Basic Freeways and Multilane Highways (LOS)

CIVL 4162/6162

Learning Objectives

- Define uninterrupted facilities
- Determine LOS of
  - Basic freeway segments
  - Multilane highways

Uninterrupted Flow Facilities

- Pure uninterrupted facilities occurs on freeways
- It can also exist on some surface facilities
  - Long stretch of rural/suburban areas between points of fixed interruption
- Example:
  - Surface facility *more than 2 miles* from the nearest point of fixed interruption can be called as uninterrupted.

Primary Types of Uninterrupted Flow Facilities

- Freeways
  - Pure uninterrupted flow
- Multilane Highways
  - Sections of multilane highways (four or six lane) that are more than two miles from the nearest point of fixed operation
- Rural Two-lane Highways
  - Sections of two-lane highways (one lane in each direction) that are more than two miles from the nearest point of fixed operation

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)

Capacity Under Ideal Conditions

Type of Facility	Free-Flow Speed (mi/h)	Capacity
Freeways	≥70	2,400 pc/h/ln
	65	2,350 pc/h/ln
	60	2,300 pc/h/ln
	55	2,250 pc/h/ln
Multilane Highways	≥60	2,200 pc/h/ln
	55	2,100 pc/h/ln
	50	2,000 pc/h/ln
	50	1,900 pc/h/ln
Two-Lane Highways	All	3,200 pc/h (total, both dir)
		1,700 pc/h (max. one dir)

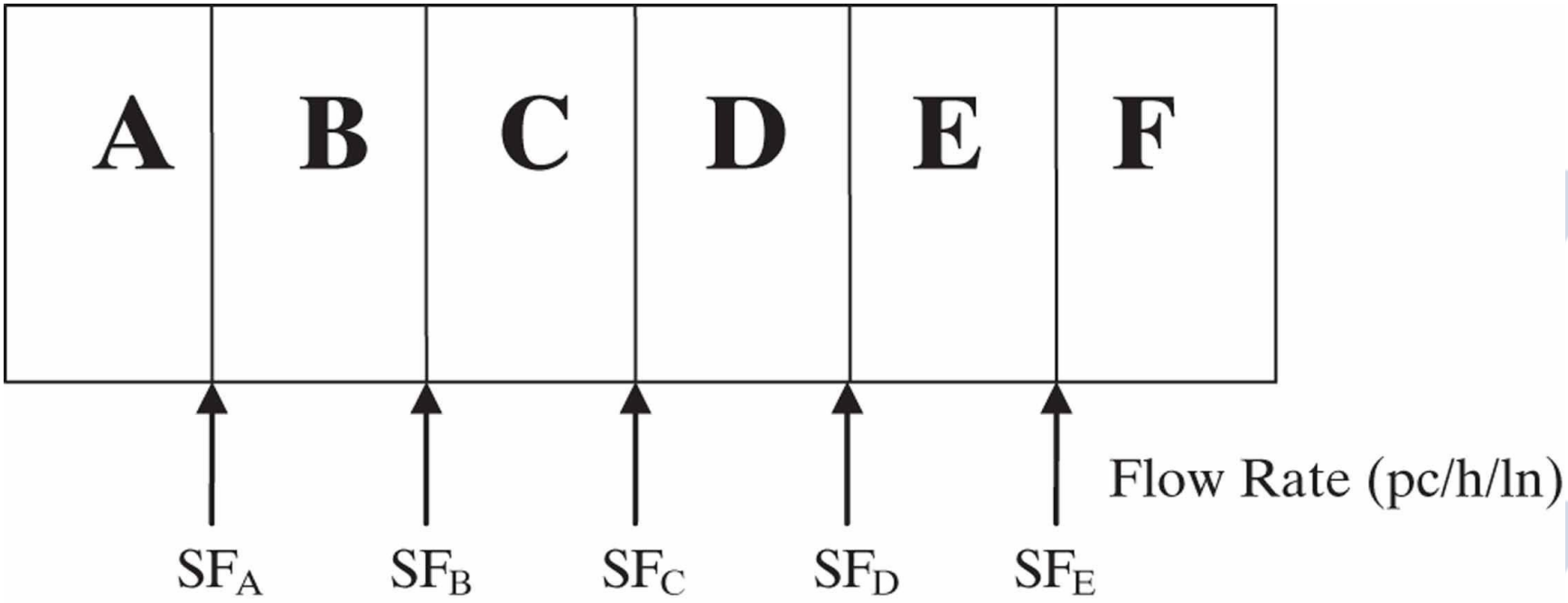
Types of Capacity (HCM 1950)

- Basic Capacity
  - Maximum number of passenger cars that can pass a given point on a lane or roadway during one hour under the most nearly ideal roadway and traffic conditions which can possibly be attained
- Possible Capacity
- Practical Capacity

Service Flow Rate

- A service flow rate is defined as the maximum flow rate of flow that can be reasonably expected on a lane or roadway under prevailing roadway, traffic, and control conditions while maintaining a particular level of service.

Service Flow Rate Illustration



Service Volume

- Service volume is described as conditions that existed over a full hour as opposed to the standard 15 minute period.

- SVi=SFi*PHF
  - SVi: Service volume for LOS *i* (veh/hr)
  - SFi: Servce flow rate for LOS *i* (veh/hr)
  - PHF: Peak hour factor

The Level of Service Concept

- 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 2010).
- Rating scale A-F indicate best to worst operation

Measures of Effectiveness for LOS

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

(a) A Typical 8-Lane Freeway

(b) A Divided Multilane Rural Highway

(c) A Divided Multilane Suburban Highway

(d) An Undivided Multilane Suburban Highway

(e) A Multilane Highway w/TWLTL

(f) An Undivided Multilane Rural Highway

Figure 14.1 Typical Freeway and Multilane Highway Alignments (*Sources:* Photo (a) courtesy of J. Ulerio; (b),(c),(d),(f) Used with permission of Transportation Research Board, National Research Council, "Highway Capacity Manual," *Special Report 209,* 1994, Illustrations 7-1 through 7-4, p. 7-3; (e) Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual,* December 2000,

Basic Freeway and Multilane Highway Characteristics

- Speed-Flow Characteristics
  - No heavy vehicles in traffic stream
  - A driver population dominated by regular or familiar users of the facility
- Level of Service Characteristics
  - LOS-A through F (see next slide)

LOS A

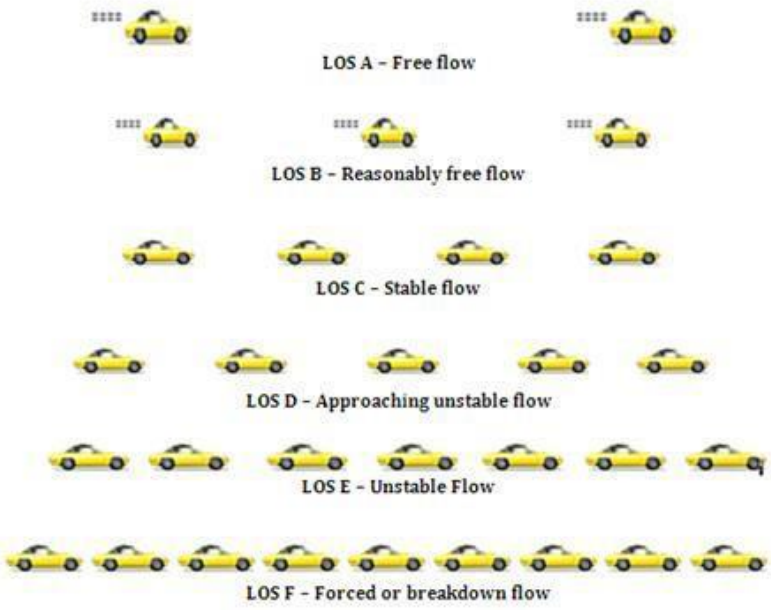
LOS B

LOS C

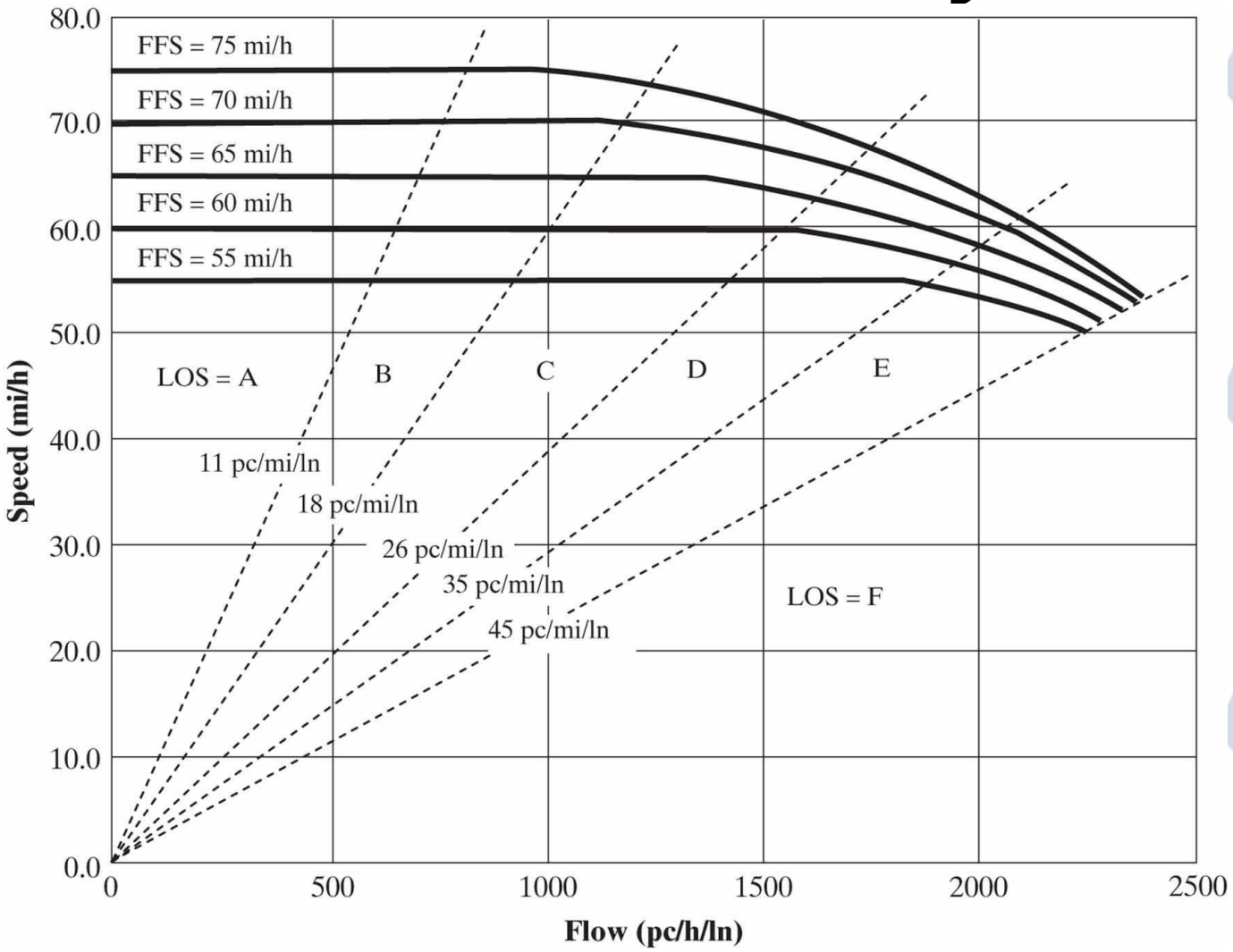
LOS D

LOS E

LOS F



LOS Estimation: Freeways



Equations for LOS Estimation-Freeways

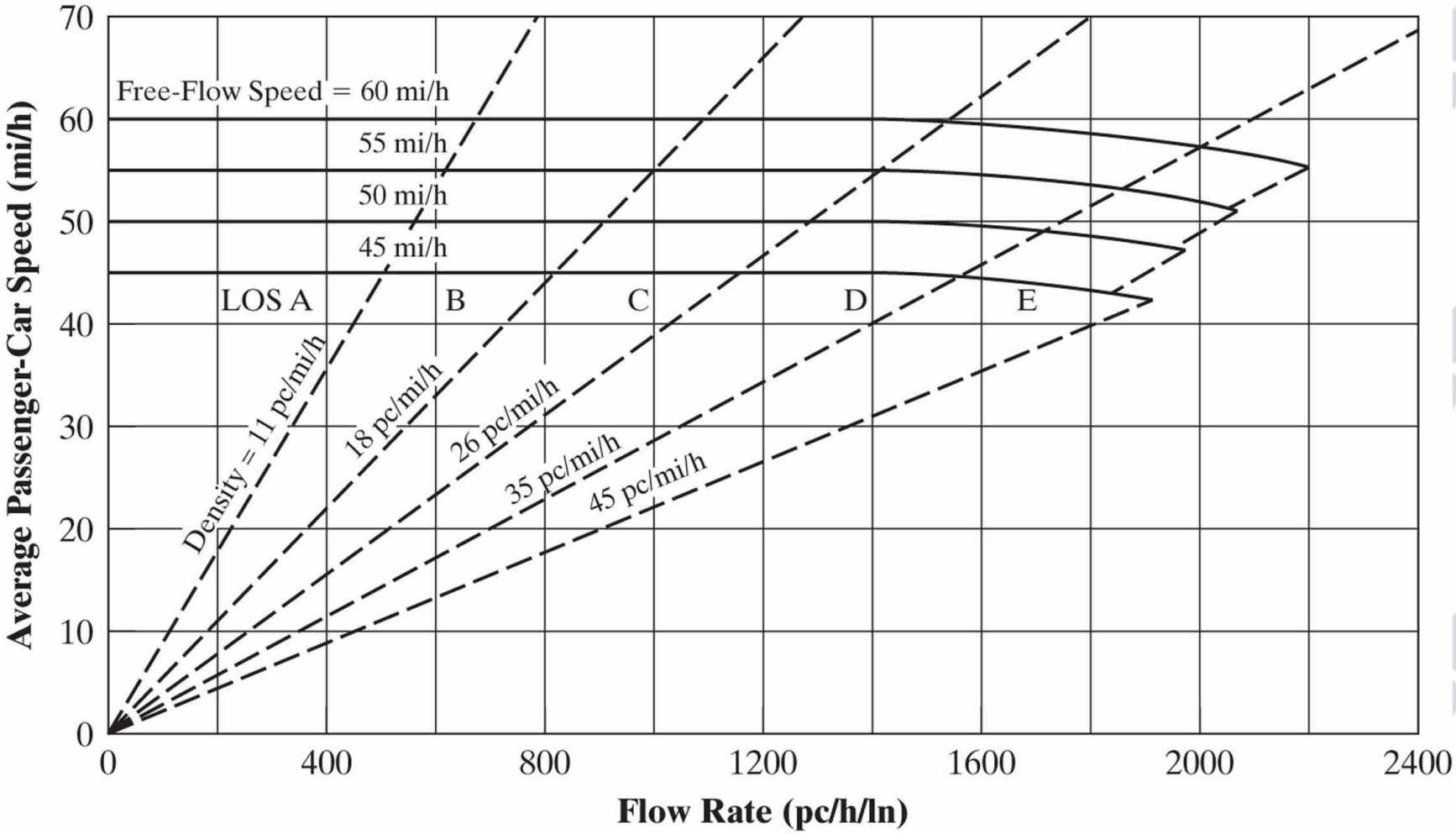
Table 14.1: Equations for Curves in Figure 14.1

FFS (mi/h)	Break-Point (pc/h/ln)	Flow Rate Range ≥ 0 ≤ Break-Point	> Break-Point ≤ Capacity
75	1,000	75	$75 - 0.00001107\ (v_p - 1{,}000)^2$
70	1,200	70	$70 - 0.00001160\ (v_p - 1{,}200)^2$
65	1,400	65	$65 - 0.00001418\ (v_p - 1{,}400)^2$
60	1,600	60	$60 - 0.00001816\ (v_p - 1{,}600)^2$
55	1,800	55	$55 - 0.00002469\ (v_p - 1{,}800)^2$

Notes:
1. FFS = free-flow speed.
2. Maximum flow rate for the equations is capacity: 2,400 pc/h/ln for 70- and 75-mph FFS; 2,350 pc/h/ln for 65-mph FFS; 2,300 pc/h/ln for 60-mph FFS; and 2,250 pc/h/ln for 55-mph FFS.

(*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 11-3, p. 11-4.)

LOS Estimation: Multilane Highways



Equations for LOS Estimation: Multilane Highways

Equations for Curves

FFS (mi/h)	For v ≤ 1,400 pc/h/ln S (mi/h)	For v > 1,400 pc/h/ln S (mi/h)
60	S = 60	$S = 60 - \left[5.00\left(\frac{v_p - 1{,}400}{800}\right)^{1.31}\right]$
55	S = 55	$S = 55 - \left[3.78\left(\frac{v_p - 1{,}400}{700}\right)^{1.31}\right]$
50	S = 50	$S = 50 - \left[3.49\left(\frac{v_p - 1{,}400}{600}\right)^{1.31}\right]$
45	S = 45	$S = 45 - \left[2.78\left(\frac{v_p - 1{,}400}{500}\right)^{1.31}\right]$

LOS Criteria

Table 14.2: Level of Service Criteria for Basic Freeway Segments and Multilane Highways

Level of Service	Density Range for Basic Freeway Sections (pc/mi/ln)	Density Range for Multilane Highways (pc/mi/ln)
A	$\geq 0 \leq 11$	$\geq 0 \leq 11$
B	$> 11 \leq 18$	$> 11 \leq 18$
C	$> 18 \leq 26$	$> 18 \leq 26$
D	$> 26 \leq 35$	$> 26 \leq 35$
E	$> 35 \leq 45$	$> 35 \leq$ (40–45) depending on FFS
F	Demand Exceeds Capacity > 45	Demand Exceeds Capacity $>$ (40–45) depending on FFS

Maximum Service Flow Rate: Basic Freeway Sections

Table 14.3: Maximum Service Flow Rates for Basic Freeway Sections

FFS (mi/h)	Level of Service				
	A	B	C	D	E
75	820	1,310	1,750	2,110	2,400
70	770	1,250	1,690	2,080	2,400
65	710	1,170	1,630	2,030	2,350
60	660	1,080	1,560	2,010	2,300
55	600	990	1,430	1,900	2,250

Note: All values rounded to the nearest 10 pc/h/ln.

(*Source: Draft Chapter 11: Basic Freeway Segments,* National Cooperative Highway Research Program Project 3–92, Transportation Research Board, Washington DC, Exhibit 11-18, p. 11-24.)

Maximum Service Flow Rate: Multilane Highways

Table 14.4: Maximum Service Flow Rates for Multilane Highways

FFS (mi/h)	Level of Service				
	A	B	C	D	E
60	660	1,080	1,550	1,980	2,200
55	600	990	1,430	1,850	2,100
50	550	900	1,300	1,710	2,000
45	490	810	1,170	1,550	1,900

Note: All values rounded to the nearest 10 pc/h/ln.

(*Source:* Used with permission of Transportation Research Board, National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 21-2, p. 21-3, Modified.)

Factors Influencing LOS

- Volume
- Lane width
- Lateral obstructions
- Traffic composition
- Grade
- Speed

Types of Analysis

- Operational Analysis
- Service Flow Rate and Service Volume Analysis
- Design Analysis

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

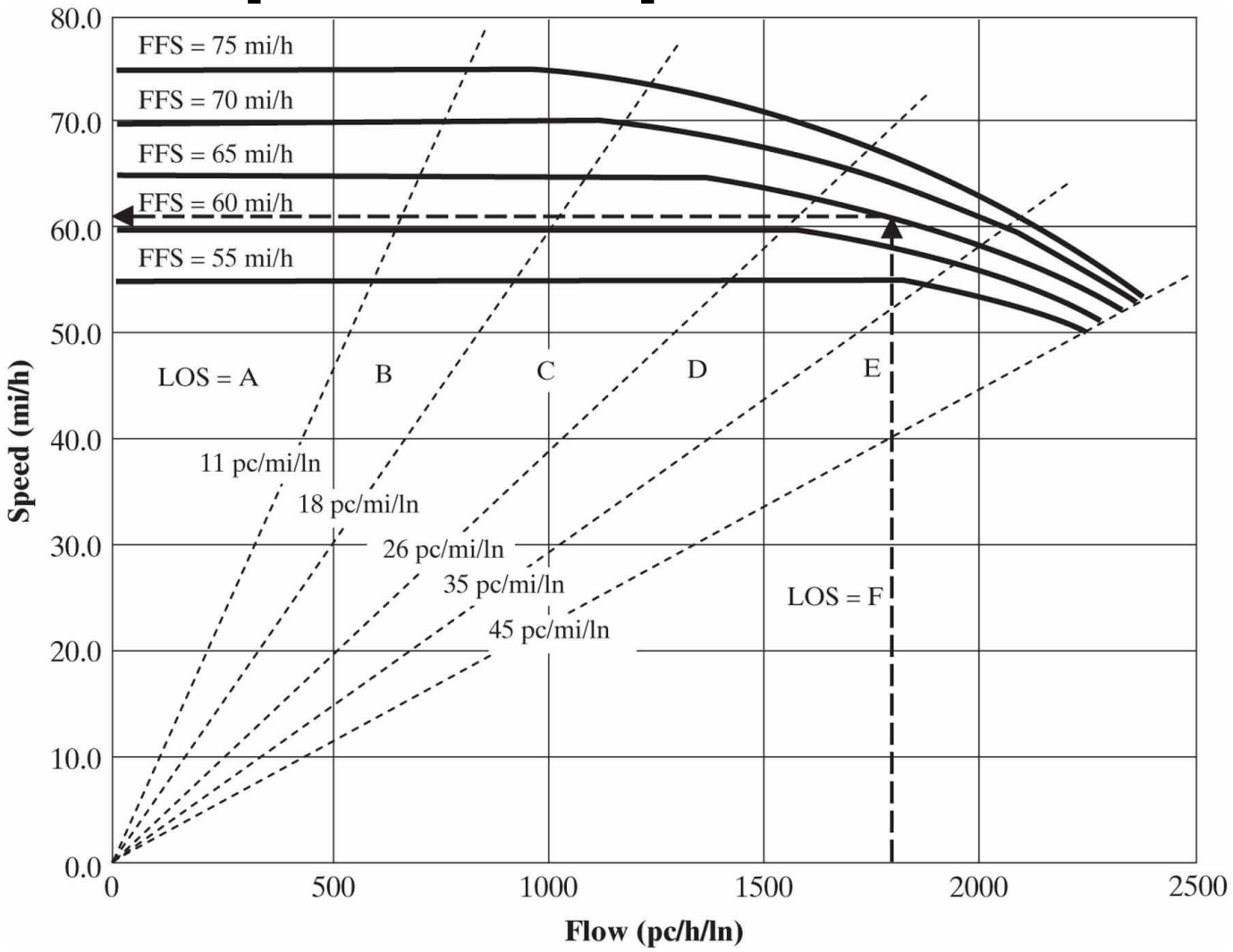
N = number of lanes in the given direction of flow

f_{HV} = an adjustment factor for th 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.

Example: Graphical Solution



Speed: 62 mph
Density: 29 pc/mi/lane
LOS: D

$S = 0.00001418\,(1800-1400)^2$
$= 62.7$ mi/h

Service Flow Rate and Service Volume Analysis

$SV_i = MSF_i \times PHF \times N \times f_{HV} \times f_p$

Where:

SV_i = service volume over a full peak hour for LOS "i", veh/h

MSF_i = maximum service flow rate for level of service "i", pc/h/ln

*Remove PHF to get SF

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

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

Free Flow Speed: Basic Freeway Segments

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$ *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)

Adjustment for Lane Width: Freeway

Table 14.5: Adjustment to Free-Flow Speed for Lane Width on a Freeway

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
≥12	0.0
11	1.9
10	6.6

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-4, p. 23-6.)

Adjustment for Lateral Clearance : Freeway

Table 14.6: Adjustment to Free-Flow Speed for Lateral Clearance on a Freeway

Right Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mi/h)			
	Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	2.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-5, p. 23-6.)

Total Ramp Density

- Total number of on-ramps and off-ramps within ± 3 miles of the mid-point of the study segment divided by 6 miles
- Ramp density is a surrogate measure that relates to the intensity of land use activity in the vicinity of study segment

Multilane Highway Characteristics

Ideal conditions for maximum service flow rate:

- Lane widths ≥ 12 feet
- Total lateral clearance ≥ 12 feet
- Divided highway
- No access points
- Only passenger cars in traffic stream
- Regular roadway users

Free Flow Speed: Multilane Highways

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$$

Where:
FFS = estimated free flow speed in mph.
BFFS = estimated base free flow speed in mph (60 mph for rural or suburban based on HCM recommendations).
f_{LW} = adjustment for lane width (if less than 12 ft), mph.
f_{LC} = adjustment for total lateral clearance (if less than 12 ft), mph.
f_M = adjustment for median type, mph.
f_A = adjustment for access-point density, mph.

Adjustment for Median Type: Multilane Highways

Table 14.8: Adjustment to Free-Flow Speed for Median Type on Multilane Highways

Median Type	Reduction in Free-Flow Speed, f_M (mi/h)
Undivided	1.6
TWLTLs	0.0
Divided	0.0

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 21-6, p. 21-6.)

Adjustment for Lateral Clearance : Multilane Highways

Table 14.7: Adjustment to Free-Flow Speed for Total Lateral Clearance on a Multilane Highway

4-Lane Multilane Highways		6-Lane Multilane Highways	
Total Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mi/h)	Total Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mi/h)
≥12	0.0	≥12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 21-5, p. 21-6.)

Adjustment for Lane Width: Multilane Highways

Base condition (f_{LW} = 0)

- Average width of 12 ft or wider across all lanes (same as freeway)

Table 14.5: Adjustment to Free-Flow Speed for Lane Width on a Freeway

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
≥12	0.0
11	1.9
10	6.6

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-4, p. 23-6.)

Adjustment for Access Point Density: Multilane Highways

Table 14.9: Adjustment to Free-Flow Speed for Access-Point Density on a Multilane Highway

Access Density (access Points/mi)	Reduction in Free-Flow Speed, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥40	10.0

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December

Heavy Vehicle Effects:

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

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 ½ mile.
No grade ≥ 3% for longer than ¼mile.

Table 14.12 Passenger-Car Equivalents for Trucks and Buses on Upgrades

Table 14.12: Passenger-Car Equivalents for Trucks and Buses on Upgrades

Upgrade (%)	Length (mi)	E_T Percentage of Trucks and Buses (%)								
		2	4	5	6	8	10	15	20	≥25
<2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2–3	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50–0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75–1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00–1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3–4	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50–0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75–1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00–1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5

Table 14.12 (continued) Passenger-Car Equivalents for Trucks and Buses on Upgrades

>4–5	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>050–0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75–1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	2.5	3.0	3.0	3.0
>5–6	0.00–0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30–0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50–0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	>0.75–1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
>6	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>0.25–0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30–0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50–0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75–1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 29-8, p. 23-10.)

Table 14.13: Passenger-Car Equivalents for RVs on Upgrades

Grade (%)	Length (mi)	E_R Percentage of RVs (%) 2	4	5	6	8	10	15	20	≥25
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
>2–3	0.00–0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
>3–4	0.00–0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.25–0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
>4–5	0.00–0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	>0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
>5	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.5
	>0.25–50	6.0	4.0	4.0	4.0	3.5	3.0	2.5	2.5	2.0
	>0.50	6.0	4.5	4.0	4.0	4.0	3.5	3.0	2.5	2.0

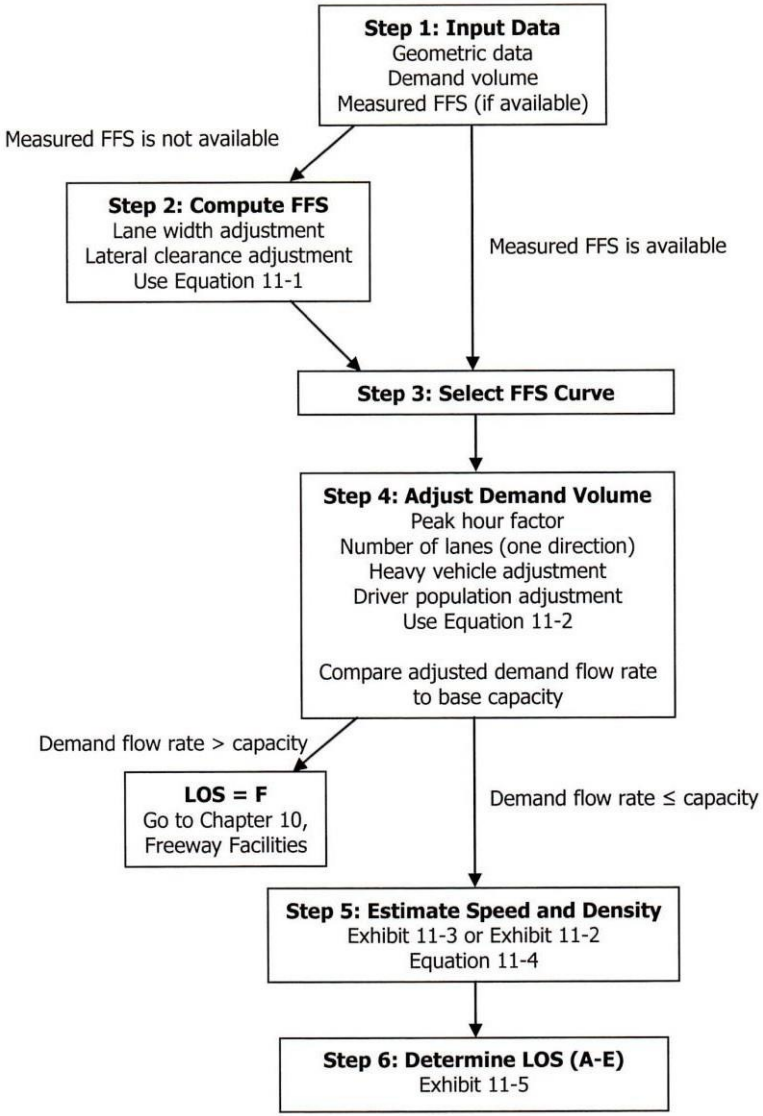
(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-10, p. 23-10.)

Table 14.14 Passenger-Car Equivalents for Trucks and Buses on Downgrades

Table 14.14: Passenger-Car Equivalents for Trucks and Buses on Downgrades

Downgrade (%)	Length (mi)	E_T Percentage Trucks and Buses (%)			
		5	10	15	≥20
< 4	All	1.5	1.5	1.5	1.5
≥4–5	≤4	1.5	1.5	1.5	1.5
	>4	2.0	2.0	2.0	1.5
>5–6	≤4	1.5	1.5	1.5	1.5
	>4	5.5	4.0	4.0	3.0
>6	≤4	1.5	1.5	1.5	1.5
	>4	7.5	6.0	5.5	4.5

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-11, p. 23-11.)


Step 1: Input Data
Geometric data
Demand volume
Measured FFS (if available)
Measured FFS is not available
Step 2: Compute FFS
Lane width adjustment
Lateral clearance adjustment
Use Equation 11-1
Measured FFS is available
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

HCM2010

Example: FFS on Freeway

Given:

Six-lane urban freeway (3 in each direction)

Lane width = 11 ft

Right-side lateral clearance = 2 ft from the pavement edge

Commuter traffic (regular users)

Find FFS

Example: FFS on Multilane Highway

- Four lane undivided multilane highway
  - Posted speed limit=50mi/hr
  - 11ft lanes
  - Frequent obstructions located 4 ft from the right pavement edge
  - 30 access points/mile on the right side of the facility
  - What is the free flow speed?

Example: LOS of Basic Freeway *(1)*

Given:

Four-lane freeway (2 in each direction)

Lane width = 11 ft

Right-side lateral clearnece = 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

Multilane Highways - Example

An existing six-lane divided multilane highway with a field-measured free-flow speed of 45 mph serves a peak-hour volume of 4,000 veh/h, with 15% trucks and no RVs. The PHF is 0.90. The highway has rolling terrain. What is the likely LOS for this section?