CHAPTER 8

TRAFFIC SIGNAL DESIGN – DETECTION

8.1 Detection

Detection is a critical component of traffic signal design. Detectors provide the traffic signal controller with the information necessary to determine the servicing of roadway users. The sections below explore detection objectives and location. Furthermore, guidelines on detection parameters and phase recalls are presented. Lastly, guidelines for detection design of low-speed and high-speed approaches are discussed in addition to pedestrian detection design and types of detection.

8.1.1 Detection Objectives

Enhancing intersection safety and efficiency are the overall goals of traffic signal detection design. The following items characterize specific detection objectives:

- Identify user presence for a movement and call its phase when the phase is red;
- Extend a phase when the phase is green;
- Identify gaps in traffic where a phase should end due to no traffic or inefficient flow;
- Provide safe phase termination at the onset of the yellow indication for high-speed vehicle movements;
- Monitor intersection performance using measure of effectiveness logs.

8.1.2 Detection Location

Detection can be located at the stop line or upstream from an intersection. Typically, stop line detection addresses intersection efficiency issues while upstream detection addresses intersection safety issues. See Sections 8.4 and 8.5 for specific detection design guidelines.

- **Stop line Detection:** Stop line detection is used for approaches below 35 mph on through lanes, exclusive left-turn lanes and exclusive right-turn lanes. Stop line detection may also be used in conjunction with upstream detection for high-speed approaches. Stop line detection is located where vehicles are anticipated to stop, but should be extended a minimum of three feet and not more than five feet beyond the stop line.
- **Advance Detection:** Advance detection is used for approaches 35 mph or higher typically located in the path of vehicles on through lanes, and in advance of the stop line (see Section 8.5). Advance detection provides information on vehicles approaching the intersection that can be used to safely terminate a phase on the onset of the yellow indication.

8.2 Detection Parameters

Several detection settings will influence intersection operation. The following modes will provide information on the typical detection parameters: presence and pulse, locking and non-locking, delay, extend, call, queue, and detector switching. *Note: The terminology of detection parameters is not consistent between vendors; therefore, specific vendor manuals should be consulted for appropriate parameter selection and settings.*

8.2.1 Detection Operating Modes

The detector's operating mode influences the duration of the actuation submitted to the traffic signal controller by the detector unit. One of two modes (presence or pulse) can be used.

- **Presence:** Presence mode is used to measure occupancy. The actuation starts with the arrival of the vehicle to the detection zone and ends only when the vehicle leaves the detection zone. The actuation time duration depends on vehicle length, detection zone length, and speed. Presence mode is typically the default mode and is typically associated with stop line detection.
- **Pulse:** Pulse mode is used to count vehicles. The actuation starts with the arrival of the vehicle to the detection zone and ends after the pulse activation (usually 0.10 to 0.15 seconds). Pulse mode is typically associated with advance detection.

8.2.2 Detection Memory Modes

The detector's memory modes affects the ability of the traffic signal controller to remember an actuation received during a red interval. It can be set to locking or non-locking mode.

- **Locking:** In the locking mode, the first actuation received by the traffic signal controller on a specified channel during the red interval is used to trigger a continuous call for service. This call is retained until the assigned phase is serviced, regardless of whether or not any vehicles are waiting to be served. Locking mode is usually associated with advance detection. Locking mode will prevent the ability of permissive movements (Right-turning vehicles) to be completed without invoking a phase change.
- **Non-Locking:** In the non-locking mode, an actuation received from a detector is not retained by the traffic signal controller after the actuation is dropped by the detection unit. The traffic signal controller recognizes the actuation only during the time when there is a vehicle in the detection zone. Non-locking mode is usually associated with stop line detection. When coupled with the delay parameter (See Section 8.2.3), non-locking mode allows permissive movements to be completed without invoking a phase change, potentially improving intersection efficiency (e.g. RTOR scenario).

All actuations received during a green interval are treated as non-locking by the traffic signal controller.

8.2.3 Detection Modifiers

Detector modifiers have the ability to alter the actuations received by the traffic signal controller to improve intersection operations.

- **Delay:** Delay is used to temporarily disable the detector output for a phase, essentially preventing vehicle actuations from being recognized right away by the signal controller. An actuation is not made available unless the delay timer has expired and the detection zone is still occupied. The delay parameter should be considered for RTOR scenarios. Its use is recommended for exclusive right-turn lanes on minor streets operating with stop line detection, presence mode detection, or adjacent through movement phases not on recall (See Section 8.3). An analysis of the number of gaps available on the major road is necessary to make sure that right-turning vehicles will not be further delayed when the delay parameter is in use. The delay setting could range from eight to twelve seconds, but should be fine-tuned for each individual location. The delay parameter should also be considered to prevent erroneous calls from being registered in the traffic signal controller if vehicles tend to traverse over another phase's detection zone. For example, left-turning vehicles often cut across the perpendicular left-turn lane at the end of their turning movement. A detector delay, coupled with non-locking memory, would prevent a call from being placed for the unoccupied detector. The delay setting could range from two to five seconds, but should be fine-tuned for each individual location.
- **Extend:** Extend is used to temporarily increase the duration of a detection actuation. An actuation continues to be made available to the traffic signal controller as the detection zone becomes unoccupied, and the call is retained until the extension timer expires. The extend parameter is typically used with detection designs that combine multiple advance detectors on high-speed intersection approaches. It is applied to advance detectors that extend the green interval to ensure that a vehicle approaching the intersection at design speed has sufficient time to reach the next downstream detector. The extend parameter setting is dependent on the approach speed, detector size; and distance between detectors. Typical values range up to two seconds.
- **Call:** The call parameter allows the traffic signal controller to receive actuations only when it is not timing a green interval. Therefore, actuations received during the green interval are ignored (no extension of the phase is possible). The call parameter is typically used with detection designs that combine advance detection and stop line detection. Here, the call parameter is set to the stop line detection to ignore the actuation these detectors receive during the green interval. Advance detection would be

used to ensure safe and efficient operation during the green interval. Locations where detection design uses only advance detection, but where a driveway exists between the stop line and the advance detection, can also benefit from a call detector. It would be placed on the driveway to ensure service to vehicles that have not crossed the advance detection.

- **Queue:** The queue parameter allows the traffic signal controller to receive actuations for a determined amount of time to service the initial queue, at which time it is deactivated until the start of the next conflicting phase. The call parameter is typically used with detection designs that combine advance detection and stop line detection. Here, the queue parameter is set to the stop line detection and practitioners would determine the amount of time necessary to serve the typical queue. Once that time is elapsed, the stop line detection is deactivated and the advance detection would be used to ensure safe operation during the remainder of the green interval.
- **Detector Switching:** Detector switching allows detectors to extend a call for one phase and then send calls to another phase (switch phase) once the extend phase ends. Detector switching is commonly used on left-turn lane detectors under protected/permissive operations. Vehicles detected on left-turn lanes are switched to extend the through phase during the permitted portion of the phase to provide more time for vehicles making left-turn movements. Detector switching is a recommended operational strategy when coordinated operation constrains and pedestrian timing requirements limit the ability of providing additional time to protected left-turn movements. Table 8.1 provides a summary of the typical settings for detector switching at a standard eight-phase intersection with protected/ permissive operation on all approaches.

Table 8.1 – Typical Detector Switching Settings

Phase	Extend Phase	Switch Phase	
		Five-Section Signal Head Protected/Permissive Operation	Flashing Yellow Arrow Protected/Permissive Operation
1	1	6	2
3	3	8	4
5	5	2	6
7	7	4	8

8.3 Phase Recalls

A phase recall causes the traffic signal controller to place a call automatically for a specified phase, regardless of the presence of any detector-actuated calls (vehicular or pedestrian). Phase recalls are most commonly used on major road through phases, causing the signal indication to rest in green on the main street in the absence of demand on other phases. There are four types of phase recalls: minimum recall, maximum recall, soft recall, and pedestrian recall. Table 8.2 provides typical phase recall settings assuming a single detector per lane.

8.3.1 Minimum Recall

The minimum recall parameter causes the traffic signal controller to place a call for vehicle service on a phase in order to serve at least its minimum green duration.

8.3.2 Maximum Recall

The maximum recall parameter causes the traffic signal controller to place a continuous call for vehicle service on a phase in order to run its maximum green duration every cycle.

8.3.3 Soft Recall

The soft recall parameter causes the traffic signal controller to place a call for vehicle service on a phase in the absence of a serviceable conflicting call.

8.3.4 Pedestrian Recall

The pedestrian recall parameter causes the traffic signal controller to place a continuous call for pedestrian service on a phase.

Table 8.2 – Typical Phase Recall Settings

<table>
<tr><th rowspan="2">Recall Mode</th><th colspan="2">Detection Location</th><th colspan="2">Memory Mode</th><th rowspan="2">Recommended Use</th></tr>
<tr><th>Stop Bar</th><th>Setback</th><th>Locking</th><th>Non-Locking</th></tr>
<tr><td rowspan="3">Minimum Recall</td><td>●</td><td></td><td></td><td>●</td><td rowspan="3">• Major road through movement phases; semi-actuated, non-coordinated intersections.
• Ensures that traffic signal controller will return to major road through movement phases regardless of demand, where it will rest in green until a conflicting call comes in. Phase green time is extended based on vehicle actuations.</td></tr>
<tr><td colspan="2">or</td><td colspan="2"></td></tr>
<tr><td></td><td>●</td><td></td><td>●</td></tr>
<tr><td>Maximum Recall</td><td colspan="2">No Detectors</td><td colspan="2">Not Applicable</td><td>• When fixed time operation is desired.
• When detection is temporarily out of service.
• Note: May result in inefficient operation.</td></tr>
<tr><td rowspan="3">Soft Recall</td><td>●</td><td></td><td></td><td>●</td><td rowspan="3">• Major road through movement phases; fully-actuated, non-coordinated intersections.
• Ensures that traffic signal controller will rest on these phases’ green in the absence of calls on conflicting phases, and allow major road through movement phases to be skipped in the absence of major street phase calls when calls exist on other phases.</td></tr>
<tr><td colspan="2">or</td><td colspan="2"></td></tr>
<tr><td></td><td>●</td><td>●</td><td></td></tr>
<tr><td>Pedestrian Recall</td><td colspan="2">Not Applicable</td><td colspan="2">Not Applicable</td><td>• Pedestrian detection is not present or out of service.
• High pedestrian demand on specific locations and/or at times of the day (downtown areas, schools, etc.).</td></tr>
</table>

8.4 Detection Design for Approaches Below 35 MPH

Providing efficient operations is the main objective when designing detection for approaches with a posted speed limit below 35 mph. Basically, the goal is to call the low-speed approach phases and clear the standing queue while minimizing delay. The use of only stop line detection is typical practice. The length of the detection zone and its parameter settings is dependent on the type of detection used. The use of large detection zones (either through a single larger detection zone or multiple smaller detectors) allows practitioners to reduce the passage time parameter (See Section 7.5.8), thus preventing premature termination of the phase due to sluggish traffic, yet allowing for snappy termination when the last vehicle passes the stop line. Fundamentally, the length of the detection zone provides the ability for the extension of the green interval, thereby improving intersection efficiency, since there is no need to time a larger passage time once the detection zone is not occupied. Figure 8.1 illustrates schematics for typical detection design for approaches below 35 mph. Figure 8.2 provides typical inductive loop (See Section 8.8.1) design for approaches below 35 mph.

Figure 8.1 – Typical Detection Design Schematics (< 35 MPH)

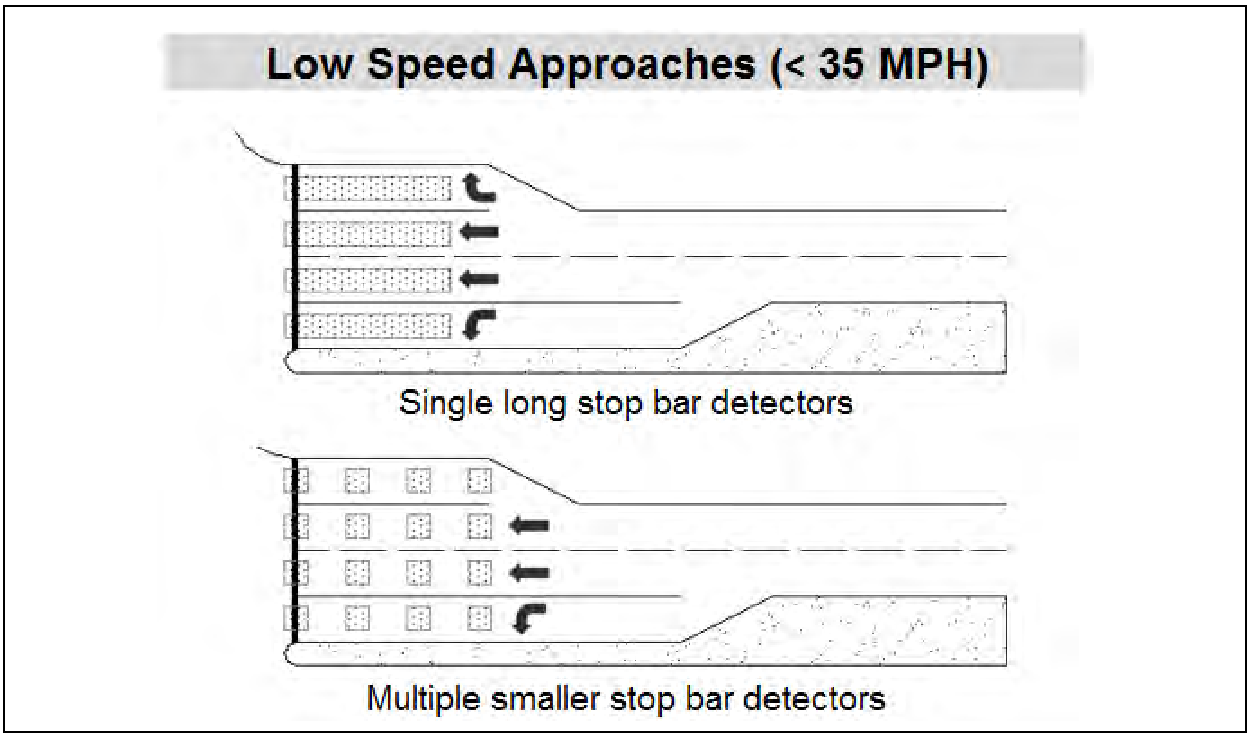
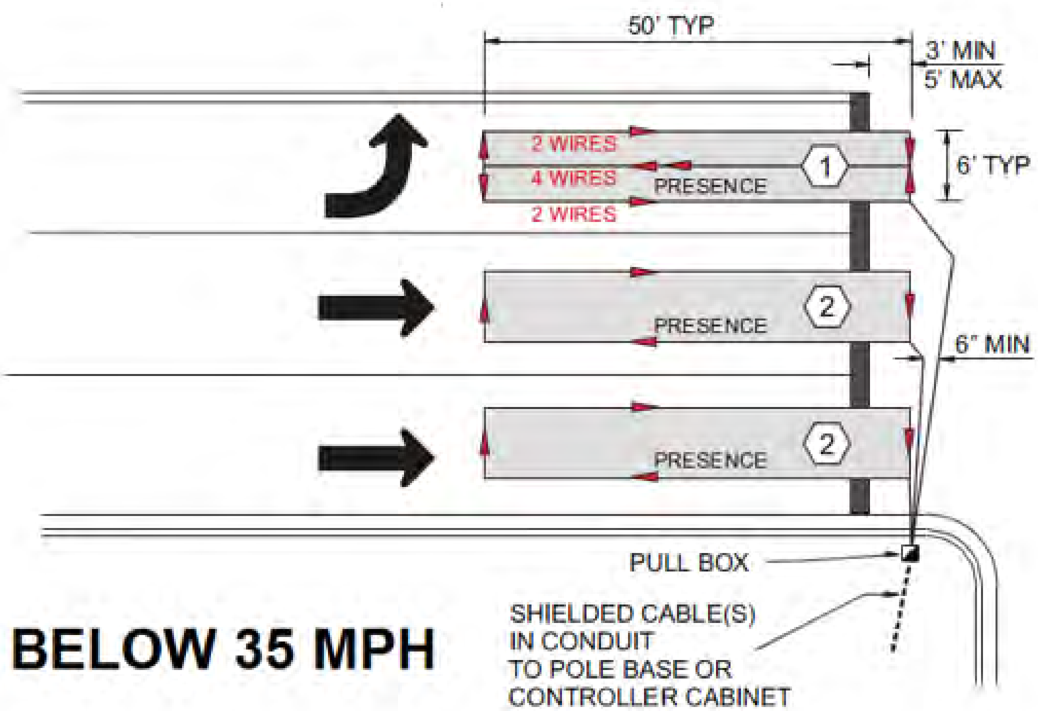


Figure 8.2 – Inductive Loop Detection (< 35 MPH)



Legend:

2 Detector numbers

Settings:

Presence, Non-Locking

Notes:

- Loops with the same number indicate wired in series;

- Quadrupole design recommended for all lanes on major road if phases are not on recall.
- Quadrupole design recommended for all lanes on minor road.

8.5 Detection Design for Approaches 35 MPH or Above

Detection design on approaches with a posted speed limit 35 mph or above should focus on serving the queue at the beginning of green and safely terminate the phase once there is a conflicting call. The design of advance detection on approaches 35 mph or above requires special attention. Drivers, when faced with the onset of the yellow indication, may have problems deciding whether to stop or to proceed through the intersection. This scenario is related to two issues that are often confused:

8.5.1 Timing of the Yellow Change Interval

Incorrect timing of the yellow change interval will lead to a dilemma zone situation where a yellow is too short for a vehicle to safely enter the intersection, but the vehicle is too close to the stop line to safely stop. See Section 7.5.5 for recommendation on the appropriate timing of the yellow change interval. It is important to note that even with well-designed yellow change intervals, drivers will still experience the dilemma zone when driving above the design speed limit.

8.5.2 Driver Behavior

The human factors of driver perception, reaction, and judgment lead to an indecision zone where each individual driver makes a different decision upon seeing the yellow signal indication; some drivers may stop and others may go. Research has shown that the limits of the indecision zone tend to be between 5.5 (beginning) and 2.5 (end) seconds of travel time from the stop line. To minimize the effects of the indecision zone, advance detection should be located at the beginning of the indecision zone and settings (passage time, extension, or a combination of both parameters) programmed to prevent a phase from terminating before a vehicle clears the indecision zone. Once the vehicle has cleared the indecision zone, the onset of the yellow takes place. Appropriate yellow change and red clearance (See Section 7.5.5) should provide enough time for the vehicle to navigate safely through the intersection. Table 8.3 provides recommended advance detection location.

Table 8.3 – Typical Advance Detection Placement

Approach Vehicular Speed (MPH)	Begin of Indecision Zone (5.5 Seconds from Stop Line) (Feet)	End of Indecision Zone (2.5 Seconds from Stop Line) (Feet)	Setback Detection Placement Distance from Stop Line (Feet)
35	285	125	285
40	325	145	325
45	365	165	365
50	405	180	405
55	445	200	445
60	485	220	485

In summary, appropriate timing of the yellow change interval for the design speed, coupled with detection and settings that minimize the chance for a vehicle to be in the indecision zone on the onset of the yellow signal display, will provide acceptable approach detection design. Detection design for approaches 35 mph or above varies from simple advance detection designs to more complex designs using two or three advance detectors, with some designs incorporating stop line detection and advance detection together. When a phase maxes out (See Section 7.5.8) or is forced off by coordination (See Section 7.6), there is no indecision zone protection. Figure 8.3 illustrates schematics for typical detection designs for approaches 35 mph or above. Figure 8.4 provides typical inductive loop (See Section 8.8.1) design for approaches 35 mph or above. The FHWA *Traffic Detector Handbook Volumes 1 and 2* provides additional information on detection designs for all approaches.

Figure 8.3 – Typical Detection Design Schematics (≥ 35 MPH)

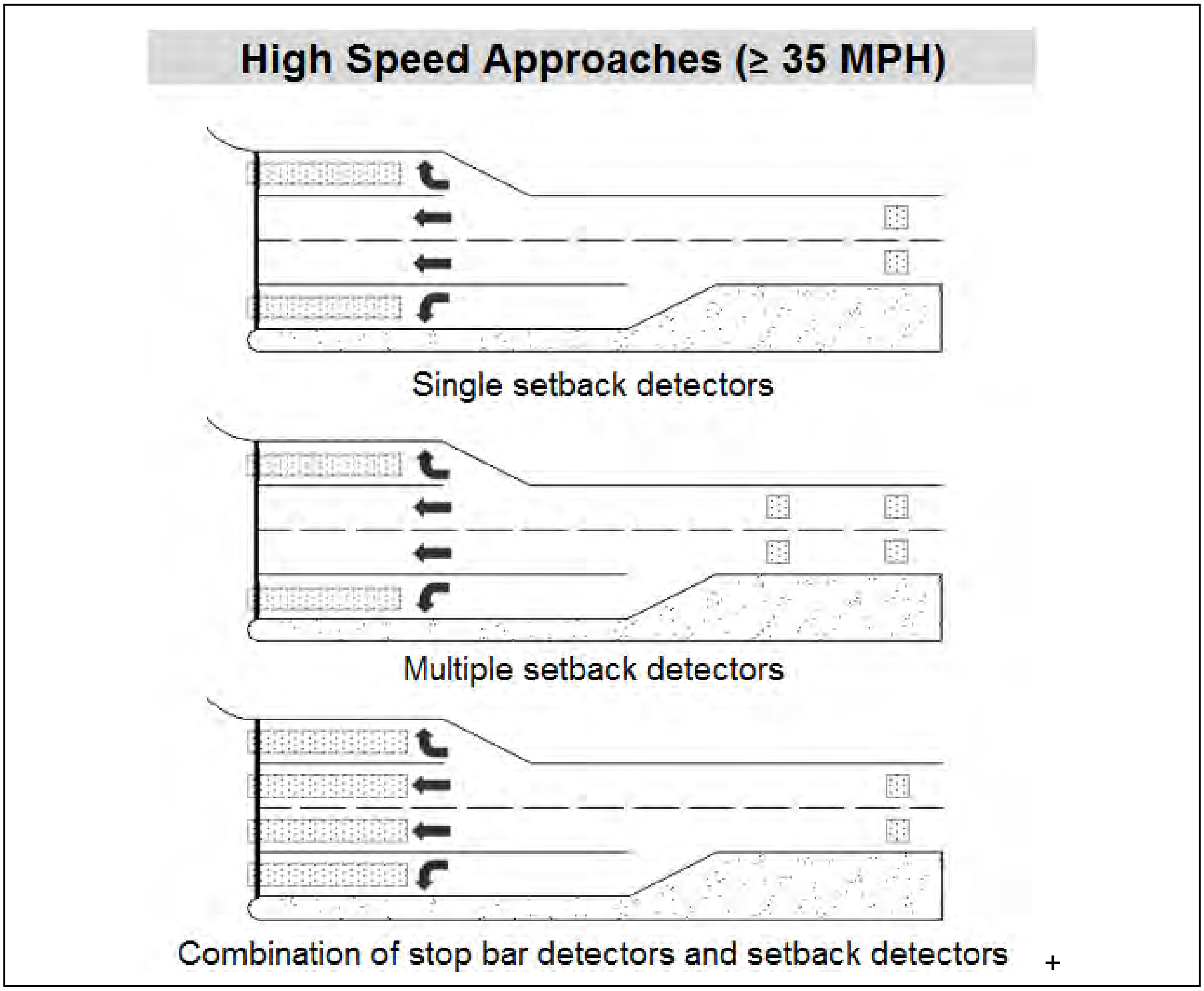
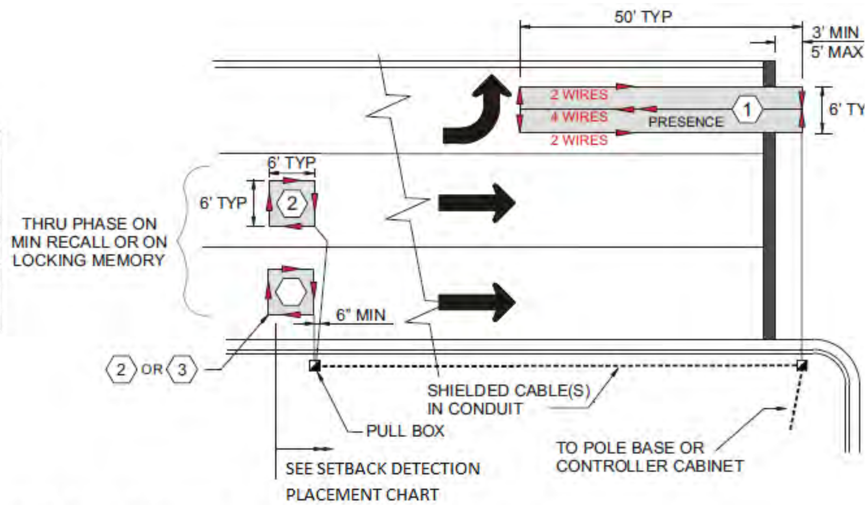


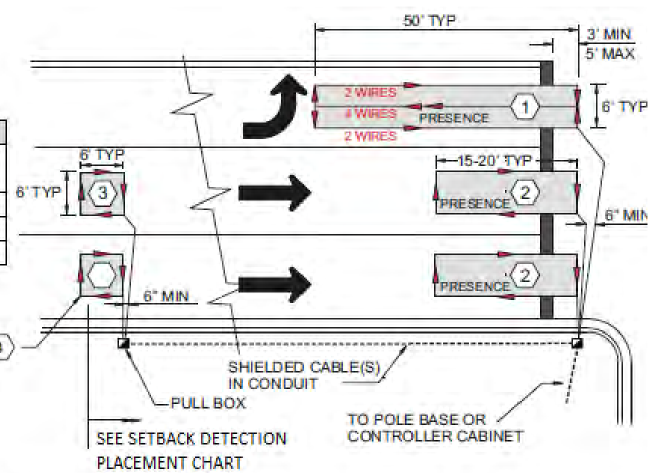
Figure 8.4 – Inductive Loop Detection (≥ 35 MPH)

SETBACK DETECTION PLACEMENT	
APPROACH SPEED (MPH)	DISTANCE TO STOP BAR (FT)
35	285
40	325
45	365
50	405
55	445
60	485



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

8.6 Detection Design for Coordinated Systems

In coordination (See Section 7.6), the coordinated phases (typically major road through movements) are guaranteed their split time every cycle. Therefore, it is common practice to have no detectors for the major road through phases. However, practitioners should plan for adequate serving of major road through phases during times that the intersection is not operating in a coordinated system. This can be accomplished with the use of detection or a maximum recall (efficiency issues). Especially in the case of video detection, there is usually no additional cost for setting up detection zones on the major road through movements, and practitioners should take advantage of traffic signal controller features that may improve intersection operational efficiency by monitoring the end of the coordinated phases.

8.7 Pedestrian Detection

When an intersection provides pedestrian signal phasing (See Section 7.4), the servicing of pedestrians shall be accomplished by the use of pushbuttons, passive detection devices, or a pedestrian recall (See Section 8.3.4). Passive detection devices register the presence of a pedestrian in a position indicative of a desire to cross without requiring the pedestrian to push a button. Some passive detection devices are capable of tracking the progress of a pedestrian as the pedestrian crosses the roadway for the purpose of extending or shortening the duration of certain pedestrian intervals. When a pedestrian recall is used, its associated vehicular green phase time shall accommodate, at a minimum, the required pedestrian interval timings. Pedestrian pushbuttons should be located within easy reach of pedestrians and should be positioned in such a way to make it obvious which pushbutton is associated with each crosswalk. Practitioners shall refer to the *MUTCD Section 4E.08* for requirements and guidance on pushbutton locations and related signs. Consideration should be given to the use of additional pedestrian pushbuttons on islands or medians and the use of pilot lights.

8.7.1 Accessible Pedestrian Signals

Practitioners shall refer to the *MUTCD Sections 4E.09 through 4E.13* for accessible pedestrian signals. The 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. The primary technique that pedestrians who have visual disabilities use to cross streets at signalized locations is to initiate their crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, which often corresponds to the onset of the green interval. The existing environment is often not sufficient to provide the information that pedestrians who have visual disabilities need to cross a roadway at a signalized location as referred to in the *MUTCD Section 4E.09*. If a particular signalized location presents difficulties for pedestrians who have visual disabilities to cross the roadway, an engineering study should be conducted that considers the needs of pedestrians in general, as well as the needs of pedestrians with visual disabilities. The engineering study should consider the following factors:

- Potential demand for accessible pedestrian signals;
- A request for accessible pedestrian signals;
- Traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high RTOR volumes;
- The complexity of traffic signal phasing (such as split phases, protected turn phases, leading pedestrian intervals, and exclusive pedestrian phases); and
- The complexity of intersection geometry.

The FHWA recommends that jurisdictions have a policy on accessibility including the use of accessible pedestrian signals on new construction projects, as well as a transition plan to retrofit established locations.

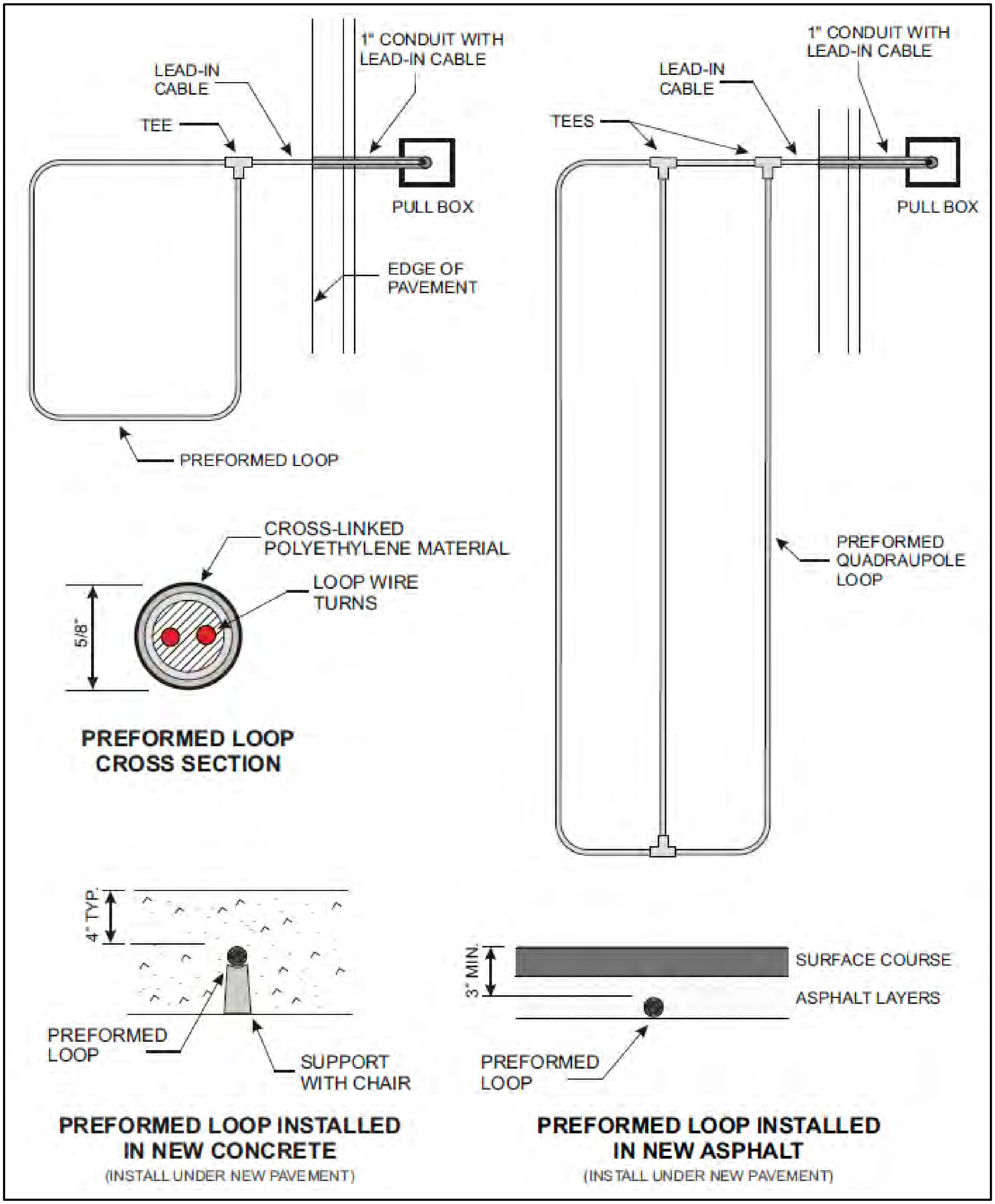
8.8 Types of Detection

Many different technologies exist to enable detection of vehicles at an intersection. These can be categorized by in-ground and above-ground detection. Inductive loops and magnetometers are in-ground types of detection and, due to the necessity of pavement cutting for installation, they are also considered intrusive detection. Video, radar (microwave), and thermal are types of above-ground detection and are considered non-intrusive detection. Pushbuttons are the most appropriate type of detection for pedestrians, while for bicycles, inductive loops are typical. Detection is also necessary for vehicles receiving preferential treatment at intersections, such as emergency vehicles, buses, light rail transit, and trains. Types of preferential treatment detection typically include GPS, hard-wired loop, light-based, radio-based, sound-based, and station pushbutton. Detailed information on types of detection can be found in the FHWA *Traffic Detector Handbook Volumes 1 and 2*. The following provides information on typical vehicular detection used in Tennessee.

8.8.1 Inductive Loop Detection

The inductive loop detects vehicles by sensing a change of inductance caused by the passage or presence of a vehicle over the loop. Inductive loops are placed in the pavement by saw cutting a slot, installing loop wire, and encapsulating the wire by filling the saw cut with sealant. The induction detector is made up of three components: a loop of wire, a lead-in (shielded) cable, and a detector processing unit (detector amplifier) in the controller cabinet. The life of a regular inductive loop which is saw cut into the pavement is dependent on the condition of the pavement and it must be replaced each time a road is milled and resurfaced. When long term maintenance is a concern, an alternative to the traditional saw cut inductive loop (other than video, radar, etc.) for new construction projects is the preformed inductive loop. Preformed inductive loops function similarly to a regular saw cut loop; however, the conductor is encased in a heavy duty plastic housing. The loops are placed within concrete or in the lower lifts of asphalt prior to final paving (See Figure 8.5). 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, preformed loops are not recommended due to the size of the saw cut required. 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. A common inductive loop configuration that provides greater detection capabilities is the quadrupole loop. Quadrupole loops also provide more accuracy in vehicle detection and minimize false detections from adjacent through lanes. Figures 8.2 and 8.4 illustrate typical inductive loop layout recommended by TDOT. Refer to TDOT *Standard Drawing T-SG-3* for additional information on inductive loop detection.

Figure 8.5 – Preformed Inductive Loop



8.8.2 Video Detection

Video detection detects vehicles by sensing a change in the properties of image pixels caused by the passage or presence of a vehicle over user-defined virtual detection zones. Video detection is provided by cameras mounted above the ground on stable fixtures, typically on mast arms, poles, or luminaire arms. Video detection can be considered for a signalized intersection or interchange when one or more of the following conditions are present:

- When a large number of detectors is needed at the location (twelve or more);
- When inductive loop life is short due to poor pavement conditions;
- When extensive intersection reconstruction will last for one or more years;
- When inductive loop installation is physically impractical due to the presence of a bridge deck, railroad tracks, or underground utilities;
- When the pavement in which the inductive loop is placed will be reconstructed in less than three years or during overlay projects at large intersections where the cost of replacing all inductive loops exceeds the cost of installing video detection.

Camera position is the primary factor for successful video detection operation. The optimal camera location maximizes detection accuracy by being stable, by having an unobstructed view of each traffic lane on the approach, and by excluding the horizon. Consideration should also be given to sight lines affected by sun glare, shadows, and headlight glare during different times of the day, or by moving power lines, utility cables, or any light-generating source that may trigger unnecessary calls. Fog, snow, and heavy rain may also be a problem for video detection and practitioners should explore equipment failsafe operation. Cameras should not be mounted below 24 feet in height to minimize equipment maintenance (dirt, spray, and mist on lenses). Detection zone layout varies by equipment vendor, but due to its ease and flexibility, the use of longer detection zones (greater than 60 feet) and low passage time (close to zero seconds) is recommended for intersection efficiency. Typically, an additional camera (located upstream from the intersection) is needed for advance detection. Refer to TDOT *Standard Drawing T-SG-3A* for additional information on video detection.

8.8.3 Radar Detection

Radar detection detects and tracks vehicles by sensing a change in the influence area of the radar transmitter caused by the passage or presence of vehicles over user-defined virtual detection zones. Radar detection continuously tracks vehicles in the influence area and is provided by corner fire and/or forward fire units. To capture true presence detection where vehicles are continually tracked throughout the presence detection phase, a second radar unit may be necessary for the mainline approaches (one unit for the stop bar detection and one unit for the advanced detection). Multiple detection zones can be designed at the stop line and vehicles can be detected and tracked as far as 600 feet upstream, providing better indecision zone protection. Radar detection should be considered for a signalized intersection or interchange for the same reasons mentioned for video detection (See Section 8.8.2). Radar detection is not influenced by obstructions and is not affected by sun glare, shadows, headlight glare, light sources, and weather-related issues, which provides very low maintenance needs. Refer to TDOT *Standard Drawing T-SG-3A* for additional information on radar detection.

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