HCM Signalized Intersection Analysis

- Overarching Characteristics
  - Each Approach (Lane Group) Calculated Separately
  - Intersection is Analyzed by Approaches and Aggregated
  - Basic Signal Timing Plan must be Assumed
    - HCM DOES NOT Optimize Traffic Signal Timing Plans
    - Results in an Iterative Process
      - Show Example
  - Other Software Packages Optimize Traffic Signal Timing Plans
    - e.g., SYNCHRO, TRANSYT 7F, PASSER
    - Show Example
- Basic Modals
  - Input Modal
  - Flow Rate Adjustments
  - Saturation Flow Rate Calculations
  - Capacity Calculations
  - MOE Calculations
**Input Data Needs for Each Analysis Lane Group**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Parameter</th>
</tr>
</thead>
</table>
| Geometric conditions | Area type, \( n \)
|                    | Number of lanes, \( B \)
|                    | Average lane width, \( W \) (ft)
|                    | Grade, \( G \) (%)                                                       |
|                    | Evidence of exclusive LT or RT lanes                                      |
|                    | Length of storage bay, \( L_s \) (ft)                                    |
| Traffic conditions | Demand volume by movement, \( V \) (veh/h)                                |
|                    | Base saturation flow rate, \( s_b \) (pcu/h/ln)                           |
|                    | Peak-hour factor, \( P_{PHF} \)                                         |
|                    | Percent heavy vehicles, \( H V \) (%)                                   |
|                    | Approach pedestrian flow rate, \( V_{ped} \) (ped/h)                    |
|                    | Local buses stopping at intersection, \( N_L \) (buses/ln)               |
|                    | Parking activity, \( N_P \) (maneuvers/ln)                              |
|                    | Arrangement, \( A \)                                                   |
|                    | Proportion of vehicles arriving on green, \( P \)                       |
|                    | Approach speed, \( S_A \) (mph)                                        |
| Signalization conditions | Cycle length, \( S \) (s)                                               |
|                    | Green time, \( G \) (s)                                                 |
|                    | Yellow plus all-red change-and-clearance interval (intergreen), \( Y \) (s) |
|                    | Actuated or pre-timed operation                                          |
|                    | Pedestrian push button                                                  |
|                    | Minimum pedestrian green, \( G_p \) (s)                                 |
|                    | Phase plan                                                              |
|                    | Analysis period, \( T \) (h)                                            |
Traffic Signal Coordination

EXHIBIT 10-18: PROGRESSION QUALITY AND ARRIVAL TYPE

<table>
<thead>
<tr>
<th>Progression Quality</th>
<th>Arrival Type</th>
<th>Conditions Under Which Arrival Type Is Likely To Occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very poor</td>
<td>1</td>
<td>Occurs for coordinated operation on two-way street where one direction of travel does not receive good progression. Signals are spaced less than 1,600 ft apart.</td>
</tr>
<tr>
<td>Unfavorable</td>
<td>2</td>
<td>A less extreme version of Arrival Type 1. Signals spaced at or more than 1,600 ft but less than 3,200 ft apart.</td>
</tr>
<tr>
<td>Random arrivals</td>
<td>3</td>
<td>Signals spaced at or more than 3,200 ft apart (whether or not coordinated).</td>
</tr>
<tr>
<td>Favorable</td>
<td>4</td>
<td>Occurs for coordinated operation, often only in one direction on a two-way street. Signals are typically between 1,000 ft and 3,200 ft apart.</td>
</tr>
<tr>
<td>Highly favorable</td>
<td>5</td>
<td>Occurs for coordinated operation. More likely to occur with signals less than 1,600 ft apart.</td>
</tr>
<tr>
<td>Exceptional</td>
<td>6</td>
<td>Typical of one-way streets in dense networks and central business districts. Signal spacing is typically under 800 ft.</td>
</tr>
</tbody>
</table>

Lane Groups

- Exclusive lanes are counted as a separate lane group
- Shared lanes must be analyzed for "de facto" exclusive lanes
- Right Turn on Red (RTOR) deducted from right-turn traffic volumes
DETERMINE SATURATION FLOW RATE

A saturation flow rate for each lane group is computed according to Equation 16-4. The saturation flow rate is the flow in vehicles per hour that can be accommodated by the lane group assuming that the green phase were displayed 100 percent of the time (i.e., g/C = 1.0),

\[ s = s_i N f_w f_p f_a f_u f_t f_b f_q f_r \]

where

- \( s \) = saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (veh/h);
- \( s_i \) = base saturation flow rate per lane (veh/h);
- \( N \) = number of lanes in lane group;
- \( f_w \) = adjustment factor for lane width;
- \( f_p \) = adjustment factor for heavy vehicles in traffic stream;
- \( f_a \) = adjustment factor for approach grade;
- \( f_u \) = adjustment factor for existence of a parking lane and parking activity adjacent to lane group;
- \( f_b \) = adjustment factor for blocking effect of local buses that stop within intersection area;
- \( f_q \) = adjustment factor for area type;
- \( f_u \) = adjustment factor for lane utilization;
- \( f_t \) = adjustment factor for left turns in lane group;
- \( f_r \) = adjustment factor for right turns in lane group;
- \( f_b \) = pedestrian adjustment factor for left-turn movements; and
- \( f_q \) = pedestrian-bicycle adjustment factor for right-turn movements.

Base saturation flow rate = 1,900 (pc/h/ln) Metro area with > 250,000 pop
= 1,750 (pc/h/ln) Otherwise

---

Lane Group Capacity

V/C Ratio

\[ e_i = \frac{g_i}{C} \]

where

- \( e_i \) = capacity of lane group \( i \) (veh/h);
- \( g_i \) = saturation flow rate for lane group \( i \) (veh/h), and
- \( g_i/C \) = effective green ratio for lane group \( i \).

\( \text{V/C Ratio} \)

The ratio of flow rate to capacity (V/C), often called the volume to capacity ratio, is given the symbol \( X_i \) in intersection analysis. It is typically referred to as degree of saturation. For a given lane group \( i \), \( X_i \) is computed using Equation 16-7.

\[ X_i = \frac{\nu_i}{C} = 1 - \frac{g_i/C}{e_i} \]

where

- \( X_i \) = (V/C) = ratio for lane group \( i \); \( \nu_i \) = actual or projected demand flow rate for lane group \( i \) (veh/h);
- \( g_i \) = saturation flow rate for lane group \( i \) (veh/h);
- \( g_i/C \) = effective green time for lane group \( i \) (s), and
- \( C \) = cycle length (s).
HCM Delay - Continuum Model

- Calculations
- Uniform Delay in HCM
  - What is the relationship to the Continuum Model?

**Determining Delay**

The values obtained from the delay calculations represent the average control delay experienced by all vehicles that arrive in the analysis period, excluding delays incurred beyond the analysis period when the lane group is unoccupied. Control delay includes movements at obverse signal stops on intersection approaches as vehicles move up to stop position or drive development of an intersection.

The average control delay per vehicle for a given lane group is given by Equation (16-5). Appendix B provides a procedure to measure control delay in the field.

\[ d = d_T + d_p + d_{ij} \]  

where:
- \( d_T \) = control delay per vehicle (s/veh)
- \( d_p \) = uniform control delay assuming uniform arrival (s/veh)
- \( d_{ij} \) = uniform delay progression adjustment factor, which accounts for effects of signal progression.
- \( d_{ij} \) = incremental delay to account for effect of uniform arrival and recommendation changes, adjusted for duration of analysis period and type of signal control; this delay component assumes that there is no initial queue for any group at start of analysis period (s/veh).
- \( d_{ij} \) = initial queue delay, which accounts for delay to all vehicles in analysis period due to initial queue at start of analysis period (s/veh) obtained in Appendix F of this chapter.

Where:
- \( x \) = uniform control delay, assuming uniform arrivals (s/veh)
- \( C \) = cycle length (s), cycle length used for protected signal control, or average cycle lengths for actuated control (see Appendix B for signal timing estimation of actuated control)
- \( g \) = effective green time for lane group, prior to time used for actuated signal control, or average lane group effective green time for actuated control (see Appendix B for signal timing estimation of actuated control parameters)
- \( X \) = vehicle or degree of saturation for lane group

**Signalized Intersection LOS**

**LOS**

The average control delay per vehicle is estimated for each lane group and aggregated for each approach and for the intersection as a whole. LOS is directly related to the control delay value.

<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 )</td>
</tr>
<tr>
<td>C</td>
<td>( &gt; 20 )</td>
</tr>
<tr>
<td>D</td>
<td>( &gt; 35 )</td>
</tr>
<tr>
<td>E</td>
<td>( &gt; 55 )</td>
</tr>
<tr>
<td>F</td>
<td>( &gt; 60 )</td>
</tr>
</tbody>
</table>
### Signalized LOS Characteristics

<table>
<thead>
<tr>
<th>Delay (sec/v)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 or less</td>
<td>10-20</td>
<td>20-35</td>
<td>35-55</td>
<td>55-80</td>
<td>Greater than 80</td>
<td></td>
</tr>
<tr>
<td>Progression (Typical)</td>
<td>High</td>
<td>Favorable</td>
<td>Fair</td>
<td>Unfavorable</td>
<td>Poor</td>
<td>Nonexistent</td>
</tr>
<tr>
<td>Cycle Length (Typical)</td>
<td>Short</td>
<td>Medium</td>
<td>Long</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Stops</td>
<td>Low</td>
<td>Significant</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle Failures</td>
<td>None</td>
<td>Rare</td>
<td>Occasional</td>
<td>Noticeable</td>
<td>Common</td>
<td>Normal</td>
</tr>
<tr>
<td>Queues</td>
<td>Minimal</td>
<td>Isolated</td>
<td>Occasional</td>
<td>Significant</td>
<td>Common</td>
<td>Long</td>
</tr>
</tbody>
</table>

### MOE

- Delay / LOS
- Volume to Capacity Ratios
- 50% Back of Queue
- 95% Back of Queue
Use of the HCS
Example Problems

- HCS
- SYNCHRO

Traffic Analysis

- Current Method: Synchro
- Synchro is a Software Application for Optimizing Traffic Signal Timing and Performing Capacity Analysis.
- Synchro Optimizes Splits, Offsets, and Cycle Lengths for Individual Intersections, an Arterial, or a Complete Network
- Synchro Provides Detailed Time Space Diagrams That Can Show Vehicle Paths or Bandwidths.
- The Software Supports the Universal Traffic Data Format (UTDF) for Exchanging Data with Various Counting Software Packages, and Signal Optimization Suites, and Signal Controller Systems
Synchro Example: Highway Interchange & Major Route

Timing Report

Time-Space Diagram
Increasing Capacity

- Increase Saturation Flow Rate
  - Reduce intersection “friction”
  - Look at HCM saturation flow rate factors
  - Add exclusive turning phases
- Increase Efficiency of Intersection
  - Decrease Lost Time (Number of Phases)
  - One Way Streets
  - SPUI
  - Eliminate Movements (Jug handle)
- Add Lanes

Homework 1

- Show (mathematically) how the Continuum Model is related to the HCM traffic signal procedures (Equation 16-11).
1. Develop an AM peak period traffic signal timing plan for the intersection of Missouri Route 141 and Meramec Station Road in St. Louis County.
   • Use traffic counts that will be emailed to you.
   • Make all measurements (e.g., lane width, shoulder width) from a program such as Google Earth. Do NOT complete any field measurements.
   • Assume approach speeds of 45 MPH on Missouri Route 141 and 30 MPH on Meramec Station Road.
   • No RTOR, Peds, Busses, RVs, grades, or bikes
   • 7% Trucks
   • State all other assumptions

Email Shawn your HCS files when you are satisfied with your timing plan.

USE OPERATIONS LEVEL – NOT PLANNING