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CHAPTER SEVENTY-SEVEN

TRAFFIC SIGNALS

77-1.0 GENERAL

The design of traffic signals is one of the most dynamic fields of traffic engineering. Although this Chapter will address most traffic-signal-design issues, it is impractical to provide a complete traffic-signal-design guide. For detailed design information, the references listed in Section 77-1.02 should be reviewed. The intent of this Chapter is to provide the user with an overview of the 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 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, see the publications as follows:

Equipment and Material Standards of the Institute of Transportation Engineers, ITE;
Highway Capacity Manual, Transportation Research Board (TRB);
ITE Journal (published monthly), ITE;
Manual of Traffic Signal Design, ITE;
Manual on Uniform Traffic Control Devices, FHWA;
Manual on Uniform Traffic Control Devices, Indiana;
manufacturers' literature;
National, State and local electrical codes;
Standard Drawings, INDOT;
Standard Specifications, INDOT;
Traffic Control Devices Handbook, FHWA;
Traffic Control Systems, National Electrical Manufacturers Association (NEMA);
Traffic Detector Handbook, FHWA;

Traffic Engineering Handbook, ITE; and
Traffic Signal Installation and Maintenance Manual, ITE.

77-1.03 Official Action

Where a new traffic signal is installed or an existing traffic signal is removed, an Official Action is required. For a State-controlled highway, the designer must obtain an approval for the proposed change from the Highway Management Deputy Commissioner. The request for an Official Action should be sent to the appropriate district traffic engineer before implementation of the proposed change. If the district traffic engineer concurs with the request to install or remove a traffic signal, an Official Action will be drafted and sent to the district Deputy Commissioner for approval of the new traffic signal or existing traffic signal removal. 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 Plan Development

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

77-1.05 Definitions

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

1. Controller Assembly. A complete electrical device mounted in a cabinet for controlling the operation of a highway traffic signal.

2. Cycle. For a pretimed 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.

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

4. Delay. A measure of the time that has elapsed between the stimulus and the response.

a. Traffic Delay. The time lost while traffic is impeded by some element over which the motorist has no control.

b. Fixed Delay. The delay caused by traffic controls.

c. Operational Delay. The delay caused by interference between components of traffic.

5. Demand. The need for service, i.e., the number of vehicles desiring to use a given segment of roadway during a specified unit of time.

6. 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.

7. Detector. A device for indicating the presence or passage of vehicles or pedestrians, e.g., loop detector, microloop detector, push button.

8. Indecision Zone. A range of distances from the intersection where a driver can react unpredictably to a yellow signal indication, i.e., deciding to stop or to continue through the intersection.

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

10. Interval. The part of a signal cycle during which signal indications do not change.

11. Interval Sequence. The order of appearance of signal indications during successive intervals of a signal cycle.

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

13. LED. A light-emitting diode used to illuminate signal indications. It is the only illumination device that complies with the U.S. Energy Policy Act of 2005.

14. Loop Amplifier. A device capable of sensing a change in the inductance of a loop detector.

15. Loop Detector. A device embedded in the roadway that senses the presence of a vehicle by changes in magnetic lines of flux that are generated around the loop, thereby increasing the inductance so that a change is detected as monitored by the loop amplifier.

16. 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 in percent of cycle length.

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

18. 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.

19. Phase Overlap. A phase that operates concurrently with one or more other phases.

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

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

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

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

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

25. Signal Coordination. The establishment of timed relationships between adjacent traffic-control signals.

26. Signal Head. An arrangement of one or more signal lenses in one direction.

27. Signal Indication. The illumination of a signal lens or equivalent device.

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

29. 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 Office of Traffic is responsible for making the determination regarding the need for a new or existing traffic signal. This determination is based on factors including traffic volumes, accident history, schools, pedestrians, local needs, driver needs, construction costs, and maintenance costs. The following provides information on 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 can be generated by FHWA, the district Office of Traffic, other INDOT divisions, local officials, or developers or local citizens. 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 others, 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 should refer to the *MUTCD*, which provides the warrants for traffic signals, to determine the appropriate information required. For additional information on the collection of traffic data, the ITE publication, *Manual of Traffic Engineering Studies*, should be reviewed, or the Environmental Services Division should be contacted.

If it is determined that a traffic signal is warranted, the district traffic engineer, the District Office of Design, the Division of Highway Design and Technical Support, 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 satisfy one or more of the primary warrants listed below. The *MUTCD* traffic signal warrants are as follows:

Warrant 1, Eight-Hour Vehicular Volume

Warrant 2, Four-Hour Vehicular Volume
Warrant 3, Peak-Hour Volume
Warrant 4, Pedestrian Volume
Warrant 5, School Crossing
Warrant 6, Coordinated Signal System
Warrant 7, Crash Experience
Warrant 8, Roadway Network

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

77-2.03 Warrant Analysis

Though traffic volume may be sufficiently high to satisfy 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. The satisfaction of one or more traffic-signal warrants should not in itself require the installation of a traffic control signal.

2. Benefits. The benefits of the traffic signal should 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 operations of the intersection or system are improved.

3. Crash History. A traffic signal is often installed to reduce certain types of crashes, e.g., right-angle collision, pedestrian crossing. However, the installation of a traffic signal can increase the number of rear-end collisions and can fail to reduce turning conflicts between vehicles and pedestrians. Consideration should be given as to whether a change in crash types and their severity will be an actual improvement for the intersection. Crash data for the location should be available for at least the past three years. Consideration should be given to alternative solutions to the problem of crashes, e.g., no longer permitting parking, using larger signs.

4. Geometrics. The geometric design of the intersection can affect the efficiency of the traffic signal. A traffic-signal placed 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 space to adequately provide

turning lanes, through lanes, etc. Chapter Forty-six provides 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 system/route/intersection basis. This may sometimes result in compromises at an individual intersection in order to optimize the overall system. The presence of a traffic signal also may encourage drivers to use local unsignalized facilities so as to bypass the signal. Intersection controls should favor the major streets to move traffic through an area.

6. Location. The intersection should be considered relative to the context of the land use, density of development (e.g., urban, suburban, rural), and the potential for future development. The location of the intersection should be considered within the context of the transportation system such as isolated locations, 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 0.5 mi.

7. Existing Signal. For a project that includes at least one existing signal, it will rarely be required 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 may be 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 high traffic volume is generated from a private source, the private entity will typically 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 agreement with others. A local municipality, through a formal contract, will rarely assume responsibility for the maintenance of a traffic signal on a State highway.

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 an 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; See *MUTCD* Part 7;
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 signs, excluding a "Stop," "Yield," or "Do Not Enter" sign.

The need for a hazard-identification beacon will be determined as required for each site. The following provide 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 one or two circular yellow lenses, each having a minimum visible diameter of 8 in. Where two lenses are used, they should be aligned vertically at 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. If the speed limit is for a school zone, the beacon indications may be positioned within the face of the sign.

77-3.03 Intersection-Control Beacon

This is intended for use at an intersection where traffic or physical conditions do not justify a traffic signal, but where conditions indicate a hazard potential. The installation of this device with yellow flashing for the preferential street and red flashing for the stop-condition street may be warranted where two or more of the following conditions exist.

1. Crash History. At an intersection with five or more reported crashes during a 12-month period that have a predominance of crash 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 especially 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-h 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 hour. For a rural area or 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, respectively.

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 40 mph.

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

Where based on engineering judgment, a supplemental beacon 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 should have at least two indications for each approach. Indications normally flash alternately, but may flash simultaneously. Supplemental indications may be required on one or more approaches to provide adequate visibility to approaching motorists.

77-3.04 "Stop" Sign Beacon

This beacon is used to draw attention to a "Stop" sign. The beacon uses one or two sections of a standard traffic-signal head with a flashing, circular red indication in each section. The lenses may be either 8 in. or 12 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 1 to 2 ft above the top of the "Stop" sign.

77-3.05 General Beacon Design

A flashing-beacon unit and its mountings should satisfy the general design specifications for traffic-control signals. These include the following.

1. Lens. Each signal-unit lens should have a visible diameter of at least 8 in. Red or

yellow lenses should satisfy the ITE *Standard for Adjustable Face Vehicle Traffic Control Signal Heads.*

2. Sight Distance. While illuminated, the beacon should be visible to all drivers it faces for a distance of 1200 ft under normal atmospheric conditions, unless otherwise physically obstructed.

3. Flashing. The flashing contacts should be equipped with filters for suppression of radio interference. Beacons should 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 flash alternately.

4. Hours of Operation. A hazard-identification beacon should be operated only during those hours during which the hazard or regulation exists, e.g., school arrival and dismissal periods; see *MUTCD* Part 7.

5. Lamp Dimming. If a 150-W lamp is used in a 12-in. dia. 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 not be located closer than 1 ft outside of the nearest edge of the sign.

8. Location. The obstruction or other condition warranting the beacon will largely 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 8 ft, but not more than 16 ft above the pavement. If suspended over the roadway, the beacon clearance above the pavement should be at least 17 ft, but not more than 19 ft.

77-4.0 TRAFFIC-SIGNAL EQUIPMENT

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

77-4.01 Traffic-Signal Controller

A traffic-signal controller is a microprocessor-based, menu-driven, fully-actuated device, including internal coordinator and preemption, 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. A controller's operation mode can be pretimed, semi-actuated, or fully-actuated. In the pretimed mode, the controller operates according to pre-determined schedules. In the semi-actuated and fully-actuated modes, the 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, an actuated controller may omit that phase in the cycle. For example, if there is not a demand for left turns, the left-turn phase will not be activated. The following provides information on the modes of operation used by the Department. Section 77-5.0 describes the phasing and timing aspects of controllers. INDOT typically uses fully-actuated operation for its new traffic signals.

77-4.01(01) Pretimed Operation Mode

In the pretimed mode, the controller can be programmed to provide several different timing plans based on the time of day or day of week.

The pretimed mode is best suited where traffic volume and pattern 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 primary advantage of the pretimed mode is the cost savings realized by not installing traffic-detection equipment around the intersection. The primary disadvantages of the pretimed mode are the lack of flexibility in timings, the inefficiency of traffic movements where vehicle arrivals are largely random, and the inability to automatically count traffic volume.

The pretimed mode should not be used where the posted speed limit on at least one approach is 40 mph or higher.

77-4.01(02) Semi-Actuated Operation Mode

The semi-actuated mode requires detection on one or more, but not all, approaches. Vehicular detectors or pedestrian detectors are installed only for the minor approaches, the left turns on the major approaches, and where traffic is light and sporadic. The through movements on the major approaches are kept in the green phase until a vehicle on a minor approach, or a major approach left turn, is detected. If there is a demand on a detected approach or movement, and the minimum green time for the major approach has elapsed, the right of way will then be assigned to the detected approach or movement. Controller timings are set to provide enough time to clear two vehicles. Additional time is added for each new detection up to the predetermined limit for the maximum green time. Once the detected approach demand has been satisfied, or once the maximum green time has been reached, the right of way returns to the major approaches and the cycle begins again.

The primary advantage of the semi-actuated mode is the reduced cost of installation because detection is not needed on some approaches and more-efficient operations.

The semi-actuated mode should not be used where the posted speed limit of at least one approach is 40 mph or higher due to the lack of indecision-zone protection. See Section 77-5.08 for further discussion of the indecision-zone requirements.

77-4.01(03) Fully-Actuated Operation Mode

The fully-actuated mode requires detection devices for all approaches or movements at the 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 once the preset maximum green time has elapsed. Once the minor approaches' or movements' demand has been satisfied, the right of way is typically returned to the major approaches.

The fully-actuated mode is the appropriate design choice for the conditions as follows:

1. the posted speed limit on at least one approach is 40 mph or higher;
2. an isolated location where the traffic volume on each approach is sporadic;
3. where a traffic signal is warranted for only short periods of the day; or
4. where turning movements are heavy only during specific time periods and are light the remainder of the time.

The advantages of the fully-actuated mode are as follows:

1. it can efficiently control a high traffic volume;
2. it is very efficient at an isolated intersection;
3. it can handle varying traffic demands such as a complex intersection where one or more movements are sporadic or subject to wide variations in traffic volume; and

4. it can count traffic volume for all detected movements.

The primary disadvantages of the fully-actuated mode are the additional costs associated with installing and maintaining detection equipment on all of the approaches.

77-4.01(04) Pedestrian Feature

The pedestrian feature commonly 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 pedestrian push buttons. The use of an accessible pedestrian signal should be considered where visually-impaired pedestrians use the crosswalks at a signalized intersection.

The advantages and disadvantages of the pedestrian feature are as follows:

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 pedestrian push buttons are required, they must be located in a convenient, accessible location.
    b. Pedestrian cycles concurrent with green time may marginally delay right-turning vehicles.
    c. They 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(05) Enhanced Modes of Operation

Coordination is an enhanced mode which is used to provide progression through a system of two or more signals. Coordination can be achieved with either a timed-based coordination (TBC) system or a closed-loop system. A TBC system operates on an internal time clock which is used to automatically select timing plans based upon the time of day and day of week. In a closed-loop system, the signals are interconnected using cables or other communication mechanism.

Preemption is the modification of a signal's normal operation to accommodate a special occurrence, such as the approach of an emergency vehicle, the passage of a train through a nearby grade crossing, priority passage of a transit vehicle, or the opening of a moveable bridge.

77-4.01(06) Controller-Design Concepts

As established by the National Electrical Manufacturers Association (NEMA), a controller has standard functions and input/output formats, and uses microprocessing to provide the functions. NEMA controllers are interchangeable between manufacturers, except where used in a coordinated system. If changes or upgrades to the controller are desired, the controller unit hardware is typically replaced.

INDOT uses the NEMA criteria for all of its traffic signal controllers. At a minimum, each INDOT-maintained traffic controller must satisfy the INDOT *Standard Specifications* and NEMA TS-2 criteria. Each controller is subject to approval per the requirements of the Department's *Traffic Signal Control Bench Test Procedures*. A list of all approved controller equipment is provided in the Department's approved-materials list, which can be obtained from the INDOT website.

A NEMA controller is configured to operate as a dual-ring controller unless special circumstances warrant the use of additional rings. Section 77-5.06 provides information on the selection of phases for an intersection. Figure 77-4A illustrates the appropriate phasing sequence for an 8-phase dual-ring controller. A multi-ring controller unit includes two or more rings that are arranged to time in a preferred sequence and to allow concurrent timing of all rings, subject to the restraint of a barrier. For the controller to advance beyond each barrier, a set of phases must cross the barrier line at the same time, i.e., no conflicting phases are displayed at the same time).

77-4.01(07) Associated Controller Equipment

Each controller unit will require a TS-2 power supply, Buss Interface Unit (BIU), load switches, and Malfunction Management Unit (MMU). Detection and communications devices may be added to enhance operation of the controller, depending on the intersection. All associated controller equipment must appear on the Department's approved materials list.

77-4.01(08) Malfunction Management Unit (MMU)

With solid-state equipment, there is a potential for the display of erroneous indications, e.g., green indications for conflicting movements. The MMU monitors the signal indications and, should such an error occur, the MMU switches the control of the signal indications to the flashing mode.

77-4.01(09) 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. Each controller cabinet must satisfy the INDOT *Standard Specifications*. Section 77-5.02 provides roadside-safety considerations for the placement of the cabinet. Foundation requirements for each cabinet type are shown on the INDOT *Standard Drawings.* The following discusses the cabinet types used by the Department.

1. Type G Cabinet. This 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 signals.

2. Type M Cabinet. This is a ground-mounted cabinet. This cabinet should be used where space limitations or sight restrictions are a factor at the intersection.

3. Type P-1 Cabinet. This is a ground-mounted cabinet. This cabinet is the preferred cabinet.

4. Type R-1 Cabinet. This is a taller version of the P-1 cabinet. It is used only where equipment needs warrant the additional space.

77-4.01(10) Preemption

Preemption-sequences details should be shown in the plans or described in the special provisions. For information on preemption equipment, the manufacturer should be contacted. The following describes situations where preemption is used.

1. Railroad Crossing. The purpose of the preemption is to clear vehicles from a railroad crossing before the arrival of a train. Where a signalized intersection is within 200 ft of a railroad grade crossing with active warning devices, preemption is required. If this distance 200 to 600 ft, a queue analysis should be performed to determine if a highway-traffic queue has the potential for extending across a nearby rail crossing. If the analysis indicates that this potential exists, consideration should be given to interconnecting the traffic signal with active warning devices at the railroad crossing. The *MUTCD* and the FHWA *Railroad-Highway Grade Crossing Handbook* describe preemption strategies and define 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 transition from the current phase into the Clear Track Green interval (CTG). The CTG interval is used to clear motorists who may be stopped between the railroad-crossing stop line and the intersection. Subsequent signal displays include only those that are not in conflict with the occupied grade crossing. Once the railroad preemption call is cleared, after the train has passed, the traffic signal is returned to normal operations. For a State route, this type of preemption requires an agreement between the State and the railroad company.

Railroad-crossing preemption should be designed using either simultaneous or advance preemption sufficient to provide for Right-of-Way Transfer Time (RTT), to transition into the CTG interval. The CTG interval should be sufficient to clear the last vehicle in the queue past the Minimum Track Clear Distance (MTCD), avoid vehicle-gate interaction, and provide separation time as required.

The designer should consider best- and worst-case scenarios with regard to the signal phase state and all known preemption traps, such as the advance, second-train, failed-circuit, and vehicular-yellow preemption traps. The designer should consider pre-signals and queue-cutter signals as options where an engineering study determines that the queue extends into the track area.

Other options to consider are blank-out signs for protected/permitted left turns, optically programmable heads for pre-signals, and pavement markings and signage to prevent vehicles from stopping on the tracks if inadequate storage distance exists for the design vehicle.

2. Fire Station or Fire Route. The most common form of this preemption is the activation of the preemption sequence at a fixed point, e.g., a push button located within the fire station. For a State route, this type of preemption requires an agreement between the State and the appropriate local governmental agency.

The simplest form of fire station preemption is the installation of a traffic signal at the fire-station driveway intersection with a major through street. The signal indication for the through street is green until called by an actuation in the fire station. The signal then provides a timed green indication to the driveway to allow emergency vehicles to enter the major street.

Where the fire station is near a signalized intersection, a preemption sequence can be designed to display a movement permitting the passage of emergency equipment through the intersection.

Where emergency vehicles frequently follow 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. <u>Moving Emergency Vehicle</u>. 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.

The system used on a State route for identifying the presence of the 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.

This system requires a specialized transmitting device on each vehicle for which preemption is desired. It requires that the driver activates the transmitter during the run and turns off the transmitter after arriving at the scene. This system also provides directionality of approach and a confirmation light at the signal that notifies the approaching emergency vehicle that the preemption call has been received by the equipment in the traffic-controller cabinet.

4. <u>Transit Vehicle</u>. 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 can 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 system. One is a light emitter/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 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/receiver equipment as used for emergency-vehicle preemption.

Two other types of transit-vehicle detectors have been used and are available. One, identified as a passive detector, can identify the electrical signature of a bus traveling over an inductive loop detector. The other, identified as 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.

77-4.02 Detector

77-4.02(01) Operation

The purpose of a detector is to determine the presence or the passage of a vehicle, bicyclist, or pedestrian. This presence or passage detection is sent back to the controller which adjusts the signal accordingly. INDOT uses only an inductive loop detector 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 usually the system of choice, this does not prevent the designer from recommending the use of newly-developed devices in the future. If, in the designer's opinion, a different detector should be considered, its use must be first coordinated with the district traffic engineer to determine special maintenance requirements or equipment needs.

The controller's detection device can operate in the modes described below.

1. Passage (Pulse) Detection. A passage detector detects the passage of a vehicle moving through the detection zone and ignores the presence of a vehicle stopped within the detection zone. The detector produces a short output pulse once the vehicle enters the detection zone. The short loop design is a single 6 ft by 6 ft loop at a location upstream of the stop line.

2. Presence Detection. A presence detector is capable of detecting the presence of a standing or moving vehicle in any portion of the detection zone. A signal output is generated for as long as the detected vehicle is within the detection zone. This is subject to the eventual tuning out of the call by some types of detectors. The long loop, or long detection area, is considered to be a presence detector.

3. Locking Mode. The controller memory holds the call once a vehicle arrives during the red or yellow signal indication, or after the vehicle leaves the detection zone until the call has been satisfied by a green display.

4. <u>Non-locking Mode</u>. 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.

5. <u>Delayed Detection</u>. This requires the 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. <u>Extended-Call or Stretch Detection</u>. 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 detection 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 four or more turns of wire embedded in the pavement surface. As a vehicle passes over the loop, it changes the inductance of the wire. This change is recorded by an amplifier and is transmitted to the controller as a vehicular detection. NEMA criteria define the requirements for the detector unit and the INDOT approved materials list identifies the detector units approved for use.

The advantages of an inductive loop detector are as follows:

1. It can detect vehicles in both presence and passage modes.
2. It can be used for vehicular counts and speed determination.
3. It can be easily designed to satisfy various site conditions.

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

Along rectangular loop is 6 ft by 20 ft to 65 ft. A short octagonal or circular loop is 6 ft by 6 ft. INDOT normally uses the short loop. The long loop, as a single entity, is being supplanted by a sequence of short loops which emulate the long loop. The INDOT *Standard Drawings* illustrate 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 satisfy 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 vehicles. The distance from the stop line to these loops is based on the posted speed limit. Section 77-5.08 provides additional information on detector location. Section 77-5.09 provides information on loops set up to count traffic.

A preformed loop is a detector loop constructed of the designated number of turns of wire contained inside a protective conduit. It is paved over with concrete or asphalt pavement. A preformed loop may be installed in a 1-, 2-, 3-, or 4-loop configuration. Wires from a preformed loop are spliced to the 2-conductor lead-in cable in a handhole or detector housing. INDOT's approved materials list identifies the preformed loops approved for use.

77-4.02(03) Other Detector Types [Rev. May 2011]

INDOT uses the inductive loop detector. However, other detector types are available, as described below.

1. Magnetic Detector. This consists of a small coil of wires located inside a protective housing embedded into the roadway surface. As vehicles pass 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 3 mph or higher. It cannot be used to determine a stopped vehicle's presence. The advantages are that it are simple to install and is resistant to pavement-surfacing problems.

2. Magnetometer Detector. This consists of a magnetic metal core with wrapped windings, similar to a transformer. This core is sealed in a cylinder of about 1 in. diameter and 4 in. length. The detector is placed in a drilled vertical hole of about 1 ft depth into the pavement surface. This 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. This detector is sufficiently sensitive to use to detect bicyclists 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. This is similar to a magnetometer detector, but it can work with a standard inductive-loop-detector amplifier. The microloop is installed by drilling a 3-in. diameter hole of 1.5 ft depth into the pavement structure, by securing it to the underside of a bridge deck, or inserting a 3-in. diameter conduit under the pavement to accommodate a series of microloops (non-invasive microloop system). 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 per lane due to its limited field of detection.

4. Video-Image Detection. This 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 the images stored in its memory. The detector can work in either the presence or passage mode. This detector also allows the images to be used for counting and vehicular classification. A housing is required to protect the camera from environmental elements. Early models experienced problems with the video detection during adverse weather conditions such as fog, rain, or snow. INDOT currently allows video detection only for a temporary signal.

5. Wireless Vehicle-Detection System.

   A wireless vehicle detector is similar to a magnetometer detector except that it uses a low-power radio to transmit the signal to a wireless repeater or receiver processor. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. The detector is placed in a drilled vertical hold of 0.2 ft depth in the pavement surface. The wireless repeaters and receiver processors should be mounted to the signal structures. The Ethernet cable for the receiver processors may be run across span wire on a span-and-strain-pole installation. See the INDOT *Standard Drawings*. Wireless vehicle detectors are sufficiently sensitive to detect bicyclists or for use as a counting device. A disadvantage of a wireless vehicle detector is that it should be replaced at least every 10 years, and the wireless repeater's batteries should be replaced every 2 years. See Figure 77-4B for wireless-system typical installation details, or Figure 77-4C for hybrid wireless-system typical installation details.

77-4.02(04) Decision-Making Criteria for Use of Detection System Other than Inductive Loops [Added Jan. 2011]

Such a system will require plans details. In specifying such a system, the designer should submit documentation that two of the following conditions have been satisfied.

1. An inductive loop design will not function due to a physical limitation such as right-of-way limitations, geometrics, pavement conditions, obstructed conduit paths, etc.

2. A full inductive loop design has been considered and there is a post-design lifecycle cost advantage to using a detection system other than loops. Design-time cost or labor savings will not be considered in lifecycle-cost calculations.

3. A hybrid design using loops at the stop line and wireless magnetometers for advance vehicle detection has been considered and evaluated where wireless magnetometers have been evaluated for advance vehicle detection only, and the hybrid design is the most cost effective, based on post-design lifecycle cost.

Written concurrence will also be required from the Office of Traffic Control Systems and the district traffic engineer, before wireless vehicle detection may be used at a specific location. For a local-agency project, such concurrence will be required from the local agency.

77-4.02(05) Pedestrian Detector

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

77-4.02(06) Bicycle Detector

The methods of bicycle detection are as follows.

1. <u>Pedestrian Push-Button Detector</u>. 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 to the sidewalk to reach the detector.

2. <u>Inductive Loop Detector</u>. This 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 this detector is that it requires a significant amount of metal to be activated. A bicycle includes a substantial amount of non-magnetic, man-made materials to increase its strength and reduce its 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 with poles on all four corners. A pedestrian signal is mounted on a pedestal or pole. A pedestal- or pole-mounted supplemental signal may be used if there is a left-turn signal head in a median or on the near side of the intersection if the intersection is significantly wide. Figures 77-4D, 77-4E, and 77-4F list the advantages and disadvantages of the post-mounted signal, cable-span signal mounting, and the cantilever signal mounting, respectively.

For spans, steel strain poles are used. Steel strain poles provide greater strength, are easier to maintain, and require less space. Wood poles require the use of down-guy cables and are limited to a temporary installation.

A cantilever structure must be designed to satisfy 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. Traffic-signal span-support poles or cantilever poles may be used for overhead highway lighting. Figure 77-4G provides an illustration of a combination signal-luminaire pole. INDOT does not use combination poles. Figure 77-4H provides the heads' orientation for a cable-span-mounted signal.

77-4.04 Signal Display

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

1. Signal-Head Housing. This are made of polycarbonate (plastic).

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

3. Lens Size. INDOT's preferred practice is to use only 12-in. diameter lenses. INDOT specifications require the use of plastic lenses in its signal displays.

4. Signal Illumination. Only Light-Emitting Diodes (LED) should be used.

5. Visors. A visor should be used with each 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 the visor. The decision on which visor type should be used is determined on a site-by-site basis. For a Department installation, partial visors are normally used. Visors are made of the same material as the housing.

6. Louvers. Louvers are sometimes used to direct the signal indication to a specific lane. Louvers are used where several signal heads may cause confusion for the approaching driver. One example of this problem is where an intersection has its approaches at angles less than 90 deg and the signal indications can be seen from both approaches. The decision on whether to use louvers depends on site conditions and will be determined for each site.

7. Optically-Programmable Signal. Like louvers, an optically-programmable signal is designed to direct the signal indication to specific approach lanes and for specific distances. An advantage is that they can be narrowly aligned so that motorists from other approaches cannot see the indications. Applications include closely-spaced intersections or an intersection where the approaches have acute angles. An optically-programmable signal requires rigid mountings to keep the indicator properly directed. The cost is higher than for louvers but the improved visibility often makes it a better choice. The decision on whether to use an optically-programmable signal depends on site conditions and will be determined for each site.

8. Backplate. A signal indication loses some of its contrast value if viewed against a bright sky or other intensive background lighting such as advertising lighting. A backplate placed around a signal assembly enhance the signal's visibility and have been shown to provide a benefit in reducing crashes. However, a backplate adds weight to the signal head and can increase the effect of wind loading on the signal. The decision on whether to use a backplate depends on site conditions and will be determined for each site.

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 traffic-signal design.

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

1. All electric service should be metered.

2. All parking regulations should be reviewed for a distance of at least 150 ft from the stop line or back to a detector.

3. All signal-head indications should be placed within 40 to 180 ft from the stop line.

4. The necessary signal heads should be verified 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. The height of a steel-strain-pole support is 30 ft or 36 ft.

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

8. All existing signal components should be field verified.

9. Position and direction of aiming for all signal heads should be in accordance with Section 77-5.01(01).

10. A detector should be provided that counts vehicles in each travel lane approaching the signalized intersection. The count loops should be identified in the loop tagging table.

11. The detection-setback-distance value shown in Figure 77-5 Z should be used.

77-5.01(01) Signal Displays

The *MUTCD* requires 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 this single indication is in addition to the minimum two for through movements. For multiple left turn lanes, one indication per lane shall be provided.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. One signal head per approach lane has been shown to provide a benefit in reducing crashes. Situations where supplemental indications can improve visibility include the following:

1. approach in excess of two through lanes;
2. location where there may be driver uncertainty;
3. where there is a high percentage of trucks which can obscure the signal indications; or
4. where the approach alignment affects the continuous visibility of normally-positioned signal indications.

The following figures illustrate the placement for signal heads.

Figure 77-5A, offsetting intersection
Figure 77-5B, urban street with parking on the near side, no left-turn lane
Figure 77-5C, urban street with parking on the far side and a near-side left-turn lane
Figure 77-5D, left-turn lanes with permissible left turns, but no separate left-turn phase
Figure 77-5E, left-turn lanes with protected left-turn phase
Figure 77-5F, left-turn lane with both protected-phase and permissible left turns, and 5-section head. This figure also illustrates the preferred 5-section head display
Figure 77-5G, multiple-lanes approach with left-turn lanes and protected left-turn phase
Figure 77-5H, multiple-lanes approach with both left- and right-turn lanes and protected phases
Figure 77-5 I, multiple-lanes approach z-span with supplemental far-side heads
Figure 77-5J, rural one-lane approach with truck obstruction
Figure 77-5K, rural one-lane approach with obstructed sight distance, near-side signal indication, advance warning sign, and flasher.

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 77-5L provides the *MUTCD* minimum visibility distance. If the visibility distance cannot be satisfied, an advance warning sign should be used to alert an approaching motorist 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 40 ft 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 desirably 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 each side of the center of the approach extended (i.e., a cone of 40 deg). There may be confusion on where to measure the center of the approach lanes for a multilane approach.

Figure 77-5M, Vision Cone, illustrates INDOT's interpretation of this requirement. The right- and left-turn lanes and parking lanes are included.

The following discusses other requirements 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 the drivers 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 10 ft apart between the centers of the heads, measured perpendicular to the direction of travel.

4. At least one, and preferably both, signal heads that control through traffic should be located not less than 40 ft nor more than 180 ft beyond the stop line.

Where the nearest signal head is more than 150 ft, but 180 ft or less, beyond the stop line, engineering judgment of the conditions, including the worst-case visibility conditions, should be used to determine if a supplemental near-side signal head should be provided. Where the nearest signal head is more than 180 ft beyond the stop line, a supplemental near-side signal head should be used.

77-5.02 Placement of Signal Equipment

There are limited options available in determining acceptable locations for the placement of signal pedestals, signal poles, pedestrian detectors, and controller cabinets. 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 following should be considered in determining the placement of traffic-signal equipment.

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

2. Controller Cabinet. In determining the location of the controller cabinet, the following should be considered.

   a. It should be placed in a position so that it is unlikely to be struck by an errant vehicle. It should be located outside the obstruction-free zone.

   b. It should be located where it can be easily accessed by maintenance personnel.

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

   d. It should be located where the potential for water damage is minimized.

   e. It should not obstruct intersection visibility.

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

3. Traffic-Signal Supports. These should be placed to provide the obstruction-free zone through the area where the traffic-signal supports are located. However, the following exceptions will apply.

   a. Channelizing 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 30 ft should be provided from all travel lanes including turn lanes in a rural area, or in an urban area where the posted speed limit is 50 mph or higher. In an urban area where the island is bordered by a barrier curb and the posted speed limit is 45 mph or lower, a minimum clearance of 10 ft should be provided from all travel lanes including turn lanes.

   b. Non-Curbed Facility with Posted Speed Limit of 50 mph or Higher, and ADT > 1500. Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 10 ft beyond the outside edge of the paved shoulder.

c. Non-Curbed Facility with Posted Speed Limit of 45 mph or Lower, or ADT ≤ 1500. Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 6 ft beyond the outside edge of the paved shoulder.

d. Curbed Facility. See Section 55-5.02. For a facility with curbs of less than 6 in. height, see items 3.a. and 3.b. above.

4. <u>Location of Signal Heads Relative to Stop Line</u>. Figure 77-5M shows this information, and the appropriate lens diameters.

5. <u>Pedestrians</u>. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflicts. The signal pole should not be placed such that will restrict a handicapped individual's access to a curb ramp. Pedestrian push buttons must be conveniently located. Section 51-1.0 provides criteria for handicapped accessibility.

77-5.03 Pedestrian Signal

Pedestrian-signal indications should be provided for each new or modernized traffic-signal installation in accordance with the *MUTCD*.

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

77-5.04 Pavement Marking and Signing

Cantilevers and span cables often include regulatory and informational signs, e.g., left turn only, name of cross street. The effect of the weight of the sign and additional wind loading on the cantilever or the span cables should be considered. The number of signs on a traffic-signal structure should be limited. Chapter Seventy-five provides additional guidance on the placement and design of signs.

For a cable-span signal installation, a lane-use-control sign should be placed over the lane on the near-side span. A street-name sign should be placed on right side of the far-side span.

An internally-illuminated street-name sign provides increased visibility at night. INDOT does not install such a sign, but a local agency may request its installation on an INDOT-controlled traffic signal. Its installation requires a contract between INDOT and the appropriate local governmental agency.

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 electrical cables or wires, connectors, conduit, handholes, etc. Electrical connections between the power supply, controller cabinet, detectors, and signal poles are carried in conduit. The following should be considered in developing the traffic-signal-wiring plan.

1. Service Connections. Service connections from the local utility lines should go directly to the service disconnect and then to the controller cabinet. The lines should be as short as practical. The service disconnect should be located as close to the controller cabinet as practical. These 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 while performing system maintenance.

2. Electric Cables. All electric cables and connections must satisfy national, State, and local electrical 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, usually only 3 or 4 combinations, to reduce inventory requirements. A 7- or greater-conductor cable is used between the controller cabinet and the disconnect hangers or cantilever base. A 5-conductor cable is used between the disconnect hanger or cantilever base and 3-section signal indication. A 7-conductor cable is used between the disconnect hanger or cantilever base and 5-section signal indication. A 5-conductor cable is used between the controller cabinet and the pedestrian-signal indication. A 5-conductor cable is used between the controller cabinet and each pair of pedestrian push buttons located in the same corner of the intersection. Connections to flashers use only a 3-conductor cable. The INDOT *Standard Drawings* illustrate the correct procedures for wiring and splicing cables.

3. Cable Runs. All cable runs should be continuous between the following:

   a. controller cabinet to base of cantilever structure or pedestal;
   b. controller cabinet to disconnect hangers;
   c. controller cabinet to service disconnect;
   d. disconnect hanger to signal indications;
   e. base of cantilever structure to signal indications; and
   f. controller cabinet 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 handhole and wiring details. The maximum spacing between handholes in the same conduit run is 250 ft.

5. Underground Conduit. Underground conduit is used to connect the controller cabinet, traffic signals, and loop detectors together. Conduits run underneath the pavement and between the handholes, using a 2-in. diameter conduit. For a run with additional cables, the conduit size may need to be increased. The NEC 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 placement details of underground conduit.

6. Grounding. Each metal pole, cantilever structure, controller cabinet, etc., should be grounded. The INDOT *Standard Drawings* illustrate the correct methods 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 wires from the loops to the lead-in cable to the detector amplifier. The INDOT *Standard Drawings* provide additional information on detector housings, including wiring details.

8. Disconnect Hangers. Disconnect hangers are used for a cable-span-mounted signal 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 cabinet to indicate which loop detector wire belongs to which loop detector. Each should be labeled according to street, direction, lane, and distance from the stop line, and if the loop is a count loop.

10. Interconnect Cable. A 7-conductor signal wire is used for hard-wiring interconnected

signals. For a closed-loop system, the hard-wired connection should use a telecommunication cable consisting of either a fiberoptic 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 should be shown on the plans 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 not be more than 8 phases per cycle and there should desirably be fewer. An 8-phase dual-ring controller should be used with a new or modernized traffic signal. 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 minimum number of phases practical that will accommodate the existing and anticipated traffic demands should be used. A capacity analysis should be conducted to determine if the proposed phasing is appropriate. Phases 2 and 6 are considered to be the preferential phases. The following provides the applications for phased 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 77-5N illustrates a typical 2-phase operation. A 2-phase operation is also appropriate for the intersection of two one-way streets. Disadvantages of a 2-phase operation are that left turns are in conflict with traffic from opposite directions, and that right- and left-turning traffic is in conflict with pedestrian flows.

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

    a. Major or Minor Street with Separate Phases. A 3-phase operation with separate phases on a major or minor street (split phase) may be used where there is heavy left-turning demand on the major or minor street from one or both directions and there is inadequate pavement width to provide a left-turn lane. See Figure 77-5 O, Three-Phase Operation, Separate Split Phases for Major Street, or Figure 77-5P, Three-Phase Operation, Separate Split Phases for Minor Street. This phase selection is not an efficient operation for a multilane 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 77-5Q). 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 are a significant number of pedestrians (e.g., college, downtown business district) and where the signal normally operates in a 2-phase operation (i.e., minimum number of left-turns). Figure 77-5R illustrates a 3-phase operation with an exclusive pedestrian phase. During the exclusive pedestrian phase, pedestrians can use all crosswalks or walk diagonally across the intersection.

d. T Intersection. A 3-phase operation will be required if there is a large 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 77-5S illustrates the options for single-lane approaches. Figure 77-5T illustrates the options for multiple-lane approaches.

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 multilane 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 many 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 77-5U illustrates an 8-phase operation, dual ring. An 8-phase operation uses the NEMA dual-ring controller.

5. Other Phases. For other phase operations, e.g., a 6-phase operation, one of the phase operations described above can be used by eliminating the nonapplicable phase from the sequence.

Figures 77-5N through 77-5U also illustrate the movements that should be assigned to the numbered phases. On 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. See Section 77-5.06(02) for more information on phase assignment.

The controller accommodates control of each individual phase. Each phase is programmed as a 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. There are phases that can be timed concurrently with a dual-ring controller. For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement, but not with another phase or vice versa. For example, Phase 2 can be timed concurrently with Phase 5 or Phase 6. 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 77-5.10). The Application Development Division can be contacted for more information on the latest software packages or versions used by INDOT.

77-5.06(02) Phase Numbering and Conventions

Phase numbers are the labels assigned to the individual movements around an intersection. For an 8-phase dual-ring controller, it is common to assign the main street's through movements as phases 2 and 6. Also, it is common to use odd numbers for left-turn signals and even numbers for through signals. The sum of phase numbers of the through movement and the adjacent left turn is equal to seven or eleven. Figure 77-5V shows typical phase-numbering schemes. Figure 77-5W shows typical phase diagrams.

For signals in a coordinated system, phases 2 and 6 are the coordinated phases.

Intersection approach directional labels and corresponding NEMA phase assignments should be shown on the plans according to standard route-numbering convention and priority routes as defined below.

1. Highest-Priority Intersecting Route. This should be determined based on route classification (US Route; State Route; local route, respectively). For equally-classified routes, the higher-priority route has the higher vehicular volume.

2. Labeling Approaches NB, SB, EB, or WB. For route-numerical designation, an odd-numbered route should be labeled NB and SB. An even-numbered route should be labeled EB and WB, for the highest-priority route (phases 2 and 6) on the intersection-design plan. All remaining minor-approach directional labels should be assigned as relative directions to the highest-priority NB or EB route. If two equally-classified routes, both even- or odd-

numbered, intersect, phase 2 should be assigned to the higher-volume NB or EB through movement. The remaining directional labels should be relatively assigned to the remaining movements.

77-5.06(03) Phase Assignments

1. 4- or 8- Phase Intersection. Phase 2 should be assigned to the highest-priority arterial NB or EB route at the intersection. The remaining even-numbered through phases should be assigned to vehicle movements clockwise around the 4-approaches intersection. Phase 4 should be immediately to the left of phase 2, followed to the left by phase 6 (opposing phase 2), and followed by phase 8 immediately left of phase 6 or right of phase 2. Odd-numbered phases should be assigned to each corresponding left-turn phase by standard NEMA convention, also increasing numerically in the clockwise direction.

   Deviation from the priority convention described above is permitted to maintain the integrity of an existing or planned coordinated system by assigning phase 2 and 6 as the coordinated phases.

2. T Intersection. A three-legged or T intersection should follow the 4- or 8- phase intersection convention, skipping those phases that are otherwise assigned to the missing vehicle movements.

3. Split-Phase Intersection. Phase assignments should follow the 4- or 8- phase intersection to the extent possible. NB and EB movements should be assigned a lower phase number than the phase number assigned to SB and WB movements, respectively.

4. Grade-Separated Intersection or Interchange. Grade-separated intersection or interchange ramps that terminate and intersect at numbered US and State arterial routes should use the through surface arterial route numerical designation to determine the NB/EB phase 2 assignment regardless of route priority. NB/WB ramp movements will be assigned to phase 8. SB/EB ramps will be assigned to phase 4.

   A ramp terminating at a local street may use either the numbered Interstate or State route as directional reference, or the nearest actual NB/EB cardinal direction of the local arterial movement in determining arterial orientation for assigning phase 2 as NB or EB. Regardless, phase 2 should be labeled NB or EB, and the remaining conventions described above should be applied.

5. TTI 4-Phase and Single-Controller Diamond Interchange. A single-controller diamond interchange should incorporate a flexible ring structure that allows TTI 4-phase, extended

3-phase, standard 3-phase, or two separate intersection modes by time-of-day selection in the controller. Phases will not strictly follow the convention described above.

77-5.06(04) Examples

1. SR 32 at SR 38 east or west side of Noblesville. SR 32 is the through movement. Phase 2 is EB SR 32.

2. SR 32 at SR 37 in Noblesville. SR 37 is the higher-volume route. Phase 2 is NB SR 37.

3. I-465 at US 31 in Hamilton County. US 31 is the odd-numbered NB route. Phase 2 is NB US 31.

4. I-465 at Allisonville Road in Indianapolis. Phase 2 is NB Allisonville Road.

5. US 30 at SR 15 in Warsaw. This is grade separated. SR 15 is the arterial route. Phase 2 is NB SR 15.

77-5.06(05) Left-Turn Phase

The most commonly added phase is for protected left-turns, for which left-turning vehicles are given a green arrow without conflicting movements. A left-turn phase can be either a leading left, where the protected left turn precedes the opposing through movements, or a lagging left, where the left-turn phase follows the opposing through movements. Opposing left turns may both be leading, lagging, or a combination of leading and lagging. The decision on whether to use either a leading-left or a lagging-left turn will be determined for each situation. The preferred practice is to use leading left turns. A combination of leading and lagging or lagging left turns can provide more-efficient operation in a coordinated signal system. Figure 77-5X provides a comparison for each left-turn phase alternative.

Not all signalized intersections will require a separate left-turn phase. The decision on whether to provide exclusive left-turn phases is dependent upon traffic volume, delays, and crash history. This will be determined on a site-by-site basis. For an intersection with exclusive left-turn lanes, the following can 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 of an approach lane is 1,200 vehicles times the percent of green time minus the opposing volume, but not less than two vehicles per cycle.

2. Delay. A left-turn phase should be considered where the delay time for left-turning vehicles is excessive for 4 h during an average day. Delay is considered excessive if left-turning vehicles are delayed for more than two complete signal cycles.

3. Miscellaneous. Intersection geometrics, total volume demand, crash history, posted speeds, etc., should also be considered.

4. Non-INDOT Facility. The ITE *Manual of Traffic Signal Design* provides alternative guidelines for consideration of left-turn phasing.

   On an approach without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined on a site-by-site basis. The inclusion of a left-turn phase at an intersection without an exclusive left-turn lane will require split phasing. Where practical, opposing left-turn arrows should also be provided.

77-5.06(06) Assignment of Right of Way

The assignment of right of way, also referred to as preferentiality, at a traffic signal determines which signal indications will flash amber if the traffic signal goes to a flash condition.

None of the signal indications should flash amber. Therefore, none of the approaches should have preferentiality over the others. This condition is also referred to as all-red flash.

A local agency is permitted to assign preferentiality to one of the roads at an intersection. This will permit the preferential road's indication to flash amber while the crossroad's indication will flash red.

77-5.07 Pretimed 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 facility, the consultant will be responsible for determining the signal timing. However, designer must still understand the aspects of traffic-signal timing so that the appropriate equipment will be selected and an efficient design can be provided.

The following should be considered in determining pretimed-signal timing.

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, such as increased lost time due to starting delays and clearance intervals. Adding concurrent phases may not reduce capacity.

2. Cycle Length. 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 following should be considered relative to cycle lengths.

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

   b. Capacity. A cycle length 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. Such a cycle length has higher capacity because, over a given time period, there are fewer starting delays and clearance intervals.

   c. Maximum. A maximum cycle length of 120 s should be 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. Green Interval. The division of the cycle into green intervals will be approximately correct if made proportional to the critical lane volume for each signal phase. The critical lane volume can be determined by using the *Highway Capacity Manual*'s Planning Methodology, or the of the Highway Capacity Software's Signalized Intersections Module. The green interval should be checked against the following.

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

   b. Minimum Lengths. Major movements relative to driver expectations should not have green intervals which are less than 15 s. An exception to this may be appropriate for special turn phases.

4. Capacity. For an intersection approach with many left turns, the capacity should be checked to determine the need for a separate left-turn lane; see Section 77-5.06(03).

5. Phase-Change Interval. Each phase-change interval (yellow plus all-red) should be designed to satisfy Section 77-5.07(02) item 2 to ensure that approaching vehicles can

either come to a stop or clear the intersection during the change interval.

6. Coordination. Traffic signals within 0.5 mi 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 satisfy the existing traffic conditions.

77-5.07(02) Cycle Determination

In determining the appropriate cycle length and interval lengths, the following should be considered.

1. Cycle Length. Cycle length should be within the range as follows:

   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 the driver that the phase has expired and that he or she should stop prior to the stop line, or allows entry to the intersection if too close to stop. The phase-change interval length should be determined using Equation 77-5.1. The yellow change interval should be followed by a red-clearance interval, or all-red phase, of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released. For a more-efficient operation, start-up time for the conflicting movements may be considered in setting the length of the all-red interval.

$$Y + A.R. = t + \frac{V}{2a \pm 64.4} + \frac{W + L}{V} \qquad \text{(Equation 77-5.1)}$$

Where:
$Y + A.R.$ = Sum of the yellow and all-red intervals, s
t = perception/reaction time of driver, s, assumed to be 1 s
V = approach speed, ft/s
W = width of intersection, ft
L = length of vehicle, ft, assumed to be 20 ft
a = deceleration rate, ft/s^2, assumed to be 10 ft/s^2

The yellow change interval is in the range of 3 to 6 s. The all-red interval is in the range of 1 to 4.4 s.

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

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

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

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

Where:
G = total green time available for all phases, s
C = cycle length, s
Y_a and Y_b = yellow and all-red phase-change interval, s, on streets A and B
G_a and G_b = green interval, s, calculated for streets A and B
V_a and V_b = critical-lane volumes on streets A and B

The effect that the pedestrian clearance interval will have on the green interval should be considered 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 pedestrians walk with the green indication or 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.

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

Where:
G = minimum green time, s
P = pedestrian start-off period, 4 to 7 s
S = walking speed, 4 ft/s
D = walking distance, ft
Y = yellow interval, s

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

4. Recheck. After the cycle length and interval lengths have been selected, the design should be rechecked to ensure that sufficient capacity is available. Several cycle lengths should be checked to ensure that the most-efficient cycle length and interval lengths are used. If the initial design is inadequate, the designer should 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, such as adding left-turn lanes.

    There are software programs available to assist in determining the most efficient design. Section 77-5.10 discusses these.

77-5.08 Actuated-Controller Setting

As with a pretimed controller, the district Office of Traffic will be responsible for timing each actuated controller on a State highway after it is installed. However, the designer should understand how the signal timing will affect the efficiency of the actuated signalized intersection. The designer should also 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 location of vehicular detection is optimized to provide safe operation while providing controller settings that will minimize intersection delay. The compromises that should be made among these conflicting criteria become increasingly difficult to resolve as approach speeds increase. For example, for an approach speed of 40 mph or higher, the detector should be located in advance of the indecision zone. The indecision zone is the decision area, on such an approach, where the driver must 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 indecision problem. Figure 77-5Y further defines the indecision zone. The following discusses the design considerations for an actuated controller.

77-5.08(01) Basic-Actuated Controller

Basic-actuated control with passage detection is limited in application to an isolated intersection with fluctuating or unpredictable traffic demands and approach speeds of 35 mph or lower. Basic-actuated control includes fully-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 relative to the stop line, this type of detection is used only with a controller that has a locking memory feature for detector calls. The controller remembers the actuation of a detector on the yellow or red interval, 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 for basic-actuated controllers, the following should be considered.

1. Minimum Assured Green (MAG). Although there is no timing adjustment labeled MAG on the controller, the MAG should still be calculated. The minimum green time is composed of the initial green interval plus one vehicle extension. A long minimum green time should be avoided. The minimum assured green time should be between 10 and 20 s for a 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.

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

Where
MAG is in s
n = number of vehicles per lane which can be stored between the stop line and the detector

The minimum green time 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 45 ft, the detector should not be placed closer than 45 ft 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, 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 held in green. However, the allowable gap should be kept reasonably short to ensure quick transfer of green to the side street. Headway between vehicles in platoons 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 on red finds that a gap of 5 s or longer is too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 s. For a quicker phase change, a shorter gap of 3 to 3.5 s should be used.

3. Initial Green. The initial green setting is 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 vehicle to stop before entering the intersection. The vehicular passage time is used to determine this placement, e.g., 5 s. The posted speed limit of the approach roadway should be used to determine the appropriate setback.

5. Maximum Green Interval. This is the maximum time that the green should be held for the green phase, given a detection from the side street. For a light to moderate traffic volume, the signal should gap out before reaching the maximum green time. However, for a period with higher 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 pretimed intersection (see Section 77-5.07). It may be somewhat longer to allow for peaking.

6. Clearance Interval. The clearance interval should be determined as for a pretimed 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. Short allowable gaps and minimum greens 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 held on green for the major street. To ensure that the mainline is not interrupted too frequently, a long minimum green interval should be used on the major street. The 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 this situation; see Section 77-5.08(03).

77-5.08(02) Advanced-Design Actuated Controller

An advanced-design controller is used at an isolated intersection with fluctuating or unpredictable traffic demands, and approach speeds of 40 mph or higher. 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-actuated control, the small-area detection requires that the controller have a locking memory.

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

1. Detector Placement. For an approach speed of 40 mph or higher, the detector should be located in advance of the indecision zone (see Figure 77-5Y). This will place the detector about 5 s of passage time from the intersection. The speed selected should be the posted speed limit of the approach roadway. Figure 77-5 Z provides the appropriate detector setback distance for each combination of passage time and approach speed. Figure 77-5 Z also provides the passage time that is appropriate for other types of detection.

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

3. Variable Initial Time. The variable initial time is the upper limit to which the minimum initial time can be extended. It should be long enough to clear all vehicles that have accumulated between the detector and the stop line during the red interval. The variable initial time is determined in the same manner as the minimum assured green for the basic-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 interval that will extend the initial green 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-possible condition, in which 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 Interval. The maximum green interval should be set the same as for the basic 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 cross-street traffic parameters such as time waiting, vehicles waiting, or density. Time waiting has been determined 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 traffic volume, and the time of day. 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 pretimed signal (see Section 77-5.07).

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

A large-area detector is used with an 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-turning-on-red vehicles. The large-area detector consists of four octagonal 6 ft by 6 ft or circular 6-ft diameter small loops, 9 ft 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 initial time 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 a left turn can be serviced on a permissive green or yellow clearance, or where a vehicle can enter the left-turn lane beyond the initial detector. The following should be considered in using the LOC for a left-turn.

   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 is to use an extended-call detector.

2. Through Lanes, Approach Speed of 35 mph or Lower. The indecision 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 30-mph approach speed and 3 s desired allowable gap, the LOC area is calculated as follows:

$$\left(\frac{30\ mi}{h}\right)\left(\frac{5280\ ft}{mi}\right)(3\ s)\left(\frac{1\ h}{3600\ s}\right) = 132\ \text{ft in 3 s}$$

The vehicular length of 20 ft should be subtracted from the LOC, so that the required detector area is 112 ft. A loop layout is only 45 ft in length; therefore, for a 30-mph 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 0 and 1 s then, under low-traffic-volume conditions, a green interval as short as 2 or 4 s may occur. Pedestrians or bicyclists presence should be determined. If so, the minimum green times for their crossings should be provided. Driver expectancy should also be considered. A driver for a major through movement expects a minimum green interval of 8 to 15 s.

3. Through Lanes, Approach Speed of 40 mph or Higher. It is not practical to extend the LOC beyond the indecision zone of 5 s of passage time back from the stop line. To address the indecision-zone problem, an extended-call detector is placed beyond the indecision 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 this approach speed 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 will routinely extend the green to the maximum setting, which is undesirable.

b. An LOC design should be used only if the AADT is 8,000 to 10,000. This approach speed with a greater AADT is better served with a density controller. The intersection of a higher-speed artery with a lower-speed crossroad is better served with a density controller on the artery and LOC for the crossroad.

77-5.09 Vehicle-Counting Loop

A new or modernized traffic signal should include vehicle-counting loops. This is an inductive loop detector that, in addition to detecting the presence or passage of a vehicle, provides a count pulse once a vehicle passes over the loop. The traffic-signal controller stores the counts in a format that can be uploaded either remotely or onsite to a personal computer.

77-5.09(01) Considerations for Counting-Loop Use

The configuration of counting loops and determination of which loops are used to count vehicles at a signalized intersection are dependent on the geometry of the intersection. The considerations include the following.

1. Encroachment. A vehicle from one movement drives over a loop providing vehicle count for another movement, causing that movement to over-count. A lane with an encroachment issue should use only loop numbers 4 or 1 to count, depending on the area of encroachment.

2. Late Entrance or Early Departure. A vehicle enters or exits the side of a count loop series and does not cross every count loop in the series, causing that movement to under-count.

3. Lane Change Within the Loop System. A vehicle changing lanes within 50 ft of the stop line is unpredictable and cannot be eliminated. This is a minor issue. For a lane where this is a major issue, use loop numbers 1 or 4 to count, avoiding issues 1 and 2 above.

4. Tractor-Trailer. A tractor-trailer may be counted once or multiple times due to the difference in height of the bed and the axles. This is inconsistent between trucks and there are too many variables to eliminate this issue. For a lane where this is a major issue, using all four loops to count may minimize over-counting.

5. Shared Lane for Through and Right Movements. Figure 77-5AA shows two methods of counting through and right-turn movements if they share a lane. The minimum distance between the loops in the through lane and the loop in the radius for a right-turning vehicle should be 6 ft. Method A should be chosen if the radius is large enough that a right-turning vehicle will not cross the front loop in the lane. If a right-turning vehicle will pass partially or completely over the front loop in the lane, method B should be used.

Figures 77-5AA, 5BB, and -5CC illustrate the effects of the considerations described above, and show suggested counting-loop configurations.

77-5.09(02) Preferred Counting-Loop Configurations

One loop will provide the most accurate count but at a higher cost in hardware and detector lead-ins than for a four-loop series. Some detectors are not as accurate with one loop.

Two loops may increase accuracy for a detector that is not as accurate in counting with one loop. Counting with two loops is equal in cost to counting with one loop of a four loop series. Counting with two loops may decrease accuracy due to encroachment, late entrance, early departure, or lane changes within the count zone. Therefore, counting with two loops is subject to approval of the district Office of Traffic.

Four loops provide an accurate count installation with the lowest cost. However, this may decrease count accuracy if there are encroachments, late entrances, early departures, or lane changes within the count zone.

The preferred counting configurations, listed from most to least desired, are as follows:

1. Four loops: Loops 1, 2, 3, and 4
2. One loop: Loop 4
3. One loop: Loop 1
4. Two loops: Loops 3 and 4; requires district Office of Traffic approval
5. Two loops: Loops 1 and 2; requires district Office of Traffic approval

Only one movement can be counted per lane. As many movements as feasible should be counted at the intersection.

77-5.10 Computer Software

There are many software programs available to help assist in preparing a traffic-signal design or timing plan. New programs, as well as updates to existing programs, are continuously being developed. Before using these programs, the Traffic Control Systems Division should be contacted to determine which software packages or versions INDOT is currently using. The following programs are used for signal-timing optimization.

1. SYNCHRO and SIMTRAFFIC. SYNCHRO is a traffic-signal simulation program that develops a timing plan for either an isolated signal or an arterial signal system. It will

optimize timing for either a fixed or an actuated traffic signal. SIMTRAFFIC is a companion microscopic simulation and animation program that uses SYNCHRO files. Both programs will estimate measures of effectiveness for a timing plan.

2. PASSER II. This is Progression Analysis and Signal System Evaluation Routine II, a bandwidth-optimization program. It develops a timing plan that maximizes the through progression band along an arterial for up to 20 intersections. It works best in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER II 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. This is Traffic Signal Network Study Tool 7F, which develops a signal-timing plan for an arterial or grid network. The objective of this program is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

4. AAP. This is Arterial Analysis Package, which allows the user to easily access PASSER II and 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 AAP, the user can generate an input file for two of the component programs to quickly evaluate an arterial signal-timing design or strategy. The package also links to the Wizard of the Helpful Intersection Control Hints (WHICH) to facilitate detailed design and analysis of the individual intersections. This program interfaces with TRANSYT-7F, PASSER II, and WHICH.

5. HCS. This is Highway-Capacity Software, which replicates the procedures described in the *Highway Capacity Manual.* It is a tool that 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. Passer III™-98. This is a diamond-interchange optimization software. The program can evaluate an existing or proposed signalization strategy, determine a signalization strategy which minimizes the average delay per vehicle, and calculate a signal-timing plan for interconnecting a series of interchanges on one-way frontage roads.

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.

77-5.11 Maintenance Considerations

After a signal is installed, the district Office of Traffic 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 and its location (e.g., controller, cabinet, signal heads, etc.). The selected equipment must satisfy 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. If 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 limit the designer's options, as there are consultants who can help a local government operate and maintain a traffic signal.

77-6.0 SIGNAL-SYSTEM DESIGN

As traffic volume continues to increase, installation of a coordinated signal system 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 0.5 mi or closer should be considered for coordination. Although not a perfect solution, the use of a coordinated traffic-signal system can satisfy the traffic needs of a highway for many 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 pretimed controller, or an actuated controller, with demand on all phases, displays a complete sequence of signal indications. 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 phases of the local controller.

3. Offset. The time relationship determined by the difference between a specific point in the local signal sequence, the beginning of the major-street green interval, and a system-wide

reference point.

4. Time of Day or Day of Week. This system selects a system-timing plan 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. Some systems permit the selection of the plan based upon a specific day of the year.

5. Traffic-Responsive. 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 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

The methodologies available to coordinate traffic signals take advantage of computer technology. As new signal controllers, computers, and software are developed, the design of a coordinated traffic-signal system will continue to improve. These systems should match existing systems or be coordinated with nearby systems. A traffic-signal system is designed by a consultant who specializes in this work. To maintain consistency, each traffic-signal-system design must be coordinated through the Highway Design and Technical Support Division. These systems are described below.

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

This system is applicable to either a pretimed 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 or via radio modem. Local intersection coordination equipment interprets these commands and implements the desired timing.

An interconnected time-of-day system can use the physical interconnection solely for the purpose of synchronizing the time clocks in the local controller. The local controller selects the desired timing from pre-programmed plans stored in the local controller.

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-base 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

This system 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 or radio modem to coordination equipment at the local intersections.

Cycle lengths are selected based on traffic-volume and possibly occupancy-level thresholds on the arterial. The higher the volume, the longer the cycle length. Splits are selected based on the side-street traffic-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 an interconnect cable or radio modem. Most 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, or Closed-Loop, System

This 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 standard 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, many 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 and 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 of only the expense of the personal computer and the monthly costs of a standard business telephone or cellphone line. Graphics displays are provided to assist in monitoring the system.

77-6.02(05) Central Computer, or Interval-Command System

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-phase green, 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. Many systems include a color-graphics monitoring system.

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

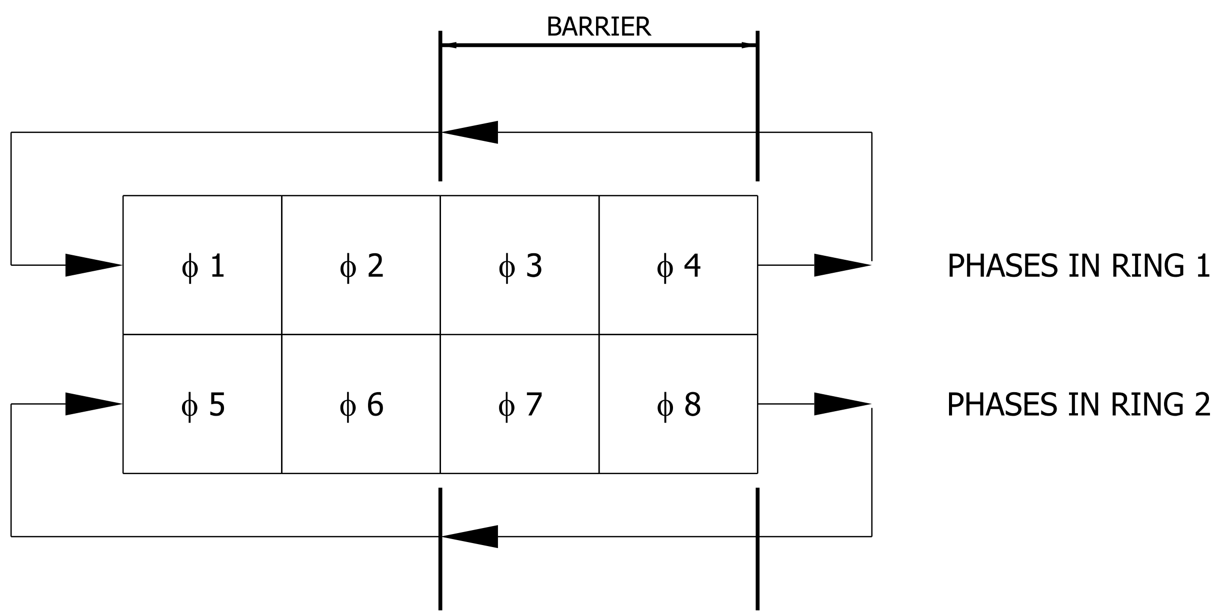
77-6.02(06) Central Database-Driven Control System

This system draws from the quality points of 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 communications data required also allows an increase in monitoring data to be returned to the computer. Thus, the complex graphics displays normally found in distributed-master systems can also be implemented in a large-scale system.

77-6.03 Communications Techniques

A system other than a time-based coordinated system requires a 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 can include leased telephone lines, cable-television lines, fiber optics, or direct wiring. Through-the-air interconnections can 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 method to use will be determined on a system-by-system basis.



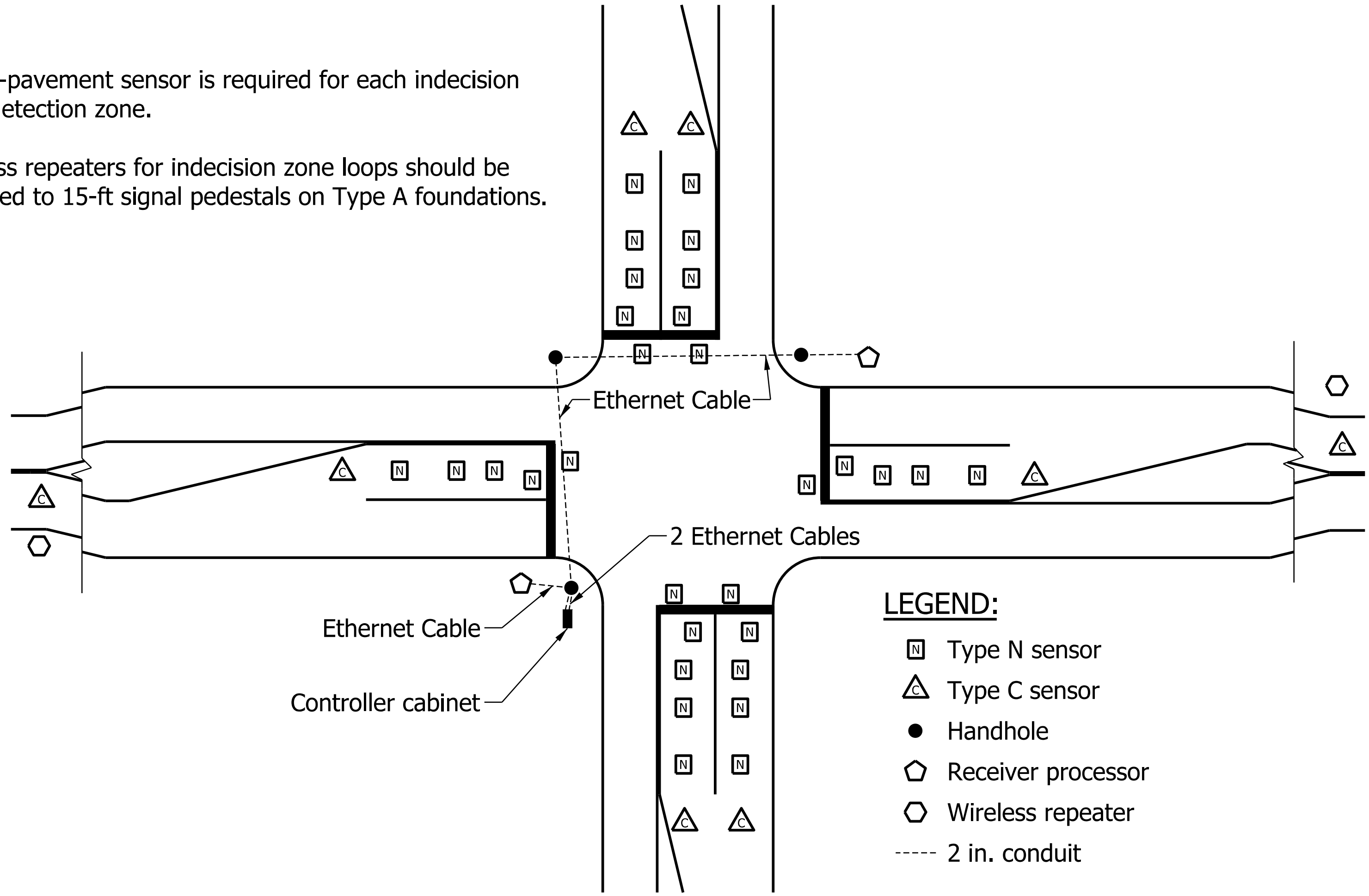
SEQUENCE OF PHASES,
8-PHASE DUAL-RING CONTROLLER UNIT

Figure 77-4A

NOTES:

1. One in-pavement sensor is required for each indecision zone detection zone.

2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.



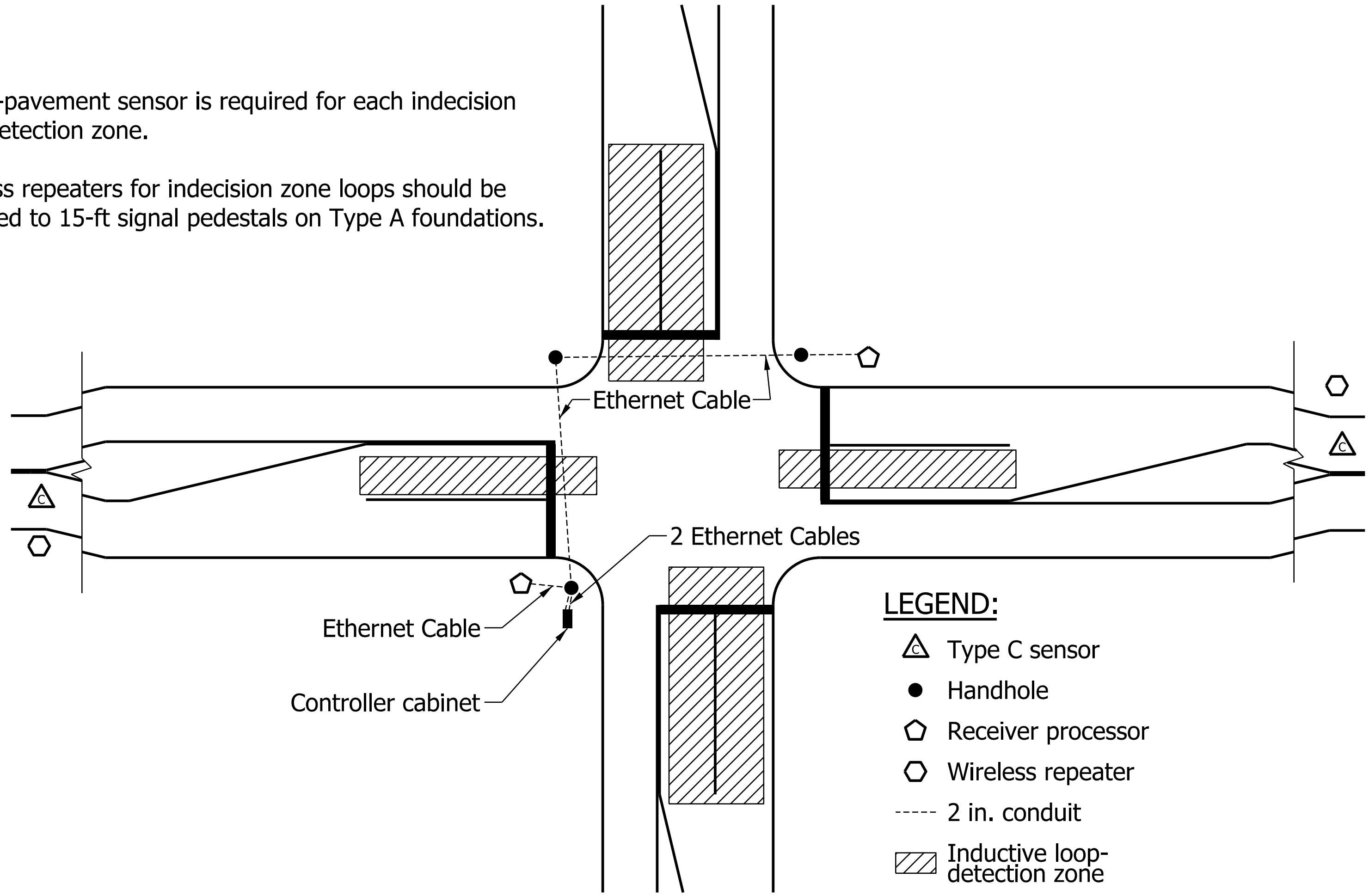
TYPICAL WIRELESS-VEHICLE-DETECTION SYSTEM

Figure 77-4B

NOTES:

1. One in-pavement sensor is required for each indecision zone detection zone.

2. Wireless repeaters for indecision zone loops should be mounted to 15-ft signal pedestals on Type A foundations.



TYPICAL HYBRID WIRELESS-VEHICLE-DETECTION SYSTEM

Figure 77-4C

Advantages
• Low installation costs. • Easy maintenance, no roadway interference. • Generally considered most aesthetically acceptable. • Generally correct locations for pedestrian signals and push buttons. • Provides adequate visibility where a wide median with left-turn lanes and phasing exist. • Unlimited roadway vertical clearance.
Disadvantages
• Requires underground wiring which can offset initial cost advantages. • Generally does not provide adequate visibility of signal indications for motorist due to lateral placement of signal indications. • May not provide mounting locations such that a display with a clear meaning is provided. • Height limitations may provide problems where approach is on a vertical curve. • Subject to vehicular impact if installed close to the roadway, particularly in a median.

POST-MOUNTED SIGNAL,
ADVANTAGES AND DISADVANTAGES

Figure 77-4D

Advantages
• Easy to install, less underground work required. • Allows excellent lateral placement of signal heads for maximum visibility. • Allows for easy future adjustments of signal heads. • Allows correct signal-placement location with respect to stop line. • Can provide convenient post locations for supplemental signal heads and pedestrian signals and push buttons. • Permits bridles to reduce distance from stop line at wide intersection (see Figure 77-4F)
Disadvantages
• Seen by some users as aesthetically unpleasing. • Requires periodic maintenance for span tightening. • Prevents passage of an overheight vehicle.

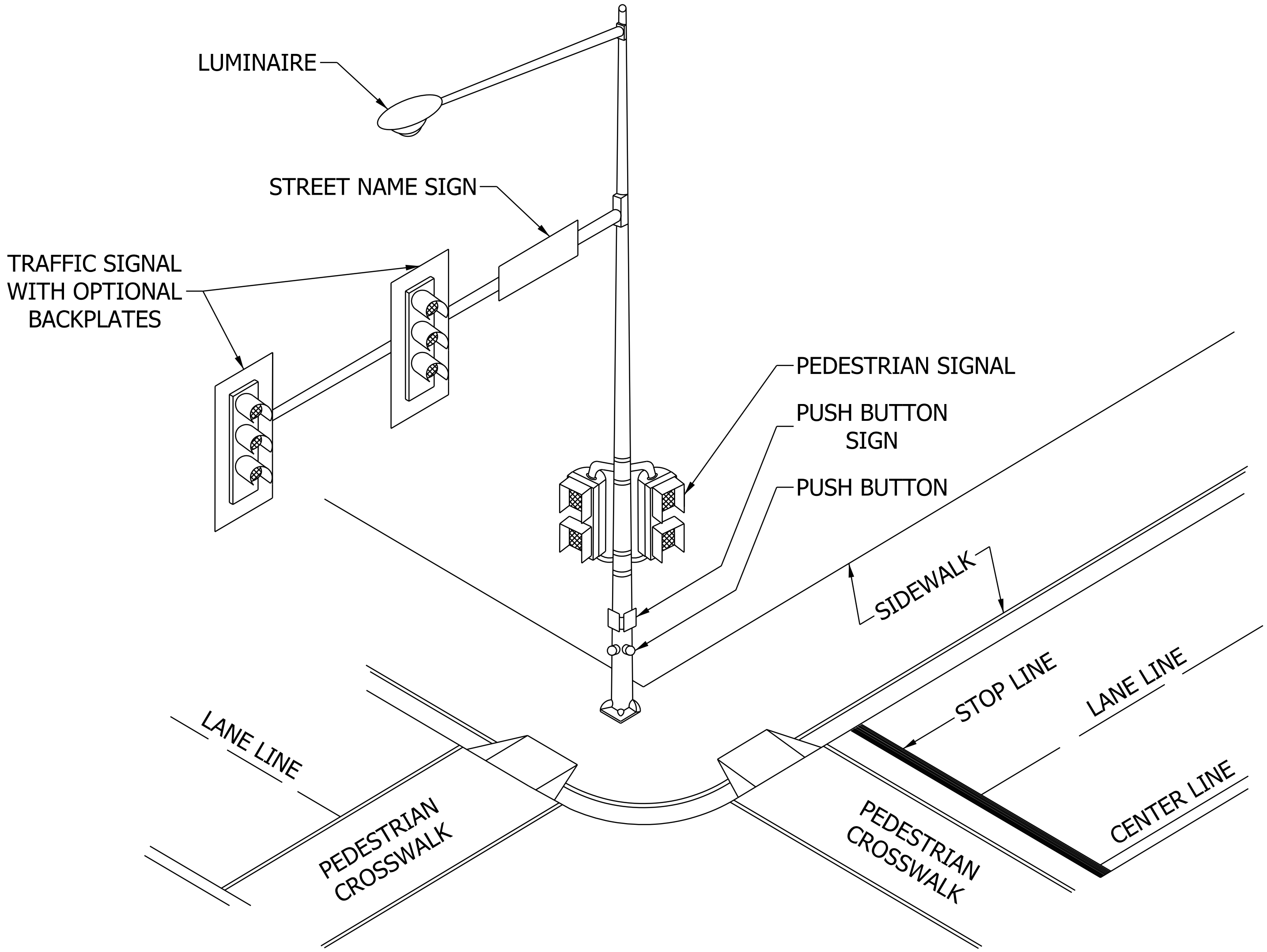
CABLE-SPAN-MOUNTED SIGNAL, ADVANTAGES AND DISADVANTAGES

Figure 77-4E

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

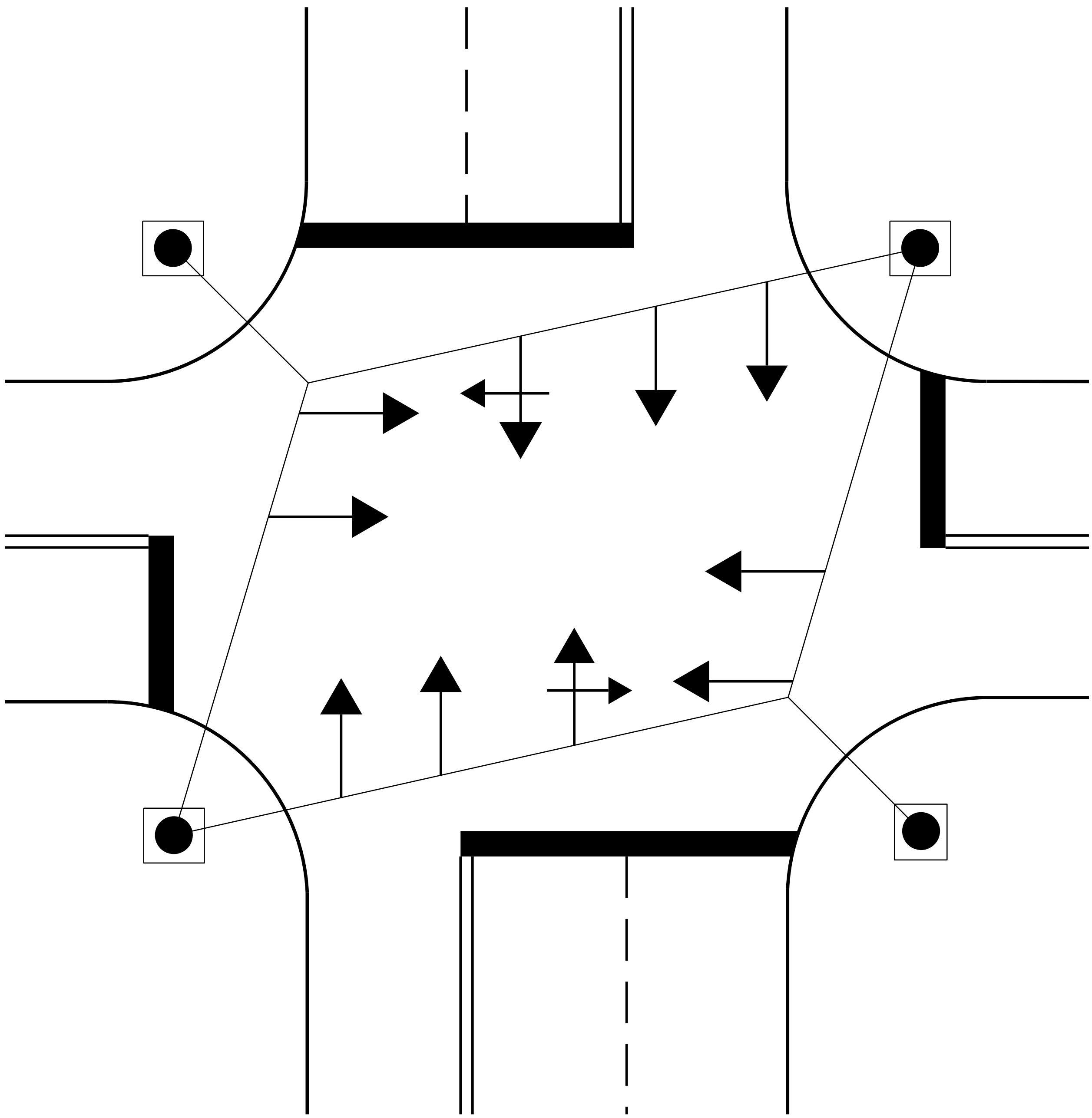
CANTILEVER-, OR MAST-ARM-, MOUNTED SIGNAL, ADVANTAGES AND DISADVANTAGES

Figure 77-4F



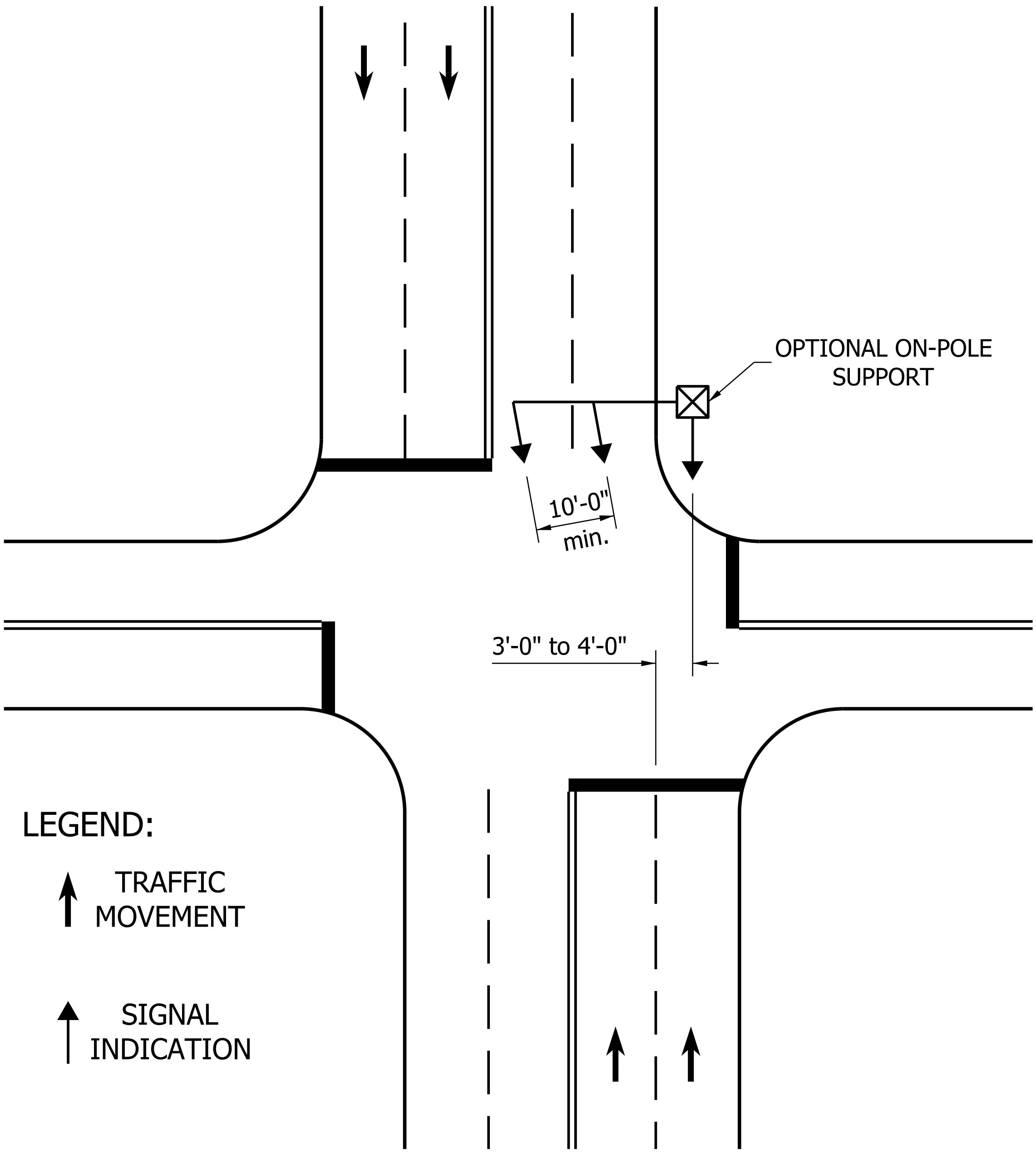
COMBINATION SIGNAL-LUMINAIRE POLE

Figure 77-4G



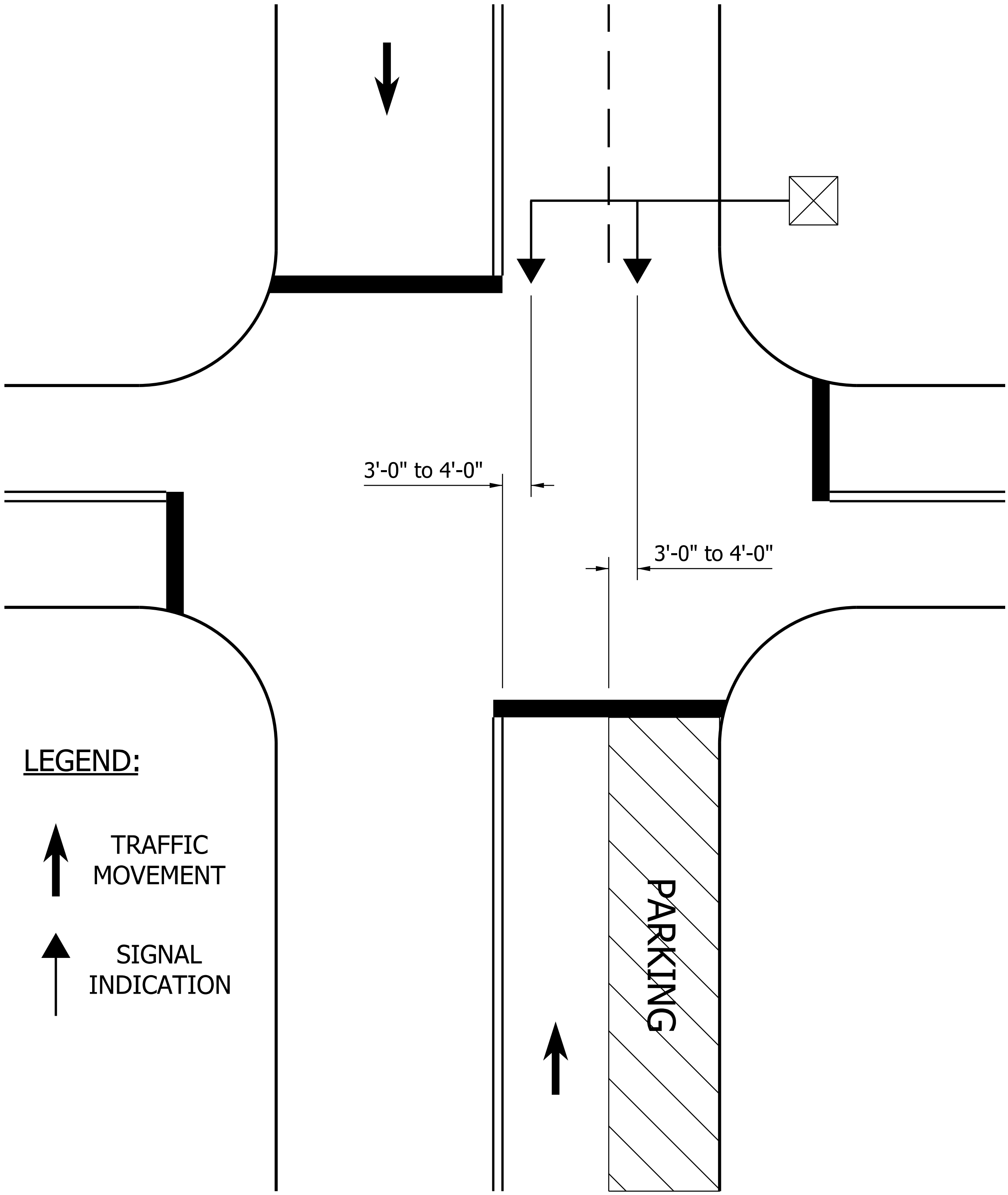
CABLE-SPAN MOUNTED SIGNAL
CONFIGURATION

Figure 77- 4H



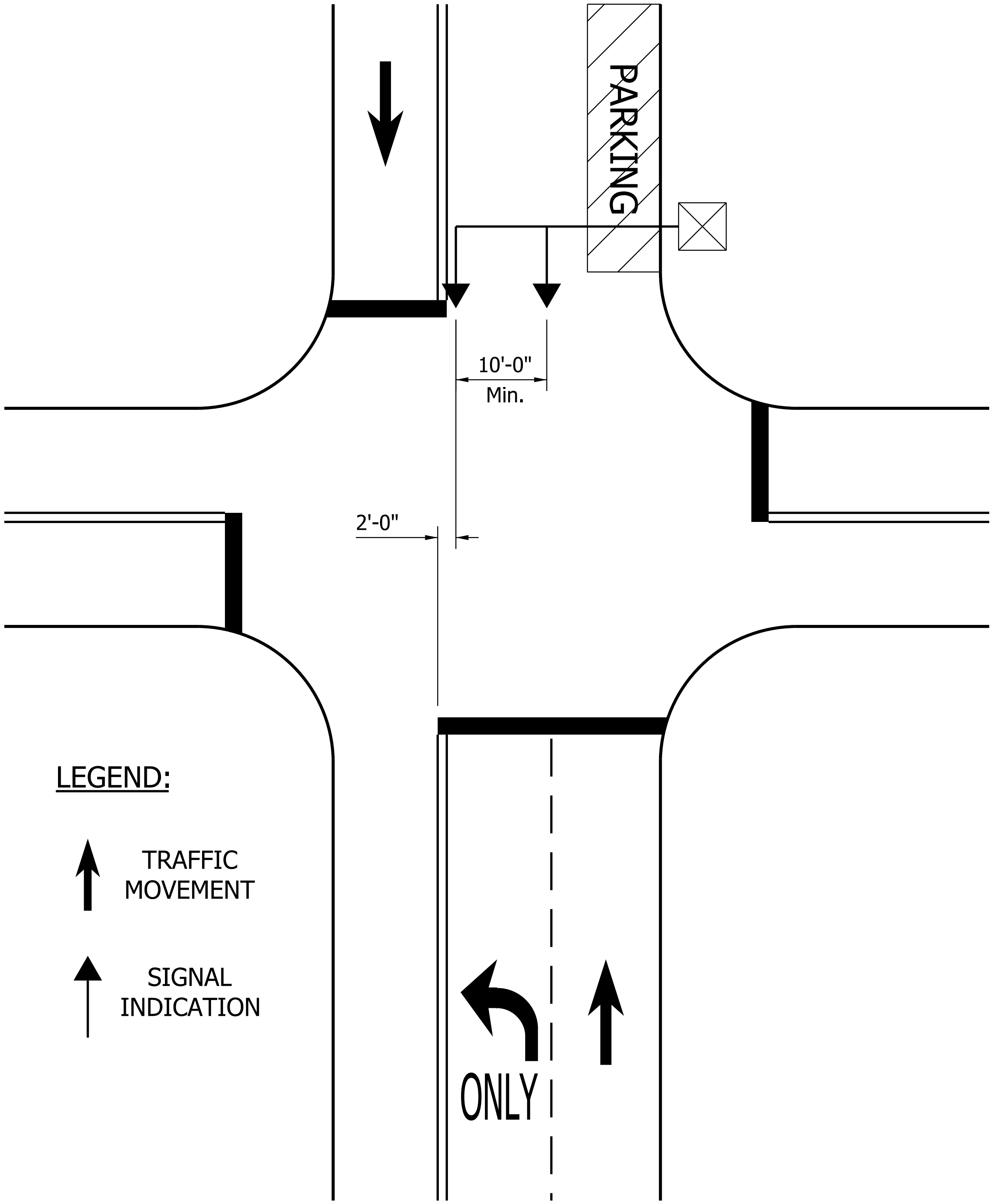
SIGNAL PLACEMENT
OFFSETTING INTERSECTION

Figure 77-5A



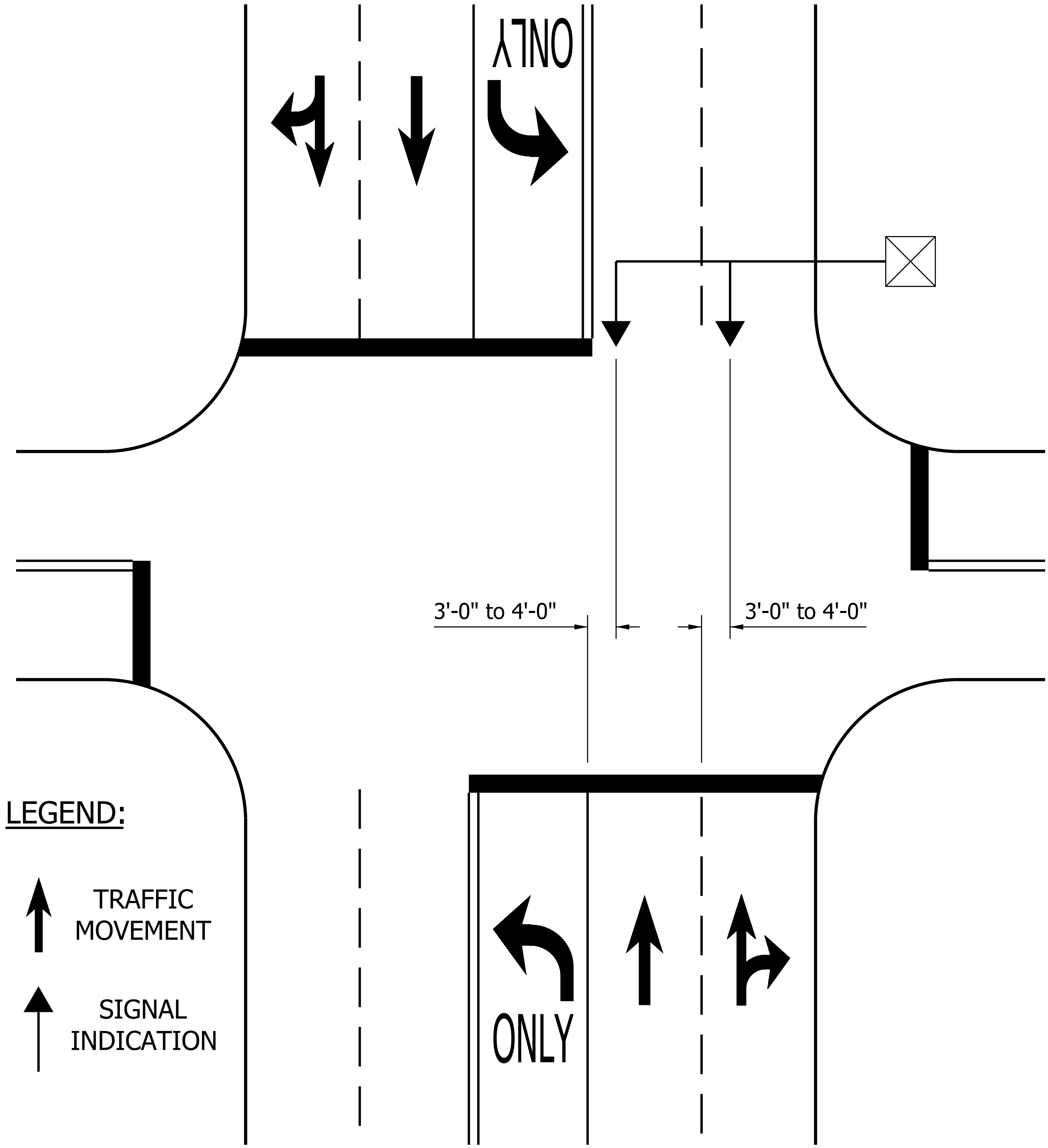
SIGNAL PLACEMENT
URBAN AREA -- NO LEFT-TURN LANE

Figure 77-5B



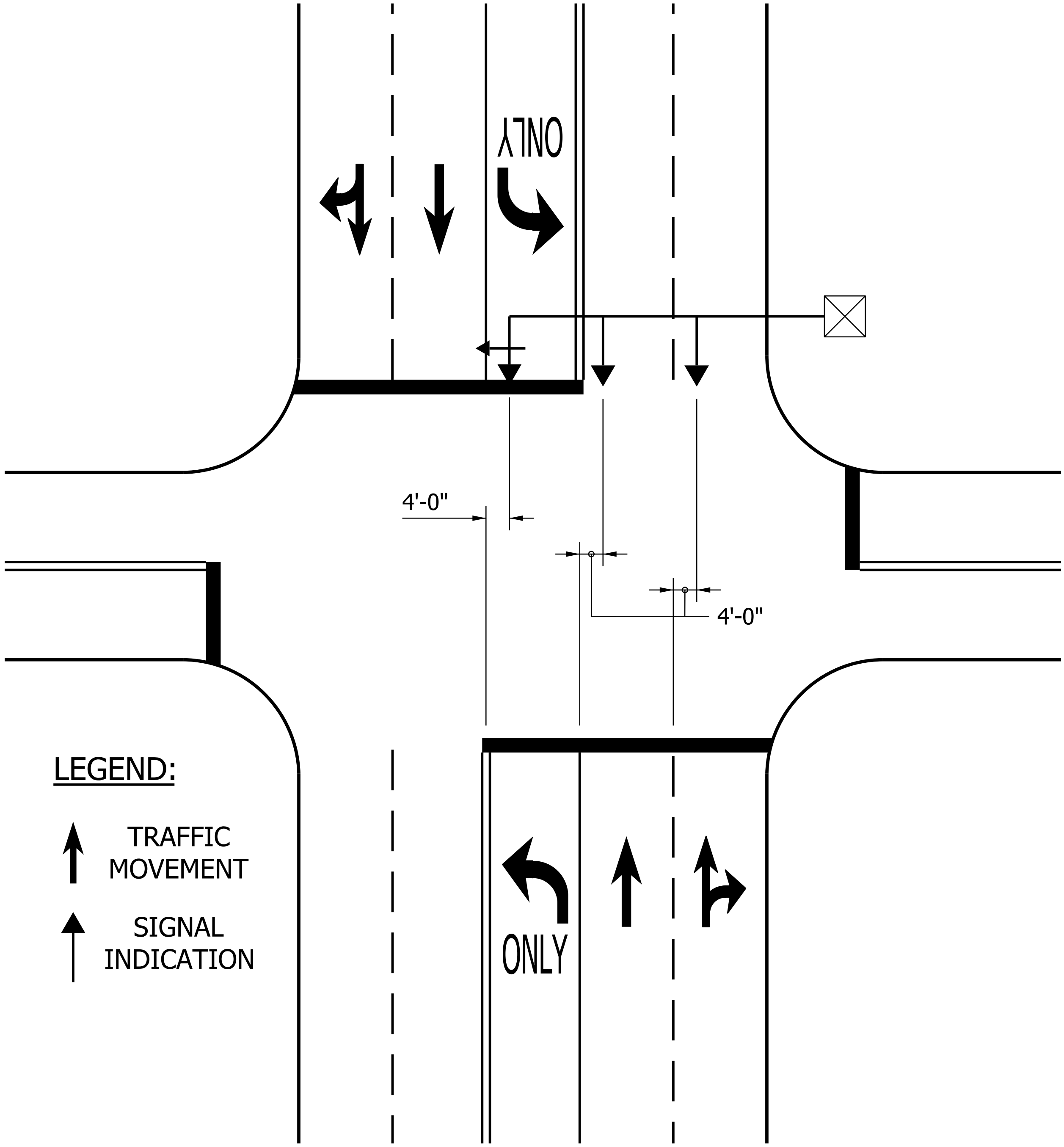
SIGNAL PLACEMENT
URBAN AREA -- LEFT-TURN LANE

Figure 77-5C



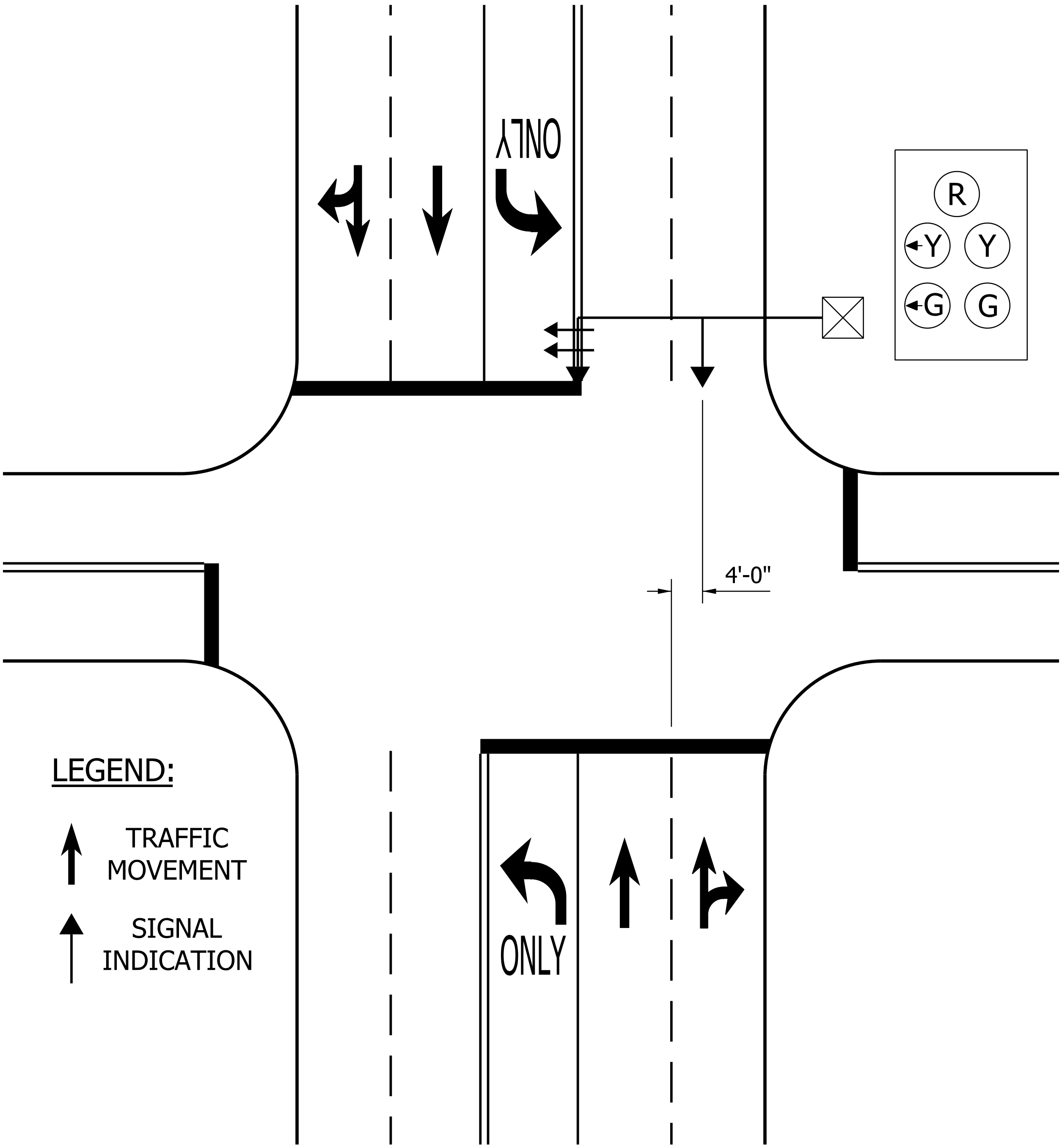
SIGNAL PLACEMENT
UNPROTECTED LEFT-TURN MOVEMENT

Figure 77-5D



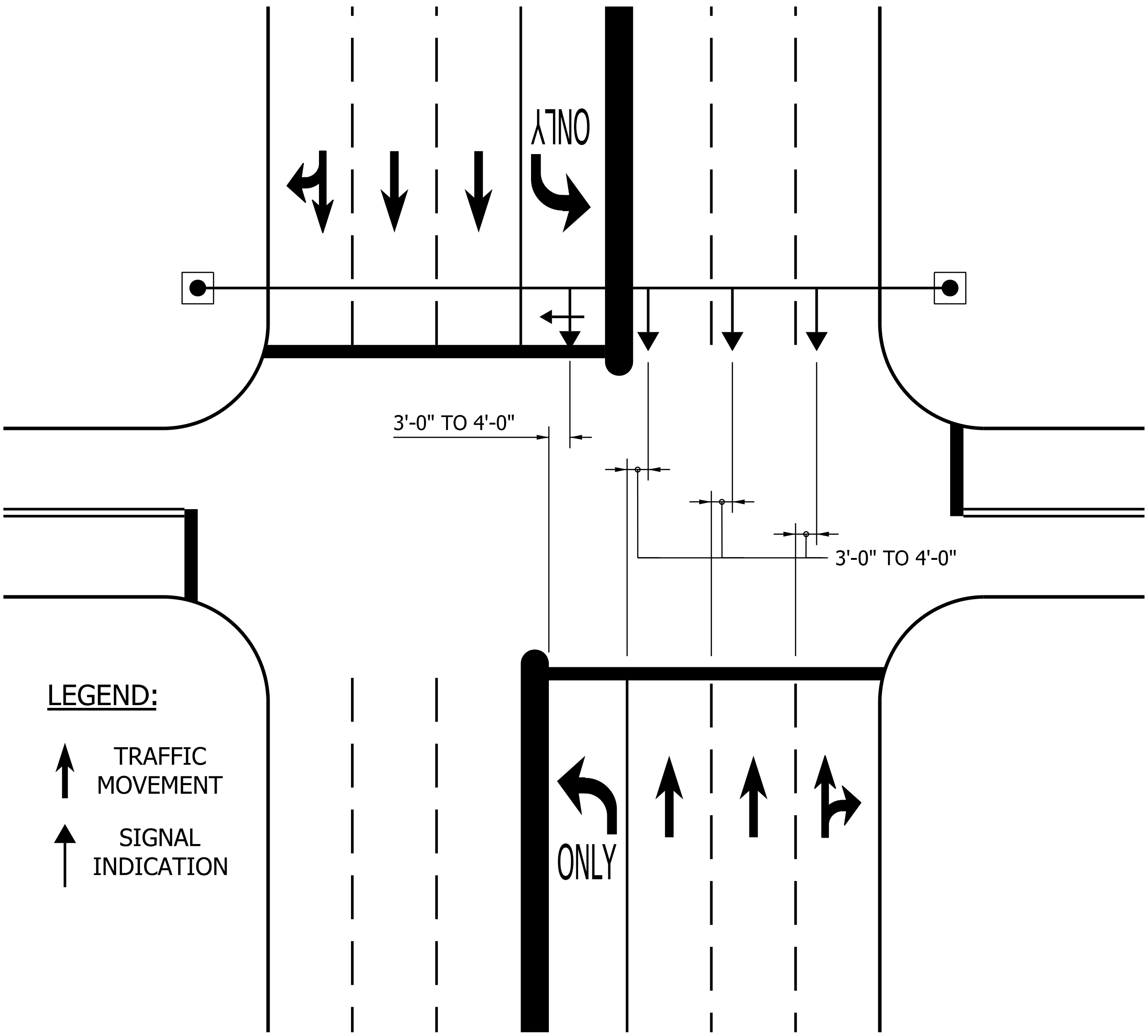
SIGNAL PLACEMENT
PROTECTED LEFT-TURN PHASE

Figure 77-5E



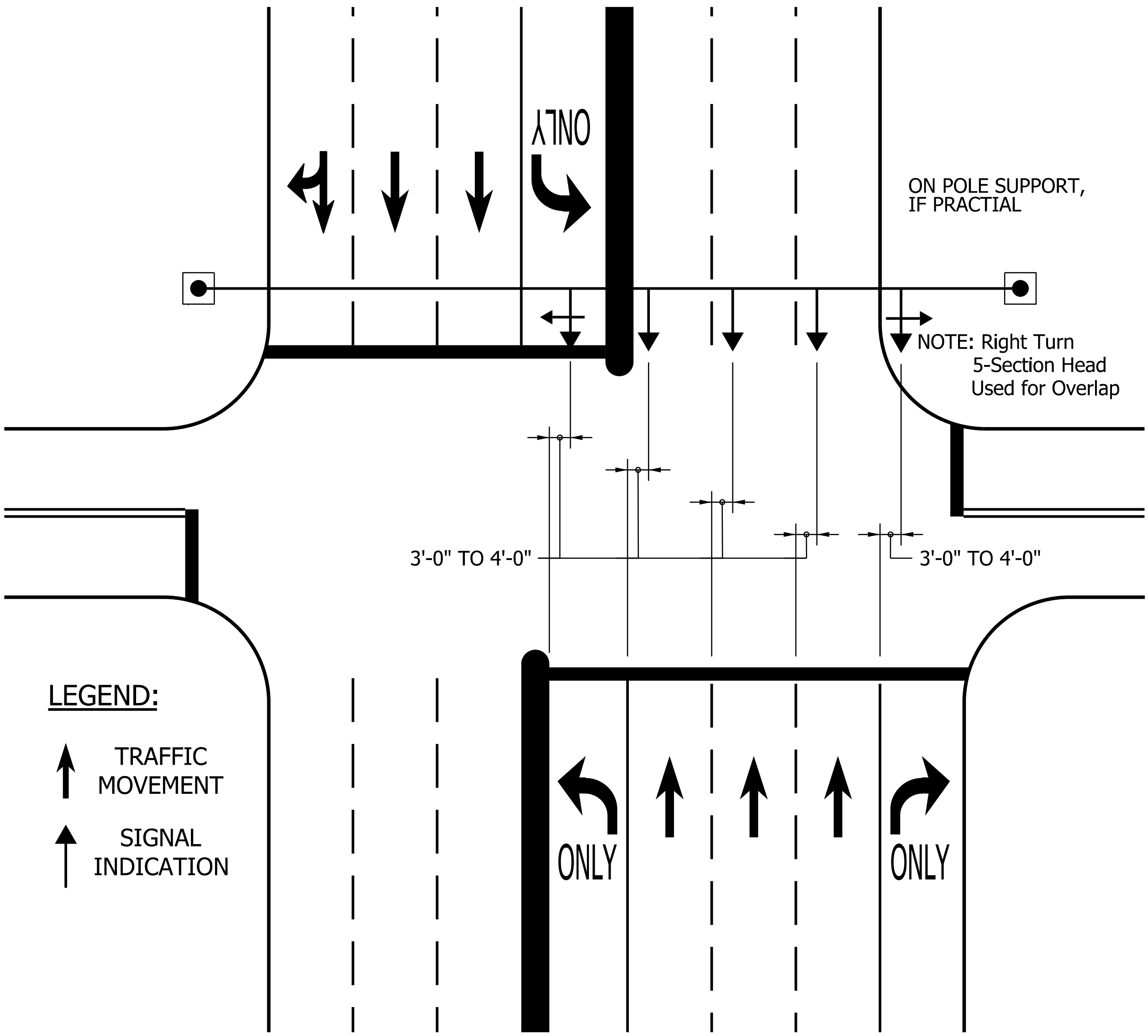
SIGNAL PLACEMENT
PROTECTED LEFT-TURN PRASE OR
PERMISSIBLE LEFT-TURN MOVEMENT

Figure 77-5F



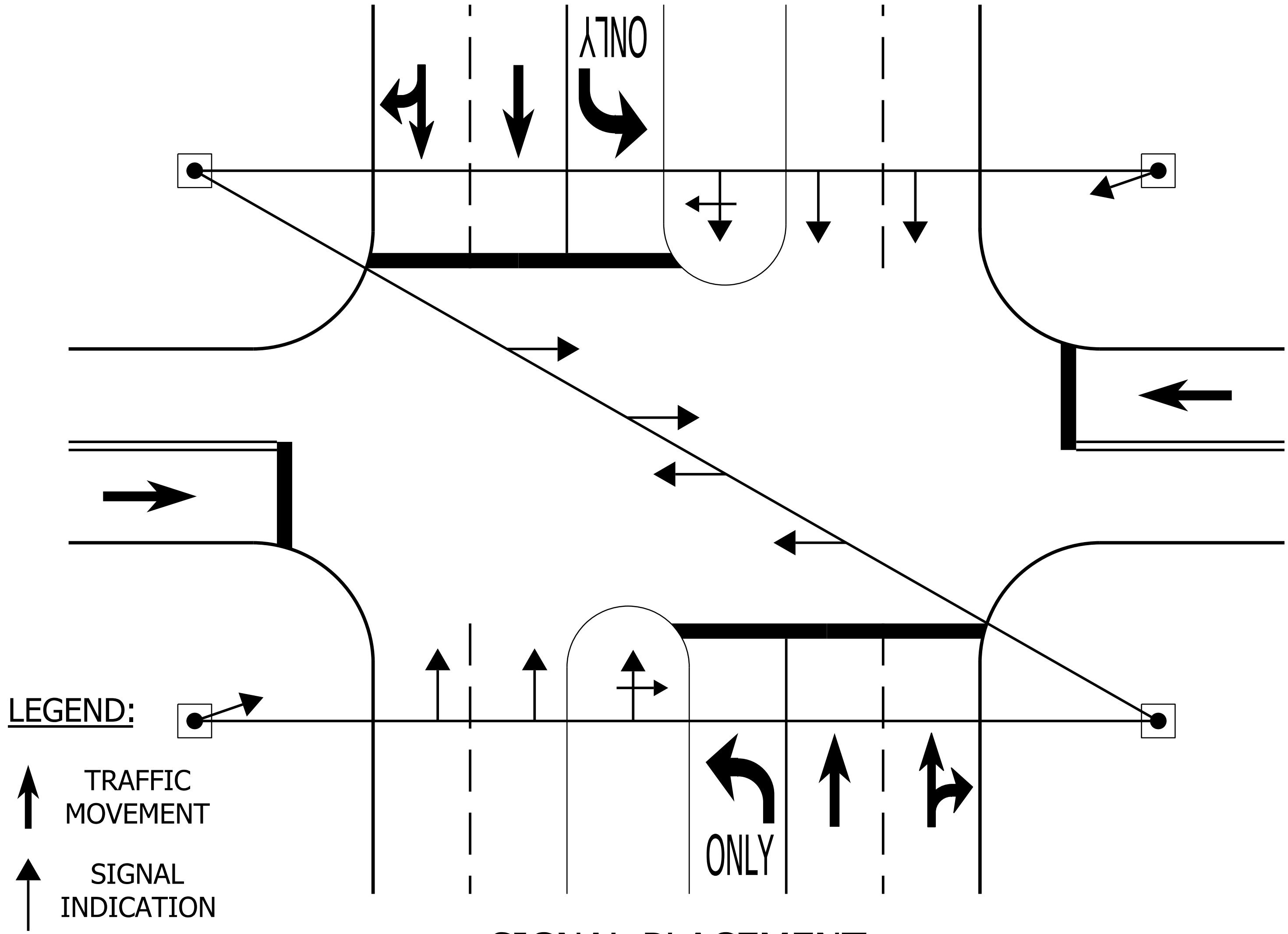
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH WITH LEFT-TURN LANES

Figure 77-5G



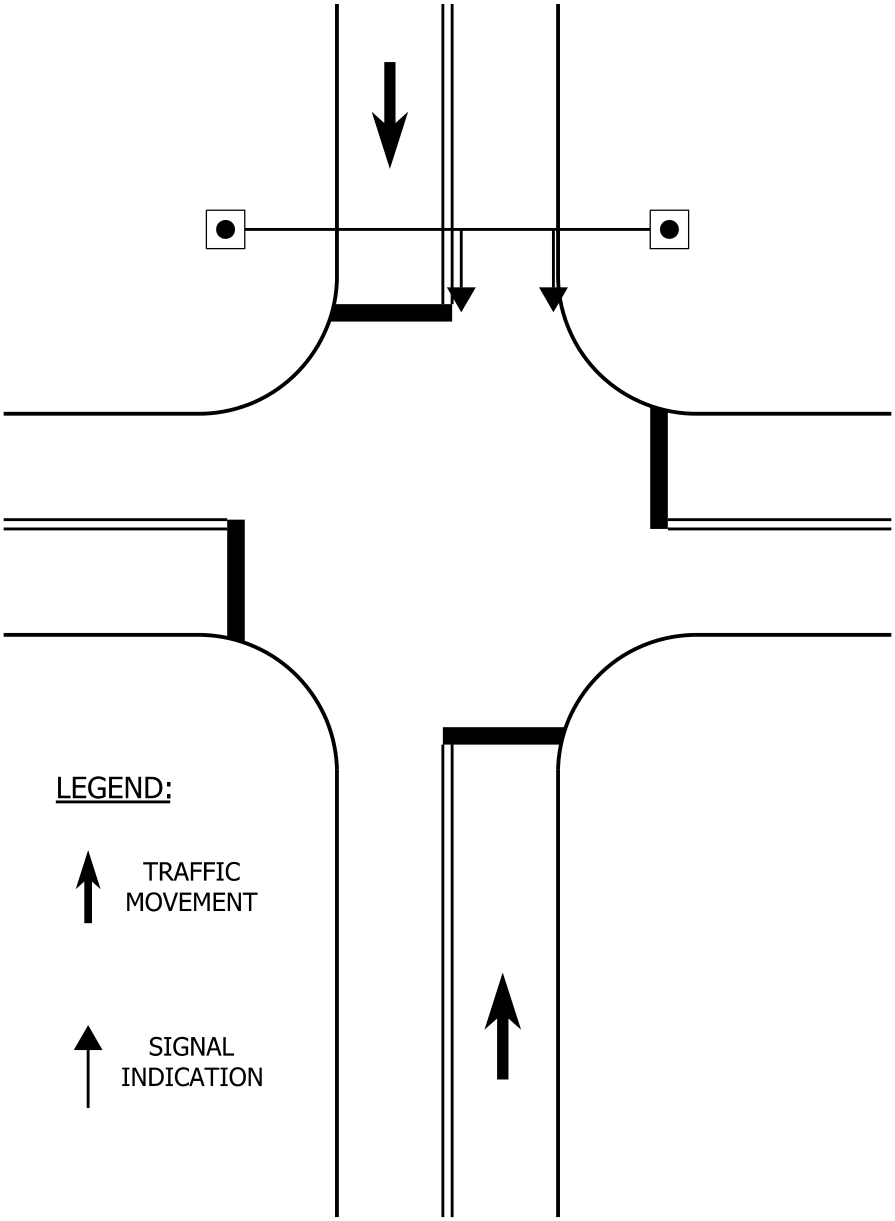
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH WITH LEFT- AND RIGHT-TURN LANES

Figure 77-5H



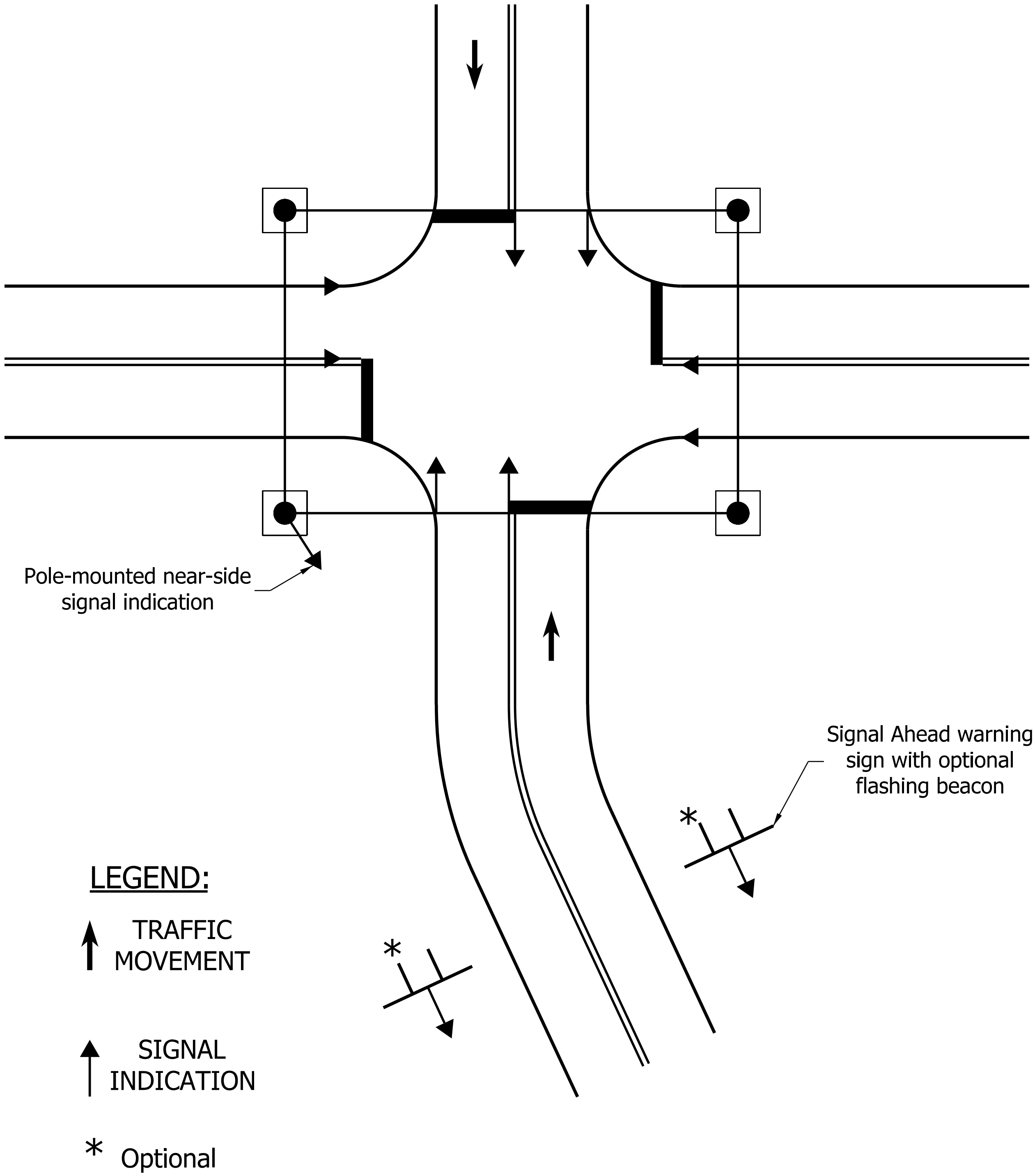
SIGNAL PLACEMENT
MULTIPLE-LANES APPROACH, Z-SPAN WITH SUPPLEMENTAL FAR-SIDE HEADS

Figure 77-5I



SIGNAL PLACEMENT
RURAL ONE LANE APPROACH,
WITH TRUCK OBSTRUCTION

Figure 77-5J



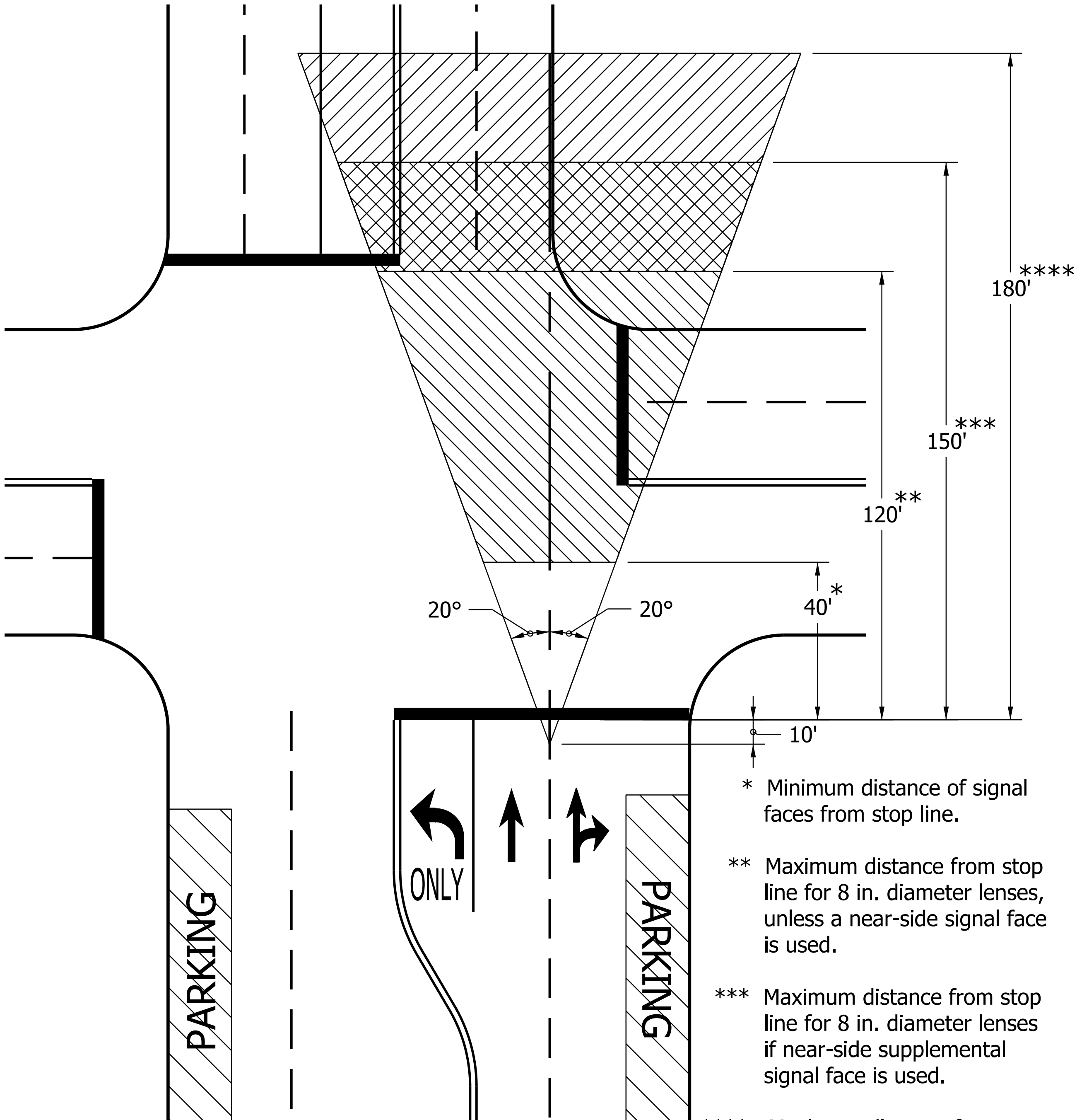
SIGNAL PLACEMENT,
RURAL ONE LANE APPROACH WITH OBSTRUCTED SIGHT DISTANCE, NEAR-SIDE SIGNAL INDICATION, ADVANCE WARNING SIGNS AND FLASHERS

Figure 77-5K

85^{th} Percentile Speed, mph	Minimum Visibility Distance, ft
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

MINIMUM-VISIBILITY DISTANCE

Figure 77-5L



* Minimum distance of signal faces from stop line.

** Maximum distance from stop line for 8 in. diameter lenses, unless a near-side signal face is used.

*** Maximum distance from stop line for 8 in. diameter lenses if near-side supplemental signal face is used.

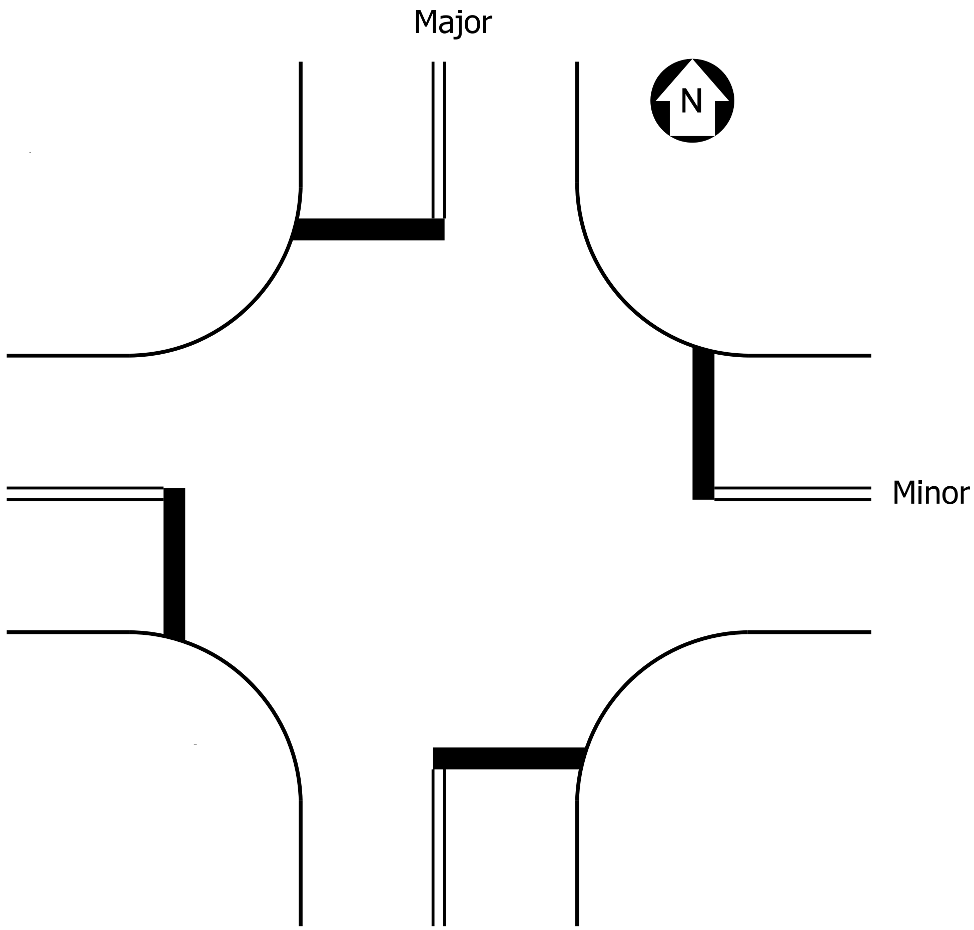
**** Maximum distance from stop line for 12 in. diameter lenses if near-side supplemental signal face is used.

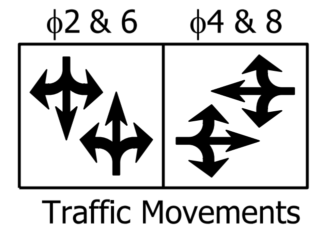
Diameter of lenses to be used

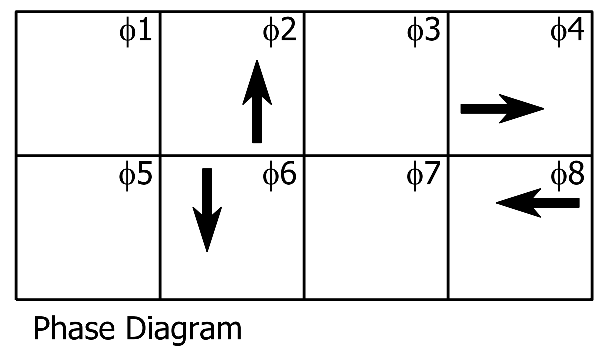
- 8 in. or 12 in. signal lenses
- 12 in. signal lenses, unless a near-side signal face is used
- 12 in. signal lenses

VISION CONE

Figure 77-5M

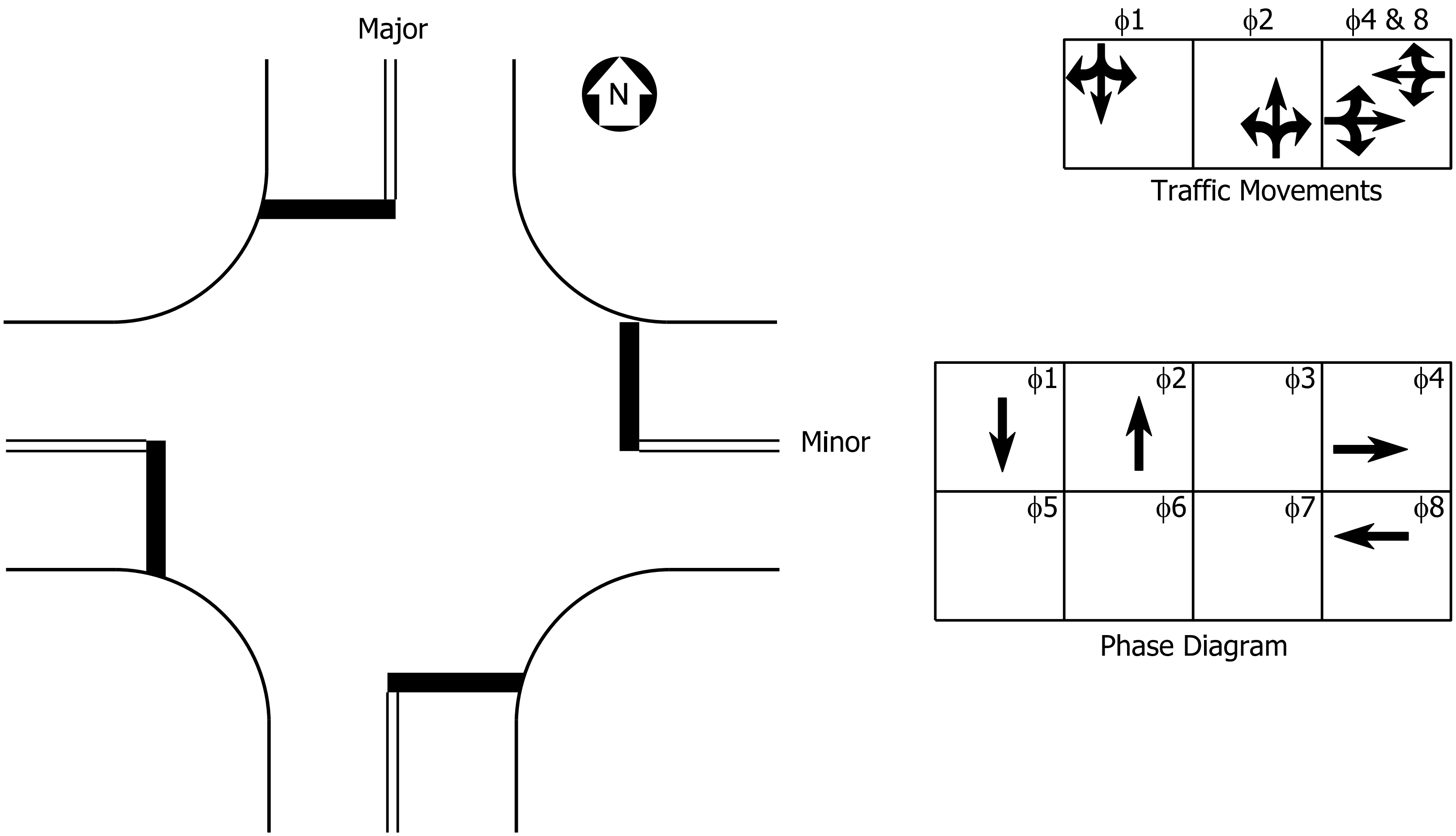






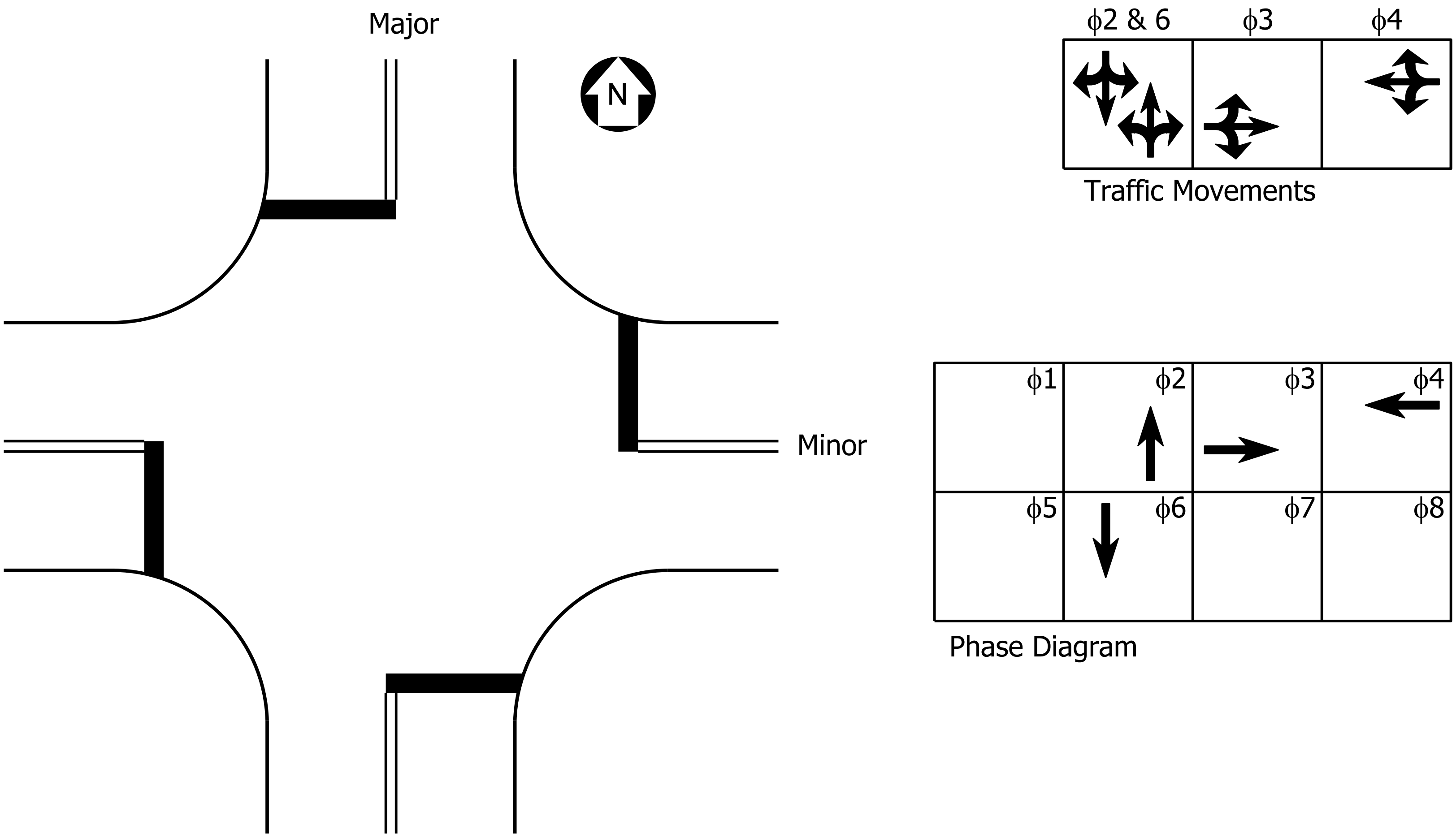
TWO-PHASE OPERATION

Figure 77-5N



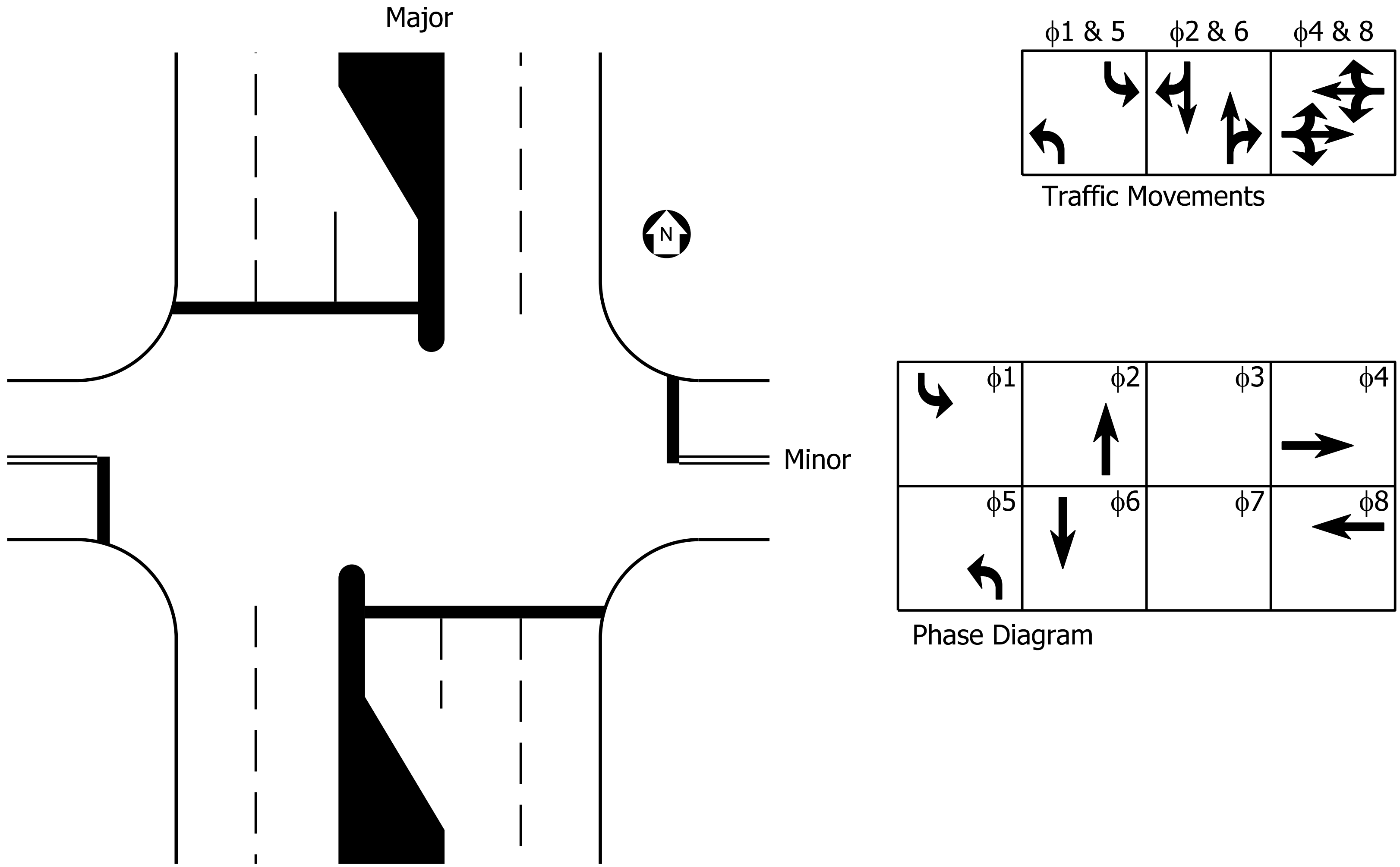
THREE-PHASE OPERATION
SEPARATE SPLIT PHASES
FOR MAJOR STREET

Figure 77-5 O



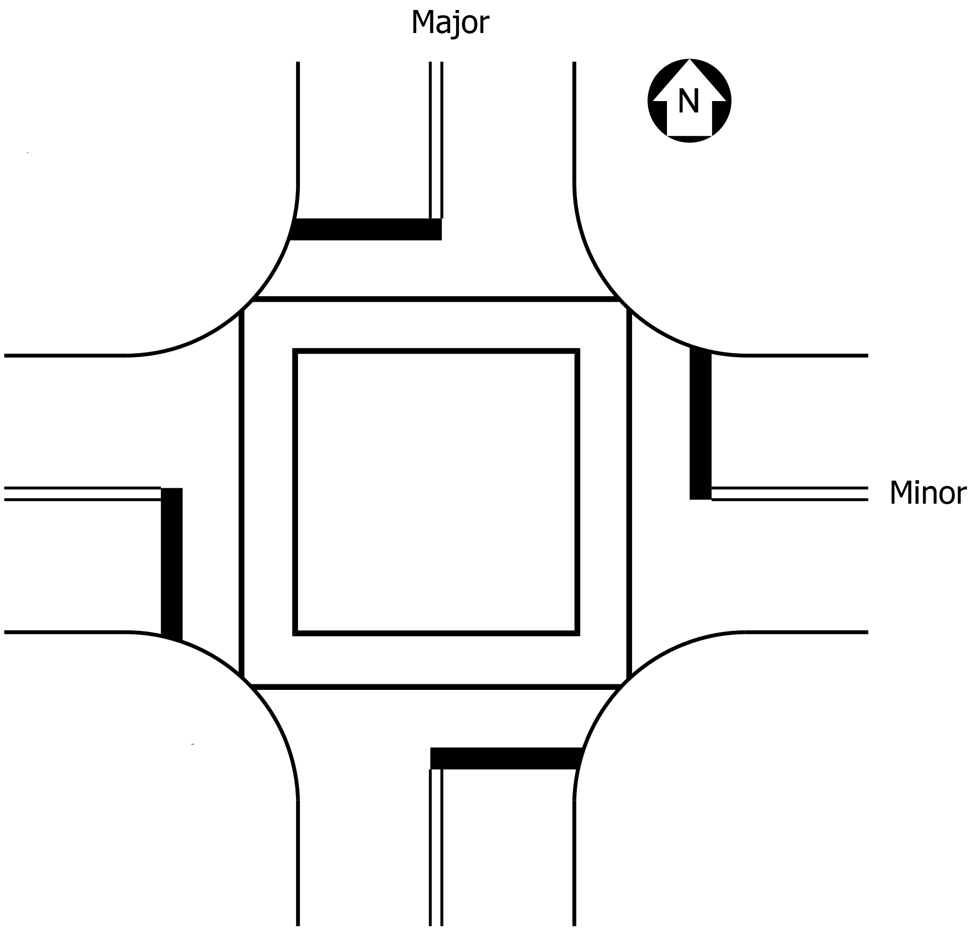
THREE-PHASE OPERATION
SEPARTE SPLIT PHASES FOR MINOR STREET

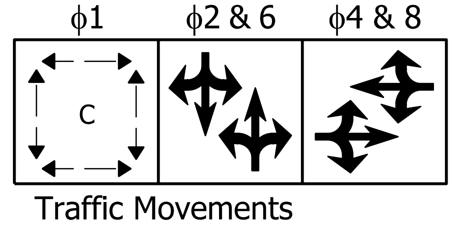
Figure 77-5P

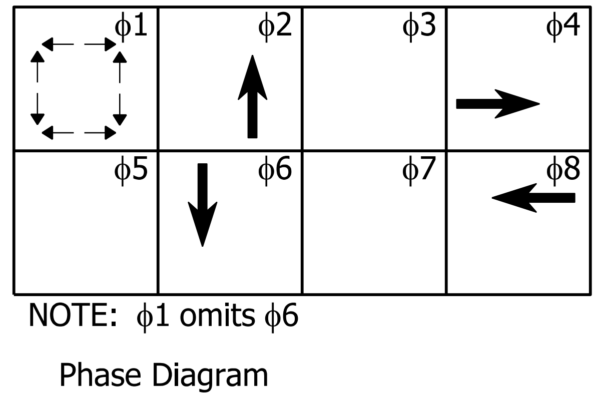


THREE-PHASE OPERATION
SEPRATE LEFT-TURN PHASE FOR MAJOR STREET

Figure 77-5Q

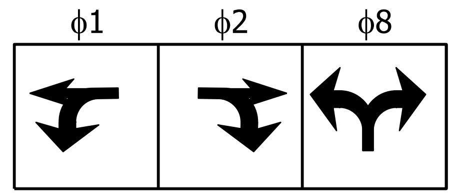




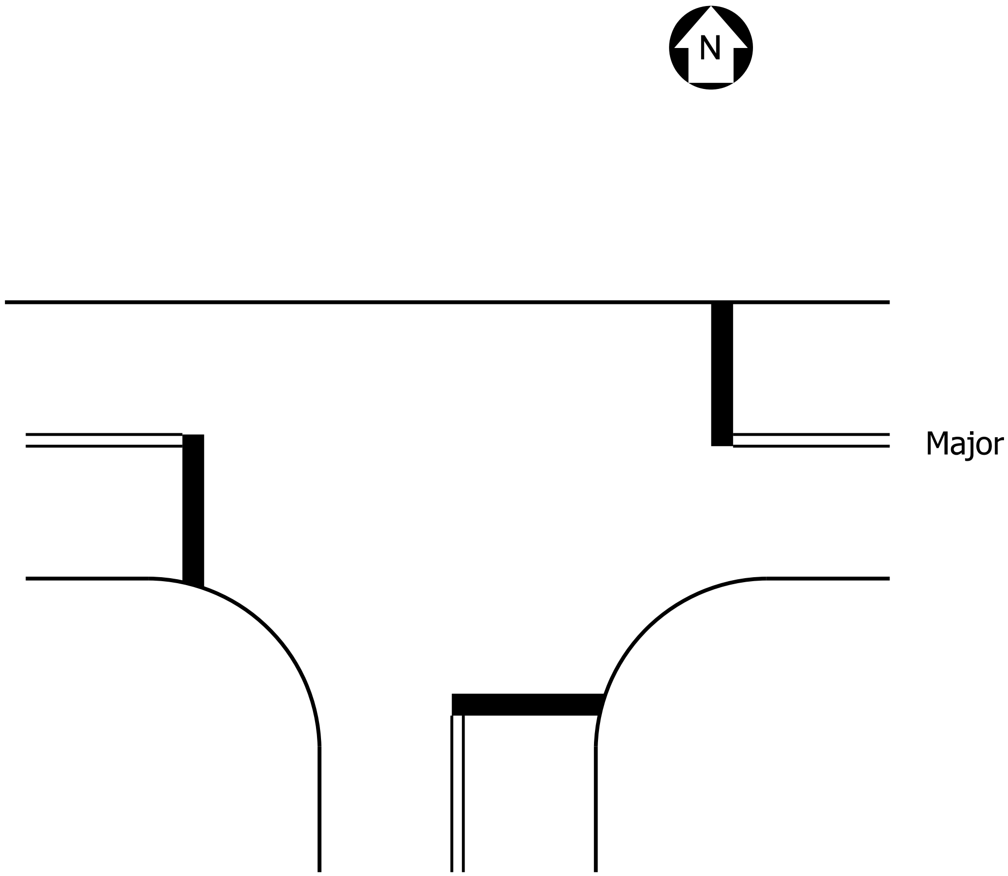


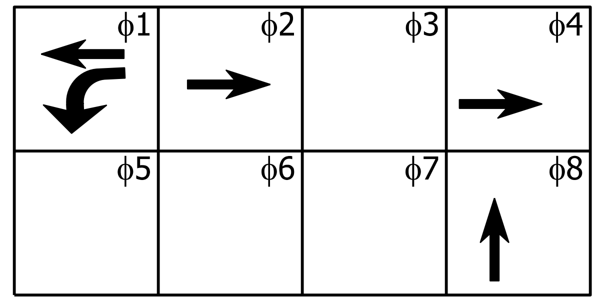
THREE-PHASE OPERATION
EXCLUSIVE PEDESTRIAN PHASE

Figure 77-5R



Traffic Movements

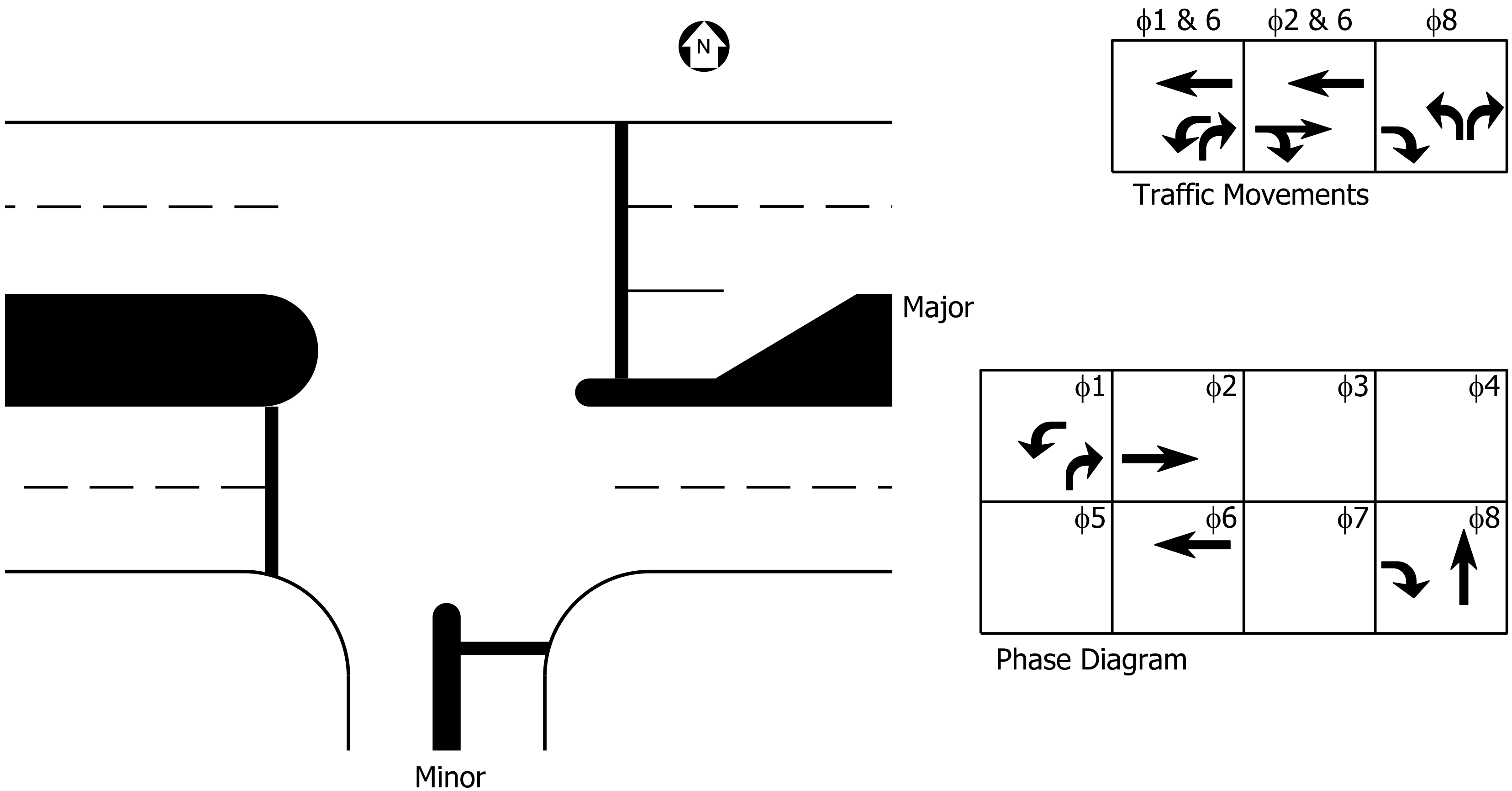




Phase Diagram

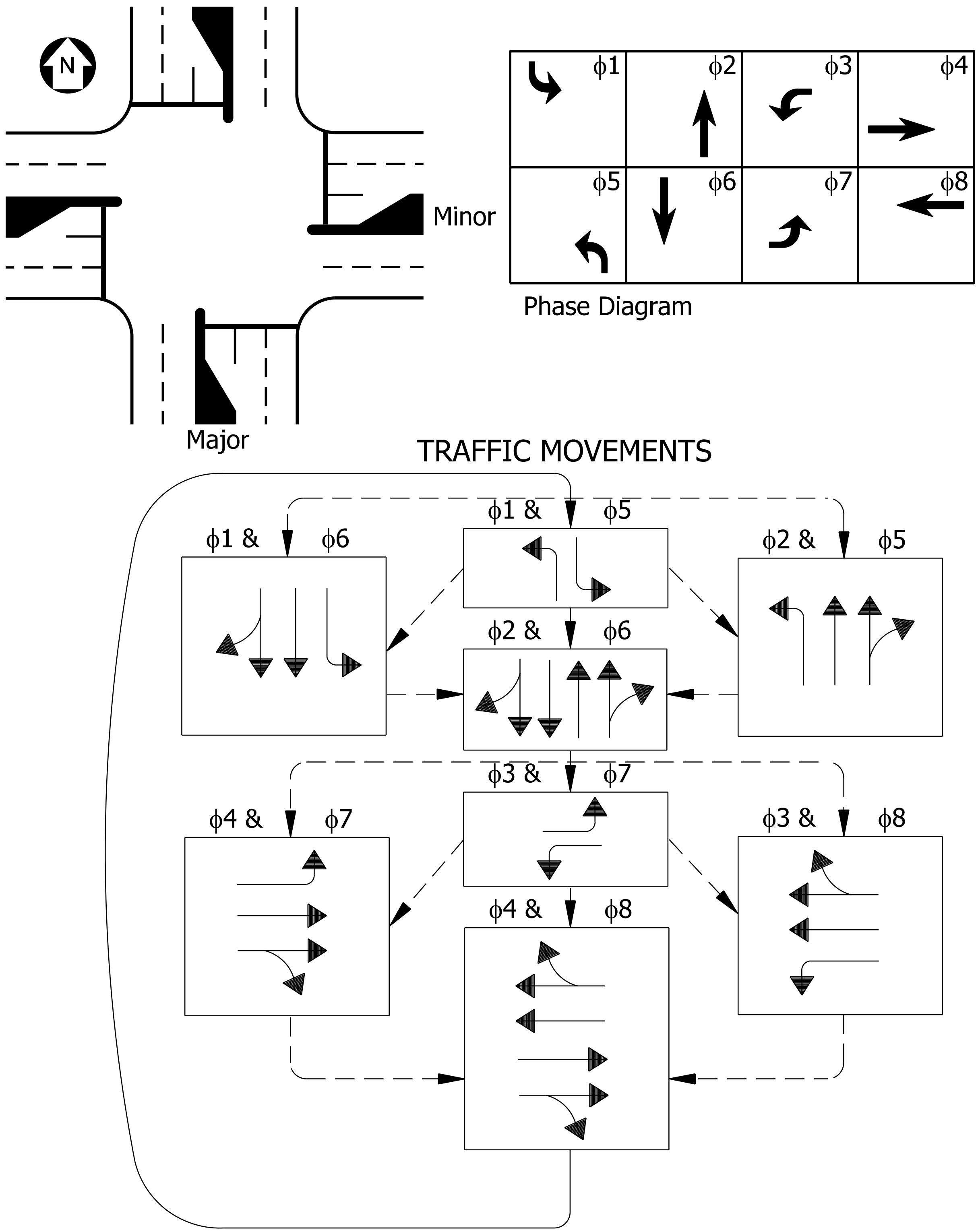
T-INTERSECTION
SINGLE LANE APPROACHES

Figure 77-5S



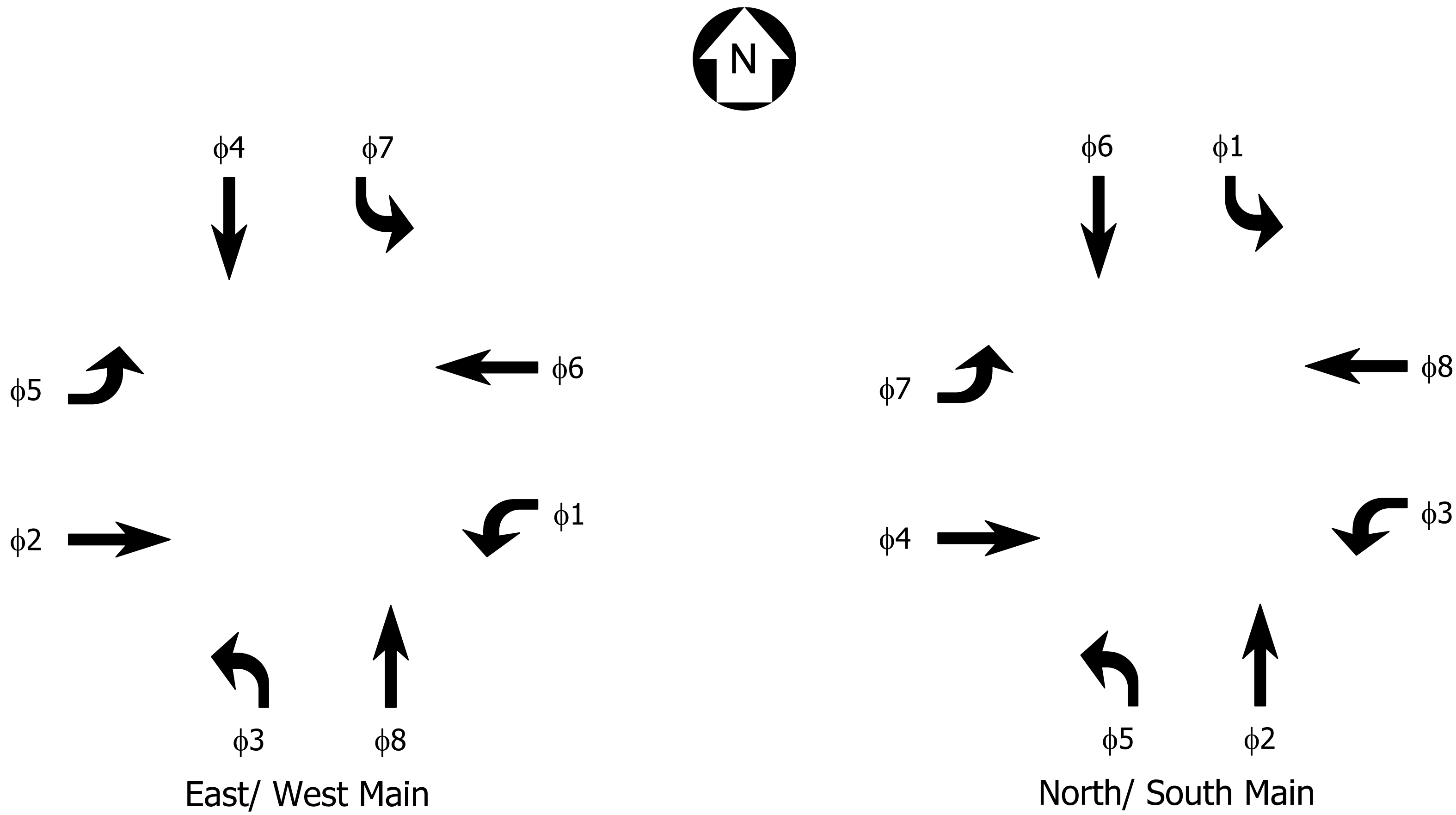
T-INTERSECTION
MULTIPLE-LANES APPROACHES

Figure 77-5T



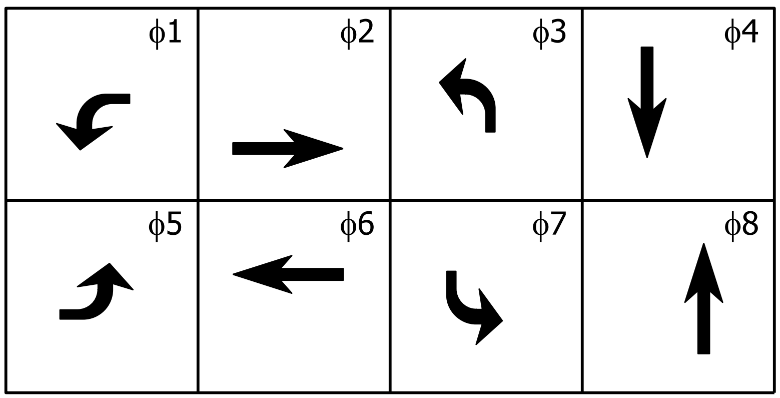
EIGHT-PHASE OPERATION, DUAL RING

Figure 77-5U

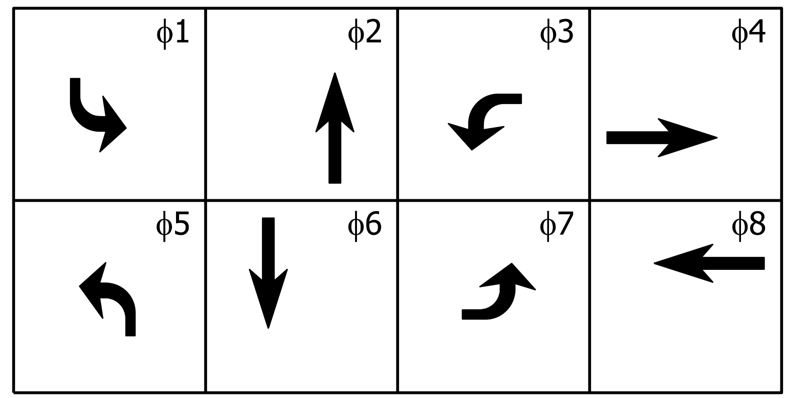


TYPICAL PHASE-NUMBERING SCHEMES

Figure 77-5V



East/ West Main



North/ South Main

TYPICAL PHASE DIAGRAMS

Figure 77-5W

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. • Minimizes conflicts between left-turn and opposing straight-through vehicles by clearing the left-turn vehicles through the intersection first. • 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. • Opposing movement may make a false start in response to the movement of a vehicle given the leading green. • Where there is no left-turn lane, an obstruction to the left-turn movement is created if a through vehicle is present.
LAGGING-LEFT-TURN PHASE	
ADVANTAGES	DISADVANTAGES
• Both directions of straight-through traffic start at the same time. • Approximates the normal driving behavior of a vehicle operator. • Provides for vehicle/pedestrian separation as pedestrians usually cross at the beginning of straight-through traffic. • Where pedestrian signals are used, pedestrians have cleared the intersection by the beginning of the lag-green interval. • 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. • 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. • Where there is no left-turn lane, an obstruction to the through movement during the initial green interval is created.

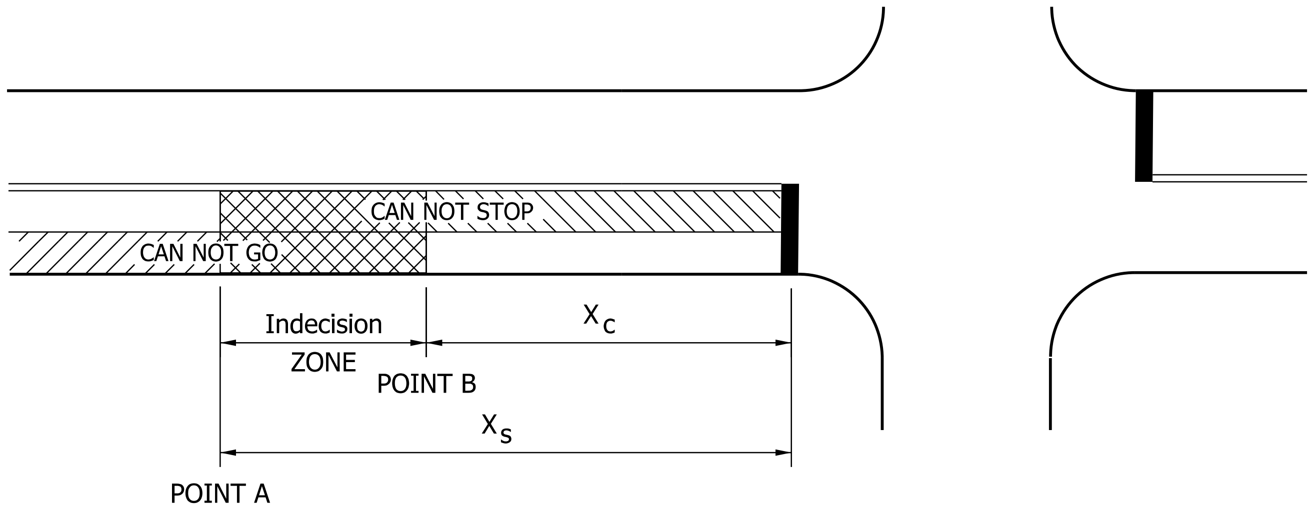
Notes:

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 77-5X



Note:

1. X_C = Maximum distance upstream of stop line from which a vehicle can clear the intersection during the yellow interval.

2. X_S = Minimum distance upstream of stop line where the vehicle can stop completely after the beginning of the 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 indecision zone, see FHWA Traffic Detector Handbook.

INDECISION ZONE

Figure 77-5Y

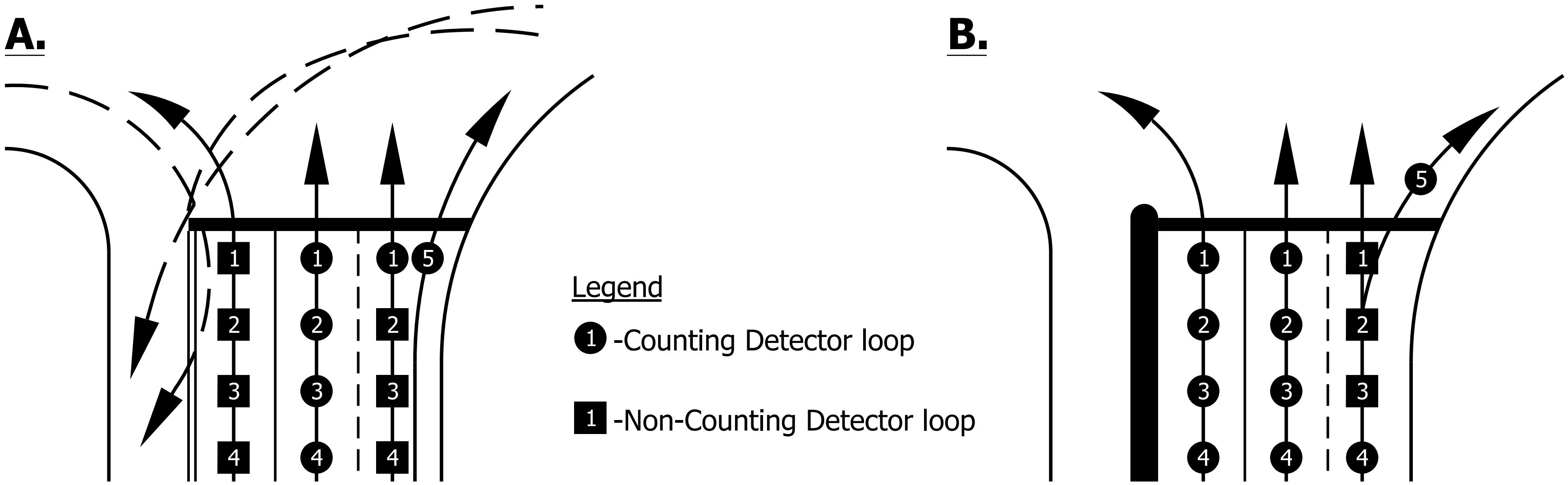
Approach Posted Speed (mph)	Passage Time from Detector to Stop Line (s)						
	1	2	3	4	5 [1]	6	7
20	29	53	87	116	145	174	193
25	36	78	108	144	180	216	252
30	44	88	132 [2]	176	220	264	308
35	51	102	153	204	255	306	357
40	59	113	177	236	295	354	413
45	66	132	198	264	330	396	462
50	73	146	219	292	365	438	511
55	81	162	243	324	405	486	567
60	88	176	264	352	475	528	616
65	95	190	285	380	550	570	665
Legend:	000 (magenta)	Basic Ctrlr.		000 (cyan)	Variable Initial Only		
	000 (green)	Density		000 (red)	Indecision Zone		

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

[2] *This value is also in the indecision zone.*

DETECTION SETBACK DISTANCE (ft)

Figure 77-5 Z



Left - Turn Lanes

Dotted lines or staggered stop lines as shown in diagram A can be used to reduce left-turn encroachment onto the left-turn lanes.

A median as shown in diagram B will eliminate such encroachment onto the left-turn lanes.

If counting with 4 loops, the lane width should remain 12 ft (3.6 m) to prevent a vehicle from missing the front loop.

Through Lanes

The through lanes should not have encroachment or early-departure concerns. If a vehicle squarely enters the loop system and crosses the center of each loop, counting with 4 loops is preferred.

Right - Turn Lanes

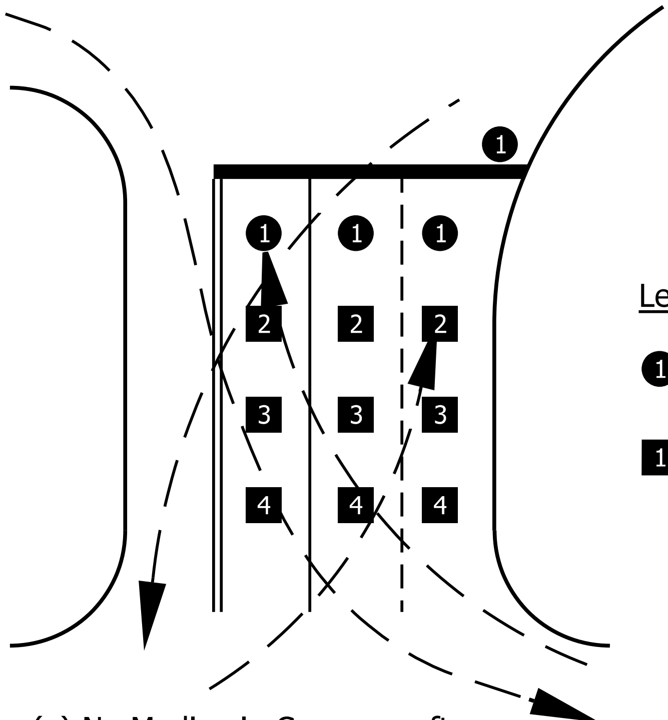
If the lane at the stop line is wider than 12 ft as shown in diagram A, a vehicle will depart before crossing loop 1. Counting with loops 1 and 5 will provide accurate through-lanes and right-turn-lane counts.

If loop 5 is beyond the stop line as shown in diagram B, a vehicle will depart before crossing loop 1. Counting with loops 4 and 5 will provide accurate through-plus-right-turn-lanes and right-turn-lane counts.

Note: The minimum distance between loops 1 & 5 should be 6 ft.

COUNTING - LOOP SELECTION GENERAL

Fig. 77-5AA



Legend

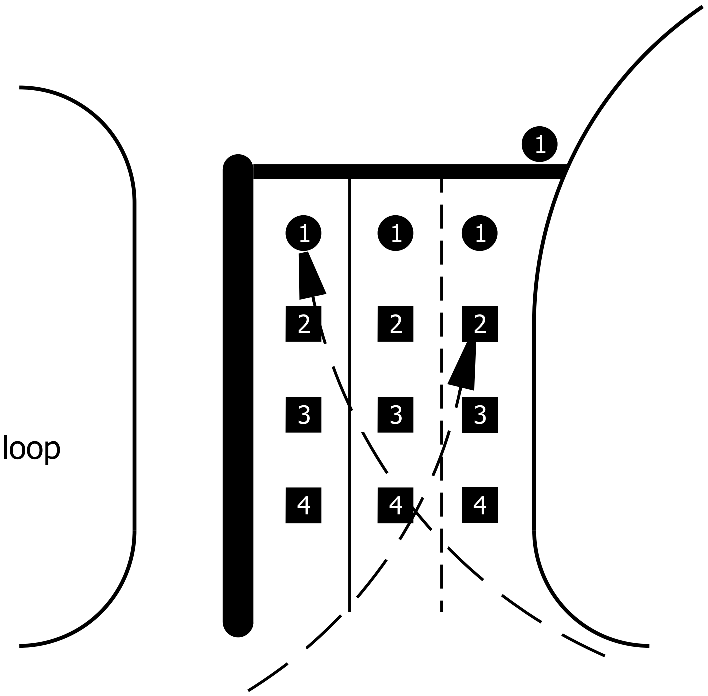
- Counting Detector loop (shown as a numbered black circle)

- Non-Counting Detector loop (shown as a numbered black square)

(a) No Median in Crossovereft

- A vehicle entering the detection zone will often cross loops in one lane to get to the desired lane. A vehicle turning off the main road will often cross these loops, causing them to overcount. This makes counting difficult.

  Access should be provided for the design vehicle.



(b) Median in Crossover

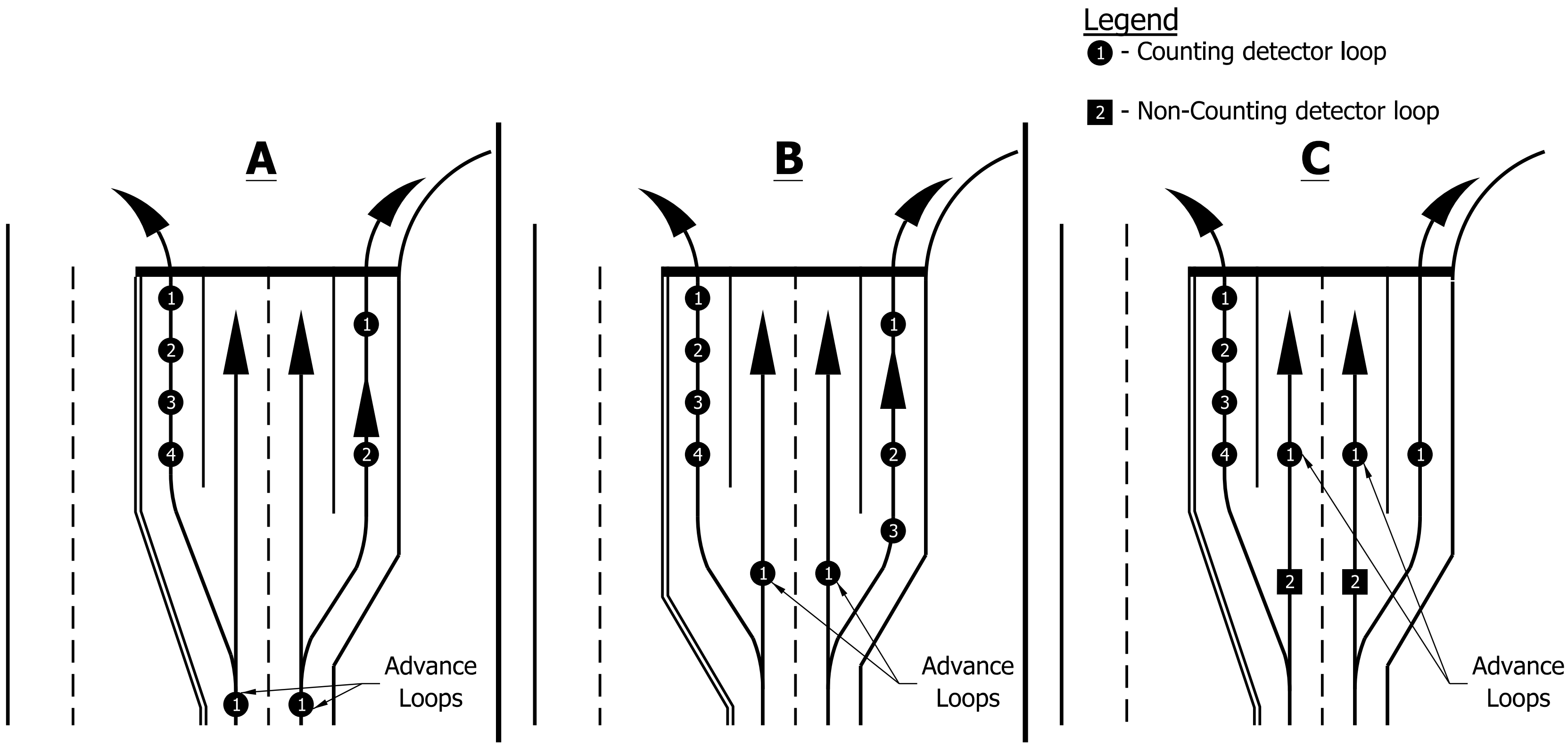
- A raised median will channel a vehicle turning off the main road, and will keep it out of the lanes being counted.

  A median will eliminate turn encroachment.

  Once a vehicle is channeled away from the counting loops into its intended lane, loop 1 can be used to provide accurate counts.

COUNTING - LOOP SELECTION FRONTAGE ROAD OR PARKING LOT

Fig. 77-5BB



* Advance counting-loop selection is based on the length of the storage lanes and placement of such loops based on the posted speed limit. Counting can be done if the advance loops are located ahead of the channelization lanes as shown in diagram A. Counting can still be done if the advance loops are located after the beginning of the channelization lanes as shown in diagram B.

* The posted speed limit can be such that the placement of the advance loops is where a vehicle will be maneuvering to the left- or right-turn lane as shown in diagram C. The advance loops should be placed in the same longitudinal location as left-turn-lane loop 4 or the right-turn-lane loop.

* The right-turn-lane loop can be placed in the same longitudinal location as the advance loops where the lane width is still 12 ft (3.6 m), as shown in diagram C.

* The same handhole should be used to minimize costs.

COUNTING - LOOP SELECTION
ADVANCE COUNTING LOOPS

Figure 77-5CC