Traffic Analysis at Signalized Intersections 4

David Levinson
(based on notes by Henry Liu
University of Minnesota)
Signal Timing Procedure (Steps)

1. Determine “Phasing”
2. Establish analysis lane group
3. Choose “Critical Lane Volumes”
4. Calculate Cycle Length
5. Determine Yellow & Clearance Intervals
6. Proportion Green Time
7. Check Pedestrian Crossing Time
8. Prepare Signal Indication Diagram
Step 1: Determine phase to use

Minimum # of phases (two):

Three phases:
Step 1: Determine phasing to use (cont.)

Left Turn protected phase should be considered if any of the following criteria is met:

- More than one turning lane is provided;
- The left turn has a demand over 240veh/h;
- The cross product of left turn demand and opposing through demand for 1 hour exceeds
  - 50,000 for one opposing lane,
  - 90,000 for two opposing through lanes, or
  - 110,000 for three or more lanes.

100 veh / hr

500 veh / hr
(in peak hr)
Example 7.6: determine if the protected left turn should be provided using cross product guideline
Solution

275,000 = 250*(900+200)

345,000 = 300*(100+150)

--> Protected LT lane for WB and EB LT movements

27,300 = 70*(340+50) < 50,000

34,200 = 90*(310+70) < 50,000

--> No Protected LT for NB and SB LT movements.
Step 2: Lane Grouping

Lane groups:
 Movements from the same lane as one lane group
 Exclusive turn lane(s) treated as separate lane group.
 Judgment for shared movement lane(s)
<table>
<thead>
<tr>
<th>Number of lanes</th>
<th>Movements by lane</th>
<th>Number of possible lane groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LT + TH + RT</td>
<td>① (Single-lane approach)</td>
</tr>
<tr>
<td>2</td>
<td>EXC LT</td>
<td>②</td>
</tr>
<tr>
<td></td>
<td>TH + RT</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>LT + TH</td>
<td>①</td>
</tr>
<tr>
<td></td>
<td>TH + RT</td>
<td>② (or)</td>
</tr>
<tr>
<td>3</td>
<td>EXC LT</td>
<td>② (or)</td>
</tr>
<tr>
<td></td>
<td>TH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TH + RT</td>
<td>③ (or)</td>
</tr>
</tbody>
</table>
Example 7.7: determine lane groups

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Solution

Here, Exclusive LT is a lane group,
Permitted LT is also a lane group
Step 3: determine critical lane groups

- For any combination of lane group movements during a particular phase, one of these lane groups will control the necessary green time. This lane group is referred as “critical lane group”.

- The lane group with highest traffic intensity

- Allocation of green time for each phase is based on the v/s ratios
### Table 7.1 Saturation Flow Rates for Three-Phase Design at Intersection of Maple Street and Vine Street

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB L: 1750 veh/h</td>
<td>EB T/R: 3400 veh/h</td>
<td>SB L: 450 veh/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NB L: 475 veh/h</td>
</tr>
<tr>
<td>WB L: 1750 veh/h</td>
<td>WB T/R: 3400 veh/h</td>
<td>SB T/R: 1800 veh/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NB T/R: 1800 veh/h</td>
</tr>
</tbody>
</table>

### Table 7.2 Flow Ratios and Critical Lane Groups for Three-Phase Design at Intersection of Maple Street and Vine Street

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB L: (\frac{300}{1750}) = 0.171 √</td>
<td>EB T/R: (\frac{1100}{3400}) = 0.324</td>
<td>SB L: (\frac{70}{450}) = 0.156</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NB L: (\frac{90}{475}) = 0.189</td>
</tr>
<tr>
<td>WB L: (\frac{250}{1750}) = 0.143</td>
<td>WB T/R: (\frac{1150}{3400}) = 0.338 √</td>
<td>SB T/R: (\frac{370}{1800}) = 0.206</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NB T/R: (\frac{390}{1800}) = 0.217 √</td>
</tr>
</tbody>
</table>
Critical v/s

Peak-hour traffic volumes

Maple

Vine
Sum of critical v/s and total lost time

\[ Y_c = \sum_{i=1}^{n} \left( \frac{v}{s} \right)_{ci} \]

where

\( Y_c \) = sum of flow ratios for critical lane groups,

\( (v/s)_{ci} \) = flow ratio for critical lane group \( i \), and

\( n \) = number of critical lane groups.

\[ L = \sum_{i=1}^{n} (t_L)_{ci} \]

where

\( L \) = total lost time for cycle in seconds,

\( (t_L)_{ci} \) = total lost time for critical lane group \( i \) in seconds, and

\( n \) = number of critical lane groups.
Minimal Necessary Cycle Length

\[ C_{\text{min}} = \frac{L \times X_c}{X_c - \sum_{i=1}^{n} Y_i} \]

\( C = \) cycle length (minimum)  
(round-up to nearest 5 sec. int.)  

\( X_c = \) critical v/c ratio

---

\[ L \times X_c \]
Step 4: Calculate Cycle Length

Webster’s Delay Formula:

\[ C = \left[ (1.5 \times L) + 5 \right] / \left( 1.0 - \sum_{i=1}^{n} Y_i \right) \]

- \( C \) = cycle length (optimal) (round-up to nearest 5 sec. int.)
- \( L \) = Lost Time / Cycle {seconds}
  = sum total yellow + sum all red
- \( Y_i \) = critical lane volume \{vph\}
  saturation flow \{vph\}
Cycle Length

\[ C_{opt} = \frac{[(1.5 \times L) + 5]}{1.0 - \sum_{i=1}^{n} Y_i} \]

\[ = \frac{[1.5 \times 4 \times 3 + 5]}{1.0 - (0.171 + 0.338 + 0.217)} \]

\[ = 83.9 \]

\[ \rightarrow 85 \text{ s} \]

\[ C_{min} = \frac{L \times X_c}{X_c - \sum Y_i} \]

\[ = \frac{[12 \times 0.9]}{0.9 - (0.171 + 0.338 + 0.217)} \]

\[ = 62.1 \]

\[ \rightarrow 65 \text{ s} \]
Step #5: Allocate Green Time

Distribute green time such that the v/c ratios are equalized for the critical lane groups

\[ X_i = \frac{v_i}{c_i} = \frac{v_i}{s_i} \ast \frac{g_i}{C} = \frac{v_i}{s_i} \ast \frac{g_i}{C} \]

Equalize \( X_i = X_c \)

\[ g_i = (v_i / s_i) \ast (C / X_c) \]

\( g_i \): effective green for phase i

\( v_i / s_i \): flow ratio for phase i from the critical lane group

C: cycle length

\( c_i \): capacity for phase i

\( X_c \): degree of saturation for the intersection

\( X_i \): v/c ratio (degree of saturation) for phase i

\[ \sum g_i = \sum (v_i / s_i) \ast \frac{C}{X_c} = C - L \]

\[ X_c = \sum (v_i / s_i) \ast \frac{C}{C - L} \]
Example 7.11

Mannering Kilareski and Washburn

Determine the green time allocations for the 85-second cycle length in example 7.10 using the method of v/c ratio equalization.

\[ X_c = \sum (v_i / s_i) \ast \frac{C}{C - L} \]

\[ = (0.171 + 0.338 + 0.217) \ast \frac{85}{85 - 4 \ast 3} \]

\[ = 0.845 \]

\[ g_i = (v_i / s_i) \ast (C / X_c) \]

\[ g_1 = 0.171 \ast \frac{85}{0.845} = 17.2s \rightarrow 17s \]

\[ g_2 = 0.338 \ast \frac{85}{0.845} = 34s \]

\[ g_3 = 0.217 \ast \frac{85}{0.845} = 21.8s \rightarrow 22s \]

\[ g_1 + g_2 + g_3 = 73 = C - L \]
Step 6: Determine Yellow and Clearance Intervals

“Dilemma Zone” -- driver can neither stop safely nor clear the intersection before the cross street green phase starts!
Determine Yellow & Clearance Intervals (cont.)

Yellow Time (ITE):

\[ y = T + \left( \frac{v}{2a + 2Gg} \right) \]

- \( T \) = the driver perception / reaction time (1.0 sec)
- \( v \) = speed of the vehicle in ft / s
- \( a \) = deceleration rate for the vehicle (10.0 ft / s^2)
- \( G \) = the percent grade divided by 100
- \( g \) = acceleration due to gravity (32.2 ft / s^2)
Determine Yellow & Clearance Intervals (cont.)

All-Red time (ITE):

\[ AR = \frac{w + l}{v} \]

AR = the all-red time
w = the width of the cross street (ft)
l = length of the vehicle (20ft)
Determine Yellow & Clearance Intervals (cont.)

Clearance Time:

\[ ci = T + \left( \frac{V}{2a + 2Gg} \right) + \frac{(w + l)}{V} \]

- Perception-Reaction Time +
- Time to stop
- Time to clear intersection
Determine Yellow & Clearance Intervals (cont.)

- **Yellow time:**  
  - Minimum = 3 sec  
  - Maximum = 5 sec

- 3 sec => 16 to 56 k/h
- 4 sec => 56 to 80 k/h
- 5 sec => greater than 80 k/h

- If more than 5 sec of yellow is needed  
  => All red must be increased to 2 sec
Clearance Time Example

Maple Street:

\[ y = T + \left( \frac{v}{2a + 2Gg} \right) \]

\[ y = 1.0 + \left( \frac{40 \times 5280 / 3600}{2 \times 10} \right) \]

\[ y = 3.9 \Rightarrow 4.0 \text{ s} \]

\[ AR = \frac{w + l}{v} \]

\[ AR = \frac{36 + 20}{40 \times 5280 / 3600} = 1.0 \text{ s} \]
Step 7: Check Pedestrian Crossing Time

**Walk “Clearance Time”** = \( \frac{\text{Roadway Width}}{\text{Walking Speed}} \)

(Walking Speed = 4.0 ft / sec)

\[ G_p = 3.2 + \frac{L}{S_p} + (2.7 \frac{N_{\text{ped}}}{W_E}) \text{ for } W_E > 10 \text{ ft} \]

\( W_E \): effective crosswalk width

\( N_{\text{ped}} \): number of pedestrians crossing

If Min. Ped Grn > Grn for \( \varphi \) \( \Rightarrow \) Grn for \( \varphi \) must be increased (also increase total cycle length)
Signal Timing Example

Peak-hour traffic volumes

60 ft (18.3 m)

60
310
70

300
900
200

90
340
50

Both roadways are level (zero grade)

Vine Street
Approach speed 35 mph
(55 km/h)

Maple Street
Approach speed 40 mph
(65 km/h)

Maple Street
Approach speed 40 mph
(65 km/h)

Vine Street
Approach speed 35 mph
(55 km/h)

36 ft
(11.0 m)
Traffic Signal Timing

Example

1. Determine phasing for signal:
   Eastbound left = 300 veh
   Westbound thru + rt = 1150 veh
   North-South approach volumes are greater than 90,000

   300 veh / hr       1150 veh / hr  (in peak hr)

Therefore, left turn phase is suggested.
Step #2: determine lane groups
Step #3: Critical Lane
Group v/s ratio

Peak-hour traffic volumes

Maple

Vine
Step #4: Cycle Length

\[ C_{opt} = \frac{[(1.5 * L) + 5]}{1.0 - \sum_{i=1}^{n} X_i} \]

\[ = \frac{[1.5 * 4 * 3 + 5]}{[1.0 - (0.171 + 0.338 + 0.217)]} \]

\[ = 83.9 \]

\[ \rightarrow 85 \text{s} \]
Step #5: Allocate Green Time

C = 85-second cycle length

\[ X_c = \sum \left( \frac{v_i}{s_i} \right) \times \frac{C}{C - L} \]
\[ = (0.171 + 0.338 + 0.217) \times 85 / (85 - 4 \times 3) \]
\[ = 0.845 \]

\[ g_i = \left( \frac{v_i}{s_i} \right) \times \left( \frac{C}{X_c} \right) \]
\[ g_1 = 0.171 \times 85 / 0.845 = 17.2s \rightarrow 17 \]
\[ g_2 = 0.338 \times 85 / 0.845 = 34s \rightarrow 34 \]
\[ g_3 = 0.217 \times 85 / 0.845 = 21.8s \rightarrow 22 \]
\[ g_1 + g_2 + g_3 = 73 = C - L \]
Step #6: Clearance Time

Example

Maple Street:

\[ y = T + \left( \frac{v}{2a + 2Gg} \right) \]

\[ y = 1.0 + \left( \frac{40 \times 5280 / 3600}{2 \times 10} \right) \]

\[ y = 3.9 \Rightarrow 4.0 \text{ sec} \]

\[ AR = \frac{w + l}{v} \]

\[ AR = \frac{36 + 20}{40 \times 5280 / 3600} = 1.0 \text{ sec} \]
Step#6 (cont.)

- Vine Street

\[ y = T + \left( \frac{v}{2a + 2Gg} \right) \]

\[ y = 1.0 + \left( \frac{35 \times 5280}{3600} \right) \]

\[ y = 3.6 \rightarrow y = 4.0 \text{ sec} \]

\[ \frac{AR}{V} = \frac{w + l}{v} \]

\[ AR = \frac{60 + 20}{35 \times 5280 / 3600} \]

\[ AR = 1.6 \text{ say} \]

\[ AR = 2.0 \text{ sec} \]
Yellow and All Red Time (summary):

<table>
<thead>
<tr>
<th></th>
<th>Vine</th>
<th>Maple (Lt)</th>
<th>Maple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>All Red</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
Step #7: Check Pedestrian Time

**Maple**

\[
\text{Ped Grn} = 3.2 + \left( \frac{36}{4.0}\right) + 0.27 \times 15 = 16 \text{ sec}
\]

Φ2: 34 sec of Green is OK

**Vine**

\[
\text{Ped Grn} = 3.2 + \left( \frac{60}{4.0}\right) + 0.27 \times 15 = 22 \text{ sec}
\]

Φ3: 22 sec of Green is OK

Assume \( N_{\text{ped}} = 15 \).
Step 8: Signal Timing

Green Display = Effective Green + lost time – Y – AR

Φ1: \( G = 17 + 4 - 4 - 1 = 16 \), \( Y = 4 \), \( AR = 1 \)

Φ2: \( G = 34 + 4 - 4 - 1 = 33 \), \( Y = 4 \), \( AR = 1 \)

Φ3: \( G = 22 + 4 - 4 - 2 = 20 \), \( Y = 4 \), \( AR = 2 \)

\( C = 85 \) s
Questions

• Questions?
Abbreviations
Key Terms
Variables