

4 SIGNALIZATION

The signalization design includes both the physical installation and the signal-operating plan. It is important that both be compatible with each other and with the geometric configuration. All of the desirable objectives of an intersection design presented in Chapter 1 must be considered and sometimes weighed against each other. This chapter sets forth the principles and criteria for signal design that are recognized by the FDOT and identifies the design methodology that is commonly used throughout the state.

4.1 SIGNIFICANT REFERENCES

The following reference documents govern the design of signalization features at intersections in Florida. The references indicated in *italics* were described in Chapter 1.

- *The MUTCD* establishes nationwide standards that promote uniformity to facilitate driver comprehension of traffic control devices. Part 4 of the MUTCD covers signals. References to MUTCD requirements pertaining to specific topics are provided in boxes throughout this chapter. The current version of the MUTCD is available in printed form and on the Internet in electronic form.

MUTCD Part 4 Sections
 - A. General
 - B. Traffic Control Signals
 - C. Signal Needs Studies
 - D. Signal Features
 - E. Pedestrian Control Features
 - F. Signals For Emergency Vehicle Access
 - G. Signals For One-Lane, Two-Way Facilities
 - H. Signals For Freeway Entrance Ramps
 - I. Traffic Control For Movable Bridges
 - J. Lane-Use Control Signals
 - K. Flashing Beacons
 - L. In-Roadway Lights
- *The HCM* prescribes a procedure for evaluating the performance of a signalized intersection as a function of the intersection configuration, the signal operation and the traffic conditions. The current version of the HCM is known as *HCM 2000*.
- *The PPM* outlines the general requirements affecting signal design in Section 7.4. The following topics are covered in the PPM:
 - Certification and specialty items,
 - Stop line location,
 - Controller timings,
 - Left turn treatments,
 - Signal preemption,
 - Lane configuration,
 - Loop detectors and
 - Mast arm supports.

A traffic control signal shall:

 - Be operated in either a steady (stop-and-go) mode or a flashing mode at all times.
 - Control traffic only at the intersection or mid-block location where the signal faces are placed.

{MUTCD}

Many of the same topics are also covered in this chapter. The guidelines presented here are consistent with the requirements of PPM, with additional details provided to assist the designer.

- *FDOT Standard Specifications for Road and Bridge Construction*: includes a section covering all traffic control signal equipment and materials used in the construction of signalized intersections.
- The *Florida Design Standards* set forth the following requirements that apply specifically to signal design:
 - *Index 17721* Conduit installation;
 - *Index 17723* Steel strain pole elevation and notes;
 - *Index 17725* Concrete poles;
 - *Index 17727* Signal cable and span wire installation details;
 - *Index 17733* Aerial interconnect;
 - *Index 17736* Electric power service;
 - *Index 11740* Instructions and examples for designers and fabricators of standard mast arm assemblies;
 - *Index 11742* Component data for standard mast arm assemblies;
 - *Index 17744* Mast arm assemblies;
 - *Index 17746* Monotube steel structures elevation, notes and camber details;
 - *Index 17748* Free-swinging, internally-illuminated street sign assemblies;
 - *Index 17764* Pedestrian control signal installation details;
 - *Index 17781* Vehicle loop installation details;
 - *Index 17784* Pedestrian detector assembly installation details;
 - *Index 17841* Cabinet installation details and
 - *Index 17870* Standard signal-operating plans.

The last index deals with the operational aspects of signalization plans. All others deal with items related to physical configuration and installation.

- *The MUTS Manual* prescribes the procedures for conducting several studies related to signal design including:
 - Signal warrant studies,
 - Roundabout justification studies,
 - Vehicular and pedestrian counts and characteristics,
 - Collision and condition diagrams,
 - Performance evaluation studies and
 - Traffic and pedestrian flow characteristics.
- *The FDOT Traffic Engineering Manual* contains sections covering:
 - Flashing signals and beacons,
 - Left-turn treatments,
 - Yellow and all red interval determination,
 - Traffic signal studies,
 - Emergency traffic control signals,

- Mast arm supports,
 - Computer models for traffic engineering and ITS analysis and design and
 - Certification and approval of traffic control devices.
- *AASHTO Guide for the Development of Bicycle Facilities (1999)* provides guidelines for:
- Intersection clearance times for bicycles,
 - Signalization at intersections with multi user trails and trails,
 - Location of push-button detectors for cyclists,
 - Visibility of signal indications and
 - Bicycle detection for traffic-actuated control.
- *The FDOT Median Handbook* provides guidance on:
- The design of medians,
 - The design and placement of medians and median openings and
 - Accommodation of U-turns.
- *Trail Intersection Handbook (1996)* offers guidelines for the treatment of bicycles and pedestrians where intersections with trails are signalized.

General reference material describing signalization concepts, design tools, controller functions, etc. may be found in the following publications:

- *National Electrical Manufacturers' Association (NEMA) Standards for Traffic-actuated Controllers*: This publication describes the physical and functional requirements of signal controllers. It creates a limited degree of interchangeability between the products of different manufacturers. Two standards, TS-1 and TS-2, are prescribed. TS-1 dates back to the 1970's but still applies to most of the equipment in current use. TS-2 is an emerging standard that incorporates contemporary computer and communications technology.
- *Methodology for Optimizing Signal Timing (M/O/S/T)* is a comprehensive reference document available from McTrans. This document covers all aspects of signal timing design, implementation and performance evaluation.
- *Manual of Traffic Signal Design (ITE)* deals with all aspects of signal design, including physical and operational characteristics, equipment, displays, installation, etc.
- A course in Basic Traffic Signal Operations is offered periodically through the Florida Engineering Education Delivery System (FEEDS).

Several software products are available to perform computations for signal timing design and performance evaluation. These tools will be described later in this chapter.

4.2 DESIGN REQUIREMENTS

Before describing the design procedure itself, a few key concepts with which the designer must be familiar will be addressed.

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

{MUTCD}

4.2.1 Signal Controller Cabinet Elements

The traffic controller cabinet contains several functional modules that require the attention of the designer, including:

- The controller itself, which requires all operating parameters to be specified;
- A conflict monitor, which requires conflicting phases to be identified;
- A coordination unit, which may require parameter settings and
- Vehicle detectors, which may require parameter settings.

The typical positioning of the controller, detectors and conflict monitor is illustrated in Figure 4-1.

Several industry standards now exist for signal controllers and this area is evolving to keep pace with the demands of intelligent transportation systems. The choice of controller standard for a given intersection will be determined by local policies beyond the scope of this document.



Figure 4-1. Controller, Detectors and Conflict Monitor in a Cabinet.

4.2.2 Design Products and Prerequisites

The products of the signalization design process are generally a plan prepared in accordance with Volume II of the PPM. In the case of simple operational modifications or upgrades to existing signals, the design product may take the form of a work order issued by the operating agency.

The general intersection design process and data requirements were discussed in Chapter 2. In this chapter, the process will be applied specifically to signalization. It will be assumed that the following information is available, either as field data or as a result of decisions that have already been made:

The signalization for each intersection should be individually designed.

{PPM}

- The intersection in question will be signalized.

- The movements and modes to be accommodated have been identified and the traffic volume, composition and speed are known for each movement. Note: The existing speed limits should be reviewed and modified if necessary as a part of the intersection design.
- The intersection configuration (cross section, angle of intersection, channelization, number and width of lanes and lane use) has already been established.
- Accommodations for bicycles and pedestrians, including sidewalks, bicycle lanes and trails have been identified.
- The design controls for coordinated operation of the intersection are known, including cycle length constraints, allowable phasing alternatives, distances to adjacent intersections and number of timing plans to be developed.
- The location and utilization of access points near the intersection, including median openings, has been identified.
- All special requirements affecting the signalization, including railroad, drawbridge and emergency vehicle preemption have been specified.

4.2.3 Signalization Design Decisions and Parameters

The key decisions affecting the signal design include:

- Location of crosswalks and determination of pedestrian signal display requirements;
- Location of stop lines for all movements that must stop at the intersection;
- Selection of left turn treatments;
- Selection of right turn treatments;
- Determination of the required lengths for turning bays;
- Selection of controller type;
- Selection of the phasing plan;
- Assignment of movements to timing functions;
- Development of the timing plan(s) for arterial coordination;
- Determination of detector locations;
- Location and configuration of the controller and cabinet;
- Location and configuration of all signal displays;
- Location of equipment required to support the signal displays and
- Wiring, conduit and pull boxes.

Pavement markings should be used at traffic control signal locations. If the road surface will not retain pavement markings, signs should be installed to provide the needed road user information.

{MUTCD}

The above list is presented more or less in the order in which the decisions must be made. It is important to note, however, that some decisions may not be entirely independent of others and therefore some iteration between decisions may be required. Requirements and guidelines for each of the key signalization design decisions will now be presented.

4.3 LOCATION OF CROSSWALKS AND DETERMINATION OF PEDESTRIAN SIGNAL DISPLAY REQUIREMENTS

At this stage of the design, the location of the crosswalks is the primary concern, because of their influence on the stop line location. Chapter 5 will cover the detailed requirements of the crosswalk as a pavement-marking feature.

The design and operation of traffic control signals shall take into consideration the needs of pedestrian as well as vehicular traffic. If engineering judgment indicates the need for provisions for a given pedestrian movement, signal faces conveniently visible to pedestrians shall be provided

{MUTCD}

4.3.1 Need for Crosswalks

Each approach to the intersection presents a potential need for a pedestrian crosswalk. Crosswalks should be incorporated into the signal design for all approaches unless the crosswalk location is not accessible to pedestrians or a decision has been made to prohibit pedestrian crossing.

The first step in the design process should be to locate crosswalks and stop lines properly.

{PPM}

Pedestrian crossing should not be prohibited unless it cannot be accomplished safely. If pedestrian crossing is prohibited across a specific approach, the prohibition should be made clear in the design of the intersection. Alternative provisions must be made for the pedestrians who would normally cross that approach.

Crosswalks should be marked at all intersections where there is substantial conflict between vehicular and pedestrian movements.

{MUTCD}

The signalization design should be such that it accommodates all modes of travel. Some compromises may be necessary when all requirements cannot be accommodated within the capacity of an existing intersection. Prohibition of pedestrian crossing in a specific crosswalk to achieve vehicular capacity goals should be considered as a last resort and only when the pedestrians may be accommodated safely by other means.

Where it is desired to prohibit certain pedestrian movements at a traffic control signal, a NO PEDESTRIAN CROSSING sign may be used.

{MUTCD}

4.3.2 Need for Pedestrian Signals

The box at the right summarizes the conditions requiring pedestrian signals as set forth in the MUTCD. There are several other conditions that also suggest a need for pedestrian signals.

Pedestrian signals shall be installed:

- When the signal is installed under the pedestrian or school crossing warrant
- When an exclusive pedestrian phase is provided
- When vehicular indications are not visible to pedestrians
- At established school crossings

{MUTCD}

- When pedestrians are expected to cross different parts of the street on different phases;
- When protected left turn phases are included in the signal sequence;
- When the crash history indicates a hazard that could be mitigated by pedestrian signals;
- When the crosswalk is a part of an established pedestrian or bicycle corridor;
- When the crosswalk is used by people with special needs or
- When an abnormal intersection configuration (skewed, multi-legged, etc.) exists.

The sum total of all of these conditions suggests that pedestrian signals should be installed at nearly all signalized crosswalks. When pedestrian signals are not included in the design, it is important that the minimum green time displayed to all approaches be adequate to accommodate pedestrian crossing requirements. The determination of minimum green times is discussed later in this chapter.

Pedestrian phase requirements:

- Indications must be visible to pedestrians
- Delays must not be excessive
- An adequate crossing interval must be provided
- Pedestrian crossing may be prohibited

{MUTCD}

4.3.3 Need for Protected or Exclusive Pedestrian Phases

It is necessary that the decision on the need for protected or exclusive pedestrian phases be made at this stage of the design process because of its effect on crosswalk and stop line location. Exclusive pedestrian phases prohibit all vehicular movements to allow pedestrians to cross simultaneously in all directions. They are not often used because they normally cause a substantial increase in delay to both vehicles and pedestrians. There are, however, conditions of high pedestrian volumes combined with high volumes of right-turning traffic that make it necessary to separate the vehicular and pedestrian movements entirely.

Protected pedestrian phases provide for pedestrian crossing with no conflict from turning vehicles. When pedestrians proceed concurrently with a through movement, they are normally in conflict with right turns and permitted left turns from the same direction. Elimination of the pedestrian conflict requires either the prohibition of (or an alternate phasing accommodation for) the conflicting turns. Both the left and right turns may be accommodated on protected phases as long as sufficient capacity is available. It is important to keep in mind that protected turning phases require exclusive turning lanes that could increase pedestrian crossing distances.

A detailed evaluation of the need for and feasibility of exclusive pedestrian phases generally requires the use of one or more of the traffic operations models described later in this chapter.

4.4 LOCATION OF STOP LINES

The stop line location is heavily influenced by the location of the crosswalks. A stop line that is not properly located invites violation by the motorist.

Stop lines, where used, should be placed 4 ft. in advance of and parallel to the nearest crosswalk line.

{MUTCD}

If no crosswalk, either marked or unmarked, is present on a given approach, the stop line should be located at the point where vehicles are expected to stop, typically 4 feet from where a crosswalk would be located if it were present. This point could also be influenced by left turning traffic approaching from the right. There is sometimes a tendency for the motorist to stop too close to the intersection, thereby obstructing the turning paths of left-turning vehicles. Proper location of the stop line may help to correct this problem.

The MUTCD places constraints on the minimum and maximum distance between the stop line and the signal face in the interest of signal visibility. A more detailed discussion of the

At least one signal face shall be located between 40 and 150 ft. from the stop line.

{MUTCD}

MUTCD requirements is presented in Section 4.14 of this chapter. The proper location of the stop line should govern the signal head placement. Stop lines should not be displaced from their proper position to accommodate the existing or proposed location of the signal displays. Sight distance restrictions should also be taken into account in locating stop lines.

When two streets intersect diagonally, the stop line location becomes more difficult. The alternatives are to paint a continuous diagonal stop line or a staggered stop line perpendicular to each lane. Preferences with respect to these alternatives vary among districts. It is generally agreed that mast arms that are used for signal mounting should be parallel to the stop bar. This consideration can affect both the signal mounting method and the stop line location.

Pavement markings should be used at traffic control signal locations. If the road surface will not retain pavement markings, signs should be installed to provide the needed road user information.

{MUTCD}

4.5 SELECTION OF LEFT TURN TREATMENTS

Left turn treatments are defined in terms of:

- The number of exclusive and optional lanes assigned to left-turning traffic;
- The degree of protection from opposing through traffic provided by the signal phasing and
- The position of a protected phase in the signal sequence with respect to the through phase.

Each of these design decisions will be discussed separately.

4.5.1 Definitions

In the following discussion, lanes that accommodate left turns only will be referred to as “exclusive” and those that accommodate left turns in combination will be denoted as “shared.”

Left turns facing a solid green signal may proceed, but must yield to oncoming traffic. This operation may not provide an adequate level of capacity or safety and it is often necessary to provide protection for left turning movements from the oncoming traffic. This introduces a protected phase into the signal sequence to provide a green arrow display for left turns. Left turns that receive a green arrow display at some point in the sequence are defined by the HCM as “protected left turns.” Left turns that are allowed to proceed, yielding to opposing traffic, are defined by the HCM as “permitted left turns.”

If it is determined that a specific left turn requires a protected phase, it must also be decided whether or not the left turn also should be allowed to proceed during the permitted phase. The situation in which a left turn may proceed only on the protected phase is defined by common usage in Florida as “protected” or “protected only.” The situation in which left turns may proceed on both a protected and permitted phase are commonly described as:

- *Protected/permitted*: in which the permitted phase follows the protected phase and
- *Permitted/protected*: in which the protected phase follows the permitted phase.

These definitions summarize the design choices that must be made with respect to left turn protection at traffic signals. Unfortunately, a consistent and universal terminology has not yet emerged in the traffic engineering vocabulary and other designations such as “permissive,” “exclusive,” and “restrictive” will be found in the literature. Furthermore, the terms are often applied in a somewhat loose and inconsistent manner. It should be noted that the MUTCD now describes the left turn treatment choices in terms of four “modes”:

- The “permissive only” mode;
- The “protected only” mode;
- The “protected/permissive” mode and
- The “variable left turn” mode. This last mode has been introduced to describe a condition in which left turn treatment changes throughout the day.

It is essential that a set of left turn protection terms be established and applied consistently in this document. In the remaining discussion, the terms “protected” and “permitted” left turns will be adopted to describe the manner in which left turns are accommodated. Phasing schemes that involve a combination of permitted and protected treatment for a specific left turn movement will be denoted as “protected-permitted” with no order of phases implied. When it is necessary to specify a phase order, the terms “leading” and “lagging” will precede the treatment identification. So, for example, the left turn treatment for a specific phase could be described as “leading protected,” “lagging protected-permitted,” etc. Where it is necessary to distinguish clearly between protected and protected-permitted phasing, the term “protected only” will be used.

4.5.2 Need for Exclusive Left Turn Lanes

Left turns may be made from shared lanes yielding to the opposing through traffic, however, the capacity of a shared lane is somewhat limited. The HCM provides a procedure for assessing the capacity of both shared and exclusive lanes under signal control.

The operational advantage of an exclusive lane is quite clear from a capacity perspective. The disadvantages apply primarily to pedestrians in the form of increased exposure in the crosswalk and reduced refuge area on the median. On roadways without medians exclusive left turn lanes must be created by widening the roadway. This can cause alignment problems as well as additional hazards or inconvenience for pedestrians.

Exclusive left turn lanes are normally required when protected left turn movements are provided in the signal phasing. Without a protected phase, signalized approaches with adequate median should normally be provided with exclusive left turn lanes unless left turning volumes are negligible or unless the addition of a left turn lane would cause problems for pedestrians. When no medians are present and a widening of the approach would be required, the decision to add an exclusive left turn lane should be based on a demonstrated operational or safety related need. Pedestrian problems that might result from a loss of sidewalk area or utility pole conflicts should also be considered.

When left turning volumes are high, multiple exclusive left turn lanes may be required to provide adequate capacity. Double left turn lanes should be considered when a capacity analysis suggests that overall intersection performance could be improved. Triple left turn lanes have performed effectively at several intersections in Florida. They do, however require more justification and attention to the design details. Pending the development of criteria and guidelines to be published in the TEM, projects involving triple left turn lanes should be reviewed by the State Traffic Operations Engineer.

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, regardless of the number of lanes.

4.5.3 Need for Left Turn Protection

There are no numerical warrants that have been adopted for determining when left turns require protected phasing. The primary determinants of the need for protection are the left turn volume and the degree of difficulty in executing the left turn through the opposing traffic. A cross-product threshold technique is used by some agencies as a guideline. The cross product is defined as the product of the left turning volume and the volume of opposing traffic. The guidelines provided by the HCM for planning purposes suggest that protection for left turns should be considered when the cross product exceeds 50,000, 90,000 and 110,000 for one, two and three lanes of opposing traffic, respectively.

A detailed capacity analysis of the operation of each movement with and without left turn protection can provide an indication of the adequacy of both phasing alternatives from a capacity point of view. The addition of a protected left turn phase for a specific left turn movement will take green time away from all other movements, thereby reducing their capacity. On the other hand, failure to provide a protected phase may leave the left turn in question without adequate capacity. A design dilemma arises when these two conditions occur simultaneously (i.e., a left turn will be over capacity without a protected phase, but the whole intersection will be over capacity if a protected phase is added).

Capacity analysis is a useful tool, however, safety concerns are generally raised by the public and sometimes by the crash records themselves at volume levels well below the capacity of the left-turning movement. The crash history of an intersection should be given more weight than capacity or other performance measures in determining the need for left turn protection. Area demographics should also be considered in assessing potential safety impacts.

Note that the feasibility of providing left turn protection depends to some extent on the lane configuration. In general, exclusive left turn lanes are required to implement left turn protection satisfactorily. It is assumed in that the availability of an exclusive left turn lane has been established as a part of the prerequisite information listed previously. The lack of an exclusive left turn lane does not necessarily preclude left turn protection, but it does constrain the available phasing plan choices to be discussed later in this chapter.

Protected-permitted phasing should be used except when there is a compelling reason not to.

{TEM}

4.5.4 Protected vs. Protected-Permitted Left Turn Treatment

Protected-permitted operation will generally improve both capacity and driver convenience for left turning traffic. At the same time, however, it may introduce hazards because of the conflicts between the left turns and the opposing traffic. There are several examples in Florida in which protected-permitted left turn phasing was eliminated because of an unusually high crash experience.

Protected-only phasing should be used at all intersections where protected-permitted phasing is likely to present a hazard to left turning traffic or pedestrians that conflict with left turning traffic. There are specific conditions that explicitly preclude left turns on permitted phases as indicated in the box at the right. As a general guideline, protected only phasing may be preferred when: {TEM}

Conditions Requiring Protected-only Left Turn Treatment

Turn lanes that are separated from the through lanes by more than 12 feet by a raised or painted island shall not be operated in the permitted mode. {PPM}

Permitted movements should not be allowed from multiple left turn lanes. {PPM}

Sight distance is less than 250 feet or 400 feet, for opposing traffic speeds less than or greater than 40 MPH, respectively. {TEM}

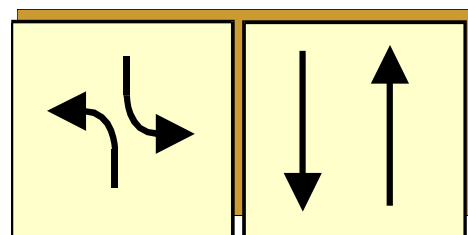
The approach is the lead portion of a lead/lag phasing sequence. {TEM}

- The posted speed is greater than 45 mph,
- The left turns must cross three or more lanes of through traffic,
- There are more than six left turn accidents per year on an approach,
- The intersection configuration is complex.

It is also important to consider the impact of permitted left turn phases on the safety of pedestrian and bicycle traffic that could produce conflicts (sometimes unexpected) with left turning vehicles. Bicycles are especially vulnerable to these conflicts because of their higher speeds that present a greater challenge to the reaction times of motorists who are expected to yield to them.

4.5.5 Leading vs. Lagging Left Turns

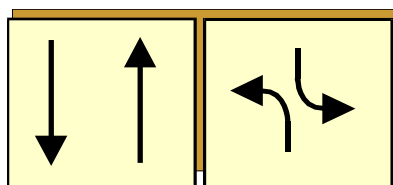
Protected left turns that precede the through movements are referred to as leading left turns. Those that follow the through movement are referred to as lagging left turns. The predominant practice in Florida strongly favors leading left turns. Lagging left turns may offer some benefit under the following conditions:



Leading left turn protection

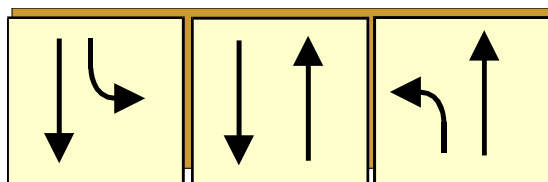
- Modeling of arterial operations indicates that better progression may be achieved by a lagging left turn in one direction, often accompanied by a leading left turn in the other direction. This scheme is generally referred to as “lead-lag” phasing.

- Unpredictable left turn peaks occur on approaches on which left turn volumes normally don’t justify protection. It is a recognized practice to employ a permitted left turn phase followed by a lagging protected phase, with the left turn detector placed two or three car lengths behind the stop line. This will prevent the left turn arrow from being displayed unless a sufficient queue exists at the end of the permitted phase. This scheme offers a more efficient signal operation, but creates a potential for confusion among motorists who expect a green arrow display on every cycle.



Lagging left turn protection

- High crash rates are observed between opposing left turns, often in the form of sideswipes. This hazard can be greatly reduced or eliminated by lead-lag phasing which accommodates the conflicting left turns at different times in the cycle.



Lead-lag phasing

It is important to note that, while protected-permitted left turn phasing and lead-lag phasing are both legitimate and recognized practices, the combination of these two schemes can produce a serious hazard, known as the “Left Turn Trap.” This term denotes 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 under this condition 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. Therefore the use of lagging left turns should be restricted to the following situations {TEM}:

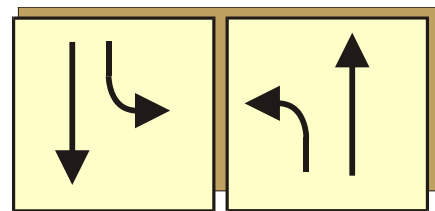
- T intersections and one-way streets where U turns are prohibited in the opposing direction;
- Four-way intersections where left turns are prohibited on the opposing approach or when the opposing approach has protected only left turn phasing.

While the left turn trap is generally associated with lead-lag operation, it will occur on any phase transition in which a permitted left turn display in one direction is followed by a through/left display in the opposite direction. This will happen on each cycle regardless of whether the permitted phase follows a leading protected phase.

It must also be recognized that the left turn trap may arise whenever unusual phase transitions occur as a controller skips phases under low volume conditions. This is inherent in the operation of traffic-actuated controllers. Such transitions are a rare occurrence and are generally not accompanied by significant numbers of left turn sneakers. This phenomenon is beyond the control of the designer and the only way to circumvent the problem with multi-phase operation is to eliminate all permitted left turns, including those that have no associated protected phase.

4.5.6 Split-Phase Operation

The term “split-phase” is commonly used to describe a phasing scheme with full directional separation between the movements on opposing approaches, as illustrated in the box at the right. This type of operation is normally less efficient in terms of intersection capacity and performance than phasing schemes in which the opposing through movements proceed concurrently. For this reason, split-phase operation is normally restricted to situations in which:



Split-phase operation

- Opposing approaches are offset such that simultaneous left turns could not be accommodated safely;
- The volume distribution by movement would not reduce the efficiency of split-phase operation;
- Left turns must be protected on an approach that does not include an exclusive left turn lane;
- Left turns are made from both an exclusive and an optional lane and
- Crash records indicate a high frequency of collisions between opposing left turns.

4.6 SELECTION OF RIGHT TURN TREATMENTS

Three parameters define the right turn treatment for each approach:

- Lane utilization: shared, exclusive or channelized;
- Right turn on red (RTOR): allowed or prohibited and
- Signal protection: permitted, protected or both.

The lane utilization will usually be established with the development of the intersection configuration prior to the signalization design. It is, however, important to ensure that the lane utilization is compatible with the signal protection and with the accommodations for pedestrians. The decision to construct multiple right turning lanes requires more analysis and justification because of the increased crosswalk lengths and pedestrian conflict with right turns. The other two parameters are an essential part of the signal design and will be examined individually.

4.6.1 Need for RTOR

Florida Statutes permit RTOR unless specifically prohibited. Therefore, the default option is that RTOR will be permitted. Prohibition will generally be justified by safety considerations, brought about by high crash rates, visibility limitations, complicated geometrics or phasing and special populations. RTOR prohibitions may also be desirable on cross streets where heavy conflicting U-Turn volumes are observed. Note that RTOR may be prohibited at school signals as a matter of local judgment.

“No right turn on Red” signs may be erected at school signals as deemed necessary by local traffic engineers.
{Index 17344}

4.6.2 Need for Protected Right-turn Phasing

The MUTCD presents a set of definitions for right turn treatments that are analogous to the definitions for left turn treatments (See Section 4.5.1). Right turns proceed as permitted movements at the vast majority of signalized approaches, yielding to conflicting pedestrians and bicycles.

A steady green arrow shall be used only when corresponding movements are protected from all conflicts, including pedestrians and bicycles.
{MUTCD}

There are, however, cases in which protected (i.e., right turn arrow) phases are desirable. At intersections with very heavy pedestrian traffic and vehicular green times that exceed pedestrian crossing time requirements, it may be beneficial to display a right turn arrow during a portion of the vehicular green to provide adequate capacity for the right turn. This could also benefit the pedestrian traffic by accommodating more of the right turns under conflict-free conditions. The pedestrian benefits could be further increased by prohibiting the right turns during the portion of the “through” phase used by pedestrians. This scheme is most practical to implement when exclusive right turn lanes are available and when green times are relatively long. Longer green times can be created by increasing the cycle length. Even though longer cycle lengths generally

produce higher delays for both vehicles and pedestrians, the safety benefits may justify the sacrifice in other performance measures.

Protected right turns are easier to implement at intersections with protected left turn phasing. Each right turn movement has a “shadowing” left turn movement that, when protected, facilitates the right turn. For example, the northbound right turn may proceed unopposed by vehicles under RTOR during a protected westbound left turn phase. Under these conditions, the right turn capacity may be increased further by displaying a right turn arrow concurrently with the protected left turn phase. This feature produces a more complex phasing and is usually implemented only when required for adequate right turn capacity. When protection is required for a specific right turn, it is advisable to prohibit U-turns for the shadowing left turn movement to avoid the display of simultaneous protected green arrows to conflicting movements. In any event, it is necessary to observe the MUTCD requirement that green arrows be shown only to fully protected movements, including protection from pedestrians. This requirement could be satisfied by installing a “U Turn must yield” sign facing the direction from which the U turn originates.

4.7 DETERMINATION OF THE REQUIRED LENGTHS FOR TURNING BAYS

Although many traffic models that provide queue length estimates have been developed, the definition, validity and applicability of their queue measures is not well understood. Some of the models are complex and theoretical, while others are more general and simplistic. The procedures used by these models are based on different queue definitions and have different computational approaches that lead to different results. A better understanding of queue length analysis procedures requires some additional explanation.

There are two very different queue definitions reported by different models, both of which are expressed in number of vehicles in the queue.

- The *queue accumulation* refers to the number of vehicles actually contained in the queue at any point in time and
- The *queue reach* refers to the position of the last vehicle in the queue.

The queue accumulation is important to the determination of delay and level of service, but the queue reach is the measure that determines the adequacy of the available storage. The main reason for the difference between these two definitions is that vehicles continue to join the back of the queue after the end of the red phase, as vehicles begin to depart from the front of the queue. The maximum queue accumulation is achieved at the end of the red phase. The maximum queue reach is not achieved until the instant before the queue has completely dissipated. The determination of the physical position of the last vehicle in the queue requires an assumption of average vehicle length, usually about 25 feet.

There are several variations of the above definitions used by the various models:

- *Uniform arrivals per cycle (UAC)*: The number of vehicles that would arrive on each cycle, assuming uniform arrival conditions;
- *Uniform maximum queue accumulation (UMQA)*: The number of vehicles in the queue at the beginning of green, assuming uniform arrival conditions;
- *Uniform maximum queue reach (UMQR)*: The maximum extent to which the queue backs up assuming uniform arrival conditions and
- *Adjusted maximum queue reach (AMQR)*: The maximum extent to which the queue backs up after performing an adjustment for randomness in the arrival conditions.

Only the last definition above reports an estimate of the queue size suitable for determining the storage lane requirements directly. All other definitions require an adjustment.

In an effort to standardize the methodology for queue length analysis, a UMQA-based queue length model has been introduced into the HCM 2000. This model was developed by Akcelik as an adaptation of the method used in the SIDRA program. The heart of this method is a detailed procedure for estimating the queue length within confidence limits for any signalized movement.

The complexity of the procedure suggests that one of the available software products should be used for the necessary computations. Several queue length estimation models are incorporated into various signal timing design and analysis software products in common use throughout the state. A summary of the queue definition used by each of these products is presented in Table 4-1.

The Plans Preparation Manual, Volume 1, Chapter 7 suggests the use of the NCHRP 279 method. This is the most approximate of all the models represented in Table 4-1. Its use should be limited to situations in which computer software is not available. The NCHRP model is based on an average vehicle spacing of 25 feet and has the following formulation:

$$Q = (2.0) (DHV) (25) / N$$

where:

Q = design length for the left turn storage (ft).

DHV = left turn volume (vph) during design peak hour.

N = number of cycles per hour for peak hour (use N = 30 as default.)

Most of the models apply one or more adjustments to account for the effects of random and overflow phenomena on queue lengths. Some use a constant multiplier in the range of 2.0 to reflect the aggregate of all effects, while others are more detailed in their treatment. The direct application of the Poisson distribution suggests that 90% confidence in the adequacy of the storage space may be achieved with queue adjustment factors between 1.5 and 2.0, depending on the average queue length. Common wisdom has evolved from this process over the years to suggest that queue adjustment factors in this range are reasonable and appropriate.

It is important to note that the queue adjustment factors produced by the HCM 2000 procedure suggest that the adjustment factor is sometimes considerably higher than the accepted value of 2.0 and may actually exceed 5.0 under very high degrees of saturation. The lesson here is that,

while the currently accepted values may be reasonable at lower degrees of saturation, it is very difficult to achieve a design that will only fail on one cycle out of 10 when volumes are very close to capacity.

Table 4-1. Queue Definitions Used by Different Estimation Procedures

MODEL	REPORTED QUEUE DEFINITION
SIDRA	AMQR
SOAP	UMQR
TRANSYT-7F	UMQR
PASSER II	UMQR
SYNCRO	UMQR (Average & 90%)
NCHRP 279	UAC
NETSIM	Historical maximum queue accumulation
SIGNAL 97	UMQA
OPPENLANDER	UMQA

4.8 SELECTION OF CONTROL EQUIPMENT

Department certification is required for each item of control equipment installed. Certification procedures are summarized in the TEM. The product of the certification process is the Approved Products List (APL). To receive certification, a product must meet all requirements of the MUTCD and of the Florida Department of Transportation Minimum Specifications for Traffic Control Signal Devices (MSTCDS).

The traffic signal equipment installed in Florida is required to be certified by the Florida Department of Transportation. Non-certified equipment cannot be used.

{PPM}

The review process involves an initial review based on documentation submitted by an applicant. The FDOT requires a subsequent review of the actual product, performed on hardware sample(s) furnished by the applicant. Products that are determined to meet the required criteria receive a certification number and are added to the APL. Copies of the APL are available from the Department's central and district offices. The Department conducts periodic follow-up reviews of certified products to ensure that conformance to requirements is maintained.

In addition, ITE offers published standards for the following items of intersection control equipment:

- Pretimed Traffic Signal Controllers,
- Traffic-Actuated Traffic Signal Controllers: solid state,
- Solid-State Pretimed Traffic Signal Controller Units,

- Controller Cabinets,
- Traffic Signal Lamps,
- Vehicle Traffic Control Signal Heads,
- Lane-Use Traffic Control Signal Heads,
- Pedestrian Traffic Control Signal Indications,
- Purchase Specification for Flashing and Steady Burn Warning Lights and
- A Standard for Vehicle Detectors.

The majority of signalized intersections now employ dual-ring traffic actuated controllers conforming to NEMA standard TS-1. Inductive loop detectors are the most common choice for vehicle detection. The control equipment to be installed at coordinated intersections must be compatible with the master control equipment. In many cases, this will dictate a vendor-specific product choice.

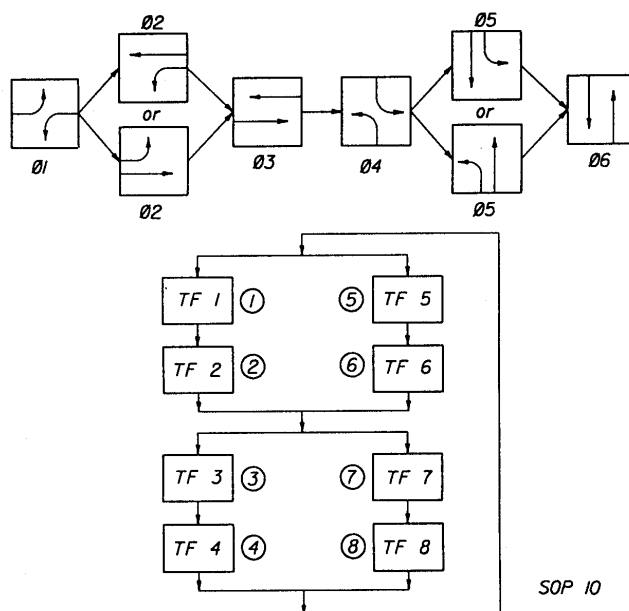


Figure 4-2. Example of a Standard Operating Plan (SOP) for Signal Phasing (Index 17870).

4.9 SELECTION OF THE PHASING PLAN

The phasing plan selection should be based on the standard eight-phase dual ring control scheme prescribed in Index 17870, as shown in Figure 4-2. The concepts of *single-ring sequential* and *dual-ring concurrent* phasing representation were discussed previously in Chapter 2. In the following discussion, it is assumed that the reader is familiar with these concepts.

By NEMA convention, timing functions (TF) 1 through 4 constitute Ring 1 and TF5 through 8 constitute Ring 2. A functional barrier exists between TF 2/6 and TF 3/7. The control in both rings must cross the barrier at the same time to avoid displaying a green indication to two conflicting movements.

Engineering judgment should be used to determine the proper phasing and timing for a traffic control signal.
{MUTCD}

4.10 ASSIGNMENT OF MOVEMENTS TO TIMING FUNCTIONS

The complete specification of the phasing plan requires that each of the traffic movements to be accommodated be assigned to one of the eight timing functions to produce the desired sequence of displays. The choice of left turn treatments discussed previously will determine which timing functions will be activated and which will be omitted from the phasing plan. One-way streets and “T” intersections can also cause certain movements and timing functions to be omitted. When the set of active phases has been determined, it is necessary to assign each of the traffic movements to a specific timing function.

4.10.1 NEMA Conventions

The NEMA conventions offer some latitude in the assignment of movements to timing functions. The following guidelines are offered for traffic movement assignment:

- *Protected Left Turns:* It is common to assign the left turn movements to odd numbered timing functions because the left turns generally precede the through movements (even numbered timing functions) on any given approach.
- *Arterial Movements:* It is common to assign the arterial movements to the left side of the barrier (TF 1, 2, 5 and 6). Using this convention, TF 2 and 6 will be coordinated by the master controller and the remainder of the timing functions will be controlled by detectors.
- *Ring Assignments:* On both sides of the barrier, either left turn can be assigned to Ring 1, with the opposing left turn assigned to Ring 2. This choice will determine the assignment of the through movements to the other timing functions. This choice is more or less arbitrary. Many agencies have adopted the convention used by PASSER II, a signal timing design program to be described later. This convention depends on the choice of arterial orientation. The PASSER movement numbering convention is presented in Figure 4-3. The use of this convention will facilitate the transfer of timing parameters from the timing design program to the field hardware.

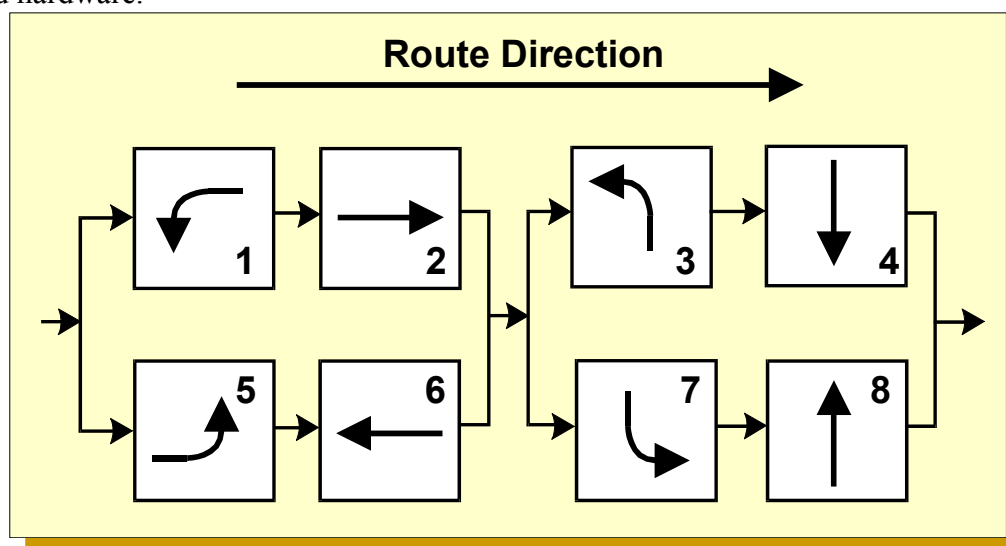


Figure 4-3. PASSER II Movement Assignment Conventions.

- **Permitted Left Turns:** When left turns are permitted, no green arrow is displayed and therefore the movement is not assigned to a timing function. The left turning traffic is accommodated on the solid green displayed by the timing function for through traffic. When two opposing left turns are omitted, it is possible to combine the through movements to be controlled by a single timing function, because both movements are displayed at exactly the same time. While this practice may simplify the field equipment configuration, it could degrade the performance of the intersection. Each through movement should therefore be assigned to its own timing function, even in the absence of protected left turns.
- **Lagging Left Turns:** Lagging left turns follow the through movement in any phase pair. There are two ways to implement lagging left turns.
 - The left turn may be assigned to the even numbered timing function with the through movement assigned to the odd number. The assignment is accomplished by the controller cabinet wiring.
 - Most controllers provide a “phase reverse” feature that is not strictly a NEMA standard. When activated, this feature instructs the controller to display the timing functions in reverse order.

It is common practice to use the latter alternative to preserve the numbering convention of Index 17870 on controllers that offer this alternative.

4.10.2 Identifying the Standard Signal Operating Plan

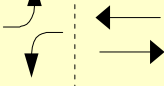
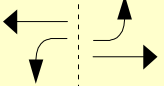
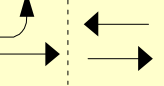
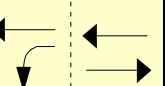
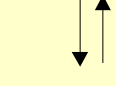
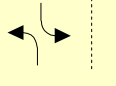
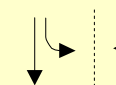
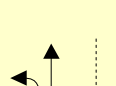
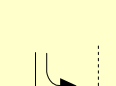
The standard operating plan (SOP) is normally used in place of the phasing diagram in the preparation of signalization plans for FDOT projects. The SOP is characterized by the choice of phase plans for the north-south and east-west movements, respectively. Table 4-2 shows a matrix of the SOP numbers that have been assigned in Index 17870 to the various movement combinations. For example, SOP 5 is characterized by leading-protected left turns in one direction and split-phase operation in the other direction.

If the phasing plan conforms to an SOP shown in Index 17870, then the index reference may be used in place of the phasing diagram.

Note also that this index presents SOP's for one-way streets and T intersections (SOP 12 and 13) that are not represented on Table 4-2. SOP's have also been developed for diamond interchanges (SOP 14, 15, 18, 19 and 20) and mid-block pedestrian signals (SOP 17). In addition, three preemption operating plans (POP's) are presented for application at railroad grade crossings.

In some cases no SOP number has been assigned, as indicated by blank cells in Table 4-2. Phasing diagrams must therefore be drawn on the signalization plans for these cases. There are, in addition, a few specific situations where the phasing is too complex to represent by a standard operating plan. Examples include:

Table 4-2. Standard Operating Plan Numbers Assigned to Various Combinations of Movements in the Phase Plan.

						Full Dual Ring
	1	2	3	11	11	7
	2	4	6			8
	3	6	5			9
	11			16	16	
	11			16	16	
Full Dual Ring	7	8	9			10

- **Exclusive Pedestrian Phases:** Where pedestrians receive an exclusive phase free of all vehicle movements, special phasing must be used. If all of the left turns have protected phases, a special controller with more than eight phases is required. If neither left turn in any opposing pair is protected (SOP 1,2,3 7 or 11), then there will be a timing function available for assignment to an exclusive pedestrian phase.
- **Protected Pedestrian Phases:** These will not usually affect the assignment of through movements and left turns, but they could influence the assignment of right turns. Right turns are normally accommodated by the same solid green display that controls the through movement. When right turns can be given adequate capacity by displaying a green right turn arrow concurrently with the shadowing left turn phase (e.g., northbound right and westbound left), a protected pedestrian phase may be created by prohibiting right turns on the through traffic phase.

4.11 DEVELOPMENT OF THE TIMING PLAN(S)

The development of signal timing plans is a process that depends heavily on reliable data and appropriate software combined with the professional experience of the designer. A recent ruling from the Board of Professional Engineers requires the signature and seal of a professional engineer on all signal timing plans. While the process involves many quantitative computations, it also requires a creative approach to the identification of feasible alternatives. A substantial body of knowledge beyond the scope of this document must be called upon. The process can only be summarized here. A general knowledge of the operating principles and characteristics of a traffic-actuated controller is assumed in this discussion.

All traffic signal designs prepared for or by the Department shall include initial timings of all controllers.

{PPM}

Since traffic flows and patterns change, phasing and timing should be re-evaluated regularly and updated if needed.

{MUTCD}

4.11.1 Information Requirements

Several signal control choices or decisions that precede the detailed timing plan development have already been discussed, including:

- Left turn treatments,
- Right turn treatments,
- Phasing plan, including the assignment of movements to timing functions,
- Phasing plan selection and
- Assignment of movements to timing functions.

Other site specific information that will influence the timing plan computations includes:

- Hourly vehicular and pedestrian demand volumes for all movements;
- Factors that will affect the capacity of each approach, including grades, parking, lane widths, traffic composition, parking, turning proportions and any unusual site characteristics and
- Constraints imposed by the system, especially the cycle length requirements of other intersections.

4.11.2 Minimum Phase Times

One very important determinant of phase times is the minimum duration for which a phase may be displayed. Minimum phase times must be imposed as a constraint on the design when the theoretical optimum phase duration (e.g., that which would minimize vehicular delay) suggests a lower value. All of the practical signal timing design software products to be discussed later recognize minimum phase time constraints.

On bikeways, signal timing shall be reviewed and adjusted to serve the needs of bicyclists.

{MUTCD}

The two principal controls that govern minimum phase times are driver expectancy and pedestrian crossing time requirements. Driver expectancy dictates that a green signal duration should not be so short that the driver reacts improperly (e.g., panic stop or violation of the red), based on his or her experience. Driver expectancy will determine minimum phase durations for phases that do not need to accommodate pedestrians, including:

Where pedestrian movements regularly occur, pedestrians should be provided with sufficient time to cross the roadway by adjusting the operation and timing to provide sufficient crossing time every cycle or by providing pedestrian detectors.

{MUTCD}

- Protected left turn phases;
- All phases at traffic-actuated controllers in which a separate pedestrian timing is generated in response to pedestrian demand and
- Phases controlling approaches on which pedestrian movements have been prohibited.

Commonly accepted values for minimum green display times based on driver expectancy are 8 seconds for protected left turns, 12 seconds for through movements on minor roads and 20 seconds for through movements on major arterial roads. Note that the inter-green interval (yellow change plus all red clearance) must be added to the minimum green times to determine the minimum phase durations.

Pedestrian crossing time requirements will generally dictate the minimum phase times on all phases that must accommodate pedestrians. The pedestrian crossing time requirement is determined as the sum of two components, including the startup time and the crossing time. The crossing time should be determined as L/S_p , where L is the crosswalk length and S_p is the assumed walking speed of pedestrians. The commonly accepted value of S_p is 4.0 ft./sec. This value should be used unless site-specific conditions suggest otherwise. For example, pedestrian walking speed depends on the proportion of elderly pedestrians (65 years of age and older) in the walking population. If a significant number of elderly pedestrians routinely cross at an intersection, a walking speed of 3.3 ft/s is recommended. The pedestrian crossing time will determine the length of the flashing don't walk pedestrian clearance interval for phases that have separate pedestrian control displays.

As suggested by the HCM, the length of the pedestrian startup interval should be determined as:

$3.2 (1 + N_p/12)$ where N_p is the number of pedestrians per cycle, in the heaviest direction for crosswalks up to 12 feet in width and

$3.2 (1 + N_p/W_c)$ where W_c is the crosswalk width, for crosswalks greater than 12 feet in width.

These computations should be subject to a minimum value of 5 seconds if no pedestrian control displays are provided for the phase. If pedestrian control displays are provided, the minimum value should be determined by the minimum length of the WALK interval.

4.11.3 Timing Plan Parameters

There are two levels of timing plan parameters that must be determined. The first is the intersection level. For a traffic-actuated controller, the most important parameters to be determined for each controller timing function to be activated include:

- The unit extension time or size of the detected gap in the traffic that will cause the phase to terminate. The controller assumes that the queue of traffic accumulated on the red phase has been serviced when a gap beyond this threshold is observed. An approximate but rational approach would be to double the average gap that would be expected between vehicles departing from the queue based on the saturation flow rate and the number of lanes.
- The initial interval time that will be displayed before the gap searching process begins: This interval determines the minimum green time for the timing function. It must be long enough to start the queue moving smoothly across the detector and to ensure that the previously established minimum green time is displayed.
- The maximum time that the timing function can retain control (i.e., display a green signal). The maximum green time is an essential override that prevents a movement from retaining control for an unreasonable length of time. This time should never be shorter than the optimal green time determined by the timing design and analysis software for the heaviest peak period. It is common practice to add 10 to 20 percent to the optimal green time to give the controller the flexibility to accommodate variations in traffic demand from cycle to cycle. Traffic-actuated controllers typically provide two maximum interval settings that may be chosen externally, usually based on time of day.
- The intergreen timing parameters (yellow and all-red), determined as indicated in sections 4.11.5 and 4.11.6. The common software products used for timing design and performance evaluation do not determine the intergreen parameters. These computations must be performed externally.

The duration of the yellow change and all-red clearance intervals shall be predetermined.

{MUTCD}
- The WALK and flashing DON'T WALK intervals of pedestrian displays are controlled by the timing function. The minimum length of the flashing DON'T WALK interval should be based on the assumed pedestrian crossing speed. The minimum length of the WALK interval is subject to local preference within constraints imposed by the MUTCD. These two pedestrian intervals override the minimum green time established by the initial interval on cycles that receive pedestrian actuations. On cycles with heavy vehicular traffic, the maximum green time can extend the phase time beyond the pedestrian timing requirement.

The WALK interval should be at least 4 to 7 seconds in length. A pedestrian clearance interval shall always be provided where pedestrian signal indications are used.

{MUTCD}

- The “recall” status of the timing function specifies the action to be taken in the absence of vehicle detection. The options are not to display the green at all, to display it for its minimum or maximum time or to invoke the full timing for the pedestrian control signals. It is common practice at isolated signals to recall only the timing function controlling the heaviest movements to encourage the right-of-way to remain in that position during periods of no demand.

These parameters represent the minimum specification for each timing function at an isolated signal. There are other more advanced parameters beyond the scope of this discussion that may be used to refine the operation.

For intersections that are coordinated with their neighbors, a second set of timing parameters must be specified at the system level. The system parameters include:

- The cycle length, which must be common to all intersections within the system. Arterial cycle lengths typically range from 60 to 150 seconds. The longer cycle lengths are generally applied during the peak periods.
- The timing functions to be designated for coordinated movements. Under normal conditions TF2 and TF6 will be so designated because they handle the through movements on the arterial street. The remainder of the timing functions will operate in a traffic-actuated mode with detector inputs. The coordinated timing functions do not recognize detector inputs. All of the time in any given cycle not used by the actuated movements will revert to the coordinated movements. This has the desirable effect of giving more time to the arterial movements during periods of light cross street traffic.
- Nominal phase times for each movement. These times must be translated into specified times for each timing function such that their sum adds up to the system cycle length. The actual green times for traffic actuated phases may be shorter than the nominal phase times if the traffic demand on any given cycle is not able to sustain the green time for its full duration. The specified times will override the maximum green times on each of the timing functions operating in the traffic-actuated mode.
- An “offset” time that establishes when a specific point in the sequence will occur with respect to a common system reference time. The offset determines the time at which the arterial green is displayed at each intersection relative to its neighbors, thereby controlling the progressive movement of traffic. The offset is applied to different points in the sequence by different vendors.

4.11.4 Signal Timing Software Products

The system level parameters are generally determined using software products that model the operation of traffic to optimize performance in terms of such measures of effectiveness as stops, delay, fuel consumption or progression quality as perceived by the motorist. Several such software products exist and are in common use. Those that are recognized by the Florida DOT include:

- SOAP, which produces design timing and performance analysis for a single signalized intersections.
- SIDRA, which is a popular international program developed in Australia. SIDRA also deals with single intersections, but extends the analysis to cover two-way stop and all-way stop control in addition to roundabouts. SIDRA is recognized as the most complex and credible of all the analytical intersection models.
- SIGNAL 2000, which contains a signal design and analysis model compatible with the HCM analysis procedures. This program is a part of the TEAPAC package which offers additional functionality including the mapping of data into formats recognized by other models.
- The Highway Capacity Software (HCS) that implements the HCM signalized intersection procedures explicitly. The HCS contains modules that analyze both signalized and unsignalized intersections.
- The above products were designed principally for the analysis of individual intersection operations. Another group of products has been developed to deal with arterial and network traffic control systems. This group includes:
 - PASSER III, which extends the analysis of single intersections to include diamond interchanges.
 - PASSER II and IV, which perform timing design and performance analysis on arterial streets and network systems, respectively. Both programs attempt to maximize the quality of driver-perceived progression along a route.
 - TRANSYT-7F, which attempts to optimize the overall performance in terms of a user-specified disutility function that may consider delay, stops, fuel consumption, total operating cost and progression quality.
 - CORSIM, which is a microscopic simulation program that analyzes traffic control networks and freeways. CORSIM produces realistic animated graphics showing the movement of each vehicle as a part of the user interface. CORSIM has no internal optimization capability but, because of its microscopic simulation model, is able to accommodate unusual situations beyond the range of the deterministic models.
 - SYNCRO/SIMTRAFFIC is a privately developed set of software tools that includes the functionality of all of the products mentioned above.
 - ART-PLAN, which is a tool developed by the Florida DOT to perform a planning level analysis of an arterial route. ART-PLAN has no design or optimization capability but its input data requirements are minimal and it provides a useful alternative for determining whether or not a proposed design will provide an acceptable capacity and level of service.

This collection of design and analysis tools defines the methodology for signal timing design and analysis in Florida. It is not intended to preclude the use of other methods, especially those that reach the market in the future.

4.11.5 Yellow Change Interval Requirements

A yellow change interval is always required to terminate a green interval. In general, solid yellow indications follow solid green indications and yellow arrows follow green arrows. Figure 4-4 shows the clearance table presented in Index 17870. This table indicates the requirement for and the nature of the clearance display that must follow each display of a solid green or green arrow.

A steady yellow arrow shall be used to terminate a green arrow indication when the arrow controls a turn in an exclusive lane or when the arrow has been displayed concurrently with a circular green or red indication.

{MUTCD}

The yellow change interval must be long enough to avoid creating a “dilemma zone” which is defined as a condition under which the motorist can neither stop nor proceed through the intersection safely.

A widely used formula for determining the minimum length of yellow change interval to avoid the dilemma zone is:

$$Y = t + \frac{v}{2\alpha}$$

where:

- Y = minimum yellow change interval length
- t_r = reaction time, sec
- v = approach speed
- α = deceleration rate

This formula is widely used and is known as the “ITE Formula.” A yellow change interval shorter than this will create a potential situation in which the driver may not be able to stop before reaching the intersection or enter the intersection before the end of the yellow as required by Florida Statutes.

SIGNAL CLEARANCE TABLE

(Blank Indicates No Clearance Required)

From To		SIGNAL INDICATIONS							
		R		G				WALK	DONT WALK
S I G N A L I N D I C A T I O N S	R			Y			Y		
				Y			Y		
	G								
									
									
	WALK								
	DONT WALK							Flash DONT WALK	

Figure 4-4. Signal Clearance Table from Index 17870.

4.11.6 All-Red Clearance Interval Requirements

The yellow change interval must be followed by an all red clearance interval of sufficient length to allow a vehicle that has entered the intersection at the end of the yellow change interval to clear that intersection before the onset of the green display for any conflicting movements. This interval length may be computed as:

$$AR=(w+l)/v$$

where:

- w = width of intersection to be cleared
- l = length of vehicle
- v = approach speed

A clearance interval shorter than the one computed above could cause vehicles to be trapped within the intersection after the beginning of a green display for conflicting traffic movements.

While the computations for the yellow change and all red clearance intervals are mathematically independent, it is common practice to limit the yellow interval display to 5 seconds and to assign any additional time to the all red interval, ensuring that the sum of the two intervals meets the minimum requirement.

4.11.7 Pedestrian Walk and Clearance Time Requirements

When pedestrian signal heads are used, a Walk signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder. A pedestrian clearance time shall begin immediately following the Walk signal indication. The first portion of the pedestrian clearance time shall consist of a pedestrian change interval. The remaining portions shall consist of the yellow change interval and any red clearance interval. During the transition into preemption, the walk interval and the pedestrian change interval may be shortened or omitted.

At intersections equipped with pedestrian signal heads, the pedestrian signal indications shall be displayed except when the vehicular traffic control signal is being operated in the flashing mode. At those times, the pedestrian signal lenses shall not be illuminated.

The walk interval should be at least 5 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. If it is desired to favor the length of an opposing signal phase and if pedestrian volumes and characteristics do not require a 5-second walk interval, walk intervals as short as 4 seconds may be used.

The pedestrian clearance time should be sufficient to allow a pedestrian who left the curb or shoulder during the Walk signal indication to travel at a normal walking speed of 4 feet per second, to at least the center of the farthest traveled lane 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 lower walking speed should be considered in

determining the pedestrian clearance time, as discussed in section 4.11.2. Passive pedestrian detection equipment, which can detect pedestrians who need more time to complete their crossing and can extend the length of the pedestrian clearance time for that particular cycle, may be used to avoid using a lower walking speed to determine the pedestrian clearance time.

4.11.8 Interconnection Requirements

Signalized intersections may operate in an isolated mode, independent from all other intersections or they may be a part of a traffic control system. In addition, their proximity to other influences such as

Signals within $\frac{1}{2}$ mile on major routes should be coordinated.

{MUTCD}

railroad grade crossings, drawbridges or fire stations might require interconnection for preemption purposes. Isolated intersections will nearly always use standard eight phase dual ring controllers of the type described earlier in this chapter. Interconnected systems tend to have vendor-specific features that could influence the timing design.

Intersection spacing is the most important consideration in the decision to interconnect signals for progressive movement between intersections. It is commonly accepted that signals within $\frac{1}{2}$ mile will always benefit from coordination. On well-designed arterial routes with minimal cross street entry and smooth traffic flow, coherent platoons of vehicles will remain intact for much longer distances.

Signals within 200 ft of a railroad grade crossing should be interconnected for preemption by the railroad crossing protection.

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4.12 DETERMINATION OF THE DETECTOR CONFIGURATION

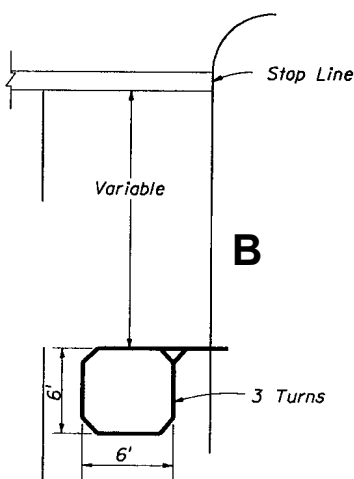
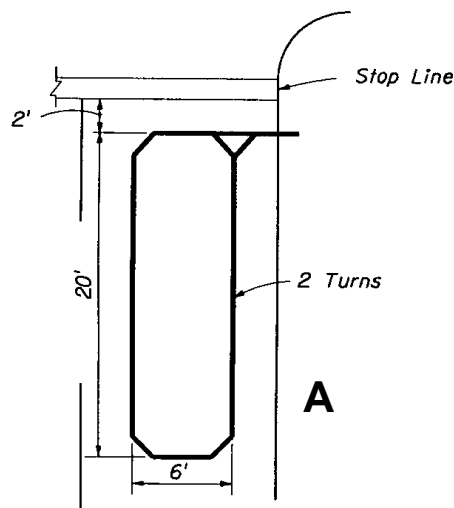
The detectors at a signalized intersection serve the singular purpose of informing the controller that a vehicle is (or is not) present on a particular approach to an intersection at any point in time. The controller uses this information to regulate the assignment of green time among competing movements at the intersection. The detector configuration is specified in terms of type, shape, length and setback from the stop line. These four parameters are all related to the physical installation of the detectors themselves.

Vehicle detectors require FDOT traffic control device certification. There are several types of detectors on the market, each of which exploits a different principle of physics to detect the presence of a vehicle. The inductive loop detector has been the predominant detector type for more than 30 years because it has demonstrated the ability to detect vehicles reliably at a lower cost than competing technologies. The “loop” consists of a few turns of wire embedded in the roadway surface. The metallic presence of a vehicle on the loop is detected electronically by a unit in the controller cabinet.

4.12.1 Loop Detector Types

The size, shape and location of the loop establish the detection area. Index 17781 prescribes seven detector shapes, labeled Type A through Type G. Each shape is suited to a particular purpose and some regional preferences exist for different types. The detector types are summarized as follows:

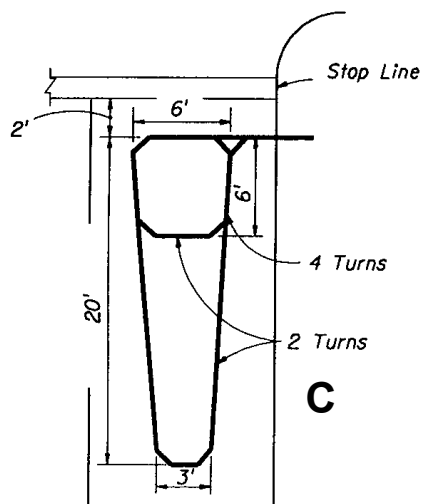
Type A Loops: consist of a simple rectangular shape generally located at or close to the stop line. The standard dimensions are 6 feet by 20 feet. This is the simplest type of loop to install. Its main drawback is that the area of influence tends to extend well beyond its lateral boundaries, creating a “spillover” effect that could cause false detection in adjacent lanes. It is also the least sensitive to bicycles. On the other hand, this shape is most sensitive to high-bodied vehicles such as semi-trailers.

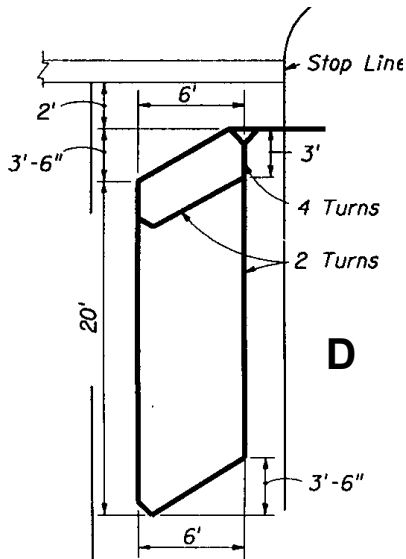


Type B Loops: are very similar to Type A except that they are square and smaller in size. The standard dimensions are 6 feet by 6 feet. They do not generally cover sufficient area to detect all vehicles at the stop line because of the wide range of stopping positions. Type B loops are best suited to counting traffic.

They are used most commonly as system level sensors in arterial control systems. They are also placed some distance from the stop line at isolated rural intersections where speeds are higher and the control strategy is oriented more to minimizing stops than maximizing capacity. A smaller version is also used in bicycle lanes and paths that are under signal control and where the bicycle positions are constrained to be predictable.

Type C Loops: have the same general dimensions as Type A loops, except that they are trapezoidal in shape, instead of rectangular. They also have a supplementary loop consisting of a few turns at the downstream end to form a “booster” which increases sensitivity to bicycles. The trapezoidal shape results in an angular vehicle motion over the loop wires, which increases the sensitivity to bicycles.

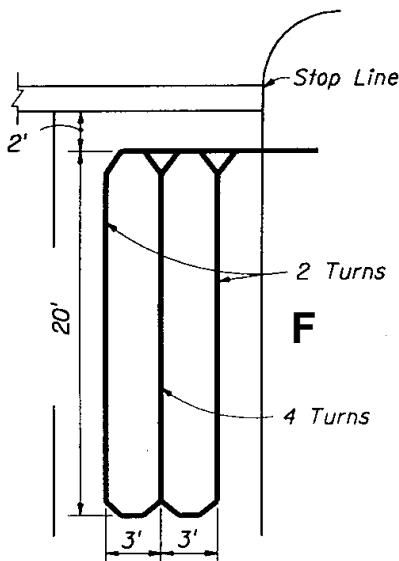
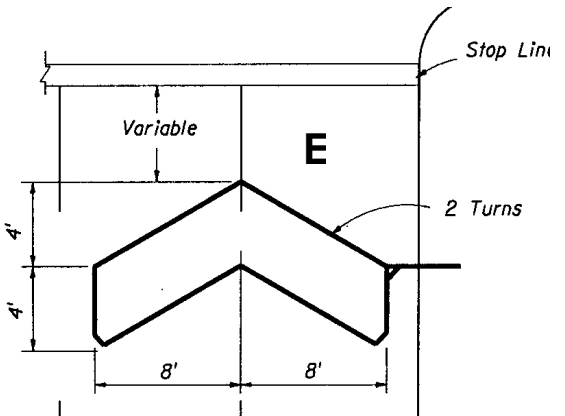




Type D Loops: have the same general dimensions as Type A and Type C loops, in a parallelogram shape. This shape implements the same principle of introducing an angular motion of the vehicle with respect to the loop wires to increase the sensitivity to bicycles and small vehicles.

Type E Loops: have a chevron shape that carries the concept of bicycle detection one step further. In addition to the angular motion, the chevron reduces the longitudinal distance between the loop wires to strengthen the sensitivity at levels closer to the pavement. This is not a good choice for detecting high-bodied trucks or vehicles that could stop in a

wide range of positions at the stop line. It does, however, offer the ability to detect most moving bicycles anywhere within its boundaries. It is therefore a feasible alternative for application on wide multi user trails and at locations where the main objective is an accurate bicycle count.



Type F Loops: have gained a widespread acceptance for their sensitivity to bicycles and their minimal spillover into adjacent lanes. This “quadrupole” shape features three longitudinal sets of wires wound in a “figure 8” so that the center set of wires has twice as many conductors as the outside sets and carries current in the opposite direction with respect to traffic flow. The effect of this shape is to concentrate the sensitivity within the loop boundaries and to increase the sensitivity close to the ground. This compact zone of influence facilitates bicycle detection and prevents false detection in adjacent lanes. It also reduces the sensitivity to high-bodied trucks.

Index 17781 also defines a *Type G Loop*, not shown here, which consists of a series of Type B (square) loops placed sequentially in the lane. A maximum of four loops may be used. This configuration provides a long detection zone without excessive spillover and places less strain on the loop conductors resulting from thermal expansion and contraction. It requires more effort to install and has lower sensitivity to bicycles than the quadrupole loop, but it has greater sensitivity to high-bodied trucks.

The maximum overall length of loop types A, C, D, and F is 60 feet, and their leading edge may extend up to 10 feet past the stop line.

{Index 17870}

Some variation in the loop configuration details presented above is allowed on Index 17781 as shown in the box at the right.

4.12.2 Detector Location Guidelines

The following design guidelines are offered with respect to detector placement:

- Vehicle detectors must be located where vehicles stop for the red signal otherwise demand for service will not be recognized.
- Loops should be designed for installation before application of the final surface course where asphalt is being placed.
- Loops are not necessary on main street dedicated, channelized right turn lanes.
- Loops should not generally extend beyond the stop bar unless the intersection layout is such that vehicles have the space to store beyond the stop bar.
- Advance loops on the major street approaches generally produce the greatest benefits at the first signal in a coordinated system. As a matter of judgement, they may be installed on any major street approach on which the speed limit is greater than 35 mph.
- Major street stop bar loops are not required in applications where advance loops are utilized unless driveways exist between the advanced loop and the stop bar. The minimum green interval should be set to service any queue that may build in the area between the stop bar and the first set of advance loops.
- It should be determined if any system sensor loops are present or necessary at the intersection and if the construction activity will affect them. Project limits should be expanded to include any such loops and provisions for their replacement should be made as applicable.
- Delay detectors should generally be used for side street right turn movements and for all permitted left turn movements. Delay for permitted left turn loops is especially important when the intersection layout is such that left turning vehicles from other approaches may impinge on a specific left turn lane by “corner cutting.”
- Vehicle detection on the major street (i.e., coordinated phase) is not recognized when the intersection is operating as a part of a coordinated system. Detectors should, however, be installed on all approaches to provide for periods of uncoordinated operation.

4.12.3 Other Detection Technology

Detectors based on other technologies have demonstrated their ability to perform acceptably, but generally at a higher cost. A variety of “above ground” devices based on infrared, microwave and ultrasonic transducers is readily available. The choice of these devices for design purposes

is normally limited to situations that preclude the installation of a loop in the roadway (e.g., unpaved roads, bridge decks, etc.). An emerging problem for inductive loop technology is the detection of “space age” bicycles with little or no metallic content.

Video image detection (VID) offers an alternative vehicle detection technology for intersections. One video camera can cover several lanes of traffic and studies have shown that the detection accuracy is comparable to loops. As the cost of this technology falls, VID may capture an increasing share of the detection market in the future.

4.12.4 Pedestrian Detectors

Pedestrian detection is accomplished by manual push buttons that connect directly to the controller timing function that controls the pedestrian signal display. When pedestrian control signals are provided, the activation of a pedestrian detector will invoke the WALK – DON’T WALK sequence to override the minimum green time for the vehicular display and to guarantee that the specified minimum crossing time for pedestrians is displayed. At locations without pedestrian signals, the pedestrian

- Pedestrian detector mounting height should be approx. 3.5 feet
- Explanatory signs required
- Applicable crosswalk should be clearly indicated
- Confirmation signal (e.g., pilot light) may be provided.

{MUTCD}



Figure 4-5. Typical Pedestrian Push-Button Detectors.

detector is connected to the controller in the same manner as the vehicle detector to ensure that a pedestrian will receive a green indication in the absence of vehicular demand. Phase recall should not be used as an alternative to providing pedestrian detection. When pedestrian signals are not installed, it is essential that the minimum green times for the vehicular movements satisfy the minimum time for pedestrian crossing discussed previously in this chapter.

Pedestrian push buttons should be located where they are conspicuous and convenient for both pedestrians and cyclists. Index 17784 sets forth the requirements for the installation of pedestrian detector assemblies, including the push button detectors and advisory signs. The advisory sign requirements are discussed in Chapter 5.

If two crosswalks, oriented in different directions, end at or near the same location, the positioning of pedestrian detectors and/or the legends on the pedestrian detector signs should clearly indicate which crosswalk signal is actuated by each pedestrian detector.

If the pedestrian clearance time is sufficient only to cross from the curb or shoulder to a median of sufficient width for pedestrians to wait and the signals are pedestrian actuated, an additional

pedestrian detector shall be provided in the median. The use of additional pedestrian detectors on islands or medians where a pedestrian might become stranded should be considered.

If used, a pilot light or other means of indication installed with a pedestrian pushbutton shall not be illuminated until actuation. Once it is actuated, it shall remain illuminated until the pedestrian's green or WALKING PERSON (symbolizing WALK) signal indication is displayed.

4.12.5 Accessible Pedestrian Signal Detectors

An accessible pedestrian signal detector is a device designated to assist the pedestrian who has visual or physical disabilities in activating the pedestrian phase. Accessible pedestrian signal detectors may be pushbuttons or passive detection devices. Pushbutton locator tones may be used with accessible pedestrian signals.

At accessible pedestrian signal locations with pedestrian actuation, each pushbutton shall activate both the walk interval and the accessible pedestrian signals. 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. This enables pedestrians who have visual disabilities to distinguish and locate the appropriate pushbutton.

Pushbuttons for accessible pedestrian signals should be located:

- 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 and
- Parallel to the crosswalk to be used.

When used, pushbutton locator tones shall be easily locatable, shall have a duration of 0.15 seconds or less and shall repeat at 1-second intervals. Pushbutton locator tones should be deactivated during flashing operation of the traffic control signal.

4.13 LOCATION AND CONFIGURATION OF THE CONTROLLER AND CABINET

The following design guidelines are offered with respect to the controller and cabinet:

- When a new controller cabinet is specified, it should be located strategically in a protected area with reasonable set back from travel lanes. Controller cabinets should be located as far as is practical from the edge of the roadway.
- The cabinet should be oriented such that the door faces away from the traveled roadway to provide maximum protection for service personnel.

- Two spare conduits to nearest pull box should be provided for future use.
- The Standard Specifications for Road and Bridge Construction require that 40 feet of ground rod be installed for all controllers and that the grounding assembly for the controller must be kept at a distance greater than 6 feet from any other grounding assembly.

4.14 LOCATION AND CONFIGURATION OF SIGNAL DISPLAYS

The display design must conform to the requirements of the MUTCD. Local practices will frequently dictate the choice of the options in cases where the MUTCD provides flexibility. The MUTCD requirements are reflected in the *Florida Design Standards*.

4.14.1 Vehicular Signal Displays

The primary design decisions with respect to vehicular signal displays include:

- Horizontal or vertical mounting,
- Size of lenses (8 or 12 inches),
- Indication for each lens (solid or arrow) and
- Position of each signal head.

The MUTCD requirements are summarized as follows:

- A minimum of two signal faces shall be provided for the major movement on the approach, even if the major movement is a turning movement. Except where the width of an intersecting roadway or other conditions make it physically impractical, at least one and preferably both of the signal faces shall be located to conform to the positioning requirements shown in Figure 4-7. Three aspects of positioning are illustrated on this figure:
 - A diagram shows the minimum horizontal position with respect to the center of the approach at the stop line;
 - A table shows the minimum sight distance as a function of the approach speed and
 - A graph shows the minimum mounting height to the top of the signal head as a function of the distance from the stop line. Note that previous editions of the MUTCD specified the minimum mounting height to the bottom of the signal head.
- Twelve-inch signal lenses are normally installed at signalized intersection on the State Highway System. The MUTCD requires that they **shall** be used:
 - Where road users view both traffic control and lane-use control signal heads simultaneously;
 - If the nearest signal face is between 120 feet and 150 feet beyond the stop line, unless a supplemental near-side signal face is provided;
 - For all signal faces located more than 150 feet from the stop line;
 - For approaches to all signalized locations for which the minimum sight distance in Figure 4-7 cannot be met;
 - For arrow signal indications and In a circular red indication when 12 inch lenses have been used for green or yellow indications in the same signal face.

- In a circular red indication when 12 inch lenses have been used for green or yellow indications in the same signal face.

Twelve-inch signal lenses **should** be used:

- On approaches with 85th-percentile speeds exceeding 40 mph;
- On approaches where a traffic control signal might be unexpected;
- On approaches without curbs and gutters where only post-mounted signal heads are used and
- At locations where there is a significant percentage of elderly drivers.

Each vehicular signal face shall have three, four or five signal sections. Single-section signal faces are only permitted for continuously illuminated GREEN ARROW indications. The proper relative positions of signal lenses within the signal face are shown in Figure 4-6.

If the minimum sight distance in Figure 4-7 cannot be met, a sign shall be installed to warn approaching traffic of the traffic control signal.

Required signal faces for through traffic on any one approach shall be located not less than 8 feet apart measured horizontally perpendicular to the approach between the centers of the signal faces.

“Protected only” left turn displays may be either red arrow lenses or solid red lenses with “Left Turn Signal” signs. There is no consistent statewide practice with respect to this choice. The increased target value of the solid red lens is generally recognized as an advantage that must be weighed against the increased sign clutter and wind loading. Red arrows should be used at all locations that require another sign (e.g., U Turn prohibition) in substantially the same position.

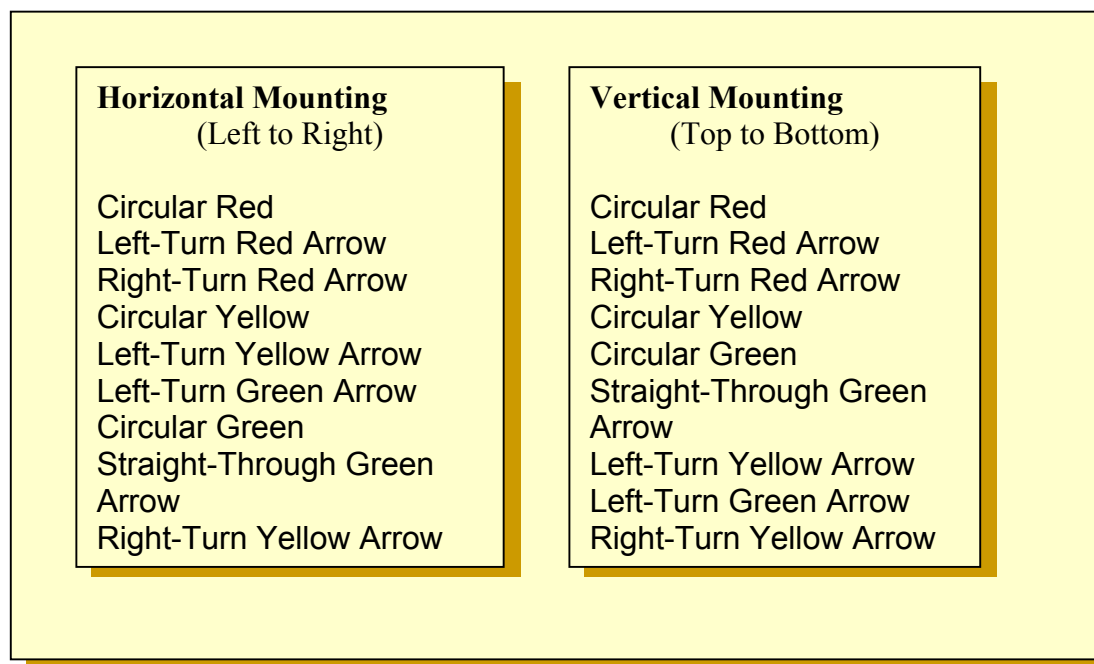
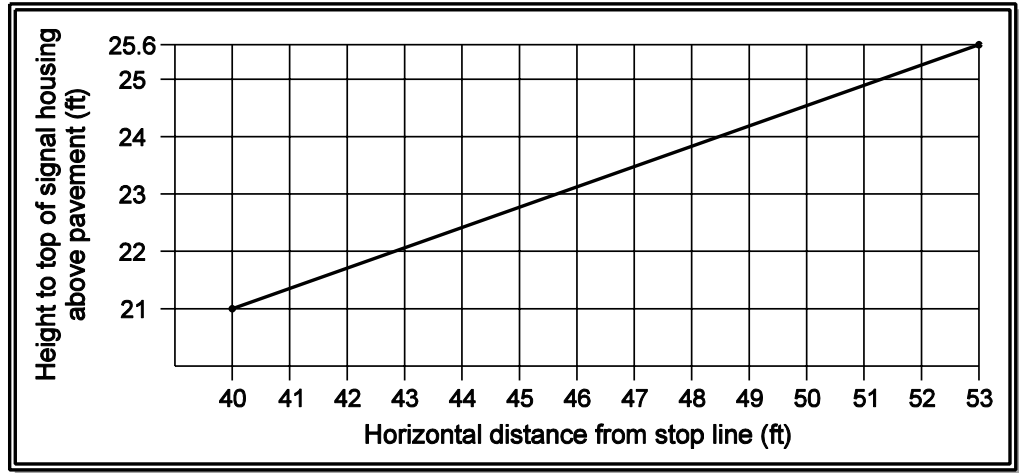


Figure 4-6. Order of Signal Lenses in Horizontally and Vertically Mounted Heads.



Location of signal heads within these areas:

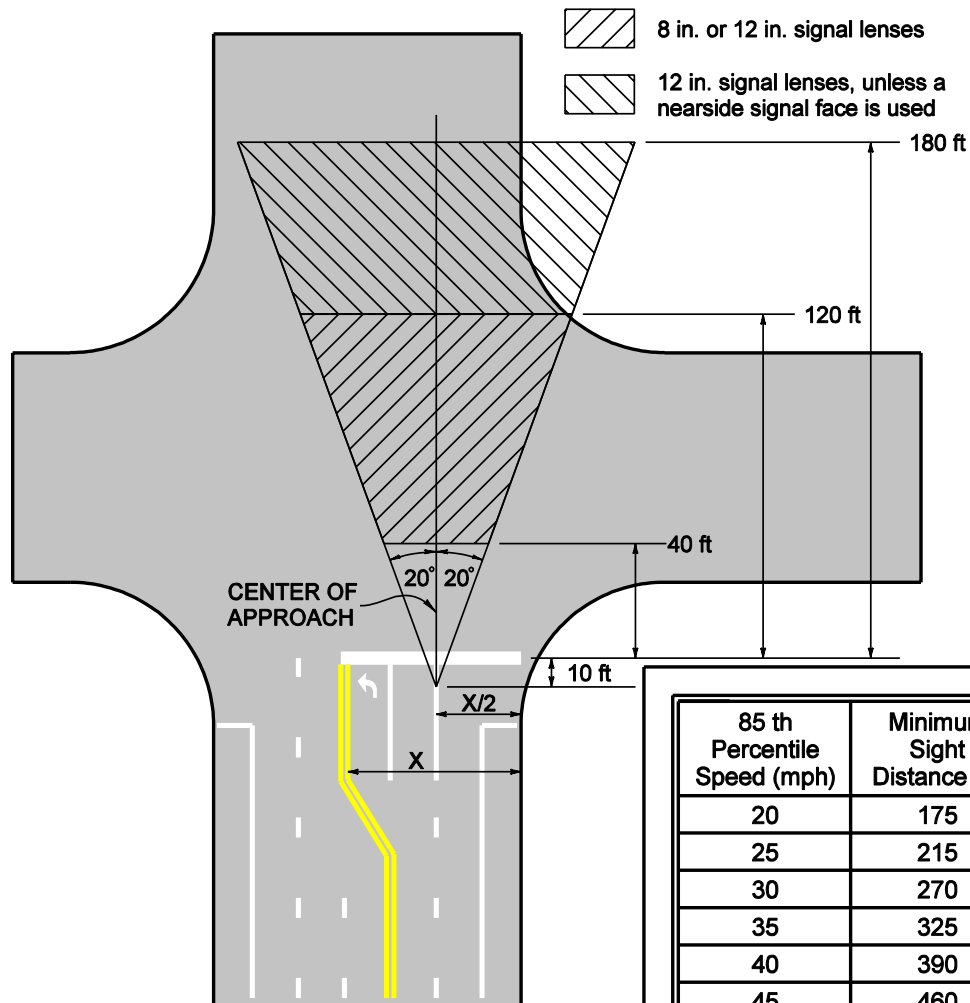


Figure 4-7. MUTCD Requirements for Location, Maximum Mounting Height and Minimum Sight Distance of Signal Displays.

85 th Percentile Speed (mph)	Minimum Sight Distance (ft)
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

4.14.2 Supplemental Signal Faces

Supplemental signal faces should be used if engineering judgment has shown that they are needed to achieve intersection visibility both in advance and immediately before the signalized location. If used, they should be located to provide optimum visibility for the movement to be controlled. If supplemental signal faces are used, left-turn arrows shall not be used in near-right signal faces and right-turn arrows shall not be used in far-left signal faces.

Visibility-limited signal faces shall be adjusted so bicyclists for whom the indications are intended can see them. If the signal faces cannot be aimed to serve the bicyclist, then separate signal faces shall be provided for the bicyclist.

{MUTCD}

Nearside signal faces should be located as near as practical to the stop line. If a signal face controls a specific lane or lanes of approach, its position should make it readily visible to road users making that movement.

4.14.3 Visibility, Shielding and Positioning of Signal Faces

Signal visors should be used on signal faces to aid in directing the signal indication specifically to approaching traffic, as well as to reduce "sun phantom," which can result when external light enters the lens. The use of signal louvers for this purpose is discouraged because of the reduction in light output caused by signal louvers.

The primary consideration in signal face placement, aiming and adjustment is to optimize the visibility of signal indications to approaching traffic

{MUTCD}

A signal backplate for target value enhancement should be used on signal faces viewed against a bright sky or bright or confusing backgrounds. The use of backplates enhances the contrast between the traffic signals and their surroundings for both day and night conditions, which is also helpful to elderly drivers.

In cases where irregular street design imposes a comparatively small angle between the orientations of signal lenses, each signal lens should, to the extent practical, be shielded or directed by signal visors, signal louvers or other means. Signal visors exceeding 12 inches in length shall not be used on free-swinging signal heads. Pedestrian movements crossing all approaches with shielded vehicular signals should be controlled by separate pedestrian signals.

If a signal is operated in the flashing mode for nighttime operation and the signal indication is so bright as to cause excessive glare, some form of automatic dimming should be used to reduce the brilliance of the signal indication.

The inside of signal visors (hoods), the entire surface of louvers and fins and the front surface of backplates shall have a dull black finish to minimize light reflection and to increase contrast between the signal indication and its background. To obtain the best possible contrast with the visual background, signal housings should be highway yellow.

4.14.4 Pedestrian Signal Heads

Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of a WALKING PERSON (symbolizing WALK) and an UPRAISED HAND (symbolizing DONT WALK).

Pedestrian signal heads **shall** be used in conjunction with vehicular traffic control:

- If a traffic control signal is justified on the basis of pedestrian volume or a school crossing;
- If an exclusive pedestrian phase is provided;
- At an established school crossing at any signalized location and
- When multi-phase signal indications would tend to confuse pedestrians guided only by vehicular signal indications.



Pedestrian signal heads **should** be used:

- If it is necessary to assist pedestrians in making a safe crossing or if engineering judgment determines that pedestrian signal heads are justified to minimize vehicle-pedestrian conflicts;
- If pedestrians are permitted to cross a portion of a street, such as to or from a median of sufficient width for pedestrians to wait, during a particular interval but are not permitted to cross the remainder of the street during any part of the same interval or
- If no vehicular signal indications are visible to pedestrians or if the vehicular signal indications that are visible to pedestrians starting or continuing a crossing provide insufficient guidance for them to decide when it is safe to cross, such as on one-way streets, at T-intersections or at multi-phase signal operations.

Pedestrian signal indications should be conspicuous and recognizable to pedestrians at all distances from the beginning of the controlled crosswalk to a point 10 feet from the end of the controlled crosswalk during both day and night.

Pedestrian signal heads shall be mounted with the bottom of the signal housing including brackets not less than 7 feet nor more than 10 feet above sidewalk level and shall be positioned and adjusted to provide maximum visibility at the beginning of the controlled crosswalk. If pedestrian signal heads are mounted on the same support as vehicular signal heads, there shall be a physical separation between them. Pedestrian signals should be designed for installation on the appropriate side of the support pole that provides for maximum protection against errant turning truck traffic.

4.14.5 Accessible Pedestrian Signals

The primary technique that pedestrians who have visual disabilities use to cross streets at signalized intersections is to initiate their 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 technique is effective at the vast majority of signalized intersections. The existing environment is often sufficient to provide the information that pedestrians who have visual disabilities need to operate safely at a signalized intersection. Therefore, the vast majority of signalized intersections will not require any accessible pedestrian signals.

Safety considerations should include the installation, where appropriate, of accessible pedestrian signals that provide information in non-visual format (such as audible tones, verbal messages, and/or vibrating surfaces).
{MUTCD}

If a particular signalized intersection presents difficulties for pedestrians who have visual disabilities to cross safely and effectively, the underlying safety and effectiveness concerns for all pedestrians should first be addressed before considering any access issues for pedestrians who have visual disabilities. Once a particular signalized intersection is reviewed for pedestrian safety in general, then an examination should ensue that considers whether accessible pedestrian signals are necessary to provide information that is not readily apparent in the existing environment.

When used, accessible pedestrian signals shall:

- Be used in combination with pedestrian signal timing.
- Clearly indicate which pedestrian crossing is served by each device.
- Not be limited in operation by the time of day or day of week.

{MUTCD}

The factors that might make crossing at an intersection difficult for pedestrians who have visual disabilities include: increasingly quiet cars, right turn on red (which masks the beginning of the through phase), continuous right-turn movements, complex signal operations, traffic circles and wide streets. Further, low traffic volumes might make it difficult for pedestrians who have visual disabilities to discern signal phase changes.

Local organizations, providing support services to pedestrians who have visual and/or hearing disabilities, can often act as important advisors to the traffic engineer when consideration is being given to the installation of devices to assist such pedestrians. Additionally, orientation and mobility specialists or similar professionals also might be able to provide a wide range of advice.

Advice from organizations who represent pedestrians who have disabilities should be given deference because such organizations are the representative voice of the affected individuals. Agreement among such organizations should be widespread to determine that there is a community demand for the installation of accessible pedestrian signals.

The installation of accessible pedestrian signals at signalized intersections should be based on an engineering study, which 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 turn-on-red volumes;
- The complexity of traffic signal phasing;
- The complexity of intersection geometry and
- Technology that provides different sounds for each non-concurrent signal phase has frequently been found to provide ambiguous information.

The MUTCD describes and sets forth requirements for three types of accessible pedestrian signals:

Audible Tone Signals

When accessible pedestrian signals have an audible tone(s), they shall have a tone for the walk interval. The audible tone(s) shall be audible from the beginning of the associated crosswalk. If the tone for the walk interval is similar to the pushbutton locator tone, the walk interval tone shall have a faster repetition rate than the associated pushbutton locator tone.

When choosing audible tones, possible extraneous sources of sounds (such as wind, rain, vehicle back-up warnings or birds) shall be considered in order to eliminate potential confusion to pedestrians who have visual disabilities. Audible pedestrian tones should be carefully selected to avoid misleading pedestrians who have visual disabilities when the following conditions exist:

- Where there is an island that allows unsignalized right turns across a crosswalk between the island and the sidewalk;
- Where multi-leg approaches or complex signal phasing require more than two pedestrian phases, such that it might be unclear which crosswalk is served by each audible tone or
- At intersections where a diagonal pedestrian crossing is allowed or where one street receives a WALKING PERSON (symbolizing WALK) signal indication simultaneously with another street.

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. The accessible walk signal tone should be no louder than the locator tone, except when there is optional activation to provide a louder signal tone for a single pedestrian phase.

Verbal Message Signals

When verbal messages are used to communicate the pedestrian interval, they shall provide a clear message that the walk interval is in effect, as well as to which crossing it applies. The verbal message that is provided at regular intervals throughout the timing of the walk interval shall be the term "walk sign," which may be followed by the name of the street to be crossed. A verbal message is not required at times when the walk interval is not timing, but, if provided:

- It shall be the term “wait,” and
- It need not be repeated for the entire time that the walk interval is not timing.

Vibrotactile Signals

A vibrotactile pedestrian device communicates information about pedestrian timing through a vibrating surface by touch. Where used, it shall 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. Vibrotactile pedestrian devices should be located next to and on the same pole as the pedestrian pushbutton, if any, and adjacent to the intended crosswalk.

4.14.6 Intersection Control Beacons

Intersection Control Beacons consist of one or more signal faces directed toward each approach to an intersection. Each signal face consists of one or more signal sections of a standard traffic signal face, with flashing circular yellow or circular red signal indications in each signal face. They shall be used only at an intersection to control two or more directions of travel.

Application of Intersection Control Beacon signal indications shall be limited to:

- Yellow on one route (normally the major street) and red for the remaining approaches;
- Red for all approaches (if the warrant for a multi-way stop is satisfied) and
- Flashing yellow signal indications shall not face conflicting vehicular approaches.

A STOP sign shall be used on approaches to which a flashing red signal indication is shown on an Intersection Control Beacon.

An Intersection Control Beacon should not be mounted on a pedestal in the roadway unless the pedestal is within the confines of a traffic or pedestrian island.

Intersection control beacons are exempt from the Florida DOT requirement that all signals within ten miles of the coastline be installed on mast arms.

4.14.7 In-Roadway Lights

In-Roadway Lights are special types of highway traffic signals installed in the roadway surface to warn road users that they are approaching a condition on or adjacent to the roadway that might not be readily apparent and might require the road users to slow down and/or come to a stop. This includes, but is not necessarily limited to, situations warning of marked school crosswalks, marked mid-block crosswalks, marked crosswalks on uncontrolled approaches and other roadway situations involving pedestrian crossings. A typical in-roadway warning signal is shown in Figure 4-8.

In-Roadway Warning Lights shall not be used at crosswalks controlled by YIELD signs, STOP signs, or traffic control signals.

{MUTCD}

In-Roadway Warning Lights at crosswalks shall:

- Be installed along both sides of the crosswalk and shall span its entire length;
- Initiate operation based on pedestrian actuation and shall cease operation at a predetermined time after the pedestrian actuation or, with passive detection, after the pedestrian clears the crosswalk;
- Display a flashing yellow signal indication when actuated. The flash rate shall be at least 50, but not more than 60, flash periods per minute. The flash rate shall not be between 5 and 30 flashes per second to avoid frequencies that might cause seizures;
- Have a minimum of two lights on one-lane, one-way roadways installed on the approach side of the crosswalk;
- Have a minimum of three lights on two-lane roadways, installed along both sides of the crosswalk;
- Have a minimum of one light per on roadways with more than two lanes, installed along both sides of the crosswalk;
- Be installed in the area between the outside edge of the crosswalk line and 10 feet from the outside edge of the crosswalk;
- Face away from the crosswalk if uni-directional and away from and across the crosswalk if bi-directional and
- Not exceed a height of 0.75 inches above the roadway surface.

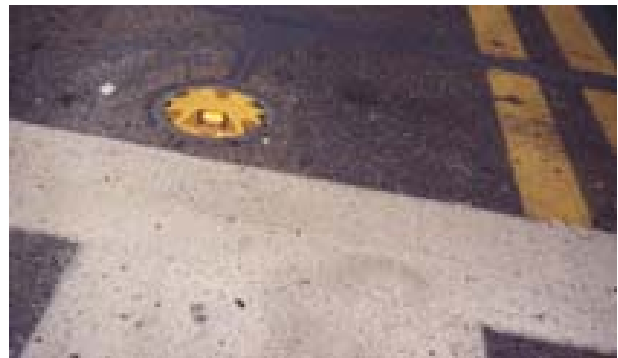


Figure 4-8. Typical In-Roadway Warning Light.

The period of operation of following each actuation should be sufficient to allow a pedestrian crossing in the crosswalk to leave the curb or shoulder and travel at a normal 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 wheel chairs, routinely use the crosswalk, a lower walking speed should be considered in determining the period of operation.

Where the period of operation is sufficient only for crossing from a curb or shoulder to a median of sufficient width for pedestrians to wait, additional measures should be considered, such as median-mounted pedestrian actuators.

In-Roadway Warning Lights should be installed in the center of each travel lane, at the centerline of the roadway, at each edge of the roadway or parking lanes or at other suitable locations away from the normal tire track paths.

In-Roadway Warning Lights at crosswalks may use pedestrian detectors to determine the duration of the operation instead of ceasing operation after a predetermined time. On one-way streets, In-Roadway Warning Lights may be omitted on the departure side of the crosswalk. Based on engineering judgment, the In-Roadway Warning Lights on the departure side of the crosswalk on the left side of a median may be omitted.

Uni-directional In-Roadway Warning Lights installed at crosswalk locations may have an optional, additional yellow light indication in each unit that is visible to pedestrians in the crosswalk. These lights may flash with and at the same flash rate as the light module in which each is installed. The purpose of these optional additional lights is to indicate to pedestrians in the crosswalk that the In-Roadway Warning Lights are in fact flashing as they cross the street.

Pending the development of guidelines for deployment of in-roadway lights by the FDOT Traffic Engineering Office and their subsequent publication in the Traffic Engineering Manual, the State Traffic Operations Engineer must approve the usage of these devices on a case-by-case basis.

4.14.8 Stop Signs at Signalized Intersections

The MUTCD prescribes that STOP signs shall not be used in conjunction with any traffic control 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 control signal, but does not require separate traffic signal control because an extremely low potential for conflict exists.

4.15 EQUIPMENT REQUIRED TO SUPPORT THE SIGNAL DISPLAYS

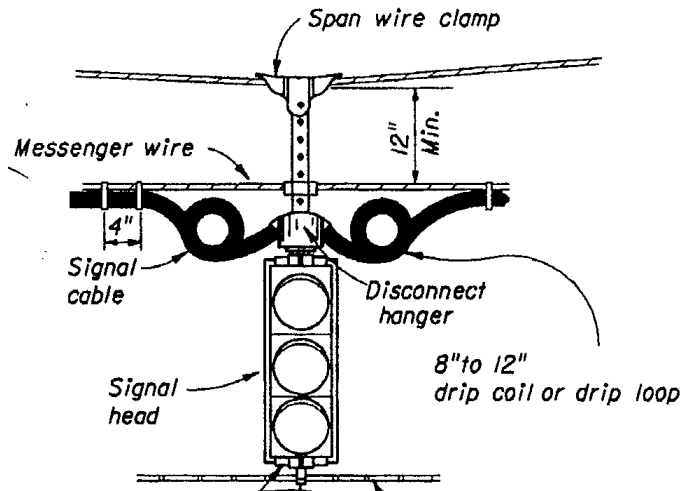
Signal displays may be mounted either on mast arms or span wires. It is a requirement in Florida that all signal displays within 10 miles of the coastline be mounted on mast arms because of the susceptibility of span wire mounting to high winds. Flashing beacon displays are exempt from this requirement. Typical horizontal (mast arm) and vertical (span-wire) installations are shown in Figure 4-9.



Figure 4-9. Typical Horizontal and Vertical Signal Installations.

The following provisions in the *Florida Design Standards* apply to the supporting equipment and structures for signal displays:

- *Index 17723 and 17725* set forth the FDOT design and installation requirements for concrete and steel poles, respectively.



- *Index 17727 Signal cable and span wire installation details* specify installation, suspension and grounding methods for signals on span-wires. A typical example of a span wire mounted signal is shown in Figure 4-10.

- *Index 17733 Aerial interconnect* specifies cable drop and termination details for overhead interconnect.

Figure 4-10. Typical Span-Mounted Signal Head as Shown in Index 17727.

- *Index 17736 Electric power service* specifies equipment, dimensions, conduit and grounding requirements for connection of the controller box to the power source.
- *Index 17740, 17742 and 17744* provide instructions, examples, component data and installation requirements for mast arms.
- *Index 17746* provides design details, elevation details, camber details and other instructions and notes concerning monotube steel structures.
- *Index 17764 Pedestrian control signal installation details* specifies pole types, anchors, conduit installation and grounding methods for pole-mounted installation
- *Index 17781 Vehicle loop installation details* deals primarily with lead-in connections from loops installed in the roadway. Specifies splicing procedures, gutter crossings, etc.
- *Index 17784 Pedestrian detector assembly installation details* specify the location of pedestrian detectors and the requirements for advisory signs giving directions to pedestrians.
- *Index 17841 Cabinet installation details* specify cabinet types, installation and grounding details for pole-mounted and pedestal-mounted controller cabinets.

All new signals installed by the Department on the State Highway System that are within ten miles of the coastline shall be supported by mast arms with signal heads rigidly attached to the mast arm.

{PPM}

The following additional guidance is offered with respect to signal mounting equipment:

- In general, mast arms with horizontal signal heads should be parallel to their intended stop bar.
- The elevation of the base for poles supporting mast arms is a critical element in the construction because it determines the final mounting height of all signal displays.
- Horizontal signal heads must be mounted at approximately the same elevation as the horizontal mast arm member. Signal heads mounted below the mast arm to remedy elevation problems are not acceptable.
- Mast arms should be of sufficient length and design to support placement of additional heads and signs that may be deemed necessary in the future.

The design of traffic signal mast arms and foundations shall be included in the plans.
{PPM}

The following items should be considered when placing signal supports and cabinets:

- Reference should be made to PPM Volume I, Chapter 2, Section 2.11 and to the Americans with Disabilities Act.
- Signal supports should not be located in medians. Flush shoulders should be located outside the clear zone. Placement to the curb or curb and gutter should be 4 feet from the face of outside curbs and outside the sidewalk. However, when necessary, the Signal Poles may be located within sidewalks such that an unobstructed sidewalk width of 4 feet or more (not including the width of the curb) is provided.
- No part of a concrete base for a signal support should extend more than 4 inches above the ground level at any point. This limitation does not apply to the concrete base for a rigid support.
- A signal support or controller cabinet should not obstruct the sidewalk or access from the sidewalk to the crosswalk.

Signal poles shall not be placed on the median.
{PPM}

This chapter has set forth the principles and criteria for signal design that are recognized by the FDOT and identified the design methodology that is commonly used throughout the state. The next chapter will do the same thing for traffic signs and markings.