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General Information

A. Introduction

The purpose of this chapter is to supplement SUDAS Specifications Section 8010 and to provide general guidance for traffic signal designs on roadways within Iowa. The information is provided as an overview for traffic signals design consideration.

B. Scope

There is no legal requirement to use the information within this chapter by local agencies. This document refers to a number of other resources available for the designer to be considered when designing a traffic control signal. The document loosely follows the format of the MUTCD, as published by The U.S. DOT, FHWA and as adopted or modified by the Iowa DOT. However, no attempt is made to re-print the content of the MUTCD herein. A variety of other technical resources are also noted for consideration by the designer.

By MUTCD definition, a traffic control signal is "any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed" with highway traffic signal being defined as "a power-operated traffic control device by which traffic is warned or directed to take some specific action. These devices do not include power-operated signs, illuminated pavement markers, barricade warning lights, or steady-burning electric lamps." From an application standpoint traffic control signals are used to assign vehicular or pedestrian right-of-way.

The design for traffic control signals shall be in conformance with the current edition of the MUTCD as adopted or modified by the Iowa DOT. The following should be used as design standards as applicable to a project (all accessed October 2012):

- MUTCD Part 4 Highway Traffic Signals
- Jurisdiction Design Standards and Construction Standards
- Iowa DOT and FHWA regarding the design of traffic control signals
- Institute of Transportation Engineers - "Manual of Traffic Signal Design," "Traffic Engineering Handbook," "Traffic Signal Timing Manual," "Manual of Traffic Engineering Studies" Robertson, H.D, Editor, J.E. Hummer, and D.C. Nelson. Institute of Transportation Engineers,Washington, DC, 1994 and "Traffic Control Devices Handbook."
- Other standard references such as the National Electrical Code by the National Fire Protection Association (NFPA), and the National Electrical Manufacturers Association (NEMA) Standards Publications.

Other resources to consider and that are referenced within this document include:

- Mn/DOT Traffic Engineering Manual
- Mn/DOT Signal Design Manual
- Mn/DOT Signal and Lighting Certification Manual
- Mn/DOT Signals 101 Course Presentation
- Mn/DOT Signal Justification Reports
- Missouri DOT Traffic Control Devices
- Arizona DOT Traffic Engineering Policies, Guidelines, and Procedures

Other traffic signal documents by state:

- Traffic Signal Design and Operations Manuals by U.S. State

C. Definitions

A resource for traffic signal definitions can be found within MUTCD Section 4A.02 "Definitions Relating to Highway Traffic Signals."

Traffic Control Signal Needs Studies

A. General

The MUTCD states that "A traffic control signal should not be installed unless an engineering study indicates that installing a traffic control signal will improve the overall safety and/or operation of the intersection." The first question that must be answered is whether a traffic control signal is justified or is the most effective treatment option. It is the responsibility of the Engineer or agency to make this determination with serious consideration given to the following MUTCD Section 4B:

Section 4B.01 General
Section 4B.02 Basis of Installation or Removal of Traffic Control Signals
Section 4B.03 Advantages and Disadvantages of Traffic Control Signals
Section 4B.04 Alternatives to Traffic Control Signals
Section 4B.05 Adequate Roadway Capacity

B. Data Collection

The engineering study should be based upon a complete collection of site and traffic data (vehicle, pedestrian, etc) pertaining to the candidate location. Section 9-4.01 of the Mn/DOT Traffic Engineering Manual notes the studies which will be helpful in assessing and demonstrating the need for a signal as follows:

- 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 completing various traffic studies are found in the ITE Manual of Traffic Engineering Studies.

MUTCD Section 4C-01 provides a detailed description of engineering study data which may be needed to conduct a warrant analysis. These include:

1. The number of vehicles entering the intersection in each hour from each approach during 12 hours of an average day. It is desirable that the hours selected contain the greatest percentage of the 24 hour traffic volume.

2. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, public-transit vehicles, and, in some locations, bicycles), during each 15 minute period of the 2 hours in the morning and 2 hours in the afternoon during which total traffic entering the intersection is greatest.

3. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in Item B above and during hours of highest pedestrian volume. Where young, elderly, and/or

persons with physical or visual disabilities need special consideration, the pedestrians and their crossing times may be classified by general observation.

4. Information about nearby facilities and activity centers that serve the young, elderly, and/or persons with disabilities, including requests from persons with disabilities for accessible crossing improvements at the location under study. These persons might not be adequately reflected in the pedestrian volume count if the absence of a signal restrains their mobility.

5. The posted or statutory speed limit or the 85th-percentile speed on the uncontrolled approaches to the location.

6. A condition diagram showing details of the physical layout, including such features as intersection geometrics, channelization, grades, sight-distance restrictions, transit stops and routes, parking conditions, pavement markings, roadway lighting, driveways, nearby railroad crossings, distance to nearest traffic control signals, utility poles and fixtures, and adjacent land use.

7. A collision diagram showing crash experience by type, location, direction of movement, severity, weather, time of day, date, and day of week for at least 1 year.

The following data, which are desirable for a more precise understanding of the operation of the intersection, may be obtained during the periods specified in item 2 of the preceding paragraph:

1. Vehicle-hours of stopped time delay determined separately for each approach.

2. The number and distribution of acceptable gaps in vehicular traffic on the major street for entrance from the minor street.

3. The posted or statutory speed limit or the 85th-percentile speed on controlled approaches at a point near to the intersection but unaffected by the control.

4. Pedestrian delay time for at least two 30 minute peak pedestrian delay periods of an average weekday or like periods of a Saturday or Sunday.

5. Queue length on stop-controlled approaches.

It is critical to present the above information in an organized fashion. Mn/DOT makes use of a Signal Justification Report, which contains the following information:

1. Intersection Location: Trunk highway cross-street name and county road numbers, municipality, and county. A map should be included that 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, and 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, and proposed or existing coordinated systems.

6. Actual Traffic Volumes at the 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. Iowa 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 adding to the Engineer's judgment that signals are necessary.

The above 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.

Mn/DOT's Section 9-4.02.04 signal justification also provides a section on "Signal Removal Justification Criteria."

C. Warrants

MUTCD Section 4C.01 "Studies and Factors for Justifying Traffic Control Signals" states, "An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.

The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the following traffic signal warrants and other factors related to existing operation and safety at the study location:

Section 4C.01 Studies and Factors for Justifying Traffic Control Signals
Section 4C.02 Warrant 1, Eight-Hour Vehicular Volume
Section 4C.03 Warrant 2, Four-Hour Vehicular Volume
Section 4C.04 Warrant 3, Peak Hour
Section 4C.05 Warrant 4, Pedestrian Volume
Section 4C.06 Warrant 5, School Crossing
Section 4C.07 Warrant 6, Coordinated Signal System
Section 4C.08 Warrant 7, Crash Experience
Section 4C.09 Warrant 8, Roadway Network

The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal."

Accompanying MUTCD figures and tables for the above warrants include:

Table 4C-1 Warrant 1, Eight-Hour Vehicular Volume
Figure 4C-1 Warrant 2, Four-Hour Vehicular Volume
Figure 4C-2 Warrant 2, Four-Hour Vehicular Volume (70% Factor)

Figure 4C-3 Warrant 3, Peak Hour
Figure 4C-4 Warrant 3, Peak Hour (70% Factor)

Mn/DOT's Traffic Signal Design Manual Section 9-4.02 provides additional guidance for the following:

- Section 9-4.02.02 Warrants for Flashing Beacons at Intersections
- Section 9-4.02.03 Advance Warning Flashers Consideration

Features

A. Traffic Control Signal Features

The MUTCD Chapter 4D Traffic Control Signal Features establishes traffic signal uniformity and serves as a critical resource for checking each traffic signal design. The features of traffic control signals of interest to road users are the location, design, and meaning of the signal indications. Uniformity in the design features that affect the traffic to be controlled, as set forth in the MUTCD, is especially important for reasonably safe and efficient traffic operations. This chapter includes the following sections:

Section 4D.01 General
Section 4D.02 Responsibility for Operation and Maintenance
Section 4D.03 Provisions for Pedestrians
Section 4D.04 Meaning of Vehicular Signal Indications
Section 4D.05 Application of Steady Signal Indications
Section 4D.06 Application of Steady Signal Indications for Left Turns
Section 4D.07 Application of Steady Signal Indications for Right Turns
Section 4D.08 Prohibited Steady Signal Indications
Section 4D.09 Unexpected Conflicts During Green or Yellow Intervals
Section 4D.10 Yellow Change and Red Clearance Intervals
Section 4D.11 Application of Flashing Signal Indications
Section 4D.12 Flashing Operation of Traffic Control Signals
Section 4D.13 Preemption and Priority Control of Traffic Control Signals
Section 4D.14 Coordination of Traffic Control Signals
Section 4D.15 Size, Number, and Location of Signal Faces by Approach
Section 4D.16 Number and Arrangement of Signal Sections in Vehicular Traffic Control Signal Faces
Section 4D.17 Visibility, Shielding, and Positioning of Signal Faces
Section 4D.18 Design, Illumination, and Color of Signal Sections
Section 4D.19 Lateral Placement of Signal Supports and Cabinets
Section 4D.20 Temporary Traffic Control Signals
Section 4D.21 Traffic Signal Signs, Auxiliary

Accompanying MUTCD figures and tables for signal features include:

Table 4D-1 Minimum Sight Distance
Figure 4D-1 Maximum Mounting Height of Signal Faces Located Between 40 Feet and 53 Feet from Stop Line
Figure 4D-2 Horizontal Location of Signal Faces
Figure 4D-3 Typical Arrangements of Signal Lenses in Signal Faces

B. Pedestrian Control Features

The MUTCD Chapter 4E Pedestrian Control Features establishes pedestrian control uniformity and serves as a critical resource for checking each traffic signal design. Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of a WALKING PERSON (symbolizing WALK) and an UPRAISED HAND (symbolizing DONT WALK). This Chapter includes the following sections:

Section 4E.01 Pedestrian Signal Heads
Section 4E.02 Meaning of Pedestrian Signal Head Indications
Section 4E.03 Application of Pedestrian Signal Heads
Section 4E.04 Size, Design, and Illumination of Pedestrian Signal Head Indications
Section 4E.05 Location and Height of Pedestrian Signal Heads
Section 4E.06 Accessible Pedestrian Signals
Section 4E.07 Countdown Pedestrian Signals
Section 4E.08 Pedestrian Detectors
Section 4E.09 Accessible Pedestrian Signal Detectors
Section 4E.10 Pedestrian Intervals and Signal Phases

Accompanying MUTCD figures and tables for pedestrian control features include:

Figure 4E-1 Typical Pedestrian Signal Indications
Figure 4E-2 Recommended Pushbutton Locations for Accessible Pedestrian Signals

C. Agency Specific Information

Agencies often have design requirements that differ or are in addition to those found in the MUTCD. Therefore, one of the first steps in the traffic signal design process is to learn the design requirements by meeting with agency staff, studying agency specific design manuals, and/or studying the MUTCD. Field observations of existing traffic signals within an agency's jurisdiction can also provide insight to specific design requirements.

Determining agency specific design requirements prior to design can be challenging. It can be difficult to ask all the right questions, give all the necessary answers, and not overlook any details. More challenges can arise when staff is less experienced or a new working relationship is being established. Most design requirements that are overlooked will be caught during the design process or review process. However, taking steps to prevent design requirements from being overlooked will accelerate the design process and minimize costs by eliminating or reducing change orders. The following are some examples of design requirements that can vary between agencies.

- The 2003 edition of the MUTCD requires a maximum distance of 180 feet from the stop line to the 12 inch signal faces unless a near side supplemental signal face is used. The previous version required a maximum distance of 150 feet and some agencies continue to follow the old requirement.
- Some agencies center mast arm mounted signal heads over the lane line and others center them over the center of the lane.
- Certain agencies elect to install supplemental signal heads on the vertical shaft of the mast arm pole and others elect not to.
- Doghouse style five section heads are used for protected / permissive left turns by some agencies but not others.

- Protected / permissive left turn lane operation can vary. Some agencies configure left turn lane loop detectors to call the protected phase only when all loop detectors are covered by vehicles while other agencies always call the protected phase.
- Detector types, sizes, and layouts vary between agencies.
- The size and number of conduits, handholes, and wiring varies greatly among agencies.
- Some agencies share conduit between signal cable, street light power, and/or interconnect while others keep these cables in separate conduits.
- Some agencies choose to install emergency preemption.
- Signal wiring details vary among agencies.
- Some agencies use the "astro" type brackets to mount all signal heads and others do not use this on side of pole mounted heads. Bracketing and banding of all hardware (typically to the poles) varies greatly among agencies.
- Traffic signal cabinets, cabinet risers, and controller types and preferences vary greatly among agencies.
- Mounting heights for signal heads, street light luminaires, detection cameras, monitoring cameras, etc. vary greatly among agencies.

D. Preliminary Signal Design Discussion List

Signal designers should meet and confer to agree on preliminary signal design details. Having a list of the basic criteria to be discussed at a preliminary stage can be of significant benefit to both the engineer and agency. The following list is based on Mn/DOT's Signal Design Manual "Pencil Sketch" review list.

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 four and five 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.

8. Placement of pedestrian pushbuttons relative to signal standards and in place sidewalks and crosswalks.

9. Need for emergency vehicle pre-emption (EVP) and police door with auto/flash switch, manual/stop time switch, and on/off power switch for signal heads only, including 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 (Mn/DOT uses a mast-arm mount that can swivel).
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).

E. Additional Information

The MUTCD Chapter 4E Pedestrian Control Features establishes pedestrian control uniformity and serves as a critical resource for checking each traffic signal design. Pedestrian signal heads provide:

Chapter 4F Traffic Control Signals for Emergency Vehicle Access
Chapter 4G Traffic Control Signals for One-Lane, Two-Way Facilities
Chapter 4H Traffic Control Signals for Freeway Entrance Ramps
Chapter 4I Traffic Control Signals for Movable Bridges
Chapter 4J Lane-Use Control Signals
Chapter 4K Flashing Beacons
Chapter 4L In-Roadway Lights

Design Considerations

In addition to basic MUTCD requirements, the safe and efficient operation of a signalized intersection requires careful attention and balance of a number of design parameters. This section provides some reference resources for the traffic signal designer in consideration of these features.

A. Geometrics

The geometrics of an intersection are a critical consideration given the potential impact on intersection safety and performance. Geometrics directly impact sight distance, vehicle separation, operations, and capacity. As a result, intersection geometrics should always be considered whether dealing with existing, reconstructed, or new signalized intersections.

References are made to Signalized Intersections: Informational Guide, FHWA-HRT-04-091, August 2004, which provides a single, comprehensive document with methods for evaluating the safety and operations of signalized intersections and tools to remedy deficiencies. The treatments in this guide range from low-cost measures such as improvements to signal timing and signage, to high-cost measures such as intersection reconstruction or grade separation. While some treatments apply only to higher volume intersections, much of this guide is applicable to signalized intersections of all volume levels.

1. **Basic Geometric Considerations:** The geometric design section of the Signalized Intersections: Informational Guide provides the following comments:

   Geometric design of a signalized intersection involves the functional layout of travel lanes, curb ramps, crosswalks, bike lanes, and transit stops in both the horizontal and vertical dimensions. Geometric design has a profound influence on roadway safety; it shapes road user expectations and defines how to proceed through an intersection where many conflicts exist.

   In addition to safety, geometric design influences the operational performance for all road users. Minimizing impedances, eliminating the need for lane changes and merge maneuvers, and minimizing the required distance to traverse an intersection all help improve the operational efficiency of an intersection.

   The needs of all possible road users must be considered to achieve optimal safety and operational levels at an intersection. At times, design objectives may conflict between road user groups; the practitioner must carefully examine the needs of each user, identify the tradeoffs associated with each element of geometric design, and make decisions with all road user groups in mind.

   The Geometric Design section addresses the following design topics to be considered when designing traffic signal controlled intersections:
   - 3.1 Channelization
   - 3.2 Number of Intersection Legs
   - 3.3 Intersection Angle
   - 3.4 Horizontal and Vertical Alignment
   - 3.5 Corner Radius and Curb Ramp Design
   - 3.6 Sight Distance

- 3.7 Pedestrian Facilities
- 3.8 Bicycle Facilities

2. Additional Sight-distance Considerations:

a. Sight distance is a safety requirement that impacts intersection geometrics as fundamental as horizontal and vertical alignments. It is a design requirement that is discussed in detail as it relates to the visibility of traffic signal indications in the MUTCD. In addition to the sight distance requirements of the MUTCD, the AASHTO "Policy on Geometric Design of Highways and Streets 2001" states that drivers of the first stopped vehicles on all approaches should have adequate sight distance to view one another. It also states that left turning vehicles should have adequate sight distance to select gaps in oncoming traffic and complete turning maneuvers. This requires consideration of offset left turn lanes to provide adequate left turn sight distance. If right turns are allowed on a red signal indication, the appropriate departure sight triangle should be provided. Finally, the policy states that the appropriate departure sight triangles should be provided for left and right turning vehicles on the minor approach for two-way flashing operations. Two-way flashing operations are flashing yellow for the major street and flashing red for the minor street. See Chapter 9 - Intersections in the AASHTO "Policy on Geometric Design of Highways and Streets 2001" for additional sight distance information.

b. One sight distance issue that deserves additional consideration is the sight triangle and the sight obstructions found within it. Certain obstructions are obvious like structures near the street. Other obstructions are not always obvious or are installed after the traffic signal is designed and constructed. These obstructions seem to blend into the background. They are obstructions like entrance monuments, special street name signs, business signs, and landscape vegetation that may not be a problem initially but become a problem as the plants reach maturity. Finally, be aware of the signal cabinet size and location including the height of the footing or cabinet riser so it does not become a sight obstruction.

c. Sight distance requirements are less restrictive at signalized intersections as drivers are required by law to obey the signal indications; however, there are instances when drivers do not obey traffic signals. A traffic signal should be designed to exceed minimum sight distance requirements when possible. Drivers are taught to drive defensively and providing additional sight distance will only aid drivers in collision avoidance.

3. Turn Lanes:

a. Traffic volumes, turning movement counts, and crash history are used to complete intersection capacity and accident analyses. The results of the analyses determine the need for turn lanes, the number of turn lanes, and the length of the turn lanes. The turn lane information is used to properly design the geometrics of signalized intersection approaches.

b. Turn lane capacity issues often create safety problems. Left or right turning vehicle queues blocking through traffic create increased potential for rear-end accidents. Sideswipe potential also increases as traffic attempts to maneuver out of defacto turn lanes or around left turn queues blocking through lanes. High volumes of turning vehicles combined with high volumes of opposing vehicles significantly reduce the number and size of available gaps needed to complete turning maneuvers increasing the potential for right angle collisions. As a result, properly designed turn lanes improve safety as well as capacity.

c. Determining turn lane design details when upgrading existing signalized intersections in largely developed areas is relatively straight forward. Capacity problems are recognized through evidence obtained from capacity analyses, visual inspections, and/or citizen comments. Capacity analyses and visual inspections of peak hour traffic often reveal long queues that do not clear after multiple signal cycles. Heavy turning volumes and a lack of turn lanes on multilane facilities often result in shared lanes acting as defacto turn lanes. If turn lanes exist, traffic volumes may exceed the capacity of the turn lanes resulting in vehicle queues spilling out of the turn lanes and into the through lanes.

d. Determining turn lane design details when constructing new signalized intersections in undeveloped or under developed areas experiencing significant growth is a challenge. In many cases, there is no visual evidence of existing capacity or safety problems. The challenge is judging future traffic patterns and the extent of the traffic growth over a given time period, usually twenty years, with no guarantees as to the type, extent, and rate of development. Judgment is improved with information and the information is obtained from capacity analyses that examine existing and proposed development, existing traffic volume data, and future traffic volume data derived from land use maps and the ITE Trip Generation Manuals. This information combined with traffic growth rates obtained from developed areas with similar land use characteristics and engineering judgment are used to arrive at an intersection design that will support existing traffic volumes as well as future growth.

e. Past experience has helped to formulate several design guidelines used to initially determine the number of lanes needed at an intersection. These guidelines are planning level guidelines and should be confirmed with the results of the operational analysis methods discussed in the Operations section of this chapter. The guidelines can be found in Chapter 10 of the Highway Capacity Manual 2000 (HCM 2000) and are summarized as follows:
   1) Exclusive Left Turn Lanes:
      - A single exclusive left turn lane should be considered when the minimum left turn volume is 100 veh/hr.
      - Dual exclusive left turn lanes should be considered when the minimum left turn volume is 300 veh/hr.
   2) Exclusive Right Turn Lanes:
      - An exclusive right turn lane should be considered when the right turn volume exceeds 300 veh/hr and the adjacent mainline volume exceeds 300 veh/hr/ln.
   3) Number of Lanes:
      - Enough lanes should be provided to prevent the total volume of the approach from exceeding 450 veh/h/ln.

f. Past experience has also helped to formulate several design guidelines used to initially determine turn lane lengths needed at intersections. Like the guidelines used to determine the number of lanes, the guidelines used to determine turn lane lengths are planning level guidelines and should be confirmed with the results of an operational analysis. Also remember that the lengths discussed here are the actual storage lengths and do not include taper lengths. Taper requirements are discussed in several sources including Chapter 5 - Roadway Design, the Iowa DOT Design Manual, and the AASHTO Policy on Geometric Design of Highways and Streets. The guidelines are as follows:
   - Enough storage length should be provided to equal one foot for each vehicle per hour (vph) turning during the peak hour in the horizon year. For example, 250 vph turning during the peak hour in the horizon year would require a 250 foot turn lane.

- Storage length can also be computed using the following equation:

  Storage Length = (h / s) (v + g) (p)

  h = horizon year peak hour volume (vph)

  s = number of signal cycles per hour
  A signal cycle is typically 60 to 120 seconds. Engineering judgment is used to select the cycle length or lengths to use in the equation.

  v = average vehicle length
  The average vehicle length often used is 20 feet.

  g = average gap between vehicles
  The average vehicle gap often used is 5 feet.

  p = probability factor
  The probability factor is based on the Poisson distribution and associated with the probability that enough length is provided to store all vehicles.

Probability Factor (p)	Probability of Storing All Vehicles
1.50	0.90
1.75	0.95
1.85	0.98
2.00	> 0.98

  A paper written by the Transportation Research Institute at Oregon State University suggests modifying the average vehicle length plus gap (v + g) based on the percentage of trucks using the turn lane. The paper suggests modifying v + g as follows:

Percent Trucks	v + g
< 2%	25’
5 %	27’
10 %	29’

  The initial storage length for dual left turn lanes can be found by dividing the storage length found from one of the two methods discussed above by 1.8.

  Example:

  h = 250 vph
  s = 100 s/cycle
  3600 s/hr / 100 s/cycle = 36 cycles/hr
  5% trucks
  v + g = 27’
  p = 1.85 (95% probability)

  Single lane storage length = (250 / 36) (27) (1.75)
  Single lane storage length = 328’: Say 325’

Determining turn lane length also requires some additional considerations. One consideration is the length of the queues in the through lanes. If the turn lanes are not long enough, through

lane queues may prevent turning vehicles from entering the turn lanes leaving the turn lanes nearly empty until the through lane queues begin clearing. This issue could be addressed with lagging lefts but lagging lefts require additional considerations to prevent left turn traps and an operational analysis to determine optimal signal phasing and timing. If through lane queues block the turn lanes, the turn lanes could be lengthened beyond the through lane queues. However, the additional length needed may not be practical.

Another consideration is maximum turn lane length. Once a turn lane becomes too long, the signal cycle cannot serve all the traffic waiting in the turn lane reducing, if not eliminating, the benefits of the extra length. At this point, it may be more practical to add turn lanes or look at other solutions to relieve congestion. When is a turn lane too long? It is difficult to point to an exact number but in the neighborhood of 350 to 400 feet. An operational analysis will provide better evidence regarding the maximum length.

The final consideration that can impact the length of a turn lane is visibility. A turn lane that starts just beyond the crest of a vertical curve may not be visible until a vehicle is at the start of the lane. It may be practical to extend the turn lane to increase its visibility giving drivers more time to react to the lane.

g. Lane balance should be considered when addressing lane geometrics. Left turn lanes should be opposing or offset to one another. If dual left turn lanes are required on one approach, dual left turn lanes or a wide median should be installed on the opposing approach to promote lane balance. Through lanes should be located so they align with one another as the intersection is traversed. Creating a lane shift through an intersection creates driver confusion.

4. Agency Geometric Considerations: The Mn/DOT Traffic Engineering Manual (Section 9-6.00 Traffic Signal Design) provides a good identification of major issues for design consideration and serves as an example of agency specific criteria. Since this is a PDF document, Sections 9-6.02 through 9-6.05 are provided below:

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. Mn/DOT Section 9-6.03 notes the following geometric elements should be considered:

a. 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.

b. 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.

c. Turn lanes must provide adequate storage in order to prevent turning traffic from interfering with other traffic movements and thus causing capacity breakdown.

d. 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.

e. Sidewalks should be constructed as close to the center of the corner as possible. Pedestrian crosswalks should be in line with the sidewalk and as close to the intersection as practical.

f. 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.

g. 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.

h. 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.

i. 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.

j. Pedestrian curb ramps should be considered in accordance with Chapter 12 - Sidewalks and Bicycle Facilities if sidewalks are present.

k. Handhole spacing should be based on the following factors:
   - Location of junction points within the signal system
   - Physical features, such as driveways, utilities, etc.
   - Cable pull length based on size of cable and diameter of conduit

B. Operational Characteristics

The behavior of the traffic at an intersection is another highly important element of signal design. Mn/DOT Section 9-6.03 notes 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. Saturated approaches should have an upstream count taken to determine the demand volume rather than the service volume at the intersection.

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 that 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. Provide pedestrian refuges in medians 6 feet and wider.

C. 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. Mn/DOT Section 9-6.04 notes the following elements should be considered.

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.

D. Signal Design Elements

Mn/DOT Section 9-6.05 notes the following elements should be considered:

1. The most efficient operation of a signal system is attained with the fewest phases that are enough to move traffic without hazardous conflicts. Procedures exist to determine the optimum number of phases for an intersection.

2. The primary consideration in signal head placement is clear visibility. Drivers approaching an intersection shall be given a clear and unmistakable indication of their right-of-way assignment. The number and placement of signal faces shall conform to the requirements of the 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 the 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.

3. Vehicle detectors should be placed according to the detector spacing chart and the loop placement diagrams.

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.

E. Traffic Signal Operations

The Mn/DOT Traffic Engineering Manual provides an exceptional discussion on basic traffic signal operations and design considerations. These are not reprinted within this document but these references are noted below.

- Mn/DOT Traffic Signal Timing and Coordination Manual
- Traffic Engineering Manual
  - Chapter 2. Traffic Signal Phasing and Operations
  - Chapter 3. Head Placement Charts
  - Chapter 4. Detection
- Mn/DOT Signal & Lighting Certification Manual

F. Pedestrian Considerations

1. Geometrics:

a. Geometrics have a significant impact on pedestrian operations and safety at signalized intersections as alluded to in the previous section. Intersection skew, number of lanes, lane width, medians, islands, and curb returns all impact the distance pedestrians must travel to cross an intersection. As the distance to traverse an intersection approach increases, so does the signal timing that must be allocated to the pedestrian clearance interval. Long pedestrian clearance intervals have a negative impact on traffic capacity and operations. A pedestrian actuation will disrupt traffic signal coordination and require several cycles to bring a corridor back into coordination. However, large pedestrian volumes may dictate signal timing resulting in less than optimal conditions for vehicles. A traffic engineer must balance the priorities of vehicles and pedestrians with no calculations or answers that clearly define a solution but do provide guidance.

b. Right turns present challenges for pedestrians. A driver of a vehicle turning right on red will be looking left for a gap in traffic. A pedestrian approaching from the right may have a walk indication. If the driver sees a gap but does not look back to the right, the pedestrian may not be seen by the driver resulting in a collision. As a result, a traffic engineer must decide whether to allow right turns on red.

c. Right turn lanes can present additional challenges for pedestrians, especially if the returns are large and channelize traffic with an island. The islands can channelize right turning vehicles away from the traffic signal indications creating difficulties signalizing the right turn movement. Using a stop sign instead of a supplemental signal indication for the channelized right turning movement is not an option. It creates a confusing message when all movements on the approach see green indications, including right turning vehicles, until they are partially through the turning maneuver and see a stop sign. Some agencies assign the right turning vehicles a yield sign but it creates an issue protecting pedestrians. If a pedestrian push button is used at the back-of-curb and pedestrians must cross a right turn lane controlled by a yield sign, it may give pedestrians a false sense of security when crossing in front of right turning vehicles. Drivers of right turning vehicles see a yield sign and look left, away from the pedestrians stepping off the curb, for a gap in traffic. In fact, drivers of right turning vehicles would be looking even farther left due to the channelization and orientation of the vehicles making it even more difficult for drivers to see pedestrians approaching from the right. Consequently, pedestrian volume and safety are important considerations when considering and designing right turn lanes.

d. The final geometric consideration as it relates to pedestrians is the pedestrian refuge. Right turn islands and medians often double as pedestrian refuges. If islands and medians are intended to be used as pedestrian refuges, they must be large enough to hold pedestrians and be ADA compliant. A traffic engineer must consider the likelihood that pedestrians will stop and get stranded in an island or median. On large approaches, it may be intended that pedestrians only cross a portion of the approach and stop in a median or island. As a result, a traffic engineer must decide whether to install supplemental push buttons in the right turn island or median. If islands and medians are not intended to function as pedestrian refuges, they must be located so they do not obstruct the path of pedestrians.

2. **Visibility:** Visibility is important to the safe operation of the pedestrian indications. Pedestrian indications as well as the push buttons should be easily located by pedestrians. Consider where vehicles, especially large trucks, may stop so they do not obstruct the view of the pedestrian indications. This will require careful location of median noses, stop bars, crosswalks, and the pedestrian heads. Finally, make sure there are no obstructions in the returns that may prevent drivers and pedestrians from seeing one another such as the signal cabinet or vegetation.

3. **Special Considerations:** Circumstances often arise that require special considerations. For example, children may have difficulty understanding the meaning of pedestrian indications. Count down pedestrian heads may be easier for children to understand; therefore, have increased value in school zones. Count down pedestrian heads may also have added value on wide approaches. The flashing numbers can attract a person's eye and the numbers tell a pedestrian how much time they have to cross which has added value on very wide approaches. There may be a particular area within a city that has a high concentration of visually impaired. In this case, audible pedestrian indications may have added benefit. In many cases, some extra thought and minimal dollars can change a design from adequate to desirable.

4. **Americans with Disabilities Act:** The Americans with Disabilities Act (ADA) addresses several design requirements relating to pedestrians. ADA addresses design requirements for items such as sidewalk ramps, truncated domes, and pedestrian push buttons. These topics are addressed in detail in Chapter 12 - Sidewalks and Bicycle Facilities and other design manuals such as the MUTCD and the AASHTO Policy on Geometric Design of Highways and Streets.

   a. **Accessible Pedestrian Signals (APS):** Each traffic signal project location should be evaluated to determine the need for accessible pedestrian signals, especially if the project location presents difficulties for individuals with visual disabilities. An engineering study should be completed that determines the needs for pedestrians with visual disabilities to safely cross the street. The study should consider the following factors:
      - Potential demand for accessible pedestrian signals
      - Requests for accessible pedestrian signals by individuals with visual disabilities
      - Traffic volumes when pedestrians are present, including low volumes or high right turn on red volumes
      - The complexity of the signal phasing, such as split phasing, protected turn phases, leading pedestrian intervals, and exclusive pedestrian phases
      - The complexity of the intersection geometry

      One tool that is available for evaluation of the need for APS and also prioritizing the order for installing APS equipment on crosswalks can be found at www.apsguide.org developed by the National Cooperative Highway Research Program (NCHRP).

If APS are warranted, it is necessary to provide information to the pedestrian in non-visual formats. This will include audible tones and vibrotactile surfaces. Pedestrian push buttons should have locator tones for the visually impaired individual to be able to access the signal. Consistency throughout the pedestrian system is very important. Contact the Jurisdictional Engineer regarding the standards and equipment types that should be incorporated into the design of the accessible pedestrian signal system. New tones such as clicks, ticks, and other electronic sounds have replaced the cuckoos and chirping tones of past systems.

b. APS Design Elements: Refer to MUTCD Sections 4E.08 through 4E.13 and the following information.

1) Push Button Stations: An APS push button station is a weather-tight housing with a 2 inch diameter push button, a speaker, and a pedestrian sign. Braille signing, raised print or a tactile map of the crosswalk may also be provided. The push button has a vibrotactile arrow pointing in the direction of the crossing.

2) Location of Pedestrian Push Buttons: Push buttons should be located adjacent to the sidewalk, between 1.5 and 6 feet from the edge of curb, shoulder, or pavement and no more than 5 feet from the outside crosswalk line. Where physical constraints make the 6 feet maximum impractical, push buttons should be located no more than 10 feet from the edge of curb, shoulder, or pavement. Where two push buttons are provided on the same corner of the intersection, they should be separated by at least 10 feet. If the 10 feet separation is not feasible, audible speech walk messages are required. Supplemental push button poles or posts will typically be needed to meet the above criteria. Push buttons should be mounted at a height of approximately 3.5 feet, but no more than 4 feet above the adjacent sidewalk. The push button should be located so pedestrians using the audible or vibrotactile indication can align themselves and prepare for the crossing while waiting close to the push button station and the crossing departure point.

3) Locator Tone: APS push buttons have a locator tone to allow visually impaired individuals to access the signal. The locator tone should be audible 6 to 12 feet from the push button. The locator tone is active during the pedestrian clearance and "DON'T WALK" intervals.

4) Walk Indications:

- In addition to visual indications, APS include audible and vibrotactile walk indications. When at least 10 feet separation is provided between pedestrian push button stations, the audible walk indication is a percussive tone. If 10 feet separation is not provided, speech messages are required. The speech message should name the street to be crossed and indicate that the walk sign is on. For example: "Main. Walk sign is on to cross Main." Other audible messages may be developed, including counting down the pedestrian clearance time, depending on the needs of the particular crosswalk or intersection. Designations such as "Street" or "Avenue" should not be used unless necessary to avoid ambiguity at a particular location. If the traffic signal rests in WALK, the tone/message should be limited to 7 seconds and be repeated with each actuation.
- The vibrotactile walk indication is provided by a high visual contrast tactile arrow on the push button that vibrates during the walk interval. The vibrotactile indication is particularly useful to individuals who have both visual and hearing impairments. The pedestrian must be able to stand with a hand on the device while being aligned and waiting to begin the crossing. The arrow should be aligned parallel to the direction of travel on the associated crosswalk.

c. APS System Options:

- Products currently in the marketplace involve use of 2-wire or 4-wire systems, indicating the number of wires between the push button station and the control unit (CU). The 2-wire system uses a central CU mounted in the controller cabinet, and may provide Ethernet connectivity. Advantages of this system include minimal field wiring required on retrofit applications and central control of multiple crossings.
- The 4-wire system requires a separate CU mounted in the applicable pedestrian signal head for each push button station. In addition to the typical two wires between the push button and the controller cabinet, a 4-wire cable must be provided between the push button station and the CU. This system may be more cost effective for installations with only one or two crossings.

d. APS Compliant Equipment: The following equipment currently meets 2009 MUTCD and 2011 proposed public right-of-way accessibility guidelines (PROWAG) for accessible pedestrian signals. Other compliant equipment may also be available.

- Advisor Guide and Advisor Advanced Pedestrian Stations (AGPS and AAPS) manufactured by Campbell Company.
- EZ Communicator Navigator APS manufactured by Polara.

e. Location of Pedestrian Push Buttons: It is common to see a narrow grass strip between the sidewalk and pole used to mount the push buttons or to only see sidewalk on one side of a pole containing multiple push buttons. It is difficult to impossible for a person in a wheelchair to reach the push button in cases like these since it often requires the person to struggle with one wheel in the grass and one on the sidewalk. As a result, sidewalks must be paved up to the pole used to mount the push buttons and be at a reasonable slope. There should also be sidewalk on each side of a pole that has a push button. The MUTCD requires a pedestrian push button mounting height of approximately 3.5 feet above the sidewalk; keep in mind that the 3.5 feet is above the grade where the pedestrian would be when accessing the button. Often times pole footing elevations end up above grade and installing a push button based on the footing elevation and not the ground elevation where the pedestrian accesses the button results in a mounting height that is too high. Finally, consider the proximity of the push buttons to the street. If the poles used to mount the push buttons are too far from the street, pedestrians will not use the push buttons. Consider installing supplemental poles closer to the street for mounting the push buttons.

G. Driver and Pedestrian Expectations

Other traffic signal design considerations involve driver and pedestrian expectancy. A traffic engineer must look beyond the traffic signal being designed and consider the characteristics of the corridor and the attributes of the existing traffic signals along the corridor. For example, left turn phasing should be applied consistently and not switch between protected only and protected/ permissive without legitimate reasons. If pedestrian signal heads are used, they should be used consistently and not sporadically where one intersection uses the heads and the next intersection relies on vehicular signal heads to guide pedestrians. Traffic signal head style, placement, and orientation should be consistent along a corridor as well as sign type, size, and location. Intersections should not randomly switch between doghouse and vertical five section heads, center of lane and lane line placement, or vertical and horizontal signal head orientation. Consistently applied design criteria improve driver and pedestrian expectations which typically promote safety and operations. However, circumstances exist that may, at times, require changes to design criteria to increase vehicle and pedestrian safety and operations.

H. Future Development and Improvements

One of the biggest traffic signal design challenges is designing a traffic signal in an area that is under developed or being redeveloped. Under these circumstances, much of the data needed for design is either unknown or unstable. Land uses are often modified and business prospects continually change often having significant impacts on existing and future traffic volumes. In addition, the rate at which traffic volumes will increase is difficult to determine. In such cases, the traffic signal designer must work closely with adjacent area land use planning agencies to work towards reasonable expectations for future travel demands and overall operations. Future phases can be accommodated for within the design to significantly reduce the need to replace footing locations, adjust mast-arm lengths, or add additional functionality to the traffic signal. These simple steps can build credibility with the public and add considerable efficiency to the traffic signal design and overall engineering process.

Specifications Information

This section provides design information that complements and is organized similar to SUDAS Specifications Section 8010, which includes:

Part 1 - General

Part 1 provides direction on general items such as submittals; substitutions; delivery, storage, and handling; scheduling and conflicts; and measurement and payment.

Part 2 - Products

Part 2 describes the products to be provided and is arranged as follows:

2.01 Underground
2.02 Detection
2.03 Communications
2.04 Cabinet and Controller
2.05 Poles, Heads, and Signs

Part 3 - Execution

Part 3 describes how these products should be installed and matches the arrangement described in Part 2, with the following additions:

3.06 Temporary Traffic Signal
3.07 Surface Restoration
3.08 Testing
3.09 Documentation

The information below provides selective guidance on the specifications.

A. Part 1 - General

1. **Submittals:** There are several key submittals required of the contractor following award of the project. These are described below.

    a. **Schedule of Unit Prices:**
        1) **Document:** Prepared by the traffic signal designer and included within the contract documents (generally attached to the back of the traffic signal specifications).
        2) **Purpose:** Contracting authority approval of the unit pricing for all major traffic signal items. Establish unit pricing for change order work if needed. Used to estimate partial payments.
        3) **Includes:** Identification of major traffic signal items along with an estimate of quantity and units of measurement. Two additional blank columns are provided (unit price, and unit extension).
        4) **Contractor Action:** Within 30 days after award, the contractor is required to submit a completed schedule of unit prices to the contracting authority for engineer approval.

5) **Engineer Action:** Review the schedule in a timely manner. Check the appropriateness of each unit price, the accuracy of each unit extension calculation, and ensure that the grand total for all unit extensions matches the lump sum bid item for traffic signalization. Upon acceptance, sign and date the document and provide a copy to the contractor.

b. Material and Equipment List:

1) **Document:** Prepared by the traffic signal designer and included within the contract documents (generally attached to the back of the traffic signal specifications).
2) **Purpose:** Contracting authority approval of the make and model numbers for all major traffic signal items.
3) **Includes:** Identification of major traffic signal items along with an estimate of quantity and units of measurement. Two additional blank columns are provided (manufacturers name and each items model number).
4) **Contractor Action:** Within 30 days after award, the contractor is required to submit a completed list of materials and equipment to the contracting authority for engineer approval.
5) **Engineer Action:** Review the schedule in a timely manner. Check the appropriateness of each identified manufacturer and model number. Upon acceptance, sign and date the schedule and provide a copy to the contractor.

c. Contractor Certification:

1) **Document:** Prepared by the contractor on company letterhead.
2) **Purpose:** Contracting authority approval of key project personnel.
3) **Includes:** Name, contact information, and certification of the Level II International Municipal Signal Association (IMSA) Certified Traffic Signal Technician(s) working on the project.
4) **Contractor Action:** Within 30 days after award, the contractor is required to submit the contractor certification to the contracting authority for engineer approval.
5) **Engineer Action:** Review the appropriateness of the information and on acceptance, sign and date the document, and provide a copy to the contractor.

d. Shop Drawings:

1) **Document:** Prepared by the traffic signal pole supplier for the contractor.
2) **Purpose:** Contracting authority approval of traffic signal poles, supports, and related hardware.
3) **Includes:** Shop drawing information detailing each traffic signal pole, accompanying parts, and necessary hardware.
4) **Contractor Action:** Within 30 days after award, submit shop drawings to the contracting authority for engineer approval.
5) **Engineer Action:** Review the shop drawings in a timely manner. Check the appropriateness of each detail. Upon acceptance, sign and date the shop drawings and provide a copy to the contractor.

e. Catalog Cuts:

1) **Document:** Prepared by the traffic signal equipment supplier for the contractor.
2) **Purpose:** Contracting authority approval of all items within the equipment and materials list as well as for supporting components.
3) **Includes:** Catalog cut information detailing the make, model number, manufacturer, and specific details for all traffic signal equipment.
4) **Contractor Action:** Within 30 days after award, submit catalog cuts to the contracting authority for engineer approval.

5) **Engineer Action:** Review the catalog cuts in a timely manner. Check the appropriateness of each item. Upon acceptance, sign and date the catalog cut documents and provide a copy to the contractor.

2. **Substitutions:** Comply with SUDAS Specifications Division 1 - General Provisions and Covenants.

3. **Delivery, Storage, and Handling:** Comply with SUDAS Specifications Division 1 - General Provisions and Covenants.

4. **Scheduling and Conflicts:** Comply with SUDAS Specifications Division 1 - General Provisions and Covenants.

5. **Special Requirements:** Comply with the current edition of the MUTCD as adopted by the Iowa DOT.

6. **Measurement and Payment:** Traffic signal work is typically bid as a lump sum item of which no measurements are made. However, partial payments to the contractor are established through measuring installed quantities and applying these quantities to the appropriate approved unit price (see Schedule of Unit Prices above).

B. Part 2 - Products

1. **Underground:**

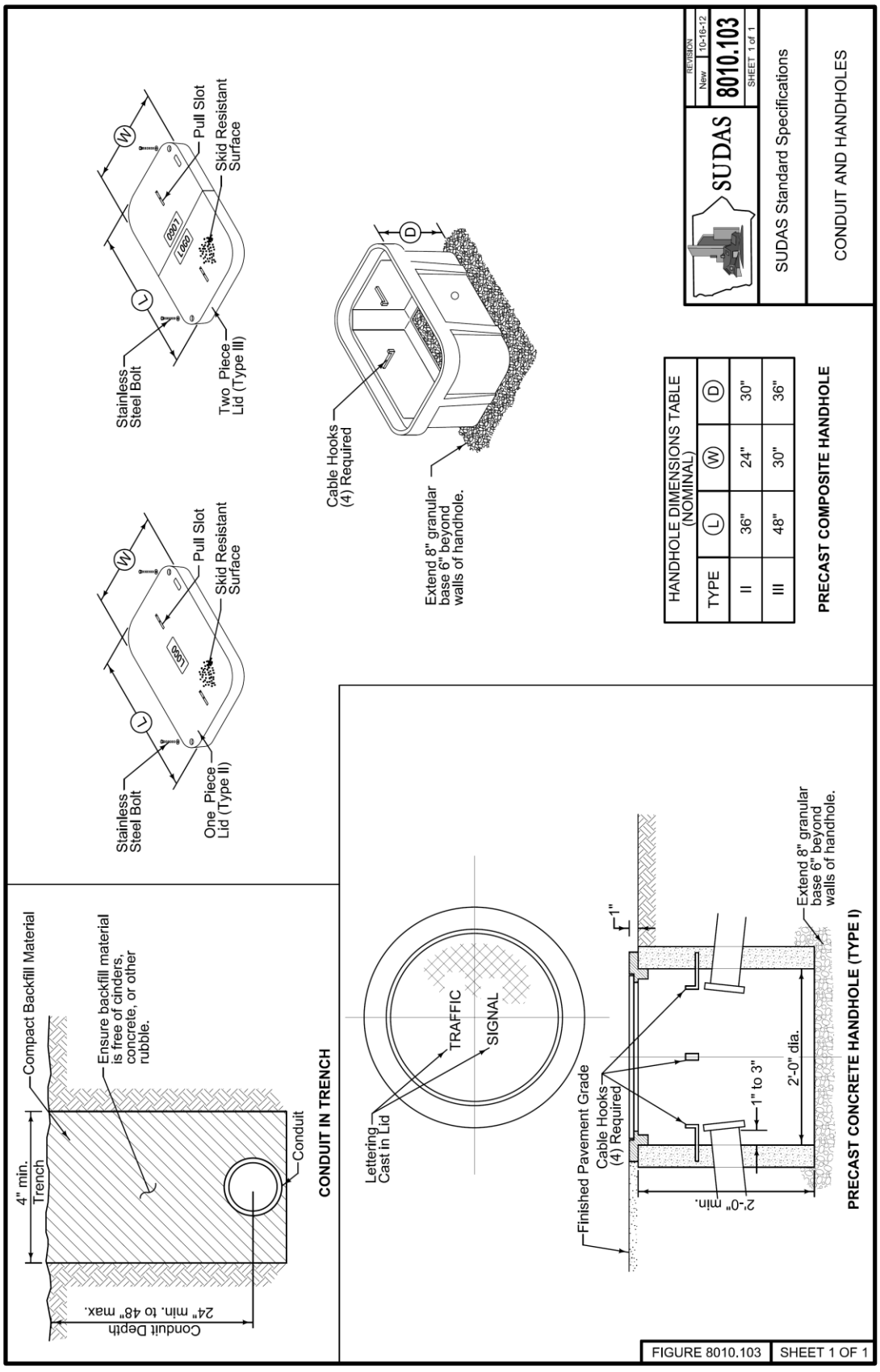
   a. **Handhole:** Handholes are a critical component to traffic signal design. The standard precast concrete handhole shown in Figure 13E-1.01 is typically used at all locations except where fiber optic cables are used and adjacent to the controller cabinet.

   Composite handholes can come in all shapes and sizes (see Quazite example table) and must be specified by the Engineer. These are typically made of a polymer concrete. Polymer concrete is made from selectively-graded aggregates in combination with a polymer resin system. When combined through a process of mixing, molding and curing, an extremely powerful cross-linked bond is formed. Precast polymer concrete is reinforced with fiberglass for strength and rigidity.

   The designer should ensure that the contract documents clearly distinguish between handhole types, sizes, and desired locations. Handholes are typically uniquely numbered on the contract documents.

   An online resource can be found through Chapter 12 Handholes from (Mn/DOT's Signal & Lighting Certification Manual) which provides the designer with a photographic resource for considering handhole features and functions along with execution issues such as installation, inspection, and key points to remember.

Figure 13E-1.01: Conduit and Handholes
(SUDAS Specifications Figure 8010.103)



b. Conduit: The SUDAS Specifications allow both steel and PVC plastic conduit. Steel conduit is typically used on all service risers and plastic PVC or HDPE is used at all other locations. A typical signal installation will use a variety of conduit sizes. When connecting HDPE conduit to PVC conduit, the designer should work with the Contractor to clarify the method or materials to be used.

A conduit check list from Mn/DOT Signal Design Documents, Checklists, and Worksheets is noted below: The designer should ensure the following:

- Conduit size and cables listed.
- Correct symbol for in-place conduit.
- Correct symbol for proposed conduit.
- Check for conflict with in place underground utilities.
- Conduit fill less than 40% (Check).
- 3 inch RSC minimum size conduit under all public traveled roadways.
- Spare 4 inches of conduit out of controller cabinet for future use, threaded and capped.
- Conduit runs for interconnect should be as straight as possible.
- No PVC above ground (for example: bridge crossings and wood pole systems).
- All conduits except those within pads shall drain.
- Primary power shall be in a separate conduit run and separate hand holes.
- Size of bends and elbows in conduit in accordance with National Electrical Code or UL guidelines.
- If conduit is suspended under a bridge, does the distance between supports conform to code, is a hanger detail given in plan, and are expansion fittings called for?
- Conduit placed under in-place pavement does not need to be labeled (bored or pushed).

An online resource can be found through Chapter 11 Conduits and Fittings (Mn/DOT's Signal & Lighting Certification Manual) that provides the designer with a photographic resource for considering conduit installation and features.

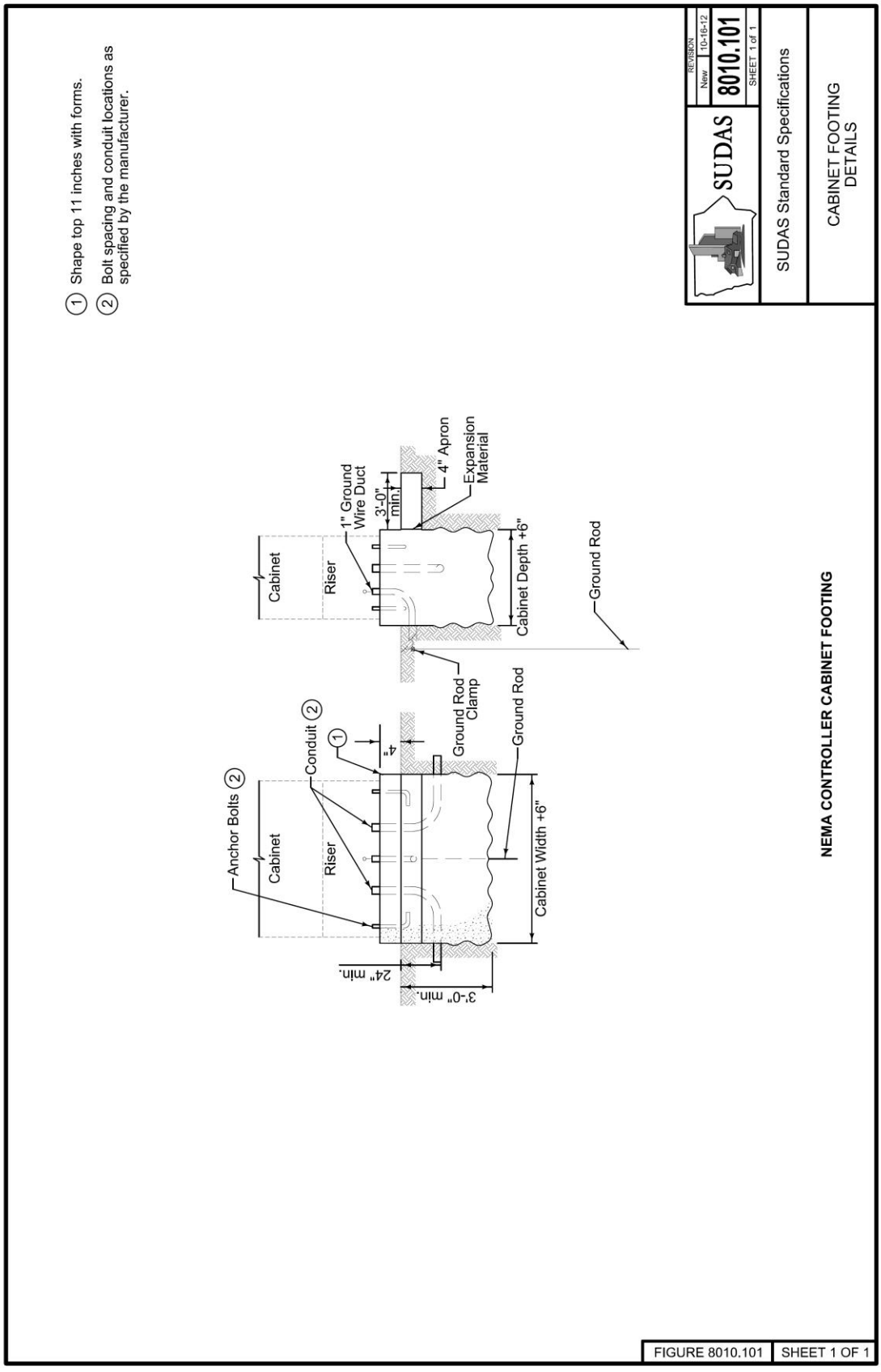
c. Wiring and Cable: Signalized intersections require a variety of standard wires and cables; however, the number, size, and quantity of extra conductors pulled can vary by agency. The designer should include sufficient details to ensure the clear identification of cable runs by conduit. The inspector should make sure all wires are terminated neatly and in an organized fashion. With the exception of detector lead-in wires, no splices are allowed within handholes. All plan terminology should be consistent for example:

- Cable symbols correct (3/C #12, 2/C #14, 3/C #20 all different, for example).
- Ped indications on different phases shall have separate 3/C #12 cables.
- Separate 2/C #14 for each detector.
- Provide spares for future expansion of system, if necessary, and label them.

An online resource can be found through Chapter 15 Wiring (Mn/DOT's Signal & Lighting Certification Manual) which provides the designer with a photographic resource for labeling and training wires (very Mn/DOT specific though).

d. Footings: Signalized intersections require footings for all poles, controller pads, and other service cabinets such as fiber optic hubs or electrical service panels. Controller footing details are included for NEMA controller cabinets as shown in Figure 13E-1.02. The designer should ensure that the plans reflect any desired future use spare conduit stubs out of the footing.

Figure 13E-1.02: Cabinet Footing Details
(SUDAS Specifications Figure 8010.101)



Footing size and depths vary according to pole style, mast-arm length, and pole loadings. The SUDAS Specifications provide figures for both pedestal poles and for mast-arm poles (Figure 13E-1.04). SUDAS standard mast arm pole footing designs (Table 13E-1.01 and Figure 13E-1.04) are based on the following guidelines, parameters, and assumptions:

- Brohm's method for lateral resistance (moment/shear design) per AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, with a safety factor of 2.0.
- FHWA *Drilled Shafts: Construction Procedures and LRFD Design Methods*, May 2010, alpha method for torsion design with a safety factor of 1.0.
- Disturbed soil due to frost: 2.5 feet for moment/shear design, 5.0 feet for torsion design.
- Groundwater assumed present for moment/shear and torsion designs.
- Pole loadings as shown in Figure 13E-1.03, with poles designed per AASHTO 1994 specifications. Wind load equals 80 miles per hour with a gust factor of 1.3.
- Cohesive soils along the length of the footing with an average blow count (N_{60}) greater than or equal to eight, which equates to an average unconfined compressive strength (Qu) greater than or equal to 2.0 kips per square foot.

For pole loading conditions greater than shown in Figure 13E-1.03, granular soils, or lower strength soils, special footing designs will be required. Soil boring testing should be performed prior to construction to verify soil types and strengths if non-typical soils are suspected.

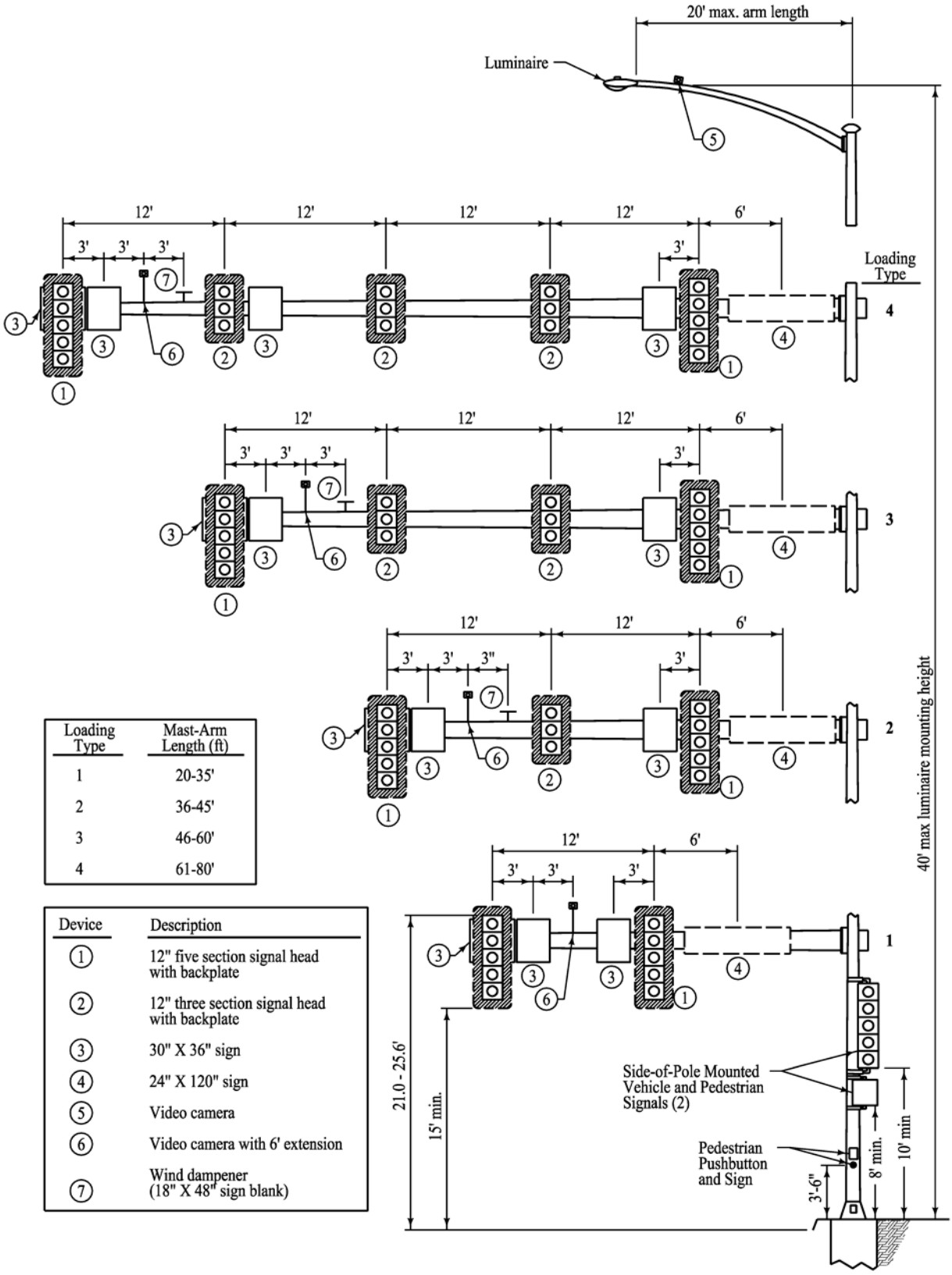
Table 13E-1.01: Standard Mast Arm Pole Footing Designs*

Loading Type (Figure 13E-1.03)	Maximum Mast Arm Length (feet)	Footing Type (Figure 13E-1.04)
1	35	A
2	45	B
3	55	C
3	60	D
4	70	E
4	80	F

*Maximum loading as per Figure 13E-1.03; for cohesive (non-granular) soils with Qu $\geq$ 2.0 ksf

The footing type for each pole should be included in the contract documents so the contractor will know what is required at the time of bidding.

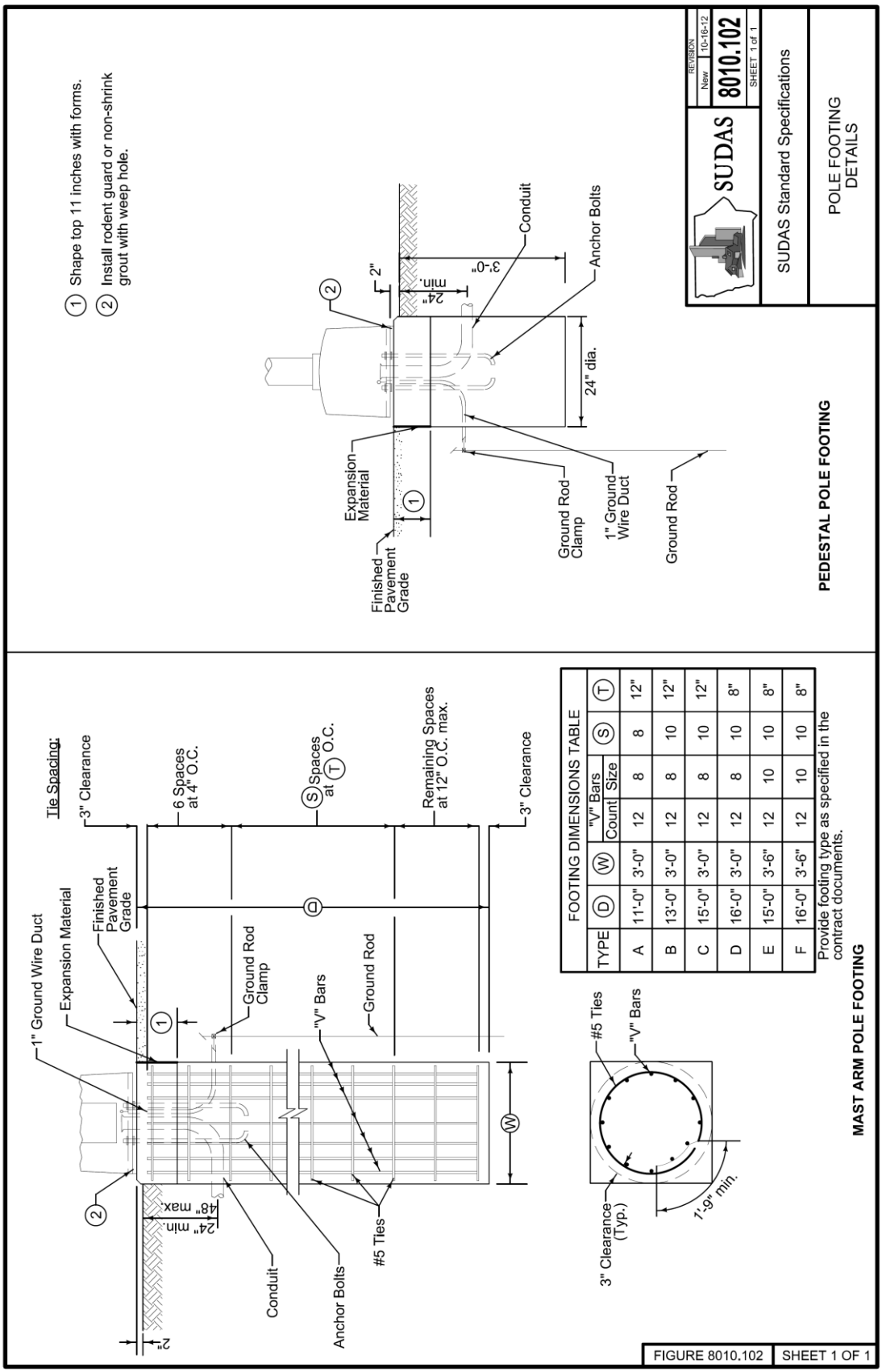
Figure 13E-1.03: Mast Arm Pole Loadings for Standard Footing Designs



Loading Type	Mast-Arm Length (ft)
1	20-35'
2	36-45'
3	46-60'
4	61-80'

Device	Description
1	12" five section signal head with backplate
2	12" three section signal head with backplate
3	30" X 36" sign
4	24" X 120" sign
5	Video camera
6	Video camera with 6' extension
7	Wind dampener (18" X 48" sign blank)

Figure 13E-1.04: Pole Footing Details
(SUDAS Specifications Figure 8010.102)



The designer should ensure that all foundations:

- Are located in compliance with applicable clear zone requirements
- Do not conflict with pedestrian walkways or ramps
- Are at the proper finish grade elevation

An online resource can be found through Chapter 14 Concrete Foundations (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for foundation types and installation details.

e. Bonding and Grounding: All traffic signal installations must be bonded and grounded according to the National Electrical Code.

Bonding is defined in the Code Book as the permanent joining of metallic parts required to be electrically connected. In a traffic signal, the term is used to describe the electrical and mechanical connection of conduit, metal poles, cabinets, and service equipment.

Grounding is defined in the Code as a conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conductive body that serves in place of earth.

The designer should ensure that the contract documents include sufficient notation for the traffic signalized intersection to be properly bonded and grounded. This includes placing ground rods at each traffic signal pole and at the controller footing as well as through use of bonding and grounding jumpers within the handholes.

An online resource can be found through Chapter 13 Bonding and Grounding (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for bonding and grounding details.

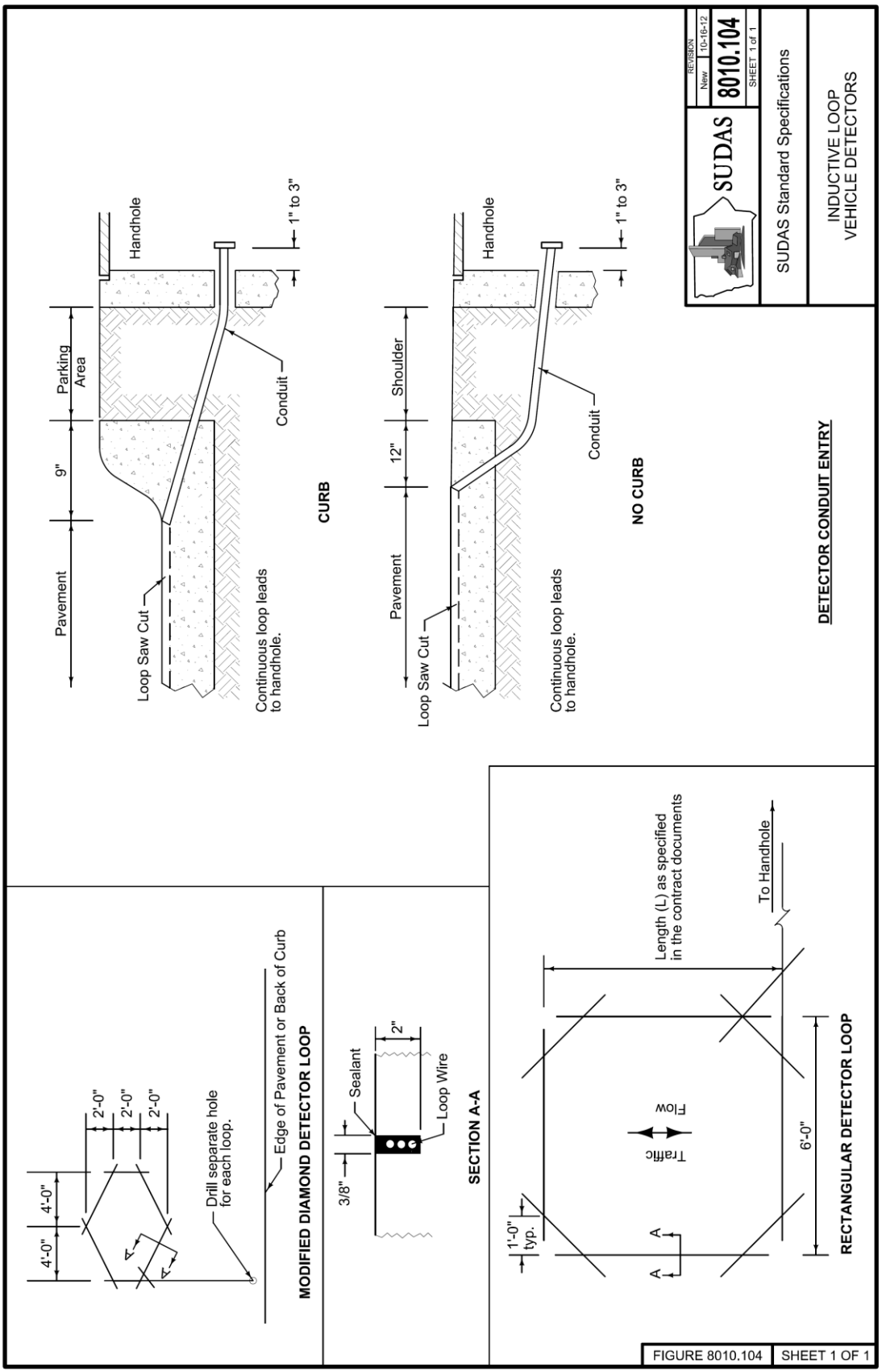
2. Detection: Detectors provide vehicle and pedestrian inputs to the traffic signal controller. Proper detector installation, operation, and maintenance is critical to the safe and efficient operation of any signalized intersection. An online resource to learn more about detection styles, modes, and typical layouts can be found within Chapter 9 Traffic Signals (Mn/DOT's Traffic Engineering Manual). Since this document is a PDF, some of the information from this source is provided below.

Detector sizes and locations vary by agency and by location. SUDAS provides a standard drawing for a typical rectangular detector loop (Figure 13E-1.05).

An online resource can be found through Chapter 16 Vehicle Detection (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for installation and mounting details.

a. Inductive Loop Vehicle Detector: The most common type of vehicle detection device in use today is the inductive loop. This is a loop of wire imbedded in the pavement (saw cut in existing concrete or NMC loop in new concrete) carrying a small electrical current. When a large mass of ferrous metal passes over the loop, the magnetic field is disturbed and generates, or induces, a change in resonant frequency in the wire. This change in frequency is then recognized by the detector amplifier and signals the controller that a vehicle is present.

Figure 13E-1.05: Inductive Loop Vehicle Detectors
(SUDAS Specifications Figure 8010.104)



b. Pedestrian Push Button Detector: There are a number of ways to provide pedestrian actuation at a signalized intersection. The most common equipment used by far is the pedestrian pushbutton detector. Pressing the button provides a contact closure that actuates the call. There are plenty of examples of good and bad pedestrian pushbutton placement; however, part of the problem is getting the pedestrian to use the button. Specific information regarding pedestrian detectors can be found in the MUCTD Section 4E.08 Pedestrian Detectors.

An online resource can be found through Chapter 20 Pedestrian Push Buttons (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for style, installation, and mounting details.

c. Video Detection Camera System: Vehicle detection by video cameras is a popular form of vehicle detection within Iowa. The rapid processing of video images provides the detection outputs to the controller. The designer should carefully consider the type of equipment necessary to provide video detection, the maintenance needs of this equipment, and the specific installation and mounting requirements necessary.

Designers should consider relevant manufacturer recommendations and other online resources such as the Guidelines for Using Video Detection at Intersections and Interchanges by Bonneson at Texas Transportation Institute.

d. Microwave Vehicle Detector: Microwave detection is often used within Iowa during temporary signal control to provide simple, non-intrusive vehicle detection. A variety of styles and levels of sophistication exist in the market today.

3. Communications: The designer may be required to provide supplemental specifications for these items given the highly proprietary nature of this equipment and the needs of the contracting agency. Generic specifications have been provided in the SUDAS Specifications.

4. Cabinet and Controller: The designer may be required to provide supplemental specifications for the controller, cabinet, and emergency vehicle pre-emption system given the highly proprietary nature of this equipment. Generic specifications have been provided in the SUDAS Specifications. New information was added to the specifications regarding uninterruptable power supply battery back-up system. The designer should carefully consider the cabinet and mounting requirements of the battery back-up system.

An online resource can be found through Chapter 23 Traffic Signal Cabinets (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for style, installation, and mounting details.

5. Poles, Heads, and Signs:

a. Vehicle Traffic Signal Head Assembly: Vehicle signal heads must comply with the following MUTCD sections:

Section 4D.16 Number and Arrangement of Signal Sections in Vehicular Traffic Control Signal Faces
Section 4D.17 Visibility, Shielding, and Positioning of Signal Faces
Section 4D.18 Design, Illumination, and Color of Signal Sections

An online resource can be found through Chapter 18 Signal Heads (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for style, installation, and mounting details.

b. Pedestrian Signal Head Assembly: Pedestrian vehicle signal heads must comply with the following MUTCD sections:

Section 4E.01 Pedestrian Signal Heads
Section 4E.02 Meaning of Pedestrian Signal Head Indications
Section 4E.03 Application of Pedestrian Signal Heads
Section 4E.04 Size, Design, and Illumination of Pedestrian Signal Head Indications
Section 4E.05 Location and Height of Pedestrian Signal Heads
Section 4E.06 Accessible Pedestrian Signals
Section 4E.07 Countdown Pedestrian Signals

c. Traffic Signal Poles and Mast Arms: Signalized intersections require poles and mast arms to achieve proper traffic signal and pedestrian head placement. Mast arm details and typical loadings are shown on Figure 13E-1.03; additional mast arm details are shown on Figure 13E-1.06. The designer should ensure that the plan locations comply with all clear zone, sight restriction, and pedestrian flow criteria. Vertical clearance to overhead utility lines is a constant issue that designers should take note of during pre-design field activities. Although the minimum height from the pavement to the bottom of the signal housing is 15 feet, the designer should consider the street classification and the volume of large trucks in establishing the signal height above the pavement. However, the top of the signal housing cannot exceed 25.6 feet above the pavement. If the project being designed has specific requirements relative to the elevation of the end of the mast arm in relation to the connecting point on the vertical pole, include those requirements in the special provisions of the contract documents.

An online resource can be found through Chapter 17 Mast Arm Poles and Pedestals (Mn/DOT's Signal & Lighting Certification Manual), which provides the designer with a photographic resource for style, installation, and mounting details.

d. Traffic Signal Pedestal Poles: Pedestal poles provide alternate mounting heights for signal and pedestrian heads and are much easier to locate within a tight right-of-way. Pedestal pole details and typical head mounting information are shown in Figure13E-1.07.

e. Traffic Signs: The designer must ensure that all signs comply with Iowa DOT standards and the MUTCD.

Figure 13E-1.06: Mast Arm Pole Details
(SUDAS Specifications Figure 8010.105)

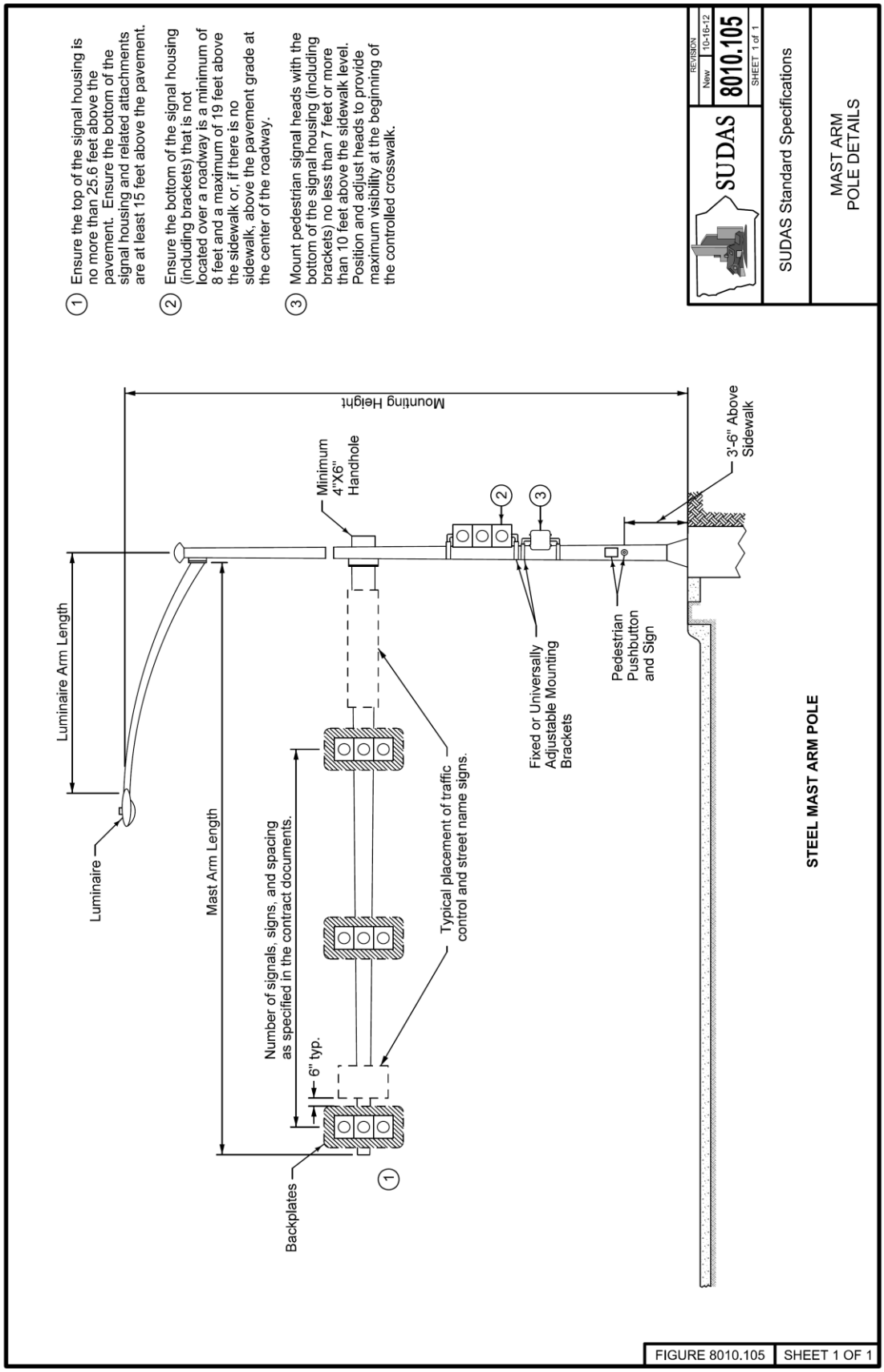
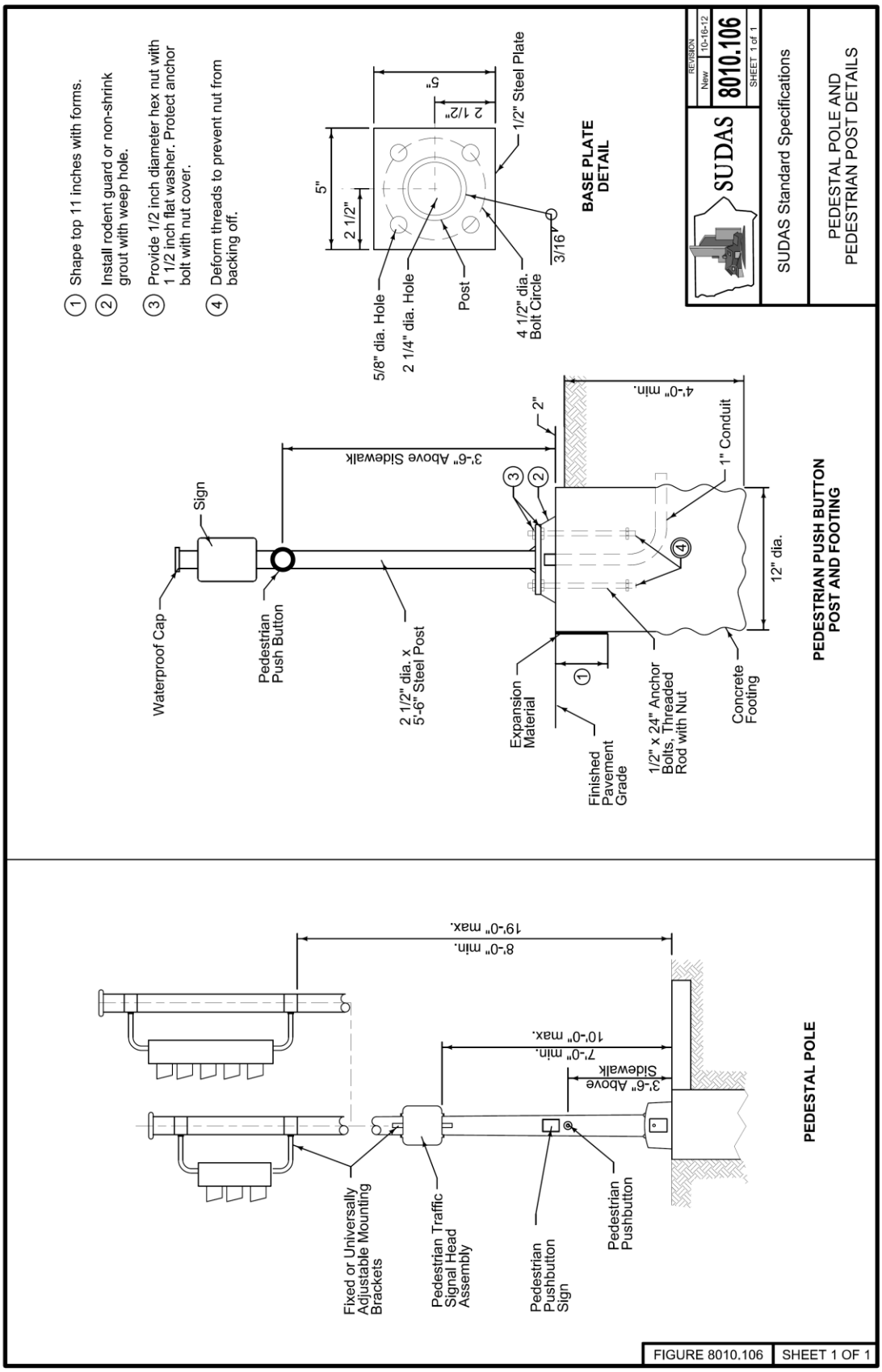


Figure 13E-1.07: Pedestal Pole and Pedestrian Post Details
(SUDAS Specifications Figure 8010.106)



C. Items Requiring Supplemental Specifications

A summary listing of items within SUDAS Specifications Section 8010 requiring supplemental specifications to be provided by the designer includes the following:

- Composite handhole and cover - specify materials and dimensions.
- Foundations - specify foundation dimensions and any conduit stubs needed for future use.
- Communications - specify all traffic monitoring equipment along with any fiber optic equipment and materials.
- Cabinet, controller, and emergency vehicle preemption - specify all relevant equipment.
- Traffic signal poles and mast arms - specify specialty finish for pole if necessary.
- Traffic signs - specify sheeting, sign dimensions, and mounting requirements.