

Chapter 9

TRAFFIC SIGNALS

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CHAPTER 9 - TRAFFIC SIGNALS

9-1.00 INTRODUCTION

9-1.01 Purpose

The purpose of this chapter is to present uniform guidelines, procedures, and preferred practice used in the design, construction, operation, revisions and maintenance of traffic signals on Trunk Highways in Minnesota.

This chapter is intended as both a training manual for all new traffic engineering personnel to familiarize them with the basic elements of traffic signal design and operation, and as a source of guidelines and procedures for the process of signal design and operation in Minnesota.

9-1.02 Scope

This chapter applies to all traffic signals that are on State Trunk Highways. Traffic signals that are installed by agencies other than the State of Minnesota and that are not on State Trunk Highways may utilize the guidelines in this chapter, as appropriate. There is no legal requirement, for using these guidelines by local agencies.

Traffic signals include all power-operated (whether manually, electrically or mechanically operated) traffic control devices (except signs) by which traffic is warned of conflicting movements or directed to take some specific action. Traffic signals assign right-of-way where conflicts exist or where passive devices, such as signs and markings, do not provide the necessary flexibility to properly move traffic safely and efficiently.

Traffic control signals, flashing beacons, railroad crossing signals, freeway ramp control signals, lane-use control signals, movable bridge signals, and temporary signals are covered in this chapter.

The planning, design, and operation of traffic signals in Minnesota must conform to the standards, limits, and alternatives provided in the "Minnesota Manual on Uniform Traffic Control Devices" (MN MUTCD). Where the standards in the MN MUTCD are broad, the Traffic Engineering Manual describes preferred practice of design and operation of signals. (For more specific guidelines and practices, which will be the subject of future technical memoranda, the reader is referred to the "Traffic Control Devices Handbook"). The standards and guidelines of the MN MUTCD and the Traffic Engineering Manual are to be a basis for engineering judgement, not a substitute for it.

This chapter should be used together with other documents to design and operate traffic signals on trunk highways in Minnesota. The MN MUTCD details minimum standards for the planning, design, and operation of traffic signals. The National Electrical Manufacturers Association (NEMA) Standards Publication No. TS 1-1983 or TS 2-1992, "Traffic

Control Systems", latest revision, gives specifications for traffic signal control equipment. Detail drawings for traffic signal construction are in the Mn/DOT "Standard Plates Manual". Symbols for use in drafting traffic signal plans are found in the Mn/DOT "Technical Manual." The Mn/DOT "Standard Specifications for Construction," latest revision, governs the construction of traffic signals. Other applicable documents include the latest version of the "National Electrical Code" by the National Fire Protection Association (NFPA), Technical Memorandums from the Office of Traffic Engineering, the "Traffic Control Devices Handbook" by the Federal Highway Administration (FHWA), Minnesota Statutes, and the "Transportation and Traffic Engineering Handbook" by the Institute of Transportation Engineers (ITE).

9-1.03 Chapter Organization

Sections 2 through 4 of this chapter present a general overview of traffic signals, including a glossary of terms, legal considerations, and a general description of traffic signal systems. Sections 5 through 7 address the justification, design, and plan preparation for a traffic signal installation. Traffic signal construction is the topic of Section 8. Traffic signal timing, operation, and revisions appear in Section 9. Section 10 covers traffic signal maintenance. Section 11 contains methods for analysis of signalized intersections and systems. References, forms and appendices appear at the end of the chapter.

9-2.00 GLOSSARY

Actuation - The presence of a vehicle or pedestrian as indicated by an input to the controller from a detector. The action of a vehicle or pedestrian which causes a detector to generate a call to the signal controller.

Added Initial Portion - An amount of time added to the minimum initial green time to accommodate to vehicles which arrived during the preceding red.

All-red - An interval during which all signal indications at an intersection display red indications.

Approach - All lanes of traffic that enter the intersection from the same direction.

Call - A demand for service registered in a controller. A call indicates a vehicle or pedestrian is waiting for a green indication.

Clearance Interval(s) - The interval(s) from the end of the right-of-way of one phase to the beginning of a conflicting phase. This is usually the yellow plus any all red phase.

Controller (or Controller Unit) - The device that determines which signal indications are to be illuminated at any given time. The controller is usually located in a cabinet near the intersection.

Cycle length - The time taken for a complete sequence of all phases at an intersection. This time is counted from the start of green for any phase until that same phased is started again. Pretimed cycle lengths do not vary, but actuated cycle lengths so because of phases skipped, extensions, etc.

Delay - Time lost while traffic impeded in its movement by some element over which it has no control. Usually expressed in seconds per vehicle.

Detector - A device that provides an input to the controller to indicate that a vehicle or pedestrian is present.

Dial Up Controller Operation - The operation of a controller unit at an intersection using a modem for direct dial up (telephone) communication.

Extensible Portion - That variable-length part of the green interval which follows the initial portion.

Extension Limit - The maximum time allowed for the extensible portion of the green.

Free Flow - Traffic flow which is not impeded.

Force Off - A command that will force the termination of the right-of-way.

Full Traffic-Actuated Controller Unit - A type of traffic-actuated controller unit which accommodates for traffic actuation on all approaches to the intersection.

Gap - The interval in time or distance from the back of one vehicle to the front of the following vehicle.

Gap Reduction - A feature whereby the "unit extension" or allowed time spacing between successive vehicle actuation on the phase displaying the green in the extensible portion of the interval is reduced.

Green Interval - The right-of-way portion of a traffic phase.

Headway - The distance or (usually) time between vehicles measured from the front of one vehicle to the front of the next.

Hold - A command that retains the existing right-of-way.

Initial Portion - The first part of the green interval for a phase, which is not affected by actuation received during the green interval for that phase.

Intersection Leg - The roadways entering or leaving one side of the intersection.

Interval - Any one of the several divisions of the cycle during which signal indications do not change.

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

Isolated Controller Unit Operation - the operation of a controller unit at an intersection without master supervision dial-up communication.

Last Car Passage - A feature that allows a non-reduced passage period for the last vehicle extending the green during gap reduction.

Locking - A mode of a controller phase in which a call is retained by the controller even if the vehicle leaves the detector.

Loop - Wire induction loop, the most-used detector in Minnesota.

Master Controller Unit - A controller unit for supervising a system of local intersection controllers.

Maximum Green - A longest period of green time allowed when there is a demand on an opposing phase.

Minimum Green - The shortest green time allowed a phase.

Non-locking - A mode of actuated-controller-unit operation which will not retain a call if the calling vehicle leaves the detector.

Offset - The relationship in time between a point in the cycle at a particular intersection and a similar point in the cycle at another intersection or reference.

Overlap - A traffic phase that services two or more traffic phases at the same time.

Passage Period - The time allowed for a vehicle to travel at a selected speed from the detector to the nearest point of conflicting traffic, i.e. from the detector into the intersection.

Pedestrian Clearance Interval - The first clearance interval following the pedestrian walk interval, normally symbolized by the flashing "HAND". The pedestrian clearance interval shall allow a pedestrian, who has already begun to cross time to reach the far side of the roadway or a safe refuge. A pedestrian shall not begin to cross during this interval.

Pedestrian Phase - A traffic phase allocated exclusively to pedestrian traffic.

Pedestrian Signal Indication - The illumination of a pedestrian signal lens or equivalent device.

Pedestrian "WALK" Interval - the controller interval during which the "WALK", symbolized by the "WALKING PERSON", indications of the pedestrian signals are illuminated. Generally the interval is 4 to 7 seconds in length during which the pedestrian begins to cross the roadway.

Permissive Period - The time period in which the controller unit is allowed to leave a coordinated phase under coordinated control and go to other phases.

Phase - The part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals, i.e. a left turn phase.

Phase Omit (Special skip, Force skip) - A command that causes omission of a phase.

Portion - A discrete subdivision of an interval during which the signals do not change.

Pre-emption - The transfer of the normal control of signals to a special signal control mode, i.e. to accommodate emergency vehicles.

Pre-Timed Controller Operation - A method for operating traffic signals where the cycle length, phases, green times, and change intervals are all preset.

Red Clearance Interval - An interval which follows the yellow change interval during which no green indication is shown on any conflicting phase.

Rest - The state in which a controller unit rests until called out of the phase.

Secondary Controller Operation (Slave) - A method for operating the traffic signals under the supervision of a master controller.

Semi-Traffic-Actuated Controller Operation - a type of traffic operation in which means are provided for traffic actuation on one or more but not all approaches to the intersection.

Signal Face - That part of a signal head provided for controlling traffic in a single direction. Turning indications may be included in a signal face.

Signal Head - An assembly containing one or more signal faces which may be designated accordingly as one-way, two-way, etc.

Signal Indication - The illumination of a traffic signal lens or equivalent device or a combination of several lenses or equivalent devices at the same time. (Note: This term usually means indications to vehicular traffic; however, pedestrians may be using these indications if no Pedestrian Signal Indications are present.)

Source of Power (SOP) - The location of the electrical service equipment associated with a traffic signal, or the location where electrical connection is made to the power company distribution system.

Spacing - The interval in distance from head to head of successive vehicles.

Split - A division of the Cycle allocated to each of the various phases (normally expressed in percent).

Traffic Control Signal (Traffic Signal) - A type of highway traffic signal, manually, electrically, or mechanically operated by which traffic is alternately directed to stop and permitted to proceed.

Traffic Phase - A part of the cycle allocated to any traffic movements receiving the right-of-way or to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

Variable Initial - A controller function consisting of the capability of adding initial green time to the minimum green.

Vehicle Extension - see Passage Time.

Vehicular Phase - A traffic phase allocated to vehicular traffic.

Walk Interval - The portion of a Traffic Phase that permits pedestrians to leave the curb.

Yellow Change Interval - The first interval following the green right-of-way interval in which the signal indication for that phase is yellow, indicating that the right-of-way for that phase is about to terminate.

Yield - See Permissive Period

9-3.0 LEGALITY

9-3.01 Legal Authority

For traffic control signals to serve any useful purpose, their indications must be clearly understood and strictly observed. To achieve these objectives, traffic signals should be uniform, the authority for the installation unimpeachable, and compliance with them legally enforceable. Thus, national standards have been developed for the installation and operation of traffic control signals, and the actions required of motorists and pedestrians are specified by statute or by local ordinance or resolution consistent with national standards. Legislation establishing the authority for installation, the meanings of the signal indications, and the required compliance to these indications by the road user, are outlined in such documents as the Uniform Vehicle Code and Minnesota Statutes.

Legal authority is established in Minnesota Statutes 169.06 (Subdivisions 1-4) for the Department and local units of government to place and maintain traffic signals, require obedience to traffic signals, prohibit the use of unauthorized traffic signals, and prohibit interference with official traffic signals.

Minnesota Statutes 169.06 refers to signals as follows: Subdivision 5 - Traffic Control Signals, Subdivision 6 - Pedestrian Control Signals, Subdivision 7 - Flashing Signals and Subdivision 8 - Lane-Direction Control Signals.

9-3.02 Jurisdiction

All traffic signals to be installed on Minnesota Trunk Highways shall have previous approval by the State Traffic Engineer.

When a traffic signal is to be installed for which agencies in addition to the State of Minnesota have responsibility, an agreement as detailed in Section 5.04 of this chapter shall detail the responsibility of each participating agency.

9-3.03 Meaning of Signal Indications

The legal meaning of traffic signal indications in Minnesota is found in the MN MUTCD, 4B-5 and in Minnesota Statutes 169.06, Subdivision 5.

9-3.04 Tort Claims

Chapter 12 of this manual discusses tort claims and shall be considered to apply to tort claims related to traffic signals.

9-4.00 GENERAL DESCRIPTION OF TRAFFIC SIGNALS

A traffic signal is a device which contains one or more lights to warn of an impending hazard or right-of-way change. Traffic Signals, are commonly called stoplights, stop-and-go lights, semaphores, or flashers. The largest percentage of traffic signals are intersection traffic control signals.

Most signals are installed to respond to high vehicle and/or pedestrian volumes, or a high number of correctable crashes. The traffic signal assigns the right-of-way to pedestrian or vehicle movements. A justified signal, properly designed, installed, operated and maintained, is an asset to the traveling public. A traffic signal that is unjustified, poorly designed, installed, operated, or maintained may decrease the safety or the efficiency of an intersection.

The decision to install a traffic signal should be made after an engineering study is performed for the intersection. The engineering study provides data for warrant analysis. If a signal the intersection is warranted and justified, a design using the latest standards will result in a safe operation. The signal is installed according to the plans and special provisions. After a signal is installed, it must be maintained to ensure safe operation.

9-4.01 Types of Traffic Signals

The general category of traffic signals includes traffic control signals, flashing beacons, railroad crossing signals, freeway ramp control signals, lane-use control signals, movable bridge signals, and temporary signals.

9-4.01.01 Traffic Control Signals

The traffic control signal is the most common type of traffic signal. The primary function of traffic control signal is to assign the right-of-way to different movements at intersecting streets or highways. It does this by giving to each movement, in turn, a green indication, which allows drivers to proceed through the intersection. Traffic control signals allow traffic and pedestrians to cross heavily traveled roadways safely, provide for the efficient operation of intersections, and reduce right angle crashes.

Steady **CIRCULAR RED** - to prohibit the movement of all traffic, except pedestrians when directed by a pedestrian signal.

Steady **CIRCULAR YELLOW** - displayed following a **CIRCULAR GREEN** in the same head and warns of an impending red indication.

Steady **CIRCULAR GREEN** - allows traffic to proceed in a lawful manner.

Steady **RED, YELLOW, or GREEN ARROWS** - allow or prohibit the movements indicated by the arrow.

Steady **YELLOW ARROW** - used to terminate a **GREEN ARROW** or displayed simultaneously with a **CIRCULAR RED**, to indicate the change interval following a **GREEN ARROW** which was displayed simultaneously with a **CIRCULAR GREEN**. A **YELLOW ARROW** must not be displayed when any conflicting movement has a **CIRCULAR GREEN** or **CIRCULAR YELLOW**.

Steady **GREEN ARROW** - displayed when the vehicle movement is protected from conflict with other vehicles moving on a green or yellow, or with pedestrians during a WALK ("WALKING PERSON") or flashing DON'T WALK ("flashing HAND").

Traffic signals can operate under two types of control, pretimed or traffic actuated.

PRETIMED - Under pretimed control the intersection is operated using predetermined, fixed cycle lengths, splits and offsets.

TRAFFIC ACTUATED - Under traffic actuated control the intersection is operated according to traffic demands. Cycle lengths, splits and offsets change according to traffic demands.

Two or more traffic control signals that are operated as a system are said to be coordinated. These coordinated traffic control signals are operated to permit continuous movement or minimize delay along an arterial highway or throughout a network of major streets.

Pedestrian or Mid-block Signal - A pedestrian signal is a traffic control signal put up, usually at a mid-block, to allow pedestrians to cross a road. Pedestrians can push a button to give them the right-of-way to cross the road. These signals are installed to benefit a nearby school or other pedestrian generator.

Emergency Traffic Signal - An emergency traffic signal is a traffic control signal in front of or near a building housing emergency equipment where a signal is not otherwise warranted, but is needed to allow emergency vehicles, to safely enter the roadway.

At mid-block locations, the traffic signal stays green for the mainline traffic until preempted in the station. This permits the emergency vehicle to receive the right-of-way and enter the roadway immediately.

Emergency vehicle preemption (EVP) which gives a green light when activated to the emergency vehicle.

One-lane, Two-way Signal - A one-lane, two-way signal is a traffic control signal used at a location, which is not wide enough to allow traffic to flow in both directions simultaneously (one lane bridge or other construction areas). These signals essentially operate as a two-directional control.

9-4.01.02 Flashing Beacons

Flashing beacons are signals that are used to draw attention to signs or pedestrian crossings. A flashing beacon is either a red or yellow circular indication.

Hazard Identification Beacon - This type of yellow flashing beacon is used to identify obstructions in or immediately adjacent to the roadway, to supplement warning and regulatory signs, except the "STOP", "YIELD" and "DO NOT ENTER" signs and to identify pedestrian crosswalks.

Speed Limit Sign Beacon - This type of yellow flashing beacon is used with fixed or variable speed limit signs. Where applicable, a flashing speed limit beacon (with an appropriate accompanying sign) may be used to indicate that the speed limit is in effect. The use with a "SCHOOL SPEED LIMIT" sign is an example.

Intersection Control Beacon - Intersection Control Beacons are used at intersections where traffic or physical conditions exist that do not justify the installation of an traffic signal, but where high crash rates indicate a special hazard. The installation of intersection control beacons is limited to: Red on all approaches (where a all-stop is warranted), or yellow on one roadway (normally the major roadway) and red for the remaining approaches.

Stop Sign Beacon - This type of red flashing beacon is located above a stop sign to emphasize and draw attention to the stop sign.

9-4.01.03 Railroad Approach Signals

Railroad approach signals are used at highway-railroad grade crossings to give warning of the approach or presence of a train. When indicating the approach or presence of a train, the signal displays to the approaching highway traffic two red lights in a horizontal line flashing alternately. The signals may be supplemented by gates which extend across the roadway lanes and that keep vehicles off the tracks while trains are present or approaching. A detailed explanation of railroad signals can be found in Chapter 8 of the MN MUTCD.

Railroad approach signals are approved by the Public Service Commission, designed and installed by the railroad companies, and reviewed by Mn/DOT's Railroad Negotiations Section.

If a signalized intersection is near, a railroad crossing, the traffic signals may have a preemption system which

allows vehicles to safely clear the railroad tracks, and modifies the operation of the signal to allow traffic movements which do not conflict with the train while it is present.

9-4.01.04 Freeway Ramp Control Signals

Freeway ramp control signals (meters) are a special application of traffic control signals used on freeway entrance ramps to limit or meter the amount of traffic entering the freeway. These signals allow the waiting vehicles to proceed one at a time rather than all at once. This allows vehicles entering the freeway to merge more easily the traffic stream presently onto the freeway, increasing safety and improving freeway traffic flow. This allows the freeway to operate at more efficient level of service.

9-4.01.05 Lane Control Signals

Lane Control Signals are special overhead indications which permit or prohibit the use of specific lanes of a street or highway. They are placed directly over the lane they control and have distinctive shapes and symbols.

Such signals consist of a red X on an opaque background or a green down arrow on an opaque background.

Lane-use control signals are most often used for reversible lane control. They may also be used to:

1. To keep mainline traffic out of certain lanes at certain hours, so that traffic from a ramp or other freeway can merge more easily.
2. To indicate that a freeway lane ends.
3. To indicate that a lane is blocked by a crash or breakdown, or closed for maintenance work.

Lane control signal indications have the following meanings:

- **Steady DOWNWARD GREEN ARROW** - A driver is permitted to drive in the lane over which the arrow is located.
- **Steady YELLOW X** - A driver should be prepared to vacate the lane over which the signal is located because the lane is being closed.
- **Flashing YELLOW X** - A driver may turn left from this lane but should be cautioned that they may be sharing a lane with opposite flow left-turning traffic.
- **Steady DOWNWARD YELLOW ARROW** - The driver should be prepared to vacate this lane because a lane closure is in progress.
- **Flashing DOWNWARD YELLOW ARROW** - The driver is allowed to occupy this lane but with extra caution.
- **Steady RED X** - A driver shall not occupy this lane.

9-4.01.06 Movable Bridge Signals

On roadway approaches to a movable (draw, swing or lift) bridge, traffic control signals are generally used to stop vehicular traffic when the bridge is opened. Signal heads are installed at both approaches to the bridge, often in conjunction with warning gates or other forms of protection. The traffic signal is coordinated with the bridge control and arranged so that adequate warning time is provided in advance of the bridge opening to ensure that the bridge will be clear of all traffic.

9-4.01.07 Temporary Traffic Signals

A temporary traffic signal differs from a permanent signal in that it uses wood poles and span wires to place the signal indications in the driver's line of sight. In all other ways, a temporary signal is just like a permanent signal.

Temporary signals are meant to be in place for only a short time, from a few months up to a few years. Most are used as intersection traffic control signals or as one-lane, two-way bridge signals, during construction projects.

9-4.01.08 Portable Traffic Signals

Another type of temporary traffic signal is the portable traffic control signal. Portable traffic control signals have limited use in conjunction with construction and maintenance projects and should normally not operate longer than 30 days. A portable traffic control signal must meet the physical display and operation requirements of conventional traffic control signals.

9-4.02 Elements of Traffic Signals

9-4.02.01 Signal Indications

A traffic signal must be seen in order for the driver to react and make the required action. The most basic part of a traffic signal is the signal indication. This is how the traffic signal transmits information to the driver. This information or message is portrayed by selective illumination of one or more colored indications.

A signal indication is made up of a lamp socket, reflector, and housing with a lens and visor. Signal indications, normally 300 mm (**12 inches**) in diameter, are red, yellow, or green, and can be circular or arrows. When three to five signal indications are mounted together vertically, they form a signal face. Each signal face is outlined with a black background shield. Traffic signal indications and heads are covered in more detail in the MN MUTCD, in sections 4B-5 through 4B-13.

These signal heads for vehicles are often accompanied by signal heads for pedestrian control. Pedestrian signal indications are rectangular, can be 230 mm (**9 inches**) or 300 mm (**12 inches**) in size, are white for WALKING PERSON and orange for HAND Section 4D of the MN MUTCD deals with the design and application of

pedestrian signal indications.

Vehicle and pedestrian signal heads are attached to poles and pedestals by pipe bracketing, which supports the signal heads and serves as a conduit for the electrical wiring. There are many different possible bracketing arrangements; the standard arrangements are shown on Standard Plates 8110 and 8111.

9-4.02.02 Poles, Mast Arms and Pedestals

Poles, mast arms and pedestals are the structures which support signal heads. They are made of metal for structural strength and for the purpose of protecting the wiring to the signal heads.

A mast arm is a structure that is extended over the roadway. The typical pole and mast arm, shown on Standard Plate 8123, consists of a tapered octagonal shaft 6.1 m (**20 feet**) high positioned on a cubical transformer base. A mast arm is attached near the top of the shaft, which is actually two arms braced together to form a truss. The mast arm can extend horizontally from the top of the pole shaft from 4.6 to 16.8 m (**15 to 55 feet**). Extending vertically from the top of the pole shaft is the luminaire arm extension, at the top of which the street light (luminaire) is placed. Street lights, or luminaires, are generally mounted 10.7 to 12.2 m (**35 to 40 feet**).

Traffic control signals on arterial highways usually use two or four mast arm poles per intersection.

Signal pedestals are 2.4 or 3.1 m (**8 to 10 feet**) tall; they are mostly used in dense urban areas. They are designed to break away from the foundation on impact, in order to minimize damage to a striking vehicle. A typical signal pedestal and its base are shown on Standard Plate 8122.

Sometimes signal heads are mounted on street light poles or wood poles, or are suspended from span wire which is stretched over the roadway.

9-4.02.03 Cabinet and Control Equipment

The control equipment for the traffic signal at an intersection is kept in a metal cabinet at the side of the intersection. The cabinets are placed close enough so that the maintenance or operation technicians can see the intersection while they are working on the cabinet; but far enough away so that the cabinet is not too likely to be hit by a vehicle out of control.

The typical signal cabinet is about 1.8 m (**6 feet**) high, 1 m (**3 feet**) wide, and 0.6 m (**2 feet**) deep; it sits on a concrete foundation. It may have a vent fan for summer and a heater for winter.

The wiring between the signal cabinet and the poles or pedestals usually travels in underground conduit.

The controller is a specialized solid-state microcomputer which is programmed to control the signal indications, and give the right-of-way to various

approaches, according to a definite plan.

There are two basic types of controllers. The pretimed (fixed time) controller will repeat the signal indications, cycle after cycle, according to one or more preset timing plans, without regard to actual vehicle or pedestrian demand on the street. A traffic actuated controller varies the timing for some or all controlled conflicting movements depending upon vehicular or pedestrian demand as determined by detectors placed in the roadway or near the pedestrian crossing.

The typical controller is an 8-phase traffic actuated NEMA controller. This means it can control up to eight separate traffic movements, including protected left turn movements, for all four approaches to an intersection. A NEMA controller is built to the specifications of the National Electrical Manufacturers' Association.

Other equipment to be found in the cabinet include load switches, a conflict monitor, detector amplifiers, flasher, coordinator, miscellaneous equipment and wiring.

Load switches are devices which, activated by the controllers low voltage output, actually turn on and off the 120-volt electric power that goes to the signal heads and powers the indications.

The conflict monitor, also called a failsafe, is a device which monitors cabinet output and internal cabinet voltages. If the conflict monitor senses an improper signal output or internal voltage, the conflict monitor puts the intersection into the flashing mode of operation.

Detector amplifiers receive signals from the loop detectors in the roadway. This signal is amplified and sent to the controller, so it can take appropriate action.

The flasher is the device which controls the signal indications when the intersection goes out of the mode of normal operation into the flashing mode. It provides a backup operation. In the flashing mode the signal indications can be flashed red for all approaches.

The time clock, which can be a separate device or internal to the controller, takes charge of such things as switching the controller to special or flashing operation according to the time of day.

The coordinator is a device which synchronizes the operation of the intersection controller with that of other controllers in a coordinated system of signals. This is usually a function of the controller.

Preemption devices, which can be a separate device or internal to the controller, override the normal operation of the controller and channel it into special operation to allow for the presence of railroad trains or emergency vehicles at an intersection.

9-4.02.04 Detection

Most traffic signal systems on trunk highways today are traffic-actuated, which means that the intersection approaches are given right-of-way in response to actual traffic demand, rather than according to a fixed time

pattern.

Detectors enable the controller to "know" which approaches to an intersection have traffic demand which must be served.

The most common type of vehicle detection device in use today is the inductive loop. This is a loop of wire imbedded in the pavement, carrying a small electrical current. When a large mass of metal passes over the loop, the electric field is disturbed and generates, or induces, current in the wire. This current is then amplified by the detector amplifier and signals the controller that a vehicle is present.

Another common type is the magnetic coil, which operates in the same way as the magnetic loop, except that it cannot continuously detect a stopped vehicle (presence detection).

Other types of vehicle detectors include radar, sonic, and visual; descriptions of which can be found in technical literature.

Vehicle detectors perform a variety of functions. They can place a call to the controller to change the right-of-way at the intersection, extend the amount of time the phase is given and can be used to count traffic.

Detector placement for most efficient operation of a traffic-actuated intersection is a complex subject and is discussed below under intersection operation.

A pedestrian detector, usually called a pedestrian pushbutton, is a push button switch mounted near a crosswalk. When the button is pushed, it indicates to the controller that a pedestrian is present and wishes to cross the street.

The installation of loop detectors is shown on Standard Plate 8130; the installation of a pedestrian push button is shown on Standard Plate 8115.

9-4.02.05 Source of Power; Service Equipment

Signal controller cabinets are powered by 120-volt electricity from the local utility company. The cabinet is wired to a disconnect switch or circuit breaker box, and meter. The power company brings power to the meter; on the load side of the meter, the wiring and circuit breakers or fuses belong to the agency that owns the signal. The combination of meter and circuit breakers is called service equipment; the location of the service equipment is called the source of power.

Service equipment can be mounted on a wood pole near the controller cabinet, or it can be mounted on the control pad. It can be a simple meter and disconnect switch, or very elaborate, depending on the electrical requirements of the signal system.

A typical simple set of service equipment is shown on Standard Plate 8118; more complex types of service equipment are detailed in the plans.

9-4.02.06 Conduit and Handholes (Pullboxes)

The electrical wiring between the signal cabinet and the poles or pedestals usually travels in underground conduit. Conduit is usually rigid steel conduit or intermediate metal conduit whose size is determined by the application and the number of cables that it must accommodate. Conduits should only be filled to forty percent by area.

Handholes can be made of concrete or PVC, and have a concrete or metal cover. They are placed in conduit runs to provide junctions for conduit, to facilitate the pulling of cables, and to provide water drainage for the conduits.

9-4.03 Phasing and Operation of a Traffic Signal

9-4.03.01 Interval

An interval is a period of time during which the signal indications do not change. Thus the mainline green interval is the period of time during which the signals display green for the main street.

9-4.03.02 Phase

A phase is the collection of all signal intervals which control the traffic on any given approach. Thus the side street phase would include all the following displays for side-street traffic:

- Green with Walking Person
- Green with Flashing Hand
- Green with Steady Hand
- Yellow with Steady Hand
- Red with Steady Hand

Note that there are actually three portions of the green interval; usually, however, we speak of "the green interval."

9-4.03.03 Cycle

A cycle is the complete rotation of phases possible to a controller. Assuming that all are served in turn, the usual rotation of phases in a typical eight-phase NEMA controller is as follows:

- Phases 1 and 5: Left turns off the mainline
- 2 and 6: Mainline through and right-turn traffic
- 3 and 7: Left turns off the cross street
- 4 and 8: Cross street through and right-turn traffic

The cycle length is the length of time required to give every phase of the intersection once. The time is set in an pretimed controller or will vary in an actuated controller.

An overlap is a right-of-way indication that allows traffic movement when the right-of-way is assigned to two or more traffic phases. An overlap occurs when one green signal indication is illuminated by more than one phase output from the controller. For diagrams of typical overlaps, see Figure 9.13.

9-4.03.04 Fixed-time (Pretimed) Signals

A fixed-time signal is one in which all the intervals have a predetermined length. Therefore, the phase lengths and the cycle length are also fixed.

Fixed-time signals are generally used in downtown or urban areas where speeds are low and the traffic demand is fairly constant.

9-4.03.05 Actuated Signals

An actuated signal is one whose operation varies, within limits, according to input from vehicle detectors. Some intervals are of fixed length, and some are variable. For instance, the green interval can be extended by detector input.

A full-actuated signal is one which has traffic detection on all approaches to the intersection. A semi-actuated signal is one which has detection on some, but not all, approaches.

Actuated signals are used on arterial routes or on high-speed routes, where traffic demand varies significantly by time of day. Without actuated signals, intersections with widely varying demand would experience long delays during times when controller timing could not be adjusted to actual traffic demands.

9-4.03.06 Signal Coordination (See also Section 9-6.04)

It is often necessary to consider the movement of traffic through a system of consecutive intersections or through an entire network, rather than through a single intersection. In this case, each signal is considered a dependent part of a system; the goal is to maximize the efficiency of the whole system rather than any one intersection in the system.

Types of Signal Systems

A system of traffic signals can be made up of a number of fixed-time controllers, a number of actuated controllers, or a combination of both kinds. A group of intersection controllers is usually interconnected by wire or telephone circuits, though sometimes time-based coordination or wireless interconnect is used.

A system may have only one operating mode, or it may have several sets of interval timings, combinations and/or changes of phase sequences, automatic or manual flash control, or preemption for emergency vehicles or railroads.

In very sophisticated systems, the entire system and all individual controllers can be controlled by a computer which receives information from detectors and adjusts the signal system according to traffic demand.

Guidelines for Signal Coordination

In general, two or more signalized intersections can be coordinated if they are less than 800 m (**one-half mile**) apart, or if the travel time between them is less than a cycle length. A timing mismatch of even a few seconds between two intersections can result in considerable delay to traffic.

A time-space diagram can be constructed to show and to help coordinate signal timing at adjacent intersections. An example of a time-space diagram will be found in Figure 9.6. There are also computer programs which help plan and execute signal coordination; these are discussed in section 9-11.

The selection and use of specific coordination equipment should take into account the nature of the area, the traffic characteristics of the roadway, and the available capital and operating budget.

9-5.00 TRAFFIC SIGNAL JUSTIFICATION AND APPROVAL PROCESS

9-5.01 General Procedure

The general procedure for justifying, approving, and planning the installation of a traffic signal is as follows:

- Engineering studies are made. The types are listed later in the chapter.
- 26 weeks before letting, a signal justification report is submitted to Central Office Traffic for concurrence. The signal justification report may be accompanied by the project memo if the project is just for the installation or revision of a signal.
- 18 weeks before letting, the final signal plan is submitted to Road Plans. A copy of the plans, the request for State-furnished materials, request for special provisions, and request for agreement are submitted to Central Office Traffic.
- 7-1/2 weeks before letting, the signal plan is reviewed, corrected, and approved by District or Metro Division personnel. The special provisions, the engineer's estimate, and the agreement is prepared by Central Office Traffic personnel.
- The contract is let.

9-5.02 Engineering Studies for Traffic Signals

If signals are proposed for an intersection, enough study should be done to demonstrate the need for a signal.

Studies which will be helpful in assessing and

demonstrating the need for a signal are the following:

- Volume studies, including approach volumes, turning movements, and peak hour detail counts;
- Pedestrian counts, including any unusual numbers of children, handicapped, and elderly;
- Traffic gap studies;
- Speed studies;
- Crash studies;
- Intersection delay studies.

Procedures for doing various traffic studies are found in the Institute of Traffic Engineers' Manual of Traffic Engineering Studies and in Chapter 6 of the Traffic Engineering Manual.

The studies which are required to be included in a signal justification report are discussed below, and in section 4C-1 of the MN MUTCD.

9-5.03 Warrants and Justification for Signals and Flashing Beacons

9-5.03.01 Traffic Signal Warrants

Warrants have been developed to determine if an intersection needs some type of intersection control. Justification for a signalized intersection should be based meeting one or more of the established warrants as stated in the Minnesota Manual on Uniform Traffic Control devices. Traffic signals should not be installed unless one or more of the signal warrants in the MN MUTCD are met, but the meeting of a warrant or warrants does not alone justify the installation of a signal.

The data that was collected as part of the engineering studies should be used in combination with the warrants to justify the need to install the traffic control device. The engineering study should show that the intersection will benefit in improved safety and/or operation.

The traffic signal warrants are stated in section 4-C of the Minnesota Manual on Uniform Traffic Control Devices. The statements that follow give intents and interpretations of the warrants.

WARRANTS 1 AND 2

Warrants 1 and 2 are the warrants that pertain to volumes, and are the most common warrants for justifying intersection control.

The same eight hour period must be used for both the Major and the Minor Streets.

Mn/DOT policy on the use of the speed reduction factor is that if a mainline has a posted speed limit of 70 km/h (**45 mph**) or above, that is sufficient evidence that the 85th percentile speed is above 60 km/h (40 mph), and a speed study is not required.

The population reduction factor mentioned in Warrants 1 and 2 states that an intersection lying "within the built-up area of an isolated community having a population of less than 10,000...". In the

seven-county metropolitan area, it is often a judgment call whether a community is isolated or not. There are no strict criteria on this.

Geometrics play an important part in determining the volume requirements for Warrants 1 and 2.

WARRANT 3

This warrant allows the installation of a traffic signal if there is a considerable number of pedestrians. To meet warrant 3 there must be pedestrian volumes of at least 100 pedestrians for any of four hours, or a peak hour volume of 190 pedestrians. These volumes can be reduced by 50 percent if the crossing speed of the pedestrians is predominantly below 1.1 m (3.5 feet) per second. A gap study must be completed to determine that there are less than 60 gaps of adequate length in an hour.

If a signal is warranted, the signal should be traffic actuated with pedestrian indications.

WARRANT 4

The Institute of Traffic Engineers' Program for School Crossing Protection contains the method Mn/DOT recommends for addressing Warrant 4.

WARRANT 5

A signal justification report addressing Warrant 5 should contain a time-space diagram of the proposed intersection and nearby signals, helping to demonstrate that a progressive system will help maintain platooning and group speed.

Signals are installed under Warrant 5 on the basis of the 85th percentile speed, so a speed study is necessary for this warrant. It is expected that any signal installed under Warrant 5 would include interconnect.

WARRANT 6

The 80% requirement is not the same as the 80% required for Warrant 8. For Warrant 6, the requirement is 80% of Warrant 1, Warrant 2, or Warrant 3.

Signal justification reports which address Warrant 6 are to include an collision diagram. A time-space diagram showing the proposed signal system will not seriously disrupt progressive traffic flow should be included. Discussion of the failure of less restrictive remedies is also required by the MN MUTCD.

Current Mn/DOT policy is that in general, Warrant 6 is not applicable to an intersection which is already signalized.

WARRANT 7

Current Mn/DOT interpretation of Warrant 7 is that its intent is the use of a signal to pull traffic away from other intersections, "to encourage concentration and organization of traffic flow

networks." Therefore, policy is that Warrant 7 does not apply to isolated intersections, but rather to intersections in urban grid systems.

WARRANT 8

Warrant 8 allows the combination of any two of Warrants 1, 2, and 3. Therefore, if a report addresses the combination of Warrant 1 and Warrant 2, the mainline criterion of Warrant 2 with the cross-street combination of Warrant 1 is the proper combination.

Note the MN MUTCD requires "adequate trial of less restrictive remedies" before signalization under Warrant 8.

WARRANTS 9-11

These warrants may not be addressed by projected or hypothetical volumes, or for as-yet-unbuilt intersections. Actual on-site studies are required.

There is not enough evidence at hand to determine a mean value or 85th percentile values for peak hour and fourth-highest hour, particularly for sites with sharp-peaking distributions.

1. Justification for revision of existing Traffic Control Signals

A Signal justification report shall be prepared for existing signals that are:

- Completely rebuilt
- Revised: updating to meet current standard; phase changes or coordination changes requiring rewiring, pole or mast arm changes and controller change out; adding or removing an approach or turn lane to an intersection

A Signal Justification Reports are not required for:

- Minor work caused by road construction: pole or cabinet relocation
- Adding new loops for detection
- Revising a signal head
- Changing out controller cabinet only for maintenance reasons
- Adding Emergency Vehicle Preemption

and it is obvious to the District/Division Traffic Engineer that the signal meets one of the MN MUTCD warrants.

Signal Removal Justification Reports shall be prepared for all existing signals that are determined to be removed.

2. Justification Criteria:

Signalized intersections that meet 80 percent of the volume requirements of MN MUTCD Warrant 1 or 2 should be considered justified.

Signalized intersections that do not meet 80 percent of the volume requirements of MN MUTCD Warrant 1 or 2, but meet 60 percent of the volume requirements of Warrant 1 are in the gray area and should be considered for signal removal. Additional studies, findings, engineering judgement and documentation beyond the volume requirements will be needed to justify retaining the signal.

Signalized intersections that do not meet 60 percent of the volume requirements of MN MUTCD Warrants 1 and meet no other Warrant should be considered unjustified traffic control signals and should be removed. The traffic signal removal decision process shall be followed as set forth in the "User Guide for Removal of Not Needed Traffic Signals, FHWA-IP-80-12, November 1980.

In the traffic signal removal process, the District/Division Traffic Engineer considers all the findings and the decision is made whether or not to remove the traffic signal. The final decision concerning signal removal is a blend of analytical procedures and political considerations coupled with professional judgement. However, the technical findings from the analysis should provide a strong factual basis for reaching, supporting and defending the final decision or recommendation.

All findings of the decision process shall be summarized by the District/Division Traffic Engineer in a signal justification report or a signal removal justification report, if so determined.

All traffic signals that are determined to be retained shall be revised to meet current standards. These traffic signals should be prioritized along with other traffic signal projects and scheduled for revision as permitted.

9-5.03.02 Flashing Beacon Warrants

Flashing beacons include beacons mounted on span wire directly over an intersection, and beacons mounted on pedestal above stop signs (red) and intersections ahead symbols signs (yellow). Both overhead pedestal mounted beacons have advantages and disadvantages. Overhead beacons may be confused with all way flashing red signals indicating or may distract the motorist from roadway signing, but they aid the motorist in locating the intersection. Pedestal mounted beacons help draw attention to stop and intersection ahead signing, but do not help locate the intersection for the mainline driver who sees only flashing yellow mounted on an intersection ahead sign, somewhere in advance of the intersection itself. Sight distance or geometry may also tend to favor one system over another. In any case, any flashing beacon must be justified under one or more of the following warrants.

WARRANT 1: Limited Visibility

Where sight distance is limited, a flashing beacon may be installed if the sight distance is less than

one-half kilometer on a rural high-speed highway, or if the sight distance is less than that shown in the table for lower-speed highways. Locations qualifying under limited visibility must have previously had adequate warning signs and pavement markings installed.

SPEED (km/h)	(mph)	SIGHT DISTANCE LESS THAN
50	20	310 m (650 ft.)
60	25	370 m (800 ft.)
70	30	440 m (975 ft.)
80	35	560 m (1125 ft.)
90	40	620 m (1275 ft.)
100	45	650 m (1450 ft.)
110	50	700 m (1600 ft.)

WARRANT 2: Crash Rate

A flashing beacon may be installed where: a high-hazard safety improvement criteria are met, as described elsewhere in the Manual or, in one year there have been four or more crashes of the right-angle or left-turn type, or of the type deemed preventable by a flashing beacon.

WARRANT 3: School Crossing

A flashing beacon may be installed at an established school crossing where, during the heavy crosswalk usage periods, there are more than 500 vehicles per hour (actual or effective rate) crossing the crosswalk, AND, insufficient usable gaps for pedestrians using the crosswalk.

WARRANT 4: Rural Trunk Highway Junctions

At or near some rural junctions of two or more high speed trunk highways, a flashing beacon may be installed to warn drivers of an unexpected crossing of another highway.

9-5.03.03 The Signal Justification Report

A signal justification report (See Figure 9.1) must be submitted for all new construction of signalized intersections, when a signal is completely rebuilt, when major work is done on a signal, or when a signal is upgraded preceding turnback to the local

jurisdiction. The signal justification report may incorporate the project memo (See Figure 9.2) when the project is only to install or revise an existing signal. When the signal is part of a larger project, the signal justification report is separate document from the project memorandum, and only its cover sheet is included with the project memorandum. The signal justification report should not be included in the project memo when the signal is only part of the project.

A signal justification report need not be submitted for minor work done on a signal if each district/division still considers the signal a justified installation. In general, work that changes the displays seen by drivers or changes the operation drivers are accustomed to requires an signal justification report. When in doubt, an signal justification report should be submitted.

The purpose of a signal justification report is to document that an engineering study has been done and that engineering judgement has been used to demonstrate that a traffic signal installation is justified. To show that an analysis of the factors contained in the warrants of the MN MUTCD has been done, and to demonstrate that the installation or improvement of a signal will improve the overall safety and/or operation of an intersection and be in the public's best interest.

This purpose can best be met when the report includes the following information:

- Intersection location: trunk highway cross-street name and county road numbers, municipality county. A map should be included which identifies the site.
- Type of work: type of signal or beacon proposed, whether temporary or permanent.
- Character of site: function and importance of roads, number of lanes, existing and proposed geometrics, channelization, grades, presence or absence of parking, bus stops and routes, posted speed limit, 85th percentile speed if markedly different, sight distance restrictions.
- Land use: present land use at the intersection, presence of any special traffic generators, proposed or likely future development.
- Traffic control: existing traffic control, present and planned adjacent signals, proposed or existing coordinated systems.
- Actual traffic volumes at an in place intersection. Volumes must include at least 16 hours of counts on all approaches, turning movement counts for at least a.m. and p.m. peak hours. Unusual numbers of heavy vehicles and unusual percentages of turning movements must be noted. Volumes shall have been counted within two years of the date of submission of the report.
- Mn/DOT-generated or-approved volume estimates for a proposed intersection, such as found in an official TAM or SPAR report, and for which warrant estimation methods are acceptable.
- Pedestrian counts, particularly if the intersection is a school crossing or is used by large numbers of elderly or handicapped pedestrians.
- Crash data: number and general types of crashes which have occurred for a minimum of 12 months before the date of the report. If Warrant

6 is addressed, a collision diagram must be included, showing crashes by type, location in the intersection, directions of movement, severity, date, time of day, weather, light, and roadway conditions.

- Any special site conditions: which add to the engineer's judgement that signs are necessary.

The information can be presented in either checklist or narrative form, so long as it is clearly and logically presented. Volumes can be presented in graph or tabular form.

The Signal Unit has a computer program for doing warrant analysis on traffic counts; its use by each district/division is encouraged.

9-5.04 Preliminary Signal Design Concurrence Process

Signal designers should meet and confer to agree on preliminary signal design. The design topics to be discussed include the following:

- general nature of the signal project: new installation, minor or major revisions
- phasing of the intersection, relation of proposed phasing to the traffic volumes and turning movements; use of protected-permissive left-turn phasing rather than protected-only; use of overlaps
- use of 4- and 5-section heads and non standard bracketing
- appropriateness of poles or pedestals for the site
- placement of signal standards to ensure legal placement of all vehicle and pedestrian signal indications. See Tables 9.4A-9.4F for signal head placement diagrams.
- placement of pedestrians pushbuttons relative to signal standards and in place sidewalks and crosswalks
- detector placement and functions. See Tables 9.3A-9.3C for loop detector placement diagrams.
- placement and type of handholes
- design of equipment pad
- type of service equipment
- for revised systems, the wording of the notes on signal structure revision

9-5.05 Signal Agreements

Cooperative agreements, which specify the sharing of cost, maintenance, and operation of signals, are prepared by the Traffic Engineering Signal Unit. Upon completion by the district/division of its work, and on receipt of the plans and agreement request by the

District/Division Traffic Engineer, the agreement will be prepared in basically the following manner:

- A pre-agreement letter shall be sent by the District or Division Traffic Office to all the municipalities that may be involved in the cost sharing of the construction and maintenance of the traffic signal. The pre-agreement letter shall contain an estimate of the costs of construction and maintenance costs. The cost will be shared by each agency depending on the number of legs at the intersection. Private entrances will be consider a municipal leg.
- The municipalities shall provide a resolution stating their willingness to participate in the cost of the project, or to perform certain duties as part of the project.
- The Signal Unit will prepare the special provisions cost estimate from the finished plan provided by the district or division.
- The request for agreement will be approved by the Plans and Coordination Engineer and by the Electrical Devices Engineer and will be submitted to the Signal Unit
- Planning and Programming will be contacted to determine the status of approval for federal-aid funds by the FHWA.
- The Signal Unit will prepare the agreement.
- The copies will then be sent to the District/Division Traffic Engineer.
- The District/Division Traffic Engineer will review the agreement and, if they approve it, will submit all copies to the municipality or county for approval, signatures, and seals. This done, the copies will be returned to the District/Division Traffic Engineer.
- The District/Division Traffic Engineer will check the agreement to ensure proper execution and inclusion of the resolution, submit to the Transportation District/Division Engineer for signature and return to the Signal Unit. Agreements should be back to the District/Division Traffic Engineer more than two weeks before the proposed letting date, and if returned later may require special handling. The District/Division Traffic Engineer should follow up all agreements being processed to ensure timely returns.
- The Signal Unit shall review the agreement for signatures and seals, and for submittal to the Assistant Commissioner for signature.
- The agreement will then be further processed through the Assistant Attorney General, Department of Administration, Budget and the Department of Finance as needed.
- Copies and originals of the fully executed agreement will be properly distributed by the Signal Unit.

Agreements for signal construction in which the municipality or county do not share cost (but share the operation and maintenance) will be identified by an "M" following the agreement number. This is a maintenance cooperative agreement and will be prepared and processed substantially as described above.

9-5.06 State Aid and Other Agencies

Traffic signal plans handled by Mn/DOT for other agencies, with or without the state aid process, are handled differently depending on whether the project has federal funding participation, and whether or not the intersection involved is on or off the trunk highway system.

If a signal at a trunk highway intersection is being built or revised by any other agency, the District/Division Traffic Engineer shall approve the final plans before bids are opened on the project. The Traffic Engineer shall approve the plans whether or not there is any federal funding participation.

If a proposed signal is not at a trunk highway location, and the job involves federal funding participation, the Traffic Engineer will indicate concurrence with the design by means of a memorandum to the State Aid office.

If a proposed signal is not at a trunk highway location, and the job does not have federal funding participation, the Traffic Engineer may indicate approval by means of a memo to the State Aid Office; however, the district/division may recommend approval of such a project if the plans have been certified by both a master electrician and registered engineer.

9-5.07 Cost Sharing

The cost of constructing and maintaining a traffic signal shall be share by the State and other municipal agencies. The costs for the signal may include intersection roadway lights, intersection roadway signs, emergency vehicle preemption (EVP) as well as the cost of construction, engineering, inspection and maintenance. The construction cost is usually divided in the same ratio as the number of legs of the intersection under each jurisdiction to the total number of legs of the intersection. If a leg is split by a division boundary, that leg should be equally divided. A private entrance leg should be divided as a municipal leg.

If after the cost sharing has been divided and the cost is below \$3000 the State will assume 100 percent of the costs that would have otherwise been municipal costs. Cities having a population under 5000 are not eligible for apportionment from the Municipal State-Aid Street Funds established by Minnesota Statutes, Chapter 162. After the costs have been divided according to the legs the State will assume 80 percent of these cities costs.

Signal construction projects that have Federal Aid Funding, the costs of the signal will be divided according to the number of legs. The federal aid will be

applied to the States, cities, and counties shares.

The State will not participate financially in a traffic signal that is not justified.

9-6.00 TRAFFIC SIGNAL DESIGN

9-6.01 General Considerations

The design of a traffic signal system is a process of balancing, among others, the requirements of MN MUTCD; intersection geometrics, operational characteristics of the intersection vehicle and pedestrian traffic; the nature and volume of arterial traffic; and the constraints of the construction process.

9-6.02 Intersection Geometry

Intersection geometry is an important element of traffic signal design. The design of traffic signal system hardware and operation of the traffic signal system should be preceded by a thorough evaluation and, if necessary, reconstruction of the existing intersection.

The following elements should be considered:

1. Pavement width should be adequate for anticipated traffic movements and future capacity requirements. Highway capacity analysis should be performed to get a better understanding of the capacity of the intersection.
2. If appropriate islands should be designed and installed so that the driver has adequate reaction to them and large enough to install a standard signal foundation. Existing shoulders should always be carried through the intersection; this will usually provide enough reaction distance to the island. However, turning radii should be checked to ensure enough setback for comfortable turns.
3. Turn lanes must provide adequate storage in order to prevent turning traffic from interfering with other traffic movements and thus causing capacity breakdown.
4. When a median width is more than 9 m (**30 feet**) between opposing through lanes, special signal design considerations are necessary (See MN MUTCD, Section 4B-12). Extremely wide medians confuse drivers, prevent them from being comfortable with opposing traffic, and causes them to lose track of their path. Wide medians also cause capacity restrictions because more time is needed for vehicle movements and clearances through the intersection.
5. Sidewalks should be constructed as close to the center of the corner as possible. Pedestrian crosswalks should always be placed in front of the stop lines, and the stop lines should be as close to the intersection as practical.
6. Alignment changes within the intersection should be avoided. Vehicles approaching the intersection

should be directed through the intersection. Vertical alignments approaching signals must allow for proper signal visibility.

7. Driveways within an intersection should be signalized and accommodated by the intersection geometrics. Whenever feasible, the driveways should be located or relocated outside the limits of the intersection.
8. The size of corner radii is an important consideration. Excessively large corner radii may obscure intersection limits and create a hazard for bicycles and pedestrians, while very small radii may create a hazard for motorists. Corner radii at signalized intersections should not be less than 6 m (**20 feet**) nor more than 18 m (**60 feet**). A turning radius guide for 17.7 m (**58-foot**) vehicles should be used to determine proper corner radii. At intersections where bus routes are located, corner radii should be analyzed giving due consideration to bus maneuvers.
9. It may be necessary to relocate utilities such as manholes, catch basins, fire hydrants, overhead power and telephone lines and power poles, to obtain adequate geometrics for signalization. The existence of these utilities must not get in the way of adequate geometrics.
10. Pedestrian curbs ramps at all corners.

9-6.03 Operational Characteristics

The behavior of the traffic at an intersection is another highly important element of signal design. The following elements should be considered:

1. Existing 15-minute vehicle volumes, by vehicle class, and pedestrians volumes, are the most basic operational consideration. Data used should represent intersection operation in peak periods.
2. Intersection capacity should be determined based on the Highway Capacity Manual and other sources.
3. The vehicle approach speeds, 85th percentile speeds, should be determined where appropriate for the location of advanced detection.
4. Adjacent land uses should be evaluated to identify activities which may conflict with intersection operation. Items which should be considered include entrances, advertising devices, and areas of high pedestrian activity (schools, manufacturing plants, shopping centers, etc.).
5. Crashes within the intersection should be studied to determine causes and possible design solutions.
6. Pedestrian volumes and school-crossing activities should be studied to determine pedestrian routes and necessary design treatments. Pedestrian movements in and around signals should be routed into the intersection crosswalks in front of vehicles stopped for the signal.

9-6.04 System (Arterial) Considerations

In most cases, an individual traffic control signal must be considered as part of a system, either as one of a series of signals along a linear route, or as one signal in a grid network. System considerations in signal design include the following:

1. Adjacent signals should be interconnected whenever they are less than 800 m (**one-half mile**) apart, when the travel time between adjacent signals is less than the cycle length at each signal, or when platoons leaving one intersection remain intact to the next signal.
2. Properly spaced signalized intersections greatly simplify coordination in planning new signals. Minimum spacing of 400 m (**one-quarter mile**) is recommended. Irregular signal spacing reduces the overall operational efficiency of the mainline movements and greatly complicates signal coordination.
3. Whenever possible, platoons should be kept intact to allow easier mainline coordination and minimize cross- street delay.
4. New street or roadway construction should anticipate the need for a future signals and the need for handholes and conduit, particularly under the roadway.
5. Pretimed controllers are used in built-up urban environments, particularly central business districts. The streets are not excessively wide and the traffic patterns are quite predictable. In this environment, a signal cycles should contain pedestrian movements; Actuated controllers are used in suburban and rural environments. In the rural environment, the actuated controller tends to reduce the number of stops and does not cut off platoons of vehicles. In the suburban environment, the arterial streets tend to be very wide, and the volumes are usually quite high on these arterials. There are not usually many pedestrians crossing such an arterial, so an actuated controller tends to operate much more efficiently, as it is not necessary to time pedestrian intervals except when an actual demand exists.
6. Splits and offsets should be carefully estimated to determine their impact on arterial flow. A split is the relative percentage of green time allocated to each of the various phases at a single intersection. An offset is the travel time between signals, usually expressed in percent of cycle length.
7. Minimum pedestrian walk and clearance timings should be anticipated when designing coordinated signal systems.

9-6.05 Signal Design Elements

1. The most efficient operation of a signal system is attained with the fewest phases that are enough to move traffic without hazardous conflicts. Procedures exist to determine the optimum number of phases for an intersection.
2. The primary consideration in signal head placement is clear visibility. Drivers approaching an intersection shall be given a clear and unmistakable indication of their right-of-way assignment. The number and placement of signal faces shall conform to the requirements of Sections 4B-11 and 4B-12 of the MN MUTCD. Overheads should be located as near as practicable to the line of the driver's normal view. When an overhead is to control two lanes, it should be installed over the center of the centerline of the two lanes. An overhead should be used over each lane when speeds are above 70 km/h. The size of lenses shall be as stated in section 4B-8 of the MN MUTCD. See Tables 9.4A-9.4F for signal head placements charts.

In general, vehicle signal faces should be placed and aimed to have maximum effectiveness for an approaching driver located a distance from the stop line equal to the distance traveled while reacting to the signal and bringing the vehicle to a stop at an average approach speed. Visors, shields, or visual delimiting should be used to help in directing the signal indication to the approaching traffic, and to reduce sun phantom resulting from external light entering a signal lens. The signal face visibility template shown in Table 9.1 should be used as an aid in placing vehicle signal faces.

3. Mainline vehicle detectors should be placed according to the through-phase detector spacing chart and the loop placement diagrams shown in Tables 9.3A-9.3C.

Side street detection is usually placed in the following manner:

There will be a detector or detectors at the stop line. Back of that will be rear detectors. The distance from the rear to the stop-line detectors should equal the distance from the stop-line detector through the intersection.

4. Provision must be made to control pedestrian activity in and around the signalized intersection. Pedestrian indications shall be provided if minimum pedestrian crossing time exceeds minimum vehicular green time, or if any of the conditions set out in section 4B-29 of the MN MUTCD are met.

Pedestrian signal indications shall be mounted, positioned, and aimed so as to be in the line of pedestrians' vision, and to provide maximum visibility at the beginning of the controlled crossing.

If it is determined to prohibit pedestrian movement across any approach, that prohibition must be clearly visible to pedestrians by use of Standard Sign R9-3a on each side of the prohibited crosswalk. See part 4 of the MN MUTCD for further information.

5. Street lighting should normally be installed with traffic signals and flashing beacons. The luminaries are generally 250-watt high-pressure sodium vapor luminaries, mounted in the far-right quadrants of the major street. Larger intersections may require additional luminaries. Twelve meter (**Forty-foot**) mounting heights provide more even light distribution than 9 m (**30-foot**). Street lights installed on type A signal mast-arm poles should be mounted at approximately 350 degrees clockwise from the mast arm in order to provide frontal illumination of any signs mounted on the mast arm.

Signal design must take into account the existing adjacent lighting system and the equipment available to provide access to the luminaries for relamping and maintenance. The presence of overhead power lines must also be taken into account; these must be designed around or moved.

A document called the Signal Design Review Check List, is available on request from the Signal Unit as an aid to designers.

9-6.06 Advanced Warning Flashers

9-6.06.01 General

An Advanced Warning Flasher (AWF) is a device which Mn/DOT uses to convey to the motorist information about the operation of a traffic signal. An AWF is typically found at certain high speed locations where it may be necessary to get the motorists attention thru a visual indication about a future change in the operation of a traffic signal. The AWF assists the motorists in making safer and more efficient driving decisions by informing them that they must prepare to stop.

The Mn/DOT AWF system consists of a flasher and a sign located on main street approaches to a high speed signalized intersection. It is connected to the traffic signal in such a way that when the main street green is about to change to yellow, the flasher is turned on to warn the approaching drivers of the impending change. Basically, the purpose of an optimally designed combination of traffic signal and AWF system is twofold: 1) to inform the driver in advance of a required drive decision (prepare to stop) and 2) to minimize the number of drivers that will be required to make that decision.

9-6.06.02 Guidelines for Consideration

The following guidelines indicate when the installation of advanced warning flashers(AWF) for signal change interval should be considered. Due to the complex nature of traffic flow characteristics, these guidelines should be applied along with engineering judgement. Guidelines should be reviewed for each prospective installation.

AWF should only be installed in response to a specifically correctable problem, not in anticipation of a future problem. Generally, AWF implementation is appropriate only at high speed locations. Before AWF are installed, other remedial action should be considered.

Combinations of the following guidelines or other considerations may justify the installation of an AWF:

1. Speed

The 85th percentile speed of the motorists must be greater than or equal to 50 mph. Meeting this guideline alone is not usually sufficient justification for the installation of AWF.

2. An isolated or an unexpected signalized intersection

This situation can occur where there is a long distance from the last intersection at which the mainline is controlled, or the intersection is otherwise unexpected. This guideline may be applicable where the distance from the last intersection is greater than 15 km (**9 miles**), a freeway terminus, or at other locations where the intersection is unexpected.

3. A Limited sight distance

This can occur where the distance to the stop bar, D, with two signal heads visible is insufficient.

$$D \leq 0.45vt + \frac{v^2}{10(a \pm 9.8s)} \quad (\text{metric})$$

$$D \leq 1.47vt + \frac{1.08v^2}{a \pm 64.4s} \quad (\text{English})$$

Where:

D = distance to stop bar in meters or feet

v = 85th percentile speed in mph

t = reaction time of 2.5 seconds

a = deceleration rate (always a positive number)

for trucks use 2.4 m/s² (metric)

8 ft/s² (English)

for all traffic use 3.0 m/s² (metric)

10 ft/s² (English)

s = decimal gradient

it is + for an upgrade approach or

- for a downgrade approach

Equation I

See Graphs of Limited Sight Distance, Figure I & Figure II.

A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

4. Dilemma zone

This situation exists when a dilemma zone exists for all traffic or for heavy vehicles. A dilemma zone exists if:

$$R = \frac{(w + 1)}{0.28 V} \quad (\text{Metric})$$

$$R = \frac{(w + 1)}{1.47 V} \quad (\text{English})$$

R = all-red interval in seconds

w = width of intersection in meters or feet

t = length of vehicle, assumed to be 6 meters or 20 feet

V = 85th percentile approach speed, in kilometers per second or miles per hour

Equation II

5. Accidents

If an approach has an accident problem, the intersection should be examined for existence of dilemma zone or sight distance restriction.

6. Engineering Judgement

If no sight distance or dilemma zone problems exist, an AWF may not be an appropriate countermeasure to accident problems.

Engineering judgment should be based on additional data such as complaints, violations, conformity of practice, and traffic conflicts. Prior to installing an AWF, consideration should be given to other countermeasures including but not limited to: adjustment of timing parameters which may include increasing yellow and/or all red intervals, improving detection, modification of the signal system as by adding signal heads, adjusting speed limits, and installing continuously operating flashers with standard "signal ahead" warning signs.

9-6.06.03 Guidelines for Installation

1. **Advanced Warning Flasher** - The Advanced Warning Flasher is as shown in the MUTCD, section 2C-17.2. The flasher shall flash yellow in a wig-wag manner prior to the termination of the green (See number 3, below), and during the yellow and red periods of the signal. The flasher will also flash if the signal goes into flashing operation. Power shall be supplied to the AWF from the signal control cabinet.

2. **Advanced Warning Flasher Sign Placement** - The AWF shall be set back from the intersection in accordance with the Table I, shown below. At locations on four lane divided roadway, the AWF shall be placed on both sides of the approach.

TABLE

Posted Speeds (mph)	AWF Placement		Leading Flash (Seconds)
	(meters)	(feet)	
40	70	560	8.0
45	170	560	7.0
50	215	700	8.0
55	215	700	7.0
60	260	850	8.0
65	260	850	7.5

3. **Leading Flash** - The Leading Flash is the amount of time, prior to the signal turning yellow, that the AWF flashes. The AWF shall flash during the Leading Flash Period and continue flashing through the signal's yellow clearance interval and the red. The Leading Flash time is shown in the Table above.

For existing systems where the placement is other than what is listed in Table 1, the Leading Flash Time can be computed by the following formula:

$$F = \frac{2.24 D}{v} - 1.5 \quad (\text{metric})$$

$$F = \frac{0.68 D}{v} - 1.5 \quad (\text{English})$$

Where:

F = Leading Flash Time in seconds

D = AWF Placement in meters or feet

v = posted speed in mph

4. **Detector Placement** - The detection of the intersection shall be determined without regard to the AWF.

9-7.00 TRAFFIC SIGNAL PLANS AND SPECIFICATIONS

9-7.01 General

The end product of the pre-construction activities in signal design is the Plan and Special Provisions. Supporting the Plans and Special Provisions are the standard design practices, Standard Plates Manual, the Minnesota Standard Specifications for Highway Construction, other applicable national and local standards, and any necessary agreements.

9-7.02 Traffic Signal Plans

1. Required Data

Standard signal design plans shall contain at least the following sheets:

- a. Title sheet. See Figure 9.14.
- b. Estimated quantities (if not shown on title sheet). The estimated quantities shall be a Lump Sum for each signal system. Traffic control interconnection, emergency vehicle pre-emption system, and other items such as conduit and handholes for a future signal system which require to be broken out due to cost participation may be itemized separately from the signal system.
- c. Details (e.g., equipment pad, service equipment, wood pole and span wire mounting). See Figure 9.14.
- d. Intersection layout sheet. See Figure 9.14. (If existing utilities are not shown, include additional sheet for utilities). All items shall be properly labeled. The mainline roadway shall be placed horizontal across the plan sheet. Cabinet shall be labeled A in a circle, source of power B. A hexagon with a number inside shall be used for all signal poles. Luminaries shall be labeled using a triangle. Handholes should also be labeled. Numbering should begin closest to the cabinet and move clockwise around the intersection. Vehicle signal faces should be number per controller phase from right to left (2-1, 2-2, etc.). Protected/permissive left turn signal faces should label as through phases. Pedestrian signal faces shall be number one to four as you move around the intersection. The should be proceeded by a P and the controller phase number (P2-1, P2- 2). Detectors shall be labeled per phase as you approach the intersection.
- e. Field wiring diagram.
- f. Type D sign data sheet. All traffic signal installations should include directional signs consistent with the standards presented in the chapter on signing.
- g. Utilities sheet if they are not shown on intersection layout.

2. Final Plan Preparation

Final signal plans should be prepared on "D" size (594 mm x 841 mm) (22" x 34") plan sheets of mylar composition. The scale for the "Intersection Layout" should be 1:250 (metric) or 1" = 20' (English). Each sheet of the plan must be properly identified in the lower right corner (State Project or Project Number and Sheet XX of XX).

The title sheet shall be signed or CADDSEALED by the registered professional engineer responsible for or under whose supervision the work is performed.

3. Plan Review

Final plans submitted by the district/division should be received in the Office of Traffic Engineering 18 weeks (16 weeks for non-Federal Projects) before proposed letting date to allow sufficient time for preparation of Special Provisions and Agreements.

9-7.03 Special Provisions

The Special Provisions for signal projects include complete detailed specifications of the signal system(s) and Maintenance of Traffic section which details the contract time schedule and provisions for traffic during construction

Responsibilities related to the Special Provisions are as follows:

1. District/Division Traffic Engineer

- a. Submits to the Office of Traffic Engineering, Signal Unit, general and detailed signal system requirements as well as any special items which would be helpful in preparing the Special Provisions. This information should be submitted along with, or preferably in advance of, final plans.
- b. Submits to the Special Provisions Engineer in the Office of Road Design (copy to Office of Traffic Engineering) a completed copy of Form 21184, Contract Time Schedule Recommendations and Misc. Data and Form 21185, Provisions for traffic During Construction. This information should be received 12 weeks prior to the proposed letting date.

2. Office of Traffic Engineer, Signal Design Unit

- a. Prepares Special Provisions for all signal projects which are let by the State.
- b. Submits Special Provisions to the Special Provisions Engineer in the Office of Road Design at least six weeks prior to the proposed letting date, at which time final plans and Special Provisions are submitted to the FHWA for approval (when Federal funding is involved).

9-7.04 Detailed Construction Estimate

The Detailed Construction Estimate (Engineer's Estimate) for all signal system projects which are let by the State is prepared by the Signal Design Unit in the Office of Traffic Engineering and submitted in memo form to the Estimates Engineer in the office of Road Design at least 6 weeks prior to the proposed letting date.

9-7.05 Standard Plates Manual

The Standard Plates Manual contains standard drawings of traffic signal equipment referred to in signal plans and Special Provisions.

9-7.06 Minnesota Standard Specifications for Highway Construction

The "Spec Book" contains standard provisions to be used and referred to in signal plans and special provisions.

9-7.07 Other Standards

Other national and local standards which are applicable to traffic signal plans and specifications are as follows:

1. National Electrical Code
2. National Electrical Safety Code
3. ICEA-NEMA Standards for Electrical Wire and Cable
4. ITE Standards
5. State and Local Statutes and Ordinances
6. Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD)

9-8.00 TRAFFIC SIGNAL CONSTRUCTION**9-8.01 State Furnished Material**

It is in the public interest for Mn/DOT to supply both new and refurbished traffic signal equipment and to assemble and modify this equipment for federal-aid projects because of the cost savings. The purchase of large quantities of products occurs using the low bid process and then supplied to the contractor for each contract. The state purchasing of material shall conform with FHWA PPM 21-6.3, Para. 14 and a Public Interest Finding will be completed.

When it is determined that there will be State furnished materials to be provided by the Electrical Services Section:

1. The District/Division Traffic Office shall write a Traffic Engineering (TE) Request on the Automated Facilities Management System (AFMS).
2. Two copies of the Traffic Signal plan are sent to the E.S.S. with the AFMS System ID and TE Request

number on the plan.

3. One or two weeks prior to the letting of the contract, the District/Division Traffic Office approves the TE Request on the AFMS.
4. The State Signal Engineer reviews the TE Request and gives concurrence.
5. After E.S.S. receives the Signal Plans it is sent to the Traffic Maintenance Superintendent (Electrical) for review. After review the electrical concurrence is entered on the AFMS and the Signal Plan is sent to the Electronic Maintenance Supervisor for review.
6. The Electronic Maintenance Supervisor reviews the TE Request and Signal Plans and enters the Electronic Concurrence in the AFMS.
7. The work is then assigned and completed by E.S.S. personnel.

9-8.02 Signal Turn-On Procedure

Advance notice should be given to the public when a signal is to be activated. Those who should be present when the signal is activated include: (1) Project Engineer, (2) Contractor, (3) City Police, (4) Electrical Services Section personnel, and (5) District/Division Traffic Engineer. New signals should operate in a "flashing" condition a few days before turn-on except where "all-red" flashing is used.

9-8.03 Post Turn-On Procedures

After a signal has been activated, a copy of a memorandum of notification should be sent to:

(1) the city, (2) the county, (3) the affected power company, (4) the State Patrol, (5) Area Maintenance Engineer, (6) Emergency Operations Officer, (7) The Electrical Services Section, and (8) the Office of Traffic Engineering (Central Office). This notice should include the location, date and time of turn-on; maintenance responsibilities (including dates of warranties affecting the project); and the vertical clearances of any objects suspended over the roadways. See the appendix for a sample memorandum. See Form 9.B & Form 9.C.

9-8.04 For additional information, see the Construction Manual**9-9.00 TRAFFIC SIGNAL OPERATIONS****9-9.01 General**

It is the responsibility of the District/Division Traffic Engineer to observe the operation of all traffic signals in their district/division. Any timing or operation that is not correct should be corrected. In the more complex type of controllers, it is necessary to enlist the assistance of the personnel in the Electrical Services Section. The determination of the timing can be assisted by personnel

in the Signal Unit. The hardware implementation will require the assistance of personnel from the Electrical Services Section. The District/Division Traffic Engineer shall maintain a complete timing record, including all preemption timing, in the controller cabinet and in the district/division office. In the event the District/Division Traffic Engineer determines a Traffic signal is to be revised, a TE request is to be written (See Section 9-8.01). The TE Request should outline the work that is to be done. Normally, the District/Division Traffic Office will be contacted by the Electrical Services Section after concurrence and before the work is done.

Each district/division shall budget for payment of electrical power usage where the State has that responsibility. The district/division shall keep a current maintenance log (see Form 9.D) in each controller cabinet and any timing change or maintenance activity performed to that signal shall be duly recorded on that log.

9-9.02 Operational Timing Practices

It should be noted that these guidelines, procedures and practices are general and should only be used as a guide. Many other factors at each individual intersection must be considered along with engineering judgement when applying these guidelines.

1. Pedestrian and Clearance Intervals

WALK INTERVAL

The MN MUTCD states that under normal conditions the WALK interval should be 4 to 7 seconds in length, during which the symbolic WALKING PERSON is displayed. This will allow adequate time for the pedestrians to leave the curb before the clearance interval begins. A walk interval of 7 seconds should only be used in certain sections of large metropolitan areas. Lowering the WALK interval to 4 or 5 seconds could be done at locations where the pedestrian volumes are low (less than 10 pedestrians per cycle). The lowering of the WALK interval should take into account the alertness of the pedestrians. In pretimed operation the WALK interval should be as long as the green interval minus the required pedestrian clearances.

PEDESTRIAN CLEARANCE INTERVAL

The pedestrian clearance interval, displayed as the FLASHING symbolic HAND, must be long enough to allow the pedestrian to safely cross the roadway. To determine the time interval for the FLASHING HAND, the distance traveled by the pedestrian is divided by the rate of travel. The distance traveled is considered from the edge of the curb or shoulder to the far side of the farthest traveled lane. The rate of travel is assumed to be 1.2 meters (**4 feet**) per second (m/s or **ft/sec**).

This rate can be lowered for children and senior citizens. At a signed handicapped crossing, the

rate of 0.75m/sec (**2.5 ft/sec**) should be used for the rate of travel. The pedestrian clearance interval may include the yellow change interval and the ALL-RED to travel to the far edge of the farthest traveled lane before opposing traffic receives a green.

Divided highways with medians of at least 2 m (**6 feet**) require special timing of the WALK and pedestrian clearance interval. The time for the WALK interval should be equal to the distance from the curb to the median, divided by the rate of travel. The clearance interval should be equal to the distance from the median to the opposite curb divided by the rate of travel.

$$\begin{aligned} \text{WALK} &= D_1/R \\ \text{FLASHING DON'T WALK} &= D_2/R \end{aligned}$$

D_1 = Distance from curb to median

D_2 = Distance from median to opposite curb

R = Rate of travel, assume 1.2 m/s (**4 ft/sec**)

Adequate signing shall be used to guide the pedestrian to areas of safe refuge.

YELLOW

The YELLOW clearance interval is to warn traffic that the related movement is about to change. The YELLOW clearance interval should be between 3 and 6 seconds. Generally, the shorter intervals are for slower approach speeds and the longer intervals approaches of higher speeds. Factors affecting the length of the YELLOW interval are grades, visibility, and intersection size. The YELLOW intervals must not be too short (causing quick stops and/or red violations) nor too long (causing regular "driving the yellow"). A formula for determining the YELLOW clearance interval is stated below.

$$Y = t + \frac{0.14 V}{a + 9.81 P} \quad (\text{Metric})$$

$$Y = t + \frac{0.733 V}{a + 32.2 P} \quad (\text{English})$$

Y = Yellow interval in seconds

t = reaction time of the driver, assumed to be 1.0 seconds

V = 85th percentile approach speed, in kilometers per second or miles per hour

a = deceleration rate, assumed to be 3.048 meters/sec² or 10 feet/sec²

P = + or - grade of approach in percent/100

Mn/DOT recommended timing for the given speeds is listed below (level ground):

85th PERCENTILE SPEED (mph)	MN/DOT RECOMMENDATION
25	3.0 SEC
30	3.5 SEC
35	4.0 SEC
40	4.0 SEC
45	4.5 SEC
50	5.0 SEC
55	5.5 SEC
60	6.0 SEC
65	6.0 SEC

The above formulas and recommended timings are only guidelines, other factors can enter into the time of the YELLOW interval (volume of heavy vehicles, sight distances, location, etc.).

ALL RED

The all-red clearance interval is used following the yellow clearance interval when more clearance time is required than can practically be displayed as a yellow. The cases generally requiring all-red intervals are higher speed approaches and large intersections (as on phases crossing divided highways) where long yellow intervals would be misused. Formulas are stated below for determining the ALL RED portion of the cycle. Values should be rounded to the nearest 0.5 second.

$$R = \frac{(w + 1)}{0.28 V} \quad (\text{Metric})$$

$$R = \frac{(w + 1)}{1.47 V} \quad (\text{English})$$

R = all-red interval in seconds
 w = width of intersection in meters or feet
 t = length of vehicle,
 assumed to be 6 meters or 20 feet
 V = 85th percentile approach speed,
 in kilometers per second or miles per hour

Engineering judgement should be used to make the final decision on the amount of time for the ALL-RED interval taking into account other factors. ALL-RED intervals usually should be in the range of 1 to 5 seconds.

2. Coordinated Operation

CYCLE LENGTH

The cycle length is critical to the proper operation of a signal. The shortest practical cycle length should be used to service the traffic demand at hand and adequately accommodate the pedestrian traffic at all times. High volume periods may require the cycle length to increase to properly service the higher volumes. The use of computer software should highly be considered when determining the cycle length, especially when working with coordinated systems.

Different cycle lengths should be developed for the different periods of the day.

SPLIT

The split selected for pretimed operation must be based upon the vehicular and pedestrian demands at the intersection. Commonly the vehicular demand dictates one split and the pedestrian demand will need another. An increase in cycle length may be needed to guarantee minimum pedestrian requirements on the cross street and still maintain a favorable proportion of green for the main street.

Splits for actuated operation are easily developed using computer software. The software will optimize the splits to a predetermined level of service and coordinated interconnected intersections. Splits developed with computer software should be examined. Depending on the software packages, left turns and cross street traffic may not get adequate time to be serviced properly.

3. ACTUATED - Non-Volume Density Intervals

MINIMUM INITIAL

The minimum initial is the amount of guaranteed green time that the given movement will receive per phase. The minimum initial must be set to guarantee that the vehicles stored between the detector and the stop line will clear the intersection before the phase terminates. Mn/DOT's recommended practice is:

$$G_{\min i} = 3 + 2n$$

n = number of vehicles that can be stored between stop line and the far detector in that lane. To determine this divide the distance between the stop line and the detector by 8 m (25 feet). The 8 m (25 feet) is the average vehicle length plus headway.

PASSAGE OR VEHICLE EXTENSION

The passage or extension time is the number of seconds required for a vehicle moving at average approach speed to travel from the detector to the stop line. The passage time serves two purposes. It is the time of traveled between the back detector and the stop line, and allowable time gap between actuations that will cause the green to remain on that approach (phase). If vehicles are getting detected in shorter intervals than the passage time (allowable gap), the phase will remain green.

The passage time should be set so that the vehicles moving (15th percentile speed) across the detector will clear the intersection when the clearance intervals are displayed. If the passage interval is too short quick stops may result as well as terminating the green before the vehicular movement has been adequately served. The 15th percentile speed can assumed to be 15 km/h (**10 mph**) lower than the 85th percentile speeds. Good engineering judgement should be used when determining the proper speed to use. The formulas are stated as follows:

$$P_t = \frac{D}{0.28 S} \quad (\text{Metric})$$

$$P_t = \frac{D}{1.47 S} \quad (\text{English})$$

D = Distance from stopline to
back of detection

S = Speed of approach in km/h or mph

MAXIMUM

The maximum intervals should be set at a limit which would generally clear the maximum number of vehicles waiting for the green. A careful capacity analysis must be made to control peak hour cycle lengths and splits. If the cycle lengths should become too long, turning vehicles may exceed the storage capability at the intersection, forcing them out of the turning lanes and thereby blocking the through movements.

Consideration should be given to utilizing the SOAP and TRANSYT programs to determine the maximum green times. SOAP should be used for isolated intersections and TRANSYT-7F for coordinated intersections.

4. Volume-Density Intervals

MINIMUM INITIAL

In density operation the minimum initial should be set low to clear the minimum of vehicles expected during the light volume period. Another function of the density operation will add time to this minimum amount. Below are Mn/DOT's recommended practices:

Major approach = 15 seconds
= 20 seconds (70 km/h (**45 mph**) or above)
Minor approach = 10 seconds
Left turn approach = 5 seconds

VARIABLE INITIAL (ADDED INITIAL)

The variable initial interval is generally used on phases for higher speed approaches where it is desirable to position the detectors quite a distance from the stop line (resulting in unacceptably long initial portion requirements). This feature allows the minimum initial to be set low for light volume cycles. Vehicles crossing the detector when that phase is red will add time to the variable initial so that when that phase is to be served, the initial portion of green will be long enough to serve the actual number of vehicles waiting for the green.

Variable initial is commonly set on the controller by one of two methods.

Method 1

"ADDED INITIAL PER ACTUATION" - the amount of time that each vehicle crossing the detector on the red should add to the variable initial and "ACTUATIONS BEFORE ADDED INITIAL" - the number of vehicles which can be adequately served by the time set on the minimum initial. This method of variable initial has no adjustable "upper limit" so the maximum time of the variable initial is controlled by the storage capability between the detector and the stop line.

Method 2

"MAXIMUM INITIAL" - the most amount of time that will be allowed in the variable initial. This adjustment is usually set to clear the vehicles stored between the detector and the stop line, and "ACTUATIONS TO REACH MAXIMUM INITIAL" - the number of vehicles crossing the detector on the red to achieve the maximum initial setting. In this variable initial method each vehicle crossing the detector will add a portion of time to the variable initial unit that limit is reached.

GAP REDUCTION

When a phase is green the time between vehicles to terminate that phase starts out at the amount of time set for the passage time (i.e., successive actuations must be closer together than the passage time to extend the green).

After the phase has been green for some time, it becomes desirable to terminate the phase on a smaller distance between vehicles. Generally, the minimum gap is set at about two seconds and the amount of time into the green to reduce to that gap is set at about 67% of the maximum interval. The allowable gap will gradually reduce in that time frame. Therefore, the last 33% of the maximum green would be extended only by tightly spaced (higher volume) vehicles.

MAXIMUM -- See MAXIMUM as stated above.

9-10.00 TRAFFIC SIGNAL MAINTENANCE

9-10.01 General

Maintenance work on traffic signal system that is the responsibility of the State is performed by the Electrical Services Section (ESS) of the Office of Traffic Engineering. ESS performs electrical and hardware field repairs, performs shop repairs of traffic signal control equipment, prepares State-furnished equipment for installation by contractors on traffic signal projects, and performs minor traffic signal upgrades and minor installation projects.

A municipality or county may, by resolution, request that the State with its own forces perform certain maintenance work assigned to the municipality or county by a Cooperative Signal Agreement, for which work the State will be reimbursed. As it may not be economically feasible for the State to do this additional work, the Assistant Maintenance Engineer, Electrical Services Section, shall be asked to evaluate any anticipated requests before the municipality is asked for a resolution. The agreement will be prepared by the Agreements Unit and processed by the District/Division Traffic Engineer, as outlined in Section 5.05 of this chapter. After the Office of Traffic Engineering obtains a maintenance agreement, it is sent to the municipality for signatures after which it is then processed and distributed by the Agreements Unit.

9-10.02 Malfunction Repair

In the event of an equipment malfunction, the District/Division Traffic Engineer, State Patrol, or other authorities shall call the Electrical Services Section to dispatch a repair crew. The District/Division Traffic Engineer assigns each intersection a Signal Maintenance Priority which indicates the order in which traffic signal malfunctions should be serviced when malfunctions are known to exist at more than one intersection. In general, any signals outside of the metropolitan area have

priorities no higher than C. The Signal Maintenance Priorities are as follows:

- A. Repair as soon as possible
- B. Repair before next peak hour
- C. Repair next scheduled workday
- D. Repair as schedule permits
- N. No State maintenance responsibility

After hours, the district/division traffic personnel shall call the Metro Division Maintenance Dispatcher. The dispatcher will contact the appropriate E.S.S. "on call" person. After the dispatcher makes contact with the Electrical Services Section person, it is the responsibility of this person to follow-up on the problem. In the seven-county metropolitan area, the ESS person will usually go to the intersection and correct the malfunction. In the rural districts, or if a difficult condition in the metropolitan division is encountered, appropriate district/division personnel may be contacted.

When a traffic signal malfunction has been reported to the district/division or E.S.S., and the local authority is responsible for the maintenance of that traffic signal, the responsible jurisdiction should be contacted immediately to arrange for prompt repair.

9-10.03 Lamp-outs

All lamp-outages that are the responsibility of Mn/DOT shall be reported to the Electrical Services Section. Lamp-outages that are the responsibility of other agencies shall be reported to them for correction. Any lamp-outage report received by the Electrical Services Section that is not the responsibility of Mn/DOT will be referred to the responsible agency for correction. All such reports shall be documented by the Electrical Services Section.

9-10.04 Control Strategy Revisions

Any proposed revisions to an existing signal system, which involve changing signal faces, detection schemes, and/or control phasing must be approved by the Assistant Traffic Engineer, Electrical, before any work will be allowed. These changes shall be shown on a revised Signal Plan and a TE request is to be written (See Section 9-8.01). The TE Request should outline the work that is to be done. If work is to be performed by the Electrical Services Section the District/Division Traffic Office will be contacted after concurrence and before work is done.

9-10.05 Signal Maintenance Log and Signal Maintenance File

Each traffic signal controller cabinet shall contain a Signal Maintenance Log. Anyone who does any repair work in the cabinet or makes any changes in the equipment in the traffic signal cabinet control equipment shall record the action in the log. The signal maintenance log provides a historical record of work

done in the cabinet to assist personnel in diagnosing problems in the cabinet and in making operational adjustments.

In addition to the signal maintenance log contained in the intersection controller cabinets, ESS maintains a record of signal maintenance on the Automated Facilities Management System (AFMS) for each intersection for which the State has maintenance responsibility. Whenever a maintenance call is made to an intersection, the work that is done is recorded and entered into the AFMS. The AFMS provides data for analysis of such factors as maintenance time apportionment and equipment reliability.

9-10.06 Automated Facilities Management System

The Automated Facilities Management System contains computer records for all traffic signals and flashing beacon systems on trunk highways in Minnesota and for any additional traffic signals or other devices for which the State has any responsibility.

9-10.07 Obtaining Electrical Power from Mn/DOT Lighting or Signal Systems

This topic has been dealt with in detail in Chapter 10, Lighting of Traffic Facilities. See section 10-6.04.

9-11.00 TRAFFIC SIGNAL COMPUTER AIDS

9-11.01 General

The computer is an important and powerful tool in traffic engineering. Through the Office of Traffic Engineering, Signal Design Unit, traffic engineers in the State of Minnesota have access to a number of computer programs which assist in the design, operation, and management of traffic signal systems. Available PC programs include the Highway Capacity Manual program, the operations analysis program Passer II, the software for signal warrant analysis of traffic counts, the Facilities Management System, and many more.

9-11.02 Desktop Computer (PC) Software

There are many PC software programs available to the traffic signal designer or operations analyst. A full list of programs and their capabilities is available from the Signal Unit.

The Highway Capacity Manual software was developed for the Federal Highway Administration and follows the capacity analysis procedures found in the latest edition of the Highway Capacity Manual.

The signal warrant analysis software, given volume, speed, and geometric data for an intersection, will produce a table and graphs, and will analyze the volume counts against warrants 1, 2, 6, 8, 9 and 11.

Signal timing programs are also available. Passer II-90 and TRANSYT-7F can be accessed through AAP for coordinated arterials. SOAP, Highway Capacity Software and Signal 85 can be accessed through WHICH for isolated intersection.

9-11.03 Computer-aided Drafting

The IGDS or Intergraph System is an extremely powerful system of computer-aided drafting with workstations, plotters, and links to each district/division. Training on the system is available through the office of Computer-Aided Engineering Services (CAES) in Central Office.

9-12.00 REFERENCES

1. Institute of Transportation Engineers. Manual of Traffic Engineering Studies, by Paul C. Box and Joseph C. Oppenlander, 4th ed. Arlington, VA.; Institute of Transportation Engineers, 1976.
2. Institute of Transportation Engineers. Transportation and Traffic Engineering Handbook, Wolfgang S. Hamburger, ed. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.
3. Capacity Analysis Techniques for Signalized Intersections, by Jack F. Leisch Arlington, VA; Institute of Transportation Engineers, 1986.
4. Minnesota Department of Transportation, Mn/SOTA Signal Design Training Course Workbook, St. Paul, MN 1993.
5. Minnesota Department of Transportation Standard Plates Manual St. Paul, MN; Minnesota Department of Transportation.
6. Minnesota Department of Transportation, Standard Specifications for Construction St. Paul, MN; Minnesota Department of Transportation.
7. Minnesota Department of Transportation, Technical Manual St. Paul, MN; Minnesota Department of Transportation.
8. National Electrical Manufacturers Association NEMA Traffic Control Systems, Standards Publication TS 1-1983 Washington, DC; National Electrical Manufacturers Association, 1983.
9. National Electrical Manufacturers Association NEMA Traffic Control Systems, Standards Publication TS 2- 1992 Washington, DC; National Electrical Manufacturers Association, 1983.
10. National Fire Protection Association National Electrical Code Quincy, MA; National Fire Protection Association.
11. National Research Council, Transportation Research Board Highway Capacity Manual Washington, DC; Transportation Research Boards, 1985.

12. United States Department of Transportation, Federal Highway Administration Manual on Uniform Traffic Control Devices for Streets and Highways Washington, DC; U.S. Government Printing Office, 1978.
13. United States Department of Transportation, Federal Highway Administration Traffic Control Devices Handbook Washington, DC; U.S. Government Printing Office, 1983.
14. United States Department of Transportation, Federal Highway Administration, User Guide for Removal of Not Needed Traffic Signals Washington, DC; U.S. Government Printing Office, 1980.
15. United States Department of Transportation, Federal Highway Administration and Transportation Research Center, University of Florida Highway Capacity Software Users Manual Washington, DC; 1987.

MINNESOTA DEPARTMENT OF TRANSPORTATION

SIGNAL JUSTIFICATION REPORT

for

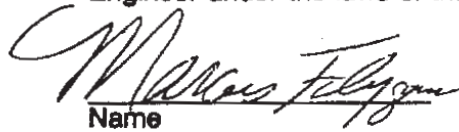
T.H. 169/C.R. 104

Blue Earth

Faribault County

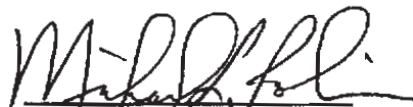
C.S. 2207

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.


Name 11815 Reg. No. 3/31/94 Date

APPROVED: 
District Engineer 3/25/94 Date

I CONCUR with your determination that a traffic signal is justified at this location based on this Signal Justification Report.


Director, Office of 4/15/94 Date
Traffic Engineering

Text Ref.: 9-5.03.03

July 1, 1994

SJR CONCURRENCE SIGNOFF LETTER

FIGURE
9.1

MINNESOTA DEPARTMENT OF TRANSPORTATION

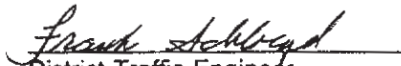
PROJECT MEMORANDUM/SIGNAL JUSTIFICATION REPORT

for T.H. 52
S.P. 5508-83
At 55th St. NW (East Ramps)
In Rochester, Olmsted County

Program: Safety Capacity (SC)
Letting Date: May, 1995

Funding Category: Surface Transp. Plan (STP)
Work Identification: Traffic Signal Construction

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.


District Traffic Engineer

9611
Reg. No.

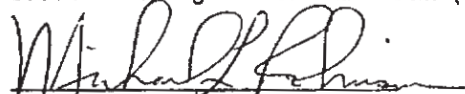
2-10-94
Date

APPROVED:


Transportation District Engineer

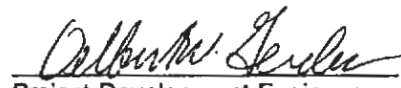
Feb 10, 1994
Date

I CONCUR with your determination that a traffic signal is justified at this location based on the Signal Justification Data (Sections XII and XIII).


Director, Office of Traffic Engineering

2/22/94
Date

APPROVED:


Project Development Engineer
Engineering Services Division

3/3/94
Date

Full Document
c: Gary Ries

Signature Page
c: Kermit McRae
Frank Schloegel
Robert Cartford
Del Gerdes
Mike Robinson

Text Ref.: 9-5.03.03

July 1, 1994

PROJECT MEMORANDUM/SJR CONCURRENCE
SIGNOFF LETTER

FIGURE
9.2

MINNESOTA DEPARTMENT OF TRANSPORTATION
CENTRAL OFFICES -- TRAFFIC ENGINEERING
SIGNAL WARRANT ANALYSIS

S.P. : CS6933
 Location : DULUTH
 Date : 04/22/87
 Factor : 1.000 ..

SPEED	APPROACH	LANES
30	Major App. 1 : TH 194 - CENTRAL AVE. E.B.	4
30	Major App. 3 : TH 194 - CENTRAL AVE. W.B.	3
30	Minor App. 2 : PECAN AVE. S.B.	2
30	Minor App. 4 : PECAN AVE. S.B.	2

POPULATION LESS THAN 10,000 : NO
 SEVENTY PERCENT FACTOR USED : NO

		600/900			200/100		200/100		1/2
HOURL	MAJOR APP.1	MAJOR APP.3	TOTAL 1+3	WARRANT MET	MINOR APP.2	MINOR APP.4	WARRANT MET APP.2	WARRANT MET APP.4	MET SAME HOURS
6-7 A.M.	0	0	0	/	0	0	/	/	/
7-8 A.M.	860	708	1568	X / X	179	123	/ X	/ X	/ X
8-9 A.M.	548	345	893	X /	93	70	/	/	/
9-10 A.M.	466	415	881	X /	52	40	/	/	/
10-11 A.M.	456	504	960	X / X	42	30	/	/	/
11-12 P.M.	590	650	1240	X / X	52	72	/	/	/
12-1 P.M.	698	699	1397	X / X	64	73	/	/	/
1-2 P.M.	681	676	1357	X / X	56	34	/	/	/
2-3 P.M.	729	752	1481	X / X	63	143	/	/ X	/ X
3-4 P.M.	723	808	1531	X / X	78	165	/	/ X	/ X
4-5 P.M.	659	1016	1675	X / X	82	65	/	/	/
5-6 P.M.	660	767	1427	X / X	56	50	/	/	/
6-7 P.M.	0	0	0	/	0	0	/	/	/
7-8 P.M.	0	0	0	/	0	0	/	/	/
8-9 P.M.	0	0	0	/	0	0	/	/	/
9-10 P.M.	0	0	0	/	0	0	/	/	/
10-11 P.M.	0	0	0	/	0	0	/	/	/

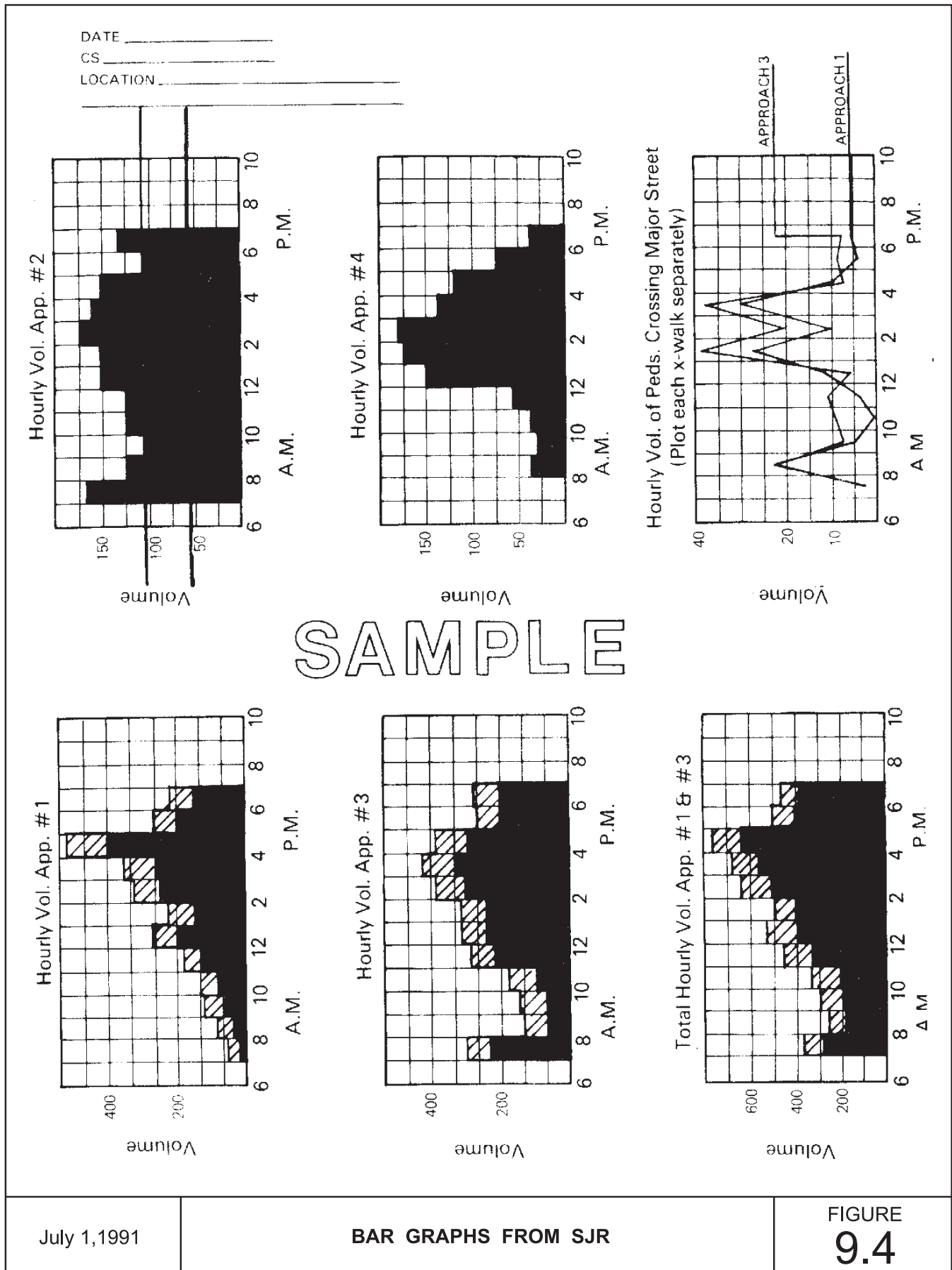
WARRANT 1 WAS NOT MET : 0 HOURS SATISFIED REQUIREMENTS
 WARRANT 2 WAS NOT MET : 3 HOURS SATISFIED REQUIREMENTS
 WARRANT 6 VOLUME REQUIREMENTS WERE NOT MET
 WARRANT 8 WAS NOT MET : 2 HOURS MET / 5 HOURS MET
 WARRANT 9 WAS NOT MET : 3 HOURS SATISFIED REQUIREMENTS
 WARRANT 11 WAS MET : 6 HOURS SATISFIED REQUIREMENTS

DATA FILE --> PECAN

July 1, 1991

COMPUTER OUTPUT -- VOLUME WARRANT ANALYSIS

FIGURE
9.3



11/18/87
 GAP EXPECTANCY TABLE
 TO USE: READ VOL. AT LEFT, MIN. USABLE GAP AT TOP. WHERE THE COLUMN AND ROW INTERSECT IS GIVEN THE EXPECTED
 NUMBER OF USABLE GAPS IN ONE HOUR. GET MIN. USABLE GAP FROM STREET WIDTH AND WALKING SPEED AND PERCEPTION-
 REACTION TIME. IF VOLUME IS FOR LESS THAN ONE HOUR, CONVERT TO VEH/HR EQUIVALENT.
 PROGRAMMED BY ROBERT G. WIRTH APRIL 1985

USABLE GAP IN SECONDS

VEH/HR	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
100	82	80	78	76	74	72	70	68	66	64	62	61	59	57	56	54	53
150	112	107	103	99	95	91	87	84	80	77	74	71	68	65	63	60	58
200	136	128	121	115	109	103	97	92	87	82	78	74	70	66	62	59	56
250	154	143	134	125	116	109	101	95	88	82	77	72	67	62	58	54	51
300	167	154	142	130	120	109	102	93	86	79	73	67	62	57	52	48	44
350	177	161	146	132	120	109	99	90	81	74	67	61	55	50	45	41	37
400	184	164	147	132	118	105	94	84	76	68	60	54	48	43	39	35	31
450	188	166	146	129	114	100	89	78	69	61	54	47	42	37	33	29	25
500	189	165	143	125	109	94	82	72	62	54	47	41	36	31	27	24	20
550	189	162	139	119	102	88	75	65	56	48	41	35	30	26	22	19	16
600	187	158	134	113	96	81	69	58	49	42	35	30	25	21	18	15	13
650	184	153	128	107	89	74	62	52	43	36	30	25	21	18	15	12	10
700	179	148	122	100	82	68	56	46	38	31	26	21	17	14	12	9	8
750	174	142	115	93	76	62	50	41	33	27	22	18	14	12	9	8	6
800	169	135	108	87	69	56	45	36	29	23	19	15	12	9	8	6	5
850	163	129	102	80	63	50	39	31	25	19	15	12	10	8	6	5	4
900	156	122	95	74	58	45	35	27	21	16	13	10	8	6	5	4	3
950	150	115	88	68	52	40	31	24	18	14	11	8	6	5	4	3	2
1000	143	108	82	62	47	36	27	20	16	12	9	7	6	5	4	3	2
1050	136	102	76	57	42	32	24	18	13	10	7	6	5	4	3	2	1
1100	130	95	70	52	38	28	21	15	11	8	6	5	4	3	2	1	1
1150	123	89	65	47	34	25	18	13	10	7	6	5	4	3	2	1	1
1200	116	83	60	43	31	22	16	11	8	6	5	4	3	2	1	1	1
1250	110	78	55	39	27	19	14	10	7	6	5	4	3	2	1	1	0
1300	104	72	50	35	24	17	12	8	6	5	4	3	2	1	1	1	0
1350	98	67	46	32	22	15	10	7	6	5	4	3	2	1	1	1	0
1400	92	62	42	29	20	13	9	6	5	4	3	2	1	1	1	1	0
1450	86	58	39	26	17	12	8	6	5	4	3	2	1	1	1	1	0
1500	81	54	35	23	15	10	7	6	5	4	3	2	1	1	1	1	0
1550	76	49	32	21	14	9	6	5	4	3	2	1	1	1	1	1	0
1600	71	46	29	19	12	8	6	5	4	3	2	1	1	1	1	1	0
1650	67	42	27	17	11	7	6	5	4	3	2	1	1	1	1	1	0
1700	62	39	24	15	9	6	5	4	3	2	1	1	1	1	1	1	0
1750	58	36	22	14	8	6	5	4	3	2	1	1	1	1	1	1	0
1800	54	33	20	12	7	6	5	4	3	2	1	1	1	1	1	1	0
1850	51	30	18	11	6	5	4	3	2	1	1	1	1	1	1	1	0
1900	47	28	16	10	5	4	3	2	1	1	1	1	1	1	1	1	0
1950	44	26	15	9	4	3	2	1	1	1	1	1	1	1	1	1	0
2000	41	23	13	8	4	3	2	1	1	1	1	1	1	1	1	1	0

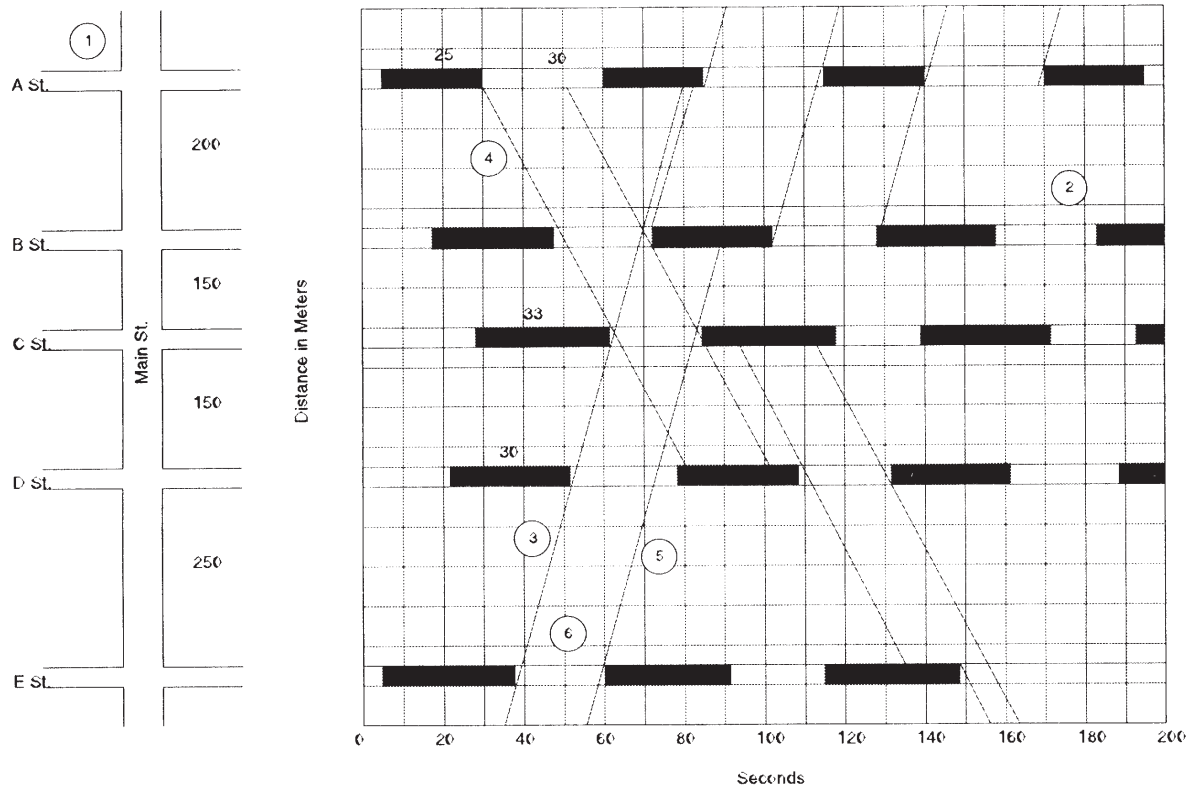
July 1, 1991

GAP TABLE

 FIGURE
 9.5

LEGEND

1. Plan of street drawn to scale.
2. "Go" intervals of Main Street designated by open space;
3. "Stop" intervals for Main Street designated by solid line.
4. Slope of this line indicates the speed and represents the first vehicle of a group or platoon moving progressively through the system from E Street to A Street.
5. As in 3 above, this line represents the first vehicle moving from A Street to E Street in the southbound direction.
6. This line is roughly parallel to line 3 and represents the last northbound vehicle in a group to go through the intersections.
7. The space between line 3 and 5 on the time scale is the width of the "through band" in seconds; this width may vary over different sections of the street.



Text Ref.: 9-4.03.06

January 1, 1996

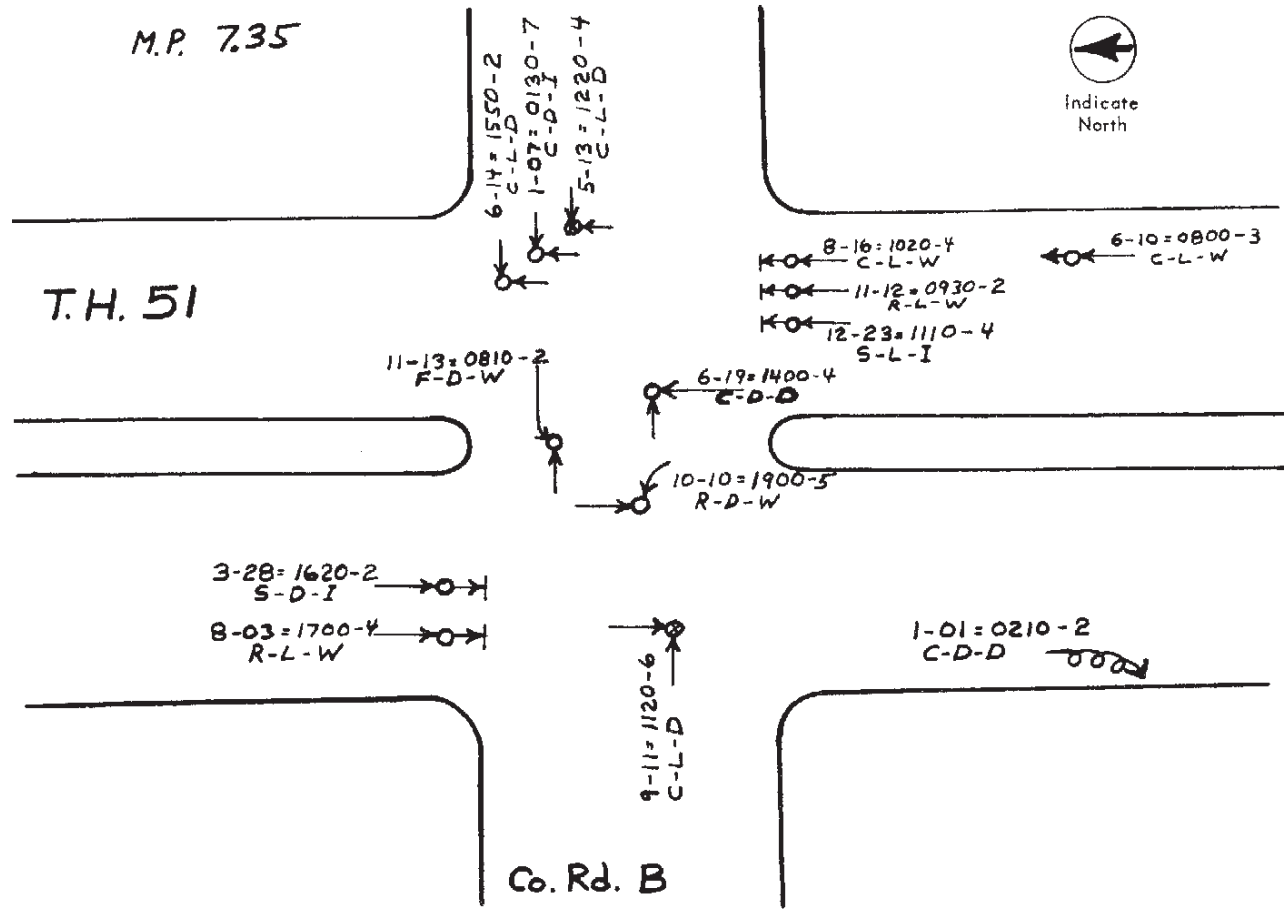
TIME -- SPACE DIAGRAM

FIGURE
9.6

Form 2942A (5-67)

MINNESOTA HIGHWAY DEPARTMENT
Traffic Engineering Section
COLLISION DIAGRAM

C. S. 6216 County Ramsey Period 1974
T. H. 51 at Co. Rd. B Location Roseville Number of Accidents 14
Data obtained from Printout By J. Smythe



- Motor Vehicle Moving Ahead
- ←←← Motor Vehicle Backing Up
- ⊥ Motor Vehicle Stopped
- Pedestrian
- Parked Vehicle
- Fixed Object
- Fatal Accident
- ⊗ Personal Injury
- Property Damage Only
- ⊗ Rear End
- ⊗⊗ Out of Control
- ⊥ Right Angle

STANDARD SYMBOLS

Weather:

C = Clear (1)
R = Rain (2)
S = Snow (3)
F = Fog (4)

Light:

L = Daylight (1)
D = Dark (2)
S = Dark w/
street lights (3)

Surface:

D = Dry (1)
W = Wet (2)
I = Snowy or
icy (3)

EXAMPLES

Mo., Day = Hr., Day of Wk., Weather-Light-Road Surface-Driver Behavior or Cause

7-25 = 1330-3 C L D 03

NOTE: Driver Behavior is used for 1966 accidents and later. Cause is used for accidents before 1966.

July 1, 1991

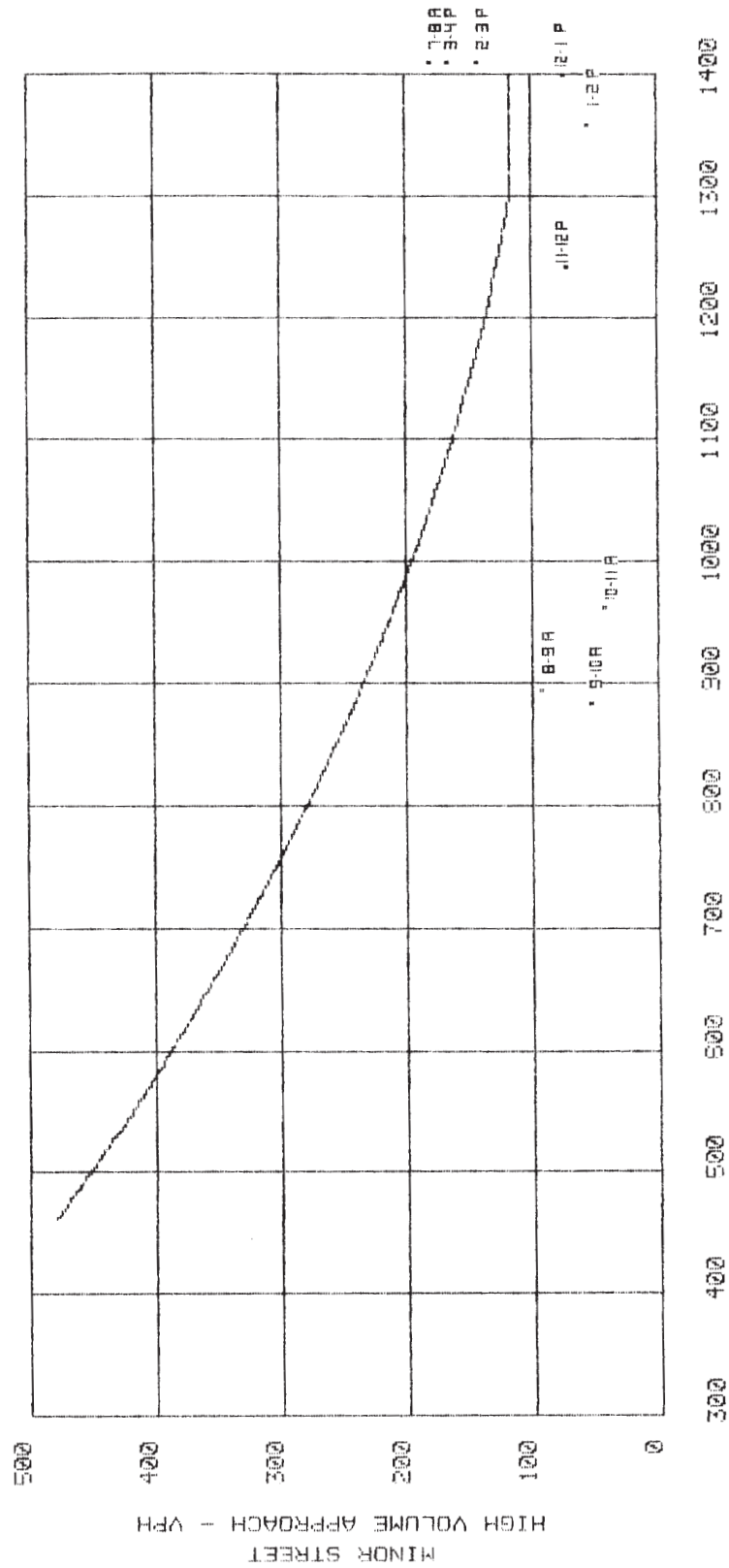
ACCIDENT COLLISION DIAGRAM

FIGURE
9.7

WARRANT 9 - FOUR HOUR VOLUME

S.P.: C56335
 DATE: 04/22/87
 FACTOR: 1.000

SPEED	APPROACH	LANES
30	MAJOR APP.1: TH 194 - CENTRAL AVE. E.B.	4
30	MAJOR APP.3: TH 194 - CENTRAL AVE. W.B.	4
30	MINOR APP.2: PECAN AVE. S.B.	2
30	MINOR APP.4: PECAN AVE. S.B.	2



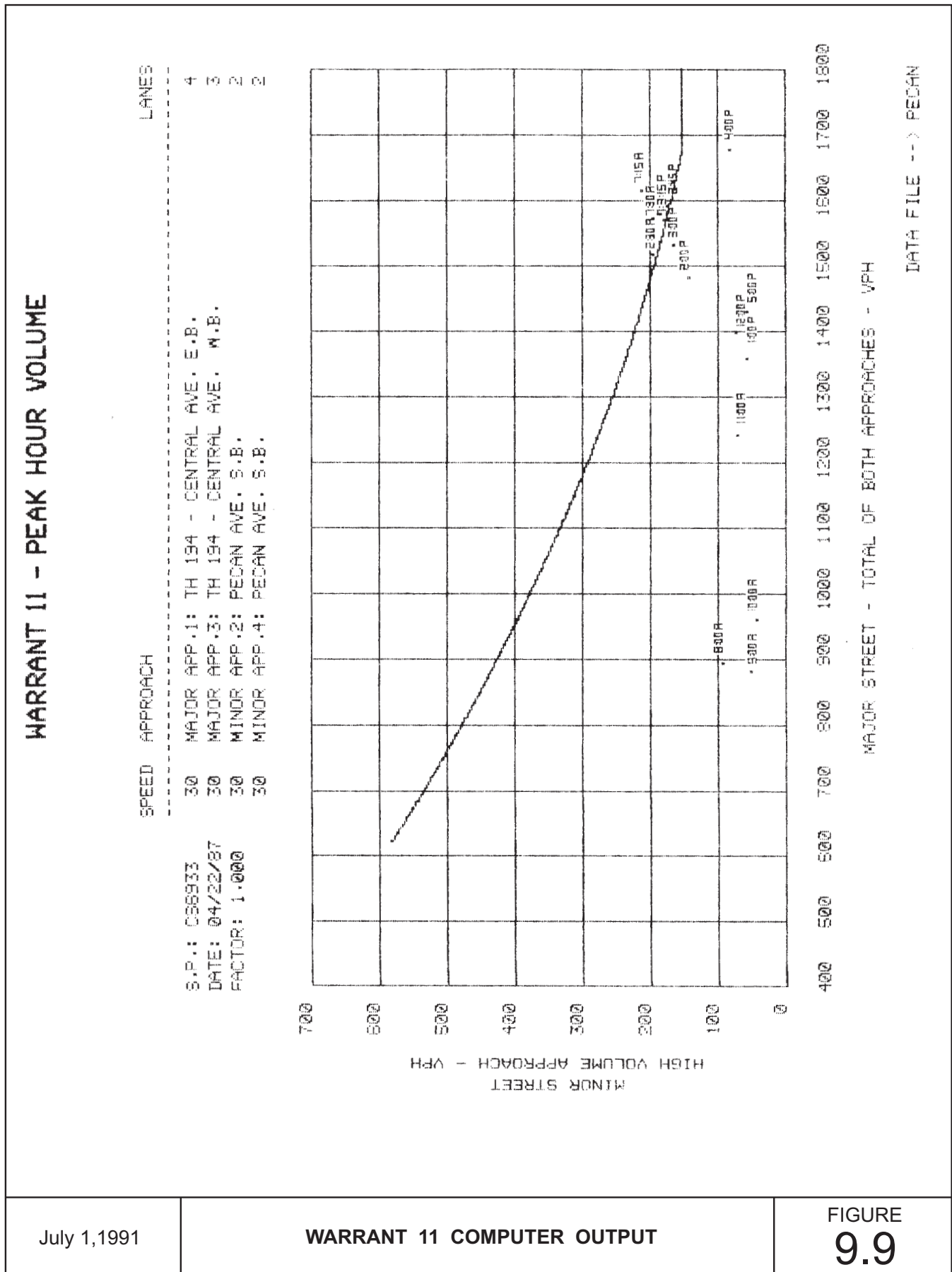
MAJOR STREET - TOTAL OF BOTH APPROACHES - VPH

DATA FILE --> PECAN

July 1,1991

WARRANT 9 COMPUTER OUTPUT

FIGURE
 9.8



July 1,1991

WARRANT 11 COMPUTER OUTPUT

FIGURE
9.9

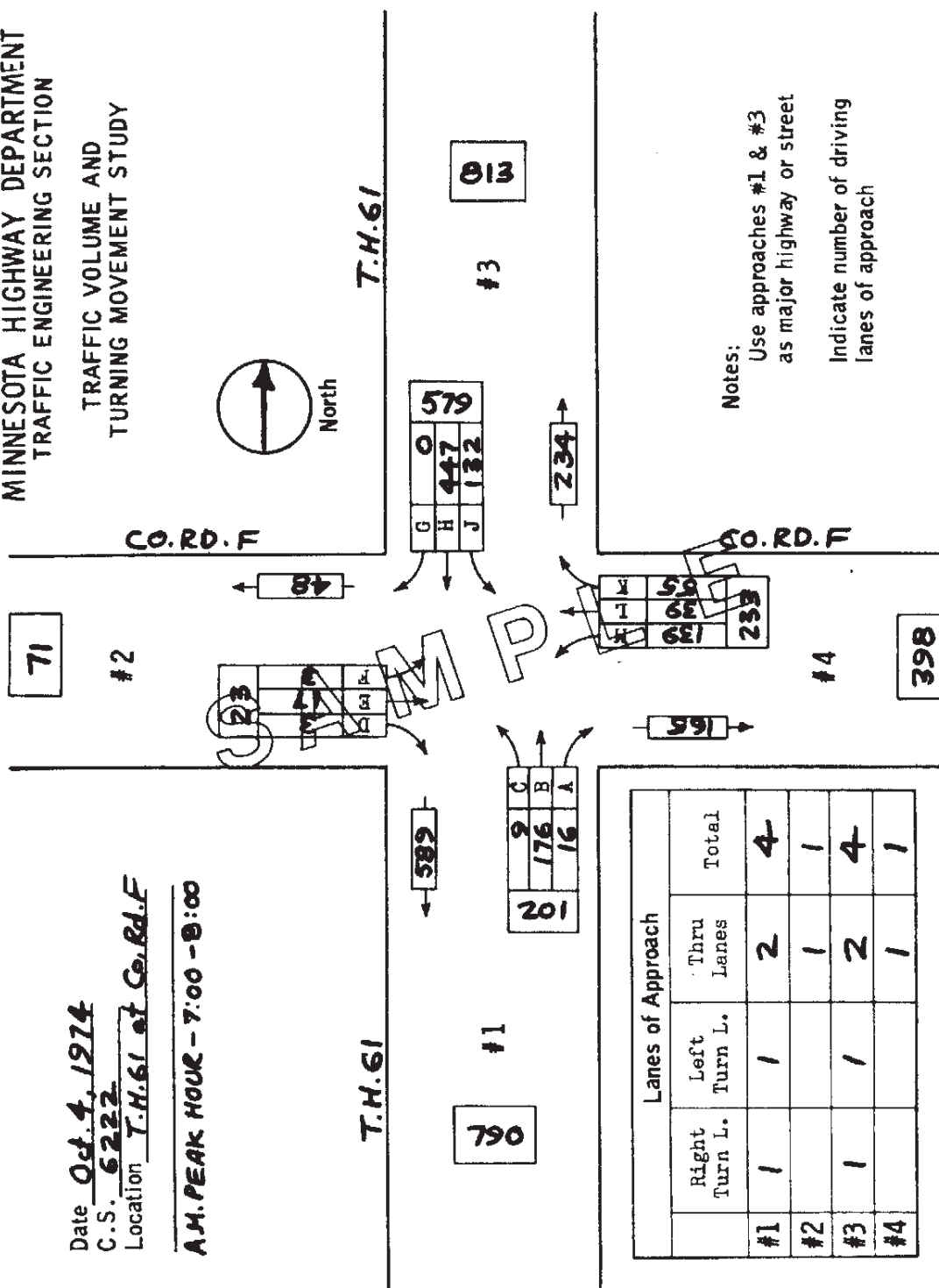
Form 2944 A Rev.

Sheet 1 of 3

MINNESOTA HIGHWAY DEPARTMENT
TRAFFIC ENGINEERING SECTION

TRAFFIC VOLUME AND
TURNING MOVEMENT STUDY

Date Oct. 4, 1974
C.S. 6222
Location T.H. 61 at Co. Rd. F
A.M. PEAK HOUR - 7:00 - 8:00



Notes:
Use approaches #1 & #3
as major highway or street
Indicate number of driving
lanes of approach

July 1, 1991

TRAFFIC VOLUME - TURNING MOVEMENT STUDY

FIGURE
9.10

Form MHD 29176 (3-73)

PORTABLE TRAFFIC RECORDER DATA SHEET

 LOCATION Jet T.H. 73 #169 COUNTY ST. LOUIS STATION NO. _____
CHISHOLM WB approach

COUNT BEGINNING DATE _____ DATA BY _____

DATE	10	11	12					AVERAGE of COUNT	
DAY	MON	TUE	WED	THUR	FRI	SAT	SUN	WEEKDAY	WEEK END
12-1AM		52	65						
1-2		22	32						
2-3		19	14						
3-4		3	4						
4-5		1	7						
5-6		10	7						
6-7		118	115						
7-8		306	309						
8-9		183	158						
9-10		177	157						
10-11		211	207						
11-12N		280	181						
12-1	234	295	34*						
1-2	193	394	241						
2-3	254	371	290						
3-4	265	195	359						
4-5	347	243*	341						
5-6	262	23*	15*						
6-7	156	117							
7-8	0*	187							
8-9	252	169							
9-10	105*	149							
10-11	45*	148							
11-12M	77	112							
TOTAL									

SKETCH

AVERAGE DAILY TRAFFIC

Remarks: * car apparently parked on tube

RECORDER TYPE: HR ☐ MR ☐ AR ☐

MACH NO. _____ TAPE NO. _____ FILE NO. _____

July 1, 1991

HOURLY TRAFFIC VOLUMES

FIGURE
9.11

Form 2944 C

Sheet 3 of 3

DETAIL OF PEAK $\frac{1}{4}$ HOURS

VEHICLES

Date Aug 18 1976C.S. 44Location Silver Lake Rd. at5th St. A.W., Ramsey Co.

Approach	Time Veh. Movement	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30	4:45
Silver Lk Rd #1	A	10	11	19	19	8	10	9	14	12	8	19	13	20	16	16	23
Southbound	B	124	112	126	122	129	113	129	133	123	113	143	144	153	131	164	171
5th St NW	C	0	2	3	4	9	11	0	3	1	5	10	2	1	3	3	7
#2	D	2	4	2	2	2	4	4	2	2	0	8	4	4	2	8	6
Westbound	E	0	2	0	2	0	0	0	1	1	0	1	0	0	1	1	0
Silver Lk Rd #3	F	2	1	14	2	2	1	0	0	3	3	1	3	1	8	6	10
Northbound	G	2	1	14	1	0	1	0	0	1	4	1	1	2	3	1	0
5th St NW	H	139	104	123	107	109	105	113	111	118	224	189	163	205	170	132	186
#4	J	13	7	3	4	2	6	5	1	5	10	11	11	20	14	15	23
Eastbound	K	3	5	1	11	4	4	7	11	12	12	10	4	4	1	7	7
MOVEMENT ACROSS	L	3	6	2	2	2	2	2	0	0	1	4	1	3	0	3	1
#1	M	2	6	12	11	11	14	12	6	6	17	10	8	8	7	9	10
PEDESTRIANS																	
#1		3	2	3	1	1	1	0	0	0	3	2	1	0	1	1	1
#2		5	2	1	2	1	4	1	2	6	2	0	2	6	1	1	3
#3		0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
#4		3	0	0	0	2	1	0	0	0	0	4	0	1	0	2	0

T - Insert total number of vehicles

H - Insert number of heavy units (Busses, semi's & dual rear tire trucks)



July 1, 1991

TURNING MOVEMENT 15-MINUTE COUNTS
AND PEDESTRIANFIGURE
9.12

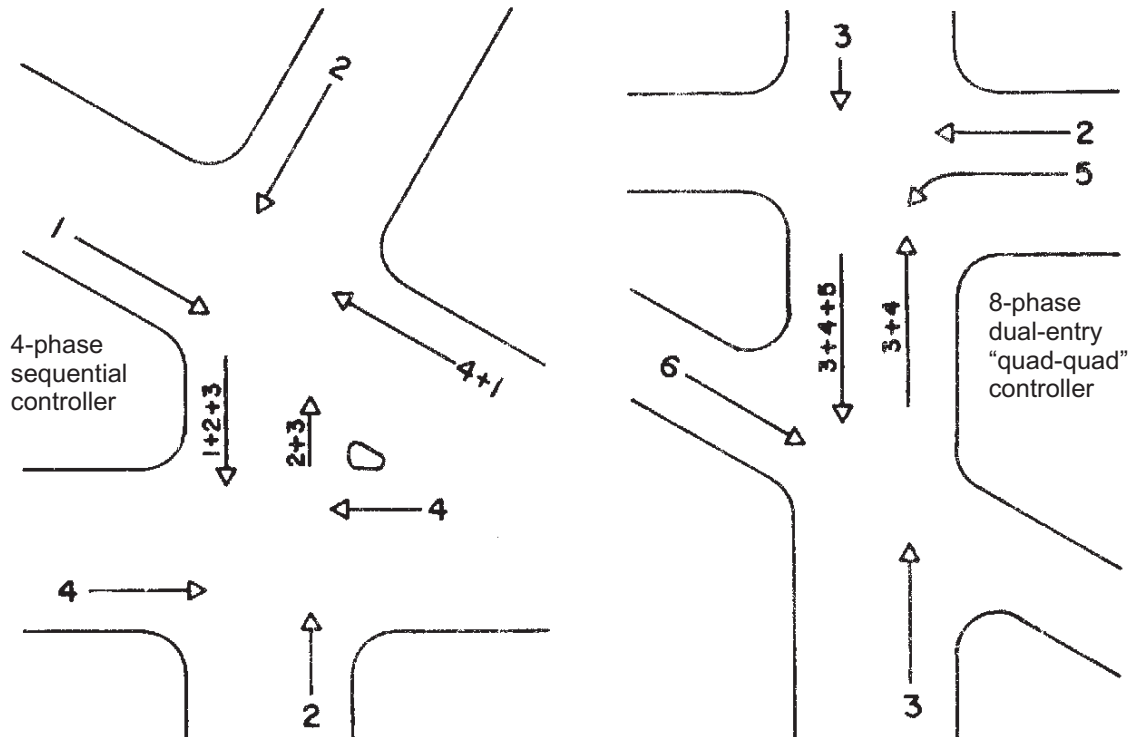
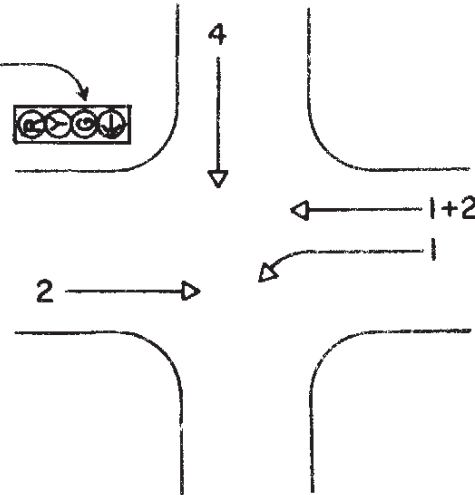
OVERLAPS

NEMA Definition: An overlap is a right-of-way indication which allows traffic movement when the right-of-way is assigned to two or more traffic phases.

An overlap occurs when one green signal indication is illuminated by more than one phase output from a controller, for example:

The circular green signal indication is illuminated while the controller is in phase 1 and while it is in phase 2.

This sequence of phases is possible on a 4-phase sequential controller.

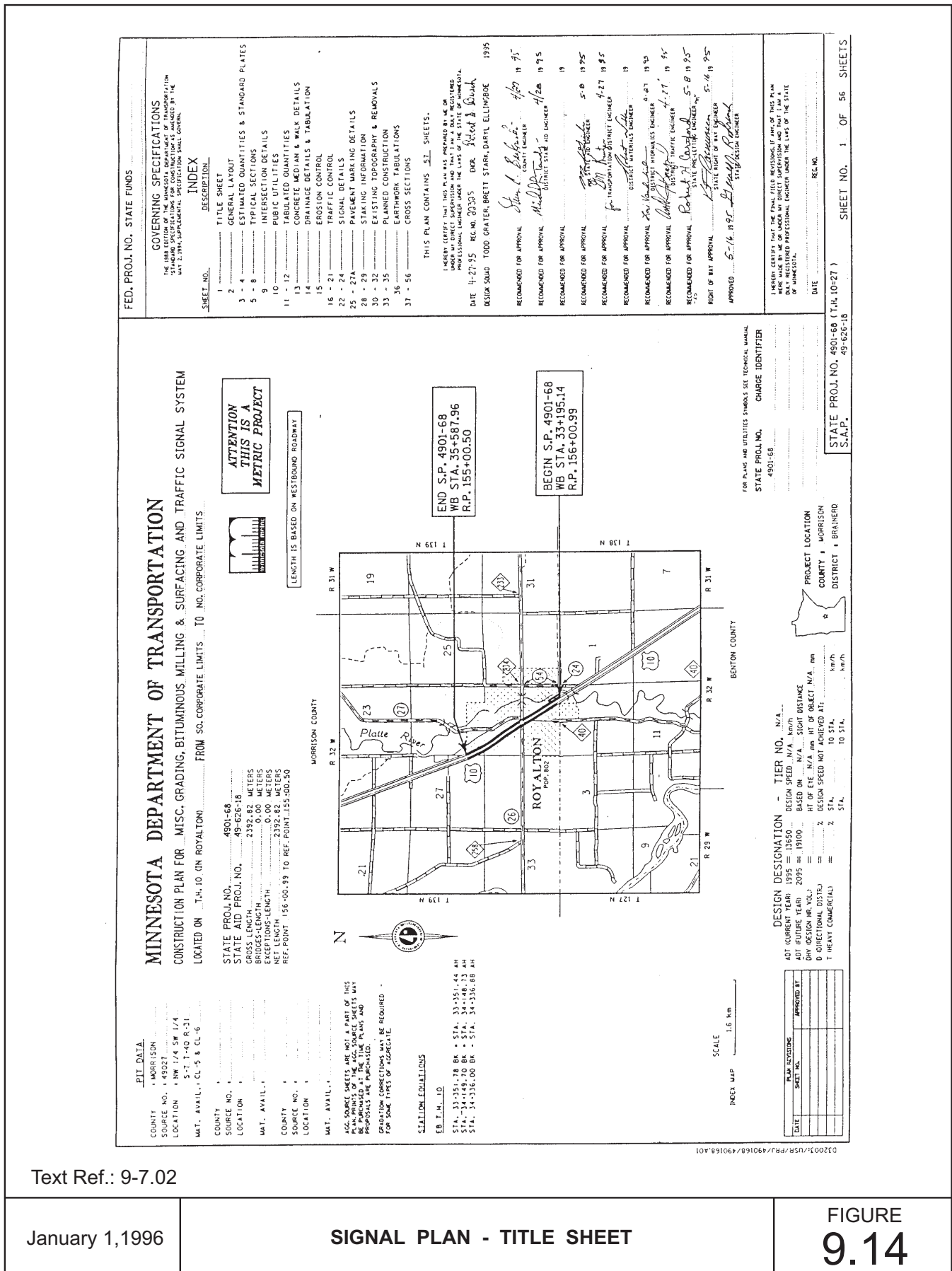


Text Ref.: 9-4.03.03

July 1, 1991

OVERLAPS

FIGURE
9.13



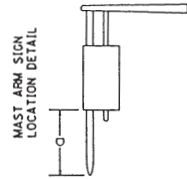
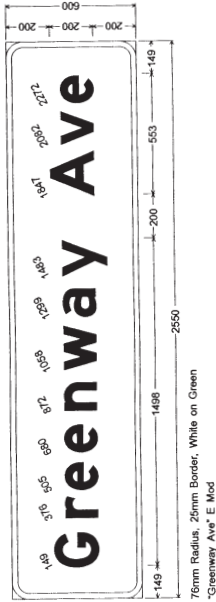
Text Ref.: 9-7.02

January 1, 1996

SIGNAL PLAN - TITLE SHEET

FIGURE
9.14

D-1

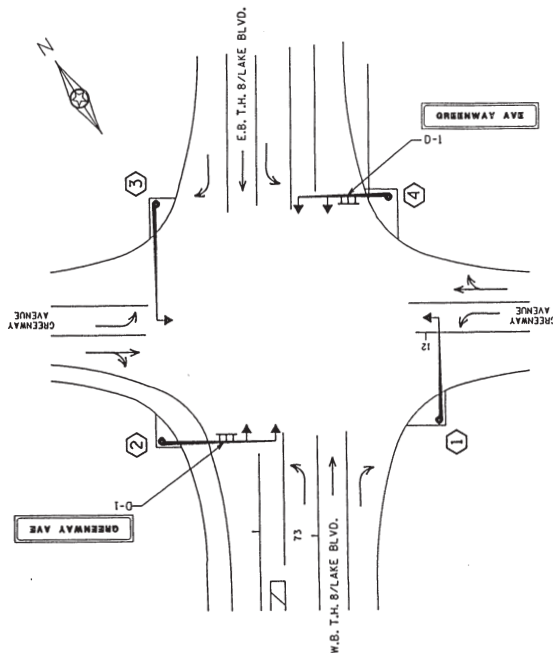


TYPE "D" SIGNS

Intersection	Sign Panel	Size (mm)	No. Req.	No. Brackets per Sign	Sq. M Bracket Spacing (M)	Pole No.	Pole (M)
T.H. 8 AT GREENWAY AVENUE	D-1	2550 x 600	1	3	1	1.53	2
T.H. 8 AT GREENWAY AVENUE	D-1	2550 x 600	1	3	1	1.53	4

NOTES:

1. ALL SIGN COLORS, WHITE LEGEND ON GREEN BACKGROUND, SHALL BE FULLY REFLECTORIZED.
2. CORNERS EXTENDING BEYOND THE BORDER SHALL NOT BE TRIMMED.
3. SEE STANDARD SIGNS MANUAL FOR ARROW AND OVERLAY DETAILS.
4. FOR STRUCTURAL DETAILS, TYPE "D" SIGNS, SEE STANDARD SIGNS MANUAL, PAGES 105A AND 105B.
5. FOR TYPE D STRINGER AND PANEL JOINT DETAIL, SEE STANDARD SIGNS MANUAL.
6. TYPE D SIGNS SHALL BE INCIDENTAL TO INDIVIDUAL SIGNAL SYSTEMS.



January 1, 1996

SIGNAL PLAN - SIGNING SHEET

FIGURE
9.15

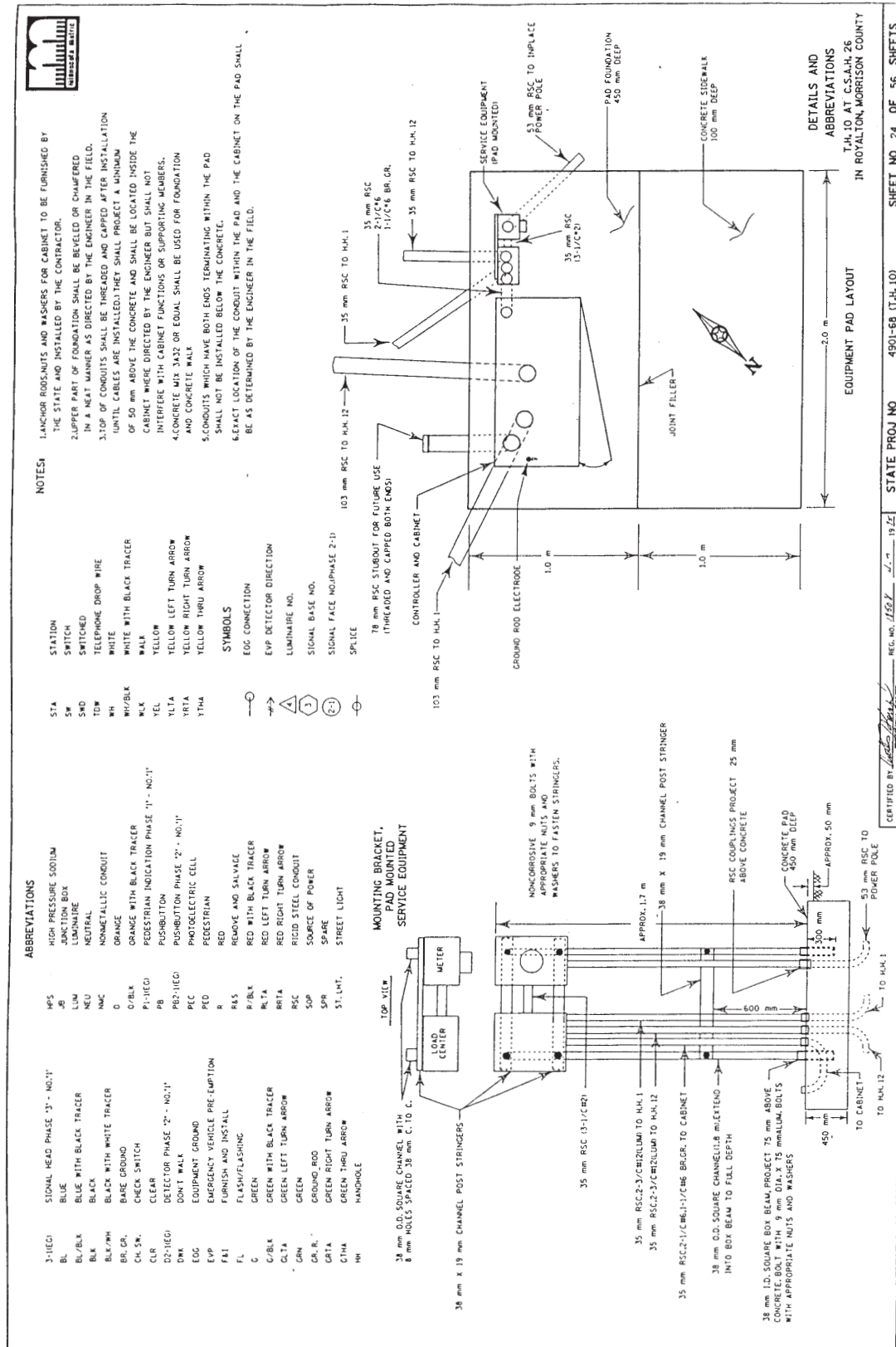
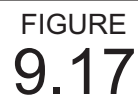
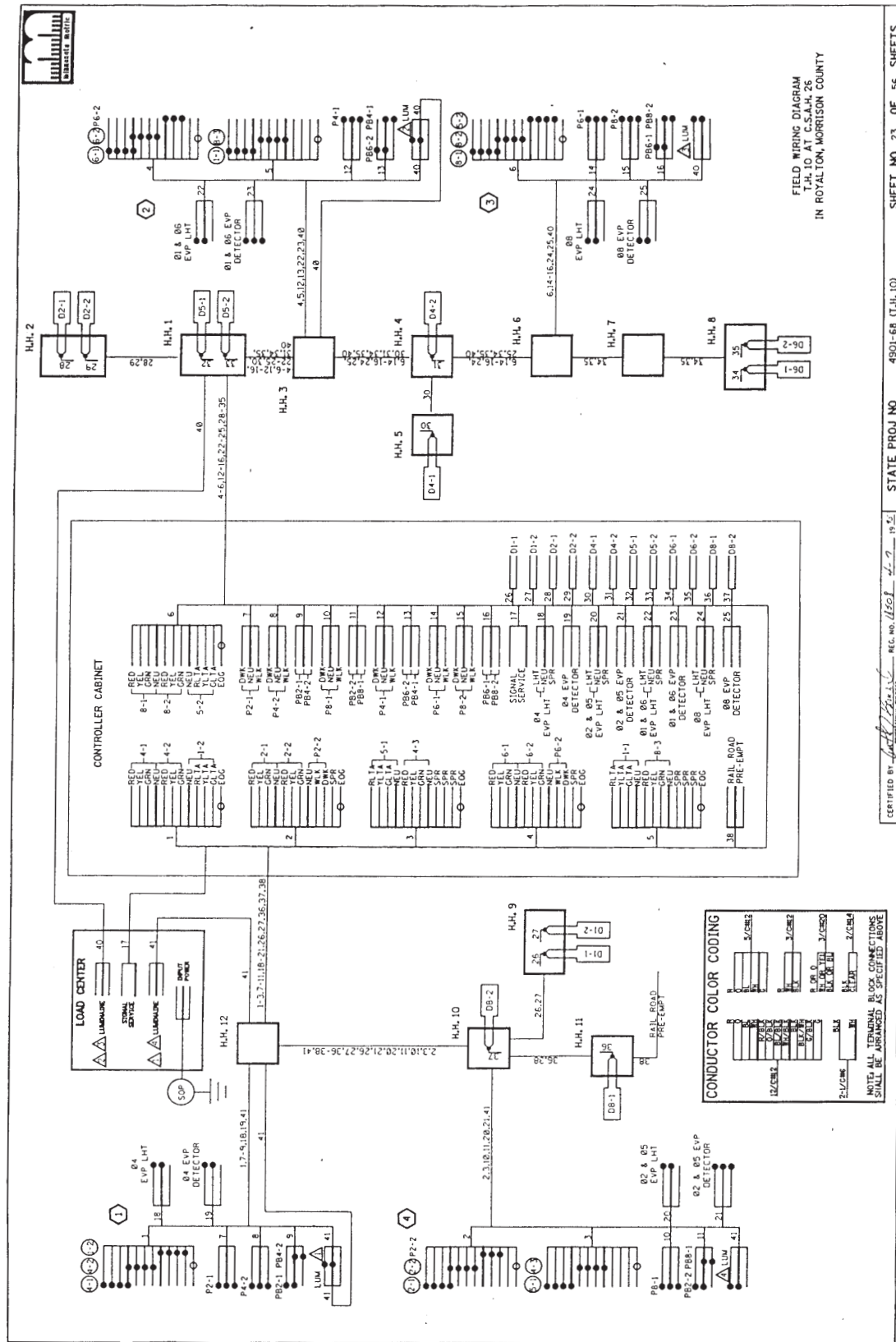


FIGURE
9.16





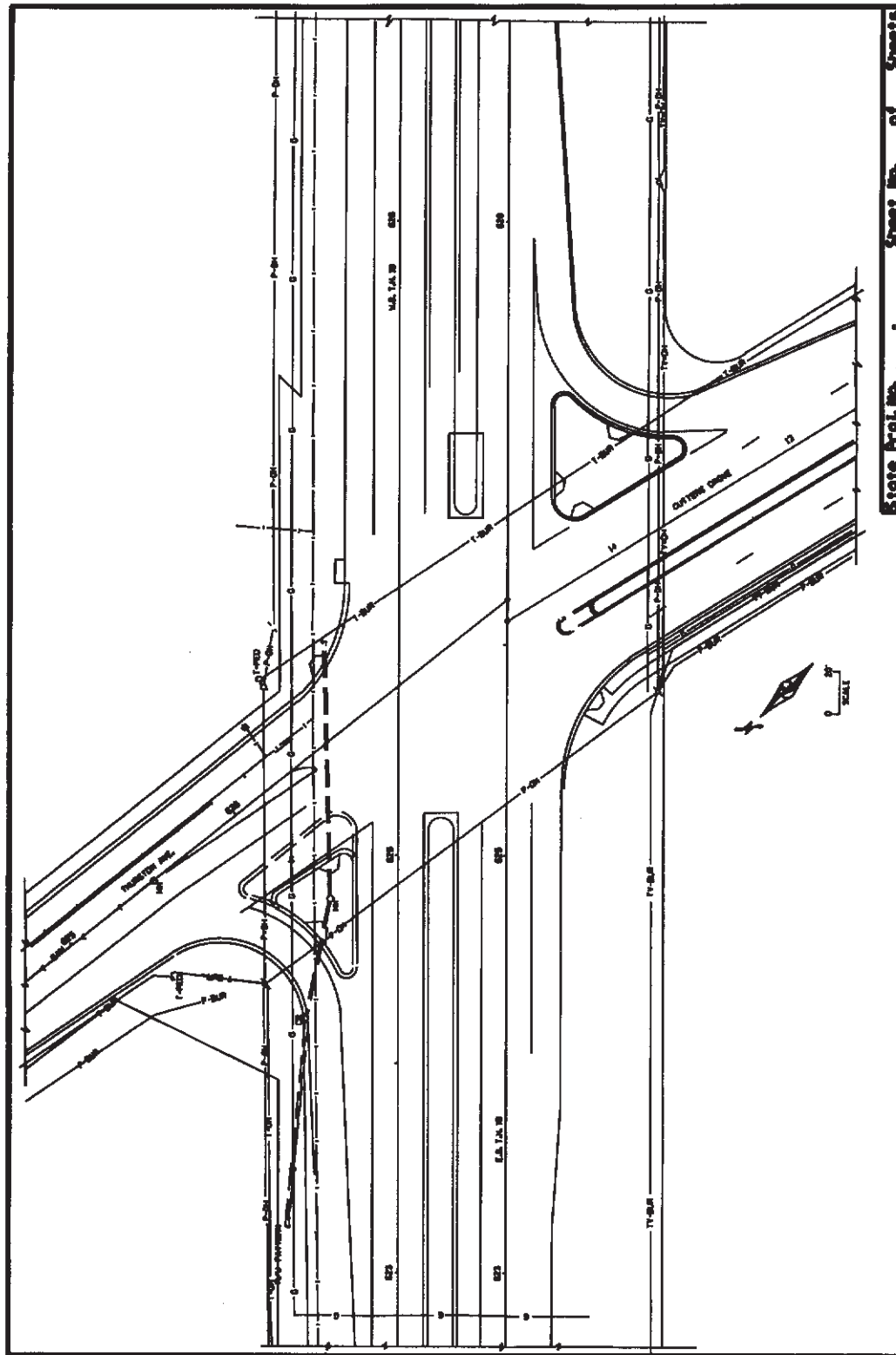
FIELD WIRING DIAGRAM
T.H.10 AT C.S.A.H. 25
IN ROYALTON, MORRISON COUNTY

CERTIFIED BY: *[Signature]* REG. NO. 11201-1-7-95
STATE PROJ NO 4901-68 (T.H.10) SHEET NO 23 OF 56 SHEETS

January 1, 1996

SIGNAL PLAN - WIRING DIAGRAM

FIGURE
9.18



July 1, 1994

UTILITIES

FIGURE
9.19

TRAFFIC COUNT SUMMARY

DATE OF COUNTS

: _____ LANES : _____ LANES

TIME	B	B	B+ B	B	B	B+ B	WARRANT MET, REMARKS IF NOT 100% PUT %AGE IN PARENS.
12 -1							19 .0122
1 -2							21 .0077
2 -3							22 .0040
3 -4							24 .0029
4 -5							23 .0034
5 -6							20 .0101
6 -7							15 .0397
7 -8							4 .0718
8 -9							9 .0530
9 -10							13 .0458
10 -11							12 .0474
11 -12							10 .0530
12 -1							7 .0551
1 -2							8 .0545
2 -3							6 .0588
3 -4							3 .0726
4 -5							1 .0881
5 -6							2 .0791
6 -7							5 .0597
7 -8							11 .0519
8 -9							14 .0427
9 -10							16 .0379
10 -11							17 .0287
11 -12							18 .0200

NTH % OF ADT
HI HRMAINLINE SPEED: _____
IF POSTED 40, REDUCTION FACTOR
DOES NOT AUTOMATICALLY APPLYPOPULATION: _____
REDUCTION FACTOR APPLIES IF
UNDER 10,000 AND NON-METRO

VOLUME REQUIREMENTS:

WARR. 1 _____

WARR. 2 _____

WARR. 6 _____

WARR. 8 _____

NOTES: _____

C3PO
3-30-81

July 1, 1991

TRAFFIC COUNT SUMMARY FORM

FORM
9.A

STATE OF MINNESOTA

DEPARTMENT Mn/DOT-Traffic Engineering
Room 309**Office Memorandum**

DATE:

TO: List Below

FROM:

District Traffic Engineer

PHONE:

SUBJECT: Signal Turn-On

LOCATION: _____
S.P. NO.: _____ PROJECT ENGINEER: _____
INTERSECTION I.D.#: _____Date signal placed in flashing operation: _____
Date signal placed in automatic operation: _____
Date old signal system turned off: _____
Date street lights turned on: _____AGREEMENTS: In force: _____ terminated: _____
WARRANTY PERIOD: date begins: _____ ends: _____MAINTENANCE Priority: _____ Date responsibilities effective: _____
Ownership of Signal: _____ Controller: _____ Timing: _____ Hardware: _____
Signal Relamping: _____ Signal Cleaning & Painting: _____ Knockdowns: _____
EVP: _____ Interconnect: _____ Signal Power: _____ Ownership of Lums: _____
Lum. Repairs: _____ Lum. Relamping: _____ Lum. Arm Clean & Paint: _____
Lighting Power: _____
(S=State C=County M=City R=Reimbursable P=Payable, to: _____
Other: _____ NA=Not Applicable)NUMBER OF LUMINAIRES: _____ TYPE: _____ WATTAGE: _____
METER ADDRESS: _____COMPLETED TIMING CHARTS (Including Preemption and coordination)
() In Cabinet () In District Office
Check if cabinet has: () Maint. Report Cards () Maintenance LogOVERHEAD STRUCTURES over the traveled roadway: () Inplace () Added
SIGNAL CLEARANCE SHEET: () *Attached () Will follow in _____ days
() Has been sent for inplace structuresCC: City of _____, Attn: _____
County of _____, Attn: _____
Power Co.: _____, Attn: _____
Minn State Patrol Dist. _____, Captain: _____

- * Area Maintenance Engineer
Project Engineer
Traffic Engineering Signal Unit, 313 DOT
- * Electrical Services Unit, Fort Snelling
- * Emergency Operations Officer, Mn/DOT Truck Center, South St. Paul

July 1, 1991

SIGNAL TURN-ON NOTICE P1

FORM
9.B

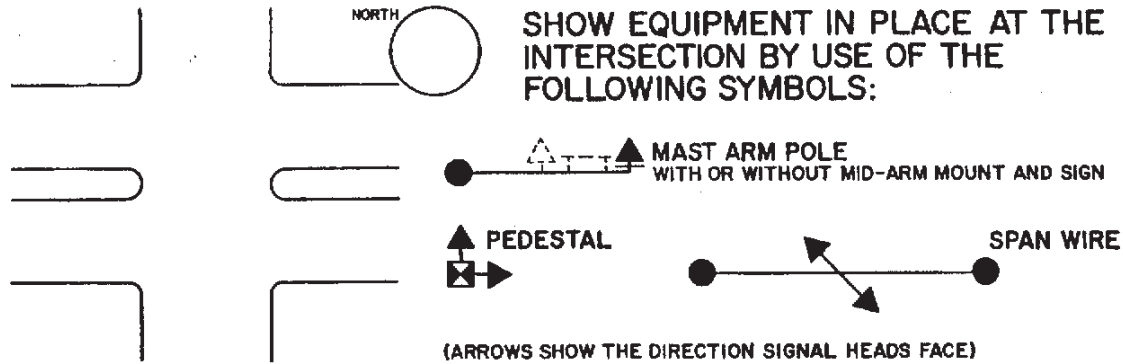
SIGNAL CLEARANCES

LOCATION _____

DATE INSTALLED _____ DATE MEASURED _____

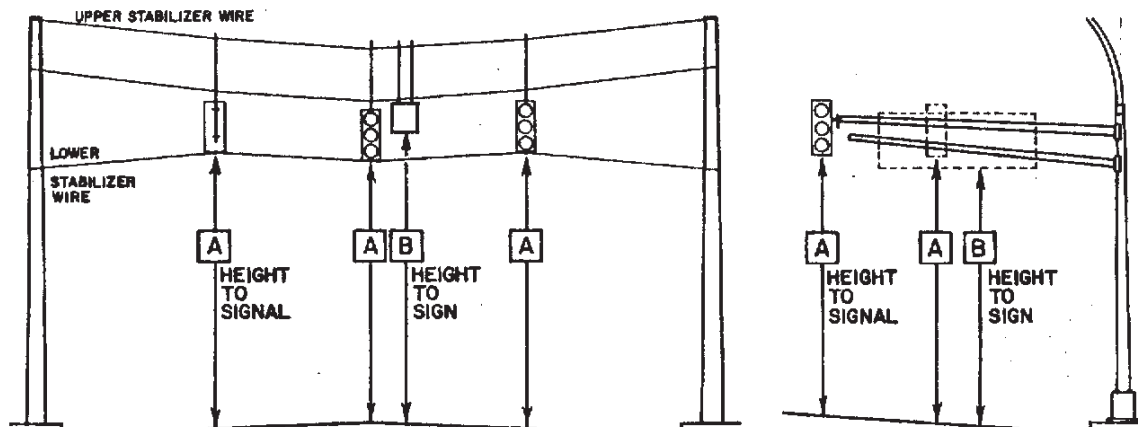
MEASURED BY _____

- ☐ MAST ARMS WITHOUT SWING-AWAY HINGES ☐ MAST ARMS WITH SWING-AWAY HINGES
☐ SPAN WIRE WITH UPPER STABILIZER WIRE ☐ SPAN WIRE WITH LOWER STABILIZER WIRE



DI- MENSION	HEAD NO.	1	2	3	4	5	6	7	8
A									
B									
C									

C=Other (specify) _____



NOTE: HORIZONTAL DIMENSIONS FOUND ON ATTACHED SHEET
 NO. _____ OF S.P. _____

Text Ref.: 9-8.03

July 1, 1991

SIGNAL TURN-ON NOTICE P2

FORM
9.C

9-54

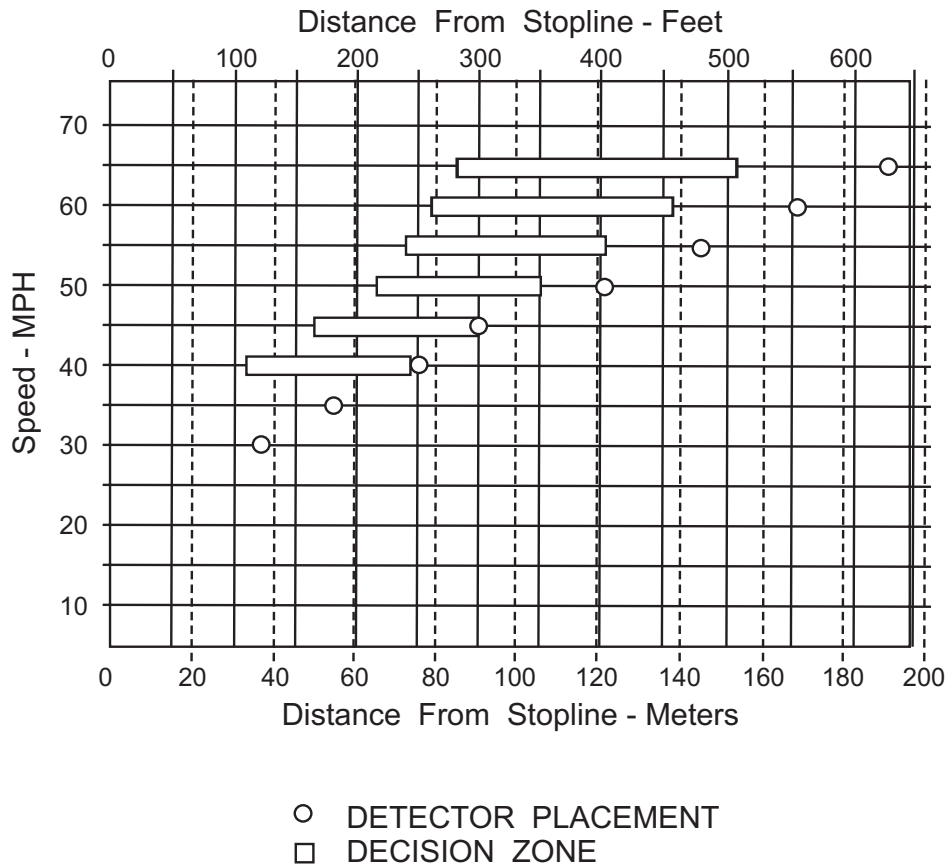
Diagram illustrating the dimensions and geometry of a tapered traffic sign:

- Overall height: 45m (150')
- Height of the upper section: 37m (120')
- Height of the lower section: 12m (40')
- Bottom width: 12m (40')
- Side slopes: 20°
- Center line: CL
- STOP LINE
- Callout: At least one, and preferably both signal faces must be located within this area.

Text Ref.: 9-6.05

January 1,1996	VISIBILITY TEMPLATE	TABLE 9.1
----------------	----------------------------	---------------------

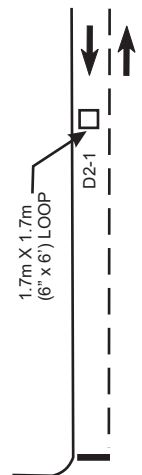
DETECTOR PLACEMENT CHART DECISION ZONES



NOTE: Grades and other factors may require adjustment from normal placement.
 Detector spacing outside of the limits shown may require additional detectors.

DZ 99

LOOP DETECTOR PLACEMENT MAJOR APPROACH



SPEED	LOCATION	OPTIONAL 2 POINT LOOP LOCATION
30	37 m (120')	
35	55 m (180')	
40	76 m (250')	
45	92 m (300')	46 m (150')
50	122 m (400')	61 m (200')
55	145 m (475')	75 m (240')
60	168 m (550')	84 m (275')
65	191 m (625')	96 m (315')

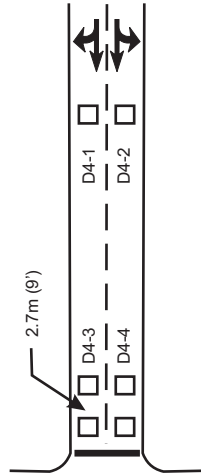
LOCATION = DISTANCE FROM STOP BAR
TO LOOP DETECTOR

NOTES:

- 1) THE LOOP DETECTOR FUNCTION IS CALL AND EXTEND, ESS FUNCTION 1.
- 2) ONE LOOP FOR EACH APPROACH LANE. DO NOT DETECT FREE RIGHT TURNS OR PROTECTED LEFT TURNS, HOWEVER YOU MUST DETECT A PROTECTED/PERMISSIVE LEFT TURN.
- 3) CONTROLLER PHASE SHALL BE ON VEHICLE RECALL.
- 4) CONTROLLER PHASE DENSITY FUNCTION SHALL BE USED.
- 5) OPTIONAL 2 POINT SPACING MAT BE USED FOR 2 LANE ROADWAY WITH SPEED LIMITS OF 45 MPH OR GREATER. SEE CHART FOR LOCATION OF ADDITIONAL LOOP DETECTOR.

FIGURE 1

LOOP DETECTOR PLACEMENT MINOR APPROACH



LOCATION = DISTANCE FROM STOP
BAR TO LOOP DETECTOR

LOOP DETECTOR FUNCTIONS
1 = CALL AND EXTEND
3 = EXTEND ONLY
7 = DELAY CALL - IMMEDIATE EXTEND

NUMBER	FUNCTION	SIZE
D4-1	3	1.7 x 1.7m (6' x 6')
D4-2	1	1.7 x 1.7m (6' x 6')
D4-3	7	2 - 1.7 x 1.7m (6' x 6')
D4-4	1	2 - 1.7 x 1.7m (6' x 6')

NOTES:

- 1) NO DENSITY FUNCTION IS NECESSARY FOR 30 AND 35 MPH. DENSITY FUNCTION MAY BE CONSIDERED FOR 40 MPH AND ABOVE.
- 2) CONTROLLER PHASE SHALL BE NON-LOCK MEMORY WITH NO RECALL.
- 3) PROVIDE GOOD COVERAGE FOR FRONT DETECTION FOR VARIABLE STOPPING LOCATIONS. USE ANY COMBINATION OF 1.7m X 1.7m (6' X 6') OR 1.7m X 3m (6' X 10') LOOP DETECTORS.
- 4) IF USING NMC LOOP, MAY COMBINE DUAL LOOPS.
- 5) ADVANCED DETECTION IS OPTIONAL.

FIGURE 2

January 1, 1996

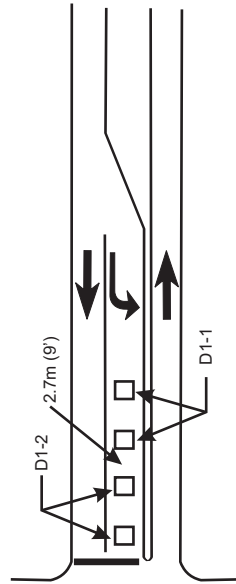
LOOP DETECTOR PLACEMENT CHARTS

TABLE
9.3A

LOOP DETECTOR PLACEMENT

PROTECTED LEFT TURN

NON-LOCK OPERATION - PAINTED & NON-RAISED MEDIAN



LOOP DETECTOR FUNCTIONS

1 = CALL AND EXTEND

NUMBER	FUNCTION	SIZE	LOCATION
D1-1	1	2 - 1.7 x 1.7m (6' x 6')	6m (20') & 15m (50')
D1-2	1	2 - 1.7 x 1.7m (6' x 6')	1.5m (5') & 11m (35')

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

NOTES:

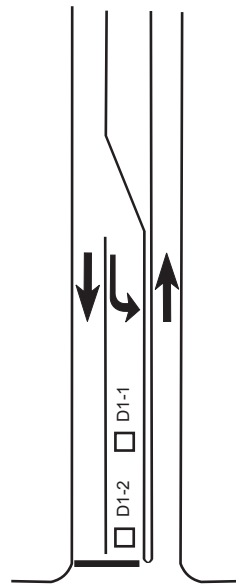
- 1) NO DENSITY FUNCTIONS ARE USED.
- 2) THE DESIGN SPEED IS 25 MPH.
- 3) EACH NUMBERED LOOP DETECTOR SHALL HAVE SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.
- 4) IF LOOPS ARE USED FOR COUNTING, ONE LOOP ON D1-1, THREE LOOPS ON D1-2.
- 5) USE IN LOCATIONS WHERE TRUCKS PUT IN FALSE CALLS.
- 6) IF USING NMC, MAY COMBINE DUALS AS LARGER LOOPS.

FIGURE 4

LOOP DETECTOR PLACEMENT

PROTECTED LEFT TURN

LOCK OPERATION - RAISED MEDIAN



LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

1 = CALL AND EXTEND

FRONT LOOP LOCATION	BACK LOOP LOCATION
3 m (10')	12 m (40')

NUMBER	FUNCTION	SIZE
D1-1	1	1.7 x 1.7m (6' x 6')
D1-2	1	1.7 x 1.7m (6' x 6')

NOTES:

- 1) NO DENSITY FUNCTIONS ARE USED.
- 2) THE DESIGN SPEED IS 25 MPH.
- 3) EACH NUMBERED LOOP DETECTOR SHALL HAVE SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.
- 4) THE BACK LOOP MAY BE PLACED GREATER THAN 12 METERS (40 FEET) FOR ADEQUATE EXTENSION.

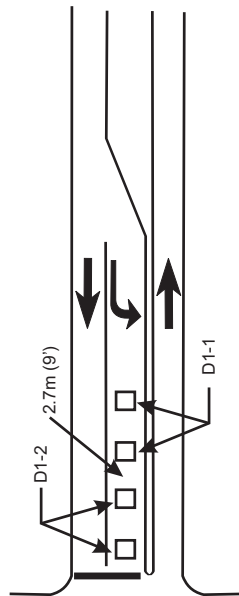
FIGURE 3

January 1, 1996

LOOP DETECTOR PLACEMENT CHARTS

TABLE
9.3B

LOOP DETECTOR PLACEMENT PROTECTED/PERMISSIVE LEFT TURN SEPARATE LEFT TURN LANE



LOOP DETECTOR FUNCTIONS

1 = CALL AND EXTEND

NUMBER	FUNCTION	SIZE	LOCATION
D1-1	1	2 - 1.7 x 1.7m (6' x 6')	6m (20') & 15m (50')
D1-2	1	2 - 1.7 x 1.7m (6' x 6')	1.5m (5') & 11m (35')

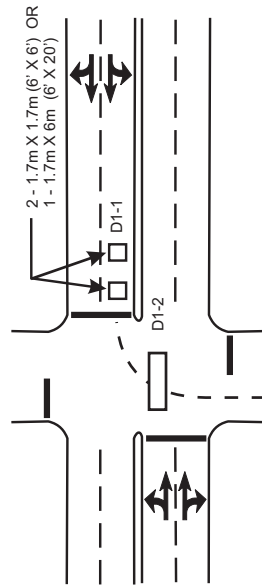
LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

NOTES:

- 1) CONTROLLER PHASE SHALL BE NON-LOCK MEMORY.
- 2) USE BACK UP PROTECT FOR LEFT TURN TRAP.
- 3) DESIGN SPEED IS 25 MPH.
- 4) THROUGH PHASE DETECTION MUST DETECT LEFT TURNING VEHICLES.
- 5) EACH NUMBERED LOOP DETECTOR SHALL HAVE SEPARATE LEAD-IN CABLE AND SEPARATE AMPLIFIER.
- 6) IF USING NMC LOOPS, A SINGLE LARGER LOOP CAN REPLACE THE DUALS.

FIGURE 5

LOOP DETECTOR PLACEMENT LEADING PROTECTED/PERMISSIVE LEFT TURN FROM A THROUGH LANE



LOOP DETECTOR LOCATION:

D1-1 IS LOCATED 1.5m (5') FROM STOP BAR.

D1-2 IS LOCATED OPPOSING THROUGH LANE, CENTERED IN THE TURNING RADIUS OF LEFT TURNING VEHICLES.

LOOP DETECTOR FUNCTIONS

3 = EXTEND ONLY
5 = DELAY CALL ONLY

NUMBER	FUNCTION	SIZE
D1-1	5	2 - 1.7 x 1.7m (6' x 6')
D1-2	3	1.7 x 6m (6' x 20')

NOTES:

- 1) LOOP D1-1 SHALL HAVE A 1-2 SECOND DELAY, 2 SECOND STRETCH (EXT.), AND IS ONLY ACTIVE DURING (CALL HOLD) YELLOW.
- 2) LOOP D1-2 WILL ONLY EXTEND IT'S OWN PHASE (ARROW).
- 3) MUST BE VEHICLE CALL ON CROSS STREET PHASE TO ALLOW LEFT TURN PHASE.
- 4) CONTROLLER PHASE DENSITY FUNCTIONS SHALL NOT BE USED.
- 5) CONTROLLER PHASE SHALL BE ON NON-LOCK MEMORY.
- 6) THE DESIGN SPEED IS 20 MPH.
- 7) IF NO OPPOSING LEFT TURN, NOTE 3 IS NOT NECESSARY.

FIGURE 6

January 1, 1996

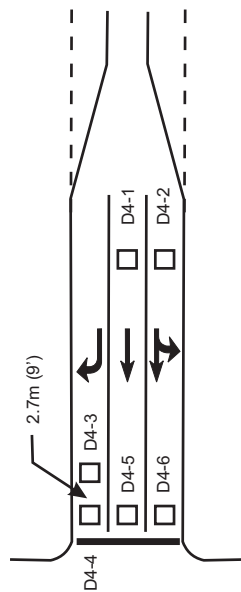
LOOP DETECTOR PLACEMENT CHARTS

TABLE
9.3C

LOOP DETECTOR PLACEMENT

MINOR APPROACH

TURN LANES OR RIGHT TURN SEGREGATION AND CONFLICTING TRAFFIC



LOCATION = DISTANCE FROM STOP
BAR TO LOOP DETECTOR

LOOP DETECTOR FUNCTIONS

1 = CALL AND EXTEND
7 = DELAY CALL - IMMEDIATE EXTEND

SPEED	LOCATION
30	37 m (120')
35	55 m (180')
40	76 m (250')
45	92 m (300')
50	122 m (400')
55	145 m (475')
60	167 m (550')
65	190 m (625')

NUMBER	FUNCTION	SIZE
D4-1	1	1.7 x 1.7m (6' x 6')
D4-2	1	1.7 x 1.7m (6' x 6')
D4-3	7	1.7 x 1.7m (6' x 6')
D4-4	7	1.7 x 1.7m (6' x 6')
D4-5	7	1.7 x 1.7m (6' x 6')
D4-6	7	1.7 x 1.7m (6' x 6')

NOTES:

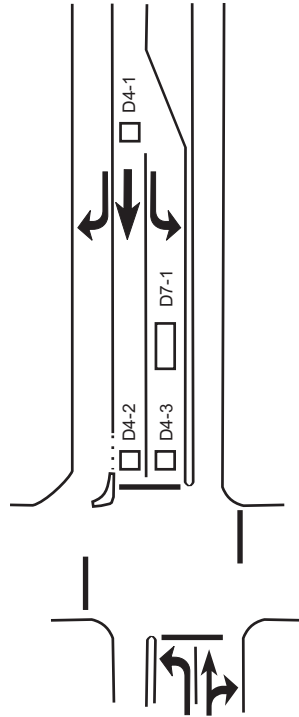
- 1) CONTROLLER PHASE SHALL BE LOCK MEMORY.
- 2) D4-3 AND D4-4 ARE 2 SEPARATE DETECTORS ON SEPARATE AMPLIFIERS FOR BACK UP COVERAGE.

FIGURE 7

LOOP DETECTOR PLACEMENT

PROTECTED LEFT TURN

APPROACH WITH SEPARATE LEFT TURN LANE
AND FREE RIGHT TURN LANE



LOOP DETECTOR FUNCTIONS

1 = CALL AND EXTEND
3 = EXTEND ONLY
7 = DELAY CALL - IMMEDIATE EXTEND

NUMBER	FUNCTION	SIZE	LOCATION
D4-1	7	1.7 x 1.7m (6' x 6')	76m (250')
D4-2	1	1.7 x 1.7m (6' x 6')	3m (10')
D4-3	1	1.7 x 1.7m (6' x 6')	3m (10')
D7-1	3	1.7 x 3.4m (6' x 12')	15m (50')

NOTES:

- 1) CONTROLLER PHASE 7 SHALL BE NON-LOCK MEMORY.
- 2) CONTROLLER PHASE 4 IN LOCK MEMORY.
- 3) DESIGN SPEED IS 40 MPH.
- 4) D4-3 MAY CALL PHASE 7.

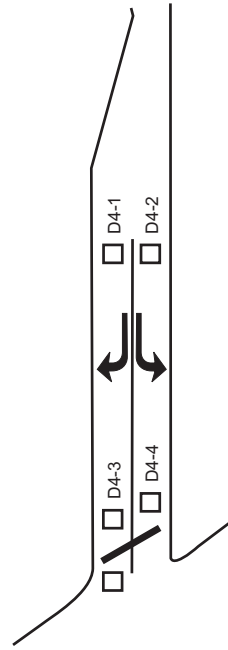
FIGURE 8

January 1, 1996

LOOP DETECTOR PLACEMENT CHARTS

TABLE
9.3D

LOOP DETECTOR PLACEMENT LAGING PROTECTED/PERMISSIVE LEFT TURN RAMP TERMINAL



LOOP DETECTOR FUNCTIONS

- 1 = CALL AND EXTEND
- 3 = EXTEND ONLY
- 7 = DELAY CALL - IMMEDIATE EXTEND

NUMBER	FUNCTION	SIZE	LOCATION
D4-1	3	1.7 x 1.7m (6' x 6')	37m (120')
D4-2	1	1.7 x 1.7m (6' x 6')	37m (120')
D4-3	7	2 - 1.7 x 1.7m (6' x 6')	-3.5 & 0m (-9' & 0')
D4-4	1	1.7 x 1.7m (6' x 6')	1.5 m (5')

LOCATION = DISTANCE FROM STOP BAR TO LOOP DETECTOR

NOTES:

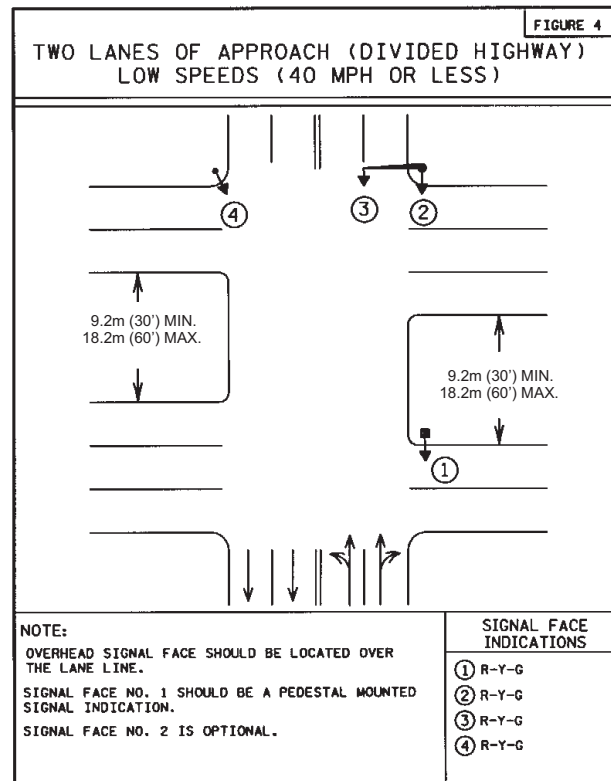
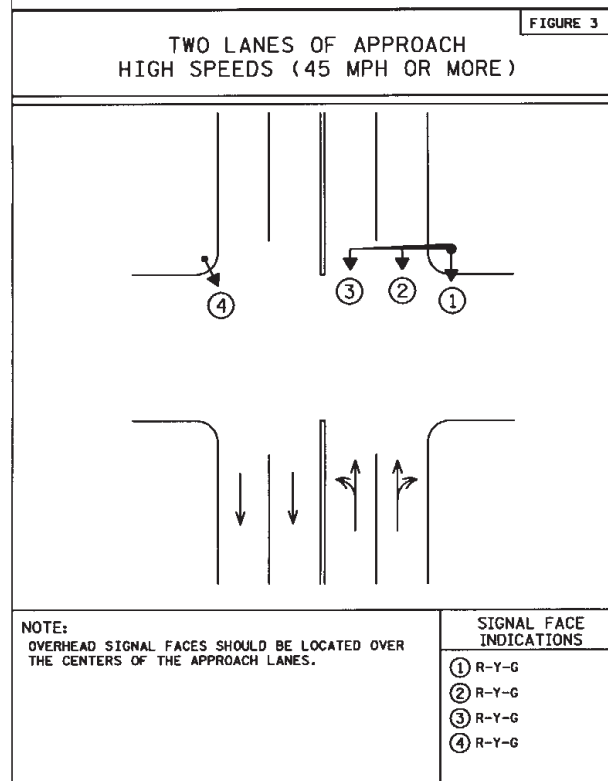
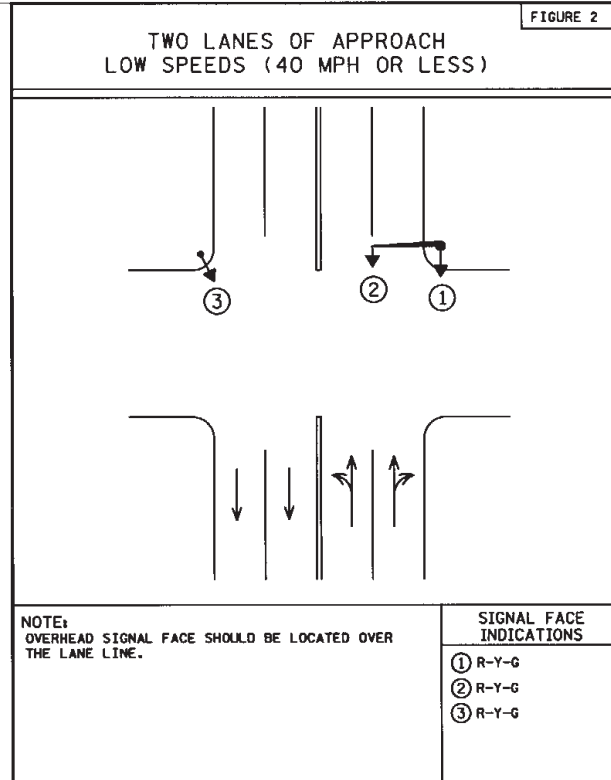
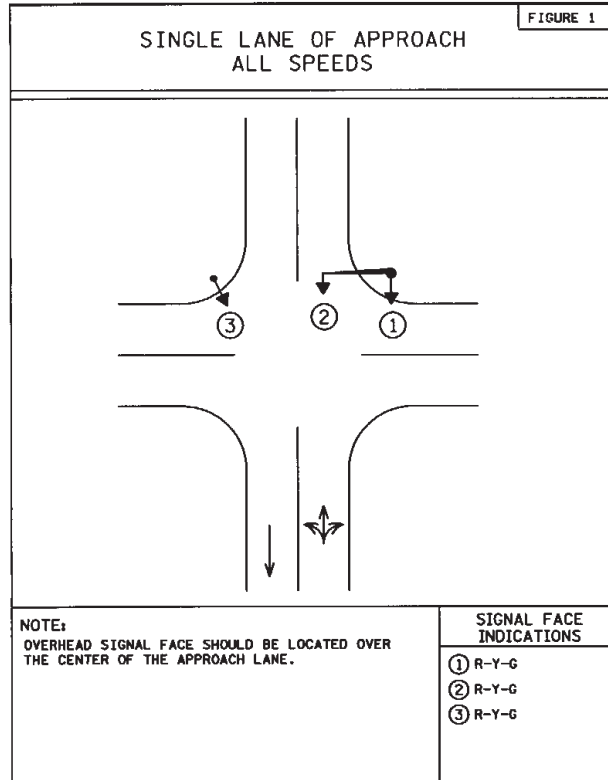
- 1) D4-3 SHALL HAVE 10 TO 12 SECONDS DELAY.
- 2) CONTROLLER SHALL BE IN LOCK MEMORY.
- 3) BACK DETECTORS ARE LOCATED FOR A 30 MPH SPEED LIMIT. IF THE SPEED LIMIT IS OTHER THAN 30 MPH, SEE THE TABLE IN FIGURE 2.

FIGURE 9

January 1, 1996

LOOP DETECTOR PLACEMENT CHARTS

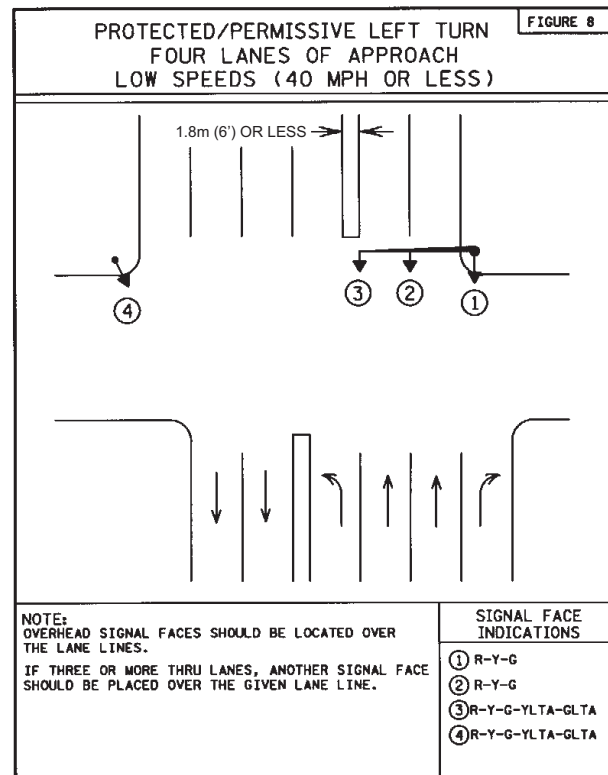
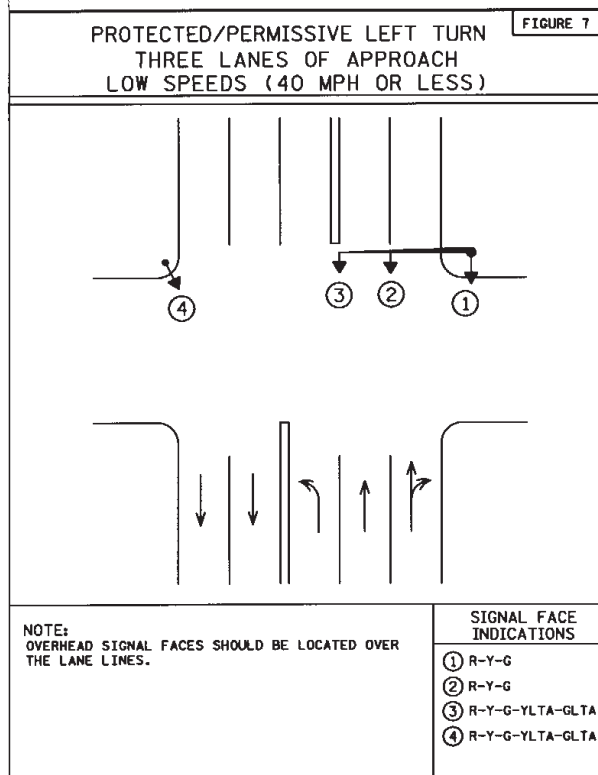
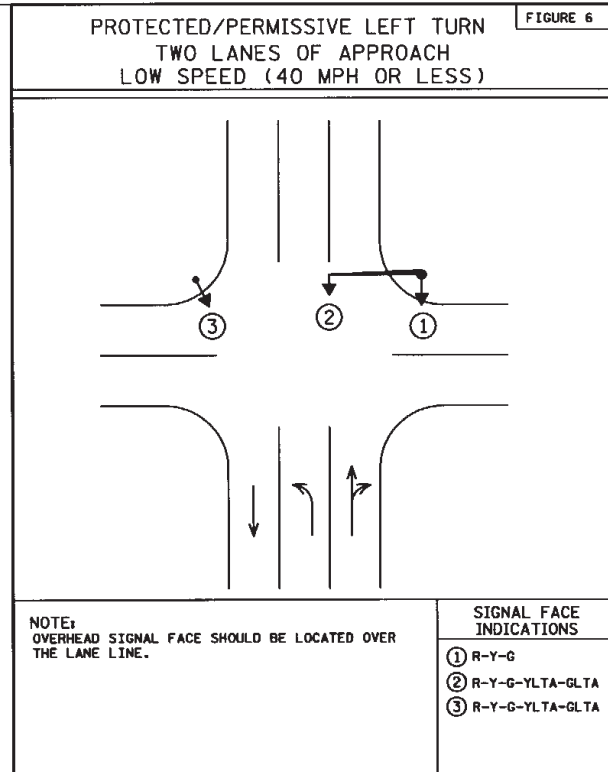
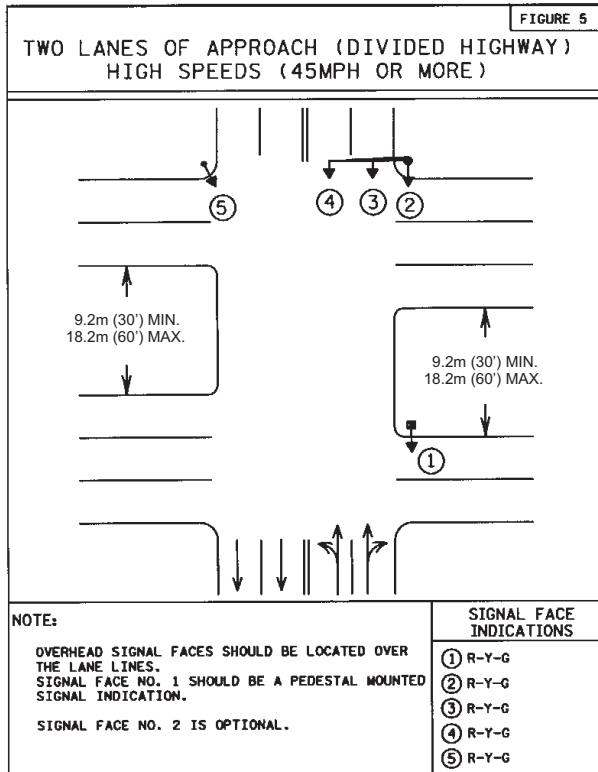
TABLE
9.3E



January 1, 1996

SIGNAL HEAD PLACEMENT CHARTS

**TABLE
9.4A**



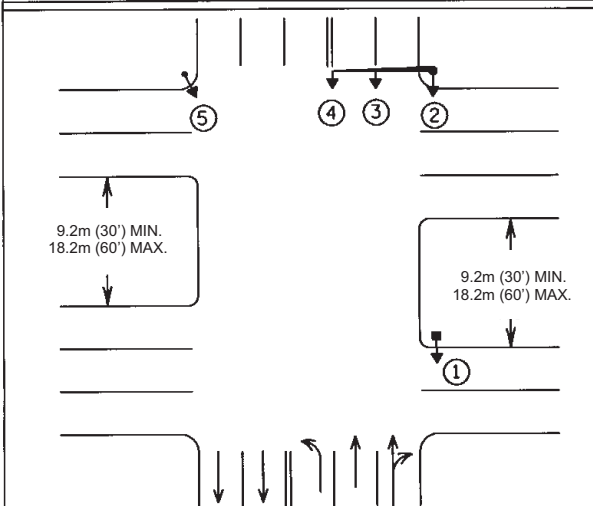
January 1, 1996

SIGNAL HEAD PLACEMENT CHARTS

**TABLE
9.4B**

PROTECTED/PERMISSIVE LEFT TURN
THREE LANES OF APPROACH (DIVIDED HIGHWAY)
LOW SPEEDS (40 MPH OR LESS)

FIGURE 9

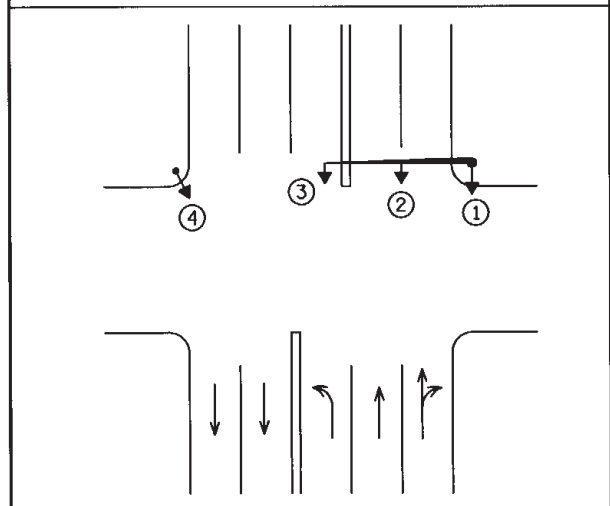


NOTE:
OVERHEAD SIGNAL FACES SHOULD BE LOCATED OVER THE LANE LINES.
SIGNAL FACE NO. 1 SHOULD BE A PEDESTAL MOUNTED SIGNAL INDICATION.
SIGNAL FACE NO. 2 IS OPTIONAL.

- SIGNAL FACE INDICATIONS**
- ① R-Y-G
 - ② R-Y-G
 - ③ R-Y-G
 - ④ R-Y-G-YLTA-GLTA
 - ⑤ R-Y-G-YLTA-GLTA

PROTECTED LEFT TURN
THREE LANES OF APPROACH
LOW SPEEDS (40 MPH OR LESS)

FIGURE 10

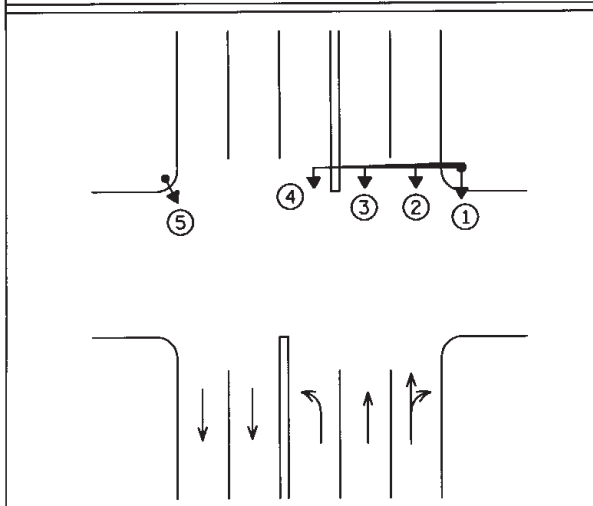


NOTE:
OVERHEAD SIGNAL FACE NO. 2 SHOULD BE LOCATED OVER THE LANE LINE.
OVERHEAD SIGNAL FACE NO. 3 SHOULD BE LOCATED OVER THE CENTER OF THE LEFT TURN LANE.

- SIGNAL FACE INDICATIONS**
- ① R-Y-G
 - ② R-Y-G
 - ③ RLTA-YLTA=GLTA
 - ④ RLTA-YLTA=GLTA

PROTECTED LEFT TURN
THREE LANES OF APPROACH
HIGH SPEEDS (45 MPH OR MORE)

FIGURE 11

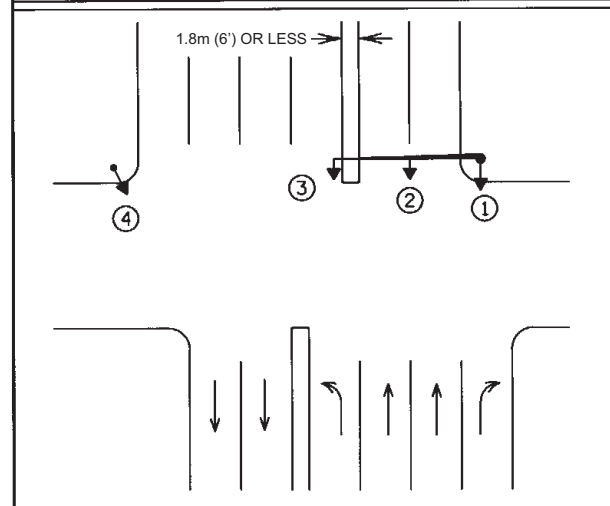


NOTE:
OVERHEAD SIGNAL FACES SHOULD BE LOCATED OVER THE CENTERS OF THE APPROACH LANES.

- SIGNAL FACE INDICATIONS**
- ① R-Y-G
 - ② R-Y-G
 - ③ R-Y-G
 - ④ RLTA-YLTA-GLTA
 - ⑤ RLTA-YLTA-GLTA

PROTECTED LEFT TURN
FOUR LANES OF APPROACH
LOW SPEEDS (40 MPH OR LESS)

FIGURE 12



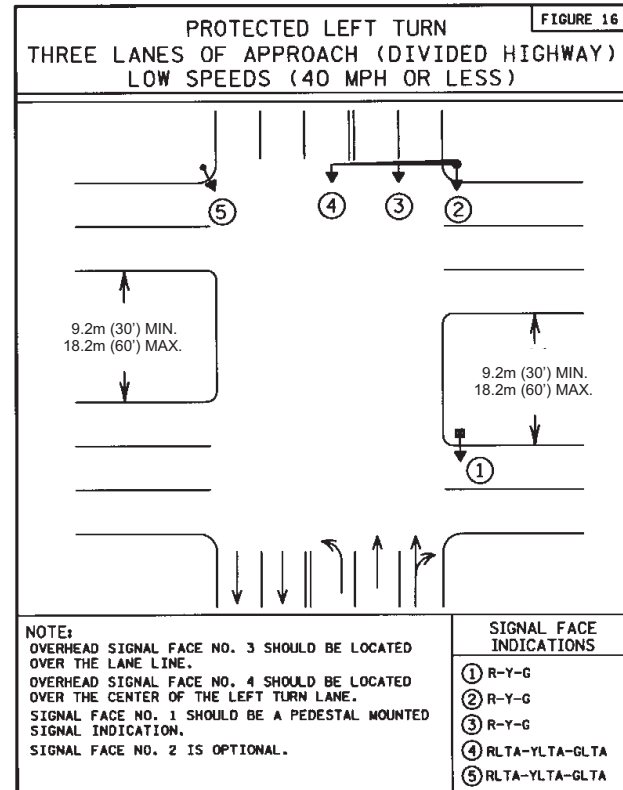
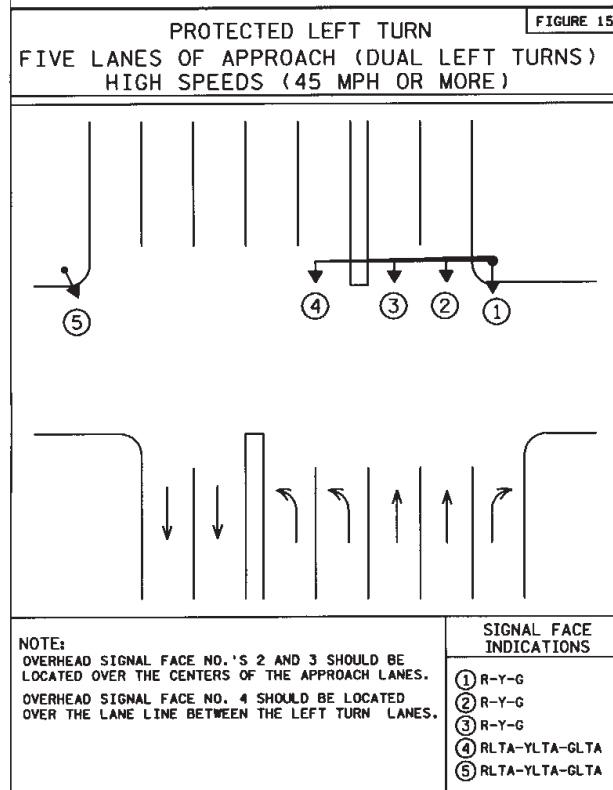
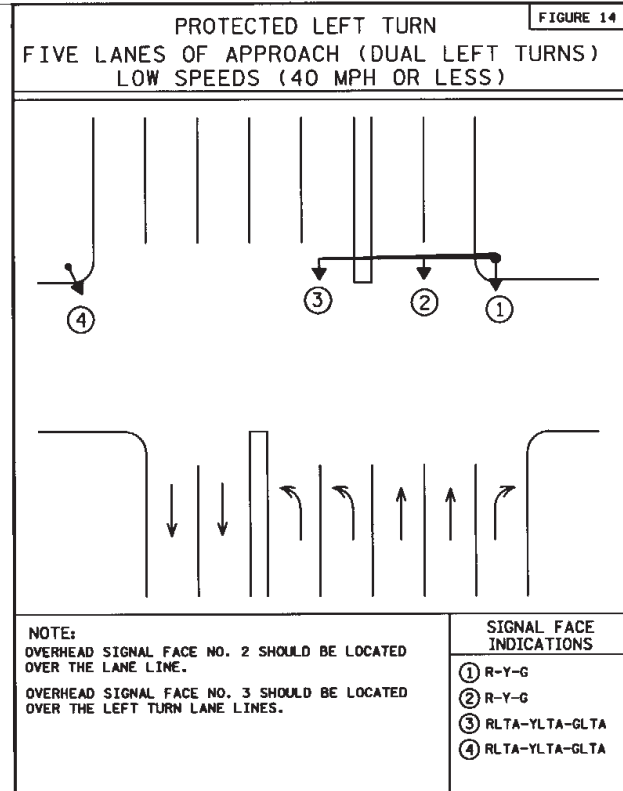
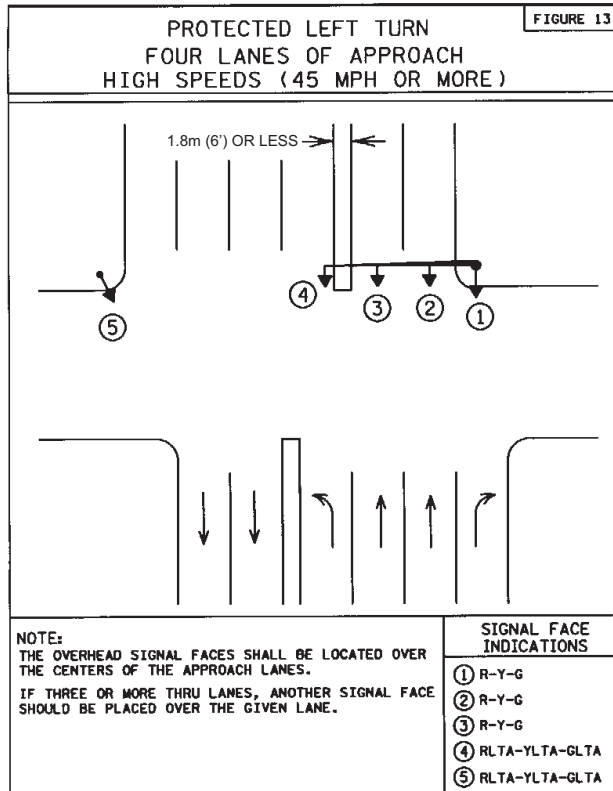
NOTE:
OVERHEAD SIGNAL FACE NO. 2 SHOULD BE LOCATED OVER THE LANE LINE.
OVERHEAD SIGNAL FACE NO. 3 SHOULD BE LOCATED OVER THE CENTER OF THE LEFT TURN LANE.
IF THREE OR MORE THRU LANES, ANOTHER SIGNAL FACE SHOULD BE PLACED OVER THE GIVEN LANE.

- SIGNAL FACE INDICATIONS**
- ① R-Y-G
 - ② R-Y-G
 - ③ RLTA-YLTA-GLTA
 - ④ RLTA-YLTA=GLTA

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SIGNAL HEAD PLACEMENT CHARTS

TABLE
9.4C

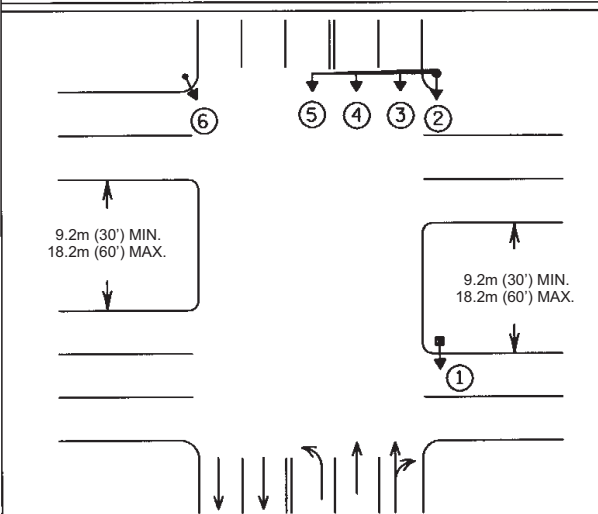


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SIGNAL HEAD PLACEMENT CHARTS**TABLE
9.4D**

PROTECTED LEFT TURN
THREE LANES OF APPROACH (DIVIDED HIGHWAY)
HIGH SPEEDS (45 MPH OR MORE)

FIGURE 17



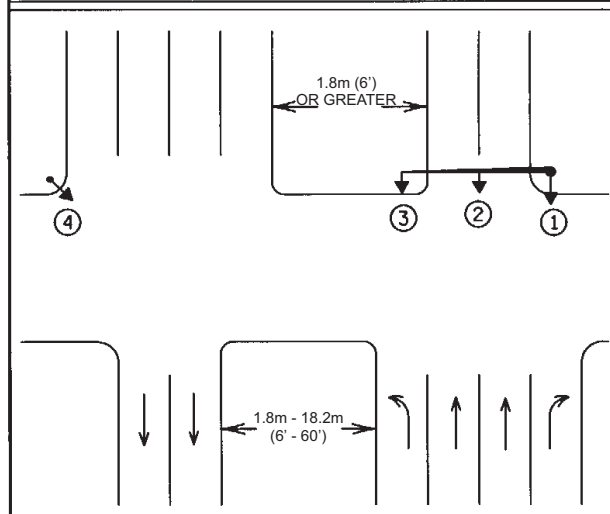
NOTE:
OVERHEAD SIGNAL FACE NO.'S 3 AND 4 SHOULD BE LOCATED OVER THE CENTERS OF THE APPROACH LANES.
OVERHEAD SIGNAL FACE NO. 5 SHOULD BE LOCATED OVER THE CENTER OF THE LEFT TURN LANE.
SIGNAL FACE NO. 1 SHOULD BE A PEDESTAL MOUNTED SIGNAL INDICATION.
SIGNAL FACE NO. 2 IS OPTIONAL.

SIGNAL FACE INDICATIONS

- ① R-Y-G
- ② R-Y-G
- ③ R-Y-G
- ④ R-Y-G
- ⑤ RLTA-YLTA-GLTA
- ⑥ RLTA-YLTA-GLTA

PROTECTED LEFT TURN
FOUR LANES OF APPROACH (WIDE MEDIAN)
LOW SPEEDS (40 MPH OR LESS)

FIGURE 18



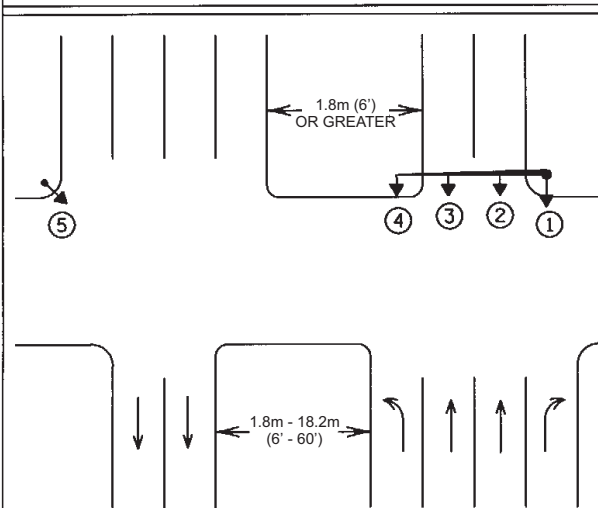
NOTE:
OVERHEAD SIGNAL FACE NO. 2 SHOULD BE LOCATED OVER THE LANE LINE.
OVERHEAD SIGNAL FACE NO. 3 SHOULD BE LOCATED OVER THE CENTER OF THE LEFT TURN LANE.
A PEDESTAL MOUNTED SIGNAL INDICATION MAY BE USED IN PLACE OF OVERHEAD SIGNAL FACE NO. 3.

SIGNAL FACE INDICATIONS

- ① R-Y-G
- ② R-Y-G
- ③ RLTA-YLTA-GLTA
- ④ RLTA-YLTA-GLTA

PROTECTED LEFT TURN
FOUR LANES OF APPROACH (WIDE MEDIAN)
HIGH SPEEDS (45 MPH OR MORE)

FIGURE 19



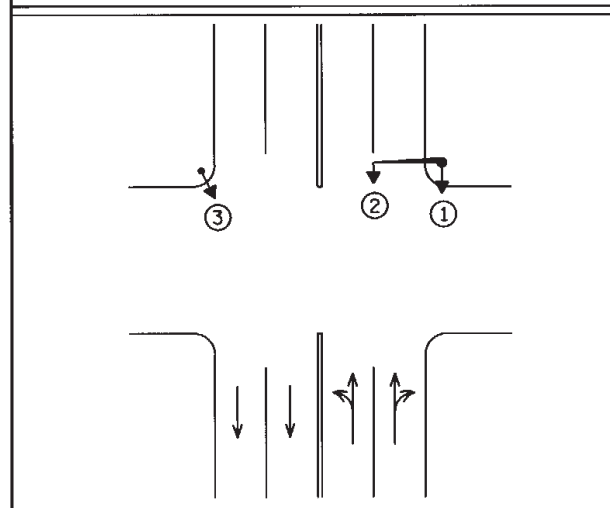
NOTE:
OVERHEAD SIGNAL FACES SHOULD BE LOCATED OVER THE CENTERS OF THE APPROACH LANES.
A PEDESTAL MOUNTED SIGNAL INDICATION MAY BE USED IN PLACE OF OVERHEAD SIGNAL FACE NO. 4.

SIGNAL FACE INDICATIONS

- ① R-Y-G
- ② R-Y-G
- ③ R-Y-G
- ④ RLTA-YLTA-GLTA
- ⑤ RLTA-YLTA-GLTA

CROSS STREET SEQUENTIAL PHASING
TWO LANES OF APPROACH
LOW SPEEDS (40 MPH OR LESS)

FIGURE 20



NOTE:
OVERHEAD SIGNAL FACE SHOULD BE LOCATED OVER THE LANE LINE.

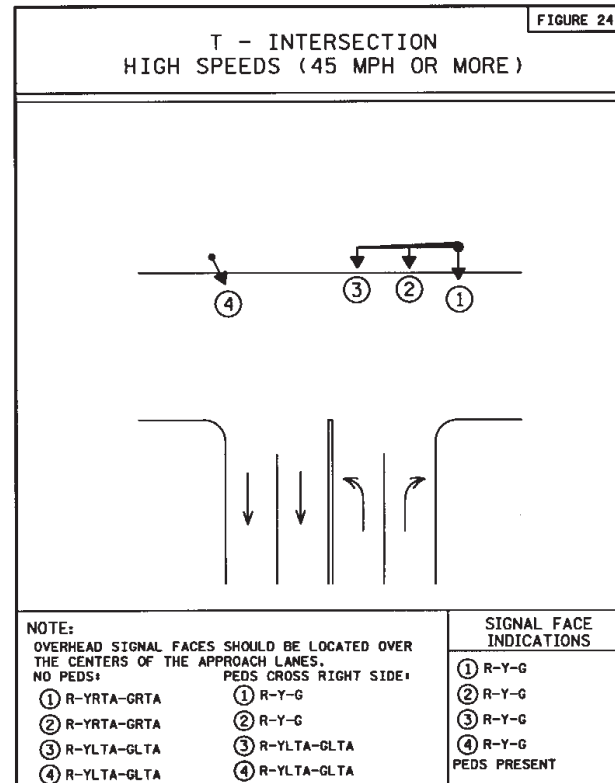
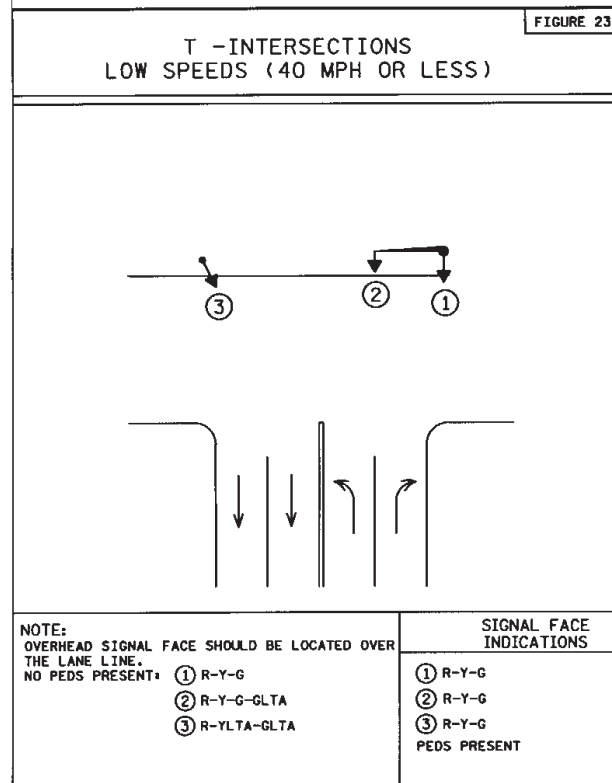
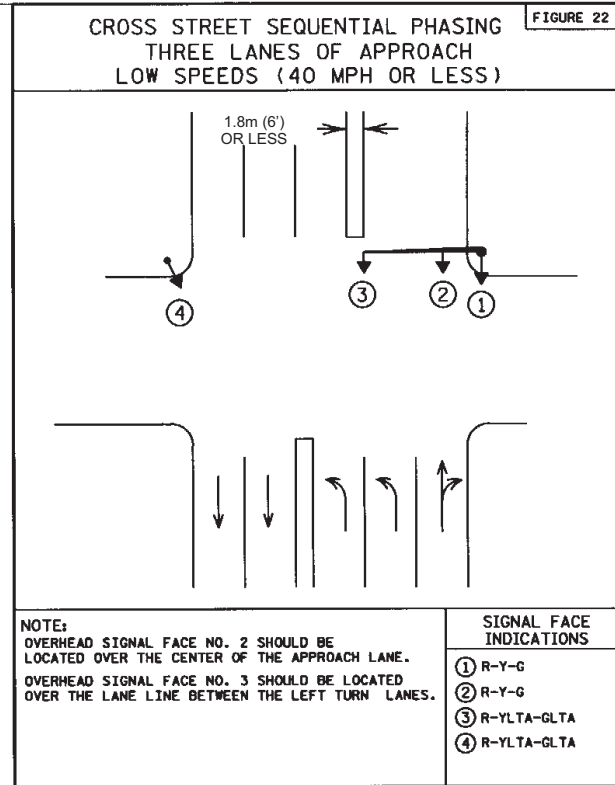
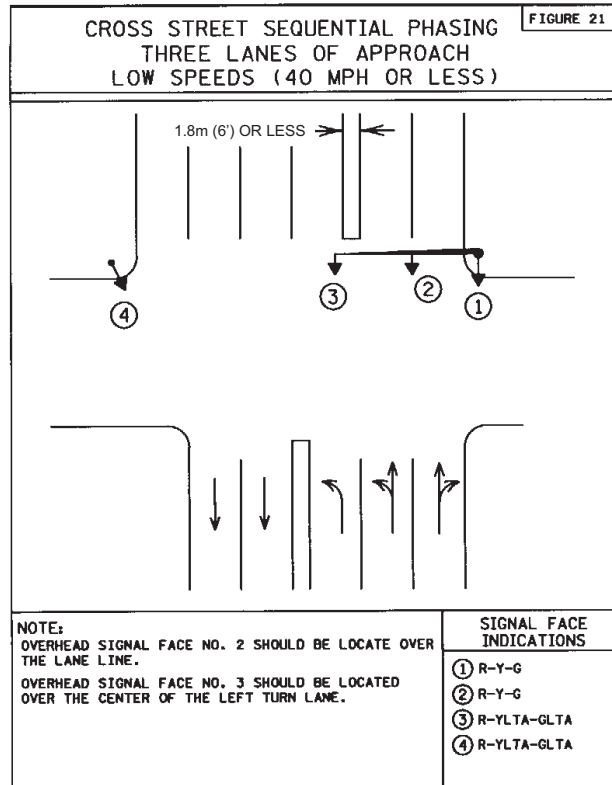
SIGNAL FACE INDICATIONS

- ① R-Y-G
- ② R-Y-G-GLTA
- ③ R-YLTA-GLTA

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SIGNAL HEAD PLACEMENT CHARTS

TABLE
9.4E

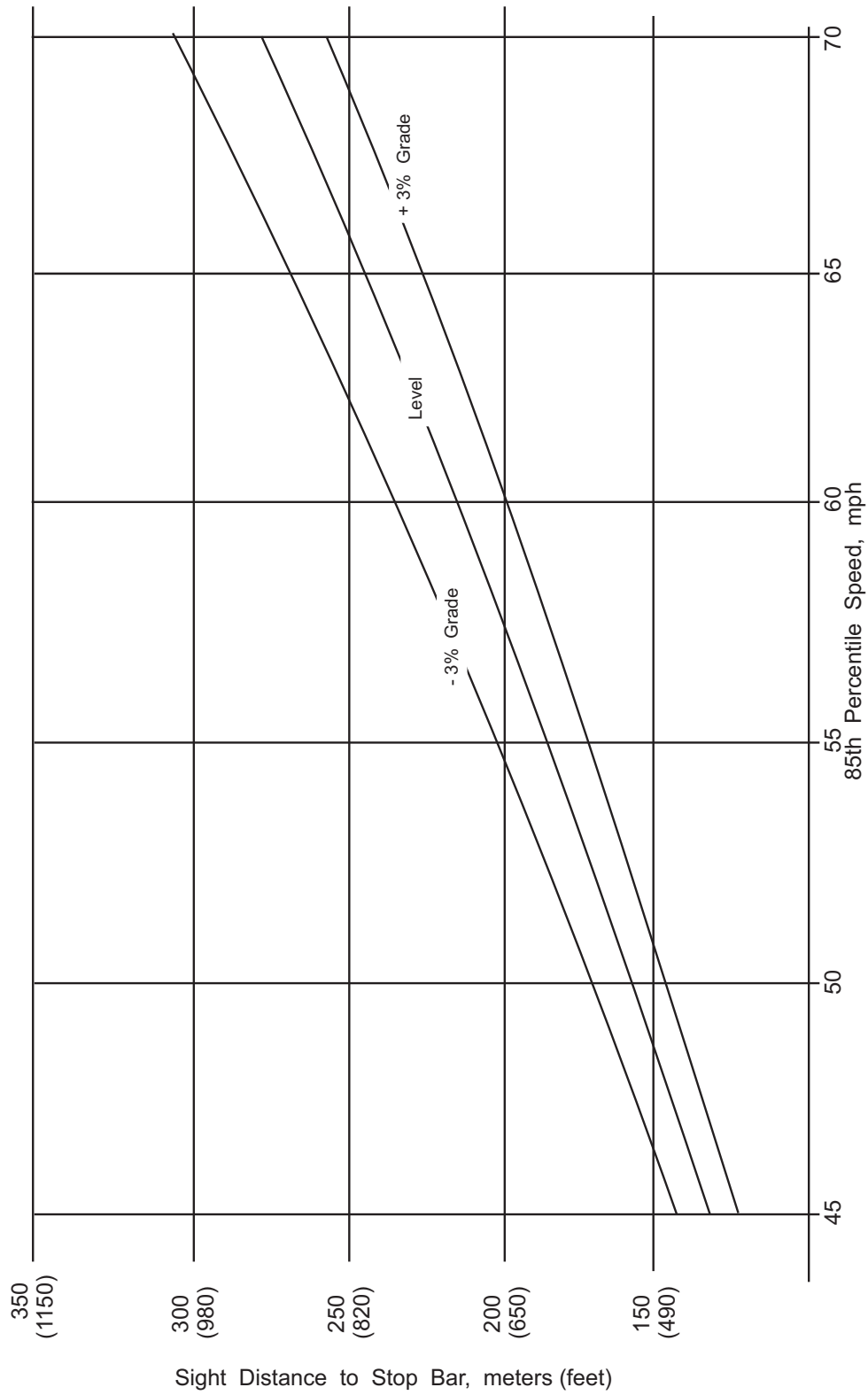


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SIGNAL HEAD PLACEMENT CHARTS

TABLE
9.4F

Limited Sight Distance
a = 2.4 meters (8 feet) per second squared (> 15% trucks)



A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

Text Ref.: 9-6.06

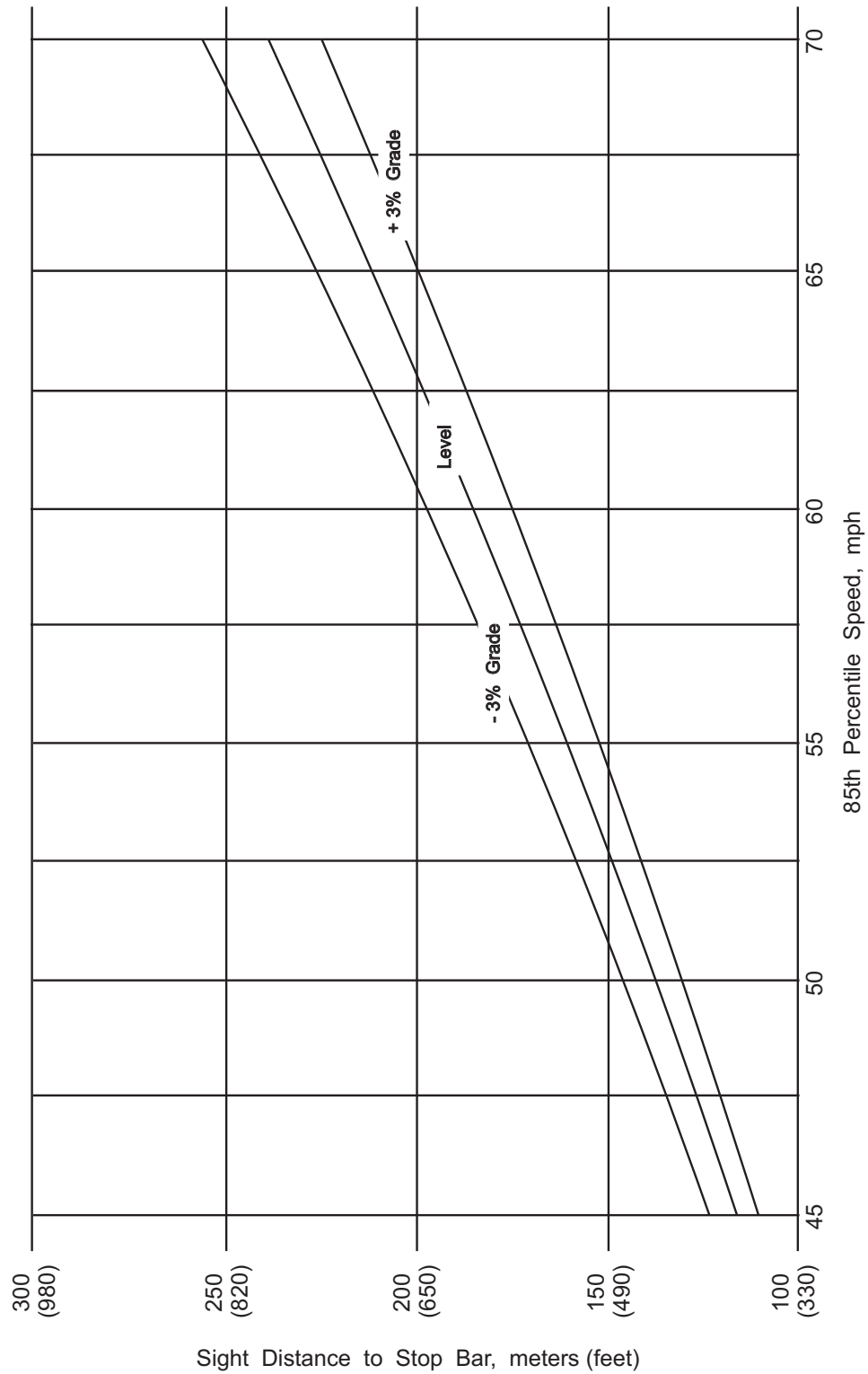
July 1, 2000

LIMITED SIGHT DISTANCE GRAPH

TABLE
9.5A

Limited Sight Distance

a = 3.0 meters (10 feet) per second squared (> 15% trucks)



A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

Text Ref.: 9-6.06

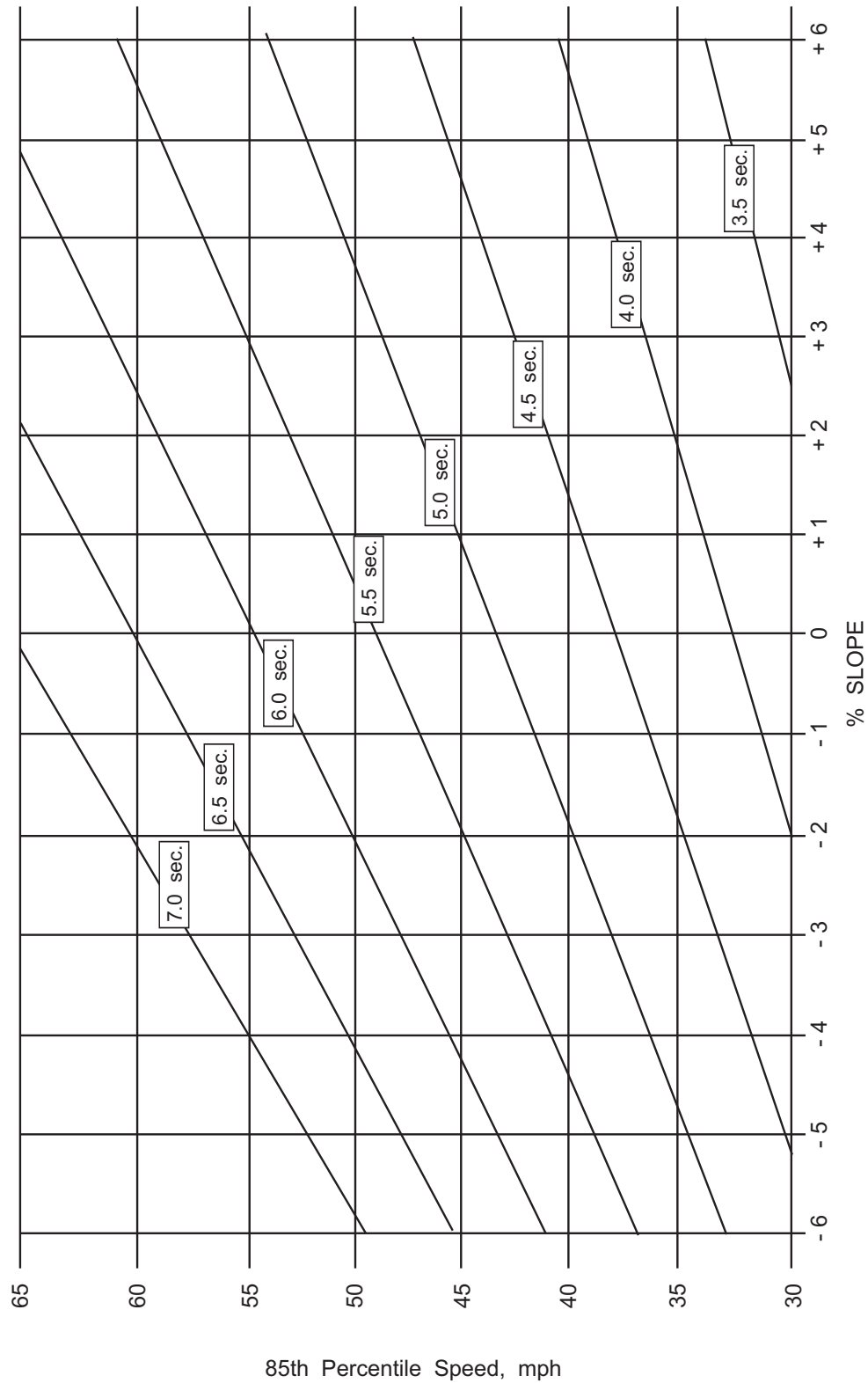
July 1, 2000

LIMITED SIGHT DISTANCE GRAPH

TABLE
9.5B

Minimum Yellow Intervals

a = 2.4 meters (8 feet) per second squared (> 15% trucks)



if the yellow interval is less than indicated, an AWF may be considered, (longer yellows should be considered first).

Text Ref.: 9-6.06

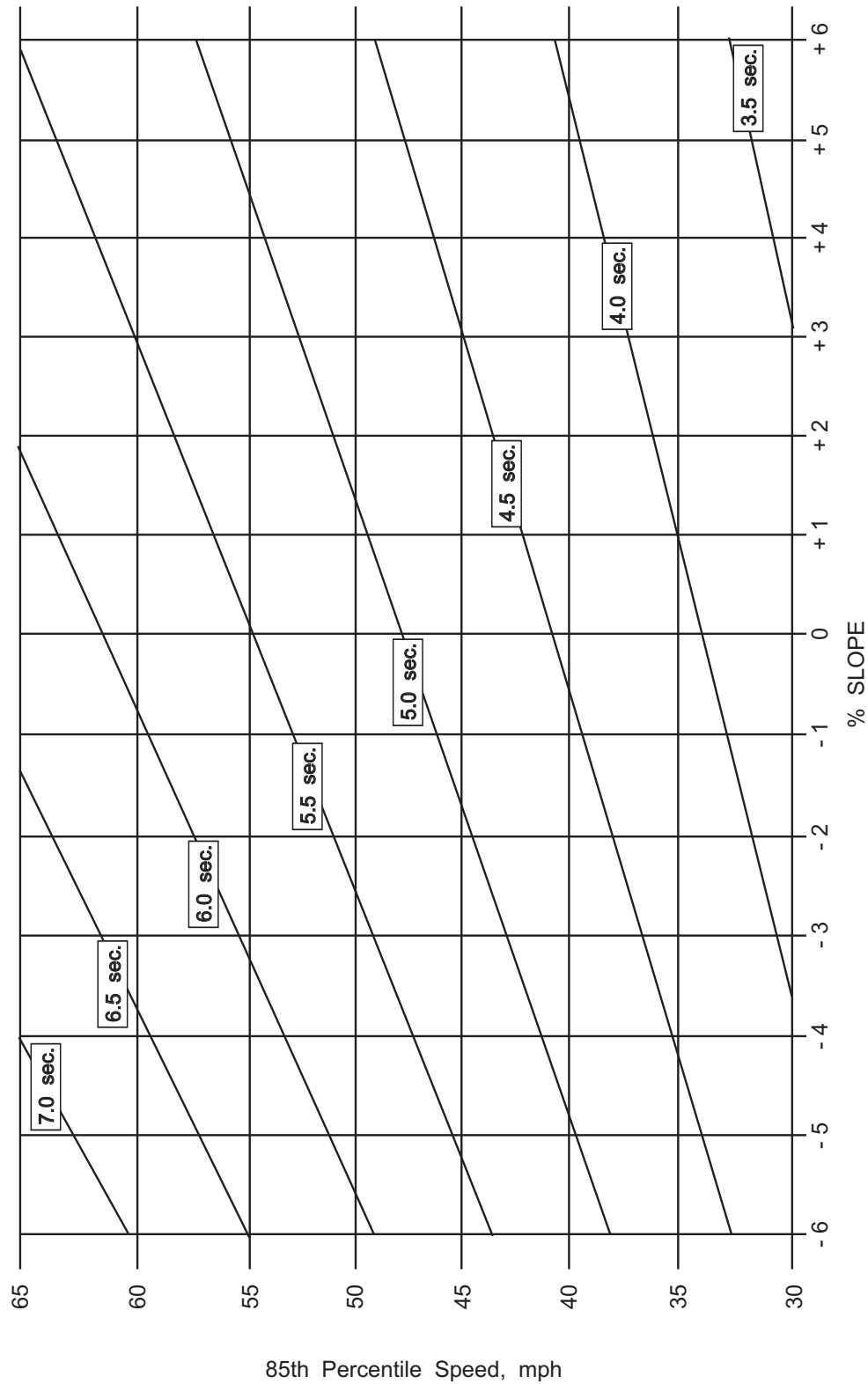
July 1, 2000

MINIMUM YELLOW INTERVALS

TABLE
9.6A

Minimum Yellow Intervals

a = 3.0 meters (10 feet) per second squared (> 15% trucks)



if the yellow interval is less than indicated, an AWF may be considered, (longer yellows should be considered first).

Text Ref.: 9-6.06

July 1, 2000

MINIMUM YELLOW INTERVALS

TABLE
9.6B