Capacity and LOS

CIVL 3161
Capacity

- The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. (HCM 2000)
Level of Service

• A quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience (HCM 2000).

• Rating scale A-F indicate best to worst operation
Factors Influencing LOS

- Volume
- Lane width
- Lateral obstructions
- Traffic composition
- Grade
- Speed
# Measures of Effectiveness for LOS

<table>
<thead>
<tr>
<th>Type of Flow</th>
<th>Type of Facility</th>
<th>Measure of Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninterrupted</td>
<td>Freeways (Basic, Weaving, Ramp)</td>
<td>Density (pc/mi/ln)</td>
</tr>
<tr>
<td></td>
<td>Multilane Highway</td>
<td>Density (pc/mi/ln)</td>
</tr>
<tr>
<td></td>
<td>Two-Lane Highway</td>
<td>Avg. Travel Speed (mph); % time spent following</td>
</tr>
<tr>
<td>Interrupted Flow</td>
<td>Signalized Intersections</td>
<td>Control Delay (s/veh)</td>
</tr>
<tr>
<td></td>
<td>Unsignalized Intersections</td>
<td>Control Delay (s/veh)</td>
</tr>
<tr>
<td></td>
<td>Urban Streets</td>
<td>Average Travel Speed (mph)</td>
</tr>
</tbody>
</table>
Basic Freeway Segment Characteristics

Ideal conditions for maximum service flow rate:
- Minimum interchange spacing 2 miles
- Only passenger cars
- Lane widths ≥ 12 feet
- Lateral obstructions ≥ 6 ft from roadway edge
- Level terrain (grades < 2%)
- Drivers typical of weekday (regular) traffic
- 10 or more lanes in urban areas **removed in HCM2010
Operational Analysis

FFS = BFFS – \( f_{LW} \) – \( f_{LC} \) – \( f_N \) – \( f_{ID} \) *HCM2000

FFS = 75.4 – \( f_{LW} \) – \( f_{LC} \) – 3.22TRD^{0.84} *HCM2010

Where:
FFS = estimated free flow speed in mph.
BFFS = estimated base free flow speed in mph (75 mph for rural freeways, 70 mph for urban based on HCM recommendations).
\( f_{LW} \) = adjustment for lane width (if less than 12 ft), mph.
\( f_{LC} \) = adjustment for right side lateral clearance (if less than 6 ft), mph.
\( f_N \) = adjustment for # of lanes (if less than 5 in one direction), mph.
\( f_{ID} \) = adjustment for interchange density if < 2 mi, mph.
TRD = total ramp density (ramps/mi)
Operational Analysis

Flow Rate:

\[ v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \]

Where:

- \( v_p \): 15-minute passenger-car equivalent flow rate (pc/h/ln)
- \( V \): hourly volume in the given direction of flow (vph)
- \( PHF \): peak-hour factor
- \( N \): number of lanes in the given direction of flow
- \( f_{HV} \): an adjustment factor for the presence of “heavy” vehicles
- \( f_p \): an adjustment factor to account for the fact that all drivers of the facility may not be commuters or regular users.

*Basis for analysis is peak 15 min flow rate.*
Heavy Vehicle Effects:

\[ f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + P_T(E_T - 1)} \]

\( P_T, P_R = \) proportion of trucks and buses, and RV’s
\( E_T, E_R = \) PCEs for trucks and buses, and RV’s

Analysis is based on general extended freeway segment
- Level – heavy vehicles maintain same speed as pc’s (grade <2%).
- Rolling – HVs travel at speeds lower than pc.
- Mountainous – HVs operate at crawl speed for significant distances.

When conditions are very severe, we will instead base on grade and length of grade.
Restrictions for use: No grade < 3% for longer than \( \frac{1}{2} \) mile.
- No grade \( \geq 3\% \) for longer than \( \frac{1}{4} \) mile.
Operational Analysis

DETERMINING LOS

The first step in determining LOS of a basic freeway segment is to define and segment the freeway facility as appropriate. Second, on the basis of estimated or field-measured FFS, an appropriate speed-flow curve of the same shape as the typical curves (Exhibit 23-3) is constructed. On the basis of the flow rate, $v_p$, and the constructed speed-flow curve, an average passenger-car speed is read on the y-axis of Exhibit 23-3. The next step is to calculate density using Equation 23-4.

$$D = \frac{v_p}{S}$$

where

- $D =$ density (pc/mi/ln),
- $v_p =$ flow rate (pc/h/ln), and
- $S =$ average passenger-car speed (mi/h).

LOS of the basic freeway segment is then determined by comparing the calculated density with the density ranges in Exhibit 23-2.
Exhibit 23-1. Basic Freeway Segment Methodology

- Geometric data
- Field-measured FFS or base free-flow speed (BFFS)
- Volume

If BFFS is input:

- BFFS adjustment:
  - Lane width
  - Number of lanes
  - Interchange density
  - Lateral clearance

- Compute FFS

If field-measured FFS is input:

- Volume adjustment:
  - Peak-hour factor
  - Number of lanes
  - Driver population
  - Heavy vehicles

- Compute flowrate

Define speed-flow curve

Determine speed using speed-flow curve

Compute density using flowrate and speed

Determine LOS
Step 1: Input Data
- Geometric data
- Demand volume
- Measured FFS (if available)

Step 2: Compute FFS
- Lane width adjustment
- Lateral clearance adjustment
- Use Equation 11-1

Step 3: Select FFS Curve

Step 4: Adjust Demand Volume
- Peak hour factor
- Number of lanes (one direction)
- Heavy vehicle adjustment
- Driver population adjustment
- Use Equation 11-2

- Compare adjusted demand flow rate to base capacity

- Demand flow rate > capacity
  - LOS = F
  - Go to Chapter 10, Freeway Facilities

- Demand flow rate ≤ capacity

Step 5: Estimate Speed and Density
- Exhibit 11-3 or Exhibit 11-2
- Equation 11-4

Step 6: Determine LOS (A-E)
- Exhibit 11-5
Figure 14.2  Base Speed-Flow Curves for Freeways (Source: Basic Freeway Segments, Draft Chapter 11, NCHRP Project 3-92, Production of the 2010 Highway Capacity Manual, Kittelson and Associates, Portland OR, 2009, Exhibit 11-6, p. 11-8.)
Figure 14.4  Graphic Solution for Speed on a Basic Freeway Segment
### Exhibit 23-2: LOS Criteria for Basic Freeway Segments

<table>
<thead>
<tr>
<th>Criteria</th>
<th>LOS</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td><strong>FFS = 75 mi/h</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Maximum density (pc/mi/ln)</td>
<td>11</td>
<td>18</td>
<td>26</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Minimum speed (mi/h)</td>
<td>75.0</td>
<td>74.8</td>
<td>70.6</td>
<td>62.2</td>
<td>53.3</td>
</tr>
<tr>
<td>Maximum v/c</td>
<td>0.34</td>
<td>0.56</td>
<td>0.76</td>
<td>0.90</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>820</td>
<td>1350</td>
<td>1630</td>
<td>2170</td>
<td>2400</td>
</tr>
<tr>
<td><strong>FFS = 70 mi/h</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum density (pc/mi/ln)</td>
<td>11</td>
<td>18</td>
<td>26</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Minimum speed (mi/h)</td>
<td>70.0</td>
<td>70.0</td>
<td>68.2</td>
<td>61.5</td>
<td>53.3</td>
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<tr>
<td>Maximum v/c</td>
<td>0.32</td>
<td>0.53</td>
<td>0.74</td>
<td>0.90</td>
<td>1.00</td>
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<tr>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>770</td>
<td>1250</td>
<td>1770</td>
<td>2150</td>
<td>2400</td>
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<tr>
<td><strong>FFS = 65 mi/h</strong></td>
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<tr>
<td>Maximum density (pc/mi/ln)</td>
<td>11</td>
<td>18</td>
<td>26</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Minimum speed (mi/h)</td>
<td>65.0</td>
<td>65.0</td>
<td>64.6</td>
<td>59.7</td>
<td>52.2</td>
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<tr>
<td>Maximum v/c</td>
<td>0.30</td>
<td>0.50</td>
<td>0.71</td>
<td>0.89</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>710</td>
<td>1170</td>
<td>1680</td>
<td>2090</td>
<td>2350</td>
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<tr>
<td><strong>FFS = 60 mi/h</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Maximum density (pc/mi/ln)</td>
<td>11</td>
<td>18</td>
<td>26</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Minimum speed (mi/h)</td>
<td>60.0</td>
<td>60.0</td>
<td>60.0</td>
<td>57.6</td>
<td>51.1</td>
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<tr>
<td>Maximum v/c</td>
<td>0.29</td>
<td>0.47</td>
<td>0.68</td>
<td>0.88</td>
<td>1.00</td>
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<tr>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>660</td>
<td>1060</td>
<td>1560</td>
<td>2020</td>
<td>2300</td>
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<tr>
<td><strong>FFS = 55 mi/h</strong></td>
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</tr>
<tr>
<td>Maximum density (pc/mi/ln)</td>
<td>11</td>
<td>18</td>
<td>26</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Minimum speed (mi/h)</td>
<td>55.0</td>
<td>55.0</td>
<td>55.0</td>
<td>54.7</td>
<td>50.0</td>
</tr>
<tr>
<td>Maximum v/c</td>
<td>0.27</td>
<td>0.44</td>
<td>0.64</td>
<td>0.85</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>600</td>
<td>990</td>
<td>1430</td>
<td>1910</td>
<td>2250</td>
</tr>
</tbody>
</table>

**Note:**
The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. The speed criterion is the speed at maximum density for a given LOS.
Determining Capacity

Capacity = $MSF_E \times PHF \times N \times f_{HV} \times f_p$

* this is total capacity - maximum service flow rates can also be determined to remain in a specific level of service using $MSF_i$. 
Design Analysis

\[ N_i = \frac{DDHV}{MSF_i \times PHF \times f_{HV} \times f_p} \]

Where:
Ni  = number of lanes required (in one direction) to provide LOS “i”
DDHV = directional design hour volume, veh/h
Example

Given:
Four-lane freeway (2 in each direction)
Lane width = 11 ft
Right-side lateral clearance = 2 ft
Commuter traffic (regular users)
Peak-hour, peak-direction demand volume = 2,000 veh/h
5% trucks, 0% RVs
PHF = 0.92
TRD = 4 ramps/mile
Rolling terrain
Find: LOS
Example

Given-
Older 4-lane freeway
11 ft lanes
Directional peak hour volume = 2100 vph
PHF = 0.95
6% trucks
TRD = 2.0/mi
Level terrain
Obstructions 2 ft from edge of traveled way at both roadside and median.

Find-
  a. Average speed for prevailing conditions.
  b. LOS
  c. The amount of additional traffic that the facility can accommodate in the peak hour before reaching capacity.