Interrupted traffic flow

- Intersections
  - Two-way STOP controlled intersections (TWSC)
  - Roundabouts
  - Signalized intersection

Examples – urban streets (HCS 2010)
Organization of HCM

Volume 1 – Concepts
Volume 2 – Uninterrupted Flow Facilities
   Freeways, rural highways, rural roads
Volume 3 – Interrupted Flow Facilities
   Urban arterials, intersections, roundabouts
   Signals at freeway interchanges,
   Bicycle and Pedestrian paths
Volume 4 – Supplemental Materials (Website)
   http://www.hcm.trb.org

Volume 3: Interrupted flow

- Urban street segments and facilities
  - Chapter 16: Urban street facilities
  - Chapter 17: Urban street segments
- Intersections
  - Chapter 18: Signalized intersection
  - Chapter 19: TWSC intersection
  - Chapter 20: AWSC intersection
  - Chapter 21: Roundabouts
  - Chapter 22: Interchange ramp terminal
- Off-street pedestrian an bicycle facilities
  - Chapter 23: Off-street P&B facilities
HCM 2010 – TWSC intersections

TWSC intersections (Ch. 19)

Limitations: isolated no traffic lights intersection without affecting adjacent intersections at a distance of at least 400m

HCM 2010 – TWSC intersections - Theory

Gap acceptance

- Availability and usefulness of gaps
- Relative priority of various movements at the intersection
- Measures are:
  - **Critical Headway** – the minimum time interval in the major street traffic stream that allows intersection entry for one minor street vehicle
    
    ![Critical Headway Diagram]

  - **Follow up Headway** – time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major street headway

- Movements of different traffic flows at the intersection
Priority of way

MAS – Major street
MIS – Minor street

Rank 1: through and right turn on MAS and pedestrian through MIS
Rank 2: left and U on MAS and right from MIS on MAS, pedestrians MAS
Rank 3: through on MIS(+) and left on MIS(T)
Rank 4: left on MIS(+)

LOS criteria

<table>
<thead>
<tr>
<th>Control Delay (s/vehicle)</th>
<th>LOS by Volume-to-Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\frac{K}{S} &lt; 1.8$</td>
</tr>
<tr>
<td>0–15</td>
<td>A</td>
</tr>
<tr>
<td>&gt;15–15</td>
<td>B</td>
</tr>
<tr>
<td>&gt;15–25</td>
<td>C</td>
</tr>
<tr>
<td>&gt;25–35</td>
<td>D</td>
</tr>
<tr>
<td>&gt;35–99</td>
<td>E</td>
</tr>
<tr>
<td>≥100</td>
<td>F</td>
</tr>
</tbody>
</table>

Note: The LOS criteria apply to each lane on a given approach and to each approach on the minor street. LOS is not calculated for major street approaches or for the intersection as a whole.

Control Delay (s/pedestrian) Comments

<table>
<thead>
<tr>
<th>LOS</th>
<th>Control Delay</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0–1</td>
<td>Usually no conflicting traffic</td>
</tr>
<tr>
<td>B</td>
<td>1–5</td>
<td>Occasional conflicting traffic</td>
</tr>
<tr>
<td>C</td>
<td>5–10</td>
<td>Delay noticeable to pedestrians, but not intimidating</td>
</tr>
<tr>
<td>D</td>
<td>10–20</td>
<td>Delay noticeable and intimidating, increased likelihood of risk taking</td>
</tr>
<tr>
<td>E</td>
<td>20–45</td>
<td>Delay approaches tolerance level, risk-taking behavior likely</td>
</tr>
<tr>
<td>F</td>
<td>≥45</td>
<td>Delay exceeds tolerance levels, high likelihood of pedestrian risk taking</td>
</tr>
</tbody>
</table>

Note: Control delay may be interpreted as subjectively group if groups of pedestrians were counted as opposed to individual pedestrians.

Bicycle mode is currently being prepared by HCM.
1. Determine and label movement priorities
2. Convert movement demand volumes to flow rates
3. Determine conflicting flow rates
4. Determine critical headways and follow-up headways

5a. Compute potential capacities
5b. Compute potential capacities adj. for effects of upstream signals

NO: Coordinated upstream signal present
YES: Next steps

NEW: Chapter 17

6. Compute Rank 1 movement capacities
7. Compute Rank 2 movement capacities
8. Compute Rank 3 movement capacities
9. Compute Rank 4 movement capacities
10. Final capacity adjustments
11. Compute movement control delay
12. Compute approach and intersection control delay (LOS)
13. Compute 95th percentile queue lengths
3. Det. the confliction flow rates

Rank 4 – movements 7 and 10 – left from MIS

Phase I:

<table>
<thead>
<tr>
<th>Two-lane major streets:</th>
<th>4.1</th>
<th>4.1</th>
<th>5.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turn from major</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Right turn from minor</td>
<td>6.2</td>
<td>6.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Through traffic minor</td>
<td>1-stage: 6.5</td>
<td>1-stage: 6.5</td>
<td>1-stage: 6.5</td>
</tr>
<tr>
<td></td>
<td>2-stage: 5.5</td>
<td>2-stage: 5.5</td>
<td>2-stage: 5.5</td>
</tr>
<tr>
<td></td>
<td>3-stage: 5.5</td>
<td>3-stage: 5.5</td>
<td>3-stage: 5.5</td>
</tr>
<tr>
<td></td>
<td>4-stage: 4.4</td>
<td>4-stage: 4.4</td>
<td>4-stage: 4.4</td>
</tr>
<tr>
<td></td>
<td>5-stage: 3.3</td>
<td>5-stage: 3.3</td>
<td>5-stage: 3.3</td>
</tr>
<tr>
<td></td>
<td>6-stage: 2.2</td>
<td>6-stage: 2.2</td>
<td>6-stage: 2.2</td>
</tr>
</tbody>
</table>

Phase II:

<table>
<thead>
<tr>
<th>Four-lane major streets:</th>
<th>4.1</th>
<th>4.1</th>
<th>5.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turn from major</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Right turn from minor</td>
<td>6.2</td>
<td>6.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Through traffic minor</td>
<td>1-stage: 6.5</td>
<td>1-stage: 6.5</td>
<td>1-stage: 6.5</td>
</tr>
<tr>
<td></td>
<td>2-stage: 5.5</td>
<td>2-stage: 5.5</td>
<td>2-stage: 5.5</td>
</tr>
<tr>
<td></td>
<td>3-stage: 5.5</td>
<td>3-stage: 5.5</td>
<td>3-stage: 5.5</td>
</tr>
<tr>
<td></td>
<td>4-stage: 4.4</td>
<td>4-stage: 4.4</td>
<td>4-stage: 4.4</td>
</tr>
<tr>
<td></td>
<td>5-stage: 3.3</td>
<td>5-stage: 3.3</td>
<td>5-stage: 3.3</td>
</tr>
<tr>
<td></td>
<td>6-stage: 2.2</td>
<td>6-stage: 2.2</td>
<td>6-stage: 2.2</td>
</tr>
</tbody>
</table>

4. Critical headway

\[ t_{c,x} = t_{c,base} + t_{c,HV} p_{HV} + t_{c,G} C + t_{c,LT} (s) \]

Adjustment factors:

- for heavy vehicles:
  1 – 1 lane in each direction MAS
  2 – 2 or more in each direction MAS

- for grade
  0.1 – movements 9, 12
  0.2 – movements 7, 8, 10, 11

- for geometry
  0.7 – left turn in three leg intersection
  0.0 – other
4. Follow-up Headway

\[ t_{f,x} = t_{f,\text{base}} + t_{f,HV}P_{HV} \quad (s) \]

Adjustment factor:
- for heavy vehicles(s):
  0.9 – 1 one lane in each direction MAS
  1.0 – 2 two or three lanes in each direction MAS

<table>
<thead>
<tr>
<th>Vehicle Movement</th>
<th>Base Follow-Up Headway, ( t_{f,\text{base}} ) (s)</th>
<th>Two Lanes</th>
<th>Four Lanes</th>
<th>Six Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turn from major</td>
<td>2.5</td>
<td>2.7</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>U-turn from major</td>
<td>N/A</td>
<td>3.1 (MM)</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Right turn from minor</td>
<td>3.2</td>
<td>3.3</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>Through traffic on minor</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Left turn from minor</td>
<td>3.1</td>
<td>3.3</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

5. Compute potential cap. if no upstream signal effects are present

\[
C_{p,x} = \nu_{c,x} \left( \frac{e^{-\nu_{c,x} t_{c,x} / 3600}}{1 - e^{-\nu_{c,x} t_{c,x} / 3600}} \right) \quad \text{(veh/h)}
\]

for each movement

- Rank 2:
  - Left on MAS, right on MIS: \( c_{w,j} = c_{p,j} \) (veh/h)
  - Other:
  - Special case:

\[
p_{w,j} = 1 - (1 - p_a) \left[ n_c \left( 1 + \frac{n_{t,2}}{n_a} \right) \right] (veh/h)
\]

10. Final cap. adjustment

- Shared capacity on MIS approaches

\[
c_{2df} = \frac{\sum \nu_y}{\sum \nu_y} \] (veh/h)

- Compute flared MIS lanes effects

\[
c_{x} = \min \left( c_{x}, \frac{\nu_{x,y}}{n_x} \right) c_{x,yc} \left( 1 + \frac{n_{t,2}}{n_x} \right) (veh/h)
\]

\[
\begin{align*}
    c_{x} &= \frac{c_{x} - c_{0}}{n_{t,2} - n_{t,0}} + c_{0} \quad \text{if } n_x \leq n_{t,0} \\
    c_{x} &= c_{x} \quad \text{if } n_x > n_{t,0}
\end{align*}
\]
11. Compute mov. control delay

\[
d_{\text{delay}} = \begin{cases} 
\frac{\left[ \frac{1}{n} - p_{0,i} \right] d_{\text{delay}} \left( \frac{v_{i,j}}{v_{c,1}} \right)}{N} & N > 1 \\
0 & N = 1 
\end{cases} \text{ (s/veh)}
\]

Rank 1: 
\[
\frac{1}{n} = \frac{v_{i,j}}{v_{c,1}}
\]

Rank 2 – 4: 
\[
\frac{1}{n} = \frac{v_{i,j}}{v_{c,1}}
\]

<table>
<thead>
<tr>
<th>Control Delay (s/vehicle)</th>
<th>LOS by Volume-to-Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\nu/c \leq 1.0)</td>
</tr>
<tr>
<td>(0-10)</td>
<td>A</td>
</tr>
<tr>
<td>(10-15)</td>
<td>B</td>
</tr>
<tr>
<td>(15-25)</td>
<td>C</td>
</tr>
<tr>
<td>(25-35)</td>
<td>D</td>
</tr>
<tr>
<td>(35-50)</td>
<td>E</td>
</tr>
<tr>
<td>(&gt;50)</td>
<td>F</td>
</tr>
</tbody>
</table>

Note: The LOS criteria apply to each lane on a given approach and to each approach on the minor street. LOS is not calculated for major-street approaches or for the intersection as a whole.

(T=0.25 for 15 min)

13. Compute Queue Lengths

\[
Q_{05} = 900T \left( \frac{v}{c_{s,1}} - 1 \right) + \frac{3,600}{c_{s,1} - \left( \frac{v}{c_{s,1}} \right)^2} \left( \frac{v}{c_{s,1}} \right) \left( \frac{v}{c_{m,1}} \right) \left( \frac{3,600}{150T} \right)
\]

(veh)
1. Identify two stage crossing (raised pedestrian median island)

2. Determine Critical Headway

3. Estimate probability of a delayed crossing

4. Calculate average delay to wait for adequate gap

5. Estimate delay reduction due to yielding vehicles

6. Calculate average pedestrian delay and determine LOS

2. Determine critical headway

- Single pedestrian
  \[ t_c = \frac{L}{S_p} + t_s \] (s)

- Group of pedestrians
  \[ t_{c,G} = t_c + 2(N_p - 1) \] (s)

Spatial distribution of pedestrians
  \[ N_p = \text{int}\left[\frac{8.0(N_p - 1)}{W_p}\right] + 1 \] (pedestrian)

Field observation: platoon size
  \[ N_t = \frac{v_p e^{v_p t} + n v}{(v_p + v) e^{v_p t} - n v} \] (pedestrian)

1 ft = 0.304 m
3. Estimate prob. of delayed crossing

Probability of a blocked lane
\[ P_b = 1 - e^{-\frac{t}{c_p}} \]

Probability of a delayed crossing
\[ P_d = 1 - (1 - P_b)^L \]

4. Calculate average delay

<table>
<thead>
<tr>
<th>LOS</th>
<th>Control Delay (s/pedestrian)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0–5</td>
<td>Usually no conflicting traffic</td>
</tr>
<tr>
<td>B</td>
<td>5–10</td>
<td>Occasionally some delay due to conflicting traffic</td>
</tr>
<tr>
<td>C</td>
<td>10–20</td>
<td>Delay noticeable to pedestrians, but not inconveniencing</td>
</tr>
<tr>
<td>D</td>
<td>20–30</td>
<td>Delay noticeable and irritating, increased likelihood of risk taking</td>
</tr>
<tr>
<td>E</td>
<td>30–45</td>
<td>Delay approaches tolerance level, risk-taking behavior likely</td>
</tr>
<tr>
<td>F</td>
<td>&gt;45</td>
<td>Delay exceeds tolerance level, high likelihood of pedestrian risk taking</td>
</tr>
</tbody>
</table>

Note: Control delay may be interpreted as pedestrian group if groups of pedestrians were counted as opposed to individual pedestrians.

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HCM 2010 – TWSC intersections - Bicycles

- No methodology specific to bicyclist has been developed
- Bicyclist may travel either as a motor vehicle or a pedestrian
- Critical headway distributions have been identified in the research for the bicycle crossing two lane MS
- Multiple bicyclist often use the same gap in the vehicular traffic stream.
16.4.2015

Using HCS 2010

HCM 2010 - Roundabouts

Roundabouts (Ch. 21)

Intersection with general circular shape, characterized by yield on entry and counter clockwise circulation around a central island.
Flows required for analysis:
- Entry flow rates,
- Conflicting flow rate
- Exit flow rate

NEW

1. Convert movement demand volumes to flow rates
2. Adjust flow rates for heavy vehicles
3. Determine circulating and exiting flow rates
4. Determine entry flow rates by lane
5. Determine the capacity of each entry lane and bypass lane (pc/ln)
6. Determine pedestrian impedance to vehicles
9. Compute the average control delay for each lane
10. **Determine LOS for each lane on each approach**
11. Compute control delay and determine LOS for each approach and the roundabout
12. Compute 95th percentile queues for each lane

3. Determine circulation flow rate

\[ \eta_{c, NR, pve} = \eta_{WBL, pve} + \eta_{SUL, pve} + \eta_{2UL, pve} + \eta_{4UL, pve} + \eta_{SBL, pve} + \eta_{EBL, pve} \] (pc/h)
3. Determine exit flow rate

\[ v_{ex,pcr} = v_{NBU,pcr} + v_{WEI,pcr} + v_{SBT,pcr} + v_{EIR,pcr} - v_{EIR,pcr,bypass} \] (pc/h)

4. Determine entry flows for lanes

<table>
<thead>
<tr>
<th>Case</th>
<th>Assumed Lane Assignment</th>
<th>Left Lane</th>
<th>Right Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LT, TR</td>
<td>( n_x \times n_y )</td>
<td>( n_x \times n_y )</td>
</tr>
<tr>
<td>2</td>
<td>LT, R</td>
<td>( n_x \times n_y )</td>
<td>( n_x \times n_y )</td>
</tr>
<tr>
<td>3</td>
<td>LT, TR</td>
<td>( (%LT, %TR) )</td>
<td>( (%LT, %TR) )</td>
</tr>
<tr>
<td>5</td>
<td>LTR, R</td>
<td>( (%LTR, %TR) )</td>
<td>( (%LTR, %TR) )</td>
</tr>
</tbody>
</table>

Notes: \( n_x \), \( n_y \), and \( n_{xy} \) are the Uturn, left-turn, through, and bypass right-turn flow rates using a given entry, respectively.

- L = left, LT = left-through, TR = through-right, LTR = left-through-right, and R = right.

<table>
<thead>
<tr>
<th>Lane Configuration</th>
<th>% Traffic in Left Lane</th>
<th>% Traffic in Right Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-through = right</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td>Left-through = right</td>
<td>0.47</td>
<td>0.33</td>
</tr>
<tr>
<td>Left-through = right</td>
<td>0.53</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Notes: These values are generally consistent with observed values for through movements at signalized intersections. These values should be applied with care, particularly under conditions estimated to be near capacity.
5. Determine the capacity

\[ C_{e,pcr} = 1,130e^{(-1.0 \times 10^{-3})v_{e,pcr}} \text{ (pc/h)} \]
16.4.2015

**HCM 2010 – Roundabout**

1 entry lanes – 2 circ. lane

![Diagram showing capacity vs. conflicting flow rate for 1 entry lane - 2 circ. lane configuration.](image)

\[ C_{c,pcr} = 1,130e^{\left(2.7 \times 10^{-3}\right) \nu_{pcr}} \text{ (pc/h)} \]

**HCM 2010 – Roundabout**

2 entry lanes – 2 circ. lane

![Diagram showing capacity vs. conflicting flow rate for 2 entry lane - 2 circ. lane configuration.](image)

\[ C_{c,R,pcr} = 1,130e^{\left(2.7 \times 10^{-3}\right) \nu_{pcr}} \text{ (pc/h)} \]

\[ C_{c,L,pcr} = 1,130e^{\left(0.73 \times 10^{-3}\right) \nu_{pcr}} \text{ (pc/h)} \]
Yielding bypass lane

Terminates at a high angle - yielding to exiting traffic

Capacity approximated using the appropriate single lane (1x1) or multilane (1x2) capacity formula

\[ c_{\text{bypass,pcv}} = 1,130e^{-1,0\times10^{-7}h_{\text{pcv}}} \text{ (pc/h)} \]

Treat the exiting flow from the roundabout as the conflicting flow

Non-yielding bypass lane

Merges at a low angle with exiting traffic or forms a new lane adjacent to exiting traffic

Capacity is expected to be relatively high due to a merging operation between two traffic streams at similar speeds.
6. Pedestrian impedance to vehicles

For 1 lane entry:

- If $v_{ped} > 861$
  \[ f_{ped} = 1 \]
- Else if $n_{ped} < 101$
  \[ f_{ped} = 1 - 0.00037n_{ped} \]
- Else
  \[ f_{ped} = \frac{1.1195 - 0.715v_{sec} - 0.644v_{ped} + 0.00073v_{sec}n_{ped}}{1.0886 - 0.654v_{sec}} \]

Estimation for 2 lane entry:

- If $n_{ped} < 100$
  \[ f_{ped} = \min \left(1 - \frac{n_{ped}}{100}, \frac{1.2606 - 0.329v_{sec} - 0.381v_{sec}n_{ped}}{1.380 - 0.5v_{sec}} \right) \]
- Else
  \[ f_{ped} = \min \left(\frac{1.2606 - 0.329v_{sec} - 0.381n_{ped}}{1.380 - 0.5v_{sec}}, 1 \right) \]
7. Convert lane flow rates into veh/h

\[ v_i = v_{i,PCE} f_{HV,i} \] (veh/h)

\[ c_i = c_{i,PCE} f_{HV,i} f_{ped} \] (veh/h)

heavy vehicle adjustment factor

\[ f_{HV,i} = \frac{f_{HV,0} v_{0,PCE} + f_{HV,0} v_{1,PCE} + f_{HV,0} v_{2,PCE} + f_{HV,0} v_{3,PCE}}{v_{0,PCE} + v_{1,PCE} + v_{2,PCE} + v_{3,PCE}} \]

8., 9. v/C and compute average delay

\[ d_i = \frac{v_i}{c_i} \]

\[ d = \frac{3.600}{c} + \frac{900}{\sqrt{x - 1 + \sqrt{(x - 1)^2 - \left(\frac{3.600}{c}\right)^2}} + 5 \times \min[x,1] \] (s/veh)

<table>
<thead>
<tr>
<th>Control Delay (s/veh)</th>
<th>LOS by Volume-to-Capacity Ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>v/c ≤ 1.0 A</td>
</tr>
<tr>
<td>&gt;10–15</td>
<td>v/c &gt; 1.0 F</td>
</tr>
<tr>
<td>&gt;15–25</td>
<td>v/c &gt; 1.0 C</td>
</tr>
<tr>
<td>&gt;25–35</td>
<td>v/c &gt; 1.0 D</td>
</tr>
<tr>
<td>&gt;35–50</td>
<td>v/c &gt; 1.0 E</td>
</tr>
<tr>
<td>&gt;50</td>
<td>v/c &gt; 1.0 F</td>
</tr>
</tbody>
</table>

Note: For approaches and intersection-to-end assessment, LOS is defined solely by control delay.

\[ d_{\text{approach}} = \frac{d_{LL} v_{LL} + d_{RL} v_{RL} + d_{\text{bypass}} v_{\text{bypass}}}{v_{LL} + v_{RL} + v_{\text{bypass}}} \quad (s/\text{veh}) \]

\[ d_{\text{intersection}} = \sum \frac{d_i v_i}{v_i} \quad (s/\text{veh}) \]

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<tr>
<td>15–25</td>
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</tr>
<tr>
<td>25–35</td>
<td>C</td>
</tr>
<tr>
<td>&gt;35–50</td>
<td>D</td>
</tr>
<tr>
<td>&gt;50</td>
<td>E</td>
</tr>
</tbody>
</table>

Note: *For approach and intersectionwide assessment, LOS is defined solely by control delay.

12. Queues length for each lane

\[ Q_{ox} = 9000 \left[ x - 1 + \sqrt{1 - x} + \frac{3600}{c} \left( \frac{c}{1500} \right)^x \right] \text{ (voz)} \]
Using HCS 2010

HCM 2010 – Signalized intersections

Signalized intersections (Ch. 18)
Analysis boundaries

Methodology is valid for isolated signalized intersections.

Driving through sem. intersection

Operational state of traffic is defined by:
- Volumes and flow rates;
- Sat. flows and departure headways;
- Control variables;
- Gaps available and conflict traffic streams;
- Control delay
**Impacts of signalization**

*Saturation flow rate (s)* is a max. number of vehicles per hour per lane, which can pass through intersection.

**Delays**

- **Control delays**: by the presence of traffic controls (MOE for LOS)
- **Geometric delays**: caused by geometric features causing vehicles for reduce speed
- **Incident delays**: additional travel time experienced as a result of an incident
- **Traffic delays**: resulting from interaction of vehicle, causing driver reduce speed
- **Total delays**: sum of all mentioned delays
What is new in HCM 2010

1. The model has been set up to handle actuated signal analysis directly.
2. The estimation of delay is partially modeled using Incremental Queue Analysis (IQA) which allows a more detailed analysis of arriving and departing vehicle distributions.
3. The definition of lane groups has been altered. Lane groups are identified and separately analyzed.

“This presentation focuses on the analysis of pretimed signals because it is more straightforward to present basic modeling theory for fixed time signals.”

Conceptual framework

Five fundamental concepts:

- The critical lane group concept
- The v/s ratio as a measure of demand
- Capacity and saturation flow rate concepts
- Level-of-service (LOS) criteria and concepts
- Effective green time and lost-time concepts
a. The Critical-Lane Group Concept

Critical lane analysis compares actual flow \( v \) with the saturation flow rate \( s \) and capacity \( c \) in a single lane.

Critical lane group analysis compares actual flow \( v \) with the saturation flow rate \( s \) and capacity \( c \) in a group of lanes operating in equilibrium.

In either case, the ratio of \( v \) to \( c \) is the same. This applies to shared lanes, also.

b. The \( v/s \) ratio as a measure of demand

c. Capacity and sat. flow rate concepts

A key part of the HCM 2010 model is a methodology for estimating the saturation flow rate of any lane group based on known prevailing traffic parameters:

\[
s_i = s_0 N \prod f_i
\]

We may not be able to compare directly lane groups because their conditions are different. So HCM use the flow ratio, \( v/s \), a dimensionless value for comparison purposes - “normalization.”
The capacity of each lane group:

- Demand does not necessarily peak at all approaches at the same time.
- Capacity may change for each approach during the day - like the effect of curb side parking, bus blocking, etc.
- Capacity is provided to movements to satisfy movement demands.

\[ c_i = s_i \frac{g_i}{C} \]

The v/c ratio ➔ “degree of saturation”

Computation of a v/c ratio (degree of saturation) for a given lane group:

\[ X_i = \frac{v_i}{c_i} = \frac{v_i}{s_i} \frac{g_i}{C} = \frac{v_i}{s_i} g_i/C \] Flow ratio/Green ratio

The critical v/c ratio for the intersection ➔ defined as the sum of the critical lane group flows divided by the sum of the lane group capacities available to serve them:

\[ X_c = \sum (v/s)_i \frac{C}{C-L} \]
Computation of a v/c ratio for an intersection as a whole:

- If the critical v/c ratio is less than 1.00, the cycle length, phase plan, and physical design provided are sufficient to handle the demand and flows specified.
- But, having a critical v/c ratio under 1.00 does not assure that every critical lane group has v/c ratios under 1.00. When the critical v/c ratio is less than 1.00, but one or more lane groups have v/c ratios greater than 1.00, the green time has been misallocated.
- If the \( X_c > 1.0 \), then the physical design, phase plan, and cycle length specified do not provide sufficient capacity for the anticipated or existing critical lane group flows. Do something to increase capacity:
  - (1) longer cycle lengths (less number of cycles, less lost time),
  - (2) better phase plans (improved LT treatment), and
  - (3) add critical lane group or groups (meaning change approach layouts > increase capacity)

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d. LOS criteria and concepts

- All the HCM delay models assume random arrivals. Hence, the delay model produce delays for approaches with random arrivals. Urban signals are coordinated - many do not have random arrivals. This is corrected by the “quality of progression” factor called “Arrival Type” factor. There are 6 arrival types: 1 = poor coordination, 6 = exceptionally good coordination.
- For signalized intersections, v/c has no a direct connection with the performance of the facility – especially when delay is used as the MOE.

✔ You may get LOS=F even if v/c is well below 1.0. For instance LT vehicles may have a long stopped delay even if its v/c is low.
The 2010 HCM uses “total control delay” consisting of time in queue delay + acceleration - deceleration delay.

<table>
<thead>
<tr>
<th>Control Delay (s/veh)</th>
<th>LOS by Volume-to-Capacity Ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤10</td>
<td>A</td>
</tr>
<tr>
<td>&gt;10</td>
<td>B</td>
</tr>
<tr>
<td>&gt;20</td>
<td>C</td>
</tr>
<tr>
<td>&gt;35</td>
<td>D</td>
</tr>
<tr>
<td>&gt;80</td>
<td>E</td>
</tr>
<tr>
<td>&gt;80</td>
<td>F</td>
</tr>
</tbody>
</table>

Note: *For approach-based and intersectionwide assessments, LOS is defined solely by control delay.

Because delay is difficult to measure in the field and because it cannot be measured for future situations, delay is estimated using analytic models.

e. Effective green times and lost times

A. Actual signal indications

B. Actual use of green and yellow:
   e is extended green, i.e. part of the yellow used as green

C. Lost times $l_1$ and $l_2$ are added and placed at the beginning of the green for modeling purposes

D. Effective green and effective red

\[
\begin{align*}
l_1 &= 2 \text{ sec/phase} \\
e &= 2 \text{ sec/phase}
\end{align*}
\]

Default by HCM2010
Effective green times and the application of the lost times:

- HCM delay models use “effective green time” and “effective red time.”
- HCM 2010 models assume that all lost times happen at the beginning of the phase.

\[ g_i = G_i + y_i + ar_i - l_i - l_2 \]
\[ g_i = G_i - l_i + e \]
\[ r_i = C - g_i \]

Watch out where \( t_L \) takes place, especially when an overlap phase exists. That’s where you must add \( y \) and \( ar \) in the phase section of the HCS input module.

---

**Pretimed phase duration**

Several aspects:

- to **equalize the volume-to-capacity ratios** for critical lane groups. The green time is allocated among the various signal phases in proportion to the flow ratio of the critical lane group for each phase;

- to **minimize the total delay** to all vehicles;

- to **equalize the level of service** for all critical lane groups.
Pretimed phase duration – cycle length

1. Compute the flow ratio \(= \frac{v_i}{(N s_i)}\) for each lane group and identify the critical flow ratio for each phase. When there are several lane groups on the approach served during a common phase, the lane group with the largest flow ratio represents the critical flow ratio for the phase.

2. If signal-system constraints do not dictate the cycle length, then estimate the minimum cycle length by setting \(X_c\) equal to 1.0.

\[
C = \frac{L X_c}{X_c - \sum_{i=1}^{n} y_{e,i}} \quad (s)
\]

- \(L\) – cycle lost time (s),
- \(X_c\) – critical intersection volume-to-capacity ratio
- \(y\) – critical flow ratio for phase

3. Calculate the target cycle length \(C_2 \rightarrow X_c = 0.8 \rightarrow 0.9\)

4. Select an appropriate \(C\) for the signal from Step 2 and 3.

5. Estimate the effective green time for each phase with and the target volume-to-capacity ratio.

\[
x_i = \frac{v_i C}{N_i s_i X_i} = \left( \frac{v_i}{N s_i} \right) \left( \frac{C}{X_i} \right) \quad (s)
\]

\[
X_c = \left( \frac{C}{C - L} \right) \sum \delta y_{e,j}
\]

6. Check the timing to ensure that the effective green time and the lost time for each phase in a common ring sum to the \(C\).
1. Determine movement group and lane group
2. Determine movement group flow rate
3. Determine lane group flow rate
4. Determine adjusted saturation flow rate
5. Determine proportion arriving during green
6. Determine signal phase duration
7. Determine capacity and v/C ratio
8. Determine delay
9. Determine LOS
10. Determine queue storage rate

For actuated only
Converge?

1. Determine MG and LG

Rules to determine movement group on approach (1 – 3 MG on approach):
- Turn movement that is served by one or more exclusive lanes and no shared lanes should be designated as MG,
- Any lanes not assigned by the previous rule should be combined into 1 MG.

Rules to determine lane group on approach (1 – more LG on approach):
- Exclusive left (or right) turn lane is separate LG
- Any shared lane should be designated as separate LG
- Any lanes that are no exclusive turn or shared should be combined into one LG
4. Determine adj. sat. flow rate

\[ s = s_0 \cdot f_w \cdot f_{HV} \cdot f_R \cdot f_P \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT} \cdot f_{lpb} \cdot f_{Rpb} \quad \text{(veh/h/ln)} \]

- \( s_0 \) = base sat. flow rate \( \approx 1750 \text{ to } 1900 \text{ veh/h/ln} \)
- \( f_w \) = for lane width (10-12.9 ft = 1; 3 – 4 m)
- \( f_{HV} \) = for HV in traffic stream
- \( f_a \) = for approach grade
- \( f_b \) = for existence of parking lane and activities
- \( f_{bb} \) = for clocking effect of local buses
- \( f_{LU} \) = for lane utilization (1 shared or exclusive lane = 1)
- \( f_{LT} \) = for left turn vehicle presence in LG (geometry)
- \( f_{RT} \) = for right turn vehicle presence in LG (geometry)
- \( f_{lpb} \) = for pedestrian impact into LT groups
- \( f_{Rpb} \) = for pedestrian and bikes impact into RT groups

8. Determine delay

\[ d = d_1 + d_2 + d_3 \quad \text{(s/veh)} \]

- \( d \) = control delay (s/veh)
- \( d_1 \) = uniform delay (s/veh)
- \( d_2 \) = incremental delay (s/veh)
- \( d_3 \) = initial queue delay (s/veh)
Pedestrian areas in intersection

<table>
<thead>
<tr>
<th>Pedestrian Space (ft²/p)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;69</td>
<td>Ability to move in cleared path, no need to alter movements</td>
</tr>
<tr>
<td>&gt;40-60</td>
<td>Occasional need to adjust path to avoid conflicts</td>
</tr>
<tr>
<td>&gt;24-40</td>
<td>Frequent need to adjust path to avoid conflicts</td>
</tr>
<tr>
<td>&gt;15-24</td>
<td>Speed and ability to pass slower pedestrians restricted</td>
</tr>
<tr>
<td>&gt;8-15</td>
<td>Speed severely restricted, frequent contact with other users</td>
</tr>
<tr>
<td>≤8</td>
<td></td>
</tr>
</tbody>
</table>

1. Determine street corner circulation area
2. Determine crosswalk circulation area
3. Determine pedestrian delay
4. Determine pedestrian LOS score for intersection
5. Determine LOS
4. Determine LOS score

\[ I_{p,\text{int}} = 0.5997 + F_w + F_v + F_s + F_{\text{delay}} \]

- \( F_w \) = cross section adj. factor
  \[ F_w = 0.681 \left( \frac{N_d}{1946} \right)^{0.514} \]

- \( F_v \) = motorized vehicle adj. factor
  \[ F_v = 0.005 \]

- \( F_s \) = motorized vehicle speed adj. factor
  \[ F_s = 0 \]

- \( F_{\text{delay}} \) = pedestrian delay adj. factor
  \[ F_{\text{delay}} = 0.0401 \ln(d_{p,d}) \]

LOS Score Table:

<table>
<thead>
<tr>
<th>LOS</th>
<th>LOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤2.00</td>
</tr>
<tr>
<td>B</td>
<td>2.00–2.75</td>
</tr>
<tr>
<td>C</td>
<td>2.75–3.50</td>
</tr>
<tr>
<td>D</td>
<td>3.50–4.25</td>
</tr>
<tr>
<td>E</td>
<td>4.25–5.00</td>
</tr>
<tr>
<td>F</td>
<td>&gt;5.00</td>
</tr>
</tbody>
</table>

1. Determine bicycles delay
2. Determine LOS score for bicycles
3. Determine LOS
2. Determine bicycles LOS score

\[ I_{b,ini} = 4.1324 + F_w + F_v \]

- \( F_w \) = cross section adj. factor
- \( F_v \) = motorized vehicle adj. factor

\( F_w = 0.0153 W_{cd} - 0.2144 W_c \)

\( W_{cd} = \text{curb to curb width of the cross street (ft)} \)

\( W_c = \text{width of bikes lane or shoulder outside through lane} \)

\( I_{on} = \text{indicator for on street parking occupancy (0 or 1)} \)

\( F_v = 0.0066 \frac{V_{vb} + V_{v} + V_{vb}}{4 N_{th}} \)

\( V_{vb} = \text{volume flow rate} \) (veh/h)

\( N_{th} = \text{number of through lanes} \)

<table>
<thead>
<tr>
<th>LOS</th>
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<tbody>
<tr>
<td>A</td>
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</tr>
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</table>

HCS 2010- Street: Operational (LOS), Design (LOS, N)
Questions?

THANKS FOR YOUR ATTENTION!

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