1 OBJECTIVE

This document provides traffic engineers with guidelines to be used for the design of traffic signal phasing and timing plans in the City of Boston. Any traffic signal under consideration is assumed to have been justified and documented in an engineering report based on the traffic signal warrant analysis procedure documented in the Manual on Uniform Traffic Control Devices (MUTCD). As in the development of any traffic engineering plan, significant professional engineering judgment should be exercised. This policy applies to all projects that impact traffic signals owned and operated by the City of Boston.

2 REQUIREMENTS AND VARIATIONS

Signals must be brought into compliance with this policy when signal sequences are adjusted, as well as during programmed retiming, equipment upgrades, and during timing changes related to development projects, with priority given to locations with documented safety issues. Any deviations from this policy require documented justification for the variation and must be approved by the Boston Transportation Department (BTD).

3 DATA COLLECTION

3.1 Intersection Geometry and Land Use Data

A condition diagram should be developed depicting existing intersection layout, including features such as roadway geometry, channelization, grades, number and width of travel lanes, lane use, speed limit, parking restrictions, driveways, bus stops, and sight distance restrictions. The location of any nearby schools, senior citizen facilities, parks or recreational areas, playgrounds, community centers, libraries, public transit stations or stops, hospitals, and other significant pedestrian generating facilities should be noted on the diagram. The traffic engineer should develop the condition diagram based on field evaluation.

3.2 Intersection Demand Data

Count data must clearly indicate the direction of travel (i.e., from the North) for all modes and include peak hour summaries (AM, midday, and PM) along with a graphic layout depicting the peak hour movements occurring within the intersection.

3.2.1 Vehicular Data

Vehicular counts should be collected for each turning movement from each approach, e.g., turning movement counts (TMC) and summarized in 15-minute intervals. Counts should cover at least 7 AM to 7 PM on a typical weekday. Additional counts and automated traffic recorders (ATRs), including nights and/or weekends, may be required to establish cycle lengths for periods with low traffic volumes or special events. Supplemental ATR data should also be collected to validate TMC data as "typical" in spot locations, usually used for corridor considerations.

3.2.2 Bicycle Data

Bicycle counts should be collected for each turning movement from each approach and summarized in 15-minute intervals. Counts should cover at least 7 AM to 7 PM on a typical weekday.

3.2.3 Pedestrian Data

Pedestrian volumes and direction on each crosswalk should be counted during the same periods as the vehicular counts.

3.3 Signal Timing Data

Existing phasing and timing data should be compiled for applicable adjacent signals, typically within 1,000 feet of subject location.

3.4 Crash Data/Safety Analysis

A crash summary should be prepared for the most recent three-year period of crash data available. Data sources should include point data from the Vision Zero Injury crash map as well as narratives and crash details from the Boston Police Department (BPD), and the MassDOT Impact Portal database.

Some locations warrant additional data collection, such as on-site observation of vehicular, pedestrian, and cyclist interactions, to support the final signal design. Additional data collection will be requested as-needed by the BTD.

4 TRAFFIC OPERATIONS ANALYSIS

4.1 Methodology/software tools

Perform intersection analysis using collected data and BTD approved methodology to determine critical movements and establish a traffic signal phasing and timing plan. If the signalized intersection is, or will be adjacent to, or between existing traffic signals operating in a coordinated system, cycle lengths must be consistent with those used in the existing network to maintain proper coordination. Otherwise, all the signalized intersections operating in the coordinated system must be analyzed for new cycles, splits and offsets.

Traffic signal timing and phasing analysis shall be performed using an approved software package such as Synchro - Version 9.0 or higher. Other software packages may be acceptable with prior BTD approval. The traffic signal timing and phasing analysis must be calibrated to reflect current conditions observed in the field on a typical weekday and approved by BTD. The traffic engineer must submit the following items for BTD review:

- Synchro model files along with both input and output files.
- Documentation showing how pedestrian timing performance measures were determined.

Printed, and/or electronic files may be required for submission.

4.2 Analysis periods and durations

Proper intersection analysis shall include AM peak and PM peak hours at a minimum. BTD will require a midday analysis for traffic signals on the City's central computer system and other locations as directed. BTD may require timing plans for periods with low traffic volumes or special events.

4.3 Performance measures

Measures of Effectiveness (MOEs) such as Average Vehicle Delay, Level of Service (LOS), Volume-to-Capacity Ratio (V/C), 50% Queues, Pedestrian Delay, Lowest Pedestrian Speed Accommodated, and selected MOEs (see example of the summary sheet in Attachment 1), shall be summarized on a table by movement, approach, and intersection total for each scenario analyzed, including the existing condition.

5 SIGNAL TIMING CONCEPTS

It is known that the goals of traffic safety and traffic capacity may conflict when determining the number of phases for an intersection and decisions related to the treatment of turn movements, pedestrian crossings, bicycle flows, and whether movements will have permitted turn conflicts or have protected phases (i.e., no turn conflicts allowed). To maximize efficiency of signalized intersections, BTD requires that traffic signal control be designed for the minimum number of phases that are necessary to provide an acceptable level of safety. Considering this, the traffic engineer must carefully select the appropriate use of protected/exclusive phases. Intersections that experience significant conflicts between turning vehicles and pedestrians and/or between turning vehicles and through traffic, or that have restricted sight distance may require a protected/exclusive phase, which is acknowledged to potentially degrade the overall intersection and network MOEs.

Likewise, the goals of traffic safety and driver convenience may conflict when it comes to arterial signal coordination. Coordination that facilitates traffic moving at a safe speed through multiple intersections with little or no delay is desirable. Policies that aim to avoid long intervals of unused green time may slightly degrade vehicular MOEs for arterial traffic, but help improve safety for all users and often improve MOEs for pedestrians. While the addition of a traffic signal is not a remediation measure for speeding, unused green time provides an opportunity to give more time to pedestrians.

During the development of signal phasing and timing plans, in addition to peak hour patterns, off-peak and overnight timing plans shall be developed. Additional plans may be necessary.

5.1 Cycle Length and Signal Coordination

Signal cycle lengths should be as short as possible to minimize unnecessary delays for all modes while maintaining safety, minimizing queues, and providing necessary traffic signal coordination. Half cycle lengths should be used whenever possible.

Where attainable, cycle lengths and signal phasing and timing plans should be designed for a maximum V/C ratio of 0.95 for each approach during peak hours and 0.90 outside of peak hours. An individual V/C ratio greater than 1.0 is not desirable, as significant queues will develop. Depending on the surrounding context of the intersection, the geometry and size, unavoidable vehicular volumes, and other constraints, exceptions will occur. In these cases, V/C ratios of all movements should be well balanced, based on engineering judgment. Given the numerous considerations, V/C ratios in excess of 1.0 may be considered by BTD engineers in order to achieve the benefits of shorter cycle lengths, improvements to safety for vulnerable users, etc.

To avoid providing excess roadway capacity and long cycle lengths, volume-capacity calculations shall:

- Use field observations to calibrate lane utilization factor as documented in the report.
- An area factor should not be used unless there is a documented reason for it.

Within each coordination zone, signal timing offsets should be chosen for a progression speed that is not greater than the speed limit. Using a progression speed 5 mph lower than the speed limit should be considered. On streets prioritized for bicycles, consider using a progression speed of 11-15 mph.

5.2 Left Turn Phasing Strategies

1. Protected-only left-turn phasing should be applied in the following cases:

    a. The cross-product of the left-turn traffic multiplied by the opposing traffic is greater than 50,000 for one lane and is greater than 100,000 for two or more lanes and the left-turn volumes are at least 75 vehicles per hour (vph), during the two peak hours.
    b. Left turning motorists do not have clear visibility toward oncoming traffic.
    c. There were four or more left turn crashes in the last year, or six in the last two years that are susceptible to correction.
    d. There is more than one left-turn lane.
    e. Intersection geometry dictates that permissive left-turns may be confusing or dangerous, or where left turns can be made at high speeds (i.e., five-legged or skewed intersections).
    f. Left turns across a center-running transitway.
    g. Left turns across three or more opposing through lanes.
    h. Left turns across two opposing through lanes if the left turn crosses a bike lane or a crosswalk, unless permitted left turn phasing would generate no more than 1.5 permitted left turns per cycle.

i. Left turns across two opposing through lanes if the left turn crosses a two-way cycle track.
j. Left turns across one opposing through lane if there is a left turn lane and the left turn crosses a bike lane, unless permitted left turn phasing would generate no more than 2.5 left turns per cycle.

2. Otherwise, protected + permitted and permitted-only left turn phasing may be considered:

   a. Where protected + permissive left-turn phasing is provided along with an exclusive turn lane, a Flashing Yellow Arrow should be installed for all new traffic signals and signal equipment upgrades and should be considered for all other cases.
   b. Left turn phasing must ensure that no “Yellow Trap” is created for vehicles performing a permissive left turn movement.

3. Where LPIs are used, any protected left-turn phase that exits across the subject crosswalk must be a lagging left.

5.3 Yellow Change and Red Clearance Intervals for Vehicular Phases

Yellow change and red clearance intervals shall be calculated using the latest MUTCD and MassDOT Guidance on Calculating Clearance Intervals at Traffic Signals.

Calculation sheets must be submitted to BTD showing that vehicular clearances for each traffic signal phase have been computed to meet the current city, state, and federal standards.

5.4 Minimum Green Intervals

Minimum green time should be eight seconds for through phases and six seconds for turn phases. For through phases that are also used by bicycles, minimum green should be long enough that a cyclist starting on a fresh green can clear the intersection before green, yellow, and red clearance expire, allowing for six seconds of startup/acceleration delay and a clearance speed of 10 miles per hour (14.7 feet/second).

5.5 No Turn on Red

1. No Turn on Red restrictions should be implemented in the following cases:

    a. In locations that meet the criteria listed in Section 2B.54 of the MUTCD.
    b. In the Downtown Area[1], Main Street Districts[2], and Neighborhood Business Districts.
    c. Where exclusive or protected pedestrian phases are implemented, including Leading Pedestrian Interval (LPI) and Leading Through Interval (also called Delayed Turn – please see Pedestrian Protection from Right Turns section).
    d. On approaches whose right turn movement crosses a shared use path (SUP) or separated bike lane (SBL). This restriction applies both to right turns whose approach crosses a SUP/SBL and to right turns whose departure crosses a SUP/SBL.
    e. At intersections near schools, senior citizen facilities, parks, recreational areas, playgrounds, libraries, mass transit stations or stops, hospitals, or other significant pedestrian generating facilities.

If used, No Turn on Red signs shall be installed near the appropriate signal head for each approach.

5.6 Overnight Operations

A timing plan appropriate for late night operations should be provided with each signal timing plan submittal. When signals that currently operate with overnight flashing mode are modified in timing, phasing, and/or equipment, they shall be configured to operate in steady (stop-and-go) mode 24 hours per day at intersections. Signals that have not been retimed may operate in flashing mode between 3 AM and 6 AM. Signals operating in flash mode shall flash yellow on the major street and red on the minor street.

6 PEDESTRIANS

BTD encourages the use of pedestrian phases that maximize safety, encourage pedestrian compliance with the WALK phase, and reduce delays to pedestrians and vehicles by keeping cycle lengths as low as possible. All crosswalks that have no conflicting vehicle movements should provide WALK indications with the corresponding vehicular green interval to reduce pedestrian delay, including when there is an exclusive pedestrian phase.

6.1 Pedestrian Intervals

1. Pedestrian WALK intervals should be maximized where possible. The minimum WALK interval duration should be seven seconds.
2. Pedestrian crossing distance shall be measured from center of Tactile Warning Panel (TWP) at curbline to same point on receiving TWP to reflect the physical conditions experienced by pedestrians in each crossing. At intersections with exclusive pedestrian phases, clearance time should generally be provided for marked crossings only.
3. Pedestrian clearance time should be calculated using a primary pedestrian design speed of 3.5 feet/second. A slower walking speed (3 feet/sec) may be considered at intersections near schools, senior citizen facilities, parks, recreational areas, playgrounds, libraries, or hospitals.
4. The pedestrian phase end buffer, which is the time between the start of solid Don't Walk and the release of conflicting traffic, must be at least three seconds long. For citywide consistency, it is desirable that the phase end buffer be between three and four seconds.
5. Needed pedestrian clearance time shall be satisfied by a combination of clearance time (Flashing Don't Walk / countdown time) and the pedestrian phase end buffer.
6. Pedestrian intervals should be designed so that pedestrians can cross the entire street in one stage. However, where a median of sufficient dimension for refuge (6' minimum, 8' preferred) would make a phase serving a single stage crossing inordinately long, multi-stage crossings may be considered.
    a. If a multi-stage pedestrian crossing is used, a pedestrian pushbutton must be installed in the median, and the median width shall not be less than six feet. A signal phasing sequence should be used that minimizes pedestrian delay in the median and reduces instances of pedestrians being trapped within the median. Where a timing plan uses multi-stage pedestrian crossings, intersection analysis shall include average pedestrian delay for the full crossing (not for individual stages) as an MOE and a coordination diagram of the crossing phases showing the volume of pedestrians expected to wait in the median, and for how long.

6.2 Pedestrian Protection from Left Turns

Pedestrian protection from left turns can be provided through protected left turn phasing (see Left Turn Phasing Strategies section).

6.3 Pedestrian Protection from Right Turns

Full pedestrian protection from right turns, and from unopposed left turns (from the stem of a T-junction and from one-way streets), can be provided both through exclusive pedestrian phases and through concurrent-protected phases, in which conflicting turn movements run during distinct phases. Partial pedestrian protection (protection during the early part of the WALK interval, when most pedestrians begin) can be provided through a Leading Pedestrian Interval (LPI) or Leading Through Interval (LTI). LTI is different than an LPI and means that the phase begins with pedestrians and through traffic, while right-turning traffic has a delayed start (typically starting 7 – 11 seconds later). LTI is typically implemented at intersections with exclusive right turn lanes.

The following table (Table 1) indicates the conditions under which full, partial, and no protection should be considered for right turn conflicts for intersection angles that are close to 90 degrees (i.e., intersections with typically low right turn speeds). For intersection angles that are less than 80 degrees, which typically cause high speed right turns, or intersections with visibility issues, full pedestrian protection strategies should be considered. Additionally, where space can be found for a right turn lane, LTI is preferred to LPI because it allows for a longer protected interval, is better for cyclists, and has less capacity impact on vehicles.

When changing from exclusive pedestrian phasing to concurrent, partial protection should be considered.

Table 1:
Pedestrian protection strategies by right turn vehicle volume threshold at locations where intersection angle is close to 90 degrees (i.e. typically where low speed right turns occur)

	Conflicting Right Turn Volume Threshold[1] in Peak Hour		
Conflicting Right Turn Volume in peak hour	0 – ≤3.5 right turns/cycle (0 to approx. 125 vph[2])	3.5 – 5.5 right turns/cycle (approx. 125-200 vph[2])	≥5.5 right turns/cycle
Critical Approaches (i.e. protection strategy increases cycle length)	no LPI or LTI	Minimum-length LPI	Fully Protected Crossing[3]
Noncritical approaches (i.e. protection strategy does not increase cycle length)	Where there is no right turn lane: LPI[4] Where there is a right turn lane: LTI		

1. Treat left turns like right turns at T intersections and at intersections on one-way streets. At T intersections with simultaneous conflicting right and left turns, the sum of both movements will be used to determine the conflicting turn volume.
2. Conversions from turns per cycle to turns per hour assume 36 cycles per hour (100s cycle). See Table 2 for the conversion calculations.
3. A fully protected crossing may be concurrent-protected or an exclusive phase.
4. A "protected intersection" layout may remove the need for an LPI because it gives pedestrians enough head start for pedestrians to become established in the crosswalk before a conflicting vehicle could arrive.

Table 2:
Vehicles per Cycle Conversions for a Given Cycle Length (seconds) and an Hourly Right Turn Volume

	Hourly Right Turn Volume												
Cycle Length (seconds)	**0**	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**
50	0.0	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2
60	0.0	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.3	3.8	4.2	4.6	5.0
70	0.0	0.5	1.0	1.5	1.9	2.4	2.9	3.4	3.9	4.4	4.9	5.3	5.8
80	0.0	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7
90	0.0	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.6	6.3	6.9	7.5
100	0.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	6.9	7.6	8.3
110	0.0	0.8	1.5	2.3	3.1	3.8	4.6	5.3	6.1	6.9	7.6	8.4	9.2
120	0.0	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0

6.3.1 Leading Pedestrian Intervals (LPI)

By default, a minimum length of three seconds should be considered for an LPI. However, at large intersections, a longer LPI may be needed. If implemented, the LPI should be long enough for pedestrians to establish themselves within the crosswalk before turning vehicles can arrive at the crossing. In general, an LPI should not be in excess of six seconds so pedestrians do not perceive time as an exclusive crossing phase.

No Turn on Red restrictions should be applied to right turns whose entry or exit crosses any crosswalk with an LPI. If used, No Turn on Red signs shall be installed near the appropriate signal head for each approach.

Where LPIs are used, any protected left-turn phase that exits across the subject crosswalk must be a lagging left.

6.4 Pedestrian Recall

Pedestrian recall should be included in the following situations:

1. At an intersection without pedestrian detection.
2. Between 7AM-11PM in the Downtown area and in Main Streets Districts and neighborhood business districts, intersections adjacent to schools, senior citizen facilities, parks, recreational areas, playgrounds, libraries, mass transit stations, hospitals, or other significant pedestrian generating facilities.
3. For pedestrian crossings that run concurrently with coordinated phases.
4. Whenever there is pedestrian demand in more than 50% of all cycles.

6.5 Rest in Walk

1. Concurrent crossings active with the coordinated vehicle phase shall Rest in Walk.
2. Concurrent crossings active with an uncoordinated phase shall be given timings that, as much as possible, provide “Rest in Walk” functionality, holding the WALK as long as possible within the minimum split of the concurrent phase.
    a. For crossings that are concurrent with the uncoordinated street (minor street), if analysis shows that the minor street’s traffic volume is such that it almost always holds the green longer than its minimum green and often runs to its maximum green, consider increasing the WALK time, or making the phase pretimed, so that the corresponding WALK interval can be longer.

7 BICYCLES

Bicycle signals should preferably be installed at all traffic control signals where separated bike lanes are present to provide a uniform indication for bicyclists. However, the need for bicycle signals shall be evaluated on a case-by-case basis. Where installed, their design and operation should follow the MassDOT publication Separated Bike Lane Planning and Design Guide [3] latest revision.

For bicycle safety, minimum green for through phases should be long enough that a cyclist starting on a fresh green can clear the intersection before green, yellow, and red clearance expire (see Minimum Green Intervals section).

For protection of bicycle crossings from left turns and right turns where cyclists use pedestrian phases, please refer to the Pedestrian Protection from Left Turns and Pedestrian Protection from Right Turns sections.

8 TRANSIT

Transit signal priority (TSP) shall be considered for all traffic signals serving high frequency bus or light rail transit routes, in coordination with the MBTA.

9 SIGNAL DESIGN

9.1 New Traffic Signal Equipment

New traffic signal equipment shall be designed to meet BTD signal system specifications and allow for maximum flexibility such as Rest in Walk on main and side streets phases, providing pedestrian recall during certain times of the day and providing pedestrian and/or vehicle overlap phases that allow pedestrians and/or vehicles to move during multiple phases when appropriate.

9.2 Detection

Vehicle detection-based actuation may not be utilized in the Downtown area and Main Streets Districts, except as part of an adaptive signal system. However, at some intersections, it may be desirable to use vehicle detection-based actuation, especially for mainline left turn phases and side streets. Elsewhere, use of detection should be reassessed when signals are retimed, based on volumes and conditions.

9.3 Accessible Pedestrian Signals and Pedestrian Countdown Timers

Accessible Pedestrian Signals (APS) and pedestrian countdown timers must be installed in accordance with Boston Transportation Department's Specification for an Accessible Pedestrian Pushbutton, latest edition. They shall be included with all new intersections, those where the equipment is modified or upgraded, where LPI is installed, and in association with nearby development projects.

Weblinks:

1. [Citywide Maps | Boston Planning & Development Agency]
2. [Main Street Districts | https://bostonmainstreets.org/districts/]
3. [MassDOT Separated Bike Lane Planning & Design Guide]

Attachments:

- *Pedestrian Delay Worksheet Example*

Issued by Boston Transportation Department Director of Engineering and Deputy Chief for Transportation May 2023.

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