from side streets may exceed the thru volume on the arterial. Every effort should be made to define the origin and destination of traffic in the system and to be sure that the major flows are incorporated into the progression.

The goal of coordination is delay reduction. Which approaches experience this reduction depends on the objectives of the system.

On a heavily traveled corridor, the goal of signal coordination would be to reduce delay on the major street by allowing uninterrupted flow without significantly impacting side street delay. In a city grid system, the goal of coordination is to reduce overall delay within the system through the elimination of bottlenecks and long queues.

To be cost effective and beneficial, signal coordination requires the following:

- 1. A plan.** Federal requirements now call for any agency that implements any kind of signal coordination or intelligent transportation system to eventually develop a citywide or regional architecture. The city will have to determine not only the equipment requirements, but all stakeholders involved in the plan.
- 2. A commitment.** To function effectively, the local agency must commit to providing proper maintenance and operation. Timing plans must be monitored and updated regularly. Whether maintenance and operations are monitored by in-house staff or by consultant, the agency must have the staff capability to understand the basic functions of the system and determine where and when changes and modifications are needed.
- 3. A need.** Signal interconnection systems have varying degrees of benefit. While any coordination may reduce delay somewhat, it has to be weighed against the costs of installation, operation, and maintenance. If the corridor functions well without excessive queuing or delay, interconnection may not be cost effective.

Traffic signals that are within 1/2 mile of one another should be strongly considered for coordination.³³ The type of coordination utilized may be dependent upon the maintenance capabilities of the maintaining agency.

4.6.1 Time Base Coordination – This type of traffic coordination is based on an internal or external electronic clock rather than a physical interconnect. Timing plans are developed and entered individually into each controller and a common time reference is used by the individual controller clocks to

³³ MUTCD, FHWA, 2003, p. 4D-12.

initiate timing patterns. Because this system has no master controller to keep individual controllers in-synch, it is totally dependent on the time clocks not drifting. This type of coordination requires frequent visits to controllers to reset time clocks.

- 4.6.2 Closed Loop Signal System** – The most common signal system used for coordination today is the “closed loop” system. This is a distributive processing, traffic responsive, control and monitoring system. Access to the system from the office is usually made through a dial-up modem.

A closed loop system utilizes on-street master controllers to monitor and manage local intersection controllers.

A “closed loop” system consists of the following elements:

- System Detectors
- Local Controller Units
- Controller-Master Communications
- On-Street Master Controller
- Master-Central Communications
- Central Computer and Windows based Software

The system’s principal operational task is to select and implement traffic signal timing plans in response to real-time traffic conditions, preset time based events and/or operator commands. The system can also provide extensive control monitoring, data collection, reporting, and analysis functions.

Typical capabilities include the ability to upload all timing settings, operation parameters and status information, as well as the ability to download all timing settings and operation parameters. Many of today’s closed loop systems utilize a building block design which enables future system expansion to occur without major modifications to the existing system.

4.6.3 Methods of Communication

- A. Hard Wire** (see Section 4.12) – A 6 pair 19 gauge copper cable may be run between controllers at adjacent intersections and on-street masters for coordination purposes. A fiber optic cable may also be used for coordination and communication purposes. While fiber optic cable has a high capacity for transmitting information and is extremely versatile, it has higher installation and maintenance costs. Fiber optic cables generally require larger termini and pull boxes.
- B. Time-Based (Wireless)** – Coordination may be accomplished internally in each coordinated controller with timing referenced to a system time base. The internal clock in each controller must be set precisely (to the second) with the clocks in the adjacent coordinated

controllers. However, these internal clocks often drift and can cause coordination problems over time.

- C. **Spread Spectrum Radio** – Communication using spread spectrum radio may be carried between units in master and local controller cabinets. Omni-directional antennas are used at master cabinet locations and uni-directional (Yagi) antennas are used at local cabinet locations.

4.6.4 Hard Wire Interconnect Installation – Generally, underground rather than overhead installation is preferred. The choice, however, may be determined by local preference, utility conflicts or cost.

- A. **Conduit** – Interconnect cable shall be run in its own conduit, separate from signal and detector cables. The cable shall be run in a 2" diameter RGS or PVC conduit at a minimum depth of 30".
- B. **Pull boxes** – To provide access and facilitate the pulling of long runs of underground interconnect cables. See Section 4.14 for details on pull box types.
 - **Types** – Pull boxes for standard interconnect cable shall be Type B Pull Boxes. Pull boxes for pulling fiber optic cable shall be larger.
 - **Spacing** – Pull boxes for interconnect cable shall be placed at distances no greater than 300 feet or at locations where access for splicing is required. Pull boxes for fiber optic cable runs shall be placed at 1000 foot intervals.
- C. **Risers** – When transitioning from overhead to underground or vice versa on a utility pole, 2" RGS diameter riser must be specified for the interconnect cable.

4.6.5 Coordinated Timing Plans – Arterial control is concerned with controlling traffic signals along an arterial highway so as to give major consideration to progressive flow of traffic along that arterial. The green should be displayed at an intersection sufficiently in advance of the arrival of a major platoon, to clear vehicles that may be stopped and to allow the platoon to continue without stopping.

It is better to arrive too early than too late. Vehicles arriving a little bit early wait a lot less time than vehicles arriving late. Early arrivals can avoid stopping by adjusting their speed. Vehicles that are a bit late are tempted to run the yellow light or increase their speed.

The timing plan of a system consists of three elements; cycle length, splits and offsets. The splits must be determined for each individual intersection in the system and may vary from intersection to intersection. The split is the segment of the cycle length allocated to each phase or interval that may occur (expressed in percent or seconds). In an actuated controller unit, split is the time in the cycle allocated to a phase. However, the cycle length for each traffic signal in a system must be the same or a multiple of

one another. Determination of an optimum cycle length is the key to any efficient signal system.

Another factor in the design of the individual intersection that may become evident during the arterial analysis is that some intersectional cycle lengths may not be compatible with the cycle length for the system during some timing plans. These intersections should be designed to have flexibility to operate fully-actuated during these time periods. The same approach should be used for traffic signals that do not have programmed flash where most of the other traffic signals in the system flash during nighttime hours to reduce delay and improve traffic flow along the corridor.

Signal Timing Plan Development Methods – The following methods of calculating signal offsets and splits are commonly used:

- Synchro Software
- PASSER II Software
- TEAPAC Software
- Transyt 7f Software

Signal timing plans should always be monitored after installation and field fine tuned to ensure safe and efficient operation.

4.6.6 Offsets – Where adjacent traffic signals are coordinated (interconnected), signal offset settings are needed. An offset is the time difference (in either seconds or percent of cycle) between the start or end of the Green Interval at one intersection and the start or end of Green Interval at another intersection, both measured from a system time base.³⁴

4.7 Preemption and Priority Control of Traffic Signals – Traffic 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 indication or as complex as replacing the entire set of signal phases and timing.³⁵

Preemption describes the transfer of normal operation of a traffic signal to a special control mode of operation. Preemption control is typically given to emergency vehicles and trains.

Typical preemption examples are:

- The prompt displaying of GREEN signal indications at signalized locations ahead of fire vehicles, law enforcement vehicles, ambulances, and other official emergency vehicles.
- A special sequence of signal phases and timing to provide additional clearance time for vehicles to clear the tracks prior to the arrival of a train.
- A special sequence of signal phases to display a RED signal indication to prohibit turning movements towards the tracks during the approach or passage of a train or transit vehicle.

³⁴ Traffic Control Devices Handbook, ITE, 2001, p. 335

³⁵ MUTCD, FHWA, 2003, p. 4D-10.

Priority control is typically given to certain non-emergency vehicles such as buses and light-rail vehicles. Priority Control describes a means by which the assignment of right-of-way is obtained or modified.

Priority control describes a means by which the assignment of right-of-way is obtained or modified usually for transit vehicles.

Typical priority control examples are:

- The displaying of early or extended GREEN signal indications at an intersection to assist public transit vehicles in remaining on schedule.
- Special phasing to assist public transit vehicles in entering the travel stream ahead of the platoon of traffic.

Railroad preemption is by far the most important and most complex type of preemption. It is discussed in detail in Section 4.8.

4.7.1 Emergency Vehicle Preemption –

Various mechanisms can be used to preempt traffic signals so that emergency vehicles are provided with safe right of way as soon as practical. The purpose of such preemption is to provide the right of way to the emergency vehicle as soon as practical.

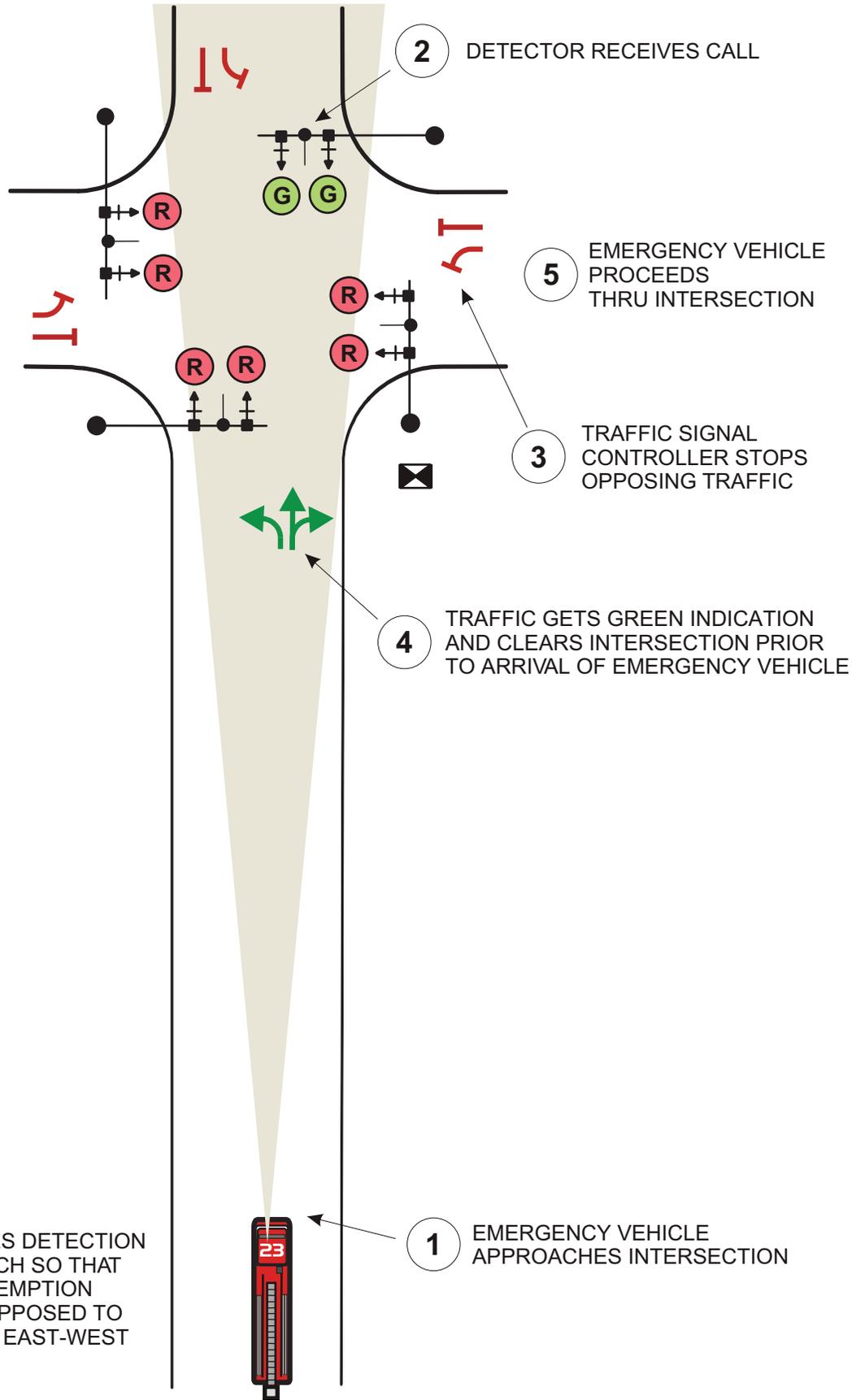
Preemption for emergency vehicles is a method of ending conflicting phases and providing a green indication for emergency vehicles in advance of their arrival.

Emergency preemption systems allow emergency vehicles to interrupt the normal sequence of traffic signal phasing and provide priority to the approach with the emergency vehicle. Traditionally, this was accomplished by communications cables between an emergency center and traffic signal controllers along predetermined emergency routes.

Newer technologies allow a flexible response system using either a light emitter or siren in the vehicle and a receiver connected to the traffic signal controller at various intersections. The receiver sends a message to the signal controller, which terminates the current phase and skips to the Green Interval on the required approach. Figure 4.23 shows a sample emergency vehicle preemption design.

- #### **4.7.2 Preemption Justification –**
- Emergency vehicle preemption should be considered at intersections that have frequent conflicts with emergency vehicles and any intersection that is along a route already using emergency vehicle preemption equipment.

Because priority control primarily benefits transit operations and is not a safety device, justification for installation of priority control should be a joint decision between the traffic engineering agency and the transit agency. Benefits to transit operations must be weighed against the possible increased delay for passenger vehicles.



NOTE: THIS EXAMPLE USES DETECTION ON EACH APPROACH SO THAT DIRECTIONAL PREEMPTION IS POSSIBLE (AS OPPOSED TO NORTH-SOUTH OR EAST-WEST PREEMPTION)

4.7.3 Preemption Sequence – Preemption of the traffic signal should provide the following sequence of operation:

1. A Yellow Change Interval and any required All Red Clearance Interval for any signal phase that is green when preemption is initiated and which will be red during the preemption interval. The length of the Yellow Change and All Red Clearance Intervals shall not be altered by preemption. Phases which will be green during the preemption period and which are already green when preemption is initiated shall remain green. Any Pedestrian Walk Interval in effect when preemption is initiated shall be immediately terminated. The normal Pedestrian Change Interval may be abbreviated.
2. An all-red intersection preemption display shall not be used.
3. The traffic signal shall return to normal operation upon termination of the demand for preemption or the termination of the assured Green Interval.

4.7.4 Multiple Preemption – A combination of railroad, emergency preemption and priority control is allowed at an intersection. There is usually a hierarchy in determining which preemption or priority occurs first when more than one is received by the traffic signal controller. “Preemption” always is serviced before “priority”. However, railroad preemption must always override emergency preemption. This hierarchy shall be as follows:

Railroad preemption must always take priority over emergency vehicle preemption.

- A. **Preemption** – Railroad Train over Emergency Vehicle (Fire, Rescue or Ambulance) over Law Enforcement Vehicle
- B. **Priority** – Light Rail over Bus

4.7.5 Methods of Emergency Vehicle Preemption – Several methods of traffic signal preemption are typically utilized for emergency vehicles.

- A. **Hardwired from Source** – A connection between the traffic signal controller and the source of an emergency call (e.g. fire station) allows preemption.
- B. **Optically Activated** – Optical priority control systems consist of an emitter mounted on a vehicle, detectors mounted above the intersection and a phase selector and other equipment in the traffic signal controller cabinet. The detector senses the optical pulses emitted by properly equipped emergency vehicles and informs the traffic signal controller of the presence of designated vehicles.
- C. **Siren Activated** – Siren priority control systems consist of detectors mounted above the intersection and a phase selector and other equipment in the traffic signal controller cabinet. The system is activated by a Class A electronic siren.

4.7.6 System Components for Optical and Siren Activated Emergency Vehicle Preemption – A particular brand can be specified provided the city has installed the same at other locations and it is the predominate brand. TDOT will normally install emergency vehicle preemption devices (optical or siren activated priority control systems) as a part of a traffic signal installation or upgrade project upon request of the local governing agency. TDOT will normally not provide emitter/transponders unless the project's purpose is to provide a citywide or area wide preemption system and conforms with the area wide or regional ITS architecture. The typical information to be shown on traffic signal construction plans for emergency vehicle preemption is shown in Figure 4.24.

When installing preemption, a footnote should be added to the Plans noting the number of sensors, the number of phase selectors or other equipment and the estimated quantity of required cable. Each intersection is measured per each.

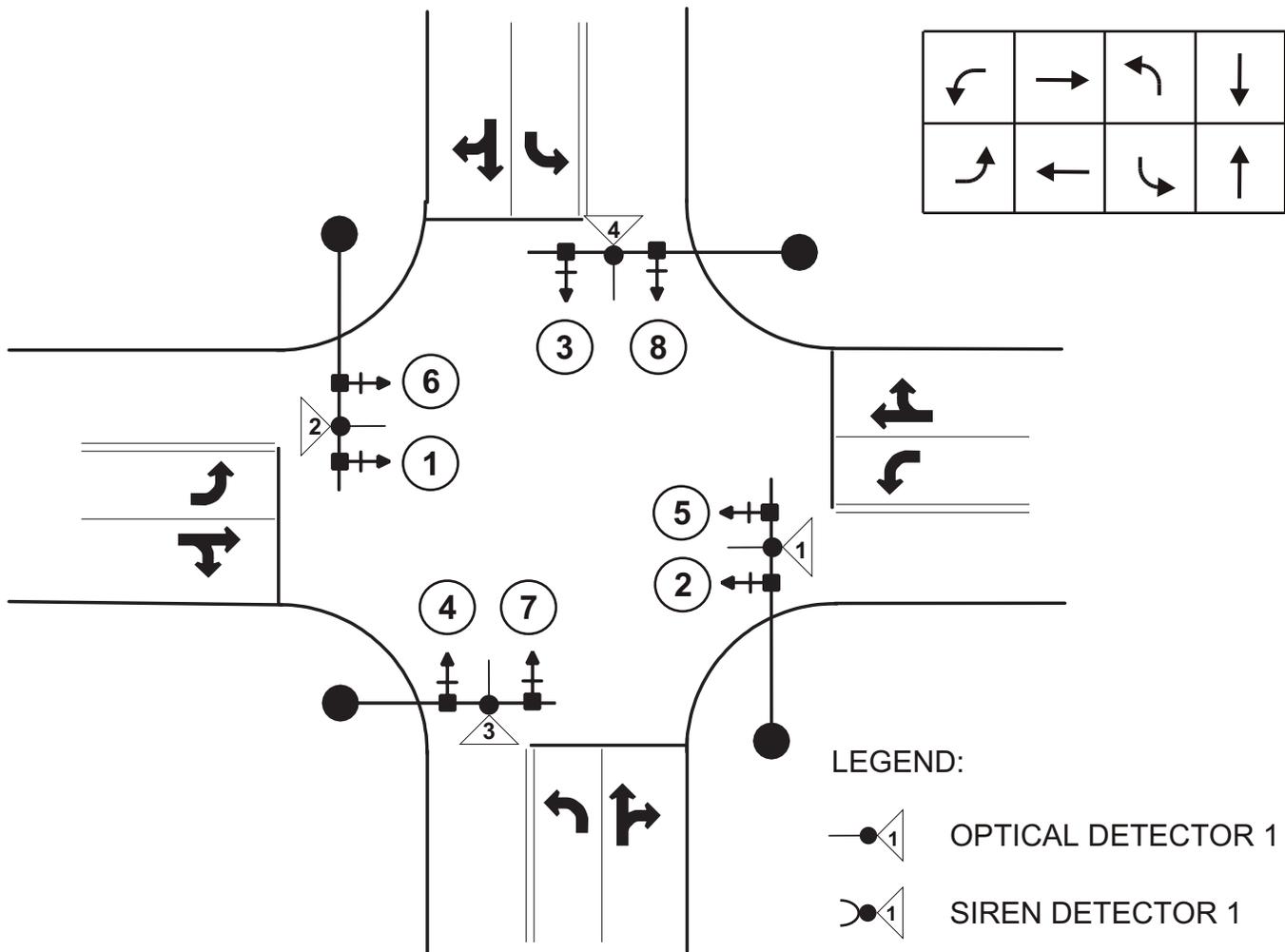
4.7.7 Priority Control – Priority control systems are less common than emergency vehicle preemption systems. While a priority control system might benefit a transit system by keeping its vehicles on a tighter schedule, it can lead to overall increased congestion at an intersection. Benefits to transit operations must be weighed against the possible increased delay for passenger vehicles. Some systems, such as the optically activated priority control system can provide both preemption for emergency vehicles and priority control for transit vehicles.

4.8 Railroad Preemption – Railroad preemption is a special signal phasing sequence which is actuated upon the detection of a train and is designed to clear traffic off the railroad tracks prior to the arrival of the train at the highway-rail grade crossing. Railroad preemption results in a special traffic signal operation depending on the relation of the railroad tracks to the intersection, the number of phases in the traffic signal and other traffic conditions. Railroad preemption is normally controlled by the highway-rail grade crossing warning equipment which sends a signal to the traffic signal controller to initiate preemption of the traffic signal

Railroad preemption is a method of ending conflicting phases, then clearing and inhibiting movements that cross the railroad tracks until the train has cleared the crossing.

Traffic signal preemption at a railroad crossing requires a permit with the railroad authority. The highway agency and railroad authority should coordinate to understand the operation of each other's system. In order to determine the minimum preemption warning time, factors such as equipment response and programmed delay times, Minimum Green signal time, vehicular and pedestrian clearances, queue clearances, and the train/vehicle separation times should be considered. An engineering study at each preempted location may be required to determine these factors.

Intersections closer than 200' to a crossing must use preemption. An engineering study should be conducted to determine the need for preemption when a crossing is near, but greater than 200' from a traffic signal.



EXAMPLE CHART TO BE INCLUDED IN PLANS

PREEMPTION ASSIGNMENTS		
DETECTOR 1	PREEMPT 1	Ø 2 AND Ø 5
DETECTOR 2	PREEMPT 3	Ø 1 AND Ø 6
DETECTOR 3	PREEMPT 3	Ø 4 AND Ø 7
DETECTOR 4	PREEMPT 4	Ø 3 AND Ø 8

4.8.1 Railroad Preemption Warrant – The coordination of the operation of a traffic signal with a nearby highway-rail grade crossing equipped with flashing lights is justified under the following conditions.³⁶

1. Where the highway-rail grade crossing is located within 200 feet of the traffic signal, preemption should be used. This distance is defined as the clear storage distance (CSD) and is measured from the intersection stop line to the railroad stop line on the near side of the tracks (typically 6 feet from the rail).
2. However, 200 feet may not be sufficient for some locations. Where the highway-rail grade crossing is located more than 200 feet from the traffic signal, but traffic from the signal is anticipated to back up across the railroad tracks, preemption should be used. Calculation of the traffic backup is determined with approximately 95% certainty using Equation 4.10 or 4.11. The traffic back up in the thru lanes as well as turn lanes should be checked.

Back Up Queue Calculation (Approach $v/c < 0.90$)

Equation 4.10³⁷

$$L = 2qr(1 + P)(25)$$

Where: L = Length of Queue (ft./lane)

q = Average flow rate

r = Effective red time (approach clearance + red)

P = Proportion of Trucks (as a decimal)

Back Up Queue Calculation (Approach $v/c \geq 0.90$ but less than 1.0)

Equation 4.11³⁸

$$L = (2qr + \Delta x)(1 + P)(25)$$

Where: L = Length of queue (ft./lane)

q = Average flow rate

r = effective red time (approach clearance + red), (sec)

$$\Delta x = 100 \left(\frac{v}{c} \text{ratio} - 0.90 \right)$$

P = Proportion of trucks (as a decimal)

3. When traffic stopped for a train at the highway-rail grade crossing frequently backs up into a nearby signalized intersection, preemption may be used.

³⁶ MUTCD, FHWA, 2003, p. 8D-7.

³⁷ Northwestern University Traffic Institute, Railroad Grade Crossing Workshop. 2003.

³⁸ Ibid.

4.8.2 Pre-Signals – A pre-signal provides a signal display on the near side of the track, supplementing the normal head placement. This operates as part of the highway intersection traffic signal, controlling traffic approaching the highway-rail grade crossing and signalized intersection.

Pre-signals should be considered when:

1. The highway intersection is less than 50 feet from the highway-rail crossing (75 feet for a road that is regularly used by multi-unit vehicles).
2. Where the clear storage distance (CSD) is greater than 75 feet and an engineering study determines the need³⁹.

A pre-signal is a set of supplemental traffic signal faces located in a position that controls traffic approaching the highway-rail grade crossing in advance of the intersection.

In general, a pre-signal should be considered when the clear storage distance (CSD) as defined in 4.8.1 is not sufficient to safely store the design vehicle, such as the largest legal truck combination, or if vehicles regularly queue across the tracks.⁴⁰

The pre-signal phase sequencing should be progressively timed with an offset adequate to clear vehicles from the track area and downstream intersection. The signal heads at the far side of the intersection (away from the crossing) should be programmable so as to limit their visibility from vehicles before the tracks⁴¹.

When the design vehicle cannot be safely stored in the CSD, or if no gates are present, a NO TURN ON RED (R10-11) shall be installed on the approach with the pre-signal to prevent trapping a vehicle⁴².

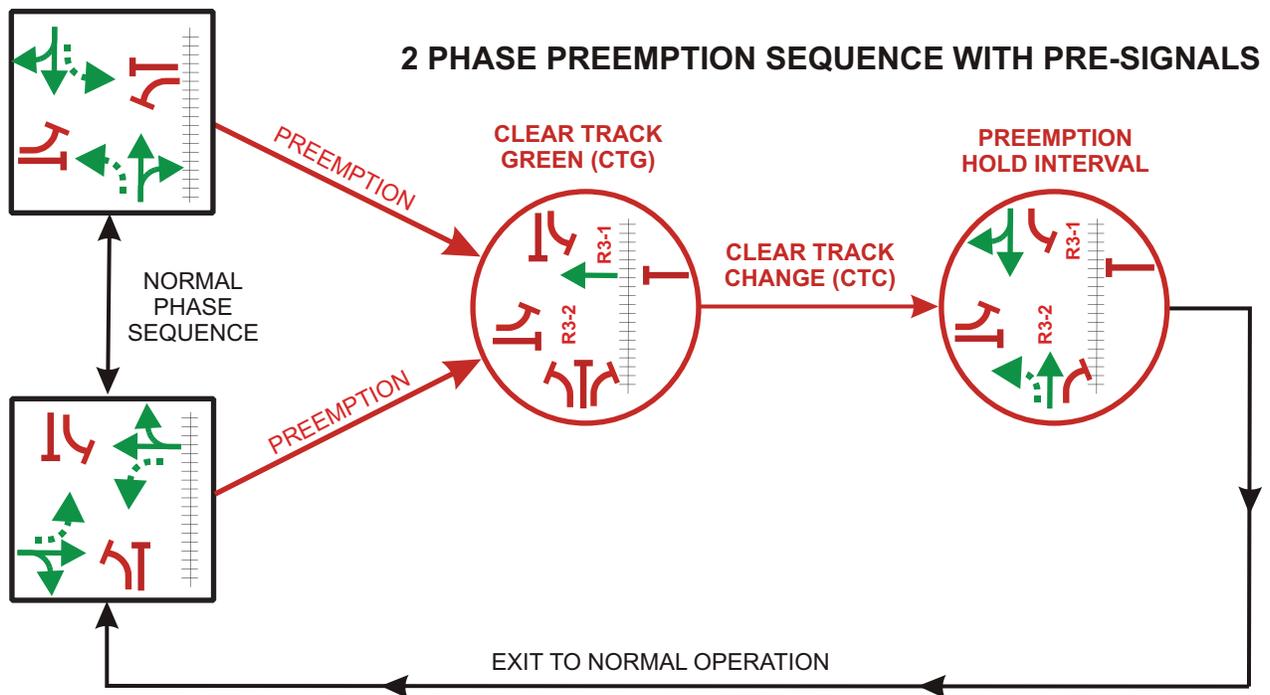
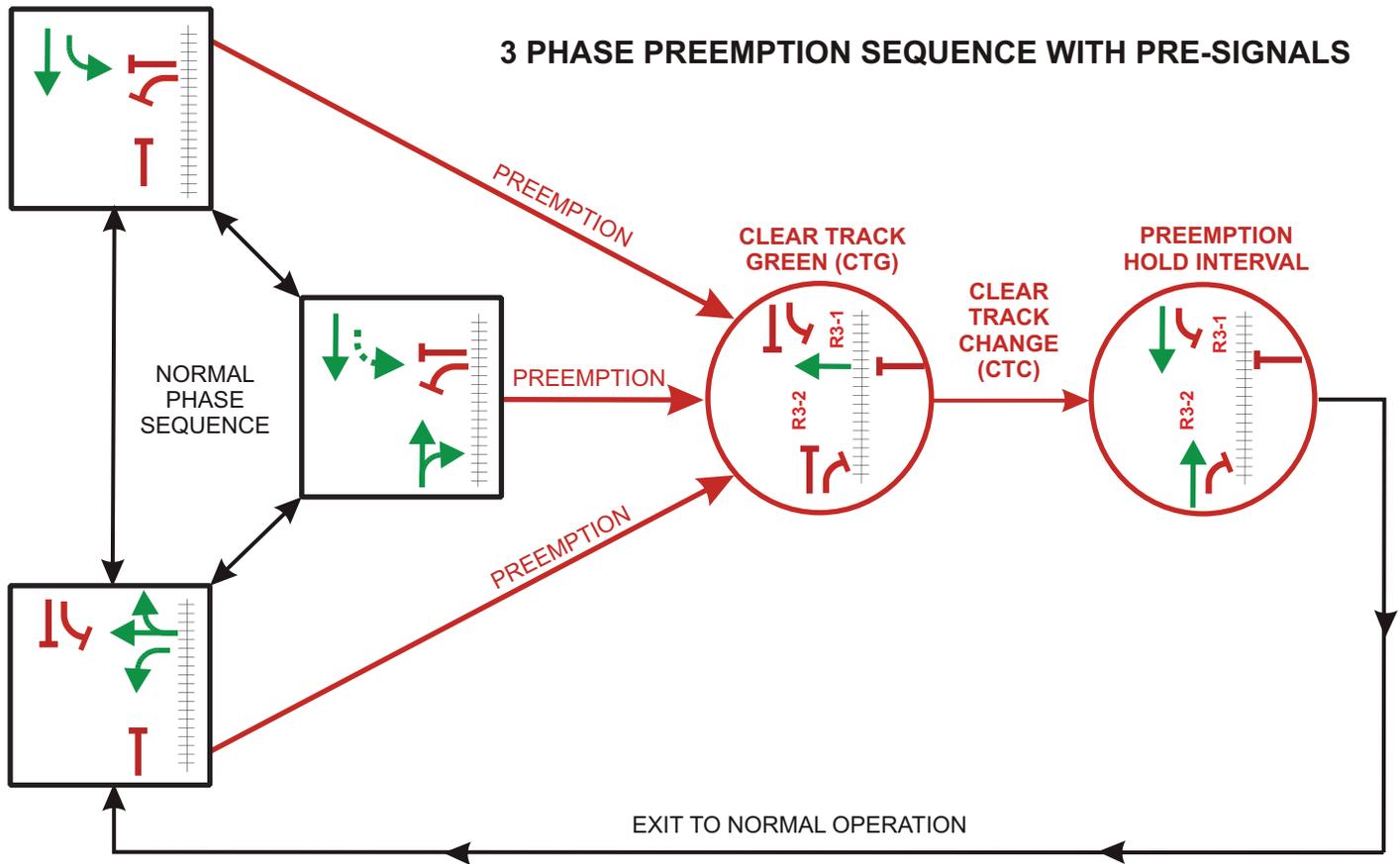
4.8.3 Railroad Preemption Sequence – The preemption sequencing of two-phase and three phase traffic signals are shown in Figure 4.25. Railroad preemption for an eight phase intersection is shown in Figure 4.26. As the figures show, the basic phases of the sequence are a right-of-way change interval, a clear track interval and preemption hold phasing (while the train is occupying the highway-rail grade crossing).

³⁹ Guidance on Traffic Control Devices at Highway-Rail Grade Crossings, FHWA, 2002, p.24.

⁴⁰ Traffic Control Devices Handbook, ITE, 2001, p. 392.

⁴¹ Guidance on Traffic Control Devices at Highway-Rail Grade Crossings, FHWA, 2002, p.24.

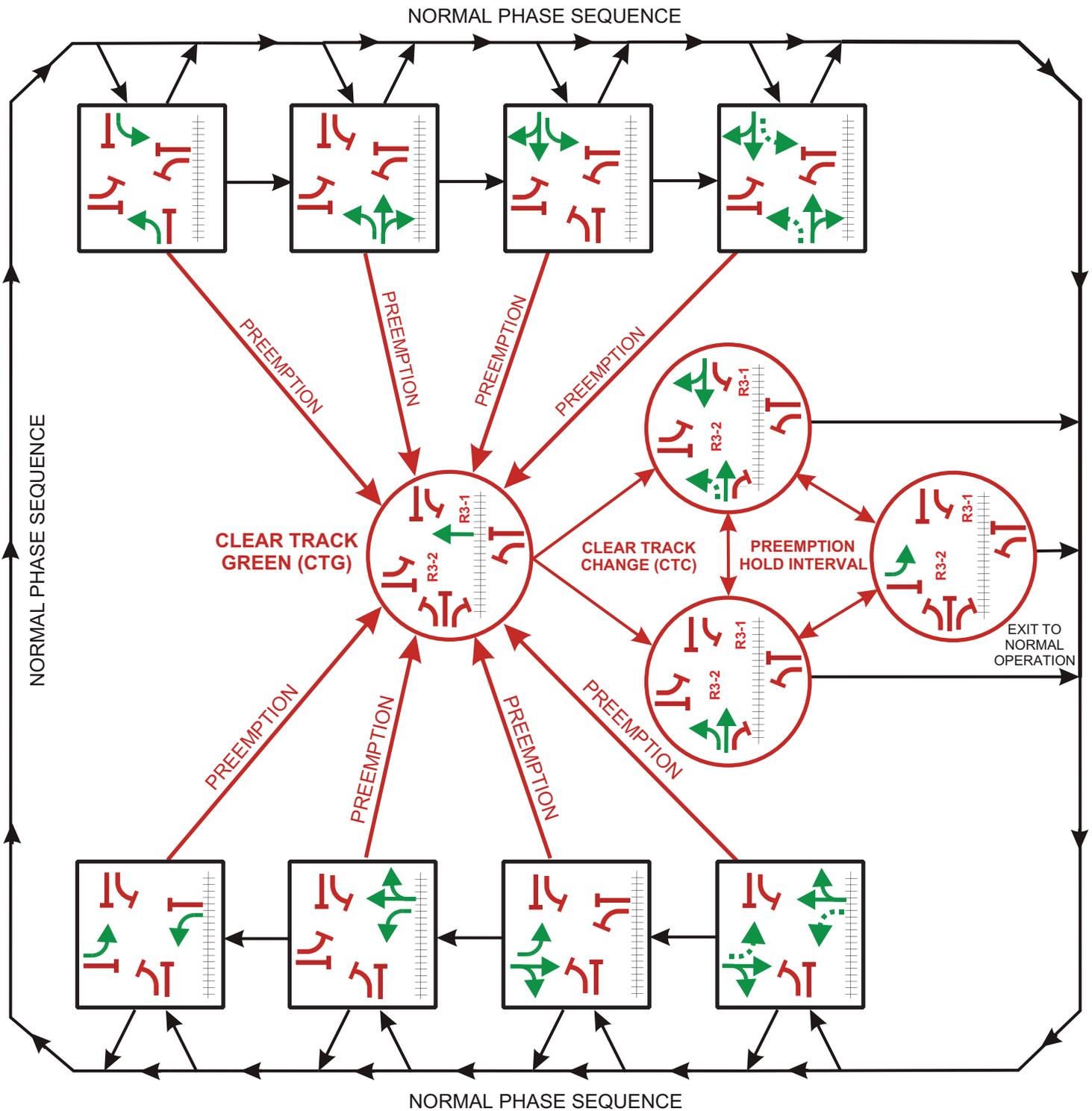
⁴² MUTCD FHWA, 2003. p. 8D-7.



Tennessee Department of Transportation
Traffic Design Manual

**Railroad Preemption Sequence
(2 and 3 Phase Operation w/ Pre-Signal)**

Figure 4.25



Railroad Preemption Sequence
(8-Phase Operation with Pre-Signal)

Preemption of the traffic signal should have the following sequence:

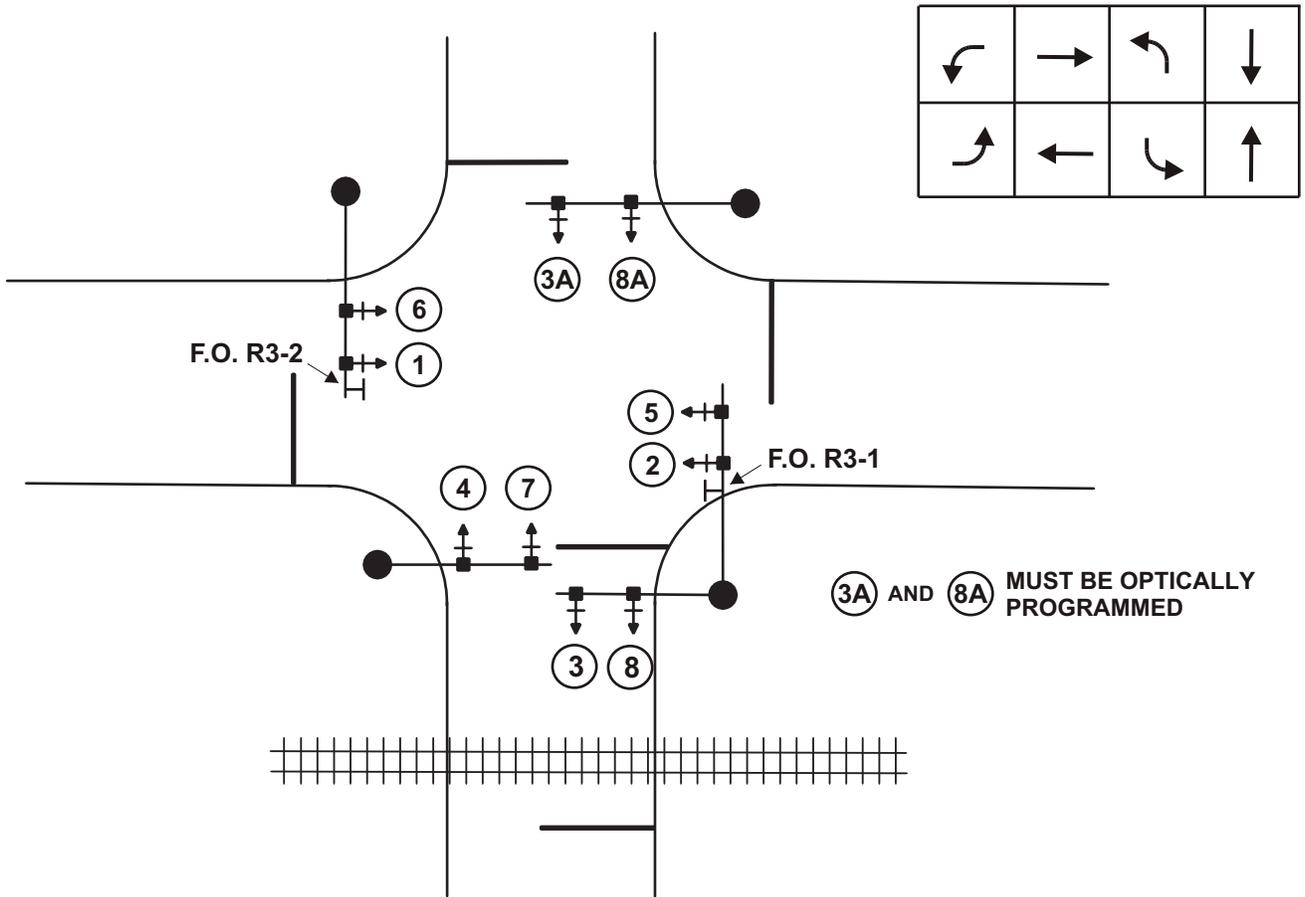
1. A Yellow Change Interval and any required All Red Clearance Interval for any signal phase that is green or yellow when preemption is initiated and which will be red during the track clearance interval. The length of Yellow Change and All Red Clearance Intervals shall not be altered by preemption. Phases which will be green during the track clearance interval and which are already green when preemption is initiated, shall remain green. Any Pedestrian Walk or Pedestrian Change Interval, in effect when preemption is initiated, shall immediately be terminated and all pedestrian signal faces shall display steady DON'T WALK indication.
2. A track clearance interval for the traffic signal phase or phases controlling the approach which crosses the railroad tracks.
3. Depending on traffic requirements and phasing of the traffic signal controller, the traffic signal may then do one of the following:
 - A. Go into flashing operation, with flashing RED or flashing YELLOW signal indications for the approaches parallel to the railroad tracks and flashing RED signal indications for all other approaches. Pedestrian signals shall be extinguished.
 - B. Revert to limited operation with those signal indications controlling thru and left turn approaches towards the railroad tracks displaying steady red. Permitted pedestrian signal phases shall operate normally.
4. The traffic signal shall return to normal operation following release of preemption control.

The typical information to be shown on traffic signal construction plans for railroad preemption is shown in Figure 4.27.

4.8.4 Railroad Preemption Warning Timing⁴³ – The total time to transfer right-of-way (including Pedestrian Change Intervals) plus the queue clearance plus the separation time is the preemption time setting. This time should be greater than the railroad warning time (the time for the circuit to activate warning devices in advance of the train arrival).

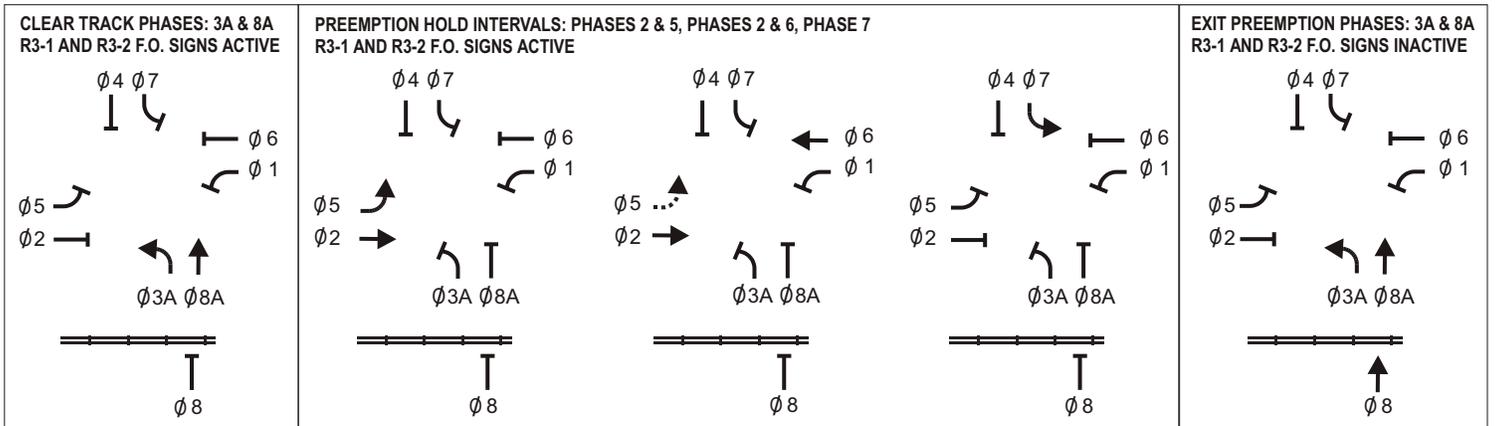
4.8.5 Blank Out Signs – These types of signs display a blank face unless internally illuminated upon activation for a specific circumstance. Such signs displaying the message/symbol “NO LEFT TURN” or “NO RIGHT TURN” are useful as part of the railroad preemption sequence at signalized intersections immediately adjacent to grade crossing. At these locations, turn prohibition blank out signs can prevent traffic from turning into and occupying the limited storage area between the tracks and intersection and eventually blocking the intersection itself. These signs are activated upon initiation of the railroad preemption and deactivated after the preemption is completed.

⁴³ Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices, ITE, 1997. p. 15



EXAMPLE CHART TO BE INCLUDED IN PLANS

RAILROAD PREEMPTION SEQUENCE



4.9 Traffic Signal Heads – Signal heads shall comply with standards of the MUTCD.

4.9.1 Lens Size and Type – Twelve inch (12”) diameter lenses are required on all new signal heads. Today, traffic signal indications and pedestrian indications are usually illuminated by light emitting diode (L.E.D.) lamps.

All new signal heads should be 12” diameter lenses using LED lamps.

Conventional incandescent lamps consume up to 150 watts of power and require routine maintenance due to filament burn out. The use of LED lamps can conserve energy and reduce maintenance costs. An LED is a current operated, semiconductor light source. Power requirements are considerably less than incandescent lamps. The life expectancy of an LED lamp is 45,000 hours or 10 years of operation.

4.9.2 Signal Housing – Vehicular signal heads are manufactured in either aluminum or polycarbonate plastic. The choice of which material to use should be made by the local agency. Because of their light weight, polycarbonate signal heads must either be tethered or rigidly mounted so wind sway will not be a factor. Signal heads shall be constructed of aluminum, unless the local agency prefers polycarbonate materials. Signal head housings shall be yellow unless otherwise specified by the local agency. Because agencies use different combinations of signal housing colors, the housing colors to be used at the intersection shall be noted on the plans if signal heads are not all yellow.

Signal heads should be aluminum unless the local agency desires polycarbonate signal heads.

Tethered signal heads must have breakaway clamps so the head will swing free during heavy wind conditions.

4.9.3 Backplates – Signal backplates increase the contrast between the signal indications and the signal background. A rising or setting sun or intensive advertising signing can lead to visibility problems. Backplates shall be used on all rural or high speed locations or urban locations where glare or other visual distractions are present. Where used, backplates shall have a dull black finish.

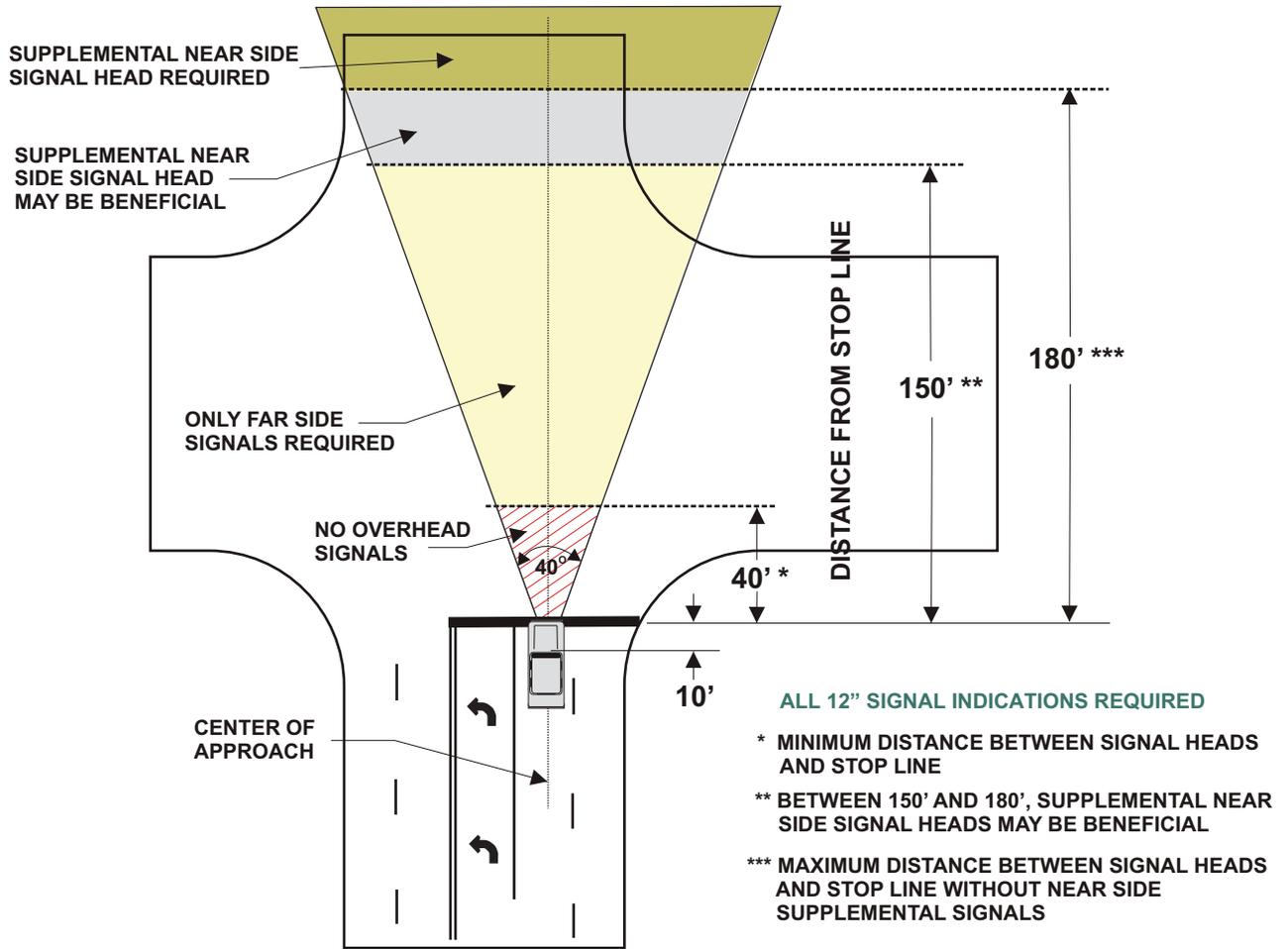
Backplates should be installed at all rural, high speed or visually distracting locations.

4.9.4 Number of Signal Faces⁴⁴

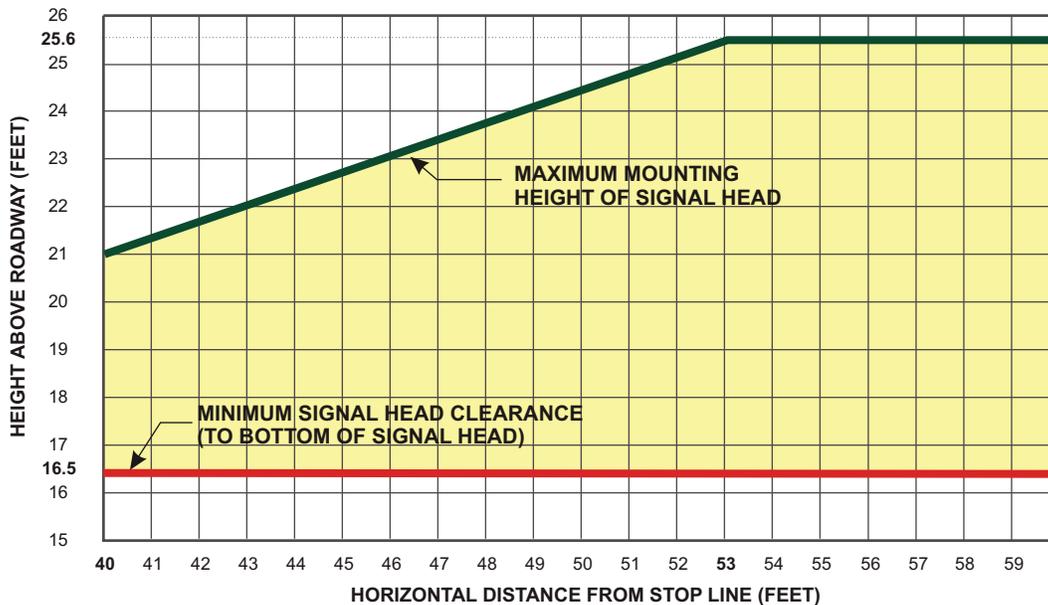
- A. Major Movement** – A minimum of two signal faces are to be provided for the major movement on each approach, even if the major movement is a turning movement.
- B. Supplemental Face** – If the signal faces are more than 180 feet beyond the stop line, a supplemental near side signal face is required.
- C. Dual (or Multiple) Left Turns** – Where two or more separate left turn lanes are provided, a separate left turn face shall be provided for each lane.

⁴⁴ MUTCD, FHWA, 2003, p. 4D-12

HORIZONTAL SIGNAL HEAD PLACEMENT



VERTICAL SIGNAL HEAD MOUNTING HEIGHT



4.9.5 Positioning Relative to the Stop Line – At least one, if not both, of the signal faces required in paragraph 4.9.4.A above should be located at a distance between 40-180 feet from the stop line. If both signal faces are more than 180 feet from the stop line, a supplemental near side signal face is required (see Figure 4.28).

Intersections with signal heads located more than 180' from the stop line require supplemental near side signal heads.

4.9.6 Horizontal Placement – At least one, if not both, signal faces required in paragraph 4.9.4.A above shall be placed in the area defined in Section 4D.15 of the MUTCD (see Figure 4.28).

A. Lane Alignment – In general, signal heads should be centered over the lanes to which they apply or on lane lines between lanes. Figures 4.29 thru 4.31 show typical left turn signal head applications and Figure 4.32 shows signal head placement for various split-phase intersections.

B. Adjacent Signal Faces⁴⁵ – Adjacent signal faces on the same span wire or mast arm should typically be placed 12 feet apart and shall be placed no closer than 8 feet apart.

C. Signal Faces – Left turn signals shall be the left most signal head and right turn signals shall be the right most signal head in the signal head arrangement for the approach (see typical examples in Figures 4.29 thru 4.32).

4.9.7 Vertical Placement – The placement of the signal head over the roadway shall be such as to provide a minimum 17.5 foot vertical clearance from the bottom of the signal head to the roadway. Where this is impractical, the minimum clearance shall be 16.5 feet. RED signal indications should be approximately the same height.

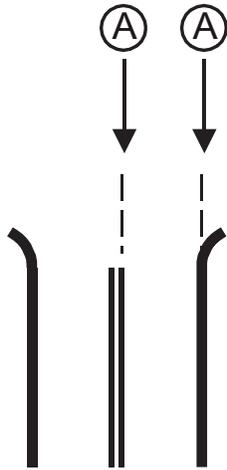
Signal heads shall be mounted with a minimum 16.5' (17.5' preferred) vertical clearance.

A maximum mounting height to the top of the signal housing for overhead signals is important to ensure visibility for signal heads that are near the stop line. The maximum mounting height shall be determined from Section 4D.15 of the MUTCD. In general, the maximum mounting height for signals can be determined on a sliding scale of 21 feet for signal heads 40 feet from the stop line and 25.6 feet for signal heads 53 feet from the stop line. For signal heads between 53 feet and 180 feet, the maximum mounting height shall be 25.6 feet (see Figure 4.28).

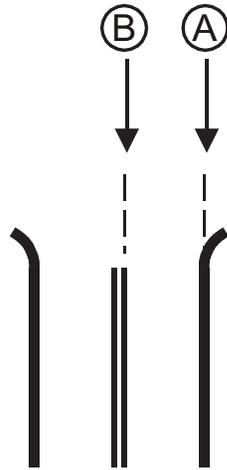
4.9.8 Face Arrangement – Individual signal sections shall be arranged vertically rather than horizontally unless sight distance or vertical clearance concerns dictate.

⁴⁵ MUTCD, FHWA, 2003,p. 4D-13

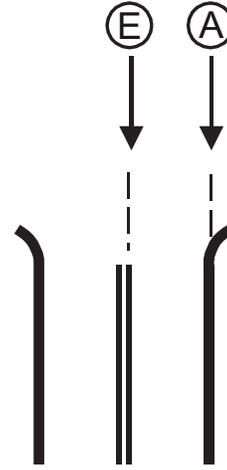
**PERMISSIVE
LEFT-TURN**



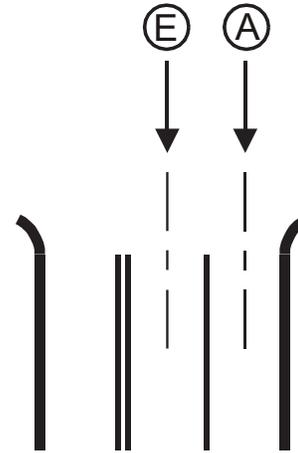
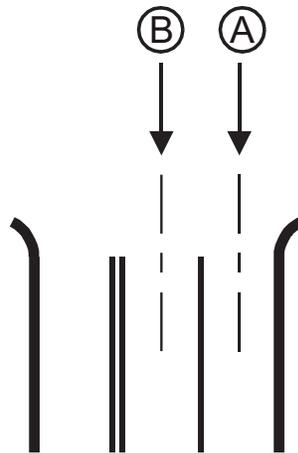
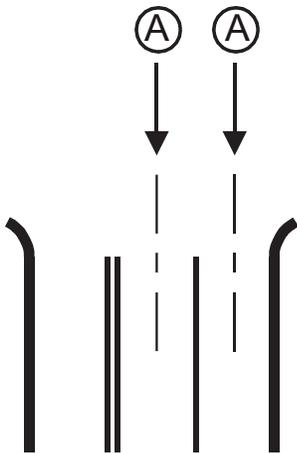
**PROTECTED/
PERMISSIVE
LEFT-TURN**



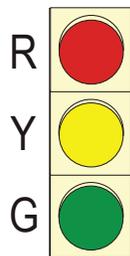
**PROTECTED
ONLY
LEFT-TURN**



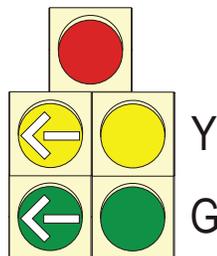
(SPLIT PHASE)



(SPLIT PHASE)



(A)



(B)

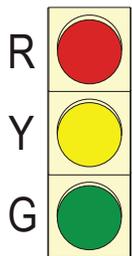
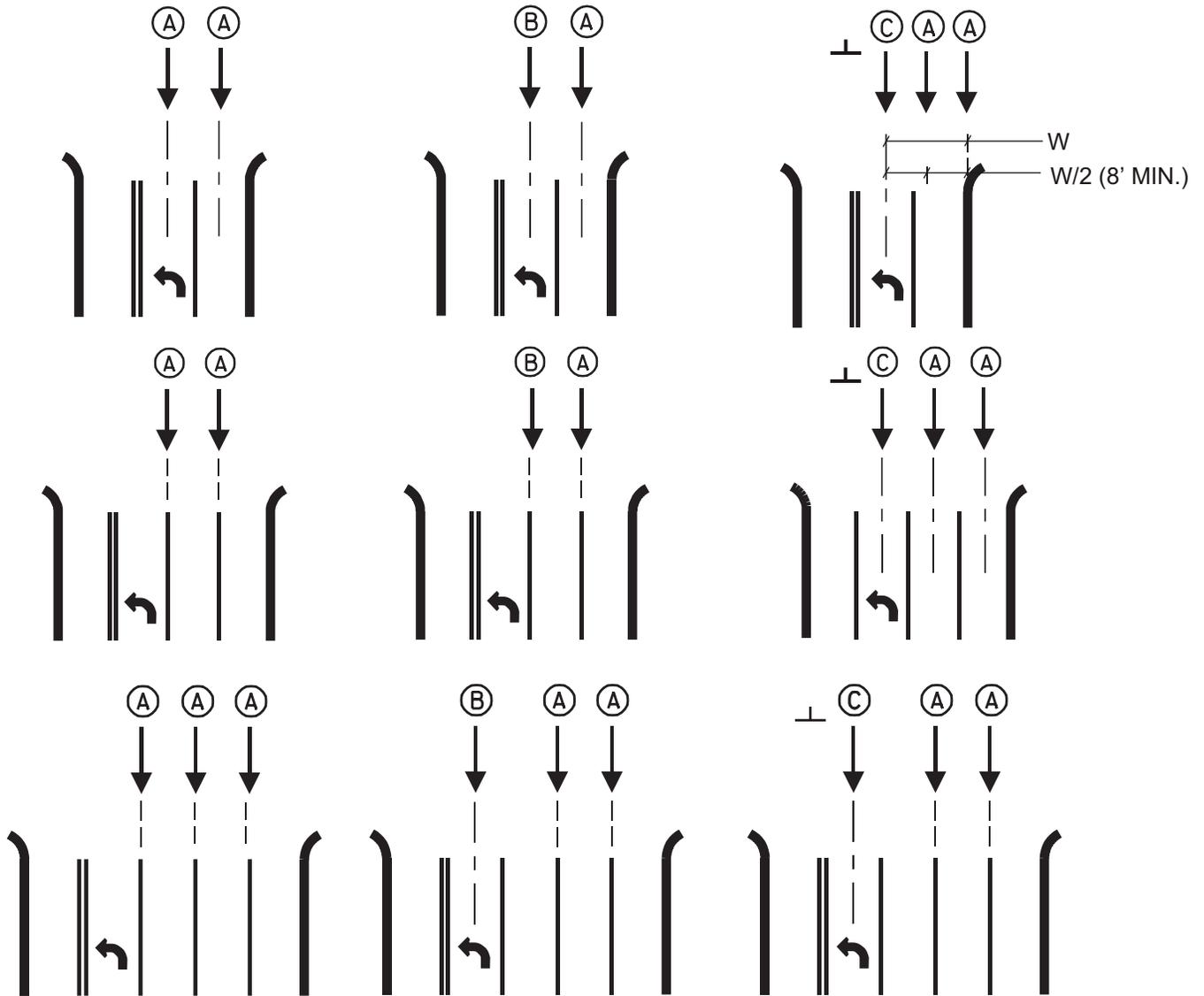


(E)

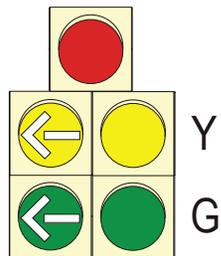
**PERMISSIVE
LEFT-TURN**

**PROTECTED/
PERMISSIVE
LEFT-TURN**

**PROTECTED
ONLY
LEFT-TURN**



(A)



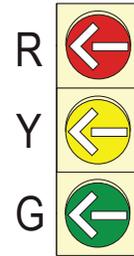
(B)



(C) With sign



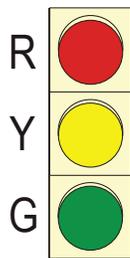
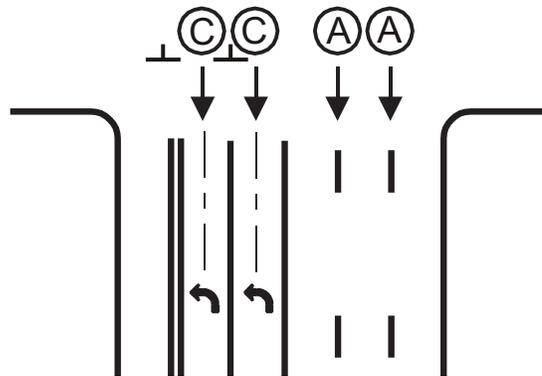
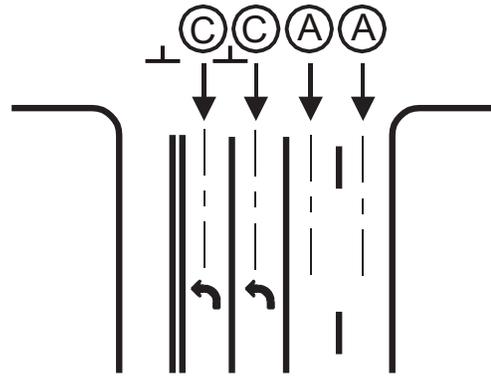
OR



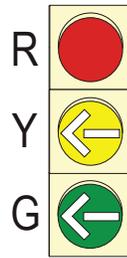
(D) Without sign

**Signal Head Placement
(One Left Turn Lane)**

**PROTECTED ONLY
LEFT-TURN**
(PERMISSIVE TREATMENTS NOT APPLICABLE)



(A)



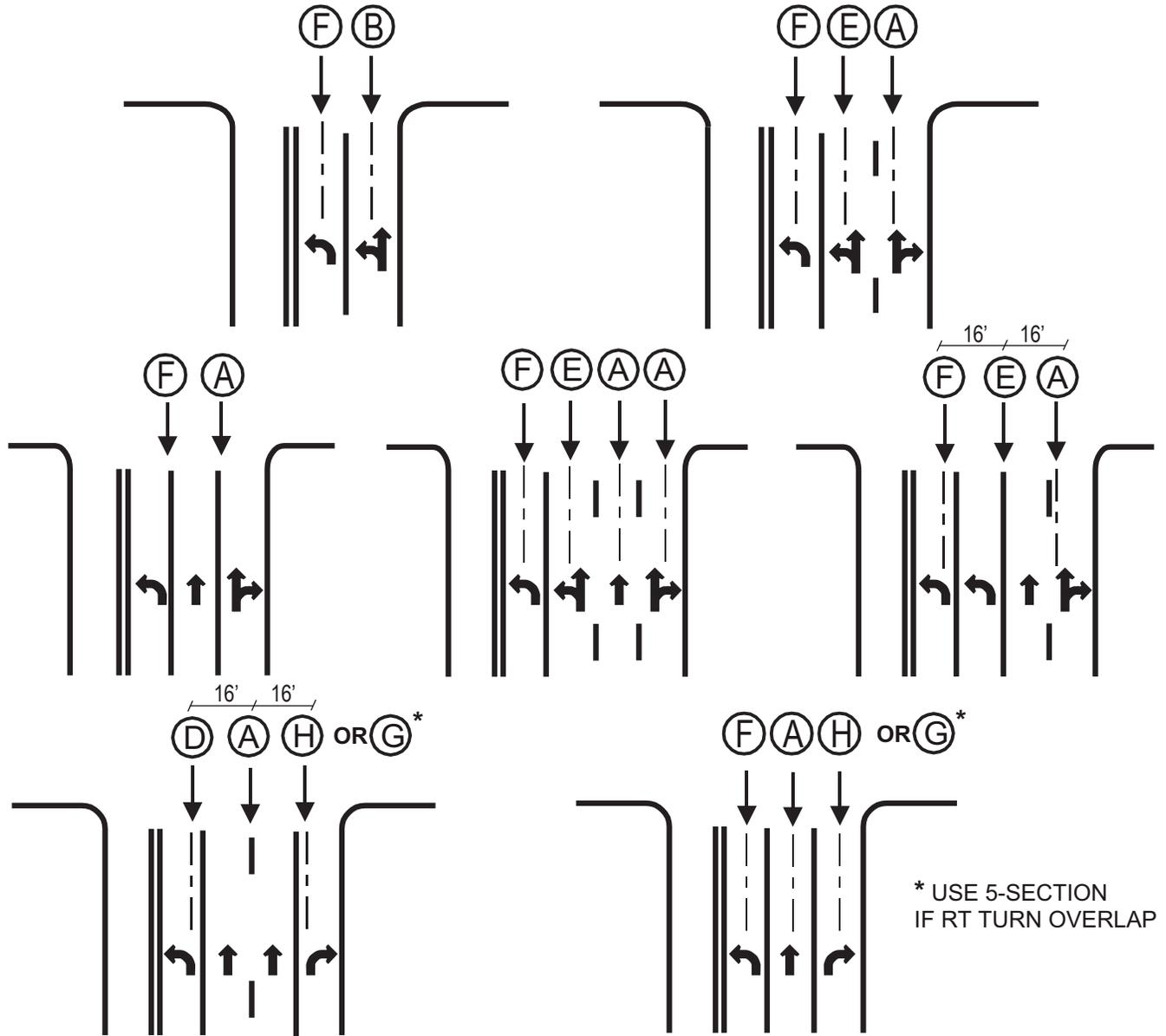
(C) With sign

OR

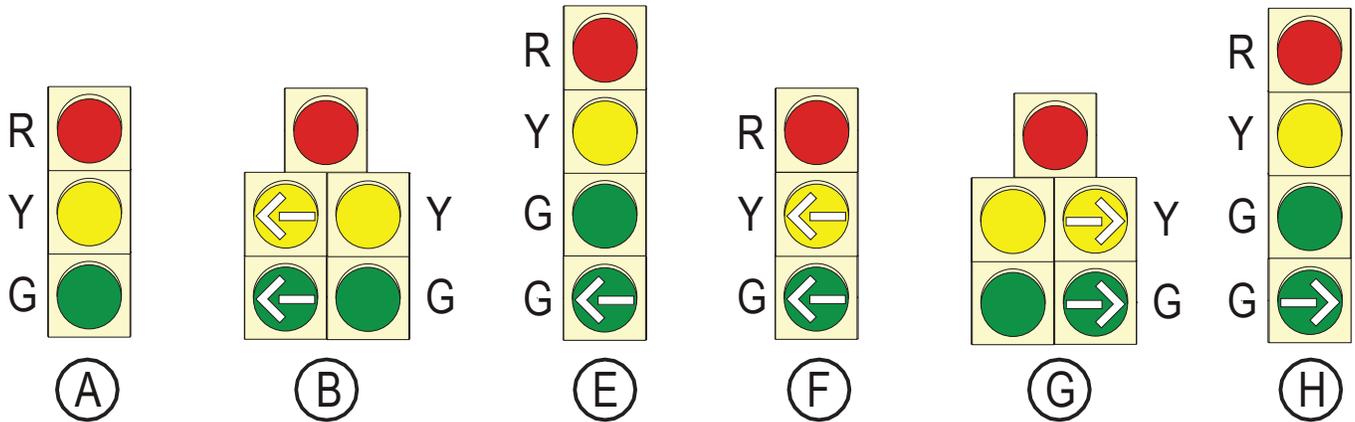


(D) Without sign

**SPLIT PHASE OPERATION
(PERMISSIVE TREATMENTS NOT APPLICABLE)**



* USE 5-SECTION
IF RT TURN OVERLAP



4.9.9 Left Turn Signals – Three types of left turn signal heads are commonly used:

- A. Three Section heads (R, ←Y, ←G with sign) and (←R, ←Y, ←G)** – Three section left turn heads are used for “protected only” left turn operation when there exists a separate left turn lane.
- B. Four Section Heads (R, Y, G, ←G)** – Four section left turn heads are used where the left turn is part of a split phase operation and also at the top of some “T” intersections.
- C. Five Section Heads (R, Y, G, ←Y, ←G)** – Five section left turn signal heads are used both with and without a separate left turn lane, and where the left turn operation is “protected/permissive” .

4.9.10 Right Turn Signals – Right turn signals are normally provided only where there is a separate right turn lane accompanied by a right turn signal overlap with a compatible cross street left turn signal phase. Typically, a five section head (R, Y, G, Y→, G→) is used.

4.9.11 Pedestrian Signal Indications⁴⁶ – All pedestrian signal indications shall use the international symbol designations. The pedestrian countdown indication is an optional feature on pedestrian signal heads. TDOT allows only the one section integrated pedestrian head on new signal installations. The bottom of the housing shall be located 7-10 feet above the sidewalk. Section 4.4 provides more information on pedestrian signals. Figure 4.33 shows several pedestrian signal mounting arrangements.

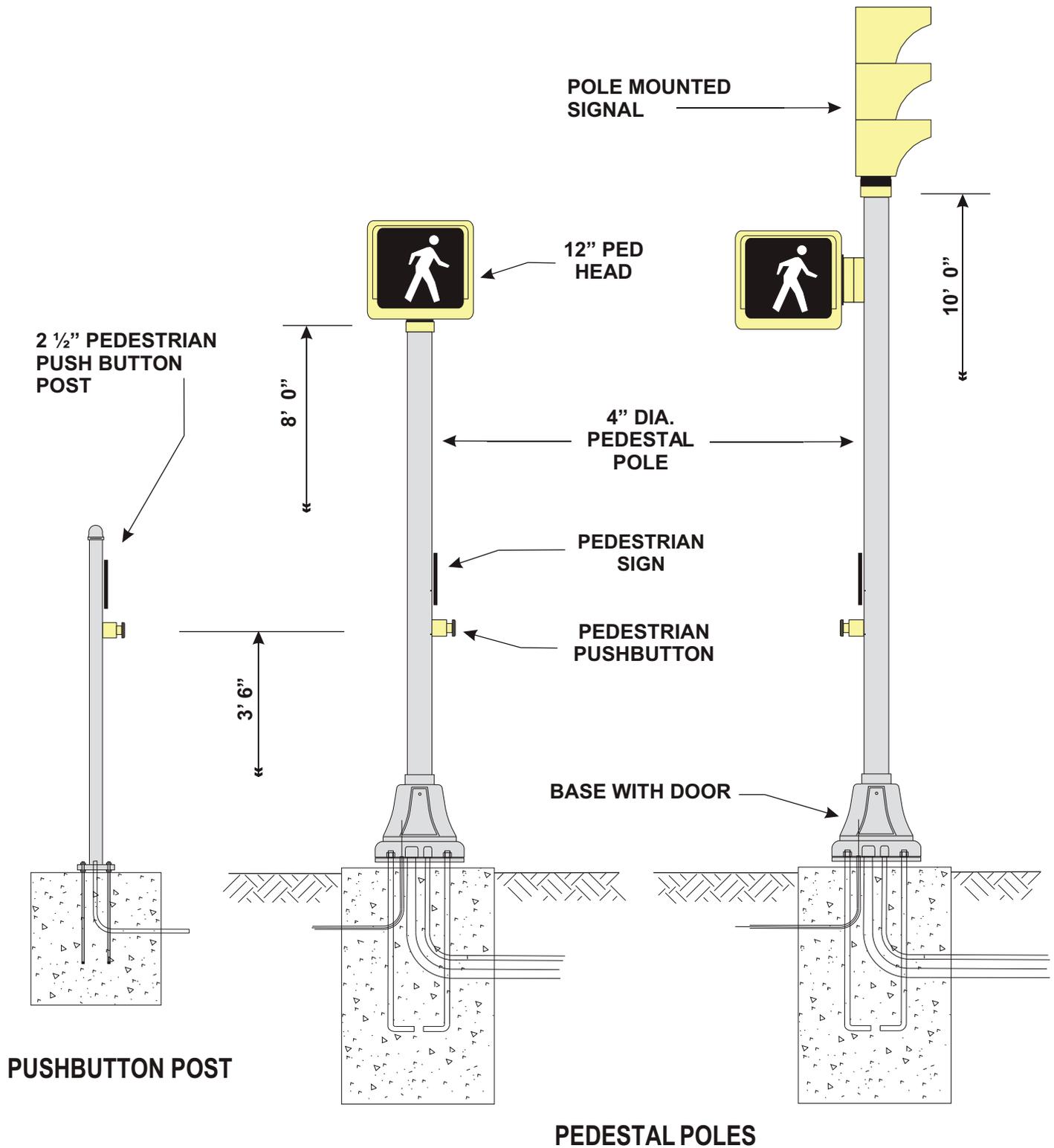
A. Walking Person Symbol (see Figure 4.17)

- **Meaning** – Walk
- **Color** – White
- **Size** – The symbol shall be approximately 12” tall.
- **Location** – Integral with and to the right of the upraised hand symbol.

B. Upraised Hand Symbol (see Figure 4.17)

- **Meaning**
 - Flashing** – Pedestrian Clearance
 - Steady** – Don’t Walk
- **Color** – Portland Orange
- **Size** – The symbol shall be approximately 12” tall.
- **Location** – Integral with and to the left of the walking person symbol.

⁴⁶ MUTCD, FHWA, 2003, p. 4E-1.



C. Pedestrian Countdown Indication (see Figure 4.17)

- **Meaning**

 - Flashing** – Countdown of Pedestrian Change Interval

- **Color** – Portland Orange

- **Size** – The digits shall be approximately 8” tall.

- **Location** – Integral with and right of the upraised hand symbol.

4.9.12 Signal Head Shielding – As a minimum, all signal indications shall be equipped with cut away (partial) visors to prevent the sun phantom effect (signal appearing to be on due to the sun reflecting on the signal indication lens).

4.9.13 Programmable Signal Heads –

Other installation problems may exist that would require the signal head to be shielded or to have its visibility limited. A programmable signal head utilizes a special optical lens that can be “programmed” to provide the signal display to only desired portions of the roadway. The programming is accomplished by masking (with tape) portions of the lens through the rear of the housing. Because the lens is programmed to be visible from certain areas, the signal head should be rigid mounted or tethered. Programmable signal heads are much more expensive than a regular signal head and require correct masking or they will not work as desired. The most common uses are as follows.

Programmable signal heads should be used for any movement where drivers could mistakenly see a signal indication that is intended for another movement.

A. Closely Spaced Traffic Signals – Where traffic signals are closely spaced and simultaneously display conflicting color indications to approaching motorists, optically programmed visibility lenses should be installed on the far signal heads.

B. Acute Angle Intersections – Where the intersection of two roadways is less than 90 degrees causing conflicting signal indications on one street to be seen by motorists on the other street, either optically programmed visibility lenses or full tunnel visors with louvers should be used on the signals heads.

C. Railroad Crossings with Pre-Signals – The signal heads at the far side of the intersection (beyond the pre-signals) should be programmable so as to limit their visibility from vehicles before the tracks.

4.10 Controllers and Cabinets

4.10.1 Traffic Signal Controllers – The standard controller to be used at all new signalized intersections shall be an 8-phase, NEMA solid state controller that meets current TDOT standards and specifications.

Eight phase dual-ring controllers should be used at all new traffic signals.

Presently, most cities in Tennessee use NEMA TS-2, Type 2 cabinets and controllers. An 8-phase controller should be used even when four phase cabinets are installed. Limited interchangeability of controller equipment is possible between different manufacturers of NEMA controllers. Many larger cities standardize on one NEMA controller brand. All controllers within a system must be of the same brand to achieve system operation.

4.10.2 Controller Cabinets

A. Cabinet Types:

- **Pole mounted cabinets** – should only be used for four phase intersections.
- **Ground mounted cabinets** – should be used for all 8-phase intersections or locations that house a master controller or significant auxiliary equipment such as video detection equipment. They may also be used for four phase intersections.

To prevent problems for sight impaired pedestrians, pole mounted cabinets should not be used within a sidewalk.

B. Interconnect/Communications – Where installed in a system, the controller cabinet shall have facilities for the appropriate communications.

C. Orientation – The controller cabinet shall be so oriented that the traffic personnel can observe the intersection while working in the cabinet.

D. Service Pad – All ground mounted controller cabinet installations not immediately adjacent to a sidewalk shall be provided with a service pad in front of the cabinet door for use by maintenance personnel.

E. Location – Controller cabinets should be located as far as practical off the edge of the roadway and in the same intersection quadrant as the power source whenever possible. Cabinets should not be placed within the pedestrian walkway portion of a sidewalk. Consideration should also be given to the effect of cabinet placement on sight distance.

F. Cabinet Construction – Cabinets shall be constructed of aluminum. Standard cabinet sizes are shown in TDOT's Standard Drawings.

G. Grounding Requirements – All controller cabinets shall be grounded separately from support poles.

4.10.3 Power Supply

A. Location – If possible, controller cabinet should be located in the same quadrant as the electrical service.

B. Quantity – In quantity calculations, the term “electrical service” or “power supply” includes the pole, circuit breaker, ground rod, conduit (riser) and conductors on the utility company's pole and/or conduit (riser) and conductor on the service pole. A separate 1”

conduit rigid steel conduit (RGS) riser must be provided where the power is brought down a wooden pole.

- C. **Street Lights** – Where street lights are installed on traffic signal poles, they shall have their own circuit breaker on the service pole and the power conductor routing shall not pass through the controller cabinet.
- D. **Cable Routing** – If the power supply cable travels underground, it shall be run in a separate rigid steel conduit (RGS) conduit from detector, signal and communications cables. If it travels overhead, it shall be run on a separate messenger cable above all other signal cables.

4.11 Traffic Signal Supports – The two basic types of traffic signal supports are strain poles and mast arm poles.

- **Strain Pole** – A strain pole is a pole to which span wire is attached for the purpose of supporting the signal wiring and signal heads (see Figure 4.34).
- **Mast Arm Pole** – A mast arm pole is a cantilever structure that permits the overhead installation of the signal heads without overhead messenger cables and signal wiring, which is run inside the arm structure (see Figure 4.35)

Traffic signal supports, including steel strain poles, concrete strain poles and mast arm poles, shall be in accordance with TDOT specifications. Adjacent utility poles shall not be used for traffic signal supports in new installations unless physical conditions preclude the installation of separate traffic signal supports.

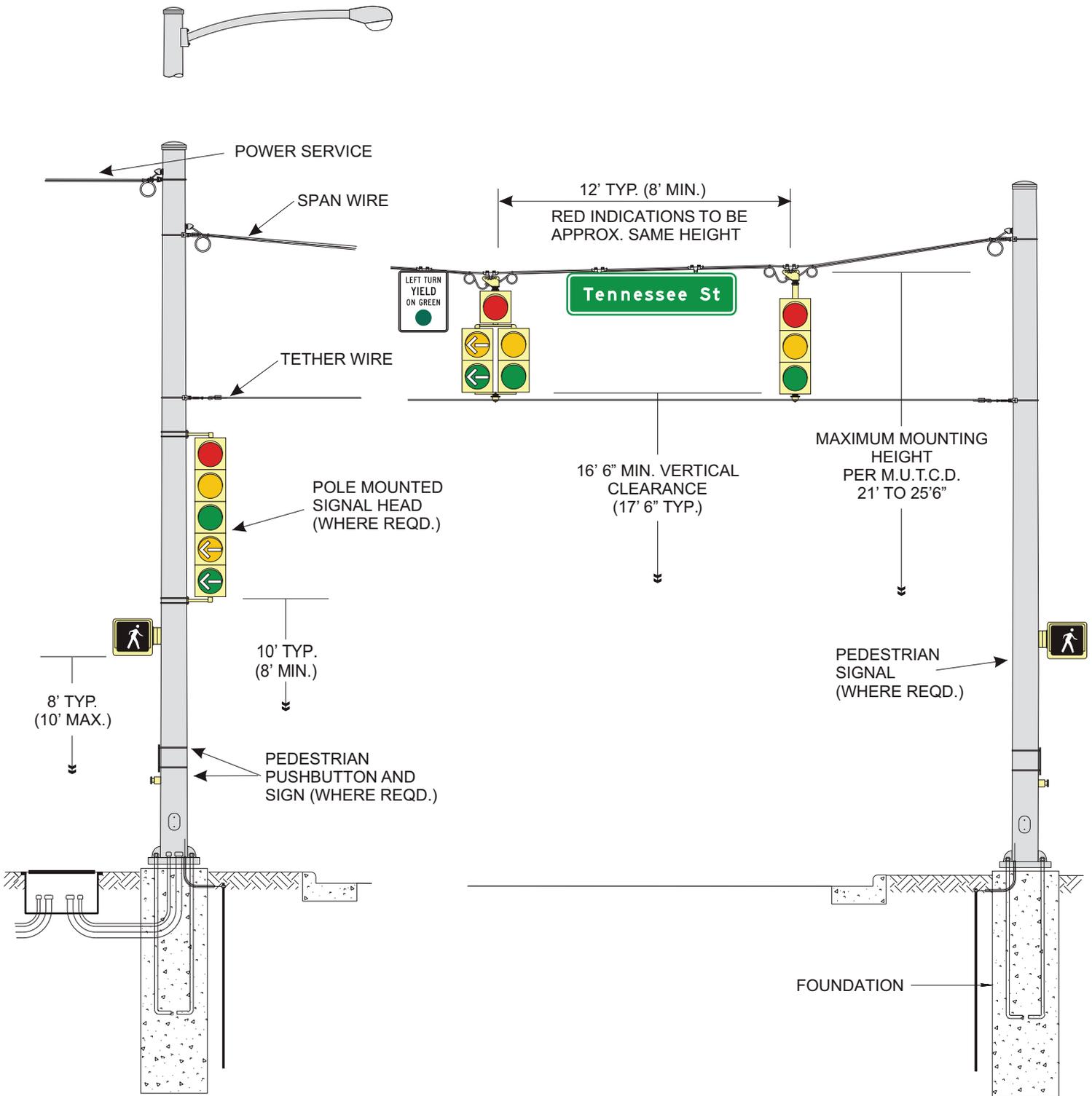
4.11.1 Selection of Support Type – Wood poles with guy wires should be considered as an option when selecting traffic signal support poles.

Steel or concrete strain poles should always be considered when span lengths exceed 90 feet or easements or right-of-way will be required for guy wires. Steel or concrete strain poles should also be considered when utilizing a box span arrangement to provide additional strength.

Mast arm poles should be considered when aesthetics are an issue. Double mast arm poles should be considered when some corners lack room for poles. Steel or concrete strain poles or mast arm poles should also be considered for areas without overhead utilities.

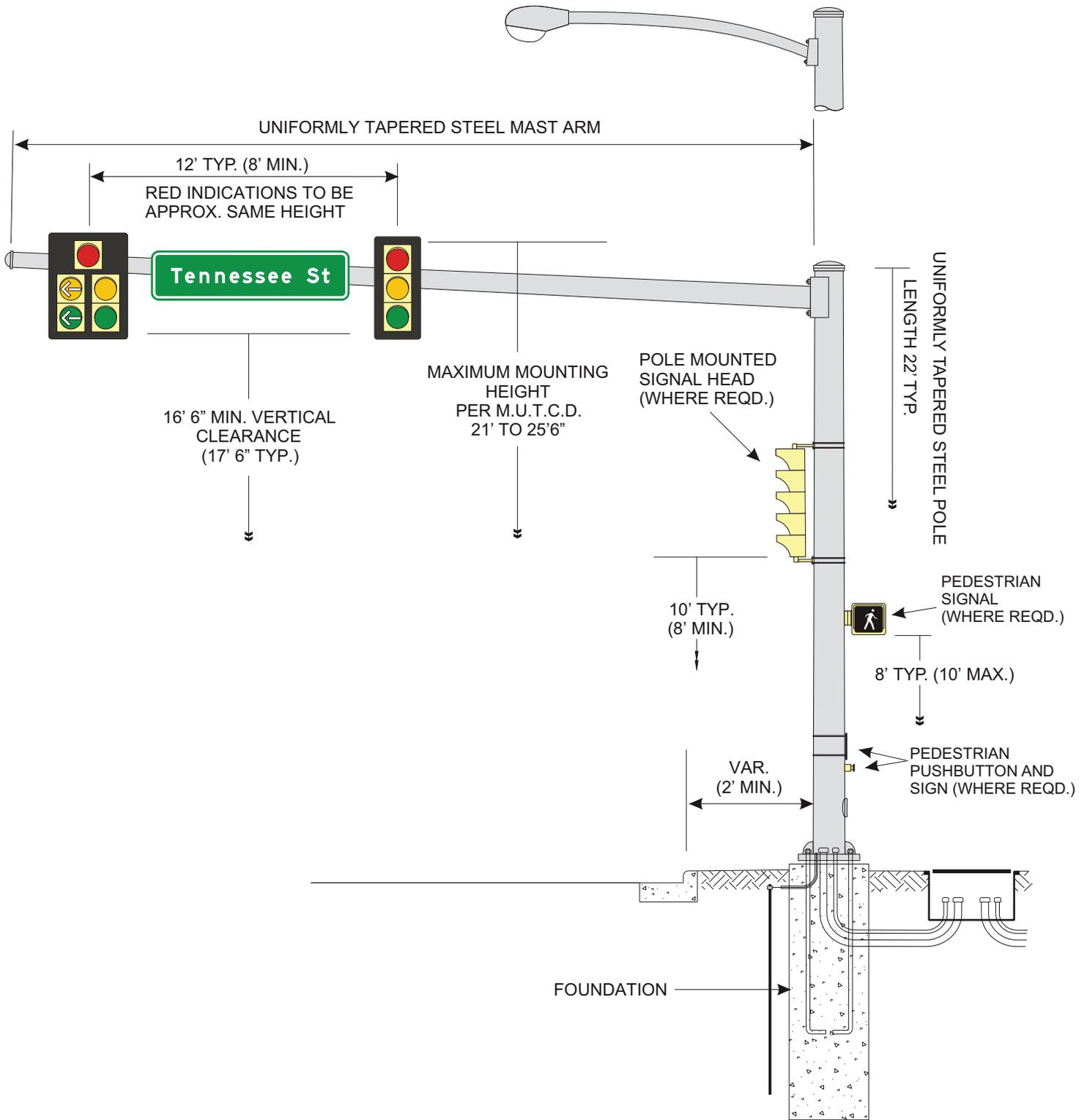
The major advantages of wood poles are their lower cost and relatively shorter delivery time. However, wood poles require guy wires and conduit risers, which may become maintenance issues over time.

The primary advantages of steel or concrete poles are better long term maintenance, aesthetics and ability to handle longer spans or heavier loads. However, they are more costly and have longer delivery times.



Typical Strain Pole Details

Figure 4.34



Typical Mast Arm Pole Details

Figure 4.35

4.11.2 Strain Poles (Wood, Steel or Concrete)

- A. **Span Length** – Strain poles should be located so as to limit the distance between the stop line and the signal heads to a maximum of 180 feet. The minimum breaking strength for span wires shall be noted in the Plans. Each span wire shall be grounded.
- B. **Span Wire Arrangements** – Span wire arrangements in general allow for further pole setbacks from the roadway than do mast arm installations. In addition, they eliminate the need for jacking and boring under the roadway by allowing signal and detector cables to be run overhead on the signal span wire. The following are the most common span wire arrangements:
- C. **Box Span Arrangement** (see Figure 4.36) – This signal arrangement places strain poles on each of the four corners of the intersection.

Typical intersections will use strain poles in a box span arrangement.

Box Span Advantages:⁴⁷

1. Allows good alignment of signal heads.
2. Provides the required minimum 40 feet distance between the signal heads and stop line on all approaches.
3. Provides shorter span wire lengths and sag than diagonal spans.
4. Provides locations for pedestrian signals.

Box Span Disadvantages:⁴⁸

1. Requires four poles.
2. Could require supplemental signal heads if the signal heads are more than 180 feet beyond the approach stop line.

- D. **Suspended Box Arrangement** (see Figure 4.36) – This signal arrangement is a box span arrangement, but the box is connected to the poles by diagonal spans. This is typically used at large intersections in order to minimize the distance between signal heads and the stop line. A variation where two corners of the box are connected by diagonal spans and two directly to poles is often used for skewed intersections.

Suspended Box Advantages:

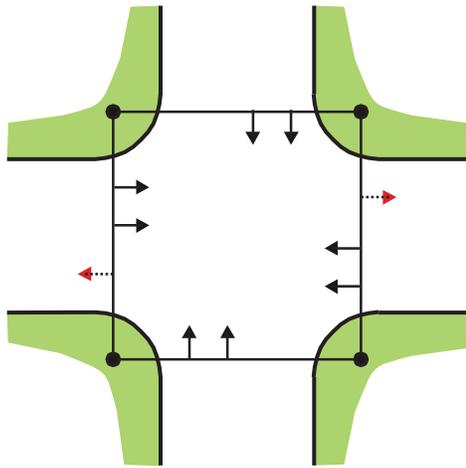
1. Same advantages as box arrangement (see 4.11.2.C).
2. Decreased distance between the signal heads and stop line.

Suspended Box Disadvantages:

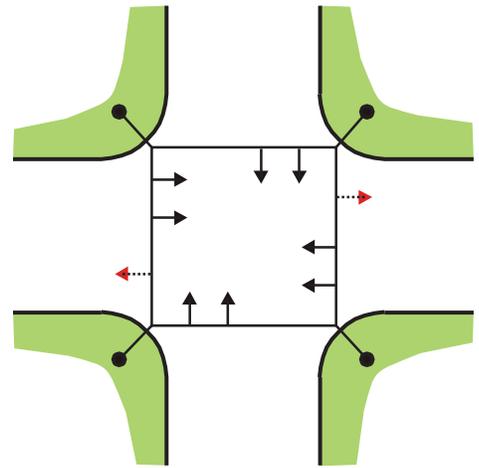
1. Same as box span arrangement but more difficult to install.

⁴⁷ Traffic Engineering Handbook, ITE, 1999, p. 506.

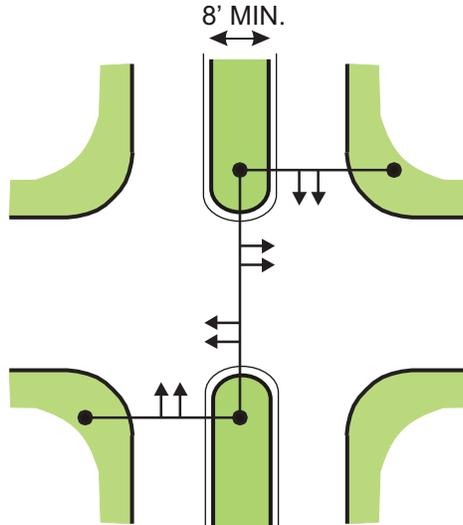
⁴⁸ Ibid.



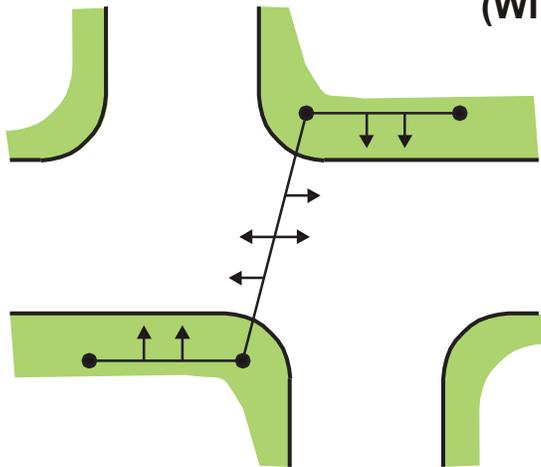
BOX SPAN



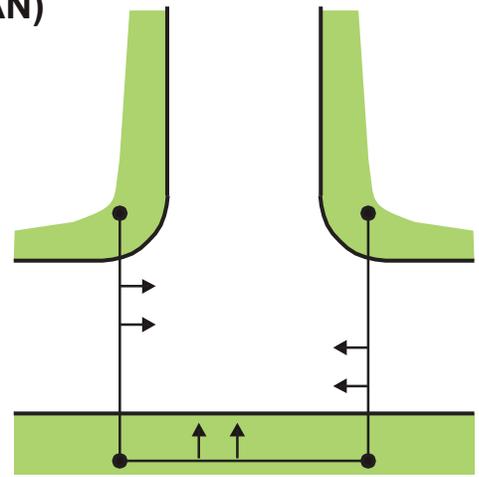
SUSPENDED BOX SPAN



**Z-SPAN
(WITH CURBED MEDIAN)**



Z-SPAN



U-SPAN

LEGEND:

- SIGNAL HEAD
-▶ SUPPLEMENTAL SIGNAL HEAD
(FOR SPANS OVER 180')
- SIGNAL POLE

**Typical Strain Pole (Span Wire)
Layouts**

- E. **Z Span Arrangement** (see Figure 4.36) – Z spans are applicable at offset intersections. Z span installations may be applicable on divided roadways where median clear zone requirements can be met.

Z Span Advantages:

1. On divided roadways, shorter span wires are required across the street with the median.
2. Provides good signal head placement for offset intersections.

Z Span Disadvantages:⁴⁹

1. On divided roadways, it places traffic signal poles in median areas where they are more likely to be struck by vehicles. Check clear zone requirements.
2. On divided roadways, additional pedestal poles may be needed if pedestrian signals and detectors are required.
3. On divided roadways, pedestrians cannot see the parallel signal indications once they get to the median area.

- F. **Diagonal Span Arrangement** – A diagonal span installation may be applicable at some locations, but generally presents problems with visibility for signal heads.

Because diagonal spans tend to create signal head visibility problems, they should not be used unless other span arrangements are not feasible.

Diagonal Span Advantages:

1. Only two poles are required.

Diagonal Span Disadvantages:

1. All loads are concentrated and place extreme pressure on poles.
2. Pedestal poles are required when pedestrian indications are used.
3. Very difficult to obtain horizontal distance requirements and vertical visibility for signal heads.

- G. **Pole Height Determination** – The height of a strain pole is determined by Equation 4.12. When providing a pole height on signal plans, it is important to specify that the top of the pole foundation should usually be at the same elevation as the roadway crown. In cut areas, fill may be required to prevent the foundation from protruding out of the ground. An exception is on high fill roadway sections where the pole must be located outside of the fill

⁴⁹ Traffic Engineering Handbook, ITE, 1999, p. 507.

area. Consideration must be made to ensure an adequate pole length is specified in such a situation.

Equation 4.12

$$PH = 2 + L_s S + c + H + d$$

Where: PH = Pole height (feet)

L_s = maximum span length (feet)

S = design sag (usually 5%)

c = clearance above road (17.5' typical)

H = height of signal head with backplate (usually 4.5')

d = side-slope drop off (feet from crown of road)

Where two span wires attach to the same strain pole, the pole height will be determined by using the longer of the two span wires. Pole heights shall be rounded up where necessary to be specified in even number feet (26, 28, 30, etc.).

H. Pole Location – Generally, strain poles should be located outside of the clear zone.

- **Signal Location** – Strain poles should be located so that signal heads hung on their span wire are located between 40 to 180 feet from the approach stop line.
- **Minimum Horizontal Clearances** – On curbed roadways, poles shall be located no closer than two feet to the front of curb. In all cases, traffic signal poles should be located as far as practical from the edge of travel lane without adversely affecting signal visibility.⁵⁰
- **Pedestrian Considerations** – When installing a pedestrian pushbutton, poles should be located adjacent to the sidewalk within reach of pedestrians.

I. Luminaires – Where street lights are installed on traffic signal poles, they are to be designed integral with the pole and mounted at a minimum height of 30 feet above the roadway. Actual mounting height shall be determined by the luminaire photometrics.

J. Tether Wires – Tether wires shall be installed to minimize signal head movement when polycarbonate signal heads, LED or optically programmed lenses are specified or at locations where wind is a consideration. Tether wires must be able to breakaway from poles when hit or snagged.

Breakaway tether wires should be installed on any spans with LED signal heads.

⁵⁰ MUTCD, FHWA, p. 4D-20.

4.11.3 Mast Arm Poles – Mast arm supports provide a more rigid mounting for signal heads and overhead signs than do span wire installations.⁵¹ Accordingly they are particularly applicable where programmed visibility signal heads are used. They also require less maintenance in regards to turned signal heads and signs. Mast arm installations are more aesthetically pleasing than span wire installations since there is no overhead span wire or signal wiring.

Very long mast arms can be extremely costly. Generally, mast arms greater than 65 feet long become unrealistic. Mast arm installations are more expensive than strain poles because they require boring and jacking under the roadway to get signal and detector cables to the controller cabinet.

Mast arm supports should be considered when they would match adjacent signals, when utilities are underground, when they would result in fewer overall poles or when aesthetics are a primary concern.

A. Single Mast Arm Layout – A typical single mast arm installation is shown in Figure 4.37 where it is used at the intersection of two undivided roadways.

Advantages:

1. Provides the required minimum 40 feet distance between the signal heads and the stop line of all approaches.
2. Provides good far side signal head visibility for pedestrians.
3. Provides locations for pedestrian signal indications and pedestrian detectors where needed.

Disadvantages:

1. Requires four mast arm poles and foundations for a typical four leg intersection.

B. Dual Mast Arms – The dual mast arm arrangement is often applicable at offset intersections and at tee intersections as shown in Figure 4.37.

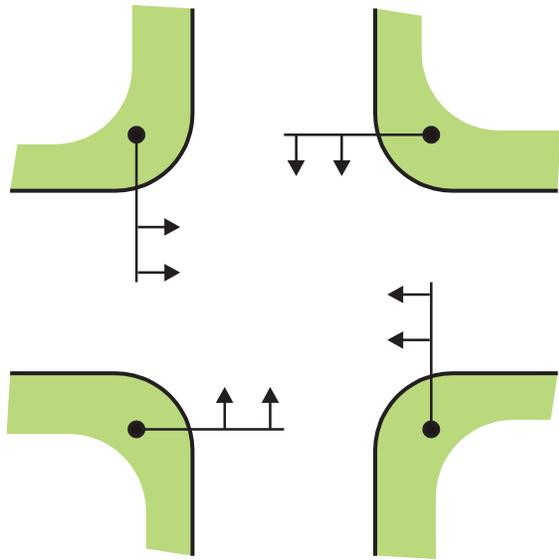
Advantages:

1. Uses fewer poles than a strain pole or single mast arm arrangement.
2. Provides good signal head placement for offset intersections.

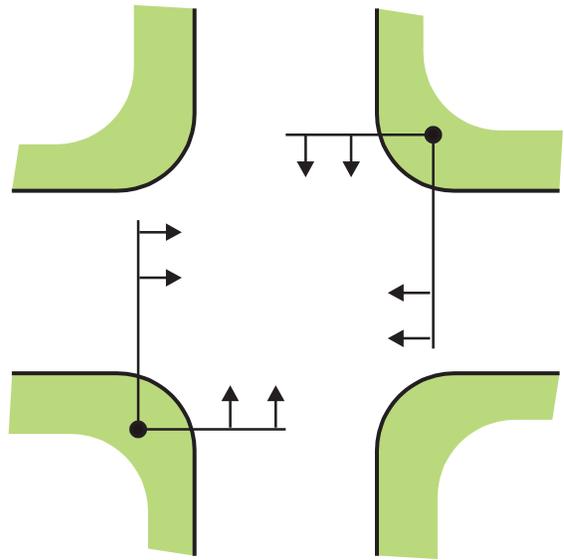
Disadvantages:

1. Additional traffic signal poles may be needed if pedestrian signals and detectors are required.
2. Sight lines to the signal heads may be obscured.

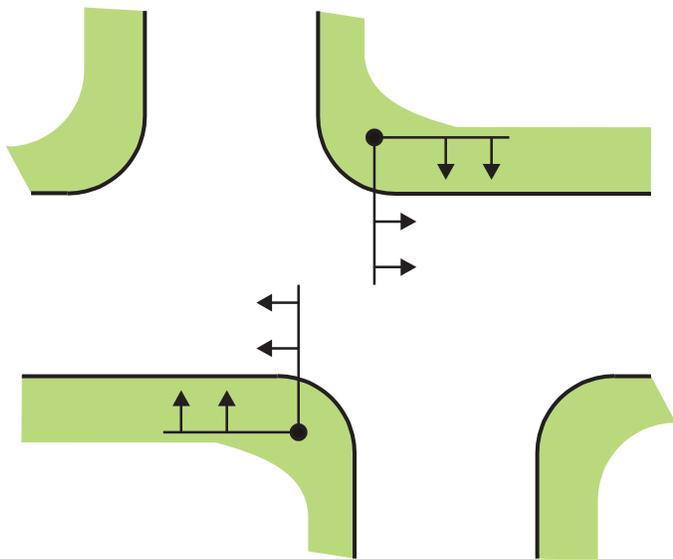
⁵¹ Traffic Engineering Handbook, 1999, p. 508



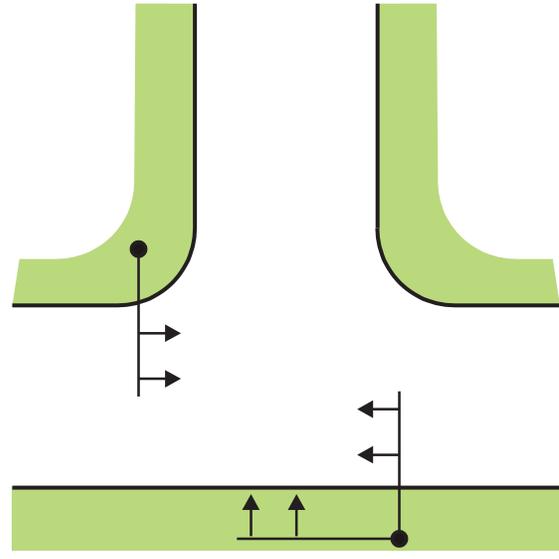
SINGLE MAST ARMS



DUAL MAST ARMS



**DUAL MAST ARMS
(OFFSET INTERSECTION)**



**COMBINATION SINGLE/DUAL
MAST ARMS**

LEGEND:

- SIGNAL HEAD
- MAST ARM SIGNAL POLE

- C. **Mast Arm Height** – Typical mast arm poles have a 22 foot shaft, unless street lighting is integral with the traffic signal pole.
- D. **Mast Arm Length** – Mast arm length must be specified on signal plan sheets. The arm length is determined by taking into account signal head placement in relation to the approach travel lanes and the pole setback off the edge of the travel way. The mast arm length shall not exceed the maximum length currently feasible in construction.

Mast arm lengths should be limited to 65' or less.
- E. **Mast Arm Pole Location** – The requirements are the same as those listed for the location of strain poles (see Section 4.11.2.H).
- F. **Luminaires** – Street lights installed on mast arm poles are to be designed integral with the pole and they are to have a minimum mounting height of 30 feet above the roadway. Actual mounting height shall be determined by the luminaire photometrics.

4.12 Signal Wiring – All conductors shall be run inside conduit except loop conductors in the pavement, cables run along messenger or span wire, or cables run inside poles. All new cable runs shall be continuous and free of splices. All signal cable shall meet the applicable requirements of IMSA and National Electric Code.

4.12.1 Signal Control Cable – All signal control cable shall conform to applicable IMSA Specification No. 19-1 or 20-1. Stranded cable color coded AWG No. 14 shall be used for all signal and accessory circuits.

4.12.2 Copper Communications Cable – Copper communications cable shall be 6 pair, AWG No. 19 polyethylene insulated, polyethylene jacket cable with electrical shielding meeting the requirements of IMSA Specification No. 40-2.

4.12.3 Fiber Optic Communications Cable – Fiber optic communications cable shall be specifically selected to meet the individual needs of a specific project. All fiber optic cables should be designed with spare fibers for future use. A rule of thumb is to double the fibers that are needed today and round up to the nearest six (fiber optic cable is manufactured in multiples of six).

4.12.4 Inductive Loop Wire – Conductors for traffic loops and home runs shall be continuous cross-linked polyethylene insulated AWG No. 14 wire, conforming to IMSA Specification No. 51-1 or 51-3, to the detector terminals or spliced with shielded detector cable within a pull box, conduit or pole base.

4.12.5 Loop Detector Lead-In (Shielded Cable) – Loop detector lead-in cable wire shall be continuous AWG No. 14 wire conforming to the requirements of IMSA Specification No. 50-2, polyethylene insulated, polyethylene jacketed shielded cable.

4.12.6 Preformed Loop Detector Wire – Preformed loop assemblies are suitable for placement under new asphalt or concrete pavement. Preformed loop detector wire shall consist of a minimum of four turns of No. 18 AWG wire or larger, not to exceed No. 14 AWG wire. The loop wires shall be installed in protective tubing with a diameter of less than 5/8". The home run cable shall be installed inside conduit or manufacturer's recommended enclosure between the pavement and the pull box to prevent damage in ground.

4.12.7 Cable Lashing – Cables shall be attached to span or messenger cable by means of non-corrosive lashing rods or stainless steel wire lashings (one 360 degree spiral of lashing wire per foot).

4.12.8 Cable Sizing for Conduit – After the signal head and signal detector arrangements/placements have been determined, the necessary signal wiring required involves the following steps:

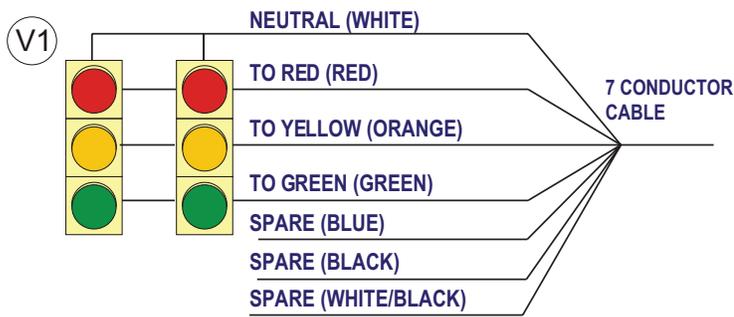
- A. Signal Head Requirements** – The typical wiring requirement of each individual signal head may be determined by using Figure 4.38.
- B. Mast Arm/Span Wire Runs** – Determine the length of wiring required for the signal heads depending on whether span wire or mast arms are used.
- C. Detectors, Power and Interconnect Cable** – Determine the wiring required for detectors, power, and interconnect cables where applicable.
- D. Sizing Conduit** – Combine the wiring requirements in 4.12.1 and 4.12.3 above and size the conduit needed for each wiring run using Table 4.7.

4.13 Conduit – All underground signal wiring shall be encased in conduit to protect the cables or conductors and facilitate maintenance. All signal wiring above ground shall be installed in conduit (risers), unless the wiring is inside of a pole or attached to a span wire or a messenger cable. Conduit used for traffic signal installation shall have the following characteristics:

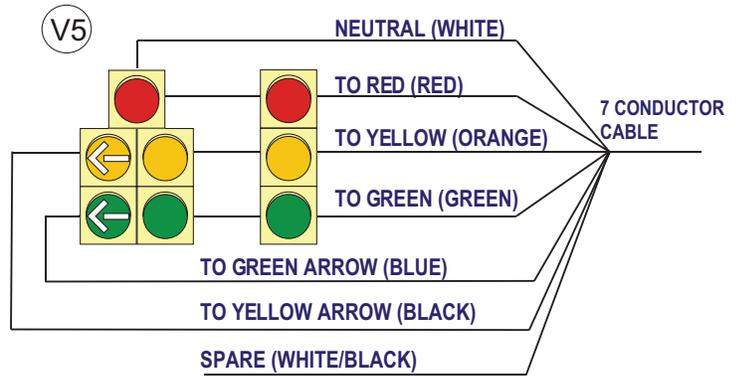
4.13.1 Conduit Material Type

- A. Underground: PVC** (Polyvinyl Chloride Conduit), Schedule 40 or **RGS** (Rigid Steel Conduit). Schedule 80 conduit may be permitted in certain situations.
 - **In Ground** – In general, typical conduit in soil should be PVC, Schedule 40. See 4.13.4, 4.13.5 and 4.13.6 for special cases.
 - **Under Driveways** – When PVC conduit is shown on the plans in areas which are subject to vehicular traffic, such as under driveways, Schedule 80 PVC conduit shall be used.
 - **Under Roadways:** All conduits under roadways shall be RGS.
- B. Risers:** All risers shall be RGS.

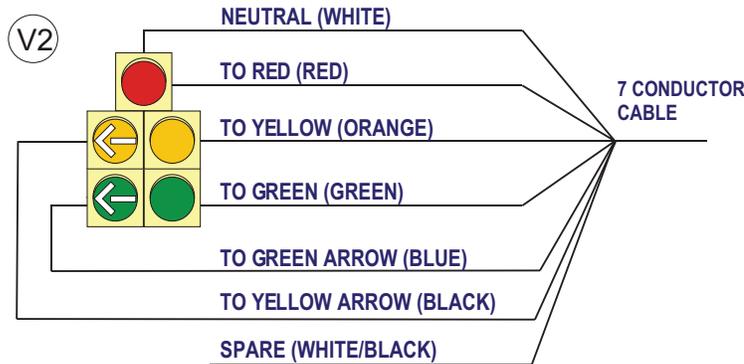
3-SECTION SIGNAL HEAD (TYPE 130)



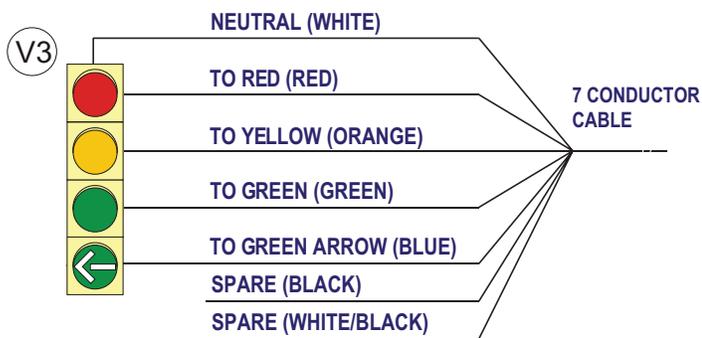
COMBINATION, TYPES 130/150A2H (LEFT TURN PERM/PROT.)



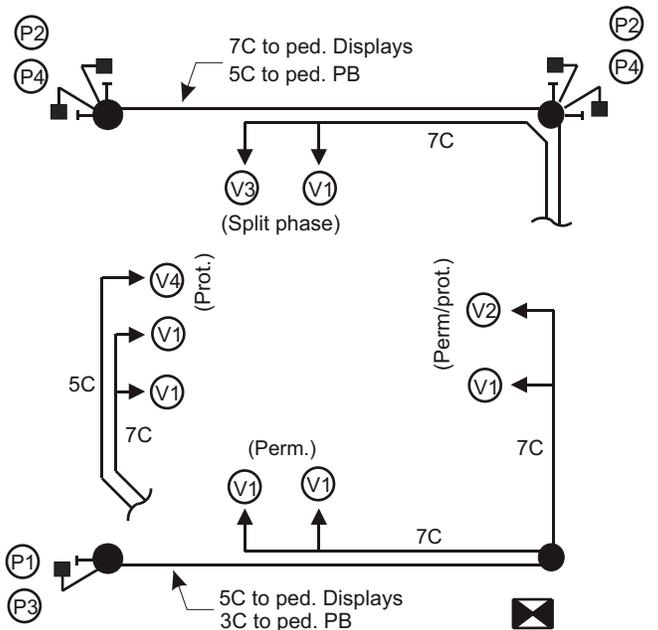
5-SECTION SIGNAL HEAD (TYPE 150 A2H OR 150 A2V)



4-SECTION SIGNAL HEAD (TYPE 140A1)



3-SECTION SIGNAL HEAD (LEFT TURN-TYPE 130A2 OR 130A3)



**TYPICAL WIRING SCHEMATIC
(DEPICTING VARIOUS LEFT TURN TREATMENTS)**

LEGEND	
	CONTROLLER
	SIGNAL SUPPORT POLE

* 8C AND 9C MAY BE SUBSTITUTED FOR 7C CABLE

Table 4.7 Typical Wire Sizes

AWG 14		
Number of Conductors	Outside Diameter (inches)	Area (in ²)
1	0.17	0.023
2	0.41	0.132
3	0.43	0.145
4	0.47	0.173
5	0.51	0.204
6	0.58	0.264
7	0.58	0.264
8	0.63	0.312
9	0.68	0.363
10	0.72	0.407
12	0.75	0.442
13	0.78	0.478
14	0.78	0.478
15	0.82	0.528
16	0.82	0.528
17	0.91	0.650
18	0.91	0.650
19	0.91	0.650
20	0.95	0.709
21	0.95	0.709
22	1.00	0.785
23	1.00	0.785
24	1.05	0.866
25	1.07	0.899
26	1.07	0.899
27	1.07	0.899
28	1.07	0.899
29	1.11	0.968
30	1.11	0.968

AWG 16		
Number of Conductors	Outside Diameter (inches)	Area (in ²)
1	0.15	0.018
2	0.34	0.091
3	0.35	0.096
4	0.38	0.113
5	0.42	0.139
6	0.45	0.159
7	0.45	0.159
8	0.49	0.189
9	0.53	0.221
10	0.60	0.283
12	0.64	0.322
13	0.67	0.353
14	0.67	0.353
15	0.70	0.385
16	0.70	0.385
17	0.74	0.430
18	0.74	0.430
19	0.74	0.430
20	0.77	0.466
21	0.77	0.466
22	0.81	0.515
23	0.81	0.515
24	0.85	0.567
25	0.91	0.650
26	0.91	0.650
27	0.91	0.650
28	0.94	0.694
29	0.94	0.694
30	0.94	0.694

Other Cables		
Type	Outside Diameter (inches)	Area (in ²)
6 pair / 19	0.53	0.221

Conduit Areas		
Conduit Size	Area (in ²)	Maximum Usable Area (40% of total)
3/4"	0.44	0.176
1" (25 mm)	0.77	0.308
1 1/2"	1.77	0.708
2" (50 mm)	3.14	1.256
2 1/2"	4.91	1.964
3"	7.07	2.828

4.13.2 Conduit Installation Methods – There are three typical construction techniques used to install underground conduits for traffic signals. The standard technique used by contractors is the open cutting (or trenching) method. When there are restrictions to using the open cut method, the conduit must be installed by either the jacking method or the directional bore method.

- **Open Cut Method** – The open cut method is generally permitted when the conduit is being installed in areas that will not affect traffic such as grass medians, or within existing roadways when the existing pavement will be replaced upon project completion.
- **Jacking Method** – The jacking method is generally used when the open cut method is not permitted. The jacking method pushes a pipe sleeve under a roadway, driveway, or railroad track that is 2” larger in diameter than the conduit(s) that it will be conveying. This method requires a jacking pit, which must be within the right of way. For 20-foot pipe sleeve sections, the jacking pit is 32-foot long and 6-foot wide. For 10-foot pipe sleeve sections, the jacking pit is 22-foot long and 6-foot wide.
- **Directional Bore Method** – The directional bore method is an optional method that can be used in lieu of the jacking method. The directional bore method installs conduits boring along a prescribed route under the roadway, driveway or railroad track. The directional bore method does not require a pit, as does the jacking method, however an 8-foot by 8-foot staging area is needed to install conduits less than 6” in diameter.

4.13.3 Depth Installed (Underground) – Conduit is placed 18” to 36” below the finished grade. Typically, conduit below sidewalk is placed 18” deep.

4.13.4 Conduit Sizing – The maximum size conduit to be used on traffic signal installations shall be 3”. Where larger conduit capacity is required, multiple conduit runs will be used. The sizing of conduit should be such as to not fill over 40% internal area of the conduit (see Table 4.7).

Conduit for traffic signal applications shall not be larger than 3” or smaller than 1”.

Typical traffic signal conduit shall be 2” diameter and detector loop conduit 1” diameter, unless otherwise indicated. Conduits smaller than 1” diameter shall not be used unless otherwise specified, except grounding conductors at service points shall be enclosed in 3/4” diameter conduit. No reducing couplings will be permitted. The conduit between a saw cut and a pull box for loop lead-ins shall be 1” diameter and not be measured for separate payment, but will be absorbed in other conduit items.

4.13.5 Communications Cable Conduit – All communications cables shall be run in a separate conduit from shielded cable, signal cable and power cable. Conduit for communications interconnect cable should be 2” diameter.

4.13.6 Power Cable Conduit – Conduit for power supply shall be run in a separate 1” diameter RGS conduit.

4.13.7 Bored and Jacked Conduit – All bored and jacked conduit shall be rigid (RGS). The estimation of the amount of boring is critical. Care should be taken for a realistic estimate (overestimation is preferred).

4.13.8 Conduit Radii – All conduit bends shall be large radius to facilitate cable pulling (6” minimum radius).

4.13.9 Spare Conduit – Spare conduit stubs for future use shall always be installed in all new controller cabinet bases and pole foundations. These stubs shall not be measured for separate payment, but will be absorbed in other conduit items.

4.13.10 Conduit for Road Widening Projects – Conduit and pull boxes should be considered for installation on collector and arterial street widening projects where there is a potential for future interconnect needs.

4.14 Pull Boxes – A pull box is an underground compartment made of various materials such pre-cast concrete or polymer concrete (composite). Pull boxes used in traffic signal installations shall meet current TDOT standard specifications.

When possible, pull boxes should be located adjacent to sidewalks rather than in the sidewalk.

4.14.1 Purpose of Pull Boxes:

- To provide access to underground detectors and interconnect cables.
- To provide locations to consolidate separate runs of signal and detector cables.
- To provide locations to facilitate the pulling of long runs of detector or interconnect cables.
- To provide locations to store spare lengths of signal detector or interconnect cables.

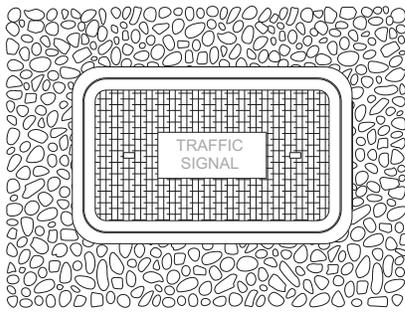
4.14.2 Type/Size/Use – Figure 4.39 shows the various size pull boxes and their normal application or use. Type A Pull Boxes shall be used exclusively for splicing loop wires to shielded cable only. Type B Pull Boxes shall be used for all other traffic signal cable applications.

Pull boxes for fiber optic cable must be larger than standard pull boxes due to the large bending requirements of fiber optic cable.

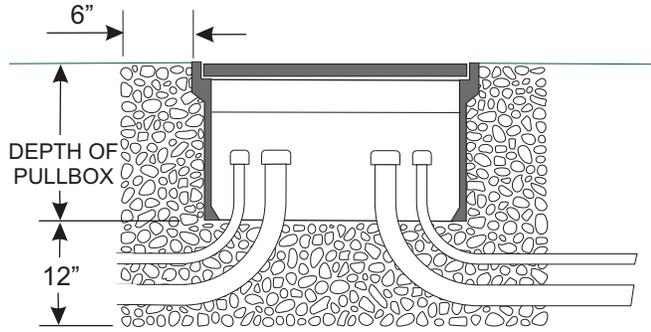
4.14.3 Spacing – Pull boxes shall be located at 150 foot intervals for signal cable and detector cable runs. Pull boxes for copper interconnect cable runs shall be located at 300 foot intervals. Fiber optic pull boxes should be located every 1,000 feet for fiber optic cable runs.

4.14.4 Material – Pull boxes and covers are to be of load bearing design in accordance with TDOT standard specifications. In general, all pull boxes shall be traffic load bearing.

TRAFFIC SIGNAL PULL BOX DETAILS



TOP VIEW

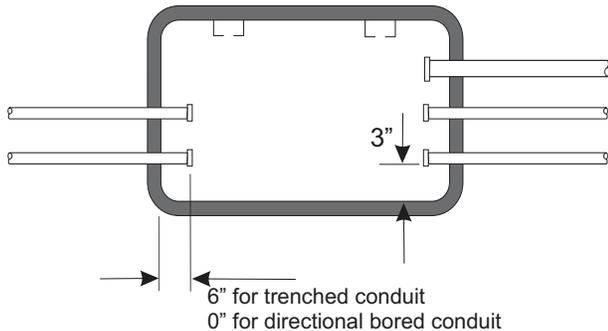


SIDE VIEW

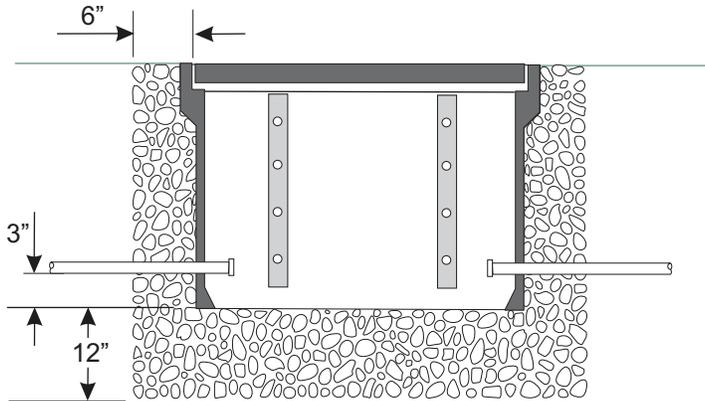
TYPE	MIN. DIMENSIONS		
	LENGTH	WIDTH	DEPTH
A	12"	12"	6"
B	28"	16"	12"

Type "A" Pull Boxes are used for splicing loop lead-ins.
 Type "B" Pull Boxes are used for all signal cable routing.

FIBER OPTIC PULL BOX DETAILS



TOP VIEW



SIDE VIEW

F.O. TYPE	MIN. DIMENSIONS		
	LENGTH	WIDTH	DEPTH
A	36"	26"	32"
B	49"	32"	36"

F.O. Type "A" Pull Boxes are used when no splicing is required in the pull box.

F.O. Type "B" Pull Boxes are used when splicing is required in the pull box.

4.15 Street Lighting on Traffic Signal Supports at Intersections (see Chapter 7 for more information)

4.15.1 Justification – Street lighting may be justified at signalized intersections as follows:

- A. Urban Locations** – In urban areas where street lighting already exists along the highway.
- B. Rural Locations** – In rural locations where street lighting at the intersection would have a positive effect on the nighttime safety of the intersection.

4.15.2 Design – Where used on mast arms or strain poles, the street light support must be designed integral with the traffic signal support. The pole manufacturer must provide an acceptable design for review by TDOT.

4.15.3 Mounting Height – Typically 30 foot minimum above roadway. The actual mounting height shall be determined by the luminaire photometrics.

4.15.4 Wiring Requirements

- A. Circuit Breaker** – A disconnect and fuse shall be located at the power pole location.
- B. Wire Type** – 1-2 conductor, #6 AWG
- C. Conduit Size** – one inch diameter RGS
- D. Isolation** – Street light conductors shall not be routed through the controller cabinet and shall have its own conduit and pull boxes.
- E. Pull Boxes** – Pull boxes used in lighting applications should be a maximum of 300' apart.

4.16 Flashing Operations – All traffic signals are programmed to operate in the flash mode for emergencies. Signals may also operate in maintenance flash, railroad preemption flash, or scheduled operational flash modes.

The type of flash used (all-red or yellow-red) must be considered carefully. Driver expectation is an important factor. Drivers are conditioned to react to situations through their experiences. Mixing the types of flash can confuse drivers if they are accustomed to the all-red flash. The benefits of operating a mixed color flash must be weighed against the disadvantages. Violation of driver expectation can be a disadvantage of a mixed color flash.

All traffic signals are capable of flashing indications. Flashing operations of a traffic signal shall comply with Sections 4D.11 and 4D.12 of the MUTCD.

4.16.1 Types of Flashing Operation

- A. Emergency Flash** – Emergency flash mode is used when the conflict monitor (malfunction management unit) senses a malfunction. Emergency flash should use all-red flash exclusively.
- B. Maintenance Flash** – Maintenance flash mode can be programmed for the operation of the intersection during routine maintenance. Yellow-red flash can be used if the main street traffic is significantly more than the minor street traffic.
- C. Railroad Preemption Flash** – When a traffic signal is preempted by a train, flashing operation may be used while the train is going through the crossing. Either all-red flash or yellow-red flash can be used.
- D. Scheduled Flash** – Traffic signals can operate in scheduled flash mode as a time-of-day operation (nighttime flash). Nighttime flash can reduce delay at intersections operating in the fixed time mode. Scheduled flash mode typically uses the yellow-red flash type operation. Nighttime flash should not be used at fully actuated intersections unless all other intersections in the area operate nighttime flash. Again, driver expectation is a major factor in this decision. Isolated actuated traffic signals do not normally have a programmed flash mode operation.

4.16.2 Signal Display

- A. All Red Flash** – This type of flashing operation flashes red to all intersection approaches. It may be used under the following conditions:
 - **Traffic Volumes** – Traffic volumes on the two intersecting streets are approximately equal.
 - **Minor Street Delay** – Minor street traffic would experience excessive delays and/or hazard in trying to cross the major street with yellow flashing signal indications. Engineering

judgment must be used to balance this benefit against the delay that will be experienced by the major street traffic.

- **Minor Street Sight Distance** – Minor street traffic has insufficient sight distance to safely enter or cross the major street with yellow flashing signal indications.
- B. Yellow-Red Flash** – This type flashing operation is the most common and flashes yellow to the major street and red to the minor street. Minor street sight distance as well as the difficulty the minor street traffic will have crossing the major street must be considered.
- C. Protected Only Left Turn Signals (3 Section Heads)** – These signal heads shall be flashed red regardless of what color indication the adjacent signal heads are flashing.
- D. Protected/Permissive Left Turn Signals (5 Section Heads)** – These signals shall flash a circular indication of the same color as indications flashed in the adjacent thru signal head(s).

4.16.3 Dimming LED Signal Indications – If a traffic signal, using LED indications, is placed in an automatic flashing mode during the night, the LED signal indications should be dimmed to reduce the brightness of the indications.

4.17 Stop Signs at Signalized Intersections – The MUTCD prescribes that STOP signs shall not be used in conjunction with any traffic signal operation, except when:

- The signal indication for an approach is a flashing red at all times.
- A minor street or driveway is located within or adjacent to the area controlled by the traffic signal, but does not require separate traffic signal control because an extremely low potential for conflict exists.

4.18 Signal Control for Driveways within Signalized Intersections – Traffic signal control for a driveway should be provided only if the driveway serves a commercial or multi-residential development. Signal control may also be provided for driveways serving non-profit land uses with significant traffic generation such as churches. Split-phase operation for these low volume driveways should be considered and detection should always be provided for the approach to avoid unnecessary delays for other approaches.

4.19 New Traffic Signal Inspection – Before allowing a new traffic signal to be turned on to traffic, a thorough inspection shall be completed to determine conformance with construction plans and specifications and proper and safe operation of the signal. Listed below are some of the items that should be inspected:

1. Confirm that all signal displays are appropriate, non-conflicting and in concurrence with the MUTCD.
2. Confirm that all controller and cabinet accessories, including controllers and conflict monitors, are in compliance with all plans, specifications and relevant national standards.
3. Confirm that signal phasing is appropriate and in concurrence with the construction plans and that no conflicts in phasing occur.
4. Confirm that pedestrian phases are appropriate with prescribed clearance phasing and not in conflict with protected left (or right) turns.
5. Confirm that all vehicular detection as specified on the plans, whether loops, video or otherwise, is properly working under all conditions, including dark and/or inclement weather.
6. If installed, confirm that system communications are working.
7. If installed, confirm that any emergency vehicle preemption is working by testing with an actual emergency vehicle and that the timings are adequate to move the vehicle through the intersection.
8. If installed, confirm that any Railroad Preemption activation circuitry activates as soon as the Railroad Crossing Equipment indicates the presence of a train. This test should be performed in the presence of appropriate railroad officials and with local law enforcement for safety. The test should assure that any phase not associated with the track clearance phase is immediately terminated through an appropriate vehicle clearance interval, the track clearance interval is of sufficient time to clear exposed vehicles, all illuminated turn restriction signs are properly activated and the dwell phase will activate after the track clearance phase also clears through an appropriate interval.

4.20 Traffic Signal Activation Procedures – Activation of a new traffic signal is a critical part of the signal installation process. The traffic signal designer should consider the possible consequences of a change in traffic control and add any notes and items which may improve the safety of the transition period.

When signalization is introduced at locations where a multi-way stop, flashing beacon operation exists, special measures may be required.

The following steps are recommended for the activation of a new traffic signal:

4.20.1 Advance Flash Period – A new traffic signal installation should be put on flash operation for a period of seven weekdays prior to the activation of normal “stop and go” operation, so as to make motorists aware of its presence.

4.20.2 Publicity – The date and time of the activation of “stop and go” operation should be advertised in both the local newspaper and on local radio stations both prior to and on the date of activation.

4.20.3 Activation – The actual activation of normal “stop and go” operation should be made during an off peak traffic period.

4.20.4 Technical Support – The contractor shall be on-hand for all new traffic signal activations to immediately trouble shoot or fix any problems that arise.

4.20.5 Signing Adjustments – Once the traffic signal is turned on normal “stop and go” operation, remove the stop signs that the traffic signal replaces.

4.20.6 Police Assistance – Police assistance should be requested and be on site at the time of traffic signal activation to provide emergency traffic control in case of a malfunction and to help emphasize the new traffic control change to the motorists.

4.20.7 School Crossing – Should the intersection include a school crossing with a crossing guard, the crossing guard should be familiarized with the operation of the new traffic signal.

4.20.8 Fine Tuning – Shortly after the traffic signal is turned on, the engineer should observe the signal’s operation during both peak and off peak periods to assure the adequacy of the signal’s timing parameters.

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