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. However, one user's convenience or mobility should not be prioritized over another user's safety. 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. Stop bars may be adjusted or truck aprons added to allow for larger vehicle turning movements while keeping speeds lower, which prioritizes the safety of all users. In areas of high pedestrian activity and/or where vulnerable users are likely to be present, e.g. near schools, hospitals, church, etc., or when a local jurisdiction's adopted transportation plan calls for prioritizing pedestrian safety, designers should incorporate geometric design features to improve safety for pedestrians, see Section 12A-5.

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.

Signals are typically timed to prioritize the “major” street movements, which under certain conditions may increase delay for pedestrians and bicyclists waiting to cross the major street. Streets in lower density, suburban settings often do not have comparable pedestrian volumes as more dense, urban networks. However, these corridors may have transit operation or land uses across the major street to encourage pedestrian crossings (e.g. a park across from a residential neighborhood), which may make road crossing decisions challenging without appropriate crossing opportunities.

In some instances, where pedestrians routinely experience long delays at signals, they may elect to cross away from the crosswalk at locations where conflicts are not controlled by a signal. Therefore, strategies to reduce overall cycle length and provision of safe crossing based on the surrounding land use is important for pedestrian safety. Designers should also evaluate the frequency and location of crossing opportunities along a linear route and provide safe crossings where needed based on the roadway context; see Section 12A-5.

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 and the needs of pedestrian and bicyclists at signalized intersections:

- Manual of Traffic Signal Design, Second Edition, ITE
- Traffic Control Devices Handbook, Second Edition, ITE
- Signalized Intersections: Informational Guide, Second Edition, FHWA
- Signal Timing Manual, NCHRP Report 812
- Achieving Multimodal Networks, FHWA
- Urban Street Design Guide, NACTO
- Walkable Urban Thoroughfares, ITE
- Don't Give Up at the Intersection, NACTO

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. Motor vehicle and pedestrian signal head locations and configurations considering visibility and proposed phasing. Where bicycle lanes are present, signals must be visible to bicyclists or provide a separate indication, see Section 12B-3, L for guidance.

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 or turn restrictions to reduce conflicts with pedestrians and bicyclists.

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:

- Signal Timing Manual, NCHRP Report 812
- Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections, NCHRP Report 731
- Section 4E.06 Pedestrian Intervals and Signal Phases, MUTCD
- Interim Approval for Optional Use of a Bicycle Signal Face, FHWA IA-16
- Section 12B-3, L

1. Left Turn Phasing Considerations: 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.

2. **Automated and Adapted Traffic Signal Control:** 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 give 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.

3. **Signal Cycle Length:** The signal cycle length at an intersection can have a significant impact on pedestrian and bicyclist travel. Signal cycle lengths of 60 to 100 seconds are common in urban areas, as they allow frequent street crossings and encourage efficient use of a street network. In suburban areas where vehicle traffic is consolidated on a relatively small number of arterial and collector streets, signal cycle lengths are typically longer - between 100 and 120 seconds, sometimes even longer during peak periods. At intersections with a longer signal cycle length, all users approaching from a minor street can experience significant delays. This can result in reduced signal compliance for both pedestrians and bicyclists where gaps are present. Consideration should be given to providing shorter signal cycle lengths during peak and off-peak times, or operating in “free” or fully actuated mode during off-peak periods so the signal switches to the side street phase more quickly to minimize delays to side street users including bicyclists. However, signal cycle length reductions must not come at the cost of adequate pedestrian crossing intervals.

4. **Pedestrian and Bicyclist Signal Timing and Phasing for Reducing Delay and Managing Conflicts:** Frequent crossings accommodating walking and biking speeds for all ages and abilities are key to creating a safe, accessible, and connected pedestrian and bicycling network. Sections 13A-4, F and 12B-3, L provide guidance on pedestrian and bicycle signal timing and detection, respectively. As motor vehicle speeds and volumes increase, separate signal phasing may be appropriate to improve safety for all users. Guidance for signal phase separation is also described in Sections 13A-4, F and 12B-3, L.

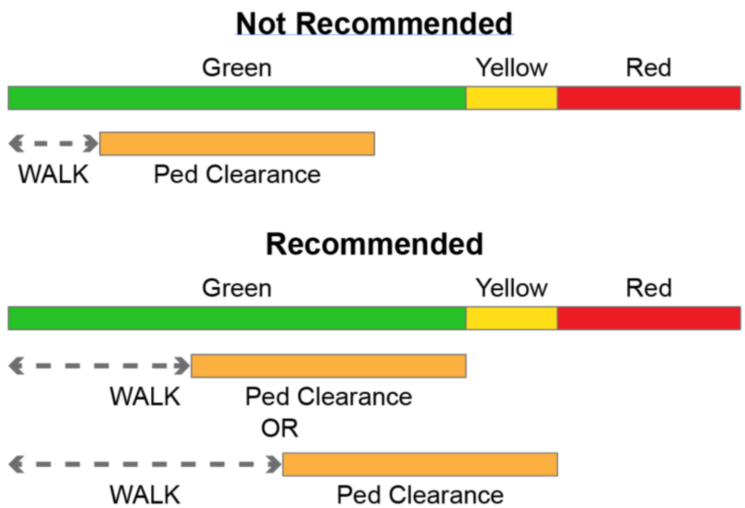
F. Pedestrian Signal Timing and Design

1. **Signal Timing:**

   a. **Signal Cycle Length:** In some instances, where pedestrians routinely experience long delays at signals, they may elect to cross away from the crosswalk at locations where conflicts are not controlled by a signal. Therefore, strategies to reduce overall cycle length can be particularly important for pedestrian safety. Where pedestrians are expected regularly, cycle lengths greater than 90 seconds should often be discouraged. In addition to reducing cycle lengths, designers may also consider using half-cycle lengths, particularly during off-peak hours. Adaptive signal control, where employed, should have limited variation in cycle length. Operations for adaptive signal control should be confined to suburban settings and event venues where traffic patterns can be highly variable.

b. Pedestrian Signal Phase Timing: Details for programming the walk and clearance interval are provided in MUTCD Section 4E.06. Signal timing should strive to maximize the WALK + FLASHING DON'T WALK phase so total pedestrian time is equal to the total concurrent vehicle green and yellow timing; see Figure 13A-4.01. To address conflicts, designers should instead use one or a combination of treatments listed in Section 13A-4, F, 2.

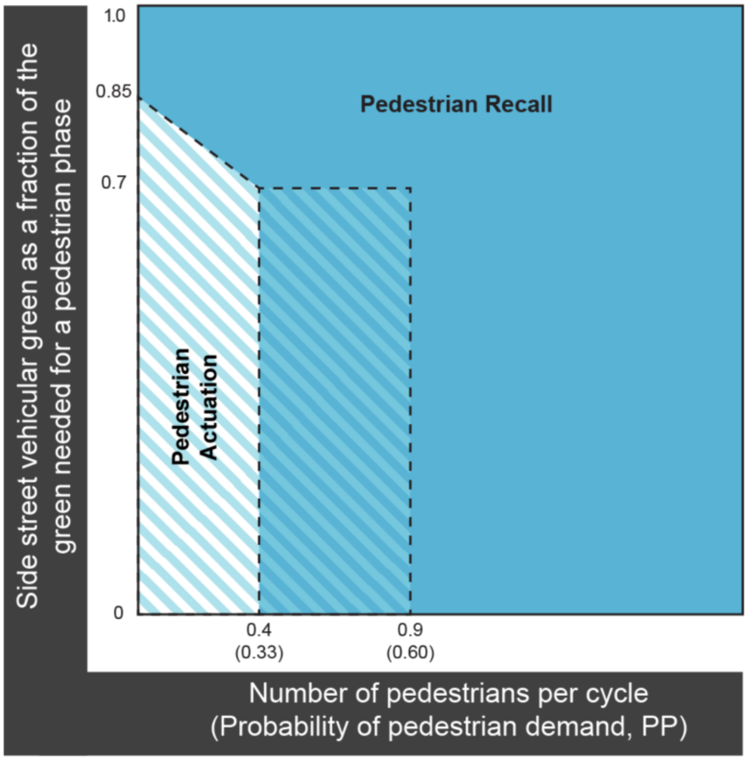
Figure 13A-4.01: Maximizing the WALK Interval.



c. Recall and Actuation: Pedestrians should not always be required to push a button to call the pedestrian phase at locations with high pedestrian volumes. This is particularly important in downtown corridors or business districts where there tends to be significant pedestrian volume and relatively short cycle lengths. In such environments, fixed time operation with time-of-day phase plans often functions more efficiently compared to actuated or semi-actuated signal timing. Fixed time operation allows for signal controllers to call pedestrian phases each cycle. In a fixed time grid, pedestrian WALK + FLASHING DON'T WALK intervals are often the maximizing factor for phase length, as the time necessary to accommodate pedestrian movements exceeds the time needed for motor vehicles. Designers may consider providing an automatic pedestrian phase according to Figure 13A-4.02. This could be accomplished based on different signal timing plans at certain times of day or day of the week.

If it is determined the pedestrian phase should switch from actuated to recall based on the time of day, designers can minimize confusion by ensuring the pushbutton includes a confirmation light. When the signal operations have switched to pedestrian recall, the detection indicator can be programmed to illuminate by default.

Figure 13A-4.02 Recall versus Actuated Pedestrian Phase for Coordinate-Actuated Arterials



Source: Cesme, Furth, Cashman, and Lee, 2021

2. **Signal Phasing for Managing or Reducing Conflicts:** There are a variety of alternative signal phasing options for reducing or eliminating conflicts between motorist and pedestrians. Designers should consider both the operational and safety impacts of signal phasing changes at an intersection. Designers should also be aware a phasing scenario may necessitate a separate motor vehicle turn lane and an additional signal phase, which may increase delay for some users, including pedestrians. Fully separated crossings may require longer cycle lengths, which may result in reduced user compliance with signal indications and increased potential for conflict. The four major phasing scenarios, criteria, and considerations are described below. There may not be one solution but a combination of treatments for specific periods or scenarios to address pedestrian safety.

   a. **Leading Intervals:** Leading pedestrian intervals (LPIs) or leading through intervals (LTIs) may be used to give pedestrians a head start (typically a minimum of 3 seconds) when crossing the street. LPIs are a proven safety countermeasure to reduce vehicle-pedestrian crashes at intersections. Implementation allows waiting pedestrians to enter the crosswalk where they become more visible to conflicting motorists. Both LPIs and LTIs accomplish the same goal through different strategies.
      - **Leading Pedestrian Intervals:** With traditional signal phasing, parallel pedestrian WALK and motor-vehicle circular green indications start at the same time, immediately after the conclusion of the red clearance interval. With LPIs, the walk phase begins as usual and parallel motor vehicle circular green indications start after a brief period. Designers should include APS units where LPIs are provided; without APS units, pedestrians with low or no vision may not be able to maximize the advantage of LPIs, as they otherwise use the noise of concurrent vehicles to determine when to begin walking.

- **Delayed Turn or Leading Through Intervals:** A delayed left (or right) turn or LTI provides a green signal to through movements while delaying permissive left (or right) turns for a specific period. This delay time may vary based on site specific conditions, but (similar to an LPI) is usually between 3 and 6 seconds. This option minimizes intersection capacity impacts while providing a partially protected pedestrian phase, allowing those on foot a head start in order to establish themselves in the intersection before turning movements are allowed after the protected left (or right) turn phase.

The following equation is used for calculating the LPI interval (rounded to the nearest second).

$$LPI(sec.) = \frac{W_1 + W_2}{S_w}$$ **Equation 13A-4.01**

where:

LPI = Leading pedestrian interval, sec
W1 = Width of first lane of moving vehicles, ft
W2 = Width of shoulder, bicycle lane, and/or parking lane, ft
S_w = Walking speed,typically 3.5 ft/sec

Source: Lin, 2017

An approach meeting any one of the following criteria may be a good candidate for the installation of an LPI:

- Reported crash history finds one or more crashes per year have occurred over the last 3 years between vehicles turning on green and pedestrians crossing the street on the associated crosswalk with the pedestrian WALK signal;
- A visibility issue exists between the driver's view of pedestrians on the crosswalk due to obstructions or poor sight distance at an intersection approach that can be improved through an LPI. LPIs by themselves don’t resolve sight distance limitations, as they don’t protect pedestrians who arrive at the end of the WALK phase. Physical measures to remove corner sight obstructions should be given primary consideration;
- Intersection observations reveal conflicts between crossing pedestrians and turning vehicles in which there is a risk of collision should their movements and speeds remain unchanged;
- One of the two movement volumes (turning vehicle volume (A), or pedestrian volume (B), identified in Equation 13A-4.01) meet at least one the thresholds identified in the table for a given warrant.

Table 13A-4.01: LPI Volume Warrant Thresholds

Warrant	Turning Vehicles Volume (A)	Pedestrian Volume (B)
Vehicle Peak Hour	≥ 130 per hour	≥ 25 per hour
Pedestrian Peak Hour	≥ 100 per hour	≥ 50 per hour
4 Hour Vehicular and Pedestrian Volume	≥ 105 per hour	≥ 30 per hour
8 Hour Vehicular and Pedestrian Volume	≥ 100 per hour	≥ 25 per hour
School Crossing	≥ 50 per hour	

Source: Modified Lin, 2017

When a protected left turn phase is provided, it should occur as a lag to prevent left turning vehicles from continuing to cross during the LPI. Designers must avoid the “yellow trap” (see NCHRP Report 812 Section 4.3.1.3) when providing a lagging turn phase.

b. Protected Pedestrian Phase and Turn Restrictions: Protected pedestrian phases or protected-only signal phasing for turn movements can significantly reduce conflicts between pedestrians and motorists. This process eliminates specific motor vehicle phases (e.g. left turns) that cross concurrent pedestrian phases. For example, if the permissive left turns (either green ball or flashing yellow arrow), the cross pedestrian WALK/FLASHING DON’T WALK phase is eliminated and there is no longer a turning conflict for the crossing during that phase. In these cases, pedestrian phases may occur before (lead) or after (lag) conflicting vehicular movements.

Turn restrictions or protected pedestrian phases may be considered when one or more of the following criteria are met:

- There are high conflicting turning vehicles volumes. High turning volumes are defined as equal to or exceeding:
  - 200 total right and left turning vehicles per hour;
  - 50 left turning vehicles per hour when crossing one lane of through traffic; or
  - 100 right turning vehicles per hour.
- There is a high volume of total approaching traffic (greater than 2,000 vehicles per hour for all approaches);
- There are high pedestrian volumes (pedestrians are 30% of vehicle volumes or 300 pedestrians per hour);
- Crash patterns at the study location or nearby locations with similar geometry support the use of separating motor vehicle and pedestrian phasing. Typically, this encompasses three or more left turn or right turn collisions where pedestrians had the right-of-way over a 3 year period;
- The available sight distance is less than the minimum stopping sight distance criteria;
- The intersection geometry is unusual (streets intersect at acute/obtuse angles or streets have significant curvature approaching the intersection), which may result in unexpected conflicts and/or visibility issues;
- The intersection is in close proximity to senior housing, elementary schools, recreational areas, playgrounds, and/or health facilities.

Protected pedestrian phases or protected-only turn phases may be implemented on a permanent basis, during specific hours, or “on-demand” when a pedestrian is present and activates the pushbutton. When used for a specific time of day (school arrival and departure, e.g.), blank out NO TURN ON RED signs or red arrows should be used for conflicting motorist movements when the protected pedestrian phase is in operation. If only one movement or street meets the criteria above, consider a treatment to address those specific issues before implementing an intersection-wide approach (i.e., provide protected-only turns for the major roadway and allow for permissive turns on the minor roadway, if turning volumes are low on the minor roadway).

c. Concurrent Pedestrian Phase with Permissive Vehicle Turns: At most signals, the WALK indication for pedestrians is displayed concurrent with the green indication for parallel through vehicular movements. Concurrent timing often allows vehicles to turn left or right across the crosswalk during the WALK and FLASHING DON’T WALK phases with change interval countdown indication (pedestrian clearance interval), provided the motorists yield to pedestrians. To mitigate conflicts and improve motorist yielding, designers may consider the following treatments:

- Regulatory signs, such as the R10-15a series “TURNING VEHICLES YIELD TO [PEDESTRIANS]”
- Flashing yellow arrows (see below)
- Geometric treatments to reduce vehicle speeds and increase sight distances such as raised pedestrian crossings and curb extensions (see Sections 12A-5 and 5M-1)

Flashing yellow arrows (FYAs) may be used for left or right turning motor vehicles to emphasis drivers may proceed after yielding to oncoming traffic and/or pedestrians in a crosswalk. FYAs allow flexibility in providing permissive turns while warning drivers of potential conflicts. Refer to the Interim Approval (IA-10) and MUTCD for additional guidance.

d. Exclusive Pedestrian Phases: An exclusive pedestrian phase (EPP), sometimes referred to as a “Barnes Dance”, stops vehicular traffic in all directions, allowing pedestrians to cross the intersection in all directions, including diagonally. This treatment can produce a safer operation over conventional phasing, but delays for both pedestrians and motorists can be higher than conventional signal timing. A protected pedestrian phase, specific turn restrictions, or LPIs are more appropriate solutions. An EPP may be preferred over a protected pedestrian crossing for the following scenarios.

- A combination of the criteria listed in Section 13A-4, F, 1, a, is met and 15% of pedestrians desire to cross diagonally
- During special events occupying a substantial portion of the public right-of-way (street fairs, parades, etc.)
- The start and end of school days for major school crossings
- Intersections where certain motor vehicle turning movements are either not allowed or not in conflict with designated pedestrian crossings

Signs may be attached to signal poles or pedestrian pushbuttons to inform people the intersection has an EPP and they may cross diagonally; to inform where an EPP must be actuated by a person waiting to cross; or to deter crossing against the pedestrian signal concurrently with vehicle traffic. Signals including EPP should time pedestrian phases to accommodate the longest possible crossing.

If a diagonal crossing is employed, designers may need to consider how a person with a visual disability would know they could cross diagonally. Such determinations need to be carefully considered along with pushbutton placement and pedestrian ramp design for accessibility. Pavement markings should be designed according to MUTCD Figure 3B-20.

3. **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 can have a negative impact on traffic capacity and operations including increased delays to pedestrians, therefore designers minimize overall crossing distance to improve safety and reduce delay for all. Pedestrian actuation will disrupt traffic signal coordination and it may take several cycles to bring a corridor back into coordination; but it can improve safety and have minimal impact to operations during motor vehicle off-peak hours. 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. Right turn on red restrictions may be used to reduce this conflict, though such signs may not be effective if sight distance is not limited by geometry or other roadway features (landscaping, business signs, etc.) without significant enforcement efforts. A NO TURN ON RED (R10-11) sign may be used to always prohibit this movement, or a dynamic NO TURN ON RED sign may be installed to limit turns at specific times or conditions. Where left turns on red are legal on one-way streets, such restrictions may be appropriate for similar reasons.

   c. Pedestrian volume and safety are important considerations when designing right turn lanes. Right turn lanes can present additional challenges for pedestrians, especially if the returns are large and channelize traffic with an island and are therefore discouraged where pedestrians are expected. Designers should work to reduce the curb radius and may use elements such as truck aprons to keep speeds low. Where intersections are skewed, channelizing islands can mitigate larger corner radii. Channelizing islands should be designed to slow speeds and maintain visibility between pedestrians and motorists through geometric design; see Exhibit 5-7 of NCHRP Report 834. For retrofits, a raised crossing may be considered to reduce speeds of right turning vehicles and encourage yielding.

   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 pushbuttons 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. See Section 12A-5 for refuge island design guidance.

4. **Visibility:** Visibility is important to the safe operation of the pedestrian indications. Pedestrian indications as well as the pushbuttons 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.

5. **Countdown Pedestrian Heads:** Pedestrian signals with countdown displays show the number of seconds remaining in the clearance interval and their use has been shown to reduce both pedestrian and vehicular crashes at signals. MUTCD requires countdown pedestrian heads where the pedestrian change interval (the flashing upraised hand signal) is more than 7 seconds; see MUTCD Section 4E.07. Traffic engineers should consider using countdown pedestrian heads for crosswalks where the pedestrian change interval is 7 seconds or less because they are easier to understand for all users.

6. **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 pushbuttons. 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. The MUTCD contains standards for APS and pedestrian pushbuttons but does not require them. PROWAG requires APS and pedestrian pushbuttons when new signals are installed. For existing pedestrian signals, PROWAG requires APS and pedestrian pushbuttons when the signal controller and software are altered, or the signal head is replaced. 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 pushbuttons 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) **Pushbutton Stations:** An APS pushbutton station is a weather-tight housing with a 2 inch diameter pushbutton, a speaker, and a pedestrian sign. Braille signing, raised print or a tactile map of the crosswalk may also be provided. The pushbutton has a vibrotactile arrow pointing in the direction of the crossing.

2) **Location of Pedestrian Pushbuttons:** Pushbuttons (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, pushbuttons should be located no more than 10 feet from the edge of curb, shoulder, or pavement. Where two pushbuttons 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 pushbutton poles or posts will typically be needed to meet the above criteria. The MUTCD requires a pedestrian pushbutton 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 pushbutton should be located so pedestrians using the audible or vibrotactile indication can align themselves and prepare for the crossing while waiting close to the pushbutton station and the crossing departure point.

   It is common to see a narrow grass strip between the sidewalk and pole used to mount the pushbuttons or to only see sidewalk on one side of a pole containing multiple pushbuttons. It is difficult to impossible for a person in a wheelchair to reach the pushbutton 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 pushbuttons and be at a reasonable slope. There should also be sidewalk on each side of a pole that has a pushbutton.

3) **Locator Tone:** APS pushbuttons 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 pushbutton. 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 pushbutton 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 pushbutton 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 pushbutton 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 pushbutton station. In addition to the typical two wires between the pushbutton and the controller cabinet, a 4 wire cable must be provided between the pushbutton station and the CU. This system may be more cost effective for installations with only one or two crossings.

G. Motorist, Bicyclists, 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. Pedestrian signal heads and audible pedestrian signals should be provided at signalized intersections in urban and suburban contexts that have sidewalks and curb ramps on the approaches in order to establish consistent expectations and safety for pedestrians. In places lacking sidewalks, other criteria may also be used to determine when pedestrian signal devices should be provided. These other criteria can be considered as part of engineering studies and could include pedestrian activity; expected or anticipated land use; transit stops; or the presence of schools, parks, or employment. 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. Similarly, where separated bicycle lanes are present, the type of signal used for bicyclists should be consistent throughout; see Section 12B-3, L. Traffic signal head style, placement, and orientation for both general purpose lanes and separated bicycle lanes 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 motorist, bicyclist, 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.

I. References

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Lin, Pei-Sung, et al. "Development of Statewide Guidelines for Implementing Leading Pedestrian Intervals in Florida." Florida Department of Transportation. 2017.