2019 NSF RET Project

Modeling of Signalized Intersection Design and Impacts

Section 5

Fundamentals to Actuated Traffic Signal System

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Types of Signal Operations

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- Pre-timed
  - Duration of Green Intervals is Predetermined Without Regard to Vehicle Demand and Sequencing of Phases is Fixed.
- Semi-Actuated
  - Some Phases Have Detection with Green Interval Duration Based on Demand on Those Phases. Other Phases Have Predetermined Green Intervals. Actuated Phases can be Skipped.
- Fully Actuated
  - All Phases Have Detection with Green Interval Duration Based on Demand on Every Phase. Any Phase can be Skipped if There is No Demand.

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Phase Plan (set sequence as pre-determined):

1. Actuated Controller Operation
2. Minimum Green Times
3. Unit or Vehicle Extension (Passage Time)
4. Maximum Green Times and the Critical Cycle
5. Detector Location Strategies
6. Yellow and All-Red Interval
7. Pedestrian Requirements for Actuated Signals
8. Examples in Actuated Signal Design and Timing

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2. Minimum Green Times
   - Each actuated phase has a minimum green time, which serves as the smallest amount of green time that may be allocated to a phase when it is initiated.
   - The minimum green is the time required to clear those vehicles which may have queued up between the detector and the stop line during the red phase
   - Example: if detector setback is 120 ft, then could be 120/20 = 6 vehicles between the detector and the stop line. You need 16.3 sec (3.7+2.1*6) according to Greenshields theory to clear them. Therefore, the minimum green time is 16.3 sec

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Modeling Minimum Green Times

- Point or Passage Detectors

  If a point detector is located *d* ft from the STOP line, a queue of vehicles is assumed to fully occupy the distance *d*

  $G_{min} = l_1 + 2*\text{Int}(d/20)$

  where, l_1 = start-up lost time (2-4 s), 20 = assumed head-to-head spacing between vehicles in queue (ft)

- Area or Presence Detectors

  In general, minimum green time varies based on the number of vehicles sensed in the queue when the green is initiated.

  $G_{min} = l_1 + 2n$ (n = # of veh stored in the detection area)

- The minimum green time and the detector location are mathematically linked.

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- The duration of minimum green is needed to satisfy driver expectancy varies among practitioners.
- The following table details typical minimum green interval duration needed to satisfy driver expectancy.

Phase Type	Facility Type	Minimum Green Needed to Satisfy Driver Expectancy (Ge), s
Through	Major Arterial (speed limit exceeds 40 mph)	10 to 15
	Major Arterial (speed limit is 40 mph or less)	7 to 15
	Minor Arterial	4 to 10
	Collector, Local, Driveway	2 to 10
Left Turn	Any	2 to 5

Simulation result [*FHWA Traffic Signal Timing Manual*] suggests that delay was minimal when the minimum green interval was less than 4 seconds. Delay for the studied intersection increased slightly as the minimum green interval increased from 4 to 8 seconds.

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- Initial interval
  - The initial interval is equal to the minimum green minus a vehicle interval (e.g., 16.3 – 3.5 = 12.8 sec)
  - ITE recommendation (Actuated Detection Locations)

Approach Speed (mph)	Detector Setback (ft)	Number of Cars Stored	Initial Interval (sec)	Vehicle Interval (sec)	Minimum Assured Green (sec)
15	77	3-4	8.5	3.5	12.0
20	103	4-5	10.5	3.5	13.0
25	120	5-6	10.0	3.5	13.5
30	120	5-6	10.0	3.5	13.5

1) 35 or more: Basic actuated controller not appropriate; use multiple detectors (Section 8A)

2) For certain new design controllers, the minimum green equals the initial interval rather than the sum of the initial and vehicle intervals as shown

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Relationship with Walk Phase

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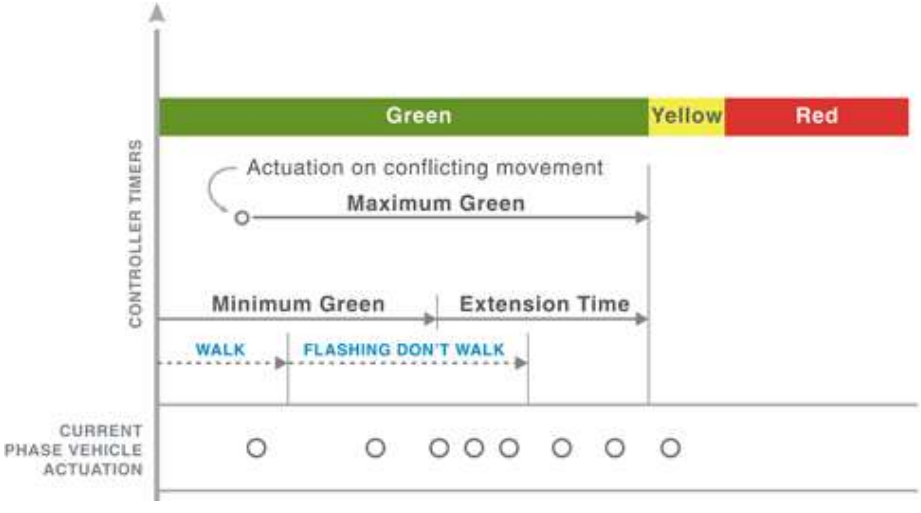

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3. Unit or Vehicle Extension (Passage Time)
   - Two purposes:
     - Allow the clearing of a queue in which vehicles are closely spaced (allowable gap)
     - Allow a vehicle to activate the detector and be able to clear the intersection (passage time)
     - Example: if the distance between the detector and the stop line in 120 ft and the approach speed is 25 mph, the passage time would be 120/(25*1.47) = 3.3 sec
   - For all types of controllers, the unit extension *U* must be equal to or more than the passage time:

Minimum Passage Time at Point Detection:

$$U \geq P = d/(1.47*S_{15})$$

Where, P = passage time (s), d = distance from detector to STOP line; S_{15}= 15th percentile approach speed (mph)

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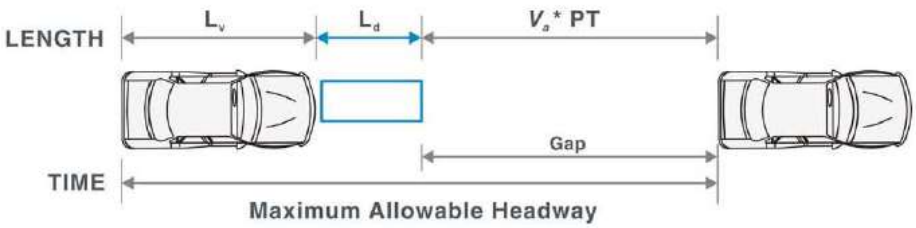
- **Passage Time at Presence Detection**: the objective when determining the passage time value is to make it large enough to ensure that all vehicles in a moving queue are served but to not make it so large that it extends the green for randomly arriving traffic.

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

where,
- PT = passage time, s;
- MAH = maximum allowable headway, s;
- v_a = average approach speed, mph;
- L_v = length of vehicle (use 20 ft); and
- L_d = length of detection zone, ft.

Figure 5-4 Relationship between passage time, gap, and maximum allowable headway



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4. Maximum Green and Critical Cycle
   - Each actuated phase has a maximum green time that limits the length of a green phase, even there are continued actuations that would normally retain the green. The maximum green time begins when there is a "call" (or detector actuation) on a competing phase
   - The maximum amount of time that a green signal indication can be displayed in the presence of conflicting demand. Maximum green is used to limit the delay to any other movement at the intersection and to keep the cycle length to a maximum amount. It also guards against long green times due to continuous demand or broken detectors. Ideally, the maximum green will not be reached because the detection system will find a gap to end the phase, but if there are continuous calls for service and a call on one or more conflicting phases, the maximum green parameter will eventually terminate the phase. A maximum green that is too long may result in wasted time at the intersection. If its value is too short, then the phase capacity may be inadequate for the traffic demand, and some vehicles will remain unserved at the end of the green interval.

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Cycle Length and Critical Cycle

- Initial cycle length C_i, s

$$C_i = \frac{L}{1 - \left[\frac{V_c}{1.615 \times PHF \times (v/c)}\right]}$$

V_c = sum of critical lane volumes (v/h)
PHF = peak hour factor
v/c = desired v/c ratio to be achieved

- Green time

$$g_i = (C - L)\left(\frac{V_{ci}}{V_c}\right)$$

g_i = effective green time;
V_{ci} = critical lane volume for Phase I, v/h

- Critical cycle length C_c

$$C_c = \sum_i (G_i + Y_i)$$

G_i = actual max green for full-actuated Phase I, or actual min green for the major street at a semi-actuated signal
Y_i = sum of yellow and all red intervals for Phase i, s

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Maximum Green Time

- The method is the same as that used for determining cycle lengths and green times for a pre-timed signal
- The "critical cycle" for a full-actuated signal is one in which each phase reaches its maximum green time
- The "critical cycle" for a semi-actuated signal involves the maximum green time for side street and the minimum green time for the major streets (which has no detectors)

Phase	Facility Type	Maximum Green, s
Through	Major Arterial (speed limit exceeds 40 mph)	50 to 70
	Major Arterial (speed limit is 40 mph or less)	40 to 60
	Minor Arterial	30 to 50
	Collector, Local, Driveway	20 to 40
Left Turn	Any	15 to 30
1.Note: Range is based on the assumption that advance detection is provided for indecision zone protection. If this type of detection is not provided, then the typical maximum green range is 40 to 60 s.		

- Two methods are commonly used to establish the maximum green setting: **Max Out** and **Gap Out**

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Special practical considerations:

- At a semi-actuated signal location with low side-street demands, the maximum green, G_{max} may compute to a value that is less than the minimum green, G_{min}.
- It may happen on a given phase at full actuated location as well, particularly where protected left-turn phases are involved.
- In such cases, the G_{max} is judgmentally set as $G_{min}+2.0*n$, where n is the maximum number of vehicles to be served during a signal green phase. The value of *n* is usually approximately set as 1.5 times the average number of vehicles expected per cycle (an interactive concept because the cycle length would be needed to determined the value of n).

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Maximum Green Duration As a Function of Cycle Length and Volume

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Phase Volume per Lane, veh/hr/ln	Cycle Length, s							
	50	60	70	80	90	100	110	120
	Maximum Green (G_{max})[1], s							
100	15	15	15	15	15	15	15	15
200	15	15	15	15	16	18	19	21
300	15	16	19	21	24	26	29	31
400	18	21	24	28	31	34	38	41
500	22	26	30	34	39	43	47	51
600	26	31	36	41	46	51	56	61
700	30	36	42	48	54	59	65	71
800	34	41	48	54	61	68	74	81

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Example 1: A minimum green on an approach to an actuated signal is to be set as 6.0 s, with an assumed start-up lost time of 4.0 s. How far may the detector be located from the stop line?

$G_{min} = l_1 + 2*\text{Int}(d/20) = 4 + 2\text{Int}(d/20)=6.0 \rightarrow \text{Int}(d/20)=1.0 \rightarrow$ the front of the detector may be located anywhere between 0.1 and 20.0 ft from the stop line.

Example 2: At an approach to an actuated signal location, a detector is to be placed such that the unit extension of 3.5 s is equal to the passage time. Initial lost time is 4 sec. The 15th percentile approach speed on this approach is 40 mph. Check detector setback and minimum green time.

$U \geq P = 3.5 = d/(1.47*S_{15}) = d/(1.47*40) \rightarrow d = 3.5*1.47*40 = 205.8$ ft $\rightarrow G_{min} = 4+2\text{Int}(205.8/20) = 26.0$ sec

Such setback is too long that leads to a very long minimum green time. So, variable minimum green is required (see the table for ITE recommendation for Actuated Detection Locations introduced earlier, use above modeling for speed ≤ 30 mph)

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– ITE recommendation (Actuated Detection Locations)
(same as that introduced earlier)

Approach Speed (mph)	Detector Setback (ft)	Number of Cars Stored	Initial Interval (sec)	Vehicle Interval (sec)	Minimum Assured Green (sec)
15	77	3-4	8.5	3.5	12.0
20	103	4-5	10.5	3.5	13.0
25	120	5-6	10.0	3.5	13.5
30	120	5-6	10.0	3.5	13.5

1) 35 or more: Basic actuated controller not appropriate; variable initial interval required (Section 8A)
2) For certain new design controllers, the minimum green equals the initial interval rather than the sum of the initial and vehicle intervals as shown

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Detectors and Detection

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- Full-Actuated Detection Locations (ITE Criteria)
  - –Use sufficient setback to minimize delay to approach vehicle (requires 6 sec)
  - –At the same time, avoid long minimum green (requires shorter setback than the first criterion)
  - –Avoid short greens and locate detector according to
    - Pedestrian needs
    - Store two car-min (45 ft-min.)
  - –Use a setback equal in passage time to the allowable gap
    - Use 3.5 sec as a allowable gap
  - –Use a setback of at least 1.5 sec of passage time
  - –Use sufficient setback to insure motion detection

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6. Yellow and All-Red Interval
   - They are determined using the models as shown in the circulated reading material (Chapter 22)
7. Pedestrian Requirements for Actuated Signals (see Chapter 22)
8. Examples in actuated Signal Design and Timing (see Chapter 22)

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Semi-Actuated Control

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- Some Phases have detection with green interval duration based on demand on those phases. Other Phases have predetermined green intervals. Actuated Phases can be Skipped.
- Semi-actuated signals are always two-phase, with all turns being made only on a permitted basis.
- Detectors are placed only on the side street.
- The green is on the major street at all times unless a "call" on the side street is noted. The number and duration of side-street greens is limited by the signal timing and cab be restricted to times that do not interfere with progressive signal-timing patterns along the collector or arterial.

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