Topic 3
(Chapters 17, 18)

Signal Timing Principles
and Terminologies
Signal Timing Terminologies

- **Basic signal terms**

  - **Cycle and cycle length**
  - **Interval**
    - Change interval (yellow)
    - Clearance interval (all-red)
    - Green interval
    - Red interval
  - **Phase** = Green + Yellow + All-red

  (*A signal phase is associated with a particular traffic movement*)
Traffic Movements

One-way Streets

Main Street

Side Street

N

Main Street

Side Street

EB

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Traffic Movements

One-way Streets

Side Street

EB

Main Street

N
Traffic Movements

One-way Streets

Main Street

Side Street

EB

N

Main Street
Traffic Movements
One-way Streets

Main Street

Side Street

EB

N

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Traffic Movements
One-way Streets

EB

Side Street

Main Street

N

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Traffic Movements

One-way Streets

Side Street

Main Street

N

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Two-Phase Operation

\[ \phi_1 \quad \phi_2 \]
Traffic Movements
Full Intersection

Main Street

Side Street

SB

EB

WB

NB

N

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Controlled Movements

Main Street

Side Street

SB

EB

NB

WB

Main Street

N
Phasing Sequence

- **Left-turn Treatment/Control**
  - Permitted (no phase)
  - Protected
  - Protected/Permitted

- **Left-turn Sequence**
  - Dual LT Leading (preferred)
  - Dual LT Lagging
  - Split
  - Lead/Lag
Guidelines on Left-turn Controls

Permitted when any of the following satisfies

- $v_{LT} \leq 2 \text{ per cycle}$
- $v_{LT} < 200 \text{ vph}$
- Cross product: $v_{LT} \times \left( \frac{v_o}{N_o} \right) < 50,000$

Protected only

- Two or more left-turn lanes
- Speed limit $\geq 45 \text{ mph}$
- $v_{LT} > 320 \text{ vph}$, or $v_o > 1,100 \text{ vph}$
- Three or more opposing through lanes
- P/P has more than 7 accidents during 3 years
Phasing Sequence
Left-turn Leading

\[ \begin{array}{c}
\phi_1 & \phi_2 & \phi_3 \\
\phi_5 & \phi_6 & \phi_7
\end{array} \]

Ring 1

\[ \begin{array}{c}
\phi_1 & \phi_2 & \phi_4 \\
\phi_8
\end{array} \]

Ring 2

Barrier

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Phasing Sequence

Lead-Lag

\[ \phi_1 \quad \phi_2 \quad \phi_3 \quad \phi_4 \quad \phi_5 \quad \phi_6 \quad \phi_7 \quad \phi_8 \]

Barriers

Ring 1

Ring 2
Phasing Sequence

Lagging Left-Turn

\[ \phi_2 \rightarrow \phi_1 \rightarrow \phi_6 \rightarrow \phi_5 \rightarrow \phi_3 \rightarrow \phi_7 \rightarrow \phi_8 \rightarrow \phi_4 \]
Phasing Sequence

Split

 Barrier

Ring 1

φ2
φ1
φ3
φ4
φ5
φ6
φ7
φ8

Ring 2

φ5
φ6
φ5
φ6
φ1
φ2
φ1
φ2
Right-Turn Phase

- SB
  - φ8 φ3

- EB
  - φ1
  - φ6

- NB
  - φ7
  - φ4

- WB
  - φ2
  - φ5

- φ4+ φ5

N
Free Right-Turn

SB
φ8 φ3

EB
φ1 φ6

NB
φ7 φ4

WB
φ2 φ5

N
Right-Turn Phase

- **Right-turn Treatment**
  - Permitted (same with adjacent through)
    - Right-turn-on-red (RTOR)
    - No RTOR
  - Protected
    - Right-turn arrow display
    - Overlap phase (adjacent through phase + right-side cross street left-turn phase)
  - Free (channelized)
Determine a feasible signal phase and control, draw phase, ring, barrier diagram
Can the westbound right-turn operate with overlap phase(s)
How are the pedestrian phases handled?
Pedestrian Phase

- Pedestrian phase (WALK + FDW) is usually concurrent with the through movement phase.
- WALK and FDW normally show only when pedestrian crossing button is pushed.
Pedestrian Phase

- **WALK** time is usually between 4~7 sec
- **FDW** is also called the pedestrian clearance time, which is to allow pedestrians entering the crosswalk to safely cross

\[ G \geq WALK + FDW \]

\[ FDW = L/S_p \]
Pedestrian Issues

- Pedestrian timing > vehicle timing (crossing major street)
- Significant impact with split phasing
- Pedestrian crossing is a random event (not every cycle has peds)
- Coordination and timing issue
Pedestrian Crossing under Split Phasing

- When there are pedestrians on both crosswalks, the side street will consume \(2 \times t_p\) seconds in a cycle, where \(t_p\) is the phase time needed to serve a pedestrian crossing.

- Strategies to minimize pedestrian crossing effect (paper by Tian et al., TRR 1748, pp. 46-54, 2001.)
  - Eliminate one-side crossing
  - Allow crossing both sides (permitted left-turn)
  - Two-stage crossing
  - Scramble pedestrian phase
Determine phase(s) that serve pedestrians on the two crosswalks.
Change and Clearance Intervals

- **Change interval (yellow)**
  - can safely stop when green ends and yellow starts
  - or can enter the intersection at the end of yellow
  - about 3~4 seconds

Stopping Distance

Distance during Perception/Reaction

Yellow Starts

Stopping Distance
Change and Clearance Intervals

- **Change interval (yellow) – ITE**

  \[ y = t + \frac{1.47S_{85}}{2d + 64.4 \times 0.01G} \]

- **Clearance Interval (all-red)**

  \[ ar = \frac{w + L}{1.47S_{15}} \]
Table 7.2.1 Uniform Acceleration Formulas

<table>
<thead>
<tr>
<th>to find</th>
<th>given these</th>
<th>use this equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>$t, v_0, v$</td>
<td>$a = \frac{v - v_0}{t}$</td>
</tr>
<tr>
<td>$a$</td>
<td>$t, v_0, s$</td>
<td>$a = \frac{2s - 2v_0 t}{t^2}$</td>
</tr>
<tr>
<td>$a$</td>
<td>$v_0, v, s$</td>
<td>$a = \frac{v^2 - v_0^2}{2s}$</td>
</tr>
<tr>
<td>$s$</td>
<td>$t, a, v_0$</td>
<td>$s = v_0 t + \frac{1}{2} at^2$</td>
</tr>
<tr>
<td>$s$</td>
<td>$a, v_0, v$</td>
<td>$s = \frac{v^2 - v_0^2}{2a}$</td>
</tr>
<tr>
<td>$s$</td>
<td>$t, v_0, v$</td>
<td>$s = \frac{1}{2} t (v_0 + v)$</td>
</tr>
<tr>
<td>$t$</td>
<td>$a, v_0, v$</td>
<td>$t = \frac{v - v_0}{a}$</td>
</tr>
<tr>
<td>$t$</td>
<td>$a, v_0, s$</td>
<td>$t = \sqrt{\frac{v_0^2 + 2as - v_0}{a}}$</td>
</tr>
<tr>
<td>$t$</td>
<td>$v_0, v, s$</td>
<td>$t = \frac{2s}{v_0 + v}$</td>
</tr>
<tr>
<td>$v_0$</td>
<td>$t, a, v$</td>
<td>$v_0 = v - at$</td>
</tr>
<tr>
<td>$v_0$</td>
<td>$t, a, s$</td>
<td>$v_0 = \frac{s}{t} - \frac{1}{2} at$</td>
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<tr>
<td>$v_0$</td>
<td>$a, v, s$</td>
<td>$v_0 = \sqrt{v^2 - 2as}$</td>
</tr>
<tr>
<td>$v$</td>
<td>$t, a, v_0$</td>
<td>$v = v_0 + at$</td>
</tr>
<tr>
<td>$v$</td>
<td>$a, v_0, s$</td>
<td>$v = \sqrt{v_0^2 + 2as}$</td>
</tr>
</tbody>
</table>

*The table can be used for rotational problems by substituting $\alpha$, $\omega$, and $\theta$ for $a$, $v$, and $s$, respectively.*
Dilemma zone is a distance area when a vehicle can neither safely stop nor safely pass the intersection.
Example

Assume the 85\textsuperscript{th} percentile speed is 57 mph, and the 15\textsuperscript{th} percentile speed is 43 mph.

(a) Calculate the yellow change interval, clearance interval

(b) If a vehicle is traveling at 50 mph, determine the dilemma zone if any

\begin{align*}
&66 \text{ ft} \\
&13 \text{ ft} \\
&L = 20 \text{ ft}
\end{align*}
Clearance Intervals and Lost Times

- Clearance interval (all-red)
  - vehicles entering in yellow can clear the intersection
  - about 1.0~2.5 sec

- Lost times
  - time that cannot be effectively used by vehicles
  - start-up lost time, $l_1$, 2 sec (default in HCM)
  - use of end of green, $e$, 2 sec (default in HCM)

\[
t_L = l_1 + y + AR - e
\]
Saturation Headway and Saturation Flow Rate

\[ s = \frac{3600}{h} \]
Effective Green and Capacity

- Effective green of \( \Phi_i, g_i \)
  \[
g_i = G_i + y_i + (ar)_i - t_{Li}
  \]

- Phase capacity, \( c_i \)
  \[
c_i = s_i \times \frac{g_i}{C}
  \]

- Volume-to-capacity ratio, \( x_i \)
  \[
x_i = \frac{v_i}{c_i} = \frac{v_i}{s_i \left( \frac{g_i}{C} \right)} = \frac{v_i}{s_i} \times \frac{C}{g_i}
  \]
Example

Given the following:

- \( C = 60 \text{ s} \)
- \( G = 27 \text{ s} \)
- \( y = 2.5 \text{ s} \)
- \( ar = 0.5 \text{ s} \)
- \( h = 2.4 \text{ s} \)
- Start up lost time \( l_1 = 2.0 \text{ s} \), Clearance lost time \( l_2 = 1.0 \text{ s} \)

What is the capacity for an approach with two lanes of identical traffic flow characteristics?
Required Green and Phase Time

- Required effective green, $g_i$ to achieve degree of saturation, $x_i$

$$g_i = \frac{v_i}{s_i} \times \frac{C}{x_i} = y_i \frac{C}{x_i}$$

- Minimum effective green, $g_i$

$$g_i = y_i C$$

- Minimum phase, $\phi_i$

$$\phi_i = g_i + \ell_i = y_i C + \ell_i$$
Critical Phases

- **Critical phases**: conflicting phases that require the most time

- **Possible critical phases**
  - $\phi_1, \phi_2, \phi_3, \phi_4$
  - $\phi_1, \phi_2, \phi_7, \phi_8$
  - $\phi_5, \phi_6, \phi_3, \phi_4$
  - $\phi_5, \phi_6, \phi_7, \phi_8$
Critical Phases

- For a 8-phase signal, there are 4 critical phases

\[ \phi_{c1} + \phi_{c2} + \phi_{c3} + \phi_{c4} = C \]

\[ g_{c1} + g_{c2} + g_{c3} + g_{c4} = C - (l_{c1} + l_{c2} + l_{c3} + l_{c4}) = C - L \]

\[
\sum_{i=1}^{4} g_i = \sum_{i=1}^{4} y_i \frac{C}{x_i} = \frac{C}{x_i} \sum_{i=1}^{4} y_i = \frac{C}{x_i} Y_{CI} = C - L
\]

\[ Y_{CI} = \frac{C-L}{C} X_{CI} \]

\[ X_{CI} = \frac{C}{(C-L)} Y_{CI} \]

\[ C = \frac{LX_{CI}}{X_{CI}-Y_{CI}} \]

\[ C_{\text{min}} = \frac{L}{1-Y_{CI}} \]

\[ C_{o} = \frac{1.5L+5}{1-Y_{CI}} \]
Determine signal timing given the following data. Assume 8-phase, dual-ring, and $l = 4.0$ sec/phase

<table>
<thead>
<tr>
<th>$\Phi_i$</th>
<th>Direction</th>
<th>$v_i$, vph</th>
<th>$s_i$, vph</th>
<th>$y_i$</th>
<th>Sum of Ring $y_i$</th>
<th>$g_i$</th>
<th>Min. Phase, $\Phi$</th>
<th>Phase, $\Phi$</th>
<th>$x_i$</th>
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<tr>
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<td>EBT</td>
<td>616</td>
<td>3600</td>
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<td></td>
<td>15.0</td>
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