# CHAPTER 15

# TRAFFIC

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# TRAFFIC SIGNAL CONTROL

## General

The objective of traffic signal control is to provide for safe and efficient traffic flow at intersections, along routes and in street networks. If traffic signals are justified, properly located and maintained one or more of the following advantages may be achieved:

1. Reduce the frequency of certain types of accidents, especially the right angle and pedestrian types.

2. Improve the traffic handling capacity of the intersection.

3. Interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to use the intersection.

## Traffic Signal Terms

**Coordination** – Establishment of a definite timing relationship between adjacent traffic signals.

**Cycle Length** – The number of seconds required for one complete sequence of signal indications at an intersection.

**Detector** - A device for indicating the presence or passage of vehicles or pedestrians.

**Interval**– A portion of the signal cycle during which the indications do not change.

**Phase** – A part of the traffic signal time cycle allocated to any combination of traffic movements receiving right of way simultaneously during one or more intervals.

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

**Preemption** – A term used when the normal signal sequence at an intersection is interrupted and/or altered in deference to a special situation such as the passage of a train or granting the right of way to an emergency vehicle.

**Traffic Signal Controller** – A device which controls the sequence and duration of signal indications at an intersection.

## Signal Poles & Signal Heads

All new signal poles shall be galvanized steel unless otherwise determined upon inspection. The signal pole must be placed at least 4 feet from the back of the curb and gutter. Always avoid placing a pole in the sidewalk.

The arrangement of the lenses in a vehicular signal face, visibility of vehicular signal heads and illumination requirements are given in the Manual of Uniform Traffic Control Devices (MUTCD). The width of the intersection, type of control, number of lanes and the alignment of the intersection determine the number of indications for an approach. Where a vehicular signal head is meant to control a specific lane or lanes of approach, its position should be in the path of that movement as specified in the Traffic Control Devices Handbook. Standard arrangements for vehicular signal heads used by the SDDOT are as follows:

> 5-lane section - 4 heads - one head is placed on the vertical pole to the left, one on the pole with the mast arm and two on the mast arm. On the mast arm, the left head is placed in line with, or to the right of the line common between the left-turn lane and the left-most through lane, the right head is placed on the lane line between the two through lanes.
>
> Signal heads should be placed a minimum distance of 8 feet apart on the mast arm. A distance of 10 feet is desirable.
>
> 3-lane section - 3 heads - one head is placed on the vertical pole to the left, one on the pole with the mast arm and one in line with, or to the right of the line common between the left-turn lane and the through lane.
>
> 2-lane section -3 heads - one head is placed on the vertical pole to the left, one on the pole with the mast arm and one on the mast arm in line with the driver.

The length of the mast arm depends upon the width of the roadway. Generally, the mast arm should not exceed 40 feet.

Pedestrian signal heads, signs and buttons are located below the vehicular signal head and mounted on the pole. It is important to show the pedestrian button on the side of the pole the pedestrian will stand to press the button.

## Traffic Signal Controllers

Traffic signal controllers are classified as pretimed or actuated.

A pretimed controller operates within a fixed cycle length using preset intervals. This type of control equipment is best suited for locations with predictable volumes and traffic patterns such as downtown areas and in coordinated systems.

Semi-actuated control requires detectors on the minor street approaches. Semi-actuated control tends to be most applicable at locations where traffic on the major street is heavy and arrivals are random on the minor street. Semi-actuated control is used in a coordinated system.

Fully actuated control requires detectors on all approach lanes. All phase green times are determined by the number of vehicles detected. Fully actuated control is not suitable for coordinated systems.

## Detector Loops

In semi-actuated control and actuated left turn lanes; detector loops should be placed at the front of the stop bar on the side streets.

In fully actuated control at low speed approaches, detector loops should be placed on the mainline as noted in Table 15-1.

| **Approach Speed** | | **Detector Set-Back Stop Line to Leading Edge of Loop** | | **Minimum Green** | **Passage Time** |
|---|---|---|---|---|---|
| mph | kph | feet | meters | seconds | seconds |
| 15 | 24 | 40 | 12 | 9 | 3 |
| 20 | 32 | 60 | 18 | 11 | 3 |
| 25 | 40 | 80 | 24 | 12 | 3 |
| 30 | 48 | 100 | 30 | 13 | 3.5 |
| 35 | 56 | 135 | 41 | 14 | 3.5 |
| 40 | 64 | 170 | 52 | 16 | 3.5 |

**Table 15-1** Detector Placement at Low Speed Approaches in Fully Actuated Control

In fully actuated control at high-speed approaches, use dilemma loops. High-speed approaches are defined as those approaches with a speed in excess of 35 mph. At these speeds, it may be difficult for the driver to decide whether to stop or proceed when faced with a yellow change indication. An abrupt stop may result in a rear-end collision, while the decision to proceed through the intersection may cause a right-angle accident. The concept of this system is simply that of detecting the vehicle before it enters the dilemma zone and then extending the green until the vehicle clears the dilemma zone. The placement scheme is shown in Figure 15-1.

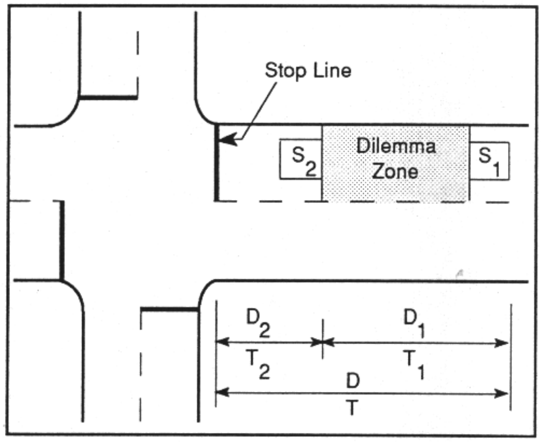



**Figure 15-1** Green Extension System – Two Detectors

The following equations are used to calculate the appropriate distances for the loops.

$$D = (1.47 \times V \times t_1) + \left( \frac{V^2}{30 \times f} \right)$$

**Equation 15-1**

$$D_2 = 1.47 \times V \times \left( \frac{V}{30} + 1 \right)$$

**Equation 15-2**

$$D_1 = D - D_2$$

**Equation 15-3**

Where:

$V$ =85th percentile speed, mph

$t_1$ =perception reaction time, sec – usually 1 sec.

$f$ =coefficient of friction

$D$ =stopping distance, ft

$D_1$ =clearing distance, ft

$D_2$ =separation between loops, ft

## Signal Preemption and Priority Control

It may be desirable to preempt the normal operation of a traffic signal to facilitate the clearance of traffic that might be backed up onto an active railroad track or to facilitate the movement of emergency vehicles. In most applications, a receiver is mounted at the signalized intersection. The receiver detects a signal emitted from the emergency vehicle. The preemptor takes control of the signals upon receipt of a signal from the railroad or emergency vehicle and flushes the intersection approach that crosses the railroad track or sets the signal display to facilitate the passage of the emergency vehicle.

Where conflicting preemptions occur, train preemption receives first priority, emergency vehicles second priority. All necessary vehicular clearance periods must be provided. However, pedestrian clearances may be abbreviated if necessary.

## Flashing Operation

There are two reasons for flashing a traffic signal: to reduce the level of control when traffic volume is low and to provide a safe method of control when a signal is inoperative. While a traffic signal may be needed at an intersection during much of the day, it is often the case that the signal is not needed all the time. During such times, a signal may be more efficient when operated in the flashing mode.

Typically, when a signal is operated in the flashing mode, the major street is flashed yellow and all other streets are flashed red. All signals facing a given approach should flash the same color. Left-turn signals should not be flashed red while their associated through movement signals are flashed yellow. Pedestrian signals should be dark during flashing operation. Flashing operation should begin and end at the same time for all/flashed signals in an area, so as not to violate drivers' expectations.

# TRAFFIC SIGNAL PHASING & TIMING

## Traffic Signal Phasing

The number of phases and phase sequence depends upon the geometry of the intersection, the volumes and directional movements of vehicular traffic and pedestrian crossing requirements. The number of phases should be kept to a minimum. Each additional phase reduces the effective green time available for the movement of traffic flows (increases lost time due to starting and stopping delays) as illustrated in Figure 15-2.

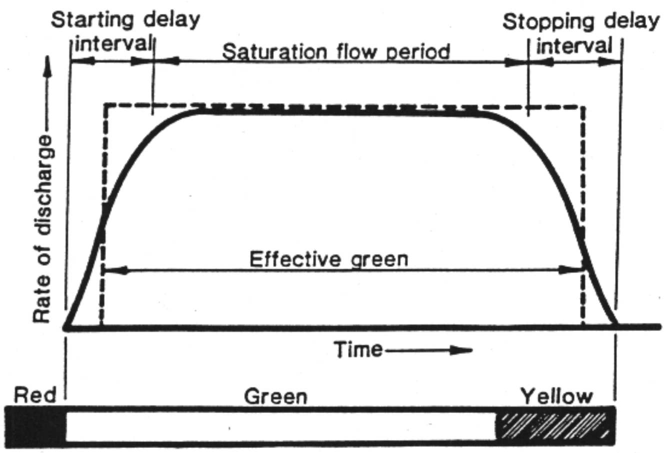



**Figure 15-2** Schematic representation of queue discharge during a signal phase.

Separate left-turn phases reduce the available green time for through traffic and tend to increase total intersection delay. Consider left-turn phasing when the volume of left-turners is greater than 100 vehicles per hour (vph) or as indicated in the Manual of Traffic Signal Design.

There are two left-turn phasing alternatives. When the protected left turn proceeds the accompanying through movement it is called lead left. When the left-turn phasing follows the through movement, it is called lag left. The most common practice is to allow opposing left turns to move simultaneously. This operation requires separate left-turn storage lanes.

## Cycle Lengths

Short cycle lengths generally yield the best performance in terms of providing the lowest average delay. A cycle length of 120 seconds should be the maximum used, irrespective of the number of phases. To meet with driver expectations, major movement green intervals should not be less than 12 seconds, minor movement green intervals should not be less than 7 seconds and left-turn green intervals should not be less than 4 seconds.

If pedestrians are to be accommodated, each green interval must be checked to insure that it is not less than the minimum green time required for pedestrians to cross the intersection.

The phase change interval (yellow and red) for each phase must be determined to ensure that approach vehicles can either stop or clear the intersection without conflicts.

## Level of Service for Signalized Intersections

Level of services for signalized intersections is defined in terms of delay. Level-of-service (LOS) criteria are stated in terms of the average stopped delay per vehicle for a 15-minute analysis period. The criteria are given in Table 15-2. Delay is a complex measure and is dependent upon a number of variables, including the quality of progression, the cycle length, the green ratio, and the volume/capacity (v/c) ratio for the lane group in question.

| LEVEL OF SERVICE | STOPPED DELAY PER VEHICLE (SEC) |
|---|---|
| A | $\leq$5 |
| B | >5.0 and $\leq$ 15.0 |
| C | >15.0 and $\leq$ 25.0 |
| D | >25.0 and $\leq$ 40.0 |
| E | >40.0 and $\leq$ 60.0 |
| F | > 60.0 |

**Table 15-2** Level-of-Service Criteria for Signalized Intersections

LOS A describes operations with very low delay, up to 5 seconds per vehicle. This level of service occurs when progression is extremely favorable and most vehicles arrive during the green phase. Most vehicles do not stop at all. Short cycle lengths may also contribute to low delay.

LOS B describes operations with delay greater than 5 and up to 15 seconds per vehicle. This level generally occurs with good progression, short cycle lengths, or both. More vehicles stop than with LOS A, causing higher levels of average delay.

LOS C describes operations with delay greater than 15 and up to 25 seconds per vehicle. These higher delays may result from fair progression, longer cycle lengths, or both. Individual cycle failures may begin to appear at this level. The number of vehicles stopping is significant at this level, though many still pass through the intersection without stopping.

LOS D describes operations with delay greater than 25 and up to 40 seconds per vehicle. At level D, the influence of the congestion becomes more noticeable. Longer delays may result from some combination of unfavorable progression, long cycle lengths, or high v/c ratios. Many vehicles stop, and the proportion of vehicles not stopping declines. Individual cycle failures are noticeable.

LOS E describes operations with delay greater than 40 and up to 60 seconds per vehicle. This level is considered by many agencies to be the limit of acceptable delay. These high delay values generally indicate poor progression, long cycle lengths, and high v/c rations. Individual cycle failures are frequent occurrences.

LOS F describes operations with delay in excess of 60 seconds per vehicle. This level, considered to be unacceptable to most drivers, often occurs when arrival flow rates exceed the capacity of the intersection. It may also occur at high v/c ratios below 1.0 with many individual cycle failures. Poor progression and long cycle lengths may also be major contributing causes to such delay levels.

## Phase Change Intervals

The phase change interval (yellow plus all-red) advises drivers that their phase has expired and either permits them to come to a safe stop prior to entering the intersection, or allows vehicles that are too near the intersection to stop, to clear the intersection.

The following equation is recommended for use in determining the phase change interval (Y + AR):

$$Y + AR = t + \frac{V}{(2 \times a) \pm (64.4 \times g)} + \frac{W + L}{V}$$

**Equation 15-4** Yellow + All Red Time

Where:

Y + AR = sum of the yellow and all-red (seconds)

t = perception/reaction time of driver (seconds)

V = approach speed (feet per second)

a = deceleration rate (feet per second per second)

W = width of intersection (feet)

L = length of vehicle (feet)

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

Figure 15-3 illustrates the determination of the phase change interval.

The value t accounts for the perception – reaction time of drivers approaching the intersection. The standard value of t used at signalized intersections is 1.0 second.

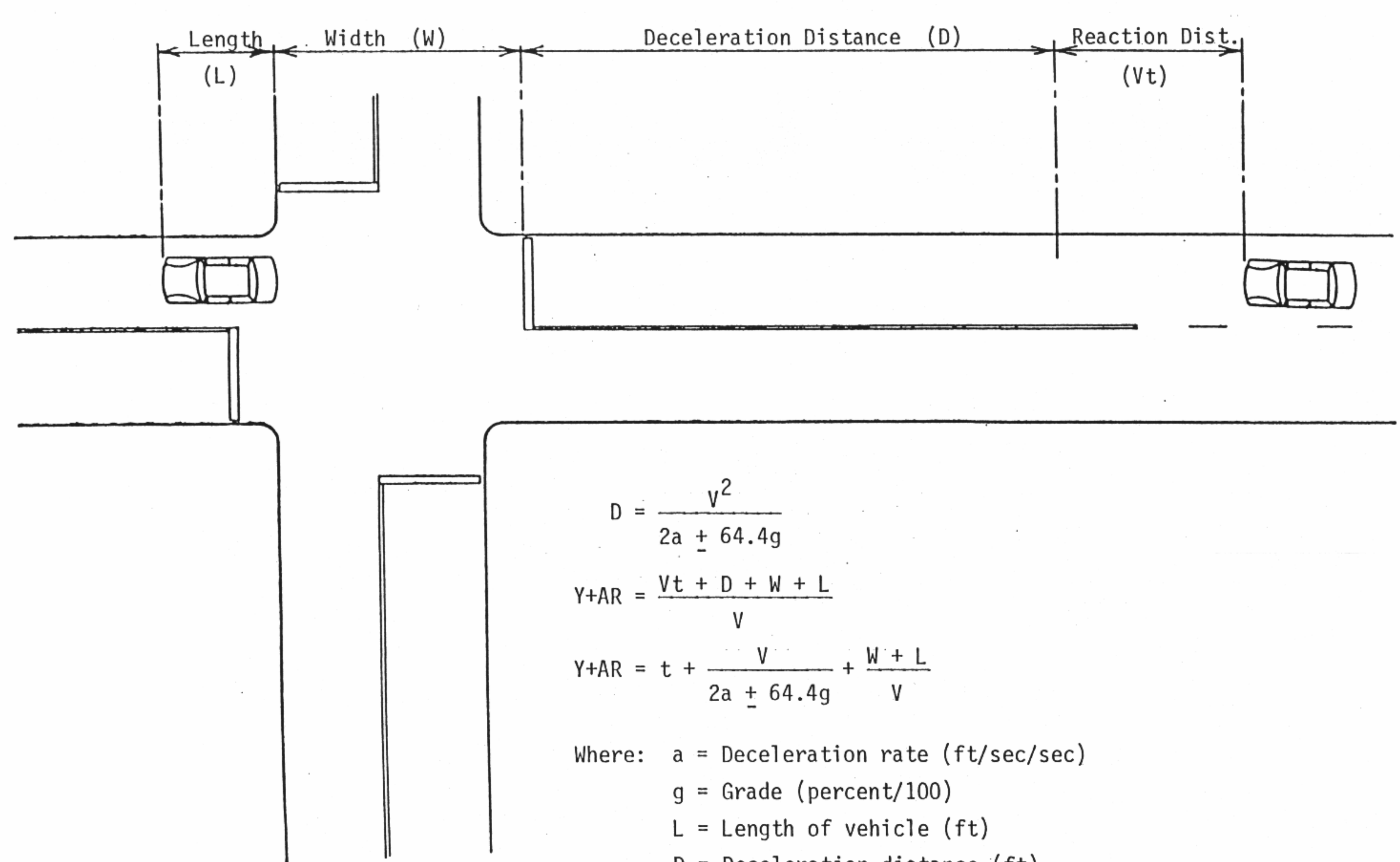
Typically, the $85^{th}$ percentile speed or the speed limit is used to determine the phase change interval

The value of deceleration rate, a is 10 feet/sec/sec.

The width of the intersection, W, is most commonly measured from the stop line to the far edge of the farthest traveled lane of cross-street traffic.  Where pedestrian volumes are heavy, it may be appropriate to measure W to the far edge of the pedestrian crosswalk or curb to curb.

L is the length of the vehicle, and is usually taken as 20 feet.

The percent of grade, g divided by 100 (added for upgrade and subtracted for downgrade) properly accounts for the effect of grades.




$$D = \frac{V^2}{2a \pm 64.4g}$$

$$Y{+}AR = \frac{Vt + D + W + L}{V}$$

$$Y{+}AR = t + \frac{V}{2a \pm 64.4g} + \frac{W + L}{V}$$

Where: a = Deceleration rate (ft/sec/sec)

g = Grade (percent/100)

L = Length of vehicle (ft)

D = Deceleration distance (ft)

t = Reaction time (sec)

V = Speed of vehicle (ft/sec)

W = Width of intersection (ft)

Y+AR = Yellow plus all-red phase change interval (sec)

**Figure 15-3** Determination of the Phase Change Interval

**Timing for Pedestrian Crossings**

Where pedestrians are present, green intervals should be checked to assure sufficient green and yellow time for crossing.

The minimum green time is determined by the following formula:

$$G = P + \frac{D}{S} - Y$$

**Equation 15-5** Minimum Green Time

Where:

G = minimum green time in seconds
P = pedestrian start-off period, normally 4-7 seconds or more
D = walking distance in feet
S = walking speed in feet per second, normally 4 feet per second
Y = yellow interval in seconds

Where there are fewer than 10 pedestrians per cycle, the lower limit of 4 seconds is normally adequate as a pedestrian start-off period. For moderate pedestrian volumes (10 to 20 per cycle), 7 seconds is frequently used. Longer intervals may be necessary for heavier pedestrian volumes.

The pedestrian clearance period (D/S) should be long enough to permit the pedestrian to complete a crossing after stepping off the curb.

The crossing distance, D, desirably should be the full curb-to-curb distance measured along the centerline of the crosswalk or normal pedestrian crossing path

A walking speed of 4 feet per second is normally assumed for average adult pedestrians. Where significant volumes of elderly, handicapped, or child pedestrians are present, a lower speed should be used. Where pedestrian traffic is congested, lower walking speeds should also be used.

When separate pedestrian displays (WALK, DON'T WALK) are used, the WALK interval should be at least equal to the pedestrian start-off time, P. The flashing DON'T WALK interval is normally equal to the pedestrian clearance, D/S.

**Highway Capacity Software**

The SDDOT uses the Highway Capacity Software to calculate cycle lengths. Listed below are the necessary steps to run the program:

1. Geometrics and Traffic:

   Number of Lanes & Usage - Number of lanes at each approach. If the lane is shared, indicate so (press the shared button).

   Volumes - Enter the traffic volume for each movement during the peak hour. Use current traffic counts from the field. The region traffic engineer is responsible for providing this information.

   Peak Hour Factor, PHF - Compute the Peak Hour Factor (PHF) for each approach;

   PHF = (Total Peak Hour Volume)÷(Peak 15 minute volume within the peak hour ∗ 4)

   Peak-15 Minute Volume – Enter the highest 15 minute volume within the peak hour.

   Right Turns on Red - Use zero, unless this information is provided from the field.

2. Operating Parameters:

   Initial Unmet Demand – Use zero.

   Arrival Type or Percent Arriving during Green -

   Type 1 - Very poor progression quality as a result of conditions such as overall network signal optimization over 80% of the lane group volume arriving at the start of the red phase.

   Type 2 - Represents unfavorable progression on two-way arrivals. 40% to 80% of the lane group volume arriving in the middle of the red phase.

   Type 3 - Represents operations at isolated and noninterconnected signalized intersections. It may also be used to represent coordinated operation in which the benefits of progression are minimal. Random arrivals less than 40% of the lane group volume throughout the green phase.

   Type 4 - Represents favorable progression quality on two-way arterials. 40% to 80% of the lane group volume arriving throughout the green phase.

   Type 5 - Represents highly favorable progression quality, which may occur on routes with low to moderate side street entries and which receive high priority treatment in the signal timing design. Over 80% of the lane group volume arriving at the start of the green phase.

   Type 6 - Represents dense traffic progressing over a number of closely spaced intersections with minimal or negligible side-street entries.

Unit Extension - Use default; 3 seconds per cycle.

Upstream Filtering/Metering Adjustment Factor, I – Use default, 1.

Start-up Lost Time - Use 3 seconds per cycle.

Extension of Effective Green - Use 3 seconds per cycle. (Should be calculated in the field)

Pedestrian Speed – Usually use 4 feet per second.

Travel Distance - Enter the length of the pedestrian path from curb to curb.

3. Phasing Design:

   Green Time – Major movement green intervals should not be less than 12 seconds, minor movement green intervals should not be less than 7 seconds and left-turn green intervals should not be less than 4 seconds.

   Yellow & All Red Time - Compute yellow and all red time for each direction (North/South and East/West).

4. Saturation Flow Adjustment:

   Ideal Saturation Flow Rate – Use 1600, except in Sioux Falls & Rapid City use 1800.

   Lane Width - Enter the lane width of each lane.

   Percent Heavy Vehicles - Use default, 2%, unless field data is available.

   Percent Grade - Use zero, unless field data is available.

   Parking Maneuvers – If there is on street parking, indicate so (check box).

   Bus Stops - Use zero.

   Area Type – Indicate if the roadway is in a central business district or similar.

   Highest Single Lane Volume in Lane Group – Only enter value if field data is available.

   Conflicting Pedestrians – Use default, 0.

   Percent Right-Turns Using Protected Phase - Use default, 0.

5. Adjustment Factors – Use defaults for all, unless factors are computed from field data.

**Signal Cable and Conduit**

Each detector loop requires a twisted shielded pair, TSP. Consecutive lane loops at the stop bar require only 1 TSP.

Each luminaire mounted on a signal pole requires 2 #6 copper cables. The 2 #6s run from the signal pole to the power source. The 2 #6s used for luminaire extensions do not accumulate.

3 #4 copper cables are needed from the power source to the controller.

Conductors run from the controller to the signal poles. There should be enough conductors for each signal head and 2-4 extra conductors. 3-section vehicle heads require 4 conductors, 5-section vehicle heads require 6 conductors, pedestrian heads require 3 conductors and pedestrian push buttons require 2 conductors. Commonly used conductors are 7, 12, 19 and 24.

2 conductors (2/c) cable for a **pedestrian push button**. 7' is needed.

3/c cable for an **opticom confirmation light** mounted unit on a mast arm. 22' + the distance from the pole to the location of the opticom mounted on the mast arm is needed.

4/c cable for a **3-section vehicle head**. 15' is needed for the signal mounted on the pole and 22' + the distance from the pole to the location of the signal head on the mast arm is needed for the head mounted on the mast arm.

4/c cable for a **pedestrian vehicle head**. 15' is needed.

4/c cable for an **opticom unit** on a mast arm. 22' + the distance from the pole to the location of the opticom mounted on the mast arm is needed.

7/c cable for a **5-section vehicle head**. 15' is needed for the signal mounted on the pole and 22' + the distance from the pole to the location of the signal head on the mast arm is needed for the head mounted on the mast arm.

7/c cable is used for **interconnect**.

Pole and bracket cable for **luminaire extensions** to a signal poles. Height of the pole + length of the arm + 7' of slack.

Typically, # 14 cable is used for the cables described above, except in Sioux Falls. When working on projects in Sioux Falls, use # 12 cable.

All signal cable is placed in conduit. 4" conduit is usually placed between the controller and the junction box, 3" conduit is usually placed under the roadway and 2" conduit is usually placed between junction boxes and signal poles. When in doubt of what conduit size to use, size the conduit using the following equation:

$$1.58 \times \sqrt{d_1^2 + d_2^2 + d_3^2 + d_4^2 + \dots\dots\dots\ d_x^2}$$

**Equation 15-6** Conduit Size

Where $d_1$, $d_2$, $d_3$, $d_4$, ………$d_x$, is the diameter of the cables in the conduit to be sized.

Table 15-3 gives the diameters and diameters squared for several cables.

| Cable | d | d2 | Cable | d | d2 |
|---|---|---|---|---|---|
| 24/c #14 | 0.8350 | 0.6972 | TSP | 0.4000 | 0.1600 |
| 24/c #12 | 0.9950 | 0.9900 | 1/c #14 | 0.1300 | 0.0169 |
| 20/c #14 | 0.7850 | 0.6162 | 1/c #12 | 0.1600 | 0.0256 |
| 20/c #12 | 0.9100 | 0.8281 | 1/c #10 | 0.2000 | 0.0400 |
| 19/c #14 | 0.7500 | 0.5625 | 1/c #8 | 0.3300 | 0.1089 |
| 19/c #12 | 0.9000 | 0.8100 | 1/c #6 | 0.4000 | 0.1600 |
| 12/c #14 | 0.6500 | 0.4225 | 1/c #4 | 0.4500 | 0.2025 |
| 12/c #12 | 0.7500 | 0.5625 | 1/c #2 | 0.5100 | 0.2601 |
| 7/c #12 | 0.5200 | 0.2704 | 1/c #1 | 0.6000 | 0.3600 |
| 7/c #14 | 0.4600 | 0.2116 | 1/c #0 | 0.7000 | 0.4900 |
| 4/c #14 | 0.4000 | 0.1600 | 1/c #00 | 0.7600 | 0.5776 |

**Table 15-3** Diameters and Diameters Squared of Cables

## Junction Boxes for Signal Conduit

A 24" diameter junction box is used at the controller, an 18" diameter junction box is used at signal poles and a 12" diameter junction box can be used to interconnect signals.

## WARRANTS FOR ROADWAY, INTERSECTION, INTERCHANGE AND CONTINUOUS INTERSTATE LIGHTING PROJECTS

**General Comments:**

Lighting may be considered if one or more of the following warrants are met. The satisfaction of a warrant or warrants is not in itself justification for roadway lighting to be installed. Engineering studies and judgment may alter the need and/or extent of the project. The engineering study should indicate the installation of roadway lighting would improve the overall safety and/or operation of the intersection/roadway.

Definitions:

- Urban: Areas of population of 5,000 or greater within a City's limits.
- Rural: Areas of population less than 5,000 within a City's limits.
- ADT: The average daily traffic

**Warrants for Roadway Lighting:**

The warrant for roadway lighting is satisfied where a local agency desires to have roadway lighting in a developed area within the city limits and is willing to maintain the lighting system and pay a match according to the policy for "Lighting on State Highways". Also, one of the following conditions must be met:

1. Where existing lighting in the area causes a distraction or unsatisfactory visibility for the driver.
2. Where two or more nighttime accidents occurred in the past 12-month period or three or more nighttime accidents occurred in the past 36-month period and it is deemed that roadway lighting would reduce the risk of accidents.
3. Where nighttime pedestrian movement occurs on a regular bases.

**Warrants for Intersection Lighting:**

The warrant for intersection lighting is satisfied when one of the following conditions is met:

1. Where the current ADT exceeds 1,000 for each roadway of the intersection.

2. Where two or more nighttime accidents occurred in the past 12-month period or three or more nighttime accidents occurred in the past 36-month period and it is deemed that roadway lighting would reduce the risk of accidents.

3. Where a traffic signal is installed.

4. Where combinations of sight distance, horizontal or vertical curvature of the roadway, channelization or other factors may constitute a confusing or unsatisfactory condition that may be improved with lighting.

5. Where existing lighting in the area causes a distraction or unsatisfactory visibility for the driver.

6. Where nighttime pedestrian movement occurs on a regular bases.

7. Railroad Crossing locations at or near the intersection.

**Warrants for Partial Interchange Lighting:**

The warrant for partial interchange lighting is satisfied when one of the following conditions is met:

1. Where the interchange is situated adjacent to a safe point of refuge (i.e. motels, gas stations, etc.).

2. Where the current ADT on either interstate off ramp exceeds 1,000.

3. Where in place commercial or industrial development lighting causes a distraction or unsatisfactory visibility for the driver.

4. Where two or more nighttime accidents occurred in the past 12-month period or three or more nighttime accidents occurred in the past 36-month period and it is deemed that roadway lighting would reduce the risk of accidents.

**Warrants for Full Interchange Lighting:**

The warrant for full interchange lighting is satisfied when one of the conditions for partial interchange lighting is met as well as one of the following conditions:

1. Where the current ADT on the interstate exceeds 10,000 for urban conditions or 5,000 for rural conditions and the current ADT on the crossroad exceeds 10,000 under urban conditions, or 5,000 under rural conditions.

2. Where the crossroad is lighted for one half mile or more on each side of the interchange.

**Warrants for Continuous Interstate Lighting:**

The warrant for continuous interstate lighting is satisfied when one of the following conditions is met:

1. Where the current ADT for the interstate exceeds 25,000.

2. Where three or more successive lighted interchanges are located with an average spacing of one and one half miles or less, and adjacent areas outside the right-of-way are urban in character.

3. Where existing lighting in the area causes a distraction or unsatisfactory visibility for the driver.

4. Where lighting may be expected to result in a significant reduction in the night accident rate.

## STANDARD ROADWAY LIGHTING

### Light Level and Uniformity

The design light level chosen is based on Table 15-4 below.

| Roadway and Sidewalk Classification | Area Classification | Average Light Level | Uniformity (Ave./Min.) |
|---|---|---|---|
| Expressway | Commercial<br>Intermediate | 1.4<br>1.2 | 3:1 |
| Major | Commercial<br>Intermediate<br>Residential | 1.2<br>1.0<br>0.8 | 3:1 |
| Collector | Commercial<br>Intermediate<br>Residential | 1.0<br>1.0<br>0.8 | 3:1 |
| Local | Commercial<br>Intermediate<br>Residential | 0.8<br>0.8<br>0.6 | 4:1 |
| Sidewalks | Commercial<br>Intermediate<br>Residential | 0.9<br>0.6<br>0.3 | 3:1<br>4:1<br>6:1 |

**Table 15-4** Light Level Recommendations

Uniformity is the ratio of the average light level to the minimum light level in the area being analyzed.

### Light Source

High Pressure Sodium (HPS) lamps are typically used. HPS lamps provide excellent luminous efficacy, good lumen-maintenance, long life, and very acceptable color.

### Mounting Height and Wattage

The mounting height is the distance from the roadway surface to the luminaire. Use a mounting height that can be maintained by the local authority. Generally, pole heights range from 40’-50’ for standard roadway lighting. Mounting heights are usually specified in 5’ increments.

Light source size is measured in wattage. Wattage and mounting height are directly related and are selected as a combination. The relationship is given in Table 15-5.

| Mounting Height | Wattage |
|---|---|
| Less than or equal to 40’ | 250W |
| Greater than or equal to 45’ | 400W |

**Table 15-5** Relationship between Roadway Lighting Mounting Height and Wattage

## Luminaire Type

The lateral light distributions are categorized by patterns established by the Illumination Engineering Society (IES) designated as Types I, II, III, IV, and V as shown below in Figure 15-4.

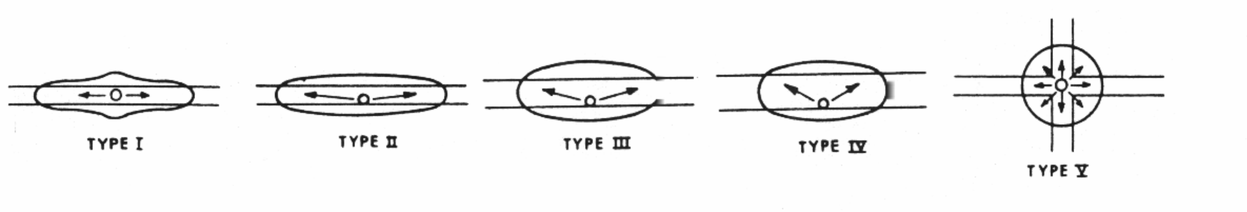



**Figure 15-4** Lateral Light Distributions

Type I applies to rectangular patterns on narrow streets. Type II applies to narrow streets. Type III applies to streets of medium width. Type IV applies to wide street applications. Type V applies to areas where light is to be distributed evenly in all directions.

Luminaires are classified as cutoff, semi-cutoff, and non-cutoff, and are shown in Figure 15-5, below. Luminaire classifications are descriptive of the position of the bulb in the socket.

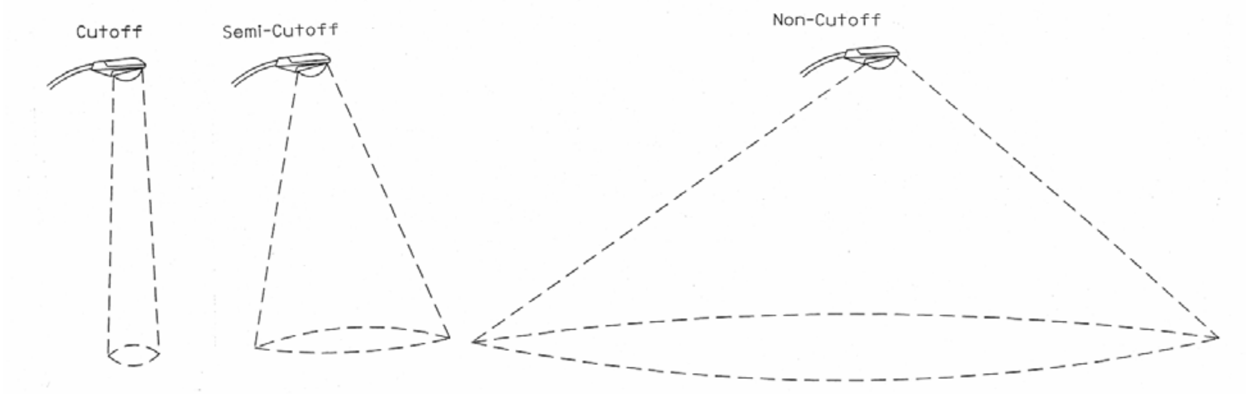



**Figure 15-5** Roadway Luminaire Classifications

Cutoff control is generally used for partial interchange lighting and rural intersections due to the ability to reduce glare.

Semi-cutoff control is typically used for standard roadway lighting. Adequate glare control is obtained with reasonable spacing

Non-cutoff control is used in areas with a lot of background light. Non-cutoff luminaires are not used at lower mounting heights because of glare.

**Luminaire Spacing and Location**

SDDOT uses PRECALA and CALA software to determine luminaire spacing. Photometrics from the luminaire manufacturers, lumens/luminaire, a light loss factor, layout type, mounting height, roadway width, setbacks, tilt and the light level are entered into the program to calculate the spacing and uniformity of a specific luminaire.

Lumens/Luminaire – A 250W luminaire = 27,500 lumens. A 400W luminaire = 50,000 lumens.

Light Loss Factor – SDDOT uses a 0.70 light loss factor for roadway lighting.

Layout Type - The luminaire layout needs to be chosen relative to the roadway geometry. Several possible layouts are shown below in Figure 15-6.

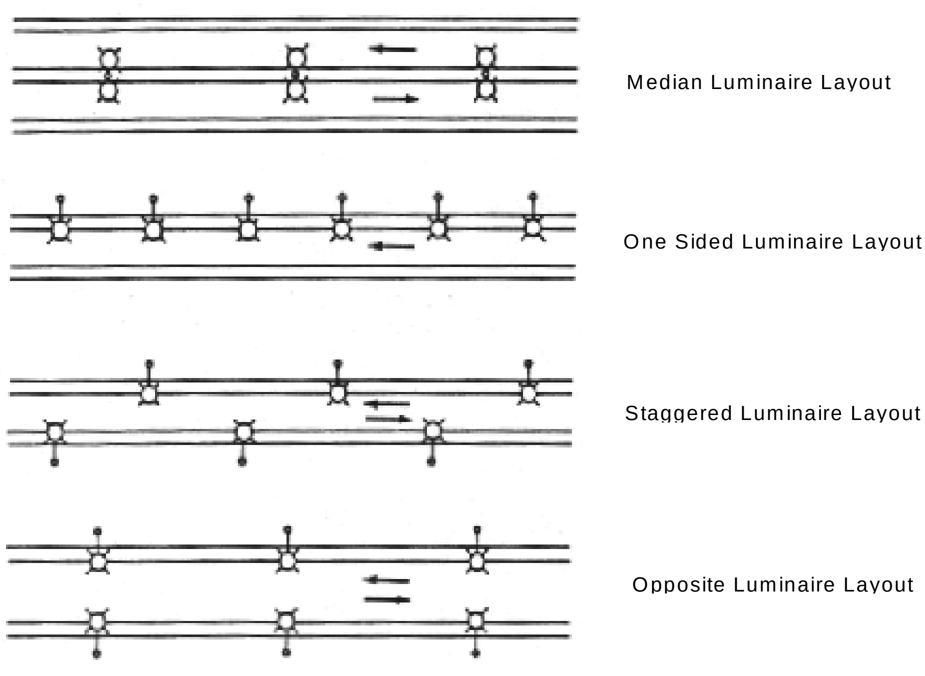



**Figure 15-6** Roadway luminaire layout types

Setbacks – The distance the luminaire is from the edge of the roadway.

Tilt – The angle of the luminaire.  Standard roadway luminaires, cobra heads, cannot be tilted.

**<u>Luminaire Supports</u>**

Luminaire poles are typically galvanized or self-weathering steel poles.  Luminaire poles generally have a breakaway base.  Fixed bases are used for luminaire poles adjacent to parking and luminaires that are barrier mounted.

**<u>Cable and Conduit</u>**

Standard roadway lighting luminaires are wired using two different configurations called "dual hots" and "alternating hots".  Dual hots are used when there **<u>are not</u>** any festoon outlets to be wired with the luminaire.  Alternating hots are used when there **<u>are</u>** festoon outlets to be wired with the luminaire.

Cable size is determined using the resistance calculation below:

$$\Omega / Mft = \frac{(V \times .05) - (I \times [MH + 10] \times R)}{(I \times L)} \times 1000$$

**Equation 15-7**  Cable Size Equation

Where;

$V$ = Voltage (240 volts for dual hots, 120 volts for alternating hots)
$I$ = Line-Operating Amperes (See Table 15-6)
$MH$ = Mounting Height in feet
$R$ = Resistance of #10 cable from NEC Table 8. Conductor Properties in ohms (.00124 ohms)
$L$ = Distance from farthest pole to the power source

Line-operating amperes can be found in Table 15-6 below.

| HPS BALLAST ELECTRICAL DATA – SINGLE VOLTAGE, 60Hz | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANSI Lamp Type | Watts | Line Volts | Line-Operating Amperes | ANSI Lamp Type | Watts | Line Volts | Line-Operating Amperes |
| **S-52** | 1000 | 120 | 9.6 | **S-66** | 200 | 120 | 2.1 |
| | | 208 | 5.8 | | | 208 | 1.2 |
| | | 240 | 4.8 | | | 240 | 1.1 |
| | | 277 | 4.4 | | | 277 | 0.9 |
| | | 347 | 3.5 | | | 347 | 0.7 |
| | | 480 | 2.5 | | | 480 | 0.6 |
| **S-51** | 400 | 120 | 4.1 | **S-55** | 150 | 120 | 1.7 |
| | | 208 | 2.4 | | | 208 | 1.0 |
| | | 240 | 2.1 | | | 240 | 0.9 |
| | | 277 | 1.8 | | | 277 | 0.8 |
| | | 347 | 1.4 | | | 347 | 0.6 |
| | | 480 | 1.1 | | | 480 | 0.5 |
| **S-50** | 250 | 120 | 2.7 | **S-54** | 100 | 120 | 1.2 |
| | | 208 | 1.6 | | | 208 | 0.7 |
| | | 240 | 1.4 | | | 240 | 0.6 |
| | | 277 | 1.2 | | | 277 | 0.5 |
| | | 347 | 0.9 | | | 347 | 0.4 |
| | | 480 | 0.7 | | | 480 | 0.3 |

**Table 15-6** HPS Ballast Electrical Data (from GE Lighting Fixtures book)

Solve for $\Omega$/Mft and using the National Electric Code (Table 8. Conductor Properties) choose the first conductor that has a larger $\Omega$/Mft than the calculated $\Omega$/Mft.

SDDOT does not use any cable smaller than #6.

Cable is placed in conduit in urban areas. In rural areas, cable is direct buried. Cable is always placed in conduit under roadways, rural or urban.

Conduit for lighting is sized like it is for signals, using Equation 15-6 on page 15-16.

**Junction Boxes**

Junction boxes should be no less than 18” and placed every 300 ft. in a lighting circuit. Always use a junction box when crossing a road if the cable within conduit is going to splice.

## Fuses

Two types of fuses can be used in a lighting circuit, Non-Time Delay and Dual Element.

The Non-Time Delay type of fuse must be able to carry 250% of the line operating amperes (Table 15-6). The Dual Element type of fuse must be able to carry 125% of the line operating amperes (Table 15-6).

For example, a 400-watt, 240-volt, dual hot luminaire draws 2.1 operating line amperes as shown in Table 15-6. The Non-Time Delay fuse would be selected by taking 2.1 amperes times 2.5 (250%) which equals 5.25 amperes. Using Table 15-7 below, the fuse size of 6 amperes would be used because it is the first fuse larger than 5.25 amperes.

| **Fuse Sizes in Amperes** | |
|---|---|
| Non-Time Delay Type Fuse | Dual Element Type Fuse |
| 1/10 | 1 1/8 |
| 1/8 | 1 1/4 |
| 2/10 | 1 4/10 |
| 1/4 | 1 6/10 |
| 3/10 | 1 8/10 |
| 1/2 | 2 |
| 3/4 | 2 1/4 |
| 1 | 2 1/2 |
| 1 1/2 | 2 8/10 |
| 2 | 3 2/10 |
| 3 | 3 1/2 |
| 4 | 4 |
| 5 | 4 1/2 |
| 6 | 5 |
| 8 | 5 6/10 |
| 10 | 6 1/4 |
| 15 | 7 |
| 20 | 8 |
| 25 | 9 |
| 30 | 10 |

**Table 15-7** Fuse Sizes

## HIGH MAST LIGHTING

High mast lighting implies an area type of lighting with groups of luminaires mounted on free standing poles. High mast lighting is used for interchange lighting, intersection lighting, rest areas and parking areas.

### Light Level and Uniformity

The design light level chosen is based on Table 15-8 below.

| Roadway and Sidewalk Classification | Average Light Level | Uniformity (Ave./Min.) |
|---|---|---|
| Interchange | 0.6-0.8 | 4:1 |
| Rest Area | 1.0 | 4:1 |
| Parking Lot | 0.8 | 4:1 |

**Table 15-8** Light Level Recommendations

### Light Source

High Pressure Sodium (HPS) lamps are typically used. HPS lamps provide excellent luminous efficacy, good lumen-maintenance, long life, and very acceptable color.

### Mounting Height and Wattage

The mounting height is the distance from the roadway surface to the luminaire. Free standing poles or towers have mounting heights varying from 80’ to 150’. Generally, towers are 150’ for interchange lighting. Mounting heights are usually specified in 5’ increments

High mast luminaires are 1000 Watts.

### Luminaire Type

The most common type of luminaire used in high mast lighting is the area type, which is usually having symmetric, asymmetric or long & narrow distribution.

### High Mast Location

The SDDOT uses CALA software to determine high mast lighting layouts. Photometrics from the luminaire manufacturers, lumens/luminaire, a light loss factor, layout type, mounting height, number of luminaires, roadway width, setbacks, tilt and the light level are entered into the program to calculate the spacing and uniformity of high mast lighting.

Towers can be placed no more than 50 ft. from the edge of the roadway.  Towers placed within the clear zone will need protection (guardrail).

## **Conduit and Wire Size**

Conduit and wire is sized in the same way as for standard lighting.