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 planning, construction, revisions and maintenance of traffic signals on Trunk Highways 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 (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, 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. The standards and guidelines of the MN MUTCD and the Traffic Engineering Manual are to be a basis for engineering judgment, not a substitute for it.

This chapter is intended as an overview of guidelines and procedures for the process of traffic signal design and operation in Minnesota. Please refer to "Mn/DOT Signal Design Manual" (Signal Design Manual) and "Mn/DOT Traffic Signal Timing and Coordination Manual" (Signal Timing Manual) when signal design and operations training and/or detailed description is needed. This chapter may reference to appropriate chapters in Signal Design Manual and Signal Timing Manual when appropriate.

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 1-1989 or TS 2-1993, "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" book, 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 Memoranda from the Office of Traffic, Safety, and Operations, 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 3 of this chapter present a general overview of traffic signals, including legal considerations, and a general description of traffic signal systems. Sections 4 through 7 address the justification, procedures, 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 gives an overview of available traffic signal computer software. References and abbreviations/acronyms appear at the end of the chapter.

9-2.00 LEGALITY

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.

9-2.01 Legal Authority

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 specific types of signals as follows: Subdivision 5 - Traffic Control Signals, Subdivision 6 - Pedestrian Control Signals, Subdivision 7 - Flashing Signals and Subdivision 8 - Lane-Direction Control Signals.

9-2.02 Jurisdiction

All traffic signals to be installed on Minnesota Trunk Highways shall have previous approval by the Mn/DOT District Engineer.

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

9-2.03 Meaning of Signal Indications

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

9-2.04 Tort Claims

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

9-3.00 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. 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 for 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.

9-3.01 Types of Traffic Signals

The general category of traffic signals includes traffic control signals, flashing beacons, railroad crossing signals, freeway ramp control signals (ramp meters), lane-use control signals, movable bridge signals, and temporary signals. See MN MUTCD for detail descriptions.

9-3.01.01 Traffic Control Signals

Intersection traffic control signal (commonly called traffic control signal) - It is the most common type of traffic signal. The primary function of an intersection 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. 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.

Traffic control signals can operate under two types of control, pretimed or traffic actuated (see Signal Timing Manual).

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 installed, 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.

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.

9-3.01.02 Flashing Beacons

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

Warning 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 a traffic signal, but where high crash rates indicate a special hazard. The installation of intersection control beacons overhead above the intersection is limited to Red on all approaches (where an all-way stop is warranted).

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

9-3.01.03 Railroad Crossing 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 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 designed and installed by the railroad companies, and reviewed and approved by Mn/DOT's Office of Freight and Commercial Vehicle Operations (OFCVO).

If a signalized intersection is near a railroad crossing, the traffic signals may have a preemption system connected with the railway approach signal 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.

9-3.01.04 Freeway Ramp Control Signals (Ramp Meters)

Freeway ramp control signals (ramp meters) are described in this Traffic Engineering Manual, Chapter 3, Freeway Corridor Traffic Management.

9-3.01.05 Lane-Use Control Signals

Lane-Use 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. Lane-Use Control Signals are described in this Traffic Engineering Manual, Chapter 3, Freeway Corridor Traffic Management, and in MN MUTCD, Part Four, Highway Traffic Signals.

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.

9-3.01.06 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.

9-3.01.07 Temporary Traffic Control 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. A temporary signal may also use a more portable means of vehicle detection, such as microwave or video detection. 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.

9-3.01.08 Portable Traffic Control 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.

9-3.02 Elements of Traffic Signals

9-3.02.01 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 and reflector, or Light-Emitting Diode (LED) array, and housing with a lens and visor. Signal indications, normally 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 or signal head. 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 4D-5 through 4D-12.

These signal heads for vehicular traffic are often accompanied by signal heads for pedestrian control. Pedestrian signal indication symbols are normally 9 inches or 12 inches in size, are white for WALKING PERSON (WALK) and orange for HAND (DON'T WALK). Section 4E 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 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.

9-3.02.02 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 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. 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.

Traffic control signals on arterial highways usually use two or four mast arm poles per intersection. Signal pedestals are mostly used in dense urban areas, they are shorter, do not have mast arms, and are not used for overheads. 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.

9-3.02.03 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 6 feet high, 3 feet wide, and 2 feet deep; it sits on a concrete foundation. It may have a vent fan for summer.

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. The controller may include a time-clock to control events by time of day and a coordinator to synchronize the operation of the intersection controller with that of other controllers in a coordinated system of controllers.

Other equipment to be found in the cabinet includes load switches, a conflict monitor, detector units, flasher, 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 units sense very small frequency changes as vehicles pass over coils of wire, also known as loops, imbedded in the roadway. This change is converted to an on/off signal connected to a controller input so that the controller 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 flashing operation. In the flashing mode the signal indications should be flashed red for all approaches.

Preemption devices override the normal sequencing of the controller and channel it into special sequence routines to allow for the presence of trains or emergency vehicles approaching or present at an intersection.

9-3.02.04 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 coil of wire imbedded in the pavement that carries a very low level, high frequency signal. When a conductive mass passes over the loop it creates an inductance change causing this frequency to change. The frequency change is sensed by the detector and it signals the controller that a vehicle is present.

Other types of vehicle detectors include magnetic coil, microwave, radar, sonic, and video; 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 in Signal Design Manual.

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 saw cut loop detectors is shown on Standard Plate 8130; the installation of the NMC saw cut loop detectors is indicated in the contract documents; the installation of a pedestrian push button is shown on Standard Plate 8115.

9-3.02.05 Source of Power and Service Equipment

Signal controller cabinets are powered by 120-volt electricity from the local utility company. The cabinet is wired to a signal service cabinet 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 equipment pad. It can be a simple meter and circuit breaker load center, or a signal service cabinet designed for the specific purpose, depending on the electrical and aesthetic 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.

9-3.02.06 Conduit and Handholes

The electrical wiring between the signal cabinet and the poles or pedestals usually travels in underground conduit. Conduit is usually rigid steel conduit or non-metallic conduit whose size is determined by the application and the number of cables that it must accommodate. For the non-metallic conduit, a grounding wire is needed if there are power conductors in the conduit.

Handholes can be made of concrete or PVC, and have a 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.

9-3.03 Timing and Coordination of Traffic Signals

Details for timing and coordination of traffic control signals are shown in the Signal Timing Manual.

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.

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.

In coordinated master or central controller 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.

In general, two or more signalized intersections can be coordinated if they are less than 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.

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.

9-4.00 TRAFFIC SIGNAL JUSTIFICATION PROCESS

9-4.01 Engineering Studies for Traffic Signals

If signals are proposed for an intersection, enough study should be done and documented 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 Transportation Engineers' Manual of Traffic Engineering Studies and a discussion of data collection for traffic studies can be found in Chapter 5 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 of the MN MUTCD.

Examples of many of these studies can be found on the Office of Traffic, Safety,, and Operations website.

9-4.02 Warrants and Justification for Signals and Flashing Beacons

9-4.01.01 Traffic Signal Warrants (New warrants in 2001 MN MUTCD)

Warrants have been developed to determine if an intersection needs some type of traffic 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 (MN MUTCD). 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 4C of the MN MUTCD. There were major changes to the structure of the warrants in the revision of 2001 MN MUTCD. Comparing to the previous version, the following are the equivalent warrants for the 1991 and 2001 MN MUTCD versions:

2001 MN MUTCD	1991 MN MUTCD
Warrant 1	Warrants 1, 2, and 8
Warrant 2	Warrant 9
Warrant 3	Warrants 10 and 11
Warrant 4	Warrant 3
Warrant 5	Warrant 4
Warrant 6	Warrant 5
Warrant 7	Warrant 6
Warrant 8	Warrant 7

The statements that follow give intents and interpretations of the warrants. Only the warrants which need clarifications are listed here.

WARRANT 1

Warrant 1 is the warrant that pertains to volume, and is the most common warrant for justifying intersection control.

The same eight hour period must be used for both the Major and the Minor Streets. The first standard in Warrant 1 combine the former warrants 1 (volume warrant) and 2 (interruption of continuous traffic). Either Condition A must be met for 8 hours or Condition B must be met for 8 hours. The second standard in Warrant 1 is the former Warrant 8 (combination of warrants). Condition A must be met for 8 hours and Condition B must be met for 8 hours. It does not need to be the same 8 hours for Condition A and Condition B.

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

The population reduction factor mentioned in warrants 1-3 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.

WARRANTS 2 and 3

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

WARRANT 4

This warrant allows the installation of a traffic signal if there is a considerable number of pedestrians. If a signal is warranted, the signal should be traffic actuated with pedestrian indications.

WARRANT 6

A signal justification report addressing Warrant 6 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 6 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 6 would include interconnect.

WARRANT 7

For Warrant 7, the requirement is the 80% columns of Warrant 1 Condition A or Condition B or 80% of the pedestrian volumes of Warrant 4.

Signal justification reports which address Warrant 7 are to include a collision diagram. A time-space diagram showing that 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 7 is not applicable to an intersection which is already signalized.

WARRANT 8

Current Mn/DOT interpretation of Warrant 8 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 8 does not apply to isolated intersections, but rather to intersections in urban grid systems.

9-4.02.02 Warrants for Flashing Beacons at Intersections

Flashing beacons at intersections include intersection control beacons mounted on span wire directly over an intersection (all-way stop only), stop beacons mounted on a pedestal above stop signs (red), and warning beacons mounted on a pedestal above intersection ahead symbols signs (yellow). Both overhead and pedestal mounted beacons have advantages and disadvantages. Overhead beacons 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. 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 that shown in the table below for any approach to the intersection. Locations qualifying under limited visibility must have previously had adequate warning signs and pavement markings installed.

SPEED mph	SIGHT DISTANCE LESS THAN feet
20	105
25	145
30	195
35	250
40	320
45	390
50	460
55	540
60	635
65	745
70	840

NOTE: The distances here are to ensure the driver (3.5 ft. height of eye) who can not see an oncoming vehicle (3.5 ft. height of object), has enough time TO react and make a stop. They are based on the 1994 AASHTO Policy for stopping sight distance (page 120) providing a PIEV time of 2.5 seconds, friction factor of 0.28 to 0.40 based on speed.

WARRANT 2: Crash Rate

A flashing beacon may be installed where high-hazard safety improvement criteria are met, as described elsewhere in this manual or, in one year where 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.

9-4.02.03 Advance Warning Flashers Consideration

An Advance 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 through a visual indication about a pending change in the indication 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 AWF configuration, placement, and timing details can be found the Chapter 4M of the MN MUTCD.

The following guidelines indicate when the installation of advance 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 judgment. Guidelines should be reviewed for each prospective installation.

An 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 an AWF is installed, other remedial action should be considered.

The following guidelines generally apply only where posted speed is 55 mph or higher:

1. 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 10 miles, a freeway terminus, or at other locations where the intersection is unexpected.

2. A Limited sight distance

   This can occur where the distance to the stop bar, D, with two signal heads visible is insufficient. See Graphs of Limited Sight Distance, Table 9.1A & Table 9-1B. A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

$$D \leq 1.467vt + \frac{v^2}{0.93(a + 32.2s)}$$

   Where:
   D = distance to stop bar in feet
   v = posted speed limit in mph
   t = reaction time, 2.5 seconds
   a = deceleration rate
   for trucks use 8 ft/s^2
   for all traffic use 10 ft/s^2
   s = positive or negative decimal gradient

3. Dilemma zone

   This situation exists when a dilemma zone exists for all traffic or for heavy vehicles. A dilemma zone exists if the yellow interval time cannot practically be set to at least the yellow interval time indicated in Signal Timing Manual. An AWF may be considered but longer yellow should be considered first.

4. Crashes

   If an approach has a crash problem, the intersection should be examined for existence of dilemma zone or sight distance restriction. If no sight distance or dilemma zone problems exist, an AWF may not be an appropriate countermeasure for accident problems.

5. Heavy Truck Volume

   Where the roadway has a grade of 3% or greater and truck volume exceeds 15%.

6. Engineering Judgment

   Combinations of the above guidelines or other considerations may justify the installation of an AWF.

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.

9-4.02.04 Signal Justification

Signal Justification Report (SJR)

A signal justification report (SJR) must be prepared 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 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 a 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 prepared for minor work done on a signal if each district 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 a signal justification report. When in doubt, a signal justification report should be prepared.

The purpose of a signal justification report is to document that an engineering study has been done and that engineering judgment 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:

1. Intersection location: trunk highway cross-street name and county road numbers, municipality, county. A map should be included which identifies the site.
2. Type of work: type of signal or beacon proposed, whether temporary or permanent.
3. 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.
4. Land use: present land use at the intersection, presence of any special traffic generators, proposed or likely future development.
5. Traffic control: existing traffic control, present and planned adjacent signals, proposed or existing coordinated systems.
6. 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.
7. 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.
8. Pedestrian counts, particularly if the intersection is a school crossing or is used by large numbers of elderly

or handicapped pedestrians.

9. 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 7 for crash experience 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.
10. Any special site conditions: which add to the engineer's judgment that signals 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.

A sample SJR can be found on the Office of Traffic, Safety,, and Operations website.

Signal Removal Justification Criteria

Signalized intersections that meet 80 percent of the volume requirements of MN MUTCD Warrant 1 should be considered justified and should not be removed. Signalized intersections that do not meet 80 percent of the volume requirements of MN MUTCD Warrant 1, 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 judgment 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 Warrant 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 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 judgment. 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 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 should be revised to meet current standards. These traffic signals should be prioritized along with other traffic signal projects and scheduled for revision as permitted.

9-5.00 TRAFFIC SIGNAL PROJECT PROCEDURES

9-5.01 Traffic Signal Project Management Flowchart

The accompanying chart illustrates a typical state let traffic signal project management flowchart based on the deliverables and important milestones.

9-5.02 Notes on Traffic Signal Project Management Flowchart

A. START PROJECT

The Statewide Transportation Improvement Plan (STIP) and the Program and Project Management System (PPMS) identify the project and project manager. This is the beginning of tracking of the project.

Signal design projects can be characterized based upon the following parameters:

1. Contracting agency - Mn/DOT let versus local agency let, or force account.
2. Funding source - State Federal funds, Local Federal funds, state funds, state funds through a cooperative agreement, state aid funds, local funds.
3. Designer - Mn/DOT, consultant, design build contractor, and city.
4. Scope - Stand alone signal project or part of larger construction project.

B. PROJECT NOTIFICATION LETTER

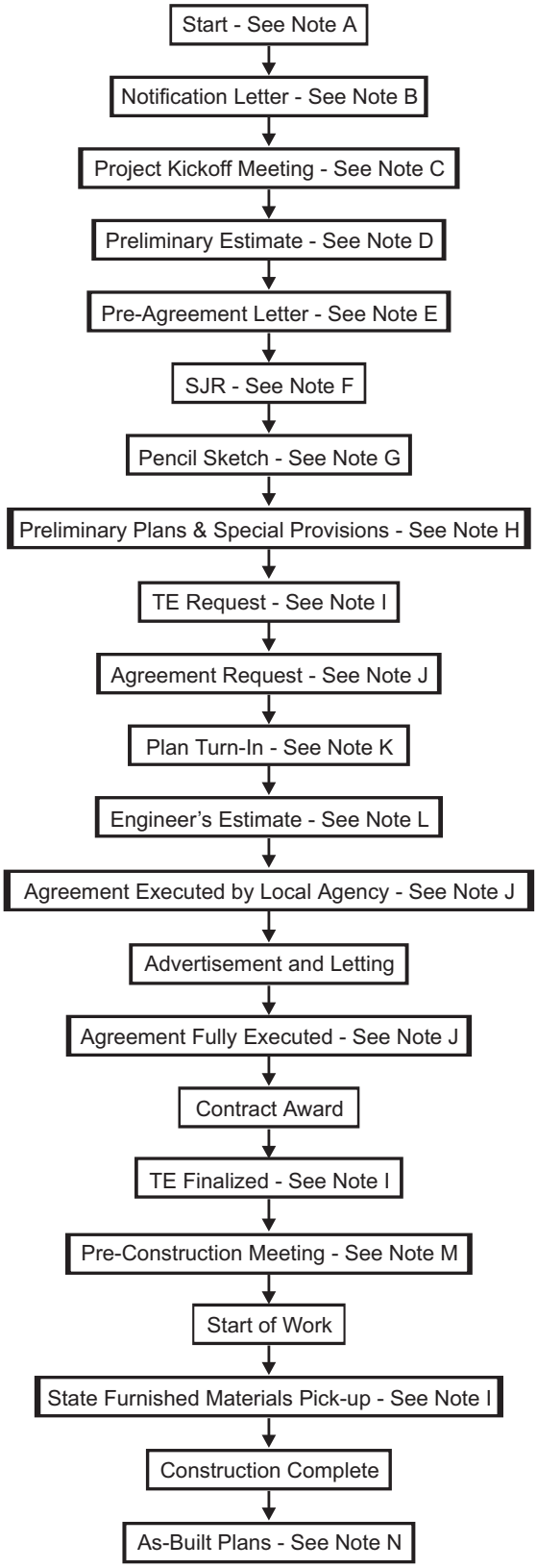
Early project coordination is the key to a successful review process. For Mn/DOT designed projects, the Project Notification Letter from the Mn/DOT district to the affected local agencies alerts the local agencies that a project is upcoming. The letter describes the project need and justification, scope, proposed letting date, expected construction duration, contact personnel (name, title, mailing address, phone, e-mail), funding source(s), and any need for in place plans and mapping.

For externally designed projects, the designer should send the Project Notification Letter to the Mn/DOT District Traffic Engineering office with similar information.

C. PROJECT KICKOFF MEETING

The designer should schedule a Project Kickoff Meeting to discuss the project scope, data collection findings and goals, and Mn/DOT and local agency issues and goals. The meeting's purpose is to make all project participants fully aware of all issues so that the project management, scope, funding, and technical issues are resolved prior to the beginning of signal design activities. This meeting should include the signal designer, local agency project manager (city, county, etc.), agencies affected by the project (cost, operation, maintenance) and Mn/DOT District Traffic Engineering office personnel.

In preparation for the Project Kickoff Meeting, the designer will begin data collection. The data to be collected (as needed) shall include: obtaining in place signal plans (or CADD files if available), obtaining mapping if available, identifying any current problems with signal operations and/or maintenance, identifying signal design standard or geometric deficiencies, checking for other proposed projects in the vicinity including project time lines, checking crash rates, checking existing cabinet/controller condition and compatibility, and obtaining a preliminary cost estimate for state furnished materials and labor.



Typical State Let Traffic Signal Project Management Flowchart

The following is the project Kick-off Meeting check List for each intersection affected by a project:

Project Management

Mn/DOT Traffic Engineering project manager
Project sponsor/lead (Mn/DOT, city, county)
Designer (Mn/DOT, city, county, consultant)
Project location (TH/Intersection)
Project process (Permit, S.A., local initiative/AM funding, Mn/DOT Programmed)
Proposed project time line

Project Scope

Work proposed (new signal, major/minor revision, EVP, phasing change, standard)
Project proposer's specific goals (lanes, phasing, heads, EVP, etc.)
Mn/DOT's specific goals (lanes, phasing, heads, EVP, etc.)
Affect/coordination with TMC systems
Affect/coordination with lighting systems
SJR/project memo required
Operation issues
Operation issues not addressed by proposed project
Maintenance issues
Safety/accident issues
Traffic engineering construction liaison scope of responsibilities

System Operation/Management

Use Cost Participation, Operations, and Maintenance Responsibilities Worksheet

Funding / Costs

State, City or County furnished materials and labor estimate for proposed work
Need for an agreement (signals/lighting) for this proposed work (Pre-agreement letter to follow, if necessary.)
Need for a permit for this work
Funding sources and Cost participation of proposed work

Technical Issues (Use Field Walk Checklist to Identify all Issues)

Field walk

Affect on in place SOP

SOP meeting and notification letter needed

Equipment pad revisions needed

EVP sight lines adequate (vertical and horizontal)

Affect on in place interconnect - need for interconnect

Affect on in place HH's - need to be moved or receive replacement covers

Standards upgrades proposed / needed (LED, EVP, pedestrian indication, etc.)

Phasing review needed

Detection needs/changes

Striping/signing affected

Approach signing affected (review conflicts)/needed (coordinate)

Utility information and process/needs - notification letter and time line

Specification requirements (design, operations, CESU for EVP card delivery, etc.)

Pedestrian amenities status (ramps, sidewalk, indications, PB placement, markings)

Further Contacts

Since the project scope can change as result of data review and this meeting, define what actions will be taken to inform all attendees and cc:s of project scope changes.

References

Refer to www.dot.state.mn.us\trafficeng site for checklists, details, standards, sample special provisions, and other significant information.

Refer to signal and lighting design manuals for processes and technical information.

D. PRELIMINARY ESTIMATE

A Preliminary Estimate will be the basis for the costs in the Pre-Agreement Letter. The Preliminary Estimate will include the preliminary construction contract cost and will additionally identify costs for state furnished materials and labor, and costs for design and construction engineering. As the project costs become better defined, the designer should update the Preliminary Estimate.

E. PRE-AGREEMENT LETTER

The District Traffic Engineering project manager will send a Pre-Agreement letter to affected local agencies and Mn/DOT offices identifying the following:

1. Preliminary Estimate with breakdown
2. Project scope
3. Funding and cost participation
4. Time line
5. Major/minor maintenance responsibilities
6. Power supply costs and responsibilities
7. Signal and coordination operation responsibilities
8. State, County or City furnished material / labor
9. Construction engineering costs

See details of cost sharing in the Signal Design Manual and Mn/DOT Policy and Procedures for Cooperative Construction Projects with Local Units of Government.

F. SIGNAL JUSTIFICATION REPORT

A Signal Justification Report shall be approved by the Mn/DOT District Traffic Engineer. This report should be completed prior to or near commencement of signal plan development, but only after the project scope is clearly defined. See Section 9-4.02.04 of this chapter for details of the SJR.

G. PENCIL SKETCH

A "pencil sketch" or preliminary CADD drawing (usually graphics and charts - no pole or construction notes) of the new signal should be provided to the Mn/DOT District Traffic Engineering office for review. This will allow Mn/DOT to comment on important design elements (head placement, detection, phasing) prior to signal plan development. This will eliminate significant design changes once the signal design has begun, and is strongly recommended.

Signal designers should meet and confer to agree on preliminary signal design. The design topics to be discussed should include but not be limited to the following:

1. General nature of the signal project: new installation, minor or major revisions.
2. 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.
3. Determine design standards based on who will operate the system.
4. Use of 4- and 5-section heads and non standard bracketing.
5. Head type (LED, Optically programmed, etc.).
6. Appropriateness of poles and pedestals for the site.
7. Placement of signal standards to ensure legal placement of all vehicle and pedestrian signal indications. See the Signal Design Manual, for signal head placement diagrams.
8. Placement of pedestrian pushbuttons relative to signal standards and in place sidewalks and crosswalks.
9. Need for EVP and placement of components.
10. Detector placement and functions. See the Signal Design Manual for loop detector placement diagrams.
11. Placement and type of handholes.
12. Design of equipment pad.
13. Type of service equipment.

14 Discuss needs for combined pad with lighting and/or TMC.

15 Need for intersection geometric improvements.

16. For revised systems, the wording of the signal pole notes for the revision.

17. Need for AWF's, supplemental heads, etc.

18. House moving route needs.

19. Painting of signal.

20. Luminaires metered or unmetered.

21. Source of power (to determine cabinet location).

22. Interconnect (determine need and type, location of master).

H. PRELIMINARY PLANS AND SPECIAL PROVISIONS

The Mn/DOT District Traffic Engineering office project manager distributes the preliminary signal design package (as distinct from a roadway design package) for review to the Mn/DOT District Traffic Engineering office, District State Aid office, Cooperative Agreements, Consultant Agreements, Permits, Metro or Regional Electrical Service Unit, and other district functional offices as appropriate. The preliminary signal design package shall consist of the appropriate number of copies of signal plans (hard copies), signal special provisions, Microstation CADD file, Preliminary Estimate, source of power letter, and power application form (if applicable). The preliminary signal design package is required for all projects. The District Traffic Engineering office project manager works directly with the designer on format and technical comments, keeping other project managers informed.

The plan should identify the TE number, the system ID number, and the master ID number (if applicable).

NOTE: To expedite the signal plan review process, the signal plan should be checked by the signal designer prior to submittal. A checklist for plan reviews is available in the Signal Design Manual.

I. TE REQUEST

A Traffic Engineering (TE) Request is a work order requesting state furnished materials and/or labor from the Central Electrical Services Unit. Most signal projects let by Mn/DOT will utilize a state furnished traffic signal controller and cabinet. Other state furnished materials, especially for temporary traffic signal systems, may include microwave or video detection systems. In addition to the state furnished materials, a TE Request may also include a request for labor, such as modifying wiring within an existing signal controller cabinet in the field. The District Traffic Engineering office prepares and submits the TE Request in the AFMS system and the Central Electrical Services Unit approves it.

The project special provisions should require the Contractor to contact the Central Electrical Services Unit to request the state furnished materials at least 30 days before the materials are needed. The Central Electrical Services Unit will final the TE Request, which ensures that the materials are correctly charged to the signal construction project.

The project special provisions should require the Contractor to again contact the Central Electrical Services Unit 3 days before picking up the state furnished materials.

J. SIGNAL AGREEMENT

Mn/DOT shall prepare a signal agreement as needed. Items typically covered within the agreement are:

1. Construction cost participation
2. Responsibility for power cost
3. Responsibility for major maintenance
4. Responsibility for minor maintenance
5. Responsibility for maintenance costs
6. Responsibility for signal timing and operation
7. Costs and responsibility for Emergency Vehicle Preemption (EVP) systems
8. Reimbursement for State, County or City furnished materials / labor
9. Construction engineering costs

The signal Agreement Request is often combined with the final Plan Turn-In.

Projects requiring signal agreements should not be let without the agreement signed by the local unit of government. The construction project should not be awarded without a fully executed agreement (signed by all parties).

K. PLAN TURN-IN

The Mn/DOT District Traffic Engineering office project manager ensures that all of the comments to the preliminary submittal have been appropriately addressed. Upon completion of the final review, Mn/DOT (either the District Traffic Engineering office project manager or the larger roadway project manager) will begin final processing of the project package. Once all the district and local signatures are obtained, the project will be submitted to the Pre-Letting Section of the Office of Technical Support for final processing.

Traffic signal plan approvals 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 Traffic Engineer shall approve the final plans before bids are opened on the project. If a proposed signal is not at a trunk highway location, the District Traffic Engineer will indicate concurrence with the design by means of a memorandum to the State Aid office.

The project submittal package shall include:

1, Hard copy and Microstation CADD files of the signal plans
2. Hard copy and Microsoft Word files of the signal special provisions
3. Tabulation of Quantities for the signal project

L. ENGINEER'S ESTIMATE

The Office of Technical Support prepares the final Engineer's Estimate based upon the tabulation of quantities provided by the signal designer.

M. PRECONSTRUCTION MEETING

For the Pre-construction Meeting the District Traffic Engineering office project manager should invite the Mn/DOT District Traffic Engineering office operations personnel as appropriate.

N. AS-BUILT PLANS

As-built signal plans should be forwarded to the Mn/DOT District Traffic Engineering office upon completion of projects administered by local agencies.

9-6.00 TRAFFIC SIGNAL DESIGN

9-6.01 General Considerations

The design of a traffic signal system is a process of balancing, among other things, 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. Please see the traffic signal project management flowchart.

See the Signal Design Manual for more detailed information.

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, geometric improvement of the existing intersection.

The following geometric 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 constructed so that the driver has adequate reaction distance to them and they are 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 30 feet between opposing through lanes, special signal design considerations are necessary (See MN MUTCD, Section 4H). Extremely wide medians confuse drivers on the crossing street, prevent them from being comfortable with opposing traffic, and cause 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 be inline with sidewalk and 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 20 feet nor more than 60 feet. A turning radius guide for 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 curb ramps are required 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 pedestrian 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 posted speeds should be determined for the location of advance 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 many 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 should include but are not limited to the following:

1. Adjacent signals should be interconnected whenever they are less than 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 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 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 cycle 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. See the Signal Design Manual for a discussion of phasing considerations.
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 4D-15, 4D-16, and 4D-17 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 lane line dividing the two lanes. An overhead should be used over each lane when speeds are above 40 mph. The size of lenses shall be as stated in section 4D-15 of the MN MUTCD. See the signal head placement charts in the Signal Design Manual. 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 Horizontal Location of Signal Faces shown in MN MUTCD Figure 4D-6 should be used as an aid in placing vehicle signal faces.
3. Vehicle detectors should be placed according to the detector spacing chart and the loop placement diagrams shown in Signal Design Manual.
4. At locations where pedestrians are expected, provisions must be made to control pedestrian activity in and around the signalized intersection. At locations where pedestrians are expected, 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 4E.3 of the MN MUTCD are met. Pedestrian push buttons should be installed at locations with pedestrian activity where it is not operationally efficient to provide pedestrian timing on every cycle. 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.
5. 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.
6. Street lighting should normally be installed with traffic signals and flashing beacons. The luminaires are generally 250-watt high-pressure sodium vapor luminaires, mounted in the far-right quadrants of the major street. Larger intersections may require additional luminaires. Forty foot mounting heights provide even light distribution. 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 systems and the equipment available to provide access to the luminaires 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 in the Signal Design Manual.

9-7.00 TRAFFIC SIGNAL PLANS AND SPECIFICATIONS

9-7.01 General

The end products of the pre-construction activities in signal design are the Plan, Special Provisions, and Engineer's Estimate. Supporting the Plans and Special Provisions are the standard design practices, Standard Plates Manual, the Mn/DOT Standard Specifications for Construction, other applicable national and local standards, and any necessary agreements. Detailed information is shown in the Signal Design Manual.

9-7.02 Traffic Signal Plans

The districts develop plans. If the districts desire they may request the review of plans by the Office of Traffic, Safety, and Operations.

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. The Special Provisions are project specific specifications that supplement the Mn/DOT Standard Specifications for Construction book.

Responsibilities related to the Special Provisions are as follows:

1. District Traffic Engineer

   a. Submits to the Special Provisions Engineer of the Office of Technical Support the Special Provisions for Mn/DOT designed signal system projects. The Special Provisions shall be submitted in accordance with the pre-determined "Project Pre-Letting Date" deadlines.

   b. Submits to the Special Provisions Engineer in the Office of Technical Support a completed copy of Form 21184, Contract Time Schedule Recommendations and Misc. Data and Form 21185, Provisions for traffic During Construction. This information shall be submitted in accordance with the pre-determined “Project Pre-Letting Date” deadlines.

2. Office of Traffic, Safety, and Operations, Signal Unit

   a. Upon request of the District, reviews Special Provisions for signal system projects let by the State or other agencies involving the trunk highway system. The Office of Traffic, Safety, and Operations website will maintain sample Special Provisions for District, Consultant, and other Agencies to access.

9-7.04 Tabulation of Quantities

The Detailed Construction Estimate (Engineer's Estimate) for all signal system projects let by the State is prepared by the Office of Technical Support. The District is responsible for providing a detailed tabulation of quantities to the Office of Technical Support as a basis for the Engineer's estimate. The Signal Design Manual provides a sample tabulation of quantities.

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 Mn/DOT Standard Specifications for 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)
7. Mn/DOT Signal Design Manual

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 materials occurs using the low bid process and then the material is 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 Central Electrical Services Unit (CESU):

1. The District Traffic Office shall write a Traffic Engineering (TE) Request on the Automated Facilities Management System (AFMS).
2. The AFMS System ID and TE Request number should be on the Traffic Signal plan.
3. One or two weeks prior to the letting of the contract, the District Traffic Office approves the TE Request on the AFMS.
4. The CESU reviews the TE Request and enters the Electronic Concurrence in the AFMS.
5. The work is then assigned and completed by CESU 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) District Traffic Engineer (4) Regional Electrical Services Unit (RESU) / Metro Electrical Services Unit (MESU), and (5) City Police, if appropriate. The MN MUTCD describes the considerations for bringing the new signal out of flashing operation into normal stop and go operation.

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) CESU & RESU/ MESU, and (6) the Office of Traffic, Safety, and Operations (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.

A sample signal turn on letter can be found on the Office of Traffic, Safety,, and Operations website.

9-9.00 TRAFFIC SIGNAL OPERATIONS

9-9.01 General

It is the responsibility of the District Traffic Engineer to observe the operation of all traffic signals in his or her district. Any timing or operation that is not correct should be corrected. The determination of the timing can be assisted by personnel in the Central Office Signal Unit. Unusual hardware implementations may require the assistance of personnel from the Central Electrical Services Unit. The District Traffic Engineer shall maintain a complete timing record, including all preemption timing, in the controller cabinet and in the District office. In the event the District Traffic Engineer determines a traffic signal is to be revised by state maintenance forces, a TE request is to be written. The TE Request should outline the work that is to be done. Normally, the District Traffic Office will be contacted by the Central, Metro, or Regional Electrical Services Unit, as appropriate, after concurrence and before the work is done.

Each district shall budget for payment of electrical power usage where the State has that responsibility.

The district shall keep a current maintenance log in each controller cabinet and any timing change performed to that signal shall be duly recorded on that log.

A sample signal maintenance log sheet can be found on the Office of Traffic, Safety,, and operations website.

9-9.02 Operational Timing Practices

Detailed information is shown in Signal Timing Manual. It should be noted that those 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 judgment when applying the guidelines.

9-10.00 TRAFFIC SIGNAL MAINTENANCE

9-10.01 General

Maintenance work on traffic signal systems that is the responsibility of the State is performed by the Metro or Regional Electrical Services Unit. Metro or Regional Electrical Services Unit personnel perform electrical and hardware field repairs and minor installation projects. The Central Electrical Service Unit (CESU) performs shop repairs of traffic signal control equipment, receives Gopher State One Call location requests, prepares State-furnished equipment for installation by contractors on traffic signal projects, and provides technical field assistance.

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. The District and the Metro or Regional Electrical Services Unit should evaluate such request for feasibility for the State to do this additional work. The signal agreement will define responsibilities for maintenance and power cost.

9-10.02 Malfunction Repair

In the event of an equipment malfunction, the District Traffic Engineer, State Patrol, or other authorities call the Metro or Regional Electrical Services Unit to dispatch a repair crew. The District 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 traffic personnel shall call the District Maintenance Dispatcher. The dispatcher will contact the appropriate Metro or Regional Electrical Services Unit "on call" person. After the dispatcher makes contact with the Metro or Regional Electrical Services Unit, it is the responsibility of this person to follow-up on the problem. If needed, appropriate District traffic personnel may be contacted after hours.

When a traffic signal malfunction has been reported to the District, 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 Metro or Regional Electrical Services Unit personnel. Lamp-outages that are the responsibility of other agencies shall be reported to them for correction. Any lamp-outage report received by the Metro or Regional Electrical Services Unit 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 Metro or Regional Electrical Services Unit.

9-10.04 Signal Maintenance Log

Anyone who does any repair work or modifications in the cabinet or at the intersection shall record the action in the signal maintenance 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.

9-10.05 Automated Facilities Management System

In addition to the signal maintenance log contained in the intersection controller cabinets, the Automated Facilities Management System (AFMS) maintains a record of signal maintenance 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.

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.

9-11.00 TRAFFIC SIGNAL COMPUTER AIDS

9-11.01 General

The computer is an important and powerful tool in traffic engineering. District traffic offices, traffic engineers and technicians in the State of Minnesota have access to a number of computer programs which assist in the intersection or network geometry setup and/or modification; traffic signal warrant analysis and justification, design, timing and coordination plan development, operations, and management of traffic signal systems. Computer programs can also help with signal inventory and maintenance management. More information can be found in the Signal Timing Manual.

9-11.02 Desktop Computer (PC) Software

There are many PC software programs available to the traffic signal designer or operations analyst.

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 traffic signal warrants defined in the Minnesota Manual of Uniform Traffic Control Devices (MN MUTCD).

There are many computer tools that users can choose from for signal timing and coordination analysis applications. A detailed introduction of the Mn/DOT most used software, Synchro, and a brief description of three other widely utilized programs, including, TRANSYT-7F, PASSER-II, and CORSIM are provided in Mn/DOT Traffic Signal Timing Manual. It is important to know that one can not (or should not) simply implement the computer-generated timing and offset settings. The engineers must carefully fine-tune the settings in the field based on observations of actual traffic flows.

9-11.03 Computer-Aided Drafting

Microstation is an extremely powerful computer-aided drafting software. Training 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 Standard Plates Manual.
5. Minnesota Department of Transportation, Standard Specifications for Construction.
6. Minnesota Department of Transportation, Technical Manual.
7. Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD)
8. National Electrical Manufacturers Association NEMA Traffic Control Systems, Standards Publication TS 1-1983 Washington, DC.

9. National Electrical Manufacturers Association NEMA Traffic Control Systems, Standards Publication TS 2-1992 Washington, DC.

10. National Fire Protection Association National Electrical Code.

11. National Research Council, Transportation Research Board Highway Capacity Manual.

12. United States Department of Transportation, Federal Highway Administration Manual on Uniform Traffic Control Devices for Streets and Highways.

13. United States Department of Transportation, Federal Highway Administration Traffic Control Devices Handbook.

14. United States Department of Transportation, Federal Highway Administration, User Guide for Removal of Not Needed Traffic Signals.

15. Mn/DOT Signal Design Manual.

16. Mn/DOT Traffic Signal Timing and Coordination Manual

ABBREVIATIONS / ACRONYMS

AFMS - Automated Facilities Management System

AWF - Advance Warning Flasher

CAES - Office of Computer-Aided Engineering Services

CESU - Central Electrical Service Unit

FHWA - Federal Highway Administration

ITE - Institute of Transportation Engineers

ITS - Intelligent Transportation Systems

LED - Light-Emitting Diode

MESU - Metro Electrical Service Unit

Mn/DOT - Minnesota Department of Transportation

MN MUTCD - Minnesota Manual on Uniform Traffic Control Devices

MUTCD - Manual of Uniform Traffic Control Devices

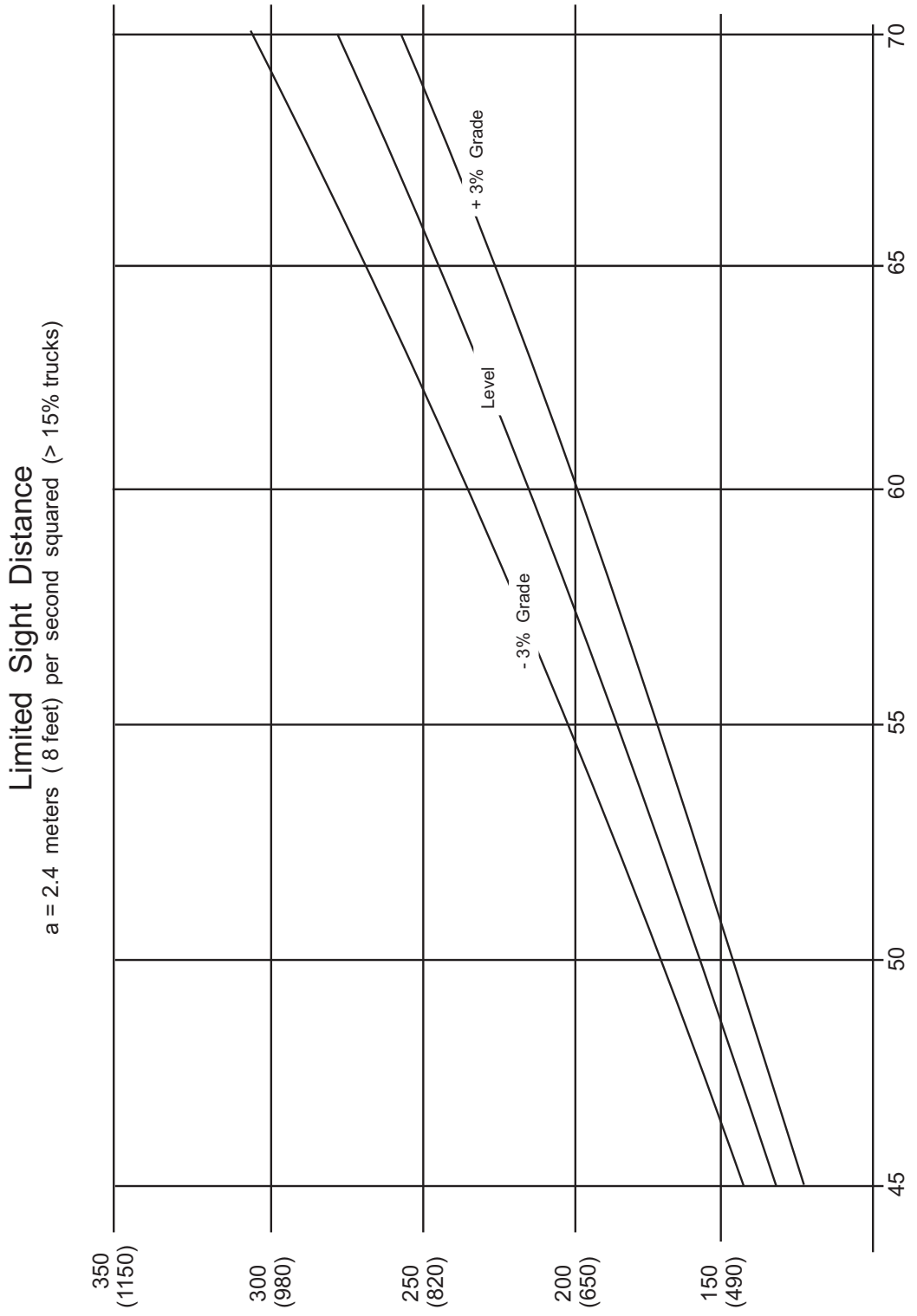
NEMA - The National Electrical Manufacturers Association

NFPA - National fire Protection association

RESU - Regional Electrical Service Unit

SJR - Signal Justification Report

TE request - Traffic Engineering Request



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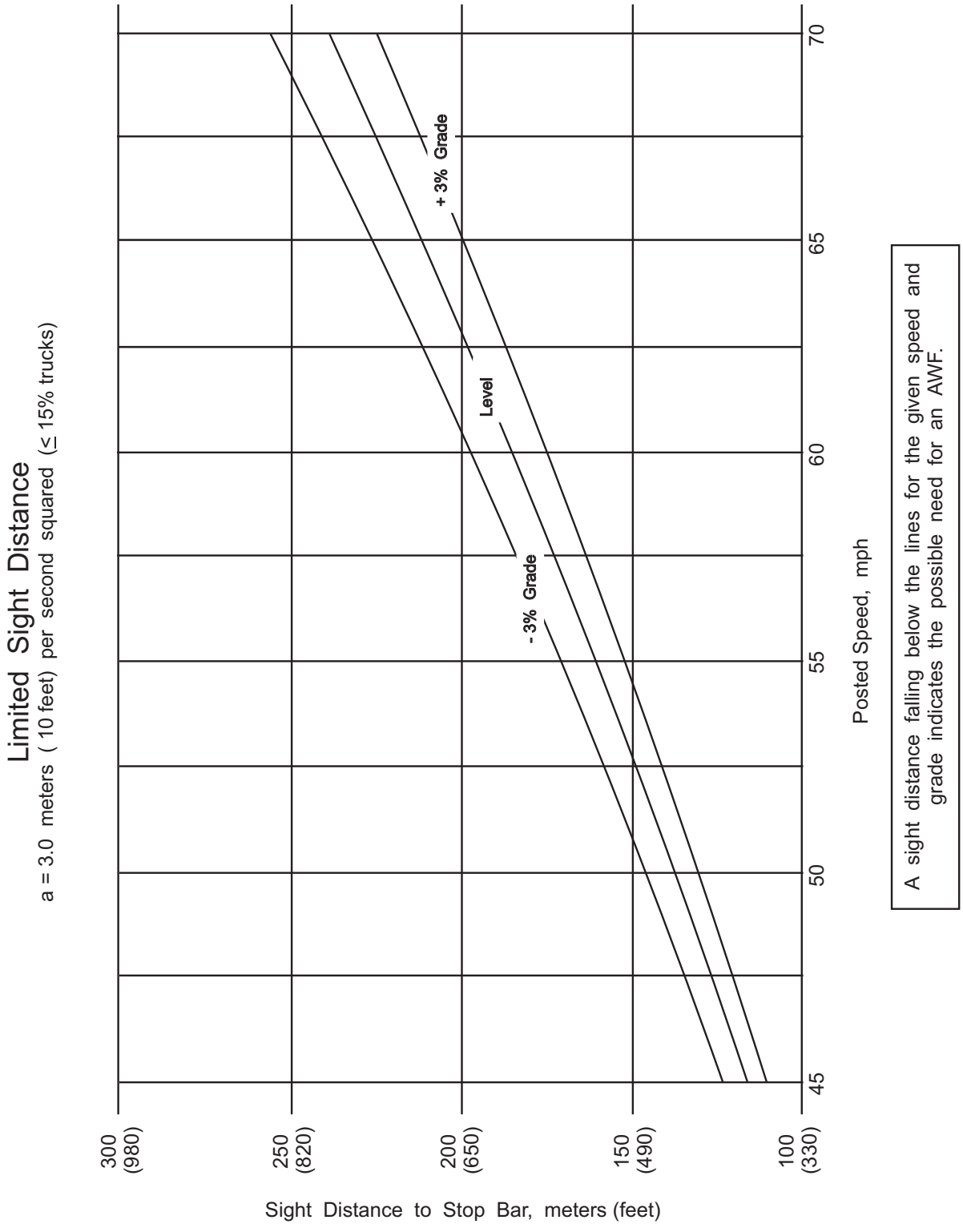
July 1, 2000	**LIMITED SIGHT DISTANCE GRAPH**	TABLE 9.1A



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July 1, 2000	**LIMITED SIGHT DISTANCE GRAPH**	TABLE 9.1B