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**CHAPTER SEVENTY-SEVEN**

# TRAFFIC SIGNALS

## 77-1.0 GENERAL

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

### 77-1.01 MUTCD Context

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

### 77-1.02 References

For additional information on traffic-signal design, the designer is referred to the publications as follows:

1. *Manual on Uniform Traffic Control Devices*, FHWA;
2. *Standard Drawings*, INDOT;
3. *Standard Specifications*, INDOT;
4 *Highway Capacity Manual*, Transportation Research Board (TRB);
5. *Traffic Control Devices Handbook*, FHWA;
6. *Manual of Traffic Signal Design*, Institute of Transportation Engineers (ITE);
7. *Traffic Engineering Handbook*, ITE;
8. *Traffic Control Systems*, National Electrical Manufacturers Association (NEMA);
9. National, State, and local electrical codes;
10. *Traffic Detector Handbook*, FHWA;
11. *Traffic Signal Installation and Maintenance Manual*, ITE;
12. *Equipment and Material Standards of the Institute of Transportation Engineers*, ITE;
13. *ITE Journal* (published monthly), ITE; and
14. Manufacturers' literature.

**77-1.03 Official Action**

Where a new traffic signal is to be installed or an existing traffic signal is to be removed, an Official Action is required. For a State-maintained highway, the designer must obtain an approval for the proposed change from the appropriate district traffic engineer before implementation of the proposed change. For a locally-controlled facility, approval must be obtained from the appropriate jurisdiction before starting design. An Official Action may also be required where other regulatory controlled items are revised in association with a traffic signal (e.g,. "No Turn On Red" sign).

**77-1.04 Project and Plans Development**

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

** *PRACTICE POINTER* **

Each signal project which is part of a road or bridge contract should include a separate cost estimate. Its Des number should be placed on the signal-details sheet and on the title sheet.

**77-1.05 Definitions**

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

1. Controller. A device that controls the sequence and duration of indications displayed by traffic signals.

2. Coordination. The establishment of a definite timing relationship between adjacent traffic signals.

3. Cycle. For a pre-timed controller, it is the period of time used to display a complete sequence of signal indications. For an actuated controller, a complete cycle is dependent on the presence of calls on all phases.

4. Cycle Length. The time required for one complete sequence of signal indications.

5. Delay. (a) A measure of the time that has elapsed between the stimulus and the response. (b) traffic delay is the time lost by a vehicle due to traffic friction or control devices.

6. Demand. The need for service. For example, the number of vehicles desiring to use a given segment of roadway during a specified unit of time.

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

8. Detector. A device for indicating the presence or passage of a vehicle or pedestrian (e.g., loop detector, microloop detector, push button).

9. Dilemma Zone. A range of distances from the intersection where a driver may react unpredictably to a yellow signal indication (i.e., deciding to stop or to continue through the intersection).

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

11. Interval. A discrete portion of the signal cycle during which the signal indications remain unchanged.

12. Interval Sequence. The sequence of operation in which the various intervals are displayed during a cycle.

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

14. Loop Detector. A device capable of sensing a change in the inductance of a loop sensor imbedded in the roadway caused by the passage or presence of a vehicle over the loop.

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

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

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

18. Phase Overlap. Refers to a phase that operates concurrently with one or more other phases.

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

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

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

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

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

24. Signal Head. An arrangement of one or more signal indications in one direction.

25. Signal Indication. The active illumination of a traffic signal lens or equivalent device.

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

27. Yield Point. The point at which the controller permits the existing phase to be terminated to service a conflicting phase.

## 77-2.0 PRELIMINARY DESIGN ACTIVITIES

The district traffic office is responsible for making the determination of the need for a new or existing traffic signal. This determination is based on traffic volume, accident history, a nearby school, pedestrians, local needs, driver needs, construction costs, and maintenance costs. The following provide information on some of the guidelines, policies, procedures, and factors used by INDOT to make these determinations.

## 77-2.01 Signal Study Request

A request for a new signal may be generated by many sources, such as FHWA, the Office of Environmental Services' Environmental Policy Team, the district traffic office, local officials, developers, or local citizens' groups. Each request for a new traffic-signal installation should be first forwarded to the appropriate district traffic engineer. If the district traffic engineer determines that the request merits further investigation, he or she will then begin coordinating the collection of the necessary traffic data.

For an in-house request, the district traffic engineer, possibly in conjunction with the Office of Environmental Services' Environmental Policy Team, will conduct the appropriate traffic studies to obtain accurate and up-to-date traffic data and projections. For another type of request, the latest traffic data and projections should be forwarded with the request. The data collector will need to refer to the *MUTCD*, which provides the warrants for a traffic signal, to determine the appropriate information required. For additional information on the collection of traffic data, the designer should review the ITE publication, *Manual of Traffic Engineering Studies*, or contact the Office of Environmental Services.

If it is determined that a traffic signal is warranted, the Production Management Division's Office of Roadway Services, or a consultant, will prepare the design for the proposed traffic signal. The district traffic engineer will be responsible for determining the traffic-signal timings. The local agency or consultant may sometimes be responsible for determining the traffic-signal timings.

## 77-2.02 Signal Warrants

Each new traffic signal should meet at least one of the primary warrants listed below. Supplemental warrants should be considered as an advisory condition and, therefore, do not mandate the installation of a traffic signal. The supplemental guidelines are additional considerations in the determination for the need to install a traffic signal. The *MUTCD* traffic-signal warrants are as follows.

1. Primary Warrants.

    a. Minimum vehicular volume
    b. Interruption of continuous traffic
    c. Minimum pedestrian volume

2. Supplemental Warrants.

a. School crossing
b. Progressive movement
c. Accident experience
d. Systems
e. Combination of warrants
f. New facility
g. Special access
h. Four-hour traffic volume

3. Supplemental Guidelines.

a. Peak-hour delay
b. Peak-hour volume

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

## 77-2.03 Warrant Analysis

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

1. Minimums. The *MUTCD* warrants are considerations for determining the need for a traffic signal. The intent of the *MUTCD* thresholds is to establish a minimum boundary below which a traffic signal should not be installed. Meeting or exceeding these thresholds does not automatically warrant a traffic signal.

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

3. Accidents. Traffic signals are often installed to reduce certain types of accidents (e.g., right-angle collision, pedestrian crossing). However, the installation of a traffic signal may increase the number of rear-end collisions and may fail to reduce turning conflicts between vehicles and pedestrians. Consideration should be given as to whether a change in accident types and their severity will be an actual improvement for the intersection. Accident data for the location should include at least the past three years. Consideration

should be given to alternative solutions to the problem of accidents (e.g., removing parking, using larger signs).

4. Geometrics. The geometric design of the intersection can affect the efficiency of the traffic signal. An installation of a traffic signal at a poorly-aligned intersection may increase driver confusion and thereby reduce the overall efficiency of the intersection. If practical, the intersection should be properly aligned and have sufficient room to adequately provide turning lanes, through lanes, etc. Chapter Forty-six provides detailed information on the geometric design of an at-grade intersection.

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

6. Location. The designer should consider the intersection relative to the context of the land use, density of development (e.g., urban, suburban, rural) and the potential for future development. The designer should consider the location of the intersection within the context of the transportation system such as an isolated location, interrelated operations, and functional classification. An isolated location is an intersection where the distance to the nearest signalized intersection or potential future signalized intersection is greater than 800 m.

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

## 77-2.04 Responsibilities

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

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

## 77-3.0 FLASHER OR FLASHING BEACON

### 77-3.01 Guidelines for Hazard-Identification Beacon

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

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

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

### 77-3.02 Speed-Limit-Sign Beacon

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

A speed-limit-sign beacon consists of two circular, yellow sections, each having a visible lens diameter of not less than 150 mm or, as an alternative, one or more circular, yellow lenses each having a minimum visible diameter of 200 mm. Where two lenses are used, they should be aligned vertically near the top and bottom of the sign. If the sign is longer horizontally than vertically, the lenses may be aligned horizontally. The beacons should flash alternately. The lenses of the school-speed-limit beacon may be positioned within the face of the sign itself.

### 77-3.03 Intersection-Control Beacon

An intersection-control beacon is intended for use at an intersection where traffic or physical conditions do not justify conventional signalization, but where conditions indicate a hazard potential. The installation of flashing beacons at an intersection with yellow flashing on the preferential street and red flashing on the stop street may be warranted where two or more of the following conditions exist.

1. Accidents. At an intersection with five or more reported accidents during a 12-month period with a predominance of accident types that may be corrected by cautioning and stopping traffic.

2. Sight Distance. In conjunction with “Stop” signs where sight distance is limited or where other physical or traffic conditions make it desirable to emphasize the need for stopping on one street and for proceeding with caution on the other.

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

4. Speed. At an intersection where excessive speed prevails. This warrant should not be considered where the 85th percentile speed is equal to or less than 70 km/h.

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

Where based on engineering judgment, supplemental beacons may be used at a multi-way, stop-controlled intersection. The intersection-control beacon should be red for all approaches.

An intersection-control beacon consists of one or more sections of a standard traffic-signal head, having flashing, circular yellow or circular red indications in each face. Each intersection must have at least two indications for each approach. Indications should flash alternately, but may flash simultaneously. Supplemental indications may be required on one or more approaches to provide adequate visibility to an approaching motorist.

## 77-3.04 “Stop” Sign Beacon

A “Stop” sign beacon is used to draw attention to the sign. The beacon consists of one or two sections of a standard traffic-signal head with a flashing, circular red indication in each section. The lenses may be either 200 mm or 300 mm in diameter. Where they are aligned horizontally, they should flash simultaneously. Where they are aligned vertically, they should flash alternately. The bottom of the housing for the beacon should be located 300 mm to 600 mm above the top of the “Stop” sign.

**77-3.05 General Beacon Design**

A flashing-beacon unit and its mounting must be in accordance with the design specifications for traffic-control signals. Some of these include the following.

1. Lens. Each signal-unit lens should have a visible diameter of at least 200 mm, except for a speed-limit sign beacon, which may be 150 mm. The red or yellow lens must be in accordance with the ITE *Standard for Adjustable-Face Vehicle Traffic Control Signal Heads.*

2. Sight Distance. While illuminated, the beacon should be clearly visible to each driver it faces for a distance of 400 m under normal atmospheric conditions, unless otherwise physically obstructed.

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

4. Hours of Operation. Hazard identification beacons should only be operated while the hazard or regulation exists (e.g., school opening or closing).

5. Lamp Dimming. If a 150-W lamp is used in a 300-mm-diameter flashing-yellow beacon and the flashing causes excessive glare during night operation, an automatic dimming device may be necessary to reduce the brilliance during night operations.

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

7. Alignment. If used to supplement a warning or regulatory sign, individual flashing beacon units should be horizontally or vertically aligned. The edge of the housing should be located not closer than 300 mm outside of the nearest edge of the sign.

8. <u>Location</u>. The obstruction or other condition warranting the beacon will govern the location of the beacon with respect to the roadway. If used alone and located at the roadside, the bottom of the beacon unit should be at least 2.4 m, but not more than 4.6 m, above the pavement. If suspended over the roadway, the beacon clearance above the pavement should be at least 5.2 m, but not more than 5.8 m.

## 77-4.0 TRAFFIC-SIGNAL EQUIPMENT

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

### <u>77-4.01 Traffic Controller</u>

A traffic-signal controller is an electric mechanism mounted in a cabinet for controlling the sequence and phase duration of the traffic signal. Right-of-way is assigned by turning the green indication on or off. There are two types of traffic controllers, pre-timed and actuated. A pre-timed controller operates according to pre-determined schedules. An actuated controller operates with variable vehicular and pedestrian timing and phasing intervals which are dependent upon traffic demands. If there is no demand for a phase, the actuated controller may omit that phase in the cycle (e.g., if there is not a demand for left turns, the left-turn phase will not be activated). The following provides general information on the controllers used by the Department. Section 77-5.0 describes the phasing and timing aspects of a controller.

#### 77-4.01(01) Pre-timed Controller

A pre-timed controller uses a fixed, consistent predetermined cycle length, usually 60 to 140 s. It can be programmed to provide several different timing programs based on the time of day or day of week. A pre-timed controller can be either solid-state (electronic) or electromechanical. For each new INDOT-route installation, only a solid-state controller can be used. An existing INDOT-route or local-agency-route signal may have either an electromechanical or solid-state controller. The solid-state design has better expansion capabilities, is easier to install, and is easier to maintain than the electromechanical controller. Replacement parts for an electromechanical controller are difficult to obtain.

A pre-timed controller is best suited to where traffic volume and patterns are consistent from day-to-day (e.g., downtown area), where variations in volume are predictable, and where control timing can be preset to accommodate variations throughout the day.

The following are some of its advantages and disadvantages.

1. Advantages.

    a. It can be easily incorporated into a progression system.

    b. It is not dependent on a detection device.

    c. It is easier to operate than an actuated controller.

    d. It has been commonly used in the past.

    e. It requires little additional training of local maintenance personnel for proper operation and maintenance.

2. Disadvantages.

    a. There is not an industry-wide interchangeability standard for replacement parts between different NEMA TS-1 controllers. However, NEMA TS-2 controllers are expected to be interchangeable.

    b. It cannot compensate for unplanned fluctuations in traffic flows which can cause excessive vehicular delays.

    c. It tends to be inefficient at an intersection with random traffic arrivals (e.g., isolated intersection).

Because the cost differential between a pre-timed and actuated controller is minimal, and an actuated controller can be set up to simulate a pre-timed controller, INDOT has limited the use of pre-timed controllers on State highways. A proposed use of a new pre-timed controller on a State highway must be approved by the Highway Operations Division's Office of Traffic Engineering.

**77-4.01(02) Semi-Actuated Controller**

A semi-actuated controller is based on vehicular detection from one or more approaches, but not on all approaches. A vehicular detector (e.g., loop detector) is placed only on the minor approach where traffic is light and sporadic. The major approach is kept in the green phase until a vehicle on the minor approach is detected. If there is a demand on the minor approach and the minimum green time for the major approach has elapsed, the right-of-way will then be given to the minor approach. To handle various fluctuations on the minor approach, the minor approach is given enough time to clear one vehicle with additional time added for each new detection up to the maximum green time. Once the minor-approach demand has been satisfied or the maximum green time has been reached, the right-of-way is then returned to the major approach and the cycle begins again. If there is no minor-approach demand, the major approach will remain in the green phase indefinitely.

Typical locations for a semi-actuated controller include the following:

1. school-crossing intersection;
2. access route to an industrial area or shopping center;
3. access route to a recreational area or sports center;
4. cross street with poorly-spaced signals along the major route; or
5. cross street with minimal traffic volume.

The following are some of its advantages and disadvantages.

1. Advantages.

    a. The major approach receives a green phase indefinitely until a vehicle is detected on the minor approach. This reduces the mainline delay during periods of light traffic because no green time is given to phases where no traffic demand exists.

    b. It can be easily incorporated into a coordinated system.

    c. It can be effectively used at an isolated intersection.

    d. It tends to provide the maximum efficiency at an intersection where fluctuation in the side-street traffic cannot be anticipated and programmed for with pre-timed control.

2. Disadvantages.

    a. Short, continuous demands on the minor street (e.g., factory shift change) can cause excessive delays to the mainline.

    b. A detection device is required; typically loop detectors on the minor street.

    c. It is more complex to operate than a pre-timed controller.

d. There is no dilemma-zone protection for any of the approaches. Consequently, it should not be used where the posted approach speed is higher than 60 km/h. Section 77-5.08 further defines the dilemma-zone requirements.

INDOT uses a fully-actuated controller to simulate a semi-actuated-controller intersection.

**77-4.01(03) Fully-Actuated Controller**

A fully-actuated controller has detection devices on all approaches to the signalized intersection. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears, or the preset maximum green time has elapsed. Once the minor street demand has been satisfied, right of way is returned to the major street whether or not a major-street detection has been registered. Where there is a continuous demand on all approaches, the intersection tends to operate as a pre-timed system.

A fully-actuated controller should be considered at a location as follows:

1. an isolated location where traffic volume on the intersection legs is more equal with sporadic and varying traffic distribution;

2. where traffic-signal control is warranted for only brief periods of the day;

3. where turning movements occur often only during specific time periods and do not in the remainder of the time; or

4. where the posted speed is higher than 60 km/h and where there is a need to avoid dilemma-zone problems (see Section 77-5.08).

The following are some of its advantages and disadvantages.

1. <u>Advantages</u>.

   a. It can handle high traffic volume.

   b. It is very efficient at an isolated intersection.

   c. It can handle varying traffic demands (e.g., complex intersection where one or more movements are sporadic or subject to variation in volume).

d. It can be programmed to operate as a pre-timed-signal or semi-actuated system.

e. It can be programmed to allow different phases to operate concurrently, if they are not conflicting.

f. Mainline delay during periods of light traffic is reduced because no green time is given to phases where no traffic demand exists.

2. Disadvantages.

a. A detection device, typically loop detectors, is required on all approaches.

b. It is more complex to operate.

**77-4.01(04) Actuated Controller with Density Feature**

The density feature is an enhancement to the actuated controller. Additional detectors are placed in advance of the intersection to determine both the number of vehicles waiting and the vehicular gaps. The density feature allows the controller to adjust the initial portion of the green time to account for the queue of waiting vehicles arriving during the yellow and red phases to clear the intersection. Once the initial queue is cleared, the allowable mainline vehicular gap is reduced over time giving greater priority to conflict calls from the side street. If the gaps on the mainline are too long, or the preset maximum green time has passed, the right of way is then given to the side street to allow the waiting vehicles a chance to enter or cross the highway. The following are some of the advantages and disadvantages of the density feature.

1. Advantages.

a. It is very efficient at a high-speed intersection.

b. It can effectively handle a large traffic volume.

c. It can effectively clear stored traffic (e.g., stored vehicles in a left-turn bay).

d. It can be programmed to give higher priority to the mainline.

e. It can be programmed to allow different phases to operate concurrently, if they are not conflicting.

f. It can be programmed to handle specific local site conditions.

2. Disadvantages.

   a. Additional detection devices are required.

   b. It is more complex to operate.

   c. It has higher initial costs.

Each new controller installation on a State highway should include the density feature. Where it the feature has been deemed unnecessary, approval must be obtained from the Office of Traffic Engineering before it can be removed from the project.

### 77-4.01(05) Pedestrian Feature

The pedestrian feature works in conjunction with the signal controller. This feature allows for the timing of the Walk and Don't Walk cycles and can be actuated by means of a pedestrian push button. The following are some of the advantages and disadvantages of the feature.

1. Advantages.

   a. It provides additional time for crossing pedestrians.

   b. Where there is minimal pedestrian demand, disruption to the vehicular phases can be minimized.

2. Disadvantages.

   a. Where a pedestrian push button is required, it must be located in a convenient, accessible location.

   b. A pedestrian cycle concurrent with motor-vehicle green time may marginally delay a right-turning vehicle.

   c. It can significantly increase the required minimum green time on the minor street if the major street is substantially wider than the minor street.

### 77-4.01(06) Controller with Specialty Features

There are other specialty features that may be used in traffic-engineering design (e.g., flashing beacon, emergency-vehicle actuation, railroad-grade-crossing signal). The use of these features is site specific.

An Integrated Traffic System controller and cabinet should each be specified if identified to be required by the Engineer's Report or the environmental document.

### 77-4.01(07) Controller Design Concepts

There are two basic design concepts for a controller, NEMA and Type 170. The National Electrical Manufacturers' Association (NEMA) controllers have standard functions and input/output formats, but use different electronic techniques, including micro processing, to provide the functions. NEMA controllers are intended to be interchangeable between manufacturers. Where changes or upgrades to the controller are desired, the controller unit hardware is replaced. The Model 170, developed by the states of California and New York, defines the hardware requirements and uses a general-purpose microprocessor. Changes for an individual intersection vary with the software applications. Where changes are required, the Type 170 controller software is rewritten and the hardware is retained. Figure 77-4A provides the advantages and disadvantages of NEMA and Type 170 controllers.

INDOT uses the NEMA criteria for all of its traffic-signal controllers. At a minimum, each INDOT-maintained traffic controller must be in accordance with the NEMA TS-1 criteria. A new traffic controller should include some of the enhancements of the NEMA TS-2 criteria. A list of all approved controller equipment is provided in the Department's *List of Approved or Prequalified Materials*. Each approved controller must be in accordance with the Department's *Traffic Signal Control Bench Test Procedures*. A copy of the list of approved controllers may be obtained by contacting the Contract Administration Division's Office of Contracting.

The NEMA controller can either be a single-ring controller or a dual-ring controller depending on the number of phases the intersection will have. Section 77-5.06 provides information on the selection of phases for an intersection. A single-ring controller is used where the conflicting phases are established in a set order. Figure 77-4B, Sequence of Phases, detail A illustrates the appropriate phasing sequence for a single-ring controller. A dual-ring controller unit includes two interlocking rings that are arranged to time in a preferred sequence and to allow concurrent timing of both rings, subject to the restraint of the barrier. For the controller to advance beyond the barrier, both sets of rings must cross the barrier line at the same time (i.e., no conflicting phase may be shown at the same time). Figure 77-4B, detail B illustrates the sequence of phases for an 8-phased, dual-ring controller.

### 77-4.01(08) Associated Controller Equipment

Each controller unit will require a power supply, surge protectors, load switches, and a conflict monitor. This equipment must be in accordance with the Department's *Traffic Signal Control Bench Test Procedures* and the NEMA TS-1 criteria. Auxiliary equipment that can be added to the controller, depending on the intersection, includes preemptors, coordinators, or detectors. Where used, this auxiliary equipment must also be in accordance with the NEMA criteria. Section 77-4.01(11) discusses preemption, Section 77-4.02 discusses detectors, and Section 77-6.0 discusses system coordination.

### 77-4.01(09) Conflict Monitor

With solid-state equipment, there is a potential for the accidental display of erroneous indications (e.g., greens for conflicting movements). The problem will be with the solid-state load switch, which switches the electric current on or off to the signal indications. To protect against failure, each solid-state controller must have a conflict monitor.

### 77-4.01(10) Controller Cabinet

A controller cabinet is an enclosure designed to house the controller unit and its associated equipment, providing for its security and environmental protection. Section 77-5.02 provides considerations for the placement of the cabinet relative to roadside safety. Foundation requirements for each cabinet type are shown in the INDOT *Standard Drawings*. Each new traffic-signal installation or modernization that requires new a controller cabinet should include a TS2-Type 1 cabinet assembly.

The following discusses the cabinet types used by the Department.

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

2. <u>M Cabinet</u>. The M cabinet is a ground-mounted cabinet. This cabinet is used with a 4-phase or smaller controller. Where there is a possibility that more phases may be necessary in the future, the P-1 cabinet should be used.

3. <u>P-1 Cabinet</u>. The P-1 cabinet is a ground-mounted cabinet. This cabinet is the preferred Department cabinet. It is used with an 8-phase controller. If used for a 4-phase or smaller controller, it allows for the possible upgrade with minimum effort.

**77-4.01(11) Preemption**

Preemption consists of the modification of a traffic signal's normal operation to accommodate a special occurrence, such as the approach of an emergency vehicle, the passage of a train through a grade crossing, or the opening of a drawbridge. Another form of preemption can also be used to provide priority to transit vehicles by minimizing the delays to these vehicles. Preemption sequences should be shown on the plans. For information on preemption equipment, the designer should contact the manufacturer. The following describes the situations where preemption is used.

1. Railroad-Crossing Preemption. The preemption of signal operations caused by the passage of a train is the most common use of preemption equipment. Where a signalized intersection is within 60 m of a railroad grade crossing, preemption is used to eliminate the potential for conflicting instructions from the railroad-crossing signals and intersection signals. The *MUTCD* describes the preemption strategies and defines the requirements for grade-crossing preemption.

   Railroad-crossing preemption requires interconnection between the traffic-signal controller and the grade-crossing signal equipment. The preemption routine at the traffic-signal controller is initiated by the approach of a train, as detected by the railroad's controller, and starts with a short track clearance phase, to clear motorists who may be stopped between the railroad-crossing stop line and the intersection. Subsequent signal displays include only those are not in conflict with the occupied grade crossing. Once the train has passed, the signal is returned to normal operations. For a State route, this type of preemption requires an agreement between the State and the railroad company.

2. Fire-Station or Fire-Route Preemption. The common denominator for this category is the activation of the preemption sequence at a fixed point (e.g., a push button located within the firehouse).

   The simplest form of fire-station preemption is the installation of an emergency signal, at the fire-station drive intersection with a major through street. Using a 2-phase, semi-actuated controller, the signal dwells in the through-street display (green or flashing yellow) until called by an actuation in the fire station. The signal then provides a timed right of way to the drive to allow an emergency vehicle to enter the major street.

   Where the fire station is near a signalized intersection, a preemption sequence can be designed to display a special movement permitting the passage of emergency equipment through the intersection. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

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

3. Moving-Emergency-Vehicle Preemption. A number of devices are available to permit the preemption of signals by moving emergency vehicles. The preemption equipment causes the signals to advance to a preempt movement display. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

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

   A second type of system uses a low-power radio transmitter on the emergency vehicle and a radio receiver at each intersection to be preempted. The driver of the vehicle activates a dashboard switch based on the heading of the vehicle, north and south or east and west. This switch codes the radio transmission, and the intersection receiver can implement the appropriate preempt sequence. One system using this technique includes a compass-based switch in the emergency vehicle. It can also encode the vehicular identification number for preemption logging purposes.

   Each of these systems requires a specialized transmitting device on each vehicle for which preemption is desired, and it requires that the driver activates the transmitter during the run and turns off the transmitter after arriving at the scene.

   A third system uses a receiver at the intersection that senses the emergency vehicle's siren to initiate preemption. This system cannot provide directionality of approach. However, it can be used to start a predetermined preemption sequence or intersection flash.

4. Transit-Vehicle Preemption. Most transit-preemption systems are designed to extend an existing green indication for an approaching bus and do not cause the immediate termination of conflicting phases, as would occur for emergency-vehicle preemption. For

a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

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

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

5. Preemption Equipment. With a microprocessor-based controller, virtually all preemption routines are performed by the controller software. The only necessary external equipment is the preemption call detection device. In a controller built to NEMA standards, internal preemption capability is provided as an option and may require a special module. Many manufacturers provide a set of preemption routines that can be tailored to an intersection's preemption scheme. Others may require a factory-designed sequence, burned into memory for the requirements of a specific intersection.

## 77-4.02 Detectors

### 77-4.02(01) Operation

The purpose of a detector is to determine the presence of a vehicle, bicyclist, or pedestrian, or the passage of a moving vehicle. This presence or passage detection is sent back to the controller which adjusts the signal accordingly. There are many types of detectors available that can detect the presence or passage of a vehicle. INDOT uses only inductive loop detectors in its signal design. The inductive loop detector is preferred because it can be used for passage or presence detection, vehicular counts, speed determinations, and it is accurate and easy to maintain. Although the inductive loop detector is the system of choice, this does not prevent the designer from recommending the use of a new device in the future. If in the designer's opinion a different detector should be considered, its use must be first coordinated with the Highway Operations Division's Office of Traffic Engineering and the district traffic engineer to detail special maintenance requirements or equipment needs.

The controller's detection device can operate in several different modes, as discussed below.

1. Passage, or Pulse, Detection. A passage detector detects the passage or movement of a vehicle over a given point. It emits a short-duration, or pulse, output signal. The short loop design for a short detection area is considered to be a passage detector.

2. Presence Detection. A presence detector registers if a vehicle is stopped or is within the detection area. A signal output is generated for as long as the detected vehicle is within the monitored area subject to the eventual tuning out of the call by some types of detectors. The long loop design for a long detection area is considered to be a presence detector.

3. Locking Mode. The detector or the controller memory holds a call in the waiting phase until the call has been satisfied by a green display even though the calling vehicle may have already vacated the approach (e.g., a vehicle turning right on red).

4. Non-locking Mode. For this operation, the call is held only while the detector is occupied. The call is voided once the vehicle leaves the detection area. The non-locking mode is used with a presence detector (e.g., with a permissive left-turn lane).

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

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

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

### 77-4.02(02) Inductive Loop Detector

An inductive loop detector consists of two or more turns of wire embedded in the pavement surface. INDOT uses four turns. As a vehicle passes over the loop, it disrupts the current running through the wire. This disruption is recorded by an amplifier and is transmitted to the controller as vehicle detection. NEMA criteria define the requirements for both self-contained loop-detector units (shelf mounting) and for card-type detector units (inserted into a multi-slotted card rack wired in the cabinet). The NEMA criteria also define optional timing features that can be used for loop detectors, including delaying or extending the detector output.

The advantages of loop detectors are as follows:

1. detect vehicles in both presence and passage modes;
2. be used for vehicular counts and speed determinations; and
3. be easily designed to meet the various site conditions.

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

There are two types of loop-detector designs: the long loop rectangular design (1.8 m by 6 m to 20 m), and the short loop octagonal design (1.8 m by 1.8 m). INDOT uses the short loop design. To emulate the long loop detection, a series of short loops are wired in series. The INDOT *Standard Drawings* illustrate typical loop layouts and installation details. The typical layouts shown on the INDOT *Standard Drawings* are for illustrative purposes only. Each intersection should be designed individually to meet local site conditions.

A sequence of loops is used at the intersection itself for presence detection of vehicles stopped at the traffic signal. A set of loops before the intersection is used to determine the passage of a vehicle. The distance from the stop line to the loops is based on the posted speed limit. Sections 77-5.07 and 77-5.08 provide additional information on detector location.

### 77-4.02(03) Other Detector Types

There are other types of vehicular detectors available. However, INDOT uses the inductive-loop detector. The following discusses other detector types that are available.

1. <u>Magnetic Detector</u>. A magnetic detector consists of a small coil of wires located inside a protective housing embedded into the roadway surface. As a vehicle passes over the device, the detector registers the change in the magnetic field surrounding the device. This signal is recorded by an amplifier and relayed back to the controller as a vehicular detection. A problem with this detector is that it can only detect the passage of a vehicle traveling at a speed of 5 km/h or faster. It cannot be used to determine a stopped vehicle's presence. The advantages are that it is easy to install and it is resistant to pavement-surfacing problems.

2. Magnetometer Detector. A magnetometer detector consists of a magnetic metal core with wrapped windings, similar to a transformer. The core is sealed in a cylinder of about 25 mm diameter and 100 mm length. The detector is placed in a drilled vertical hole, about 300 mm into the pavement surface. A magnetometer detector senses the variation between the magnetic fields caused by the passage or presence of a vehicle. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. A magnetometer detector is sufficiently sensitive to use to detect a bicyclist or as a counting device. A problem with the magnetometer detector is that it does not provide a sharp cutoff at the perimeter of the detection vehicle (i.e., it may detect a vehicle in an adjacent lane).

3. Microloop Detector. A microloop detector is similar to a magnetometer detector, but it can work with a standard inductive loop-detector electronic unit. The microloop is installed by drilling a 75-mm diameter hole 500 mm into the pavement structure, or by securing it to the underside of a bridge deck. A disadvantage of the microloop detector is that it requires some motion to activate the triggering circuitry of the detector and does not detect a stopped vehicle. This type of detector requires two detectors placed side-by-side due to its limited field of detection.

4. Video-Image Detection. The video-image detector consists of one to six video cameras, an automatic control unit, and a supervisor computer. The computer detects a vehicle by comparing the images from the cameras to those stored in memory. The detector can work in both the presence and passage modes. The detector also allows the images to be used for counting and vehicular classification. Housings are required to protect the camera from environmental elements. Early models experienced problems with the video detection during adverse weather conditions (e.g., fog, rain, snow).

**77-4.02(04) Pedestrian Detector**

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

**77-4.02(05) Bicycle Detector**

The two most common methods for bicycle detection include the following.

1. Pedestrian Push-Button Detector. With the push-button detector, the bicyclist must stop and push the detector button for the controller to record the detection. This may require the bicyclist to leave the roadway and proceed on the sidewalk to reach the detector.

2. Inductive-Loop Detector. The inductive-loop detector can detect the bicycle without the bicyclist's interaction. For the greatest sensitivity of the detector, the bicycle should be guided directly over the wire. A problem with a bicycle inductive-loop detector is that it requires a significant amount of metal to be activated. Today's bicycle designs tend to use a substantial amount of non-magnetic man-made materials to increase their strength and reduce their weight. This has substantially reduced the metal content that can be detected.

## 77-4.03 Signal Mounting

The Department's preferred practice is to install a traffic signal using span, catenary, and tether cables, or cantilever structures in a box design (i.e., poles on all four corners). A pedestal- or post-mounted signal may be used if there is a left-turn signal in a median, or on the near side of the intersection if the intersection is significantly wide, or for a pedestrian signal. Figure 77-4C, 77-4D, and 77-4E provide the advantages and disadvantages of the post-mounted signal, cable-span signal mounting, and the cantilever signal mounting, respectively.

For the span, steel strain poles should be used. Steel strain poles provide greater strength, are easier to maintain, and require less space. Wood poles require the use of down-guy cables. Therefore, wood poles are limited to an area with sufficient right of way (e.g., a rural area), or for a temporary installation. The INDOT *Standard Drawings* and the INDOT *Standard Specifications* provide the criteria for both steel and wood poles and for attachments to the pole.

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

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

## 77-4.04 Signal Display

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

1. Signal-Head Housing. A signal-head housing can be made from either aluminum or polycarbonate. Polycarbonate (plastic) is lighter and retains its color throughout its service life. However, plastic is not as strong as aluminum and tends to break when used in a top- or bottom-mounted rigid installation.

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

3. Lens Size. Although a 200-mm-diameter lens is allowed by the *MUTCD*, INDOT's preferred practice is to use only a 300-mm size. INDOT specifications require the use of plastic lenses in its signal displays.

4. Signal Illumination. Relative to signal illumination, the designer should consider the following.

    a. Incandescent. Incandescent bulbs should only be used for the solid-yellow indication. The designer is referred to ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* for INDOT criteria on signal lamps. The ITE publication discusses lamp illumination, light center length, rated initial lumens, lamp life, and operating voltages.

    b. Light-Emitting Diode (LED). An LED should be used for all other indicators, including flashing yellow. An LED uses less energy and has a longer life expectancy than an incandescent bulb. The use of a new signal-illumination method should be first coordinated with the Office of Traffic Engineering

5. Reflector. The reflector directs the light output from the lamp forward through the signal lens. The reflector has a parabolic shape and is designed for the lamp filament. Reflectors are available as mirrored glass, specular anodized aluminum, or metalized plastic. INDOT specifications require the use of the specular anodized aluminum reflector.

6. Visor. INDOT practice is to use a visor for each signal lens. A visor is used to direct the signal indication to the appropriate approaching traffic and to reduce sun phantom. A tunnel visor provides a complete circle around the lens. A cutaway visor is a partial

visor, with the bottom cut away. A partial visor reduces water and snow accumulation and does not let birds build nests within it. The decision on which visor type that should be used is determined on a site-by-site basis. INDOT uses partial visors. The visor is made of the same material as the housing.

7. Louver. A louver is used to direct the signal indication to a specific lane (e.g., left-turn signal for a left-turn bay). A louver is used where several signal heads may cause confusion for the approaching driver. One example of this problem is where a left-turn signal indication is red, but the through-lane indication is green. The decision on whether to use a louver depends on site conditions and will be determined as required for each intersection.

8. Optically-Programmable Signal. Like a louver, an optically-programmable signal is designed to direct the signal indication to specific approach lanes and for specific distances. An advantage is that it can be narrowly aligned so that other motorists cannot see the indication. Applications include closely-spaced intersections, a left-turn signal at a skewed intersection, or a left-turn signal on a high-speed approach. An optically-programmable signal requires rigid mountings to keep the indicator properly directed. Although the initial cost may be higher than for a louver, the advantage of being less confusing often makes it cost effective. The decision on whether to use an optically-programmable signal depends on site conditions and will be determined as required for each intersection.

9. Backplate. A signal indication may lose some of its contrast value when viewed against a bright sky or other intensive background lighting (e.g., advertising lighting). A backplate placed around a signal assembly can enhance the signal's visibility. However, a backplate adds weight to the signal head and can increase the effect of wind loading on it. The decision on whether to use a backplate depends on site conditions and will be determined as required for each intersection.

## 77-5.0 TRAFFIC-SIGNAL DESIGN

### 77-5.01 Design Criteria

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

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

1. All electric service should be metered.

2. All parking regulations should be determined for at least 45 m from the stop line or back to a detector.

3. Each signal head should be placed from 12 to 45 m from the stop line.

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

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

6. Steel-strain-pole support height is 9.1 m or 11 m.

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

8. All existing signal components should be field verified.

9. Position and direction of aiming of all signal heads should be in accordance with Section 77-501(01).

10. The values for detection setback distances shown in Figure 77-5S should be used.

**77-5.01(01) Signal Displays**

The *MUTCD* requires that there be at least two signal indications for each through approach to an intersection or other signalized location. A single indication is permitted for control of an exclusive turn lane, provided that the single indication is in addition to the minimum two for the through movement.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. Situations where supplemental indications may improve visibility include the following:

1. approach in excess of three through lanes;

2. location where there may be driver uncertainty;

3. where there is a high percentage of trucks which may block the signal indications; or

4. where the approach alignment affects the continuous visibility of normally-positioned signal indications (e.g., left turn beyond the signal indication).

The following figures illustrate the INDOT placement of signal heads.

1. Figure 77-5A - multi-lane highway with an offsetting intersection.

2. Figure 77-5B - urban street with parking on the far side and a near side left-turn lane.

3. Figure 77-5C - urban street with parking on the near side with no left-turn lane.

4. Figure 77-5D - left-turn lane with permissible-left-turn indication (i.e., no separate left-turn phase).

5. Figure 77-5E - left-turn lane with protected-left-turn indication (3-section head).

6. Figure 77-5F - left-turn lane with both protected- and permissible-left-turn indications (5-section head). Figure 77-5F also illustrates the preferred arrangement of the 5-section head (i.e., the clustered or doghouse display).

7. Figure 77-5G - multi-lane approach with a left-turn lane.

8. Figure 77-5H - multi-lane approach with both left- and right-turn lanes.

**77-5.01(02) Visibility Requirements**

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

A driver’s vision is vertically limited by the top of the vehicle’s windshield. This restriction requires the signal to be located far enough beyond the stop line to be seen by the driver. The *MUTCD* requires a minimum distance of 12 m from the stop line. The lateral location of the indication should be in the driver’s cone of vision. Research indicates that this cone of vision should be within 5 deg on either side of the center line of the eye position (i.e., a cone of 10 deg). The *MUTCD* requires that at least one and preferably two signal faces be located within 20 deg on either side of the center of the approach lanes extended (i.e., a cone of 40 deg). There may be confusion as to where to measure the center of the approach lanes for a multi-lane approach.

Figure 77-5J, Vision Cone, illustrates INDOT's interpretation of this requirement. Parking lanes should not be included in this determination, but right- and left-turn lanes should be included.

The following discusses other requirements that should be met in determining the location of a signal indication.

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

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

3. Signal heads for one approach should be mounted not less than 3.0 m between the centers of the heads, measured perpendicular to the direction of travel.

4. Where practical, at least one, and preferably both signal heads that control through traffic should be located neither less than 12 m nor more than 45 m beyond the stop line.

5. Where the nearest signal head is more than 36 m, but 45 m or less beyond the stop line, a 300-mm-diameter signal indication or a supplemental near-side signal head should be used. Only a 300-mm-diameter lens should be used on a State highway. Where the nearest signal head is more than 45 m beyond the stop line, a supplemental near-side signal head should be used.

## 77-5.02 Placement of Signal Equipment

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

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

2. Controller. In determining the location of the controller cabinet, the designer should consider the following.

   a. The controller cabinet should be placed so that it is unlikely to be struck by an errant vehicle. It should be outside the clear zone or obstruction-free zone.

   b. The controller cabinet should be located where it can be easily accessed by maintenance personnel.

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

   d. The controller cabinet should be located where the potential for water damage is minimized.

   e. The controller cabinet should not obstruct intersection visibility.

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

3. Traffic-Signal Support. A traffic-signal support should be placed to provide the obstruction-free-zone width through the area where it is located. However, the following exceptions will apply.

   a. Channelized Island. Installation of a signal support in a channelizing island should be avoided, if practical. However, if a signal support must be located in a channelizing island, a minimum clearance of 9.0 m should be provided in a rural area from all travel lanes including turn lanes, or in an urban area where the posted speed limit is 50 mph (80 km/h) or higher. In an urban area where the island is bordered by a barrier curb and the posted speed limit is 45 mph (70 km/h) or lower, a minimum clearance of 3.0 m should be provided from all travel lanes including turn lanes.

   b. Non-Curbed Facility, Posted Speed Limit ≥ 50 mph (80 km/h) or ADT > 1500. Where conflicts exist such that the placement of a signal support outside of the obstruction-free zone is impractical (e.g., conflict with buried or utility cable), the signal support should be located at least 3.0 m beyond the outside edge of the paved shoulder.

   c. Non-Curbed Facility, Posted Speed Limit ≤ 45 mph (70 km/h) or ADT ≤ 1500. Where conflicts exist such that the placement of the signal support outside of the obstruction-free zone is impractical (e.g., conflict with buried or utility cable), the signal supports should be located at least 2.0 m beyond the outside edge of the paved shoulder.

d. Curbed Facility. For a curbed facility, see Section 55-5.02. For a facility with curbs less than 150 mm in height, see Items 3.a. and 3.b. above.

4. Pedestrian Conflict. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflict. The signal pole should not be placed so as to restrict a handicapped individual's access to a curb ramp. A pedestrian call button must be conveniently located. Section 51-1.0 provides criteria for handicapped accessibility.

## 77-5.03 Pedestrian Signal

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

## 77-5.04 Pavement Marking and Signing

Cantilevers or span cables often include regulatory and informational signs (e.g., left turn only symbol, street-name sign). The designer should consider the effect the weight of the sign and additional wind loading will have on the cantilever or the span cables. The designer should strive to limit the number of signs on a traffic-signal structure. Chapter Seventy-five provides additional guidance on the placement and design of signs.

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

## 77-5.05 Electrical System

The electrical system consists of electric cables or wires, connectors, conduit, handholes, etc. Electric connections between the power supply, controller, detectors, and signal poles are carried in conduit. The designer should consider the following when developing the traffic-signal wiring plan.

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

2. Electric Cables. All electric cables and connections must meet national, state, and local electric codes, in addition to the NEMA criteria, except for the green wire, which is used for the green indication or interconnect function and not for the system ground. The number of conductor cables should be kept to a minimum of 3 or 4 combinations, to reduce inventory requirements. A 7-conductor cable is used between a controller and disconnect hanger or cantilever base. A 5-conductor cable is used between the disconnect hanger or cantilever base and the signal indications. Connections to flashers use a 3-conductor cable. The INDOT *Standard Drawings* illustrate the correct procedures for wiring and splicing cables.

3. Cable Run. Each electric-cable run should be continuous between the following:

    a. controller to base of cantilever structure or pedestal;
    b. controller to disconnect hanger;
    c. base of cantilever structure or disconnect hanger to signal indication; and
    d. controller to detector housing.

4. Handhole. A handhole should be located adjacent to the controller cabinet, each signal pole, and each detector location. The INDOT *Standard Drawings* provide additional details for handholes and wiring. The maximum spacing between handholes is 75 m.

5. Underground Conduit. Underground conduit is used to connect the controller, traffic signals, and loop detectors. Most conduits run underneath the pavement and between the handholes, typically using a 50-mm-diameter conduit. For a run with additional cables, the conduit size may need to be increased. The national electrical codes should be checked to determine the appropriate conduit size for the number of electric cables that can be contained within the conduit. The INDOT *Standard Drawings* provide additional details on the placement of underground conduit.

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

7. Detector Housing. A detector housing should be a cast-aluminum box encased in concrete. A detector housing is used to splice the 1C/14 wires from the loops to the

2C/16 lead-in cable to the detector amplifier. The INDOT *Standard Drawings* provide additional information on detector housings, including wiring details.

8. Disconnect Hanger. A disconnect hanger is used for cable-span-mounted signal heads to provide a junction box between the signal heads and the controller.

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

10. Interconnect Cable. INDOT uses a 7C/14 signal wire for hard-wiring interconnected signals. For a closed-loop system, the hard-wired connection should use a telecommunication cable consisting of either a fiber optic cable or a 6-pair twisted cable.

## 77-5.06 Phasing

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

### 77-5.06(01) Phasing Types

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

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

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

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

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

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

   d. T-Intersection. A 3-phase operation will be required if there is heavy turning volume on the through street. The 3-phase operation allows a number of options depending on the traffic volume and geometrics of the intersection (e.g., left- and right-turn lanes). Figure 77-5 O, T Intersection, illustrates two options.

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

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

5. Other Phases. For other phase operations (e.g., 6-phase operations), one of the above phase operations can be used by eliminating the non-applicable phase from the sequence.

Figures 77-5K, 77-5L, 77-5M, 77-5N, 77-5 O, and 77-5P also illustrate the movements that should be assigned to the numbered phases. For a 4- or 8-phase operation, the through phases are assigned to the even-numbered phase-diagram locations, and the left turns are assigned to the odd-numbered phase-diagram locations.

The controller accommodates control of each individual phase. Each phase is programmed as single-entry operation in which a single phase can be selected and timed alone if there is no demand for service in a non-conflicting phase. Where a 2-through 4-phase controller is involved (single-ring controller), there are no concurrent phases timed. For a controller with 5 to 8 phases, there are phases that can be timed concurrently (dual-ring controller). For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement (i.e., Phase 1 can be timed concurrently with Phase 5 or Phase 6), but not with another phase or vice versa. This concurrent timing is not an overlap because each phase times individually. An overlap is dependent on the phase or phases with which it is overlapped for time and is terminated as the phase or phases terminate.

There are computer programs available that can assist the designer to determine the appropriate phasing requirements (see Section 77-5.09). The Office of Traffic Engineering may be contacted for more information on the latest software packages or versions used by INDOT.

**77-5.06(02) Left-Turn Phase**

The most commonly added phase is for protected left-turns (i.e., left-turning vehicle is given a green arrow without a conflicting movement). A left-turn phase can be either a leading left, where the protected left turn precedes the opposing through movement, or a lagging left, where the left-turn phase follows the opposing through movement. The decision on whether to use either a leading-left or a lagging-left turn will be determined as required for each intersection. INDOT's preferred practice is to use the leading left. Figure 77-5Q provides a comparison for each left-turn phase alternative.

Not every signalized intersection will require a separate left-turn phase. The decision on whether to provide an exclusive left-turn phase is dependent upon traffic volume, delays, and accident history, and this will be determined as required for each intersection. For an intersection with exclusive left-turn lanes, the following guidelines may be used to determine the need for a left-turn phase.

1. Capacity. A left-turn phase should be considered where the demand for left turns exceeds the left-turn capacity of the approach lane. The left-turn capacity, $C_{lt}$, of an approach lane can be determined as follows:

   $$C_{lt} = 1200t_g – V_{opp}$$

   Where $t_g$ is the percent of total green time for the direction expressed as a decimalized fraction, and $V_{opp}$ is the opposing-direction's total traffic volume.

   $C_{lt}$ should not be less than two vehicles per cycle.

2. Delay. A left-turn phase should be considered where the delay time for a left-turning vehicle is excessive for four hours during an average day. Delay is considered excessive if a left-turning vehicle is delayed for more than two complete signal cycles.

3. Miscellaneous. In addition to capacity and delay guidelines, the designer should consider intersection geometrics, total volume demand, accident history, posted speeds, etc.

4. Non-INDOT Facility. The ITE *Manual of Traffic Signal Design* provides guidelines for where left-turn phasing may be considered.

On an approach without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined as required for each situation. Where practical, opposing left-turn arrows should also be provided.

## 77-5.07 Pre-timed Traffic-Signal Timing

### 77-5.07(01) Guidelines for Signal Timing

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

The following provides guidelines that the designer should consider when developing the signal timing for pre-timed signals.

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

2. <u>Cycle Length</u>. A short cycle length yields the best performance by providing the lowest average delay, provided the capacity of the cycle to pass vehicles is not exceeded. The designer should consider the following.

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

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

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

3. <u>Green Interval</u>. The division of the cycle into green intervals will be approximately correct if made proportional to the critical-lane volume for the signal phases. The critical-lane volume can be quickly determined by using the *Highway Capacity Manual*'s Planning Methodology. The designer should check the green interval against the following.

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

    b. Minimum Length. A major movement relative to driver expectation should not have a green interval of less than 15 s. An exception to this may be appropriate for special turn phases.

4. <u>Capacity</u>. For an intersection approach with a high left-turn volume, the capacity of an intersection should be checked to determine the need for a separate left-turn lane; see Section 77-5.06(02).

5. <u>Phase-Change Interval</u>. Each phase-change interval (yellow plus all red) needs to be checked to ensure that an approaching vehicle can either come to a stop or clear the intersection during the change interval.

6. <u>Coordination</u>. Traffic signals within 800 m of each other should be coordinated together in a system. Section 77-6.0 further discusses signal-system coordination.

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

**77-5.07(02) Cycle-Length Determination**

In determining the appropriate cycle length or interval length, the designer should consider the following.

1. General. Cycle length should be within the following ranges.

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

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

$$Y + AR = t + \frac{V}{2a \pm 19.6g} + \frac{W + L}{V} \qquad \text{(Equation 77-5.1)}$$

Where:

$Y + AR$ = Sum of the yellow and any all-red, s

$t$ = perception/reaction time of driver, s (typically assumed to be 1 s)

$V$ = approach speed, m/s

$a$ = deceleration rate, $m/s^2$ (assumed to be 3.0 $m/s^2$)

$W$ = width of intersection, m

$L$ = length of vehicle, m (assumed to be 6.0 m)

$g$ = approach grade, percent of grade divided by 100 (add for upgrade or subtract for downgrade)

The yellow change interval is in the range of 3 to 6 s. The maximum all-red interval used by INDOT is 2 s.

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

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

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

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

Where:

$G$ = total green time available for all phases, s

$G_a$, $G_b$ = green interval in seconds calculated for street A or B

$V_a$, $V_b$ = critical-lane volume on street A or B

$Y_a$, $Y_b$ = phase-change interval, yellow plus all red, on street A or B, s

$C$ = cycle length, s

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

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

Where:

$G$ = minimum green time, s
$P$ = pedestrian start-off period, 4-7 s
$D$ = walking distance, m
$Y$ = yellow interval, s
$S$ = walking speed, should be taken as 1.2 m/s

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

4. Recheck. After the cycle length and interval lengths have been selected, the designer should recheck the design to ensure that sufficient capacity is available. Also, the designer may want to check several cycle lengths to ensure that the most-efficient cycle length and interval lengths are used. If the initial design is inadequate, the designer will need to perform the following:

   a. select a different cycle length;

   b. select a different phasing scheme; or

   c. make geometric or operational changes to the intersection approaches (e.g., add left-turn lanes).

   There are software programs available to assist in determining the most-efficient design. Section 77-5.09 discusses several of these programs.

## 77-5.08 Actuated-Controller Settings

As with a pre-timed controller, the district traffic engineer will be responsible for timing an actuated controller on a State highway after it is installed. However, the designer must understand how the signal timing will affect the efficiency of the actuated-signalized intersection. The designer must understand how the signal timing will affect the placement of the traffic detectors.

The design of actuated control is a trade-off process where the designer attempts to optimize the location of vehicular detection to provide safe operation, but yet provide controller settings that will minimize the intersection delay. The compromises that must be made among these conflicting criteria become increasingly difficult to resolve as approach speed increases. For example, on an approach with a posted speed limit of 35 mph (60 km/h) or higher, the detector should be located in advance of the dilemma zone. The dilemma zone is the decision area, on such an approach, where the driver needs to decide whether to go through the intersection or stop once the yellow interval begins. Depending on the distance from the intersection and vehicular speed, the driver may be uncertain whether to stop or continue through the intersection, thus, creating the dilemma problem. Figure 77-5R further defines the dilemma zone. The following discusses some of the design considerations for an actuated controller.

**77-5.08(01) Basic-Design Actuated Controller**

Basic-design actuated control with passage detection is limited in application to an isolated intersection with fluctuating or unpredictable traffic demands and an approach speed of 50 km/h or lower. Basic-design actuated control includes full-actuated and semi-actuated control equipment. INDOT does not use this type of signal control; see Section 77-5.08(02).

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

In developing the timing criteria and the detector placement, the designer should consider the following.

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

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

Where $n$ is the number of vehicles per lane which can be stored between the stop line and the detector.

The MAG selected should be able to service at least two vehicles per lane. Using Equation 77-5.6, this translates into a time of approximately 8 s. Assuming two vehicles occupy approximately 14 m, the detector should not be placed closer than 14 m from the stop line. Closer placement will not reduce the MAG.

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

2. Vehicular Extension. The vehicular extension setting fixes both the allowable gap and the passage of time at one value. The extension should be long enough so that a vehicle can travel from the detector to the intersection while the signal is in the green phase. However, the allowable gap should be kept reasonably short to assure quick transfer of the green phase to the side street. The headway between vehicles in a platoon average between 2 and 3 s. Therefore, the minimum vehicular extension time should be at least 3 s. For the maximum gap, studies have shown that a driver waiting during the red phase finds that gaps of 5 s or more are too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 s. For a quicker phase change, a shorter gap should be used (e.g., 3 to 3.5 s).

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

4. Detector Placement. The detector setback distance should be set equal to the time required for a typical vehicle to stop before entering the intersection. The vehicular passage time is used to determine this placement (e.g., 5.0 s). The posted speed of the approach roadway should be used to determine the appropriate setback.

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

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

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

8. Semi-Actuated Controller. For a minor street with semi-actuated control, the signal is green for the major street. To ensure that the mainline is not interrupted too frequently, a

longer minimum green interval should be used on the major street. It is expected that the low-volume minor street will experience delay.

9. Intermediate Traffic. Where a vehicle can enter the roadway between the detector and intersection (e.g., driveway, side parking) or where a vehicle may be traveling so slow that it does not clear the intersection in the calculated clearance time, the signal controller will not register its presence. A presence detector at the stop line may be required to address these situations; see Section 77-5.08(03).

### 77-5.08(02) Advanced-Design Actuated Controller

An advanced-design actuated controller is used at an isolate intersection with fluctuating or unpredictable traffic demands, and an approach speed of higher than 50 km/h. INDOT uses this type of controller, irrespective of the approach speed. An advanced-design actuated controller is one that has a variable initial interval. It can count waiting vehicles beyond the first one and can extend the initial interval to meet the needs of the number of vehicles actually stored between the stop line and the detector. As with basic-design actuated control, the small detection area requires that the controller have a locking memory.

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

1. Detector Placement. For an approach speed of higher than 50 km/h, the detector should be located in advance of the dilemma zone (see Figure 77-5R). This will place the detector at a location of about 5 s of passage time from the intersection. The speed selected should be the posted speed limit of the approach roadway. Figure 77-5S provides the appropriate detector set-back distance for a given combination of passage time and approach speed. Figure 77-5S also provides the passage time that is appropriate for other types of actuated controllers.

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

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

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

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

6. Maximum Green Phase Length. This should be set the same as for the basic-design controller, see Section 77-5.08(01).

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

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

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

A large-area detector is used with a basic-design actuated controller in the non-locking memory mode and with the initial interval and vehicular extension set at or near zero. This is referred to as the loop occupancy control (LOC). A large-area detector is used in the presence mode, which holds the vehicle call for as long as the vehicle remains over the loop. One advantage of a large-area detector is that it reduces the number of false calls due to right-turn-on-red vehicles. A large-area detector consists of four octagonal 1.8-m by 1.8-m small loops, 2.7 m apart connected in series; see the INDOT *Standard Drawings*. With a large-area detector, the length of the green time is determined by the time the area is occupied. However, a minimum green time of 8 to 15 s should be provided for driver expectancy. The following discusses the applications for LOC.

1. Left-Turn Lane. An LOC arrangement is appropriate for a left-turn lane where left turns can be serviced on a permissive green or yellow clearance or where vehicles can enter the left-turn lane beyond the initial detector. The designer should consider the following if using the LOC for a left-turn lane.

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

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

2. Through Lane, Low-Speed Approach. For an approach speed of 50 km/h or lower, the dilemma zone protection is not considered a significant problem. The detection-area length and controller settings are determined based on the desired allowable gap. For example, assuming a 50 km/h approach speed and 3-s desired allowable gap, the LOC area is calculated to be as follows:

$$\left(\frac{50\ km}{h}\right)(3\ s)\left(\frac{1000\ m}{km}\right)\left(\frac{h}{3600\ s}\right) = 42\ m$$

The vehicular length (6 m) should be subtracted from the LOC, so that the required detector-area length is 36 m. INDOT's loop layout length is only 14 m. Therefore, for a 50-km/h approach speed, the vehicular extension setting should be set at 1.5 s to provide the 3-s gap.

If the initial interval is set at zero and the vehicular extension is between zero and 1 s, then, under low traffic volume conditions, a green interval as short as 2 or 4 s may occur. The designer should check to determine if there are pedestrian or bicyclists present. If so, the minimum green times for their crossings should be provided. Driver expectancy should also be considered. A driver in a major through movement should expect a minimum green interval of 8 to 15 s.

3. Through Lane, High-Speed Approach. For an approach speed of 60 km/h or higher, it is not practical to extend the LOC beyond the dilemma zone (5 s of passage time back from the stop line). To solve the dilemma-zone problem, an extended-call detector is placed beyond the dilemma zone. This detector is used in a non-locking mode. The time extension is based on the time for the vehicle to reach the LOC area. An intermediate detector may be used to better discriminate the gaps.

The concerns with using the LOC concept for a high-speed approach include the following:

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

b. For a high-speed approach, an LOC design should only be used if the route ADT is 8,000 to 10,000. A high-speed approach with a higher traffic volume is better served with a density controller. The intersection of a high-speed artery with a low-speed crossroad is better served by using a density controller on the artery and LOC for the crossroad.

## 77-5.09 Computer Software

There are software programs available to help assist the designer in preparing traffic signal designs and timing plans. New programs, as well as updates to existing programs, are continuously being developed. Before using the programs, the designer should contact the Office of Traffic Engineering to determine which software packages or versions INDOT is currently using. The following programs are the most widely used for signal-timing optimization.

1. SOAP. The Signal Operations Analysis Package (SOAP) program develops a fixed-time, signal-timing plan for an individual intersection. SOAP can develop timing plans for six design periods in a single run. It can also analyze 15-min volume data for up to 48 continuous time periods and determine which timing plan is best suited for each 15-min period. A data-input manager is included with the program to facilitate data entry.

2. PASSER II and MAXBAND. Progression Analysis and Signal System Evaluation Routine (PASSER II) and MAXBAND are known as bandwidth-optimization programs. Each develops timing plans that maximize the through progression band along an arterial with up to 20 intersections. Each program works best in unsaturated traffic conditions and where turning movements onto the arterial are relatively seldom. PASSER II or MAXBAND can also be used to develop arterial phase sequencing for input into a stop-and-delay optimization model such as TRANSYT-7F.

3. TRANSYT-7F and SIGOP-III. The Traffic Signal Network Study Tool (TRANSYT-7F) and the Signal Timing Organization Program (SIGOP-III) can each develop a signal-timing plan for an arterial or a grid network. The objective of each program is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

4. Arterial Analysis Package. The Arterial Analysis Package (AAP) allows the user to easily access PASSER II or TRANSYT-7F to perform a complete analysis and design of arterial signal timing. The package includes a user-friendly forms display program so

that data can be entered interactively on a microcomputer. Through the AAP, the user can generate an input file for two of the component programs to quickly evaluate various arterial signal-timing designs and strategies. The package also links to the Wizard of the Helpful Intersection Control Hints (WHICH) to facilitate detailed design and analysis of an individual intersection. The current program interfaces with TRANSYT-7F, PASSER II, and WHICH.

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

6. TRAF-NETSIM. TRAF-NETSIM is a microscopic program that can be used to simulate traffic operations for an arterial, isolated intersection, or roadway network. It can be used to determine delay, queue length, queue time, stops, stop times, travel time, speeds, congestion measures, etc. However, it does not have optimizing capabilities (i.e., the user must conduct multiple simulations to determine the best signal timing). It can be used with either a fixed-timed or actuated-controlled intersection.

7. COPTRAFLO. COPTRAFLO can be used to develop a time-based diagram for an arterial. It can be used to determine the optimal traffic band for either a one-way or a two-way arterial. The program will also allow the user to review all available solutions and will provide the offsets for the system signals based on speed and cycle length.

Most of these software programs can be purchased from McTrans Center, 512 Weil Hall, Gainesville, Florida 32611-2083; or from PC-TRANS, Kansas University Transportation Center, 2011 Learned Hall, Lawrence, Kansas 66045. Many of these software programs can be purchased for either a mainframe or PC-based computer.

## 77-5.10 Maintenance Considerations

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

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

## 77-6.0 SIGNAL-SYSTEM DESIGN

As traffic volumes continue to grow, installation of coordinated signal systems is an important tool to improve traffic flow. By coordinating two or more traffic signals together, the overall capacity of the highway can be significantly increased. Traffic signals which are 800 m or closer to one another should be considered for coordination. Although not a perfect solution, the use of a coordinated traffic-signal system should satisfy the traffic needs of the highway for several years. It is also a relatively inexpensive method of improving capacity, thereby reducing delay, with minimal disruption to the highway as compared to the construction of additional lanes.

### 77-6.01 System-Timing Parameters

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

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

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

3. Offset. The time relationship determined as the difference between a specific point in the local signal sequence (typically the beginning of the major street green interval) and a system-wide reference point.

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

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

## 77-6.02 System Types

There are different methodologies available to coordinate traffic signals. Most of these take advantage of computer technology. As new signal controllers, computers, and software are developed, the design of coordinated traffic-signal systems will continue to improve. These systems should match existing systems or be coordinated with nearby systems. Traffic-signal systems are designed by consultants who specialize in this work. To maintain consistency, all traffic-signal system designs must be coordinated through the Office of Traffic Engineering. The following briefly describes some of these systems.

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

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

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

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

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

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

### 77-6.02(03) Traffic-Responsive Arterial System

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

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

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

### 77-6.02(04) Distributed-Master (Closed-Loop) System

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

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

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

### 77-6.02(05) Central Computer Systems (Interval-Command Systems)

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

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

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

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

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

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

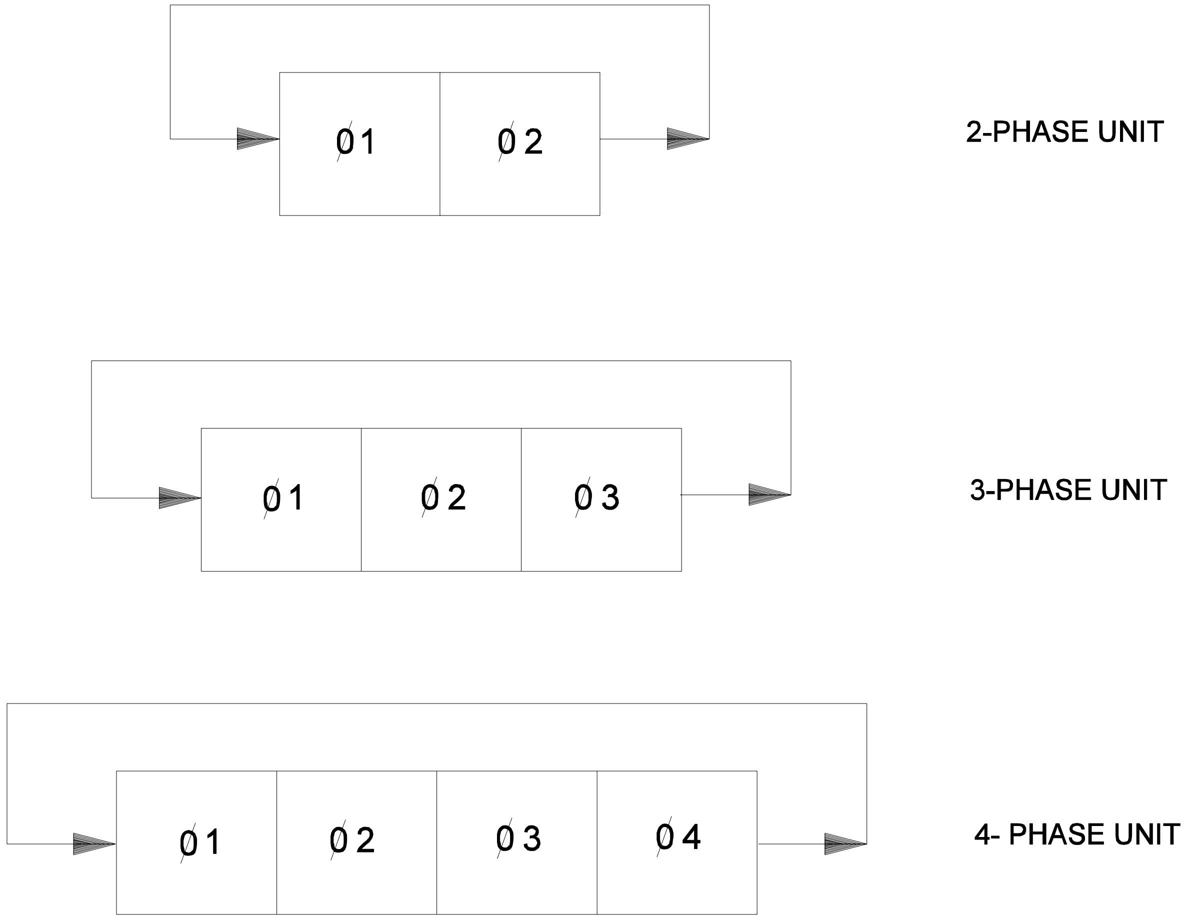
## 77-6.03 Communications Techniques

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

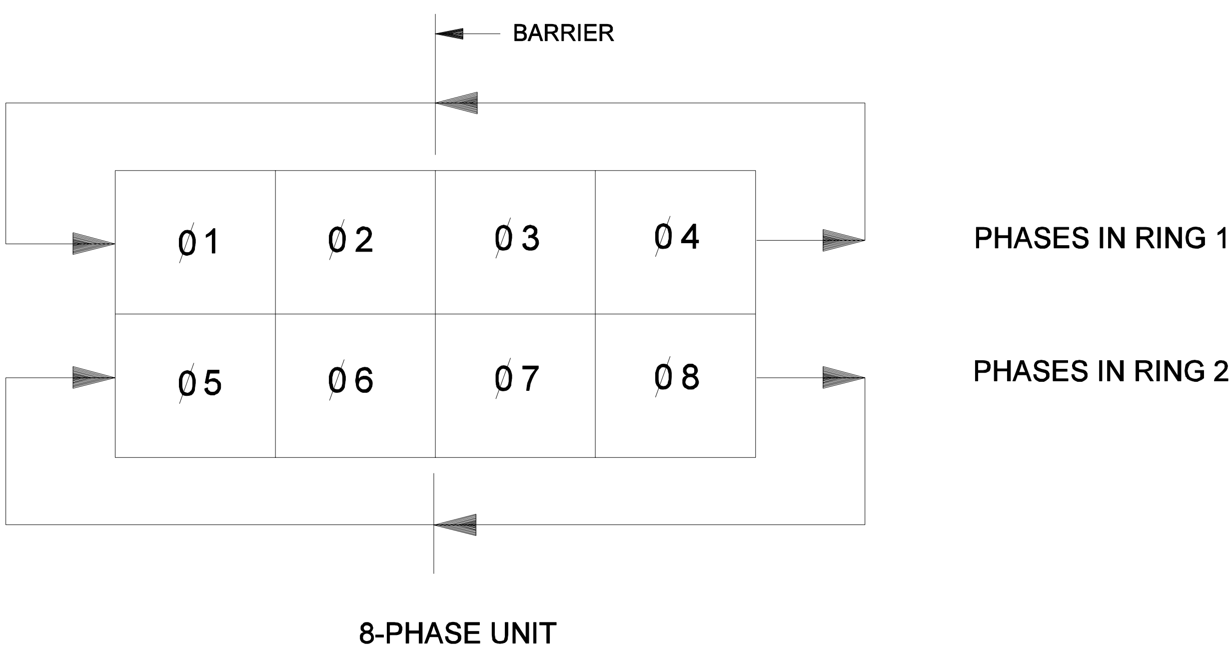
| NEMA CONTROLLER | |
|---|---|
| *Advantages* | *Disadvantages* |
| • Tested vendor software is updated as needed<br><br>• Interchangeability on a unit basis for basic 2- to 8-phase operations<br><br>• Includes several different man-machine interfaces<br><br>• Software liability is reduced<br><br>• Standard functional specifications | • Cabinets are not standardized between manufacturers<br><br>• Units are often physically larger than Model 170 types<br><br>• More difficult to adapt to special applications (i.e., ramp metering)<br><br>• May require large inventory of spare parts |
| **170 CONTROLLER** | |
| *Advantages* | *Disadvantages* |
| • Standard cabinet wiring and layout<br><br>• Controller can handle any control mode<br><br>• Considered to be cost effective for greater than five phases<br><br>• Reduced spare parts inventory | • Software costs may be high for one-of-a-kind applications<br><br>• Liability of software<br><br>• Keyboard interface is not optimal for setting or displaying information<br><br>• Not cost effective for less than five phases<br><br>• Reportedly lacks board interchangeability between manufacturers<br><br>• Software is available from reportedly only two sources<br><br>• NY/CA units are not interchangeable<br><br>• Software is not always interchangeable between units<br><br>• Requires relatively large purchase to be cost effective |

**NEMA AND MODEL 170 CONTROLLERS**

**Figure 77-4A**




(A) SINGLE-RING CONTROLLER UNITS




(B) DUAL-RING CONTROLLER UNIT

SEQUENCE OF PHASES

Figure 77-4B

| *Advantages* |
|---|
| • Low installation costs.<br>• Easy maintenance, no roadway interference.<br>• Considered most aesthetically acceptable.<br>• Good locations for pedestrian signals and push buttons.<br>• Provides good visibility where a wide median with left-turn lanes and phasing exist.<br>• Unlimited vertical clearance of roadway. |
| *Disadvantages* |
| • Requires underground wiring which may offset initial cost advantages.<br>• May not provide a location which provides minimum conspicuity.<br>• Does not provide good conspicuity for motorist.<br>• May not provide mounting location such that a display with clear meaning is provided.<br>• Height limitations may provide problems where approach is on a vertical curve.<br>• Subject to vehicular impact if installed close to the roadway, particularly in a median. |

**POST-MOUNTED SIGNALS**

**Figure 77-4C**

| *Advantages* |
|---|
| • Easy to install, less underground work required.<br>• Allows excellent lateral placement of signal heads for maximum conspicuity.<br>• Allows for easy future adjustments of signal heads.<br>• Allows complementary signal placement with respect to stop line.<br>• May provide convenient post locations for supplemental signal heads and pedestrian signals and push buttons.<br>• Permits bridles to reduce distances from stop line at an extremely wide intersection (see Figure 77-4G) |
| *Disadvantages* |
| • Requires four posts and is more expensive than a simple span.<br>• Adds to intersection clutter by adding the two posts.<br>• Seen by some users as aesthetically unpleasing. |

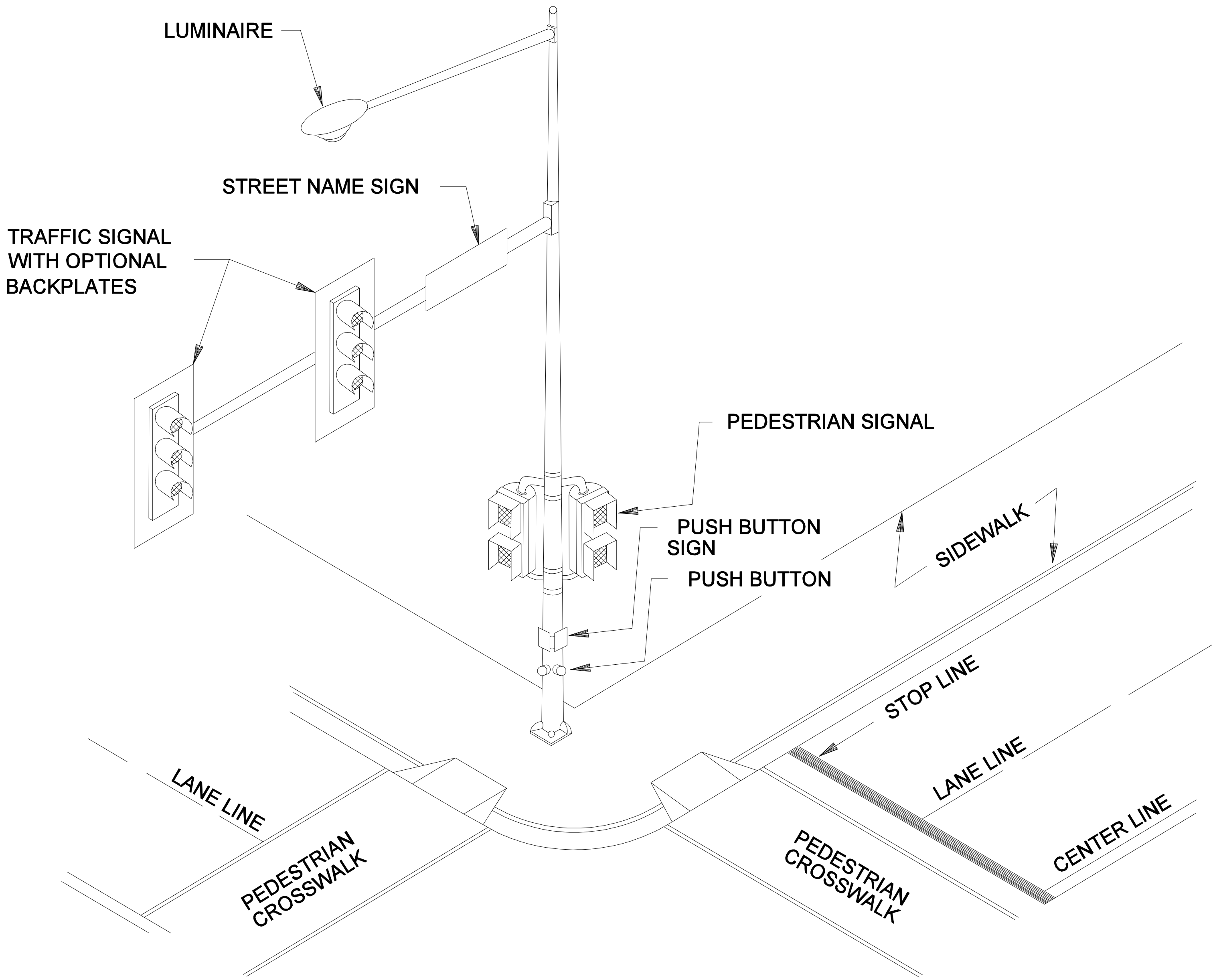
**CABLE-SPAN MOUNTED SIGNALS**

**Figure 77-4D**

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

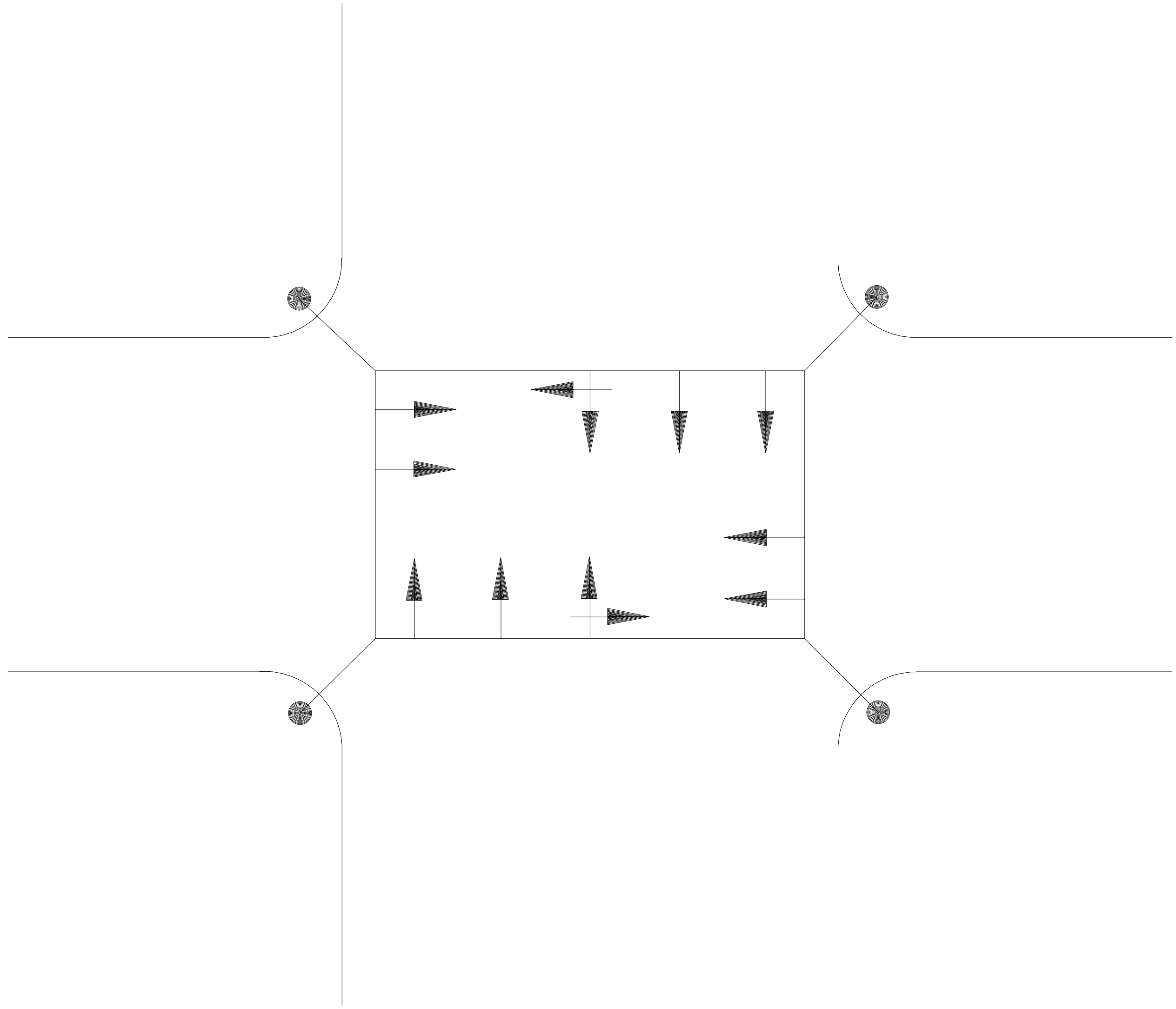
**CANTILEVER-MOUNTED MAST-ARM SIGNALS**

**Figure 77-4E**



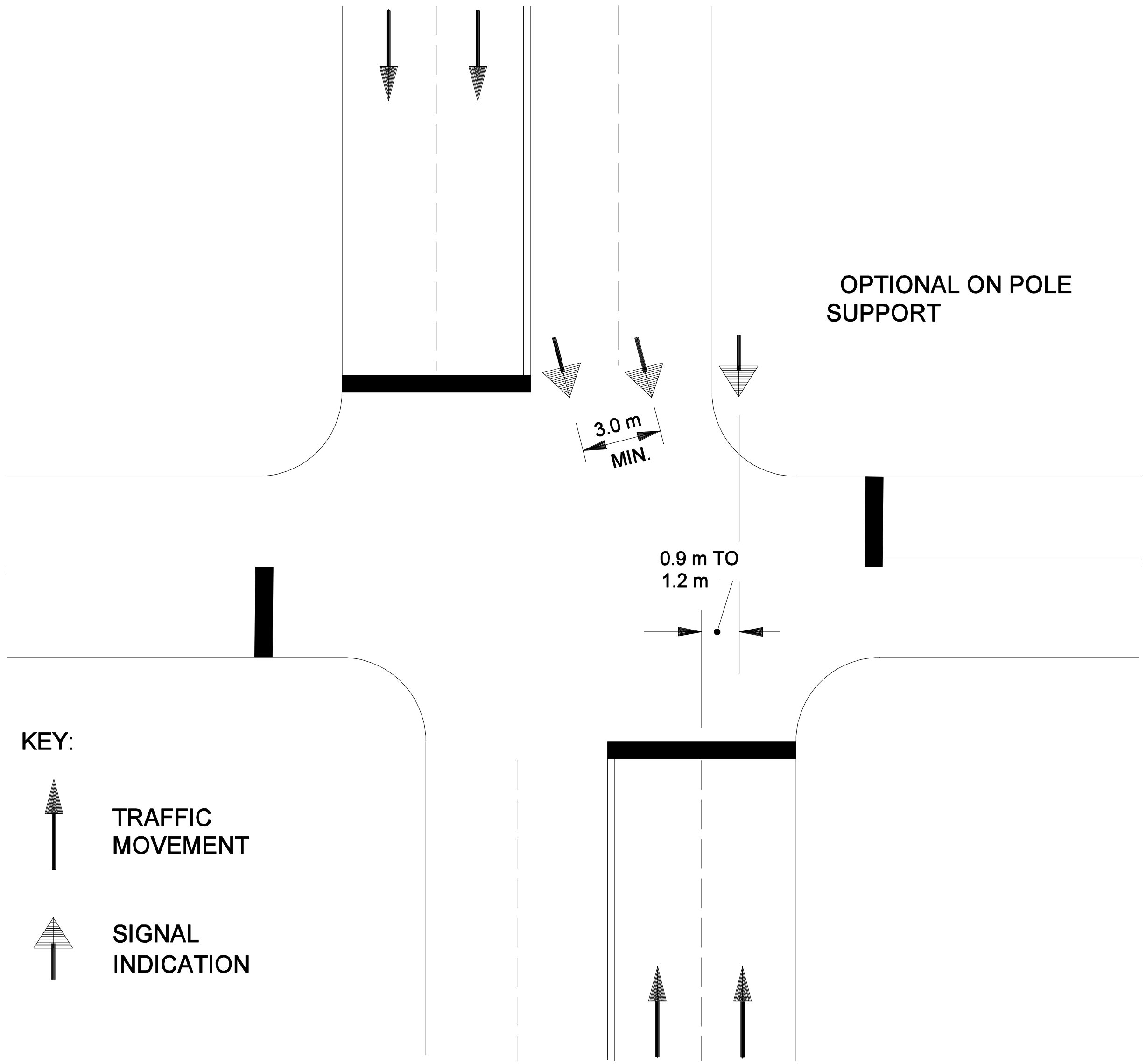

COMBINATION SIGNAL-LUMINAIRE POLE

Figure 77-4F



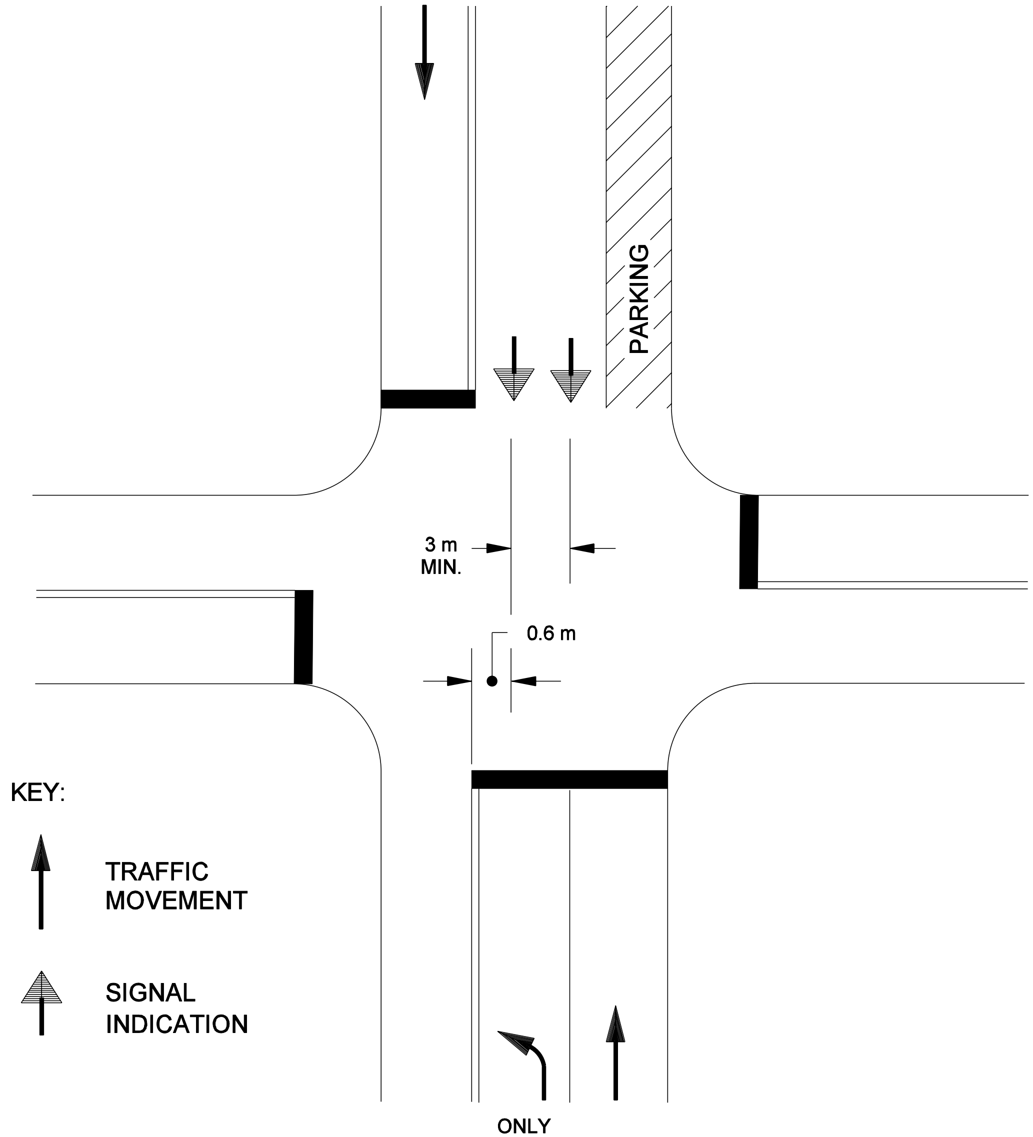
# CABLE-SPAN MOUNTED SIGNALS
(Bridle Configuration)

Figure 77-4G



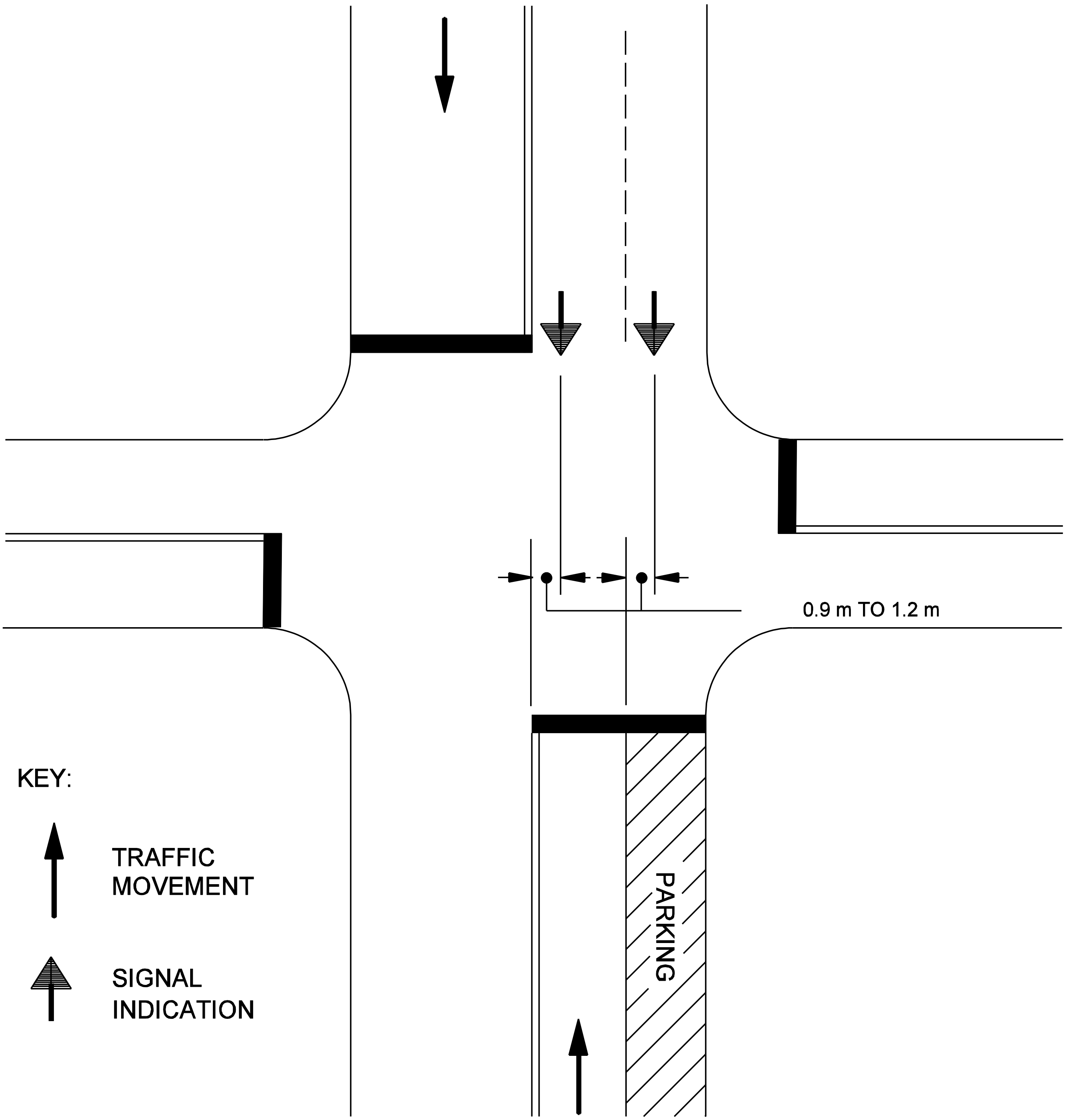

SIGNAL PLACEMENT
(Offsetting Intersections)

Figure 77-5A



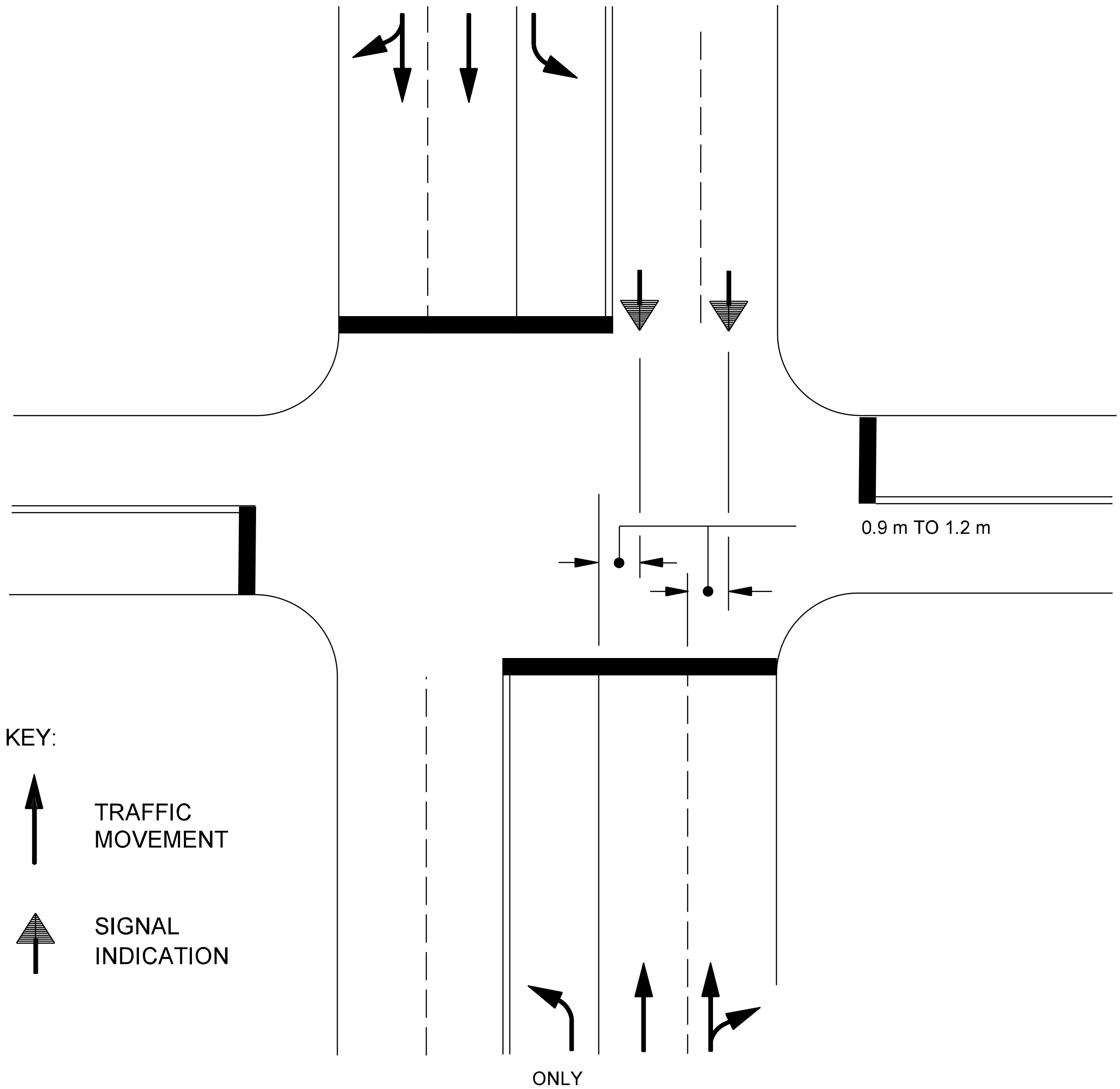

SIGNAL PLACEMENT
(Urban --- Left Turn Lane)

Figure 77-5B



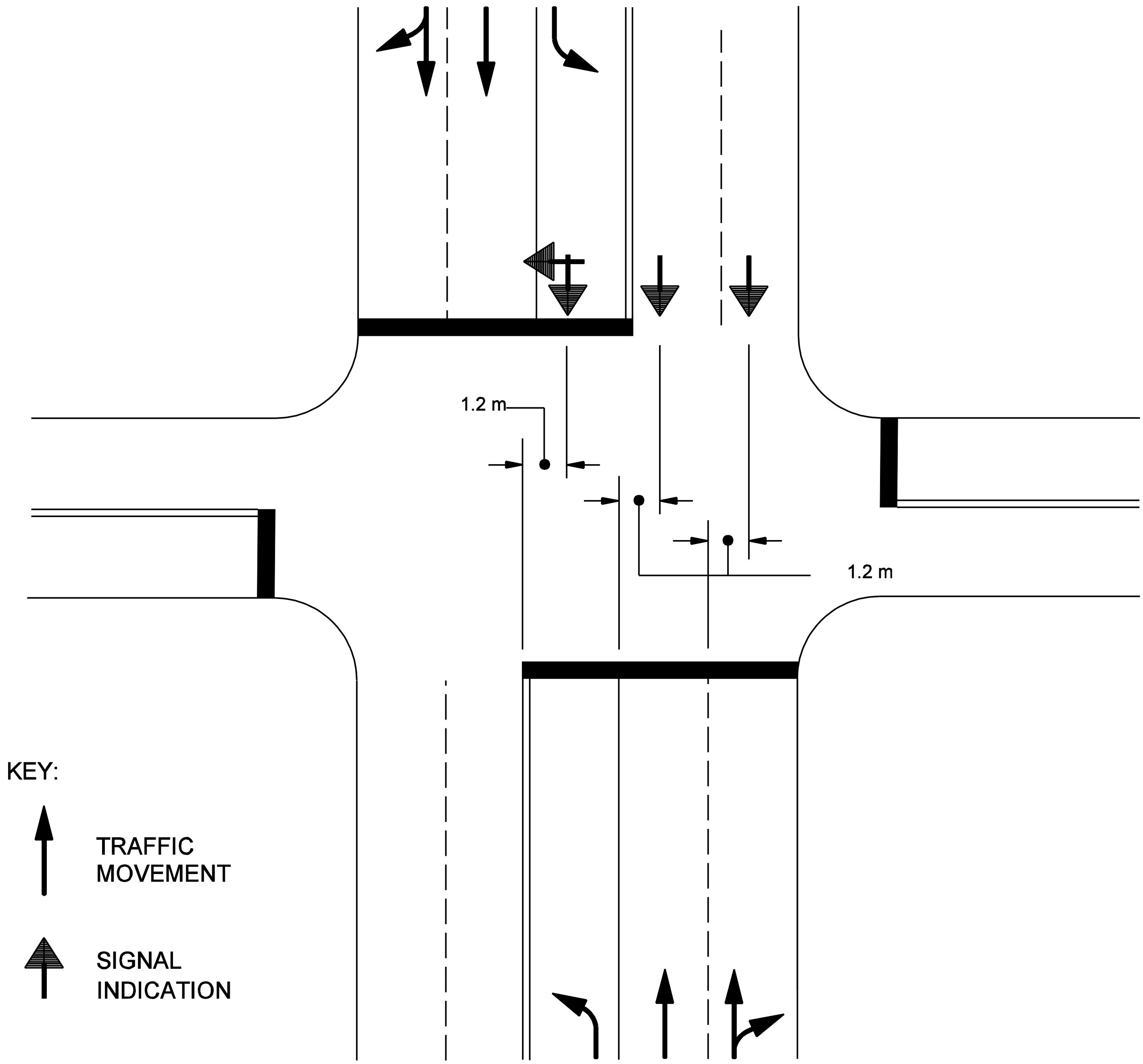

SIGNAL PLACEMENT
(Urban -- No Left-Turn Lane)

Figure 77-5C



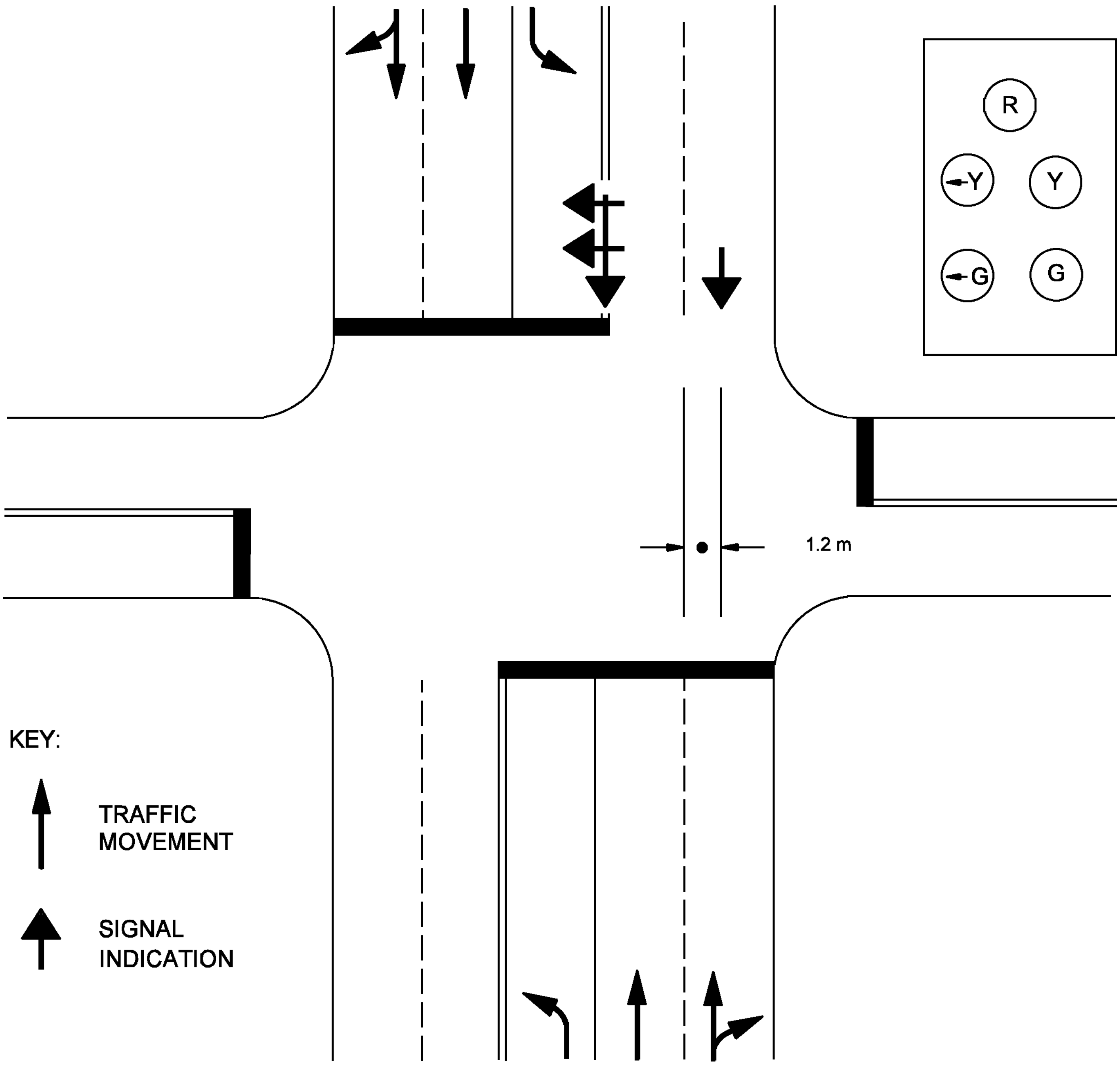

SIGNAL PLACEMENT
(Permissible Left Turn)

Figure 77-5D



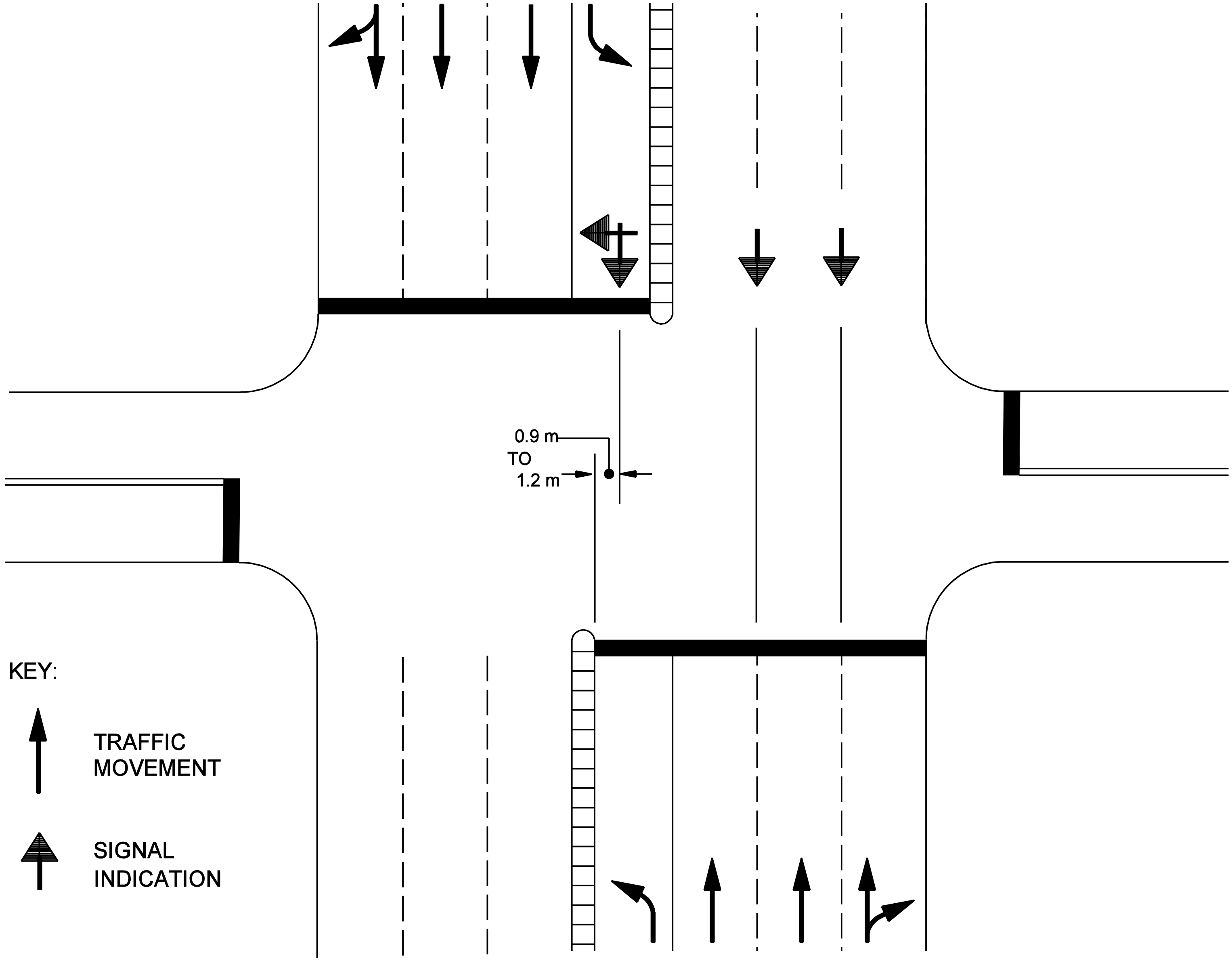

SIGNAL PLACEMENT
(Protected Left Turn)

Figure 77-5E



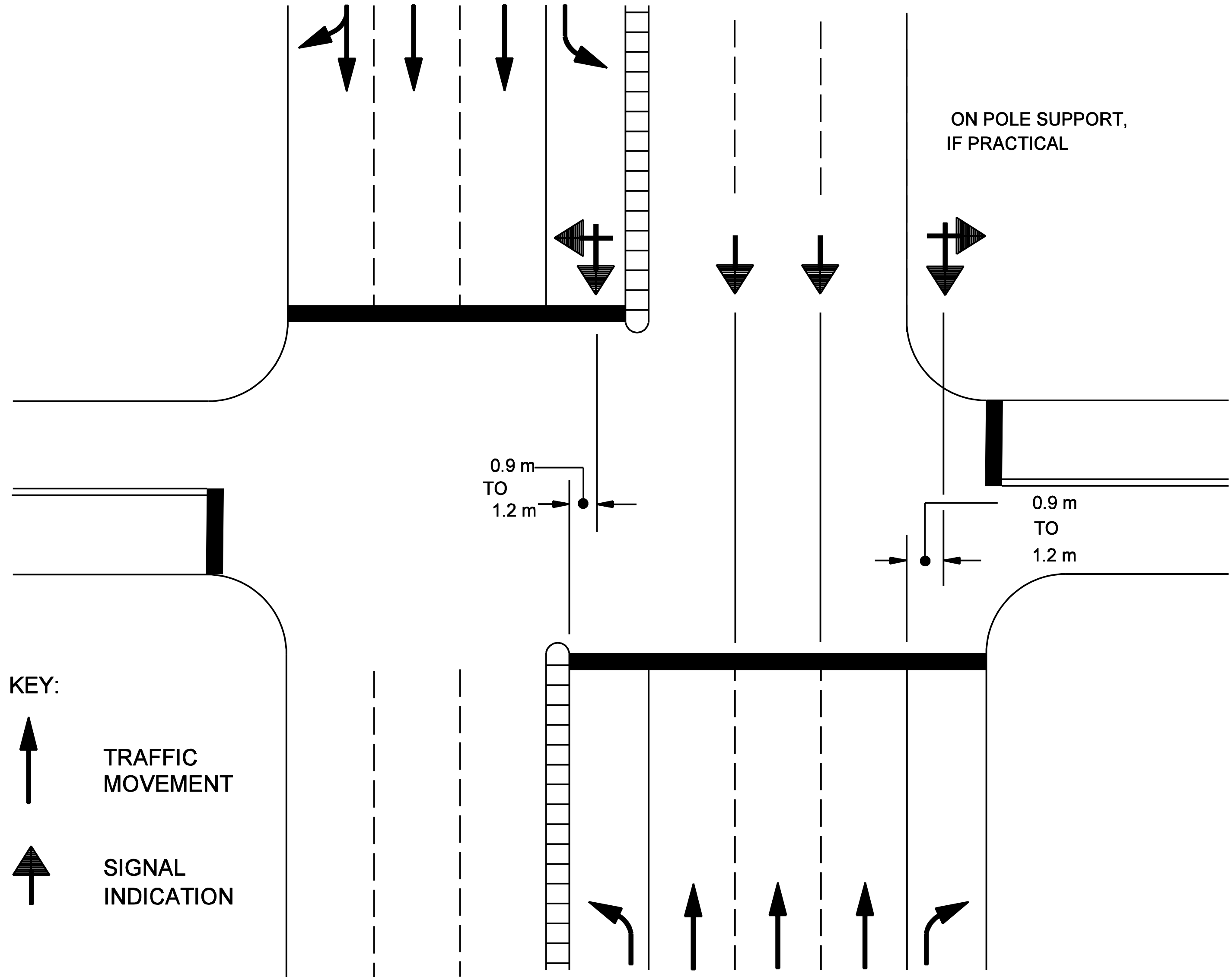

SIGNAL PLACEMENT
(Protected/Permissible Left Turn)

Figure 77-5F




SIGNAL PLACEMENT
(Multi-Lane Approach -- Left-Turn Lane)

Figure 77-5G




SIGNAL PLACEMENT
(Multi-Lane Approach -- Right/Left-Turn Lanes)

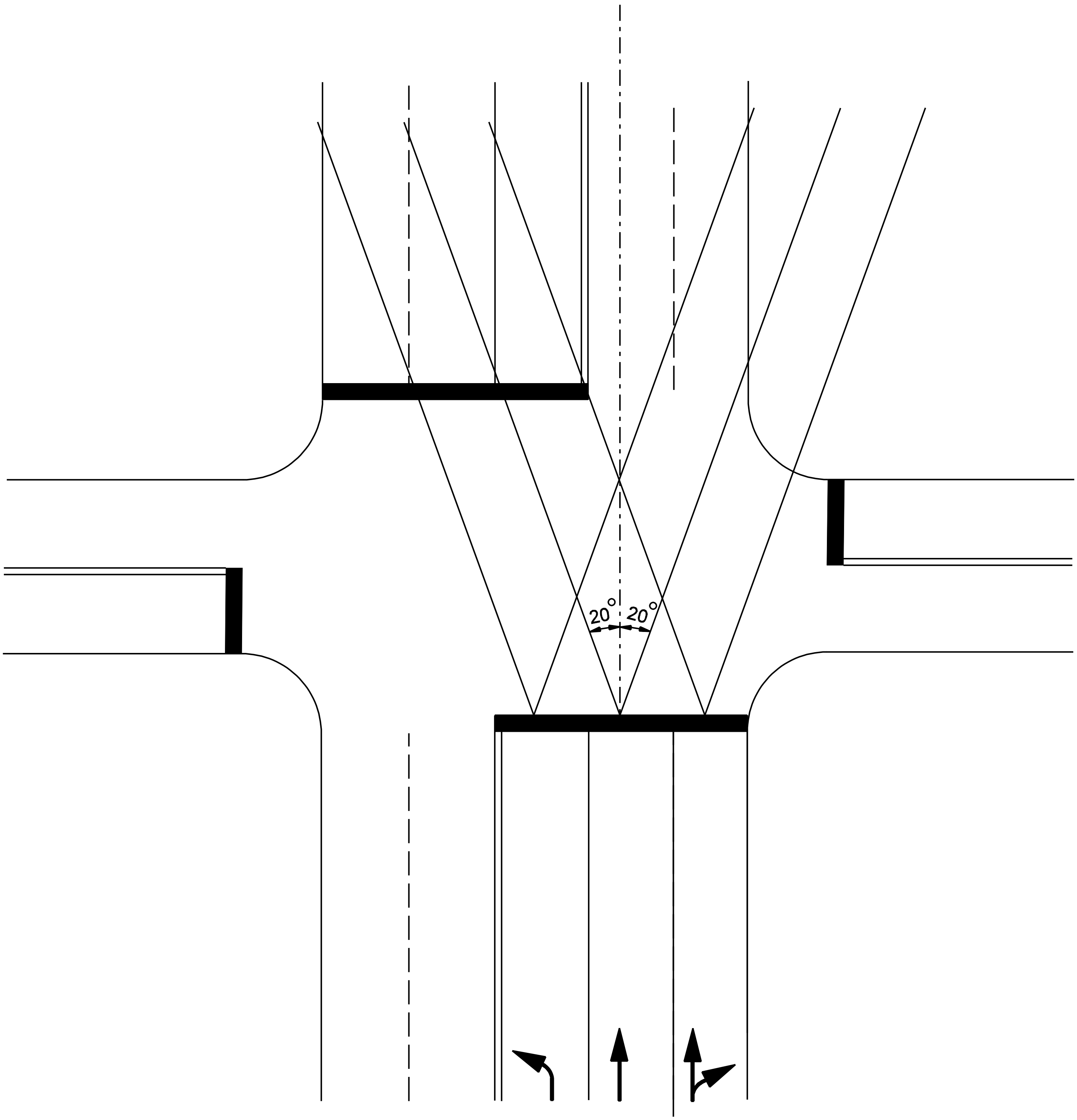
Figure 77-5H

| 85th Percentile Speed, km/h | Minimum Visibility Distance, m |
|---|---|
| 30 | 50 |
| 40 | 65 |
| 50 | 85 |
| 60 | 110 |
| 70 | 135 |
| 80 | 165 |
| 90 | 195 |
| 100 | 230 |

*Note: The distance is based on the Federal MUTCD.*

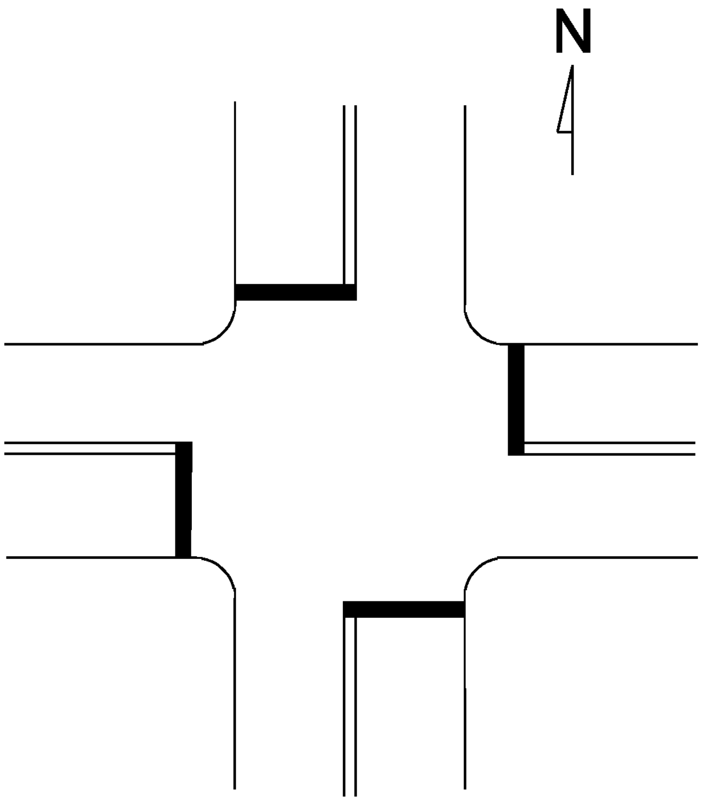
**MINIMUM-VISIBILITY DISTANCE**

**Figure 77-5 I**

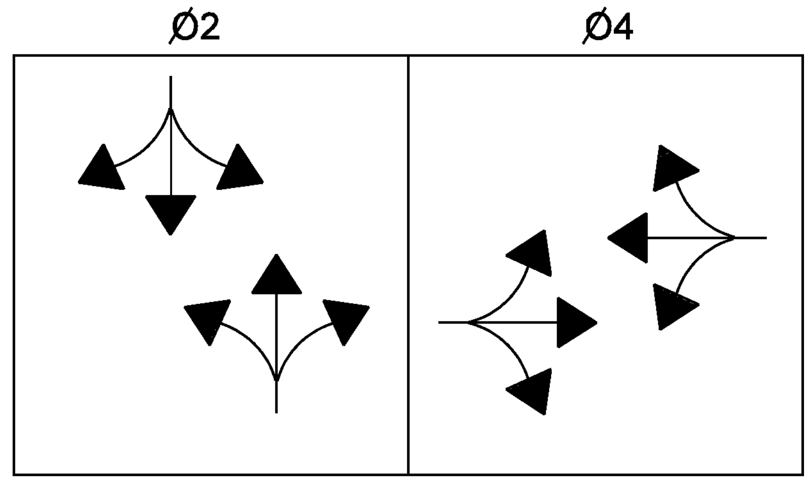



VISION CONE

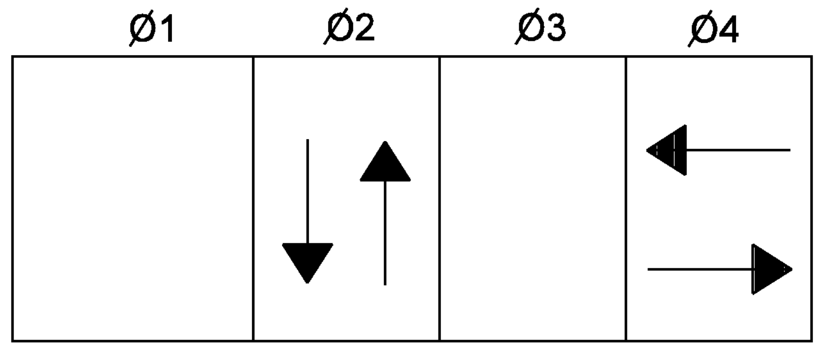
Figure 77-5J




TRAFFIC MOVEMENTS




PHASE DIAGRAM

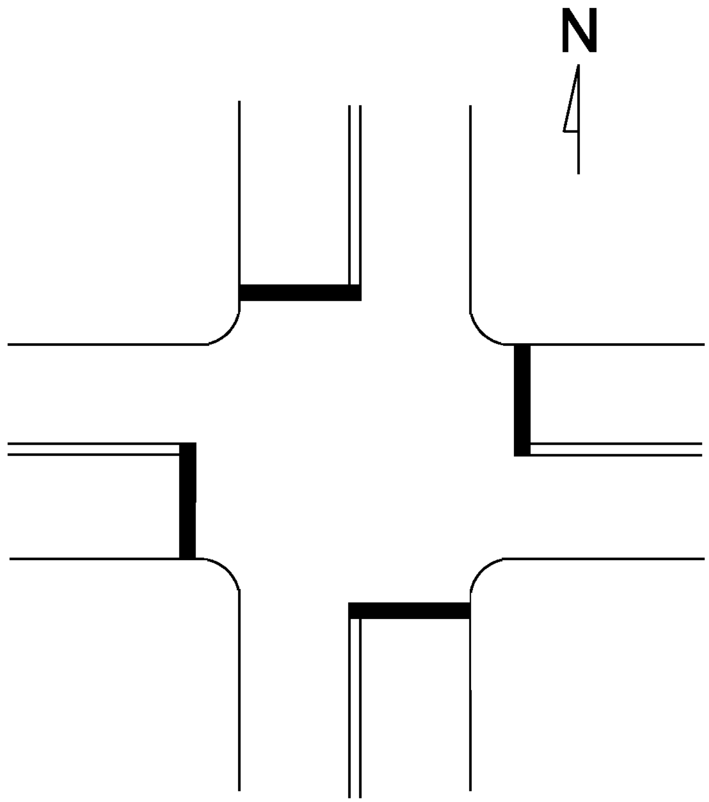


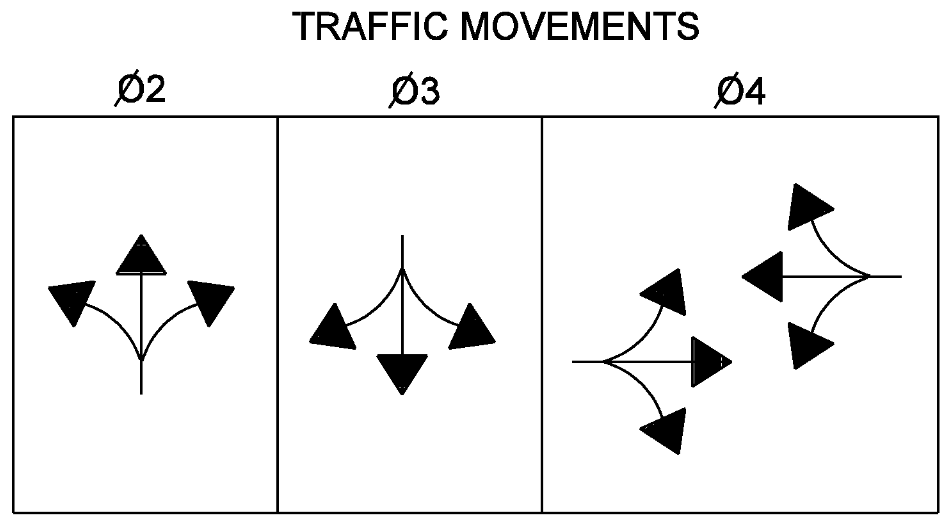

NOTES:

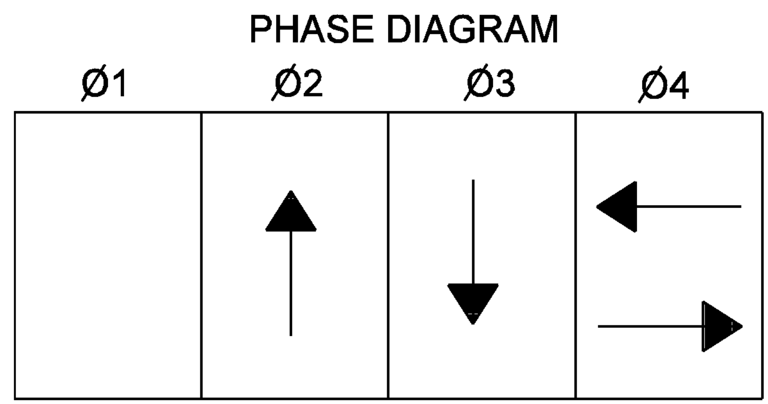
N-S IS PREFERENTIAL
N-S FLASHES AMBER
E-W FLASHES RED

# TWO-PHASE OPERATION

Figure 77-5K




NOTES:

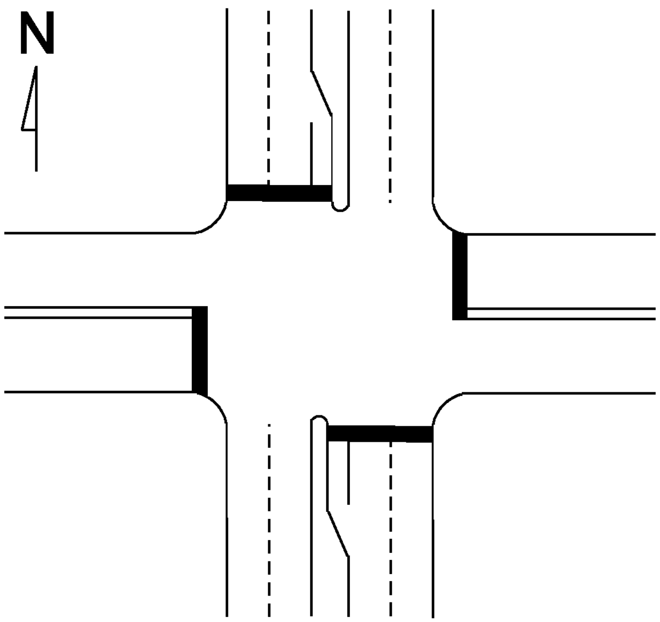
N-S IS PREFERENTIAL

N-S FLASHES AMBER

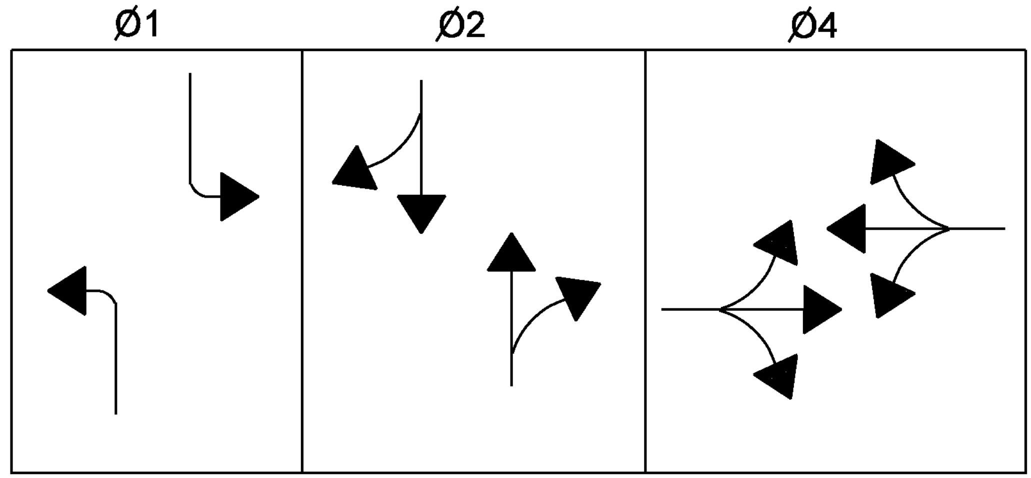
E-W FLASHES RED

# THREE-PHASE OPERATION
## (Separate Split Phases for Major Street)

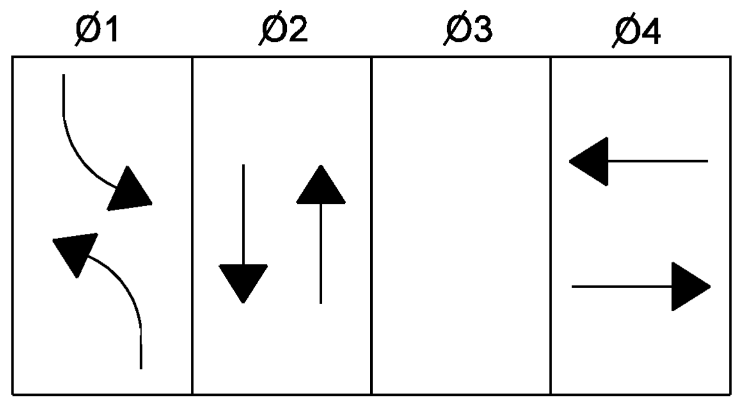
Figure 77-5L




TRAFFIC MOVEMENTS




PHASE DIAGRAM




NOTES:

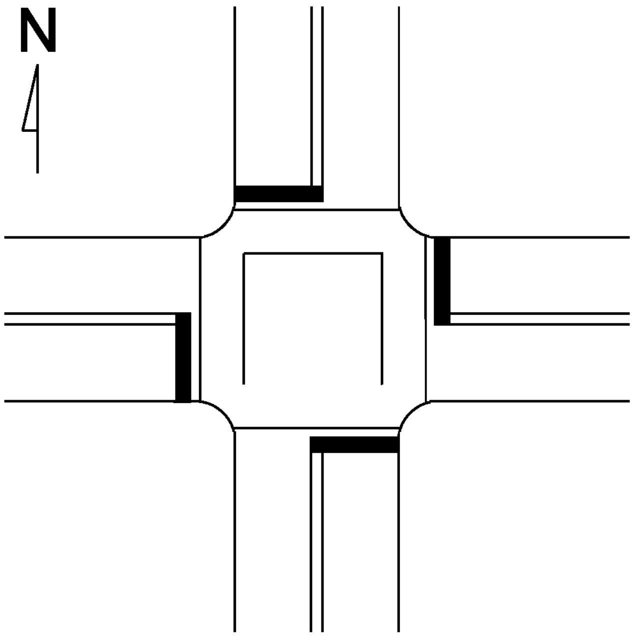
N-S IS PREFERENTIAL

N-S FLASHES AMBER

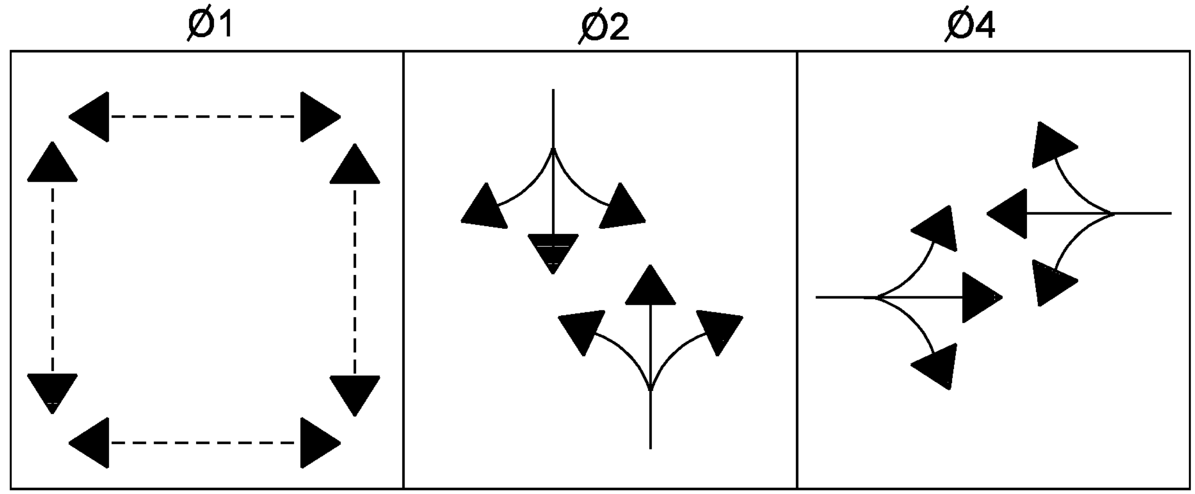
E-W FLASHES RED

# THREE-PHASE OPERATION
## (Separate Left-Turn Phase on Major Street)

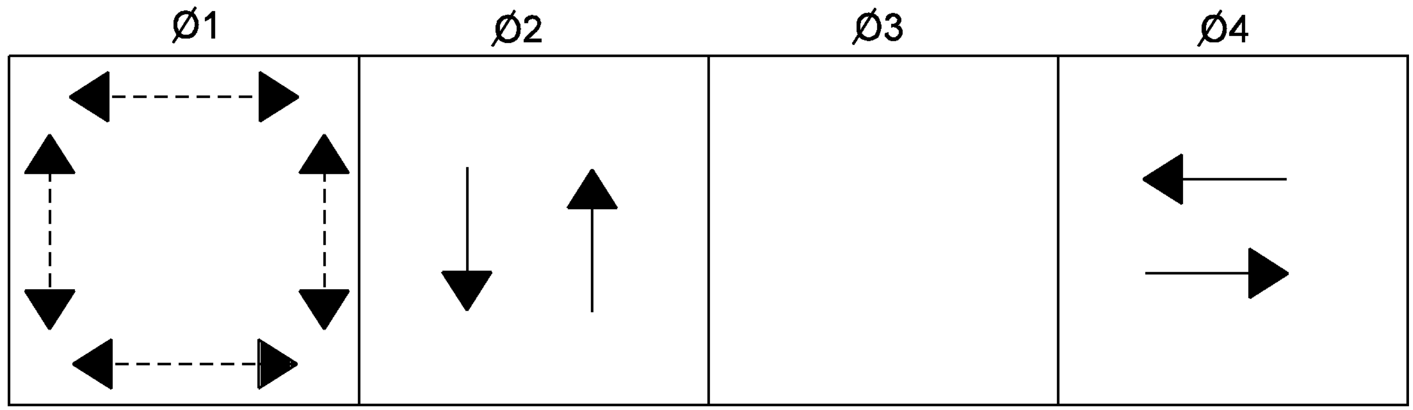
Figure 77-5M




TRAFFIC MOVEMENTS




PHASE DIAGRAM

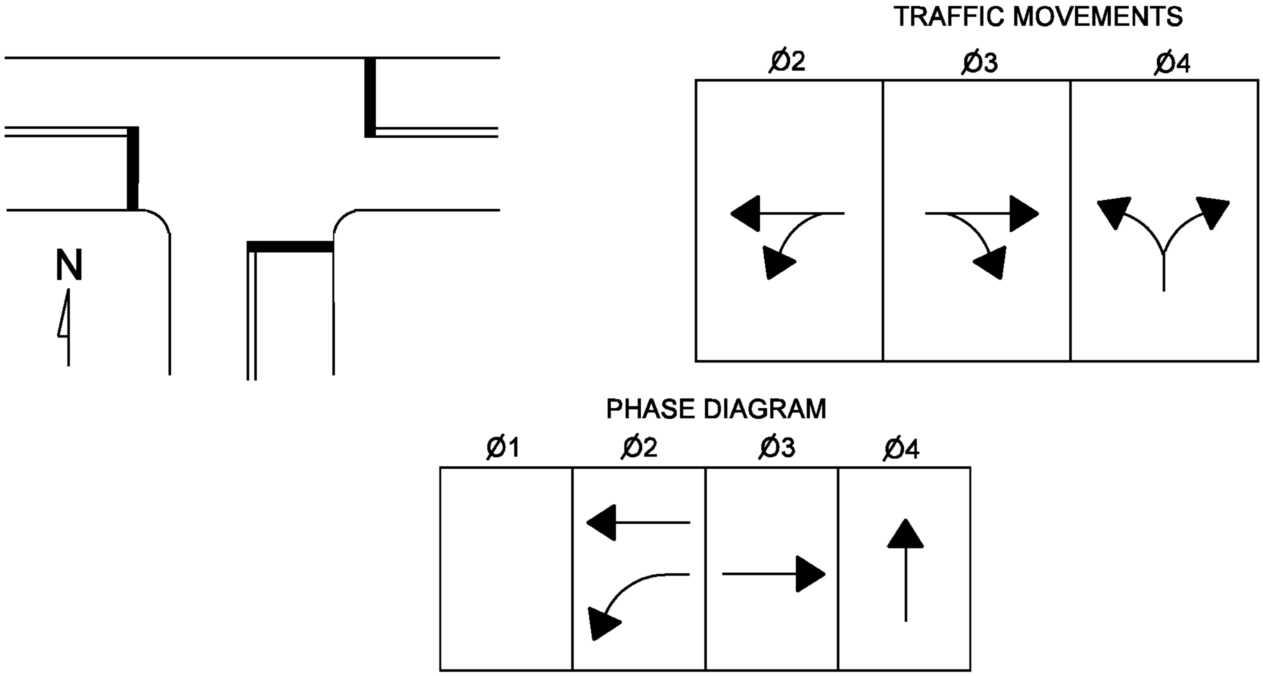



NOTES:

N-S IS PREFERENTIAL
N-S FLASHES AMBER
E-W FLASHES RED

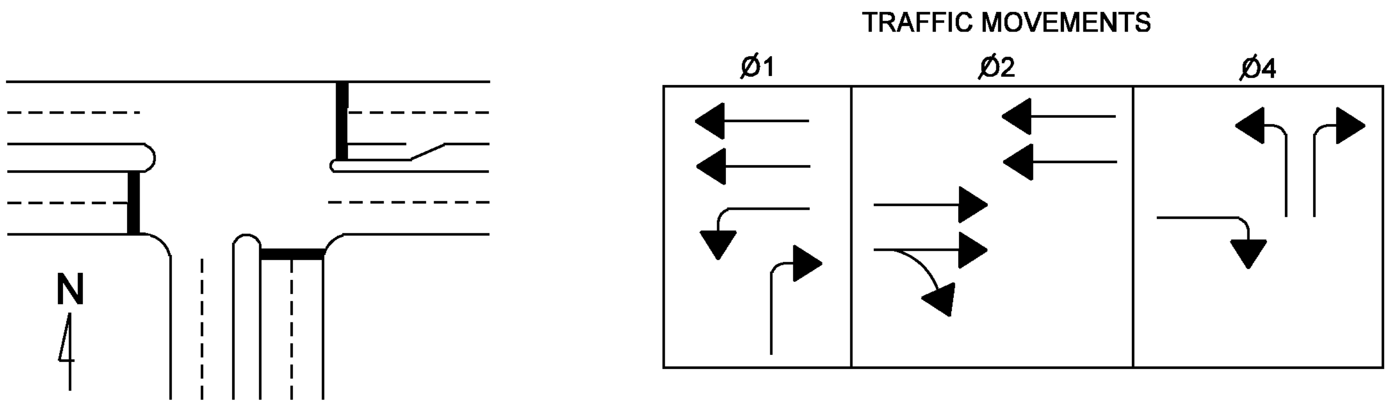
# THREE-PHASE OPERATION
## (Exclusive Pedestrian Phase)

Figure 77-5N



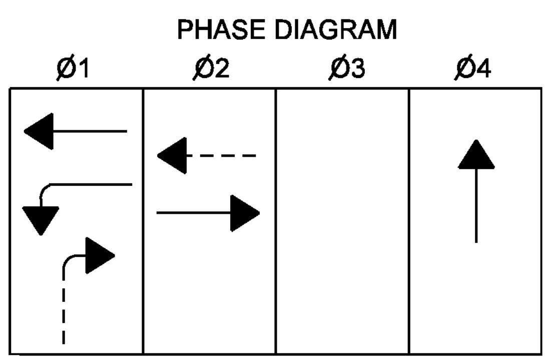

(A) T INTERSECTION

(SINGLE LANE APPROACHES)




NOTES:

W-E IS PREFERENTIAL
W-E FLASHES AMBER
N FLASHES RED



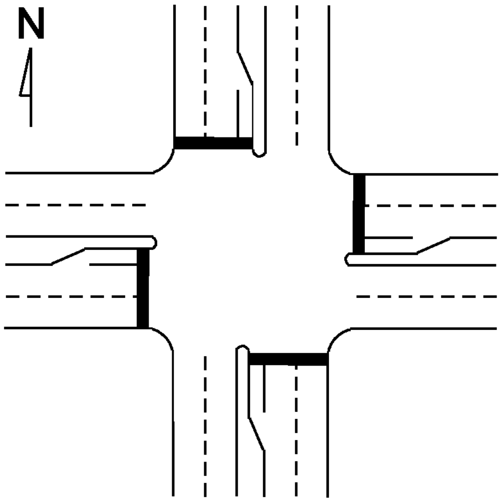

OVERLAP Ø1 AND OØ

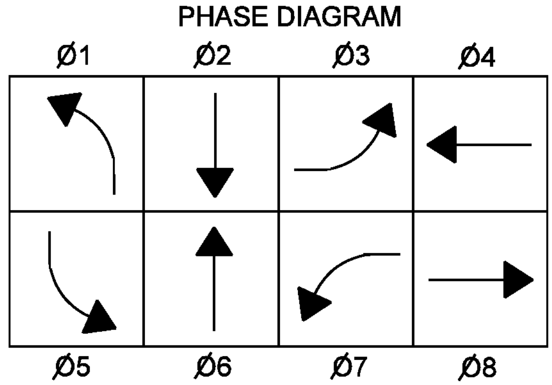
(B) T INTERSECTION

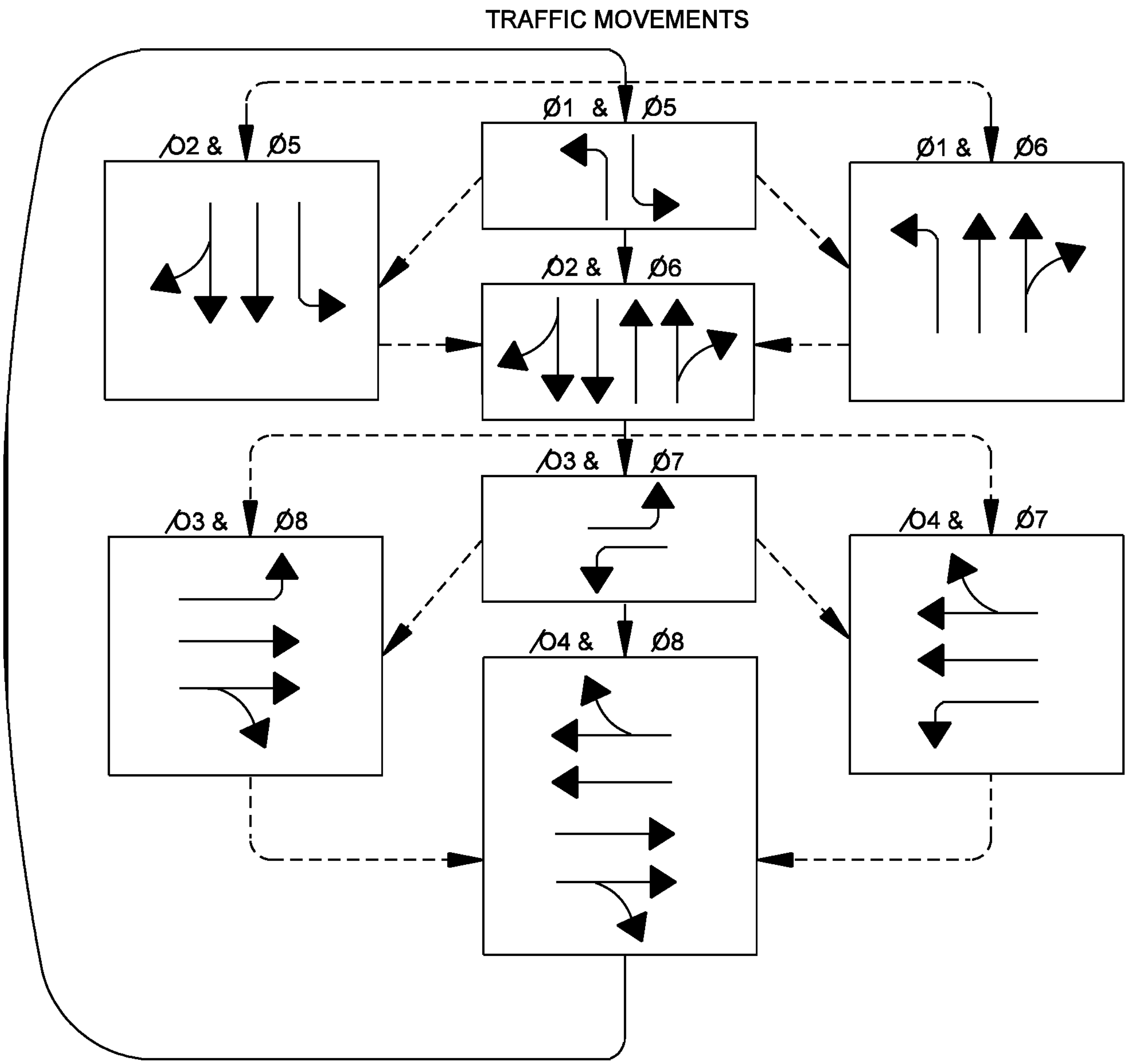
(MULTI-LANE APPROACHES)

# T INTERSECTIONS

## Figure 77-5O




EIGHT-PHASE OPERATION
(Dual Ring)

Figure 77-5P

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

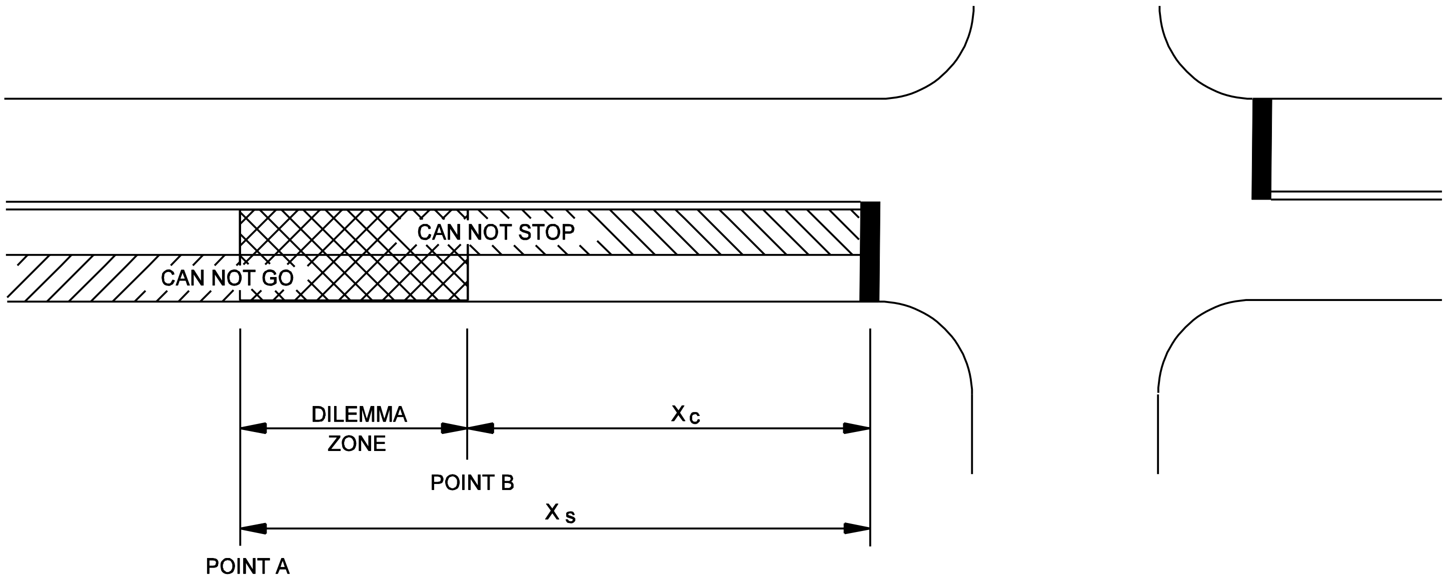
*Notes:*

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

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

**COMPARISON OF LEFT-TURN PHASE ALTERNATIVES**

**Figure 77-5Q**




Note:

1. $X_C$ = *Maximum distance upstream or stop bar from which a vehicle can clear the intersection during the yellow interval.*

2. $X_S$ = *Minimum distance from stop bar where the vehicle can sop completely after the beginning of yellow interval.*

3. *At "Point A," 90% of the drivers will decide to stop at the onset of the yellow indication while 10% of the drivers will continue through the intersection.*

4. *At "Point B," 10% of the drivers will decide to stop at the onset of the yellow indication while 90% of the drivers will continue through the intersection.*

5. *For further information on dilemma zones, see FHWA Trafic Detector Handbook.*

DILEMMA ZONE

Figure 77-5R

| Approach Posted Speed (km/h) | Passage Time from Detector to Stop Line (s) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 [1] | 6 | 7 |
| 30 | 9 | 17 | 27 | 36 | 45 | 53 | 59 |
| 40 | 11 | 24 | 33 | 44 | 55 | 66 | 77 |
| 50 | 14 | 27 | 41 | 54 | 67 | 80 | 94 |
| 60 | 18 | 35 | 54 | 72 | 90 | 108 | 126 |
| 70 | 20 | 41 | 61 | 81 | 101 | 121 | 141 |
| 80 | 23 | 45 | 67 | 89 | 112 | 134 | 156 |
| 90 | 25 | 50 | 74 | 99 | 124 | 149 | 173 |
| 100 | 27 | 54 | 81 | 108 | 135 | 161 | 188 |
| 110 | 29 | 58 | 87 | 116 | 145 | 174 | 203 |
| Legend: | 000 | Basic Ctrlr. | | 000 | Variable Initial Only | | |
| | 000 | Density | | 000 | Dilemma Zone | | |

[1] *INDOT uses 5 s passage time.*

**DETECTION SETBACK DISTANCE (m)**

**Figure 77-5S**