Traffic Signal Timing: Basic Principles

- 2 types of signals
  - Pre-timed
  - Traffic actuated

Objectives of signal timing
- Reduce average delay of all vehicles
- Reduce probability of accidents by minimizing possible conflict points

Objectives may conflict!
Development of a Traffic Signal Phasing and Timing Plan

- Select Signal Phasing
  - Determine if protected or permitted left turns will be used
    - HCM Guidelines - Consider using protected phase when the product of left turning vehicles and opposing traffic volume exceeds:
      - 50,000 during the peak hour for one opposing lane
      - 90,000 for two opposing lanes
      - 110,000 for three or more opposing lanes
Two Phase and Three Phase Signal Operation

- **Two-phase operation**
  - Phase 1
  - Phase 2

- **Three-phase operation**
  - Phase 1
  - Phase 2
  - Phase 3

Allowed traffic movements:
Typical Phasing Configurations and Sequencing
Example: Determining Signal Phasing Plan

Peak-hour traffic volumes

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

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

Both roadways are level
(zero grade)

60 ft
(18.3 m)

35 ft
(11.0 m)

F07_09
Example: Recommended Signal Phasing

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
</tbody>
</table>
Development of a Traffic Signal Phasing and Timing Plan

- Establish Analysis Lane Groups
- Determine critical lane groups
- Calculate cycle length
- Allocate green time
### Typical Lane Groupings for Analysis

<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</td>
</tr>
<tr>
<td>3</td>
<td>EXC LT</td>
<td>②</td>
</tr>
<tr>
<td></td>
<td>TH</td>
<td>③</td>
</tr>
<tr>
<td></td>
<td>TH + RT</td>
<td></td>
</tr>
</tbody>
</table>
Summary

- There is one lane (or lane group) for each phase requiring the maximum amount of effective green time. For this lane or lane group, we have the critical lane volume (CLV).
- There is an effective green time requirement and critical lane volume for each phase in the cycle.
- The "required green" for the cycle is the sum of the effective green requirements for each phase. We must provide at least this amount of effective green (per hour) to pass the traffic (without queuing).
Determining Cycle Length

\[ C_{\text{min}} = \frac{L \times X_c}{X_c - \sum_{i=1}^{n} \left( \frac{CLV}{s} \right)_i} \]

where:

- \( C_{\text{min}} = \) minimum cycle length
- \( L = \) total lost time in cycle, sec
- \( X_c = \) critical v/c ration for the intersection

*Round \( C \) to nearest 5 seconds. Choose \( X_c \) based on desired degree of utilization of the intersection.

Cycle lengths should typically be in the range of 40 – 120 seconds (unless intersection is very complex (5+ phases)).
Determining Cycle Length

- Webster’s Optimal Cycle Length

\[ C_{opt} = \frac{1.5L + 5}{1.0 - \sum_{i=1}^{n} \left( \frac{CLV}{s} \right)_i} \]

*approximately minimizes vehicle delay*
\[ X_c = \left( \frac{C}{C-L} \right) \sum_{i \in c_i} y_{c,i} \]

\[ C = \frac{L X_c}{X_c - \sum_{i \in c_i} y_{c,i}} \]

\[ g_i = \frac{v_i C}{N_i s_i X_i} = \left( \frac{v}{N s} \right)_i \left( \frac{C}{X_i} \right) \]

where

- \( C \) = cycle length (s),
- \( L \) = cycle lost time (s),
- \( X_c \) = critical intersection volume-to-capacity ratio,
- \( y_{c_i} \) = critical flow ratio for phase \( i = \frac{v_i}{N s_i} \),
- \( c_i \) = set of critical phases on the critical path,
- \( X_i \) = volume-to-capacity ratio for lane group \( i \),
- \( v_i \) = demand flow rate for lane group \( i \) (veh/h),
- \( N_i \) = number of lanes in lane group \( i \) (ln),
- \( s_i \) = saturation flow rate for lane group \( i \) (veh/h/ln), and
- \( g_i \) = effective green time for lane group \( i \) (s).
HCM 2010

Procedure

1. Determine flow ratio for each lane group and identify critical ratio for each phase.

2. Estimate cycle length. (desired Xc typically ranges from 0.8-0.9. Xc of 1 is capacity operation.)

3. Estimate effective green time for each phase.

4. Check $C = g_i + L$. 
Real World Constraints

- **Cycle length constraints:**
  - Cycle lengths typically minimized (increases $L$, and decreases capacity!)
  - $C$ typically ranges 40-120 sec, do not use excessive cycle length unless have very complex/unusual circumstances

- **Display time constraints:**
  - Do not show drivers something unexpected. General guidelines:
  - 12 sec (minimum for exclusive left turns)
  - 15 sec (minimum for through)

- Design flow – we use peak 15 minute flowrate for design of intersections.
Real World Constraints

- Composition:
  Saturation flow rate should be adjusted from its "ideal" value \( s_0 \) of 1900 (large metro areas) or 1750 (all other areas) pc/hr/ln. As an approximation, we will use:
  \[
  s = s_0 \times f_{hv}
  \]
  where
  \( s = \) saturation flow rate (pc/hr/ln)

  Where \( f_{hv} \) is the proportion of trucks in the stream. Assume \( E_T = 2 \), this reduces to:
  \[
  f_{hv} = \frac{1}{1 + P_T}
  \]
  Our approximation to saturation flow rate, then, is:
  \[
  s = \frac{s_0}{1 + P_T}
  \]

  (This is both a variation and simplification of the HCM technique for signalized intersections, but it is sufficient for our purposes).
Real World Constraints

- **Unprotected left turns:**
  Assume that each unprotected left turn is the equivalent of 2.0 through vehicles.

- **Pedestrian constraints (where pedestrian volumes are significant):**
  Ped time = 5 sec + walk time
  (Typical walk rate was 4 ft/sec, now 3.5 ft/sec)

- **All signal timing methods are approximate - checking and adjustments must be made in the field.**
Example 1

Find cycle length and splits for the intersection configuration shown below. Assume saturation headways of 1.9 sec/veh-lane and lost times of 5 sec/phase for all approaches.
Example 2 – Part A

As city traffic engineer of Attapulgus, Georgia, you are responsible for timing the town's traffic signal, which operates with two phases. Lost time is 4.5 seconds for each of the two phases and peak hour factor is 0.83. Peak hour data for each of the four approaches is given in the table below.

<table>
<thead>
<tr>
<th>APPROACH</th>
<th>Peak Hour Volume</th>
<th>Percent Trucks</th>
<th>Percent Left Turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB</td>
<td>548</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>WB</td>
<td>672</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>NB</td>
<td>598</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>SB</td>
<td>606</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

Intersection geometry is as shown below. Find the required cycle length and splits.
Example 2 – Part B

The mayor is up for re-election and has promised, if returned to office, to provide funds to significantly improve these two streets. What cycle length and splits would you implement if the intersection was improved by adding lanes as shown below?
Example – Part C

Well, the mayor's opponent, who campaigned on a platform of fiscal conservatism, won the election. This means that there will be no major improvements to the intersection. However, the new mayor is willing to foot the bill for a can of paint, and you do have enough pavement width to add left-turn bays for the east-west approaches. For your "new" intersection (shown below), can you re-time the signal to give a more reasonable operation than what you got in part a?