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, 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 foundation elevations end up above grade and installing a push button based on the foundation 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 foundation 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.