Signalized Intersection Analysis and Level of Service

CE322 Transportation Engineering
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Traffic Signal Control

- **Pretimed** A signal whose timing (cycle length, green time, and so on) is fixed over specified time periods and does not change in response to changes in traffic flow at the intersection. No vehicle detection is necessary with this mode of operation.

Traffic Signal Control

- **Semi-Actuated** A signal whose timing (cycle length, green time, and so on) is affected when vehicles are detected (by video or pavement-embedded inductance loop detectors) on some, but not all, approaches.
- This mode of operation is usually found when a low-volume road intersects a high-volume road, often referred to as the minor and major streets, respectively. In such cases, green time is allocated to the major street until vehicles are detected on the minor street, then the green indication is briefly allocated to the minor street and then returned to the major street.

Traffic Signal Control

- **Fully-Actuated** A signal whose timing (cycle length, green time, and so on) is completely influenced by the traffic volumes, when detected, on all of the approaches. Fully actuated signals are most commonly used at intersections of two major streets and where substantial variations exist in all approach traffic volumes over the course of a day.
Recall that level of service (LOS) is a qualitative assessment of facility operations based upon a quantitative performance measure.

The performance measure that is used to assess level of service for signalized intersections is average control delay per vehicle.

Analysis Procedure (assuming phasing, cycle length, and effective green times have already been determined)
- Establish Analysis Lane Groups
- Calculate Analysis Flow Rates and Adjusted Saturation Flow Rates
- Calculate Capacities
- Calculate Delay
- Determine Level of Service (LOS)

Lane groups will generally be dictated by geometry (i.e., lane allocation) and phasing
- Signalized intersection phasing can range from simple to complex
  - Pretimed single ring
  - Fully actuated dual ring

The methodology for signalized intersections is disaggregate; that is, it is designed to consider individual intersection approaches and individual lane groups within approaches.

Segmenting the intersection into lane groups is a relatively simple process that considers both the geometry of the intersection and the distribution of traffic movements. In general, the smallest number of lane groups is used that adequately describes the operation of the intersection.
Lane Grouping

- Dual-ring Signal Control

Calculate Analysis Flow Rates

- Adjust hourly volumes for RTOR
- Adjust for peak hour factor (PHF)

Assume already accounted for in book problems

Calculate Adjusted Saturation Flow Rates

- Start with a base value, usually 1900 pc/hr/ln per the *Highway Capacity Manual*
- This value is then adjusted for a variety of roadway and traffic related conditions.
- Factors such as lane width, grade, heavy vehicle percentage, bus activity, parking activity, pedestrian and bicyclist activity, and turn movement geometry and phasing
Calculate Lane Group Capacities

- Capacity is determined on a lane group basis
  \[ c = s \times \frac{g}{C} \]

Where:
- \( s \) = adjusted saturation flow rate
- \( g/C \) = eff. green to cycle length ratio

Determining Delay

- Average control delay per vehicle
  \[ d = d_1 \times PF + d_2 + d_3 \]  
  Eq. 7.14

Where:
- \( d \) = average signal delay per vehicle in seconds,
- \( d_1 \) = average delay per vehicle due to uniform arrivals in seconds,
- \( PF \) = progression adjustment factor,
- \( d_2 \) = average delay per vehicle due to random arrivals in seconds, and
- \( d_3 \) = average delay per vehicle due to initial queue at start of analysis time period, in seconds.

- Uniform delay
  \[ d_1 = \frac{0.5C \left(1 - \frac{g}{C}\right)^2}{1 - \min\left(l, X\frac{g}{C}\right)} \]  
  Eq. 7.15

Where:
- \( d_1 \) = average delay per vehicle due to uniform arrivals in seconds,
- \( C \) = cycle length in seconds,
- \( g \) = effective green time for lane group in seconds, and
- \( X = v/c \) ratio for lane group.

- Random delay
  \[ d_2 = 900T \left( X - 1 \right) + \sqrt{(X - 1)^2 + \frac{50X}{cT}} \]  
  Eq. 7.16

Where:
- \( d_2 \) = average delay per vehicle due to random arrivals in seconds,
- \( T \) = duration of analysis period in h,
- \( X = v/c \) ratio for lane group,
- \( k \) = delay adjustment factor that is dependent on signal controller mode,
- \( I \) = upstream filtering/metering adjustment factor, and
- \( c \) = lane group capacity, in veh/h.
Delay Calculation Assumptions

For problems in this class, all intersections are assumed to be isolated, under pretimed control, and have no initial queue at beginning of analysis period; thus:

- $d_i \rightarrow 0$
- $PF \rightarrow 1.0$
- $k \rightarrow 0.5$
- $I \rightarrow 1.0$

Determining Delay

Aggregating Delays

$$d_A = \frac{\sum_i d_i v_i}{\sum v_i}$$

Where:
- $d_A$ = average delay per vehicle for approach $A$ in seconds,
- $d_i$ = average delay per vehicle for lane group $i$ (on approach $A$) in seconds,
- $v_i$ = analysis flow rate for lane group $i$ in veh/h.

$$d_I = \frac{\sum d_i v_i}{\sum v_i}$$

Where:
- $d_I$ = average delay per vehicle for the intersection in seconds,
- $d_i$ = average delay per vehicle for approach $A$ in seconds,
- $v_i$ = analysis flow rate for approach $A$ in veh/h.

Level of Service

Delay Thresholds

<table>
<thead>
<tr>
<th>LOS</th>
<th>Control Delay per Vehicle (s/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$\leq 10$</td>
</tr>
<tr>
<td>B</td>
<td>$&gt; 10 - 20$</td>
</tr>
<tr>
<td>C</td>
<td>$&gt; 20 - 35$</td>
</tr>
<tr>
<td>D</td>
<td>$&gt; 35 - 55$</td>
</tr>
<tr>
<td>E</td>
<td>$&gt; 55 - 80$</td>
</tr>
<tr>
<td>F</td>
<td>$&gt; 80$</td>
</tr>
</tbody>
</table>

Example

Traffic Volumes & Lanes
Phasing

Analysis Flow Rates and Adj. Sat. Flow Rates

- Adjusted Analysis Flow Rates
  - Use given volumes
- Adjusted Saturation Flow Rates
  - Phase 1 (E/W prot. LT’s): 1800 veh/h
  - Phase 2 (E/W Th/RT’s): 3450, 3500 veh/h
  - Phase 3 (N/S perm. LT’s): 500, 350 veh/h
    (N/S Th/RT’s): 1800 veh/h

Calculate Flow Ratios (v/s) and Identify Critical Ones

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB L:</td>
<td>320</td>
<td>0.122</td>
</tr>
<tr>
<td>WB L:</td>
<td>250</td>
<td>0.139</td>
</tr>
<tr>
<td>NB L:</td>
<td>300</td>
<td>0.145</td>
</tr>
<tr>
<td>SB L:</td>
<td>500</td>
<td>0.145</td>
</tr>
<tr>
<td>NB T/R:</td>
<td>530</td>
<td>0.294</td>
</tr>
<tr>
<td>SB T/R:</td>
<td>450</td>
<td>0.294</td>
</tr>
</tbody>
</table>

Determine Cycle Length

\[ Y_i = \sum \left( \frac{v}{s} \right)_{j,i} = 0.139 + 0.271 + 0.294 = 0.704 \]

Assuming 4 seconds of lost time per phase

\[ L = \sum_{i=1}^{4} (c_i)_{j,i} = 4 + 4 + 4 = 12 \]

Assuming a critical intersection v/c ratio of 0.8

\[ C_{min} = \frac{L \times X_{j,i}}{X_{j,i} - \sum \left( \frac{v}{s} \right)_{j,i}} = \frac{12 \times 0.8}{0.8 - 0.704} = 100.0 \]
Determine Effective Green Times for each Phase

\[ g_i = \left( \frac{v_i}{X} \right) \left( \frac{C}{X} \right) \]

\[ g_1 = 0.139 \left( \frac{100}{0.8} \right) = 17.4 \]

\[ g_2 = 0.27 \left( \frac{100}{0.8} \right) = 33.9 \]

\[ g_3 = 0.294 \left( \frac{100}{0.8} \right) = 36.8 \]

\[ C = 17.4 + 33.9 + 36.8 + 12 = 100.1 \]

Determine Delays & LOS

Calculate EB approach delay

**Left turn lane group**

\[ \frac{g}{C} = \frac{17.4}{100} = 0.174 \text{ (moves in phase 1)} \]

\[ c = s \times \frac{g}{C} = 1800 \times 0.174 = 313.2 \]

\[ \frac{v}{c} = 220/313.2 = 0.702 \]

**Uniform Delay**

\[ d_i = \frac{0.5(100)(1 - 0.174)^2}{1 - 0.702 \times 0.174} = 38.9 \text{ sec} \]

**Random Delay**

With:

\[ T = 0.25 \text{ (15 min)} \]

\[ X = 0.702 \text{ (from above)} \]

\[ k = 0.5 \text{ (pretimed control)} \]

\[ I = 1.0 \text{ (isolated mode)} \]

\[ c = 313.2 \text{ veh/h (from above)} \]

\[ d_2 = 900(0.25) \left[ (0.702 - 1) + \sqrt{(0.702 - 1)^2 + \frac{8(0.5)(1.0)(0.702)}{(313.2)(0.25)}} \right] = 12.4 \text{ sec} \]

Determine Delays & LOS

**Total Delay**

With \( PF = 1.0 \) (for isolated signal)

\[ d_{EB\_LT} = 38.9 \times 1.0 + 12.4 + 0 = 51.3 \text{ sec} \]
Determine Delays & LOS

**Calculate EB approach delay**

Through/Right turn lane group

\[ \frac{g}{C} = \frac{33.9}{100} = 0.339 \text{ (moves in phase 2)} \]

\[ c = s \times \frac{g}{C} = 3450 \times 0.339 = 1169.6 \]

\[ v/c = \frac{880}{1169.6} = 0.752 \]

Uniform Delay

\[ d_{i} = \frac{0.5(100)(1-0.339)^{2}}{1-0.752 \times 0.339} = 29.3 \text{ sec} \]

Random Delay

With:

\[ T = 0.25 \text{ (15 min)} \]

\[ X = 0.752 \text{ (from above)} \]

\[ k = 0.5 \text{ (pretimed control)} \]

\[ I = 1.0 \text{ (isolated mode)} \]

\[ c = 1169.6 \text{ veh/h} \text{ (from above)} \]

\[ d_{i} = 900(0.25) \left[ (0.752 - 1) + \sqrt{(0.752 - 1)^{2} + \frac{80(0.5)(1.0)(0.752)}{(1169.6)(0.25)}} \right] = 4.5 \text{ sec} \]

Determine Delays & LOS

**Total Delay**

With \( PF = 1.0 \text{ (for isolated signal)} \)

\[ d_{EB,T/R} = 29.3 \times 1.0 + 4.5 + 0 = 33.8 \text{ sec} \]

Aggregate delays for LT and T/R lane groups

\[ d_{EB} = \frac{d_{EB,LT}v_{EB,LT} + d_{EB,T/R}v_{EB,T/R}}{v_{EB,LT} + v_{EB,T/R}} \]

\[ d_{EB} = \frac{51.3 \times 220 + 33.8 \times 880}{220 + 880} = 37.3 \text{ sec} \]