Multilane Highways

(a) Divided multilane highway in a rural environment.
(b) Divided multilane highway in a suburban environment.
(c) Undivided multilane highway in a rural environment.
(d) Undivided multilane highway in a suburban environment.
Multilane Highways

- Chapter 21 of the Highway Capacity Manual
- For rural and suburban multilane highways
- Assumptions (Ideal Conditions, all other conditions reduce capacity):
  - Only passenger cars
  - No direct access points
  - A divided highway
  - FFS > 60 mph
  - Represents highest level of multilane rural and suburban highways
Multilane Highways

- Intended for analysis of uninterrupted-flow highway segments
  - Signal spacing > 2.0 miles
  - No on-street parking
  - No significant bus stops
  - No significant pedestrian activities
EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY

Input
- Geometric data
- Free-flow speed (FFS) field measured, or base free-flow speed (BFFS)
- Volume

If BFFS is input
BFFS adjustment
- Lane width
- Median type
- Access point
- Lateral clearance

If field-measured FFS is input
Compute FFS

If field-measured FFS is input
Volume adjustment
- Peak-hour factor
- Number of lanes
- Driver population
- Heavy vehicles

Compute flow rate

Define speed-flow curve

Determine speed using speed-flow curve

Compute density using flow rate and speed

Determine LOS

Source: HCM, 2000
Step 1: Gather data

Step 2: Calculate capacity (Supply)
## EXHIBIT 21-2. LOS CRITERIA FOR MULTILANE HIGHWAYS

<table>
<thead>
<tr>
<th>Free-Flow Speed</th>
<th>Criteria</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>60 mi/h</td>
<td>11 18 26</td>
<td>35 40</td>
</tr>
<tr>
<td>55 mi/h</td>
<td>11 18 26</td>
<td>35 41</td>
</tr>
<tr>
<td>50 mi/h</td>
<td>11 18 26</td>
<td>35 43</td>
</tr>
<tr>
<td>45 mi/h</td>
<td>11 18 26</td>
<td>35 45</td>
</tr>
</tbody>
</table>

Note:
The exact mathematical relationship between density and volume to capacity ratio (v/c) has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.
EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA

Free-Flow Speed = 60 mi/h
55 mi/h
50 mi/h
45 mi/h

LOS A B C D E

Density: 11 pc/mi/h
18 pc/mi/h
26 pc/mi/h
35 pc/mi/h
45 pc/mi/h

Average Passenger-Car Speed (mi/h)

Flow Rate (pc/h/ln)

0 400 800 1200 1600 2000 2400
EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA

Note:
Maximum densities for LOS E occur at a v/c ratio of 1.0. They are 25, 26, 27, and 28 pc/km/ln at FFS of 100, 90, 80, and 70 km/h, respectively. Capacity varies by FFS. Capacity is 2,200, 2,100, 2,000, and 1,900 pc/h/ln at FFS of 100, 90, 80, and 70 km/h, respectively.
For flow rate (v_p), v_p > 1400 and
90 < FFS ≤ 100 then

Source: HCM, 2000
Multilane highway

Free Flow Speed FFS

ESTIMATING FFS

The FFS can be estimated indirectly when field data are not available.

\[ FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \]

where

\[ BFFS \] = base FFS (mi/h);
\[ FFS \] = estimated FFS (mi/h);
\[ f_{LW} \] = adjustment for lane width, from Exhibit 21-4 (mi/h);
\[ f_{LC} \] = adjustment for lateral clearance, from Exhibit 21-5 (mi/h);
\[ f_M \] = adjustment for median type, from Exhibit 21-6 (mi/h); and
\[ f_A \] = adjustment for access points, from Exhibit 21-7 (mi/h).

Source: HCM, 2000
**Lane Width**

- **Base Conditions:** 12 ft lanes

<table>
<thead>
<tr>
<th>Lane Width (ft)</th>
<th>Reduction in FFS (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Source: HCM, 2000
Lane Width (Example)

EXHIBIT 21-4. ADJUSTMENT FOR LANE WIDTH

<table>
<thead>
<tr>
<th>Lane Width (ft)</th>
<th>Reduction in FFS (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>6.6</td>
</tr>
</tbody>
</table>

How much does use of 10-foot lanes decrease free flow speed?

$F_{lw} = 6.6 \text{ mph}$

Source: HCM, 2000
Lateral Clearance

- Distance to fixed objects
- Assumes
  - $\geq$ 6 feet from right edge of travel lanes to obstruction
  - $\geq$ 6 feet from left edge of travel lane to object in median

Source: HCM, 2000
Lateral Clearance

\[ \text{TLC} = \text{LC}_R + \text{LC}_L \]

\text{TLC} = \text{total lateral clearance in feet}
\text{LC}_R = \text{lateral clearance from right edge of travel lane}
\text{LC}_L = \text{lateral clearance from left edge of travel lane}

Source: HCM, 2000
### Exhibit 21-5. Adjustment for Lateral Clearance

<table>
<thead>
<tr>
<th>Four-Lane Highways</th>
<th>Six-Lane Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Lateral Clearance(^a) (ft)</strong></td>
<td><strong>Reduction in FFS (mi/h)</strong></td>
</tr>
<tr>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>8</td>
<td>0.9</td>
</tr>
<tr>
<td>6</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>3.6</td>
</tr>
<tr>
<td>0</td>
<td>5.4</td>
</tr>
</tbody>
</table>

**Note:**

a. Total lateral clearance is the sum of the lateral clearances of the median (if greater than 6 ft, use 6 ft) and shoulder (if greater than 6 ft, use 6 ft). Therefore, for purposes of analysis, total lateral clearance cannot exceed 12 ft.

Source: HCM, 2000
**Example:** Calculate lateral clearance adjustment for a 4-lane divided highway with milepost markers located 4 feet to the right of the travel lane.

\[
\text{TLC} = \text{LC}_R + \text{LC}_L = 6 + 4 = 10
\]

\[
F_{le} = 0.4 \text{ mph}
\]

Source: HCM, 2000
**EXHIBIT 21-6. ADJUSTMENT FOR MEDIAN TYPE**

<table>
<thead>
<tr>
<th>Median Type</th>
<th>Reduction in FFS (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undivided highways</td>
<td>1.6</td>
</tr>
<tr>
<td>Divided highways (including TWLTLs)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

\( f_m \): Accounts for friction between opposing directions of traffic in adjacent lanes for undivided

No adjustment for divided, \( f_m = 1 \)

Source: HCM, 2000
$F_a$ accounts for interruption due to access points along the facility.

Example: if there are 20 access points per mile, what is the reduction in free flow speed?

$F_a = 5.0$ mph
Estimate Free flow Speed

ESTIMATING FFS

The FFS can be estimated indirectly when field data are not available.

\[ FFS = BFFS - f_{LW} - f_{LC} - f_{M} - f_{A} \]

where

- \( BFFS \) = base FFS (mi/h);
- \( FFS \) = estimated FFS (mi/h);
- \( f_{LW} \) = adjustment for lane width, from Exhibit 21-4 (mi/h);
- \( f_{LC} \) = adjustment for lateral clearance, from Exhibit 21-5 (mi/h);
- \( f_{M} \) = adjustment for median type, from Exhibit 21-6 (mi/h); and
- \( f_{A} \) = adjustment for access points, from Exhibit 21-7 (mi/h).

BFFS = free flow under ideal conditions
FFS = free flow adjusted for actual conditions
From previous examples:

\[ FFS = 60 \text{ mph} - 6.6 \text{ mph} - 0.4 \text{ mph} - 0 - 5.0 \text{ mph} = 48 \text{ mph} \] (reduction of 12 mph)
Step 3: Estimate demand

Source: HCM, 2000
Multilane highway

Flow rate

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

where

- \( v_p \) = 15-min passenger-car equivalent flow rate (pc/h/ln),
- \( V \) = hourly volume (veh/h),
- \( PHF \) = peak-hour factor,
- \( N \) = number of lanes,
- \( f_{HV} \) = heavy-vehicle adjustment factor, and
- \( f_p \) = driver population factor.
Heavy Vehicle Adjustment

- Heavy vehicles affect traffic
- Slower, larger
- $f_{hv}$ increases number of passenger vehicles to account for presence of heavy trucks

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

where

- $E_T, E_R$ = passenger-car equivalents for trucks and buses and for recreational vehicles (RVs), respectively;
- $P_T, P_R$ = proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction); and
- $f_{HV}$ = adjustment factor for heavy vehicles.
General Grade Definitions:

- **Level**: combination of alignment (horizontal and vertical) that allows heavy vehicles to maintain same speed as pass. cars (includes short grades 2% or less)
- **Rolling**: combination that causes heavy vehicles to reduce speed substantially below P.C. (but not crawl speed for any length)
- **Mountainous**: Heavy vehicles at crawl speed for significant length or frequent intervals
- **Use specific grade approach if grade less than 3% is more than 1 mile or grade more than 3% is more than 0.5 mile**
Example: for 10% heavy trucks on rolling terrain, what is $F_{hv}$?

For rolling terrain, $E_T = 2.5$

$$F_{hv} = \frac{1}{1 + 0.1 (2.5 - 1)} = 0.87$$

$$f_{HV} = 1 + P_T (E_T - 1) + P_R (E_R - 1)$$
<table>
<thead>
<tr>
<th>Upgrade (%)</th>
<th>Length (km)</th>
<th>( E_T )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Percentage of Trucks and Buses</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>&lt;2</td>
<td>All</td>
<td>1.5</td>
</tr>
<tr>
<td>≥2–3</td>
<td>0.0–0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8–1.2</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.2–1.6</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6–2.4</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 2.4</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>0.0–0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8–1.2</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.2–1.6</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6–2.4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 2.4</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>0.0–0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8–1.2</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.2–1.6</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>0.0–0.4</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.5</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.5–0.8</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8–1.2</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.2–1.6</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6</td>
<td>6.0</td>
</tr>
<tr>
<td>≥5–6</td>
<td>0.0–0.4</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.5</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.5–0.8</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8–1.2</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.2–1.6</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6</td>
<td>7.0</td>
</tr>
</tbody>
</table>
## Exhibit 21-10. Passenger-Car Equivalents for RVs on Uniform Upgrades

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Length (km)</th>
<th>( E_R )</th>
<th>% of RVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>( \leq 2 )</td>
<td>All</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>&gt; 2–3</td>
<td>0.0–0.8</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 3–4</td>
<td>0.0–0.4</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>&gt; 4–5</td>
<td>0.0–0.4</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>4.5</td>
<td>3.5</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>0.0–0.4</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.4–0.8</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>6.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>
### EXHIBIT 21-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS ON DOWNGRADES

<table>
<thead>
<tr>
<th>Downgrade (%)</th>
<th>Length (km)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4</td>
<td>All</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>4-5</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>4-5</td>
<td>&gt; 6.4</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 5-6</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 5-6</td>
<td>&gt; 6.4</td>
<td>5.5</td>
<td>4.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>&gt; 6.4</td>
<td>7.5</td>
<td>6.0</td>
<td>5.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Driver Population Factor \( (f_p) \)

- Non-familiar users affect capacity
- \( f_p = 1 \), familiar users
- \( 1 > f_p \geq 0.85 \), unfamiliar users
Step 4: Determine LOS

Demand Vs. Supply

Source: HCM, 2000
Calculate $v_p$

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

**Example:** base volume is 2,500 veh/hour
- PHF = 0.9, $N = 2$
- $f_{hv}$ from previous, $f_{hv} = 0.87$
- Non-familiar users, $f_p = 0.85$

$$v_p = \frac{2,500 \text{ vph}}{0.9 \times 2 \times 0.87 \times 0.85} = 1878 \text{ pc/ph/pl}$$
Calculate Density

\[ D = \frac{v_p}{S} \]  \hspace{1cm} (21-5)

where

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

Example: for previous

\[ D = \underline{1878 \text{ vph}} \underline{= 39.1 \text{ pc/mi/lane}} \]

48 mph
LOS = E

Also, D = 39.1 pc/mi/ln, LOS E
Design Decision

- What can we change in a design to provide an acceptable LOS?
- Lateral clearance (only 0.4 mph)
- Lane width
- Number of lanes
Lane Width (Example)

EXHIBIT 21-4.  ADJUSTMENT FOR LANE WIDTH

<table>
<thead>
<tr>
<th>Lane Width (ft)</th>
<th>Reduction in FFS (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>6.6</td>
</tr>
</tbody>
</table>

How much does use of 10 foot lanes decrease free flow speed?

\[ F_{lw} = 6.6 \text{ mph} \]

Source: HCM, 2000
Recalculate Density

\[ D = \frac{v_p}{S} \]  

(21-5)

where

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

Example: for previous (but with wider lanes)

\[ D = \frac{1878 \text{ vph}}{55 \text{ mph}} \Rightarrow 34.1 \text{ pc/mi/ln} \]
Now $D = 34.1 \text{ pc/mi/ln}$, on border of LOS E.
Recalculate $v_p$, while adding a lane

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

**Example:** base volume is 2,500 veh/hour

- PHF = 0.9, $N = 3$
- $f_{hv}$ from previous, $f_{hv} = 0.87$
- Non-familiar users, $f_p = 0.85$

$$v_p = \frac{2,500 \text{ vph}}{0.9 \times 3 \times 0.87 \times 0.85} = 1252 \text{ pc/ph/pl}$$
Calculate Density

\[ D = \frac{v_p}{S} \]  

(21-5)

where

\[ D = \text{density (pc/mi/ln),} \]
\[ v_p = \text{flow rate (pc/h/ln), and} \]
\[ S = \text{average passenger-car travel speed (mi/h).} \]

Example: for previous

\[ D = \frac{1252 \text{ vph}}{48 \text{ mph}} = 26.1 \text{ pc/mi/lane} \]
EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA

Now $D = 26.1 \text{ pc/mi/ln}, \text{ LOS D (almost C)}$
Example:

a divided multilane highway in rolling terrain and has an access density of 10 accesses/mile in the southerly direction and 4 accesses/mile in the northerly direction with the following features:

- Four 11 ft wide lanes
- Obstruction 4 ft away from the travelled lane on the right side and 8 ft wide median
- The basic free flow speed is 52 mph
- Peak hour volume is 2300 veh/hr/direction
- 10% trucks
- PHF is 0.9

What LOS can be expected in this segment
Solution:

**ESTIMATING FFS**

The FFS can be estimated indirectly when field data are not available.

\[ FFS = BFFS - f_{LW} - f_{LC} - f_{M} - f_{A} \]

where

- \( BFFS \) = base FFS (mi/h);
- \( FFS \) = estimated FFS (mi/h);
- \( f_{LW} \) = adjustment for lane width, from Exhibit 21-4 (mi/h);
- \( f_{LC} \) = adjustment for lateral clearance, from Exhibit 21-5 (mi/h);
- \( f_{M} \) = adjustment for median type, from Exhibit 21-6 (mi/h); and
- \( f_{A} \) = adjustment for access points, from Exhibit 21-7 (mi/h).

\[ F_{LW} = 1.9 \text{ mph} \quad F_{LC} = 0.4 \text{ mph (LC = 4+6=10)} \quad F_{M} = 0.0 \text{ mph (divided)} \]

\[ F_{A South} = 2.5 \text{ mph (10 access points/mile)} \quad F_{A North} = 1.0 \text{ mph (4 access points/mile)} \]

**FFS (south)** = 52 -1.9 – 0.4 – 0 – 2.5 = 47.2 mph

**FFS (north)** = 52 -1.9 – 0.4 – 0 – 1.0 = 48.7 mph
\[ V_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \]

where

\[ V_p = \text{15-min passenger-car equivalent flow rate (pc/h/ln)}, \]
\[ V = \text{hourly volume (veh/h)}, \]
\[ PHF = \text{peak-hour factor}, \]
\[ N = \text{number of lanes}, \]
\[ f_{HV} = \text{heavy-vehicle adjustment factor}, \text{ and} \]
\[ f_p = \text{driver population factor}. \]

\[ V = 2300 \text{ vph} \quad \text{Rolling terrain} \quad 10\% \text{ truck} \quad \text{PHF} = 0.9 \quad N = 2 \]

\[ f_{hv} = \frac{1}{1 + 0.1 (2.5 - 1)} = 0.870 \]

\[ V_p = 2300 / (0.9 \times 2 \times 0.87 \times 1) = 1469 \text{ pc/h/ln} \]
EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA

LOS = D