An Introduction to Traffic Signal Operations

Kevin Chang, Ph.D., P.E.
qwertykc@gmail.com

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About the Instructor

Traffic Engineer (Seattle, WA)
King County Department of Transportation

Professional Engineer (Washington, Idaho, California)

Member, Safety Management Committee, Transportation Research Board

Ph.D., University of Washington, Department of Civil and Environmental Engineering

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Learning Outcomes

- Develop a basic understanding of traffic signal operations
- Describe key signal timing parameters at a signalized intersection
- Identify appropriate values for signal timing parameters at an intersection
- Determine pedestrian crossing needs at a signalized intersection

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Webinar Outline

- Overview
- Signal Timing Parameters
  - Minimum Green Time
  - Maximum Green Time
  - Passage Time
  - Yellow Change Interval
  - Red Clearance Interval
- Pedestrian Timing Intervals
- Key Takeaways

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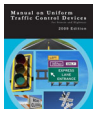
Resources / References

- Signal Timing Manual (STM)
  www.trb.org/OperationsTrafficManagement/Blurbs/173121.aspx

- Manual on Uniform Traffic Control Devices (MUTCD)
  mutcd.fhwa.dot.gov/kno_2009r1r2.htm



- Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections
  www.trb.org/Publications/Blurbs/168017.aspx

- (Your) Agency Guidelines

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Why Signalized Intersections?

- Traffic Volumes
- Pedestrian Volumes
- Crash History
- Signal Coordination

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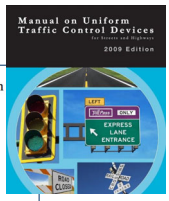
Why Signalized Intersections?



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CHAPTER 4C. TRAFFIC CONTROL SIGNAL NEEDS STUDIES

Section 4C.01 Studies and Factors for Justifying Traffic Control Signals

Standard:

01 **An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.**

02 **The investigation of the need for a traffic control signal shall include an analysis of factors related to the existing operation and safety at the study location and the potential to improve these conditions, and the applicable factors contained in the following traffic signal warrants:**

Warrant 1, Eight-Hour Vehicular Volume
Warrant 2, Four-Hour Vehicular Volume
Warrant 3, Peak Hour
Warrant 4, Pedestrian Volume
Warrant 5, School Crossing
Warrant 6, Coordinated Signal System
Warrant 7, Crash Experience
Warrant 8, Roadway Network
Warrant 9, Intersection Near a Grade Crossing

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

Support:

04 Sections 8C.09 and 8C.10 contain information regarding the use of traffic control signals instead of gates and/

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Why Signalized Intersections?

- Conflicting traffic movements concern traffic engineers
- Vehicles must yield to avoid conflicts with other vehicles
- Intersections can be a source of crashes and vehicle delay

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Why Signalized Intersections?

Advantages:

- Allows side-street vehicles to enter traffic stream
- Allows pedestrians to cross street
- Accommodates coordinated signal system
- Reduces crashes (i.e., angle crashes)
- Reduces overall delay

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Why Signalized Intersections?

Disadvantages (due to poor timing or not justified):

- Increases vehicle delay
- Contributes to vehicle crashes (i.e., rear-end crashes)
- Disrupts traffic progression
- Contributes to cut-through traffic (i.e., motorists divert to alternate or neighborhood routes)

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Signal Timing Parameters

Controller Timing Plan (MM)2-1
Plan 1

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction																
Min Green	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0
BK Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delay Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk	0	5	0	5	0	5	0	5	0	0	0	0	0	0	0	0
Walk 2	0	0	0	0	0	0	0									
Walk Max	0	0	0	0	0	0	0									
Ped Clear	9	21	9	11	9	19	9									
Ped Clear 2	0	0	0	0	0	0	0									
Ped Clear Max	0	0	0	0	0	0	0									
Ped CO	0	0	0	0	0	0	0									
Vehicle Ext	2.0	2.0	2.0	4.0	2.0	2.0	2.0									
Vehicle Ext 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
Max 1	20	30	20	35	20	30	20									
Max 2	100	100	100	100	100	100	100									
Max 3	0	0	0	0	0	0	0									
DYM Max	0	0	0	0	0	0	0									
DYM Stp	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
Yellow	3.2	3.2	3.2	3.2	3.2	3.2	3.2									
Red Clear	2.8	2.5	1.9	1.8	2.7	2.6	1.8									
Red Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
Red Revert	2.0	2.0	2.0	2.0	2.0	2.0	2.0									
ACT B4	0	0	0	0	0	0	0									
SEC/ACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
Max Int	0	0	0	0	0	0	0									
Time B4	0	0	0	0	0	0	0									
Cars Wt	0	0	0	0	0	0	0									
STPT Duc	0.0	0.0	0.0	0.0	0.0	0.0	0.0									
Time To Reduce	0	0	0	0	0	0	0									
Min Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0									

TIMING SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	PED	HOLD
Lanes and Sharing (#RL)													—	—
Traffic Volume (vph)	150	575	75	90	515	145	75	160	75	100	220	80	—	—
Future Volume (vph)	150	575	75	90	515	145	75	160	75	100	220	80	—	—
Turn Type	Perm	—	Perm	Perm	—	—	Perm	—	—	Perm	—	—	—	—
Protected Phases		4			8	—		2	—		6	—	—	—
Permitted Phases	4		4	8		—	2		—	6		—	—	—
Permitted Flashing Yellow	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Detector Phases	4	4	4	8	8	—	2	2	—	6	6	—	—	—
Switch Phase	0	0	0	0	0	—	0	0	—	0	0	—	—	—
Leading Detector (ft)	20	100	20	20	100	—	20	100	—	20	100	—	—	—
Trailing Detector (ft)	0	0	0	0	0	—	0	0	—	0	0	—	—	—
Minimum Initial (s)	5.0	5.0	5.0	5.0	5.0	—	5.0	5.0	—	5.0	5.0	—	—	—
Minimum Split (s)	22.5	22.5	22.5	22.5	22.5	—	22.5	22.5	—	22.5	22.5	—	—	—
Total Split (s)	22.5	22.5	22.5	22.5	22.5	—	22.5	22.5	—	22.5	22.5	—	—	—
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5	—	3.5	3.5	—	3.5	3.5	—	—	—
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	—	1.0	1.0	—	1.0	1.0	—	—	—
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	—	—
Lagging Phase?	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Allow Lead/Lag Optimize?	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Recall Mode	Max	Max	Max	Max	Max	—	Max	Max	—	Max	Max	—	—	—
Speed limit (mph)	—	35	—	—	35	—	—	25	—	—	25	—	—	—
Actuated Effct. Green (s)	18.0	18.0	18.0	18.0	18.0	—	18.0	18.0	—	18.0	18.0	—	—	—
Actuated g/C Ratio	0.40	0.40	0.40	0.40	0.40	—	0.40	0.40	—	0.40	0.40	—	—	—
Volume to Capacity Ratio	0.68	0.44	0.12	0.35	0.50	—	0.21	0.34	—	0.24	0.44	—	—	—
Control Delay (s)	30.6	11.1	3.3	13.8	10.2	—	10.7	8.6	—	10.8	10.5	—	—	—
Queue Delay (s)	0.0	0.0	0.0	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	—	—
Total Delay (s)	30.6	11.1	3.3	13.8	10.2	—	10.7	8.6	—	10.8	10.5	—	—	—
Level of Service	C	B	A	B	B	—	B	A	—	B	B	—	—	—

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Signal Operation Modes

- Fixed
  - signal timing is unchanged from one cycle to the next
- Semi-Actuated
  - signal timing impacted by detected vehicles on select approaches (i.e., minor or side streets)
  - green time typically assigned to major street
- Fully Actuated
  - signal timing dictated by traffic volumes on all approaches
  - intersection of two major streets

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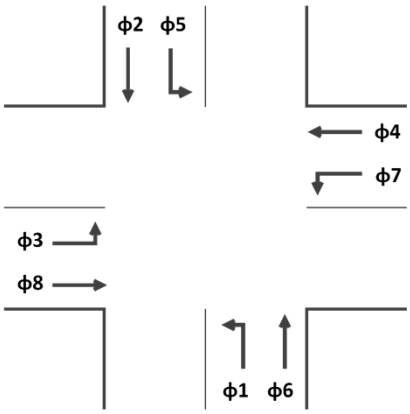
Phasing (NEMA)



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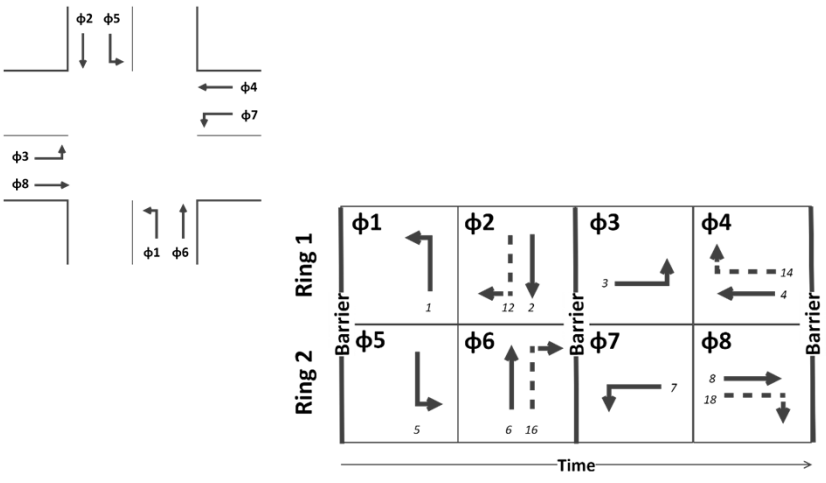
Ring Barrier Diagram



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Minimum Green Time

- Defined as least amount of time that a green signal indication will be displayed for a phase
- Display timing interval for at least as long as driver expectation

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Minimum Green Time

- Assess intersection geometry
- Assess queue lengths
- Consider driver perception / reaction time

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Minimum Green Time

Exhibit 6-4 (Signal Timing Manual)

Phase Type	Facility Type	Minimum Green (Seconds)
Through	Major Arterial (> 40 mph)	10 to 15
	Major Arterial (≤ 40 mph)	7 to 15
	Minor Arterial	4 to 10
	Collector, Local, or Driveway	2 to 10
Left Turn	Any	2 to 5

- Different timing intervals for left turns vs. through movements

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Maximum Green Time

- Defined as maximum amount of time that a green signal indication can be displayed *in the presence of a call on a conflicting phase*
- If too long, then wasted time at an intersection may result (i.e., undue impacts to side street traffic)
- If too short, then phase capacity may be inadequate for traffic demand (i.e., some vehicle unserved at end of green interval)
- Can also guard against excessively long green times due to continuous demand or a failed detector

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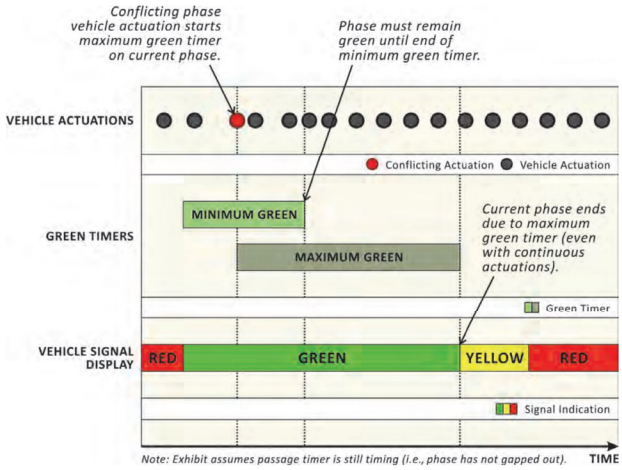
Maximum Green Time

Exhibit 6-8 (Signal Timing Manual)



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Maximum Green Time

- Properly timed maximum green duration will commonly result in frequent phase termination by *gap out* (where a gap in traffic, indicating inefficient flow, results in end of the phase) during low to moderate volumes
- During peak periods, green duration may occasionally *max out*, resulting in end of phase even though queue may not be entirely served

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Maximum Green Time

Exhibit 6-9 (Signal Timing Manual)

Phase Type	Facility Type	Maximum Green (Seconds)
Through	Major Arterial (> 40 mph)	50 to 70
	Major Arterial (≤ 40 mph)	40 to 60
	Minor Arterial	30 to 50
	Collector, Local, or Driveway	20 to 40
Left Turn	Any	15 to 30

- Adjust maximum green duration by time of day as traffic volumes will likely fluctuate between peak and off-peak hours

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Passage Time

- Defined as a parameter that can be used to terminate current phase when a gap in traffic is identified
- Also known as gap time or vehicle extension time
- Need to factor in detection zone length

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Passage Time

- When volumes are low enough, passage time allows a phase to end prior to its maximum green time
- If too short, then green interval may end prematurely (i.e., before vehicles have been adequately served)
- If too long, then an unnecessary extension of the phase may occur (i.e., causing delays to other movements)

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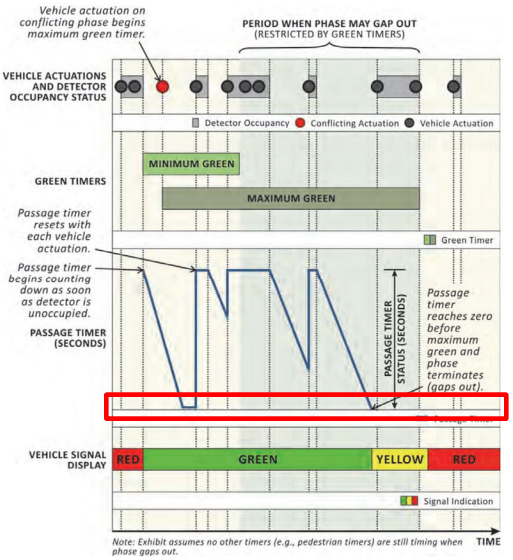
Passage Time

Exhibit 6-10 (Signal Timing Manual)



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Passage Time

Exhibit 6-12 (Signal Timing Manual)

Detection Zone Length (Feet)	Passage Time (with a Headway of 3 Seconds) (Seconds)						
	Posted Speed (MPH)						
	25	*30*	*35*	*40*	*45*	*50*	*55*
6	2.3	2.4	2.5	2.6	2.6	2.6	2.7
20	1.9	2.1	2.2	2.3	2.4	2.5	2.5
40	1.4	1.6	1.8	2.0	2.1	2.2	2.3
60	0.8	1.2	1.4	1.6	1.8	1.9	2.0
80	0.3	0.7	1.1	1.3	1.5	1.6	1.8

$$PT = MAH - \frac{L_v + L_d}{1.47 v_a}$$

- *MAH* = maximum allowable headway (sec)
- L_v = vehicle length (feet)
- L_d = detection zone length (feet)
- v_a = average vehicle speed (mph)

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Yellow Change Interval

- Purpose of this interval is to warn users that there will be a change in right-of-way assignment at intersection
- Longer intervals are typically associated with higher speed facilities

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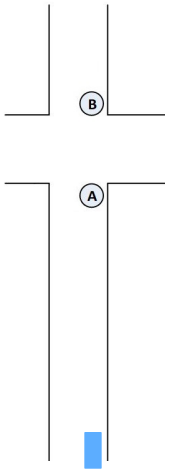
Yellow Change Interval



- Accounts for perception-reaction time and braking time

$$Y = t + \frac{1.47v}{2(a + 32.2g)}$$

- Y = yellow change interval
- t = perception-reaction time
- v = approach speed (mph)
- a = deceleration rate (ft/sec^2)
- g = grade (ft/ft)

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Yellow Change Interval

Exhibit 6-2 (Signal Timing Manual)

Approach Speed (MPH)	Minimum Yellow Change[1] (Seconds)
25	3.0*
30	3.2
35	3.6
40	3.9
45	4.3
50	4.7
55	5.0
60	5.4

[1] Based on negligible approach grades. Adjustments are required for upgrades and downgrades.
* The MUTCD (*2*) recommends a minimum duration of 3 seconds for the yellow change interval.

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Red Clearance Interval

- Purpose is to allow time for vehicles that entered intersection during yellow change interval to reach an appropriate location prior to next phase

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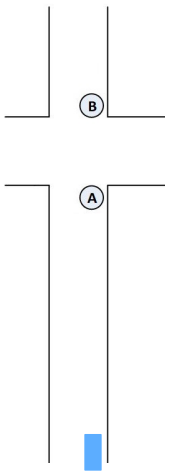
Red Clearance Interval



- Need to provide additional time for vehicle to travel from “A” to “B”:

$$RC = \frac{w + l}{1.47v}$$

- *RC* = red clearance interval
- *w* = intersection width (feet)
- *l* = vehicle length (feet)
- *v* = approach speed (mph)

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Red Clearance Interval

Exhibit 6-3 (Signal Timing Manual)

Approach Speed (MPH)	Red Clearance[1] (Seconds)				
	Width of Intersection (Feet)				
	30	*50*	*70*	*90*	*110*
25	0.4	0.9	1.5	2.0	2.5
30	0.1	0.6	1.0	1.5	2.0
35	0.0	0.4	0.8	1.1	1.5
40	0.0	0.2	0.5	0.9	1.2
45	0.0	0.1	0.4	0.7	1.0
50	0.0	0.0	0.2	0.5	0.8
55	0.0	0.0	0.1	0.4	0.6
60	0.0	0.0	0.0	0.2	0.5

[1] Based on recent research reported in *NCHRP 731* (*6*), the calculated red clearance values have been reduced by 1 second.

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Yellow Change and Red Clearance Intervals

- What if a driver has a slower (or faster) reaction time?
- What if a driver has a lower (or higher) approach speed?
- How should trucks and buses (with varying deceleration rates) be treated?

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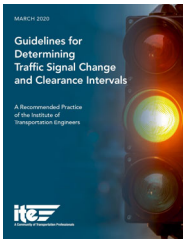
Yellow Change and Red Clearance Intervals

- Calculation (**kinematic**, uniform value for all intersections, tabular, other)
- Perception-reaction time (i.e., **1.0**, 1.5, 1.8, 2.0, 2.5 secs)
- Approach speed (i.e., **posted speed limit**, 85th percentile speed, design speed, other)
- Deceleration (i.e., 9.8, **10.0**, 11.2 ft/sec^2, other)
- Vehicle length (i.e., 0, **20**, 25 feet, other or not used)



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Yellow Change and Red Clearance Intervals

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Yellow Change and Red Clearance Intervals

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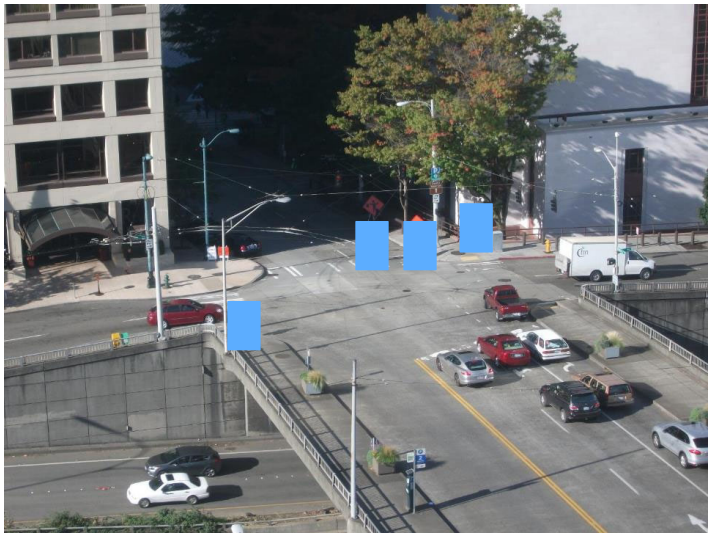
Signalized Intersections – Vehicles and Pedestrians



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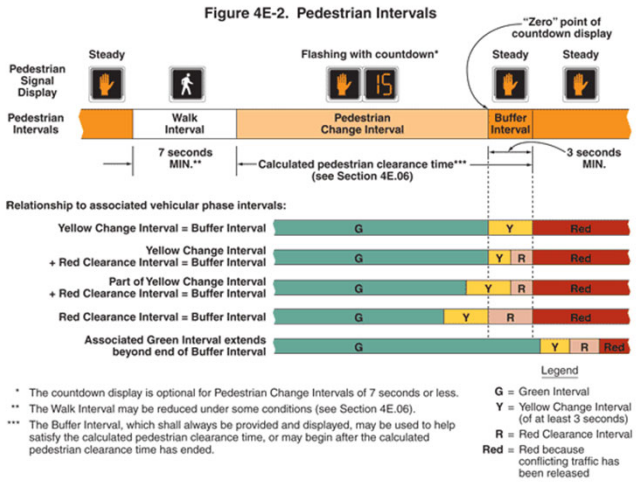
Pedestrian Intervals



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Pedestrian Intervals and Signal Phases

- Walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave curb or shoulder before ped clearance time begins
- Walk intervals as short as 4 seconds may be used
- Walk interval is intended for pedestrians to start their crossing; pedestrian clearance time is intended to allow pedestrians who started crossing during walk interval to complete crossing

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SOURCE: MUTCD 4E.06

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Pedestrian Intervals and Signal Phases

- Ped clearance time should be sufficient to allow a pedestrian crossing in crosswalk who left curb or shoulder at end of WALK signal indication to travel at a walking speed of 3.5 feet per second to at least far side of traveled way or to a median of sufficient width

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SOURCE: MUTCD 4E.06

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Pedestrian Intervals and Signal Phases

- Where pedestrians who walk slower than 3.5 feet per second, or pedestrians who use wheelchairs, routinely use the crosswalk, consider a walking speed of less than 3.5 feet per second in determining pedestrian clearance time

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SOURCE: MUTCD 4E.06

40

Pedestrian Intervals and Signal Phases

- Total of walk interval and ped clearance time should be sufficient to allow a ped crossing who left ped detector at beginning of WALK signal indication to travel at a walking speed of 3 feet per second to far side of traveled way being crossed (or to median if a two-stage ped crossing sequence is used)
- Any additional time that is required to satisfy these conditions should be added to walk interval
- If no ped detector is present, use a location 6 feet from face of curb or from edge of pavement

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SOURCE: MUTCD 4E.06

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Pedestrian Intervals

- Crossing distance = 70 feet; Detector to curb = 8 feet
- Ped clearance: (70) / (**3.5**) = 20.0 seconds
- Walk + ped clearance: (70 + 8) / (**3.0**) = 26.0 seconds

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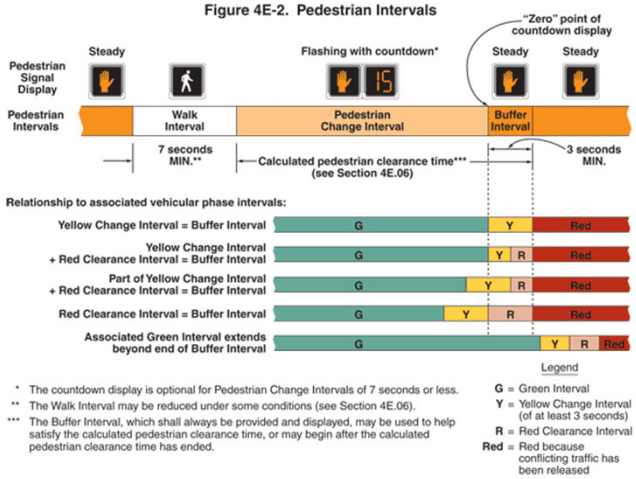
Pedestrian Intervals

Figure 4E-2. Pedestrian Intervals



* The countdown display is optional for Pedestrian Change Intervals of 7 seconds or less.
** The Walk Interval may be reduced under some conditions (see Section 4E.06).
*** The Buffer Interval, which shall always be provided and displayed, may be used to help satisfy the calculated pedestrian clearance time, or may begin after the calculated pedestrian clearance time has ended.

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Signal Timing Parameters

Controller Timing Plan (MM)2-1
Plan 1

Phase	1	2	3	4	5	6	7	8
Direction								
Min Green	5	5	5	5	5	5	5	5
BK Min Green	0	0	0	0	0	0	0	0
CS Min Green	0	0	0	0	0	0	0	0
Delay Green	0	0	0	0	0	0	0	0
Walk	0	5	0	5	0	5	0	5
Walk 2	0	0	0	0	0	0	0	0
Walk Max	0	0	0	0	0	0	0	0
Ped Clear	0	21	0	11	0	16	0	12
Ped Clear 2	0	0	0	0	0	0	0	0
Ped Clear Max	0	0	0	0	0	0	0	0
Ped CO	0	0	0	0	0	0	0	0
Vehicle Ext	2.0	2.0	2.0	4.0	2.0	2.0	2.0	4.0
Vehicle Ext 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max 1	20	30	20	35	20	30	20	35
Max 2	100	100	100	100	100	100	100	100
Max 3	0	0	0	0	0	0	0	0
DYM Max	0	0	0	0	0	0	0	0
DYM Stp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Red Clear	2.8	2.5	1.9	1.8	2.7	2.6	1.8	1.9
Red Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Revert	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
ACT B4	0	0	0	0	0	0	0	0
SEC/ACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Int	0	0	0	0	0	0	0	0
Time B4	0	0	0	0	0	0	0	0
Cars Wt	0	0	0	0	0	0	0	0
STPT Duc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce	0	0	0	0	0	0	0	0
Min Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Learning Outcomes

- Develop a basic understanding of traffic signal operations
- Describe key signal timing parameters at a signalized intersection
- Identify appropriate values for signal timing parameters at an intersection
- Determine pedestrian crossing needs at a signalized intersection

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Final Thoughts

- Good signal timing relies on many different inputs and factors.
- Different timing plans exist depending on time of day, day of week, and other factors (i.e., special events).
- Spend time in the field to observe both signal operations and driver behaviors.
- Value the partnership between engineers, technicians, and maintenance staff.
- Traffic safety is a shared responsibility.

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Questions

qwertykc@gmail.com

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