Traffic Signal 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, Second Edition, FHWA-SA-13-027, July 2013, 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 profoundly influences 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 impediments, reducing the need for lane changes and merge maneuvers, and minimizing the required distance to traverse an intersection all improve intersection safety and operational efficiency.

   All possible road users’ (Chapter 2 of the guide) needs must be considered to achieve optimal safety and operational levels at an intersection. When road user groups’ design objectives conflict, 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. For instance, practitioners may design corner radii to accommodate large vehicles. However, these larger radii could be detrimental to pedestrian safety due to the increase in walking distances and the increase in speed of turning vehicles.

   The geometric design chapter (Chapter 4 of the guide) addresses the following design topics to be considered when designing traffic signal controlled intersections:
   - 4.1 Number of Intersection Legs
   - 4.2 Channelization
   - 4.3 Horizontal and Vertical Alignment
   - 4.4 Corner Radius
   - 4.5 Sight Distance
   - 4.6 Pedestrian Treatments
   - 4.7 Bicycle Facilities
   - 4.8 Transit 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 2018” states that at signalized intersections, the first vehicle stopped on one approach should be visible to the driver of the first vehicle stopped on each of the other approaches. It also states that left turning drivers need sufficient site distance to decide when to turn left across the lane(s) used by opposing traffic. This requires consideration of offset left turn lanes for permissive left turns to provide adequate left turn sight distance. If right turns are allowed on a red signal indication, the appropriate sight distance to the left of the right turning vehicle should be provided. See Chapter 9 - Intersections in the AASHTO “Policy on Geometric Design of Highways and Streets 2018” 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, parked vehicles, 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 safety analyses. The results of the analyses determine the need for and length of 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 crashes. 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. The need for turn lanes, turn lane storage lengths, and other geometric or traffic control improvements should be determined based on traffic operations analyses of existing and projected design year peak hour traffic. Traffic engineers typically use traffic analysis and/or simulation software for these analyses.
B. Operational Characteristics

The behavior of the traffic at an intersection is another highly important element of signal design. The MnDOT Traffic Engineering Manual Section 9-7.03 notes the various elements that should be considered.

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. MnDOT Section 9-7.04 notes the elements to be considered. In addition, note the following:

Traffic actuated controllers are most often used. 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 traffic volumes are often significant. At intersections with low volumes of pedestrians crossing such as an arterial, an actuated controller tends to operate much more efficiently, as it is not necessary to time pedestrian intervals except when an actual demand exists.

A split is the relative percentage of green, yellow, and red clearance time allocated to each of the various phases at a single intersection. An offset is a system reference time, usually expressed in seconds but sometimes in percent of cycle length.

D. Signal Design Elements

The following publications provide a wide range of guidance in the design of traffic signals:


Traffic signal designs should be based on project and intersection-specific design criteria (Section 13A-3, D). Key elements to consider and include in the design, as appropriate, include the following:

1. Signal Layout:
   a. Pole locations considering clear zone requirements, existing and proposed utilities, signal head locations, mast arm lengths, lighting needs, elevation differences, pedestrian pushbutton locations, and right-of-way constraints.
   b. Cabinet location considering proposed power service, signal interconnect, sight distance, and cabinet accessibility.
   c. Signal head locations and configurations considering visibility and proposed phasing.
   d. Handhole locations and conduit layout to minimize lengths of conduit runs. Consider providing a larger (Type III or IV) handhole near the signal cabinet and routing all signal conduits to the cabinet through this handhole.
   e. Signing needs.
   f. Stop line and advance detection.
   g. Miscellaneous equipment (EVP, traffic monitoring camera, etc.)
2. **Conduit and Wiring:**
   a. Conduit sizes considering conduit fill percentage.
   b. Wiring quantities and configurations based on equipment needs.
   c. Fiber optic cable configuration, terminations, and splicing.

3. **Phasing and Timing:**
   a. Type of left turn phasing (protected-only, protected-permissive, permissive-only) for each approach.
   b. Possible right turn overlap for right turn lanes.
   c. Phasing sequence diagram.
   d. Recommended initial timings.

4. **Miscellaneous Items:**
   a. Traffic signal notes and supplemental specifications, as needed.
   b. Estimated traffic signal quantities.
   c. Specific equipment or materials requirements.
   d. Reference or include applicable SUDAS Specifications Section 8010 figures and/or special details needed.

**E. Traffic Signal Operations**

The following publications provide guidance regarding traffic signal timings and operations:
- Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections, NCHRP Report 731

Traditionally, protected-only left turn phasing has been used for dual left turn lanes, due to safety concerns with permissive operation. However, protected-only left turn phasing can be inefficient, particularly during off-peak times. If protected-permissive or permissive-only left turn phasing is being considered, a traffic engineering study should be performed, including evaluation of the following:
- Operating speeds
- Possible sight distance obstructions (vehicles in opposing left turn lane(s), horizontal/vertical roadway geometry)
- Left turn and opposing through traffic volumes (vehicle mix - trucks)
- Left turn crossing distance
- Crash history
- Vehicle delays and queuing
- Potential pedestrian crossing conflicts
- Controller, cabinet and equipment flexibility and limitations
If protected-permissive or permissive-only operation is determined to be acceptable, flashing yellow arrow signal heads are required for separate signal faces per the MUTCD. Consideration should be given to providing this type of operation only during off-peak times.

To help jurisdictions better manage the variations in traffic volumes and operating speeds along signalized corridors, the use of automated traffic signal performance measures (ATSPMs) and/or adaptive traffic signal control (ATSC) could be considered.

The use of ATSPMs gives agencies a better idea of how signal timing plans are performing throughout the day / week / month / year and provide the information needed to make adjustments to fine tune timing plans and coordination plans. New traffic signal controllers, or third party equipment added to existing traffic signal controllers, collect the real-time data needed to produce the performance reports. More information can be found on the FHWA ATSPM Website.

The data produced through the ATSPMs can be used to determine the potential need for an ATSC system, which utilizes much of the same data collected for ATSPMs and adjusts traffic signal plans or coordination plans automatically. ATSC systems can be useful for corridors in which traffic is more variable or unpredictable than what could be addressed with specific time-of-day timing and coordination plans. More information can be found on the FHWA ATSC Website.

**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 and safety of vehicles and pedestrians at signalized intersections.

   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. Pedestrian volume and safety are important considerations when considering and designing right turn lanes.

   d. An additional 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 guides such as the MUTCD and the AASHTO Policy on Geometric Design of Highways and Streets.

   a. **Accessible Pedestrian Signals (APS)**: Evaluate each traffic signal project location to determine the need for accessible pedestrian signals, especially if the project location presents difficulties for individuals with visual disabilities. Some jurisdictions elect to provide APS for all new or modified signal installations. 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](http://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 (APS and non-APS) 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 (extended). 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 for APS. Supplemental push button poles or posts will typically be needed to meet the above criteria. 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. 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.

   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.

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.” 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 recalled by a button press during the WALK interval, provided that the crossing time remaining is greater than the pedestrian change interval.
   - 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 place 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.

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 improved 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 development 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. It may be possible for anticipated future intersection improvements to be accommodated for within the design to significantly reduce the need to replace signal poles, mast arms, and foundations 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.