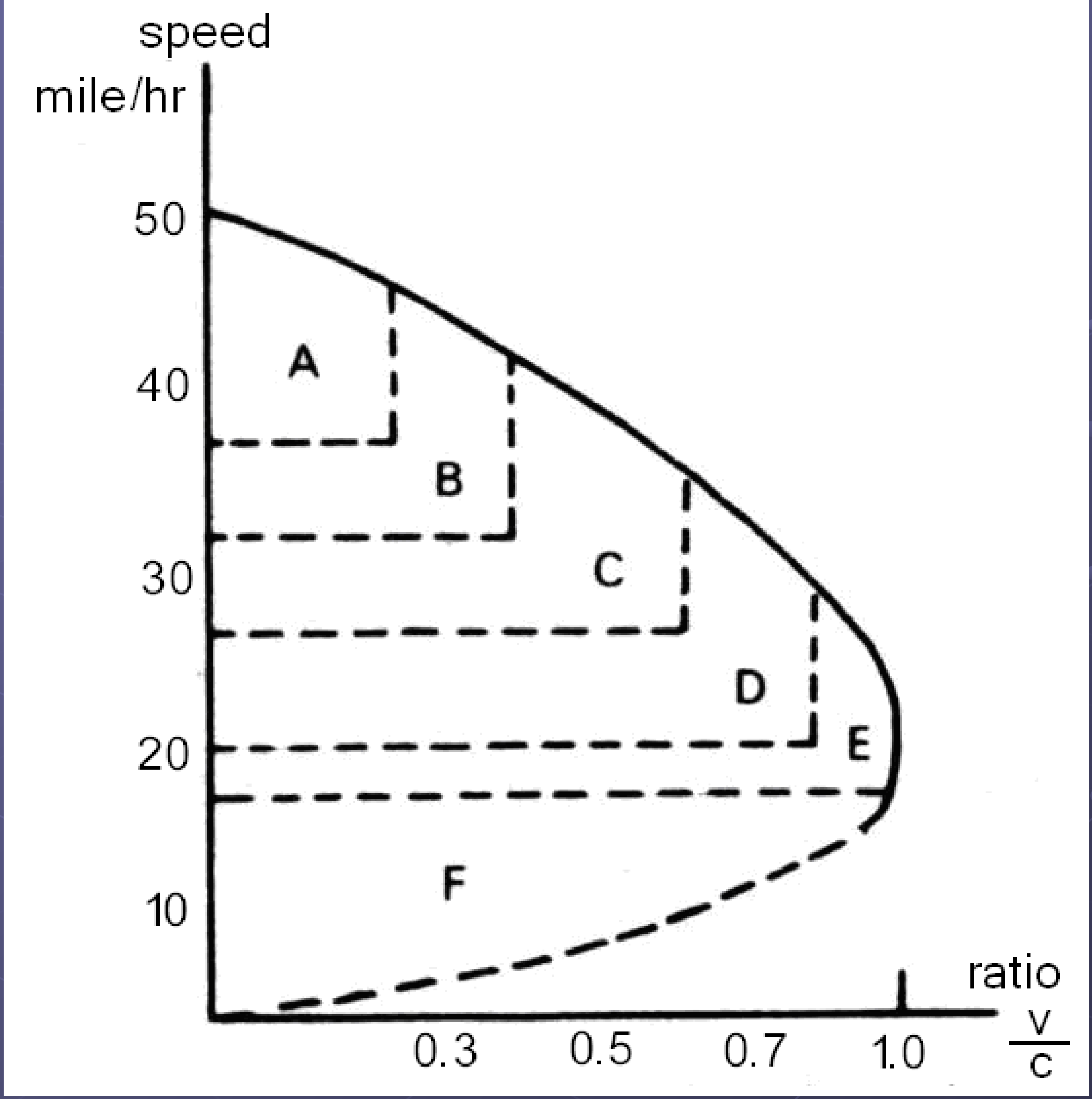
Capacity Analysis

Objectives

- Review LOS definition and determinants
- Define capacity and relate to “ideal” capacities
- Review calculating capacity using HCM procedures for basic freeway section
- Focus on relations between capacity, level-of-service, and design

Level of Service (LOS)

- Concept – a qualitative measure describing operational conditions within a traffic stream and their perception by drivers and/or passengers
- Levels represent range of operating conditions defined by measures of effectiveness (MOE)


speed
mile/hr
50
40
30
20
10
A
B
C
D
E
F
ratio
0.3
0.5
0.7
1.0
v
c

LOS A (Freeway)

- Free flow conditions
- Vehicles are unimpeded in their ability to maneuver within the traffic stream
- Incidents and breakdowns are easily absorbed

LOS B

- Flow reasonably free
- Ability to maneuver is slightly restricted
- General level of physical and psychological comfort provided to drivers is high
- Effects of incidents and breakdowns are easily absorbed

LOS C

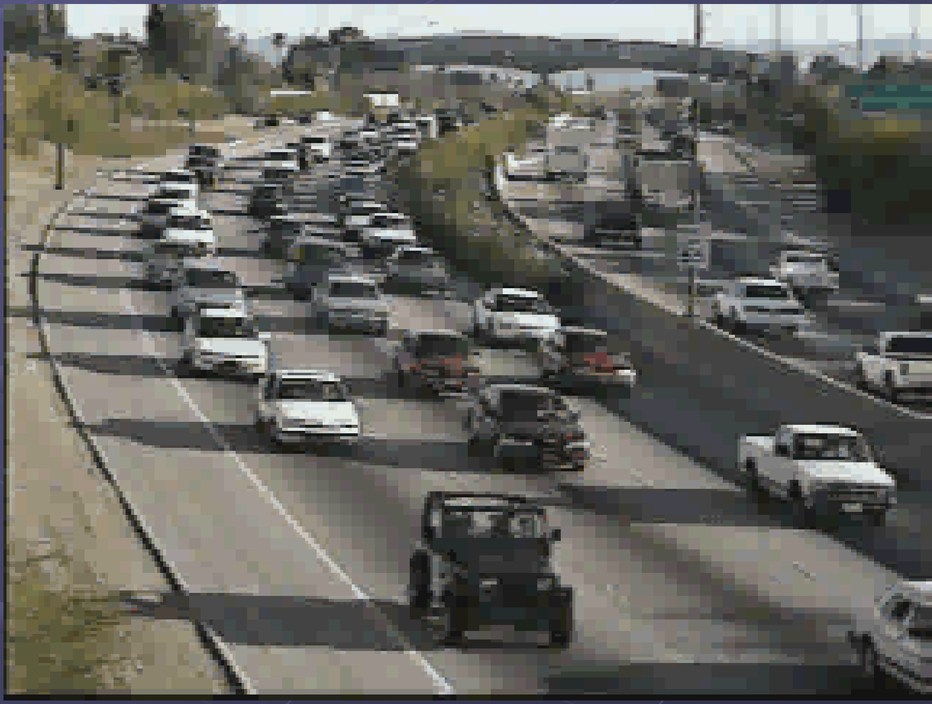
- Flow at or near FFS
- Freedom to maneuver is noticeably restricted
- Lane changes more difficult
- Minor incidents will be absorbed, but will cause deterioration in service
- Queues may form behind significant blockage

LOS D

- Speeds begin to decline with increasing flow
- Freedom to maneuver is noticeably limited
- Drivers experience physical and psychological discomfort
- Even minor incidents cause queuing, traffic stream cannot absorb disruptions

LOS E

- Capacity
- Operations are volatile, virtually no usable gaps
- Vehicles are closely spaced
- Disruptions such as lane changes can cause a disruption wave that propagates throughout the upstream traffic flow
- Cannot dissipate even minor disruptions, incidents will cause breakdown



LOS F

- Breakdown or forced flow
- Occurs when:
  - Traffic incidents cause a temporary reduction in capacity
  - At points of recurring congestion, such as merge or weaving segments
  - In forecast situations, projected flow (demand) exceeds estimated capacity

Design Level of Service

This is the desired quality of traffic conditions from a driver's perspective (used to determine number of lanes)

- Design LOS is higher for higher functional classes
- Design LOS is higher for rural areas
- LOS is higher for level/rolling than mountainous terrain
- Other factors include: adjacent land use type and development intensity, environmental factors, and aesthetic and historic values
- Design all elements to same LOS (use HCM to analyze)

Design Level of Service (LOS)

	Type of Area and Appropriate Level of Service			
Highway Type	**Rural Level**	**Rural Rolling**	**Rural Mountainous**	**Urban and Suburban**
Freeway	B	B	C	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

Source: Adapted from the AASHTO Green Book

Capacity – Defined

- Capacity: Maximum **hourly rate** of vehicles **or persons** that can *reasonably be expected* to pass a point, **or traverse a uniform section of lane or roadway**, during a specified time period under *prevailing conditions* (traffic and roadway)
- Different for different facilities (freeway, multilane, 2-lane rural, signals)
- Why would it be different?

Ideal Capacity

- Freeways: Capacity (Free-Flow Speed)

  2,400 pcphpl (70 mph)

  2,350 pcphpl (65 mph)

  2,300 pcphpl (60 mph)

  2,250 pcphpl (55 mph)

- Multilane Suburban/Rural

  2,200 pcphpl (60 mph)

  2,100 (55 mph)

  2,000 (50 mph)

  1,900 (45 mph)

- 2-lane rural – 2,800 pcph
- Signal – 1,900 pcphgpl

Principles for Acceptable Degree of Congestion:

1. Demand <= capacity, even for short time
2. 75-85% of capacity at signals
3. Dissipate from queue @ 1500-1800 vph
4. Afford some choice of speed, related to trip length
5. Freedom from tension, esp long trips, < 42 veh/mi.
6. Practical limits - users expect lower LOS in expensive situations (urban, mountainous)

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

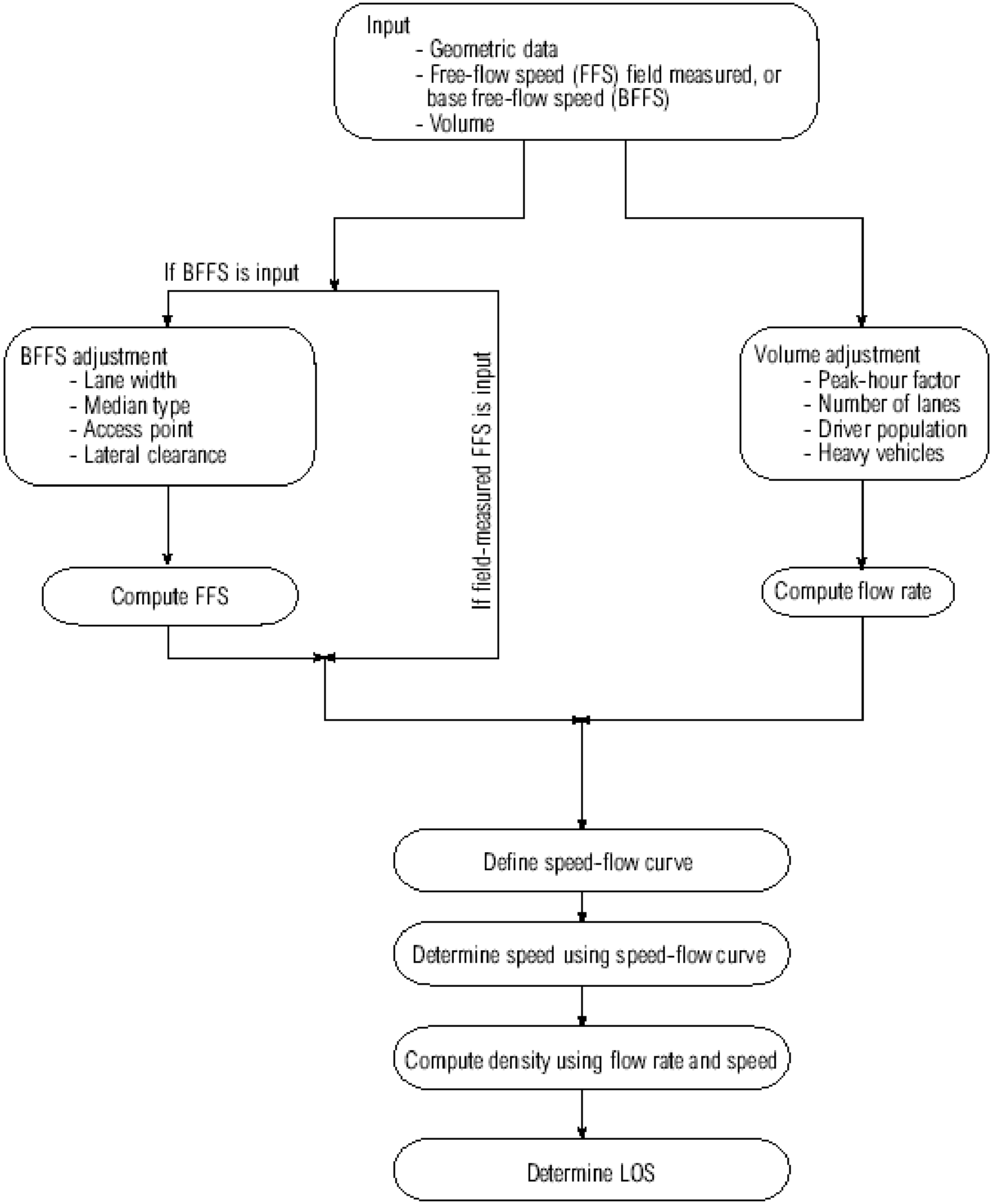
Base Conditions

- 1. 12-ft lane widths
- 2. A minimum of 12 ft of total lateral clearance in the direction of travel. Clearances are measured from the edge of the traveled lanes (shoulders included) and of 6 ft or greater are considered to be equal to 6 ft
- 3. No direct access points along the highway
- 4. A divided highway
- 5. Only passenger cars in the traffic stream
- 6. A free-flow speed of 60 mph or more
- 7. Driver population consisting primarily of commuters

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

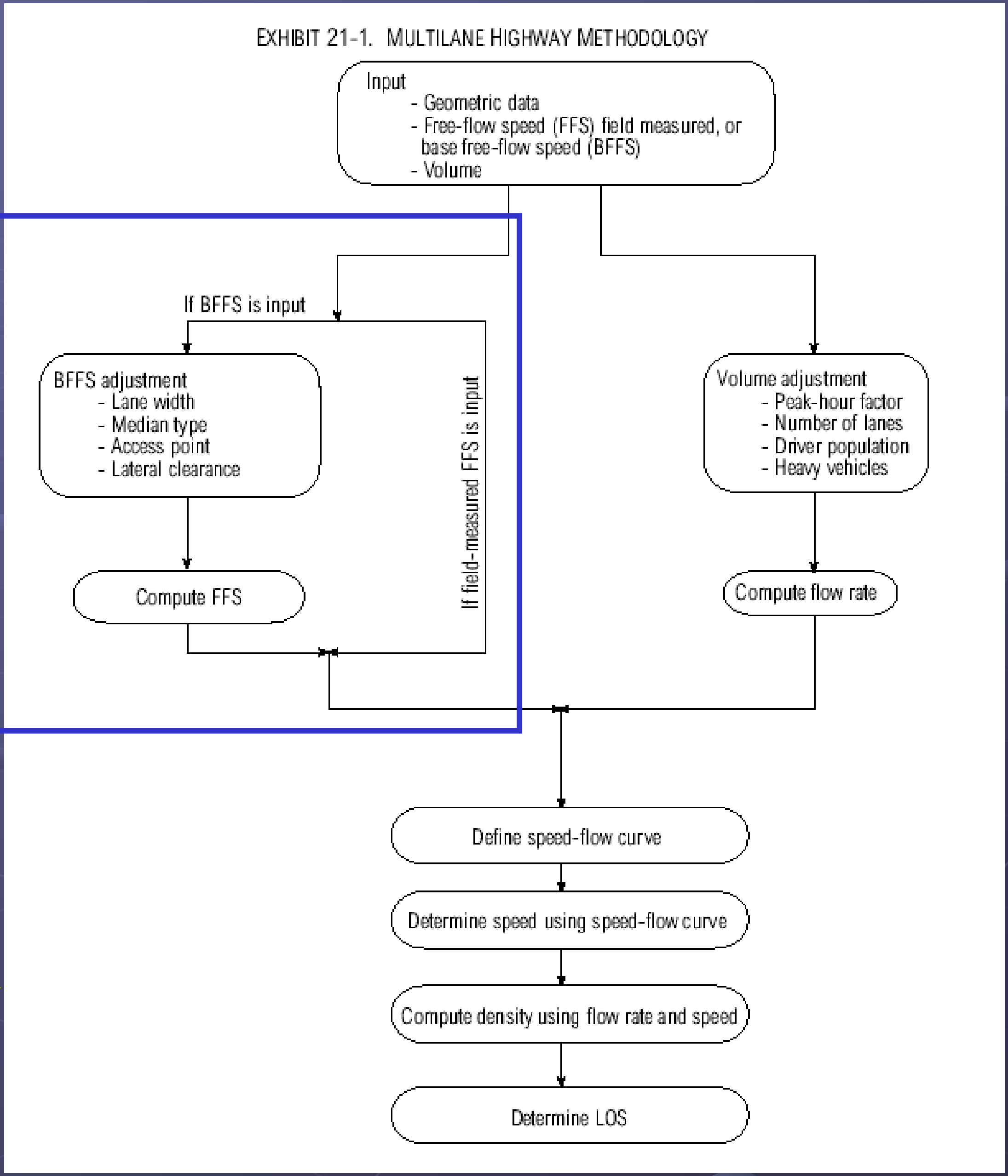
EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY



Source: HCM, 2000

The prediction of level of service for a multilane highway involves three steps:

- 1. Determination of free-flow speed
- 2. Adjustment of volume
- 3. Determination of level of service



Step 1: Gather data

Step 2: Calculate capacity (Supply)

Source: HCM, 2000

EXHIBIT 21-2. LOS CRITERIA FOR MULTILANE HIGHWAYS

Free-Flow Speed	Criteria	LOS A	LOS B	LOS C	LOS D	LOS E
60 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	40
	Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
	Maximum volume to capacity ratio (v/c)	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate (pc/h/ln)	660	1080	1550	1980	2200
55 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	41
	Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
	Maximum v/c	0.29	0.47	0.68	0.88	1.00
	Maximum service flow rate (pc/h/ln)	600	990	1430	1850	2100
50 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	43
	Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
	Maximum v/c	0.28	0.45	0.65	0.86	1.00
	Maximum service flow rate (pc/h/ln)	550	900	1300	1710	2000
45 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	45
	Average speed (mi/h)	45.0	45.0	45.0	44.4	42.2
	Maximum v/c	0.26	0.43	0.62	0.82	1.00
	Maximum service flow rate (pc/h/ln)	490	810	1170	1550	1900

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.

Source: HCM, 2000

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

Base Free-flow speed also can be estimated from:

1- 85th-percentile speed

2- posted speed limits,

if it is not possible to measure directly in the field.

BFFS = 85% Speed – (1:3) mph
(if 85% = 40 - 60 mph)

BFFS = Speed Limit + 7 mph
(if speed limit = 40 - 50 mph)

BFFS = Speed Limit + 5 mph
(if speed limit = 50 - 55 mph)

Lane Width

- Base Conditions: 12 foot lanes

EXHIBIT 21-4. ADJUSTMENT FOR LANE WIDTH

Lane Width (ft)	Reduction in FFS (mi/h)
12	0.0
11	1.9
10	6.6

Source: HCM, 2000

Lane Width (Example)

EXHIBIT 21-4. ADJUSTMENT FOR LANE WIDTH

Lane Width (ft)	Reduction in FFS (mi/h)
12	0.0
11	1.9
10	6.6

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

F_{lw} = 6.6 mph

Source: HCM, 2000

Lateral Clearance

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

Source: HCM, 2000

Lateral Clearance

$TLC = LC_R + LC_L$

TLC = total lateral clearance in feet

LC_R = lateral clearance from right edge of travel lane

LC_L = lateral clearance from left edge of travel lane

Source: HCM, 2000

EXHIBIT 21-5. ADJUSTMENT FOR LATERAL CLEARANCE

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance[a] (ft)	Reduction in FFS (mi/h)	Total Lateral Clearance[a] (ft)	Reduction in FFS (mi/
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

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 gr than 6 ft, use 6 ft). Therefore, for purposes of analysis, total lateral clearance cannot exceed 12 ft.

Source: HCM, 2000

EXHIBIT 21-5. ADJUSTMENT FOR LATERAL CLEARANCE

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance[a] (ft)	Reduction in FFS (mi/h)	Total Lateral Clearance[a] (ft)	Reduction in FFS (mi/
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

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 gr than 6 ft, use 6 ft). Therefore, for purposes of analysis, total lateral clearance cannot exceed 12 ft.

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

$TLC = LC_R + LC_L = 6 + 4 = 10$

F_{lc} = 0.4 mph

Source: HCM, 2000

EXHIBIT 21-6. ADJUSTMENT FOR MEDIAN TYPE

Median Type	Reduction in FFS (mi/h)
Undivided highways	1.6
Divided highways (including TWLTLs)	0.0

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

EXHIBIT 21-7. ACCESS-POINT DENSITY ADJUSTMENT

Access Points/Mile	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

F_a accounts for interruption due to access points along the facility

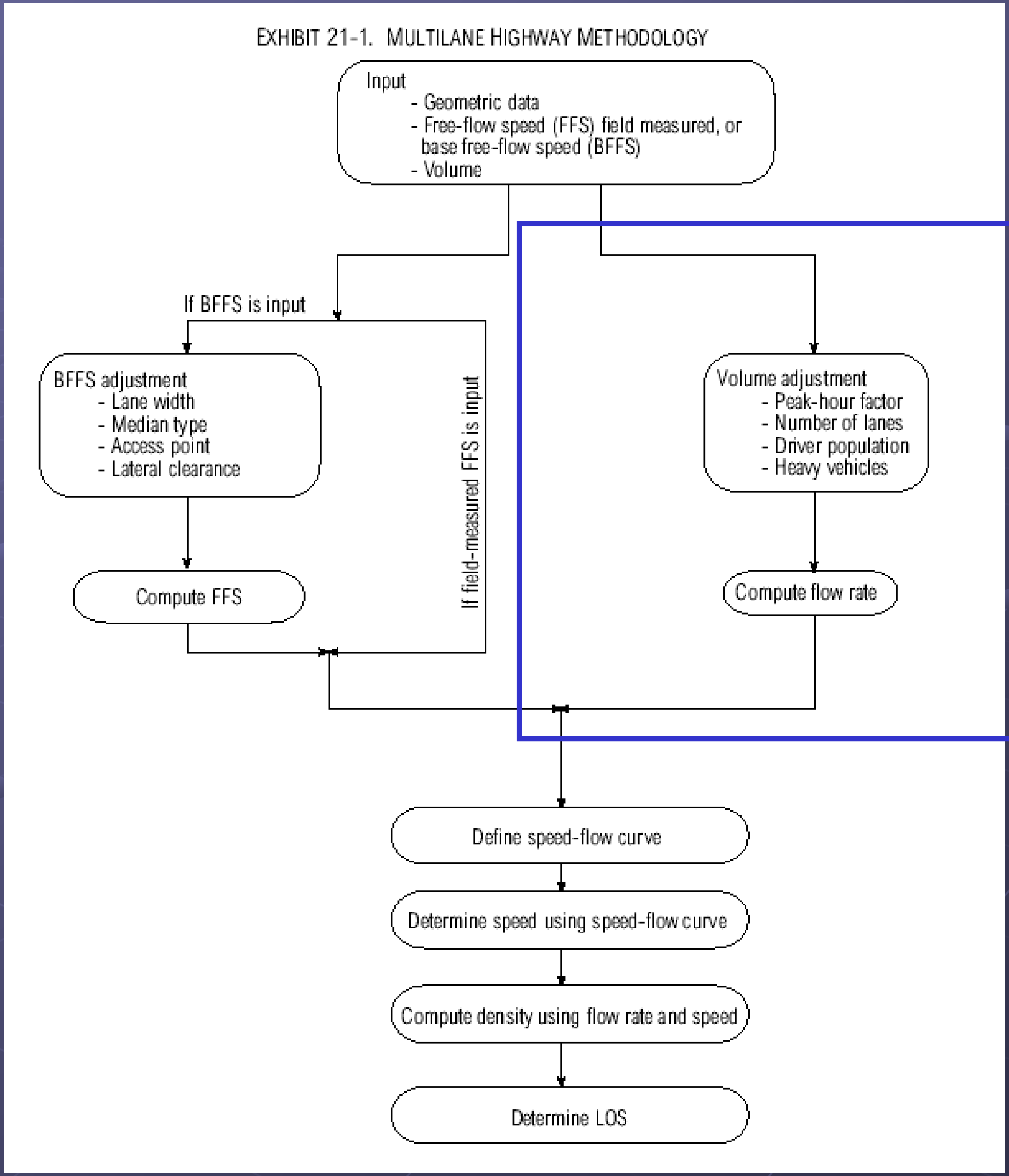
Example: if there are 20 access points per mile, what is the reduction in free flow speed?

F_a = 5.0 mph

Default Access-Point Density

Development Type	Default Value	Access Points/mi (One Side)
Rural	8	0–10
Low-density suburban	16	11–20
High-density suburban	25	≥21

Source: TRB, 2000.



Step 2: Estimate demand

Source: HCM, 2000

Calculate Flow Rate

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

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.

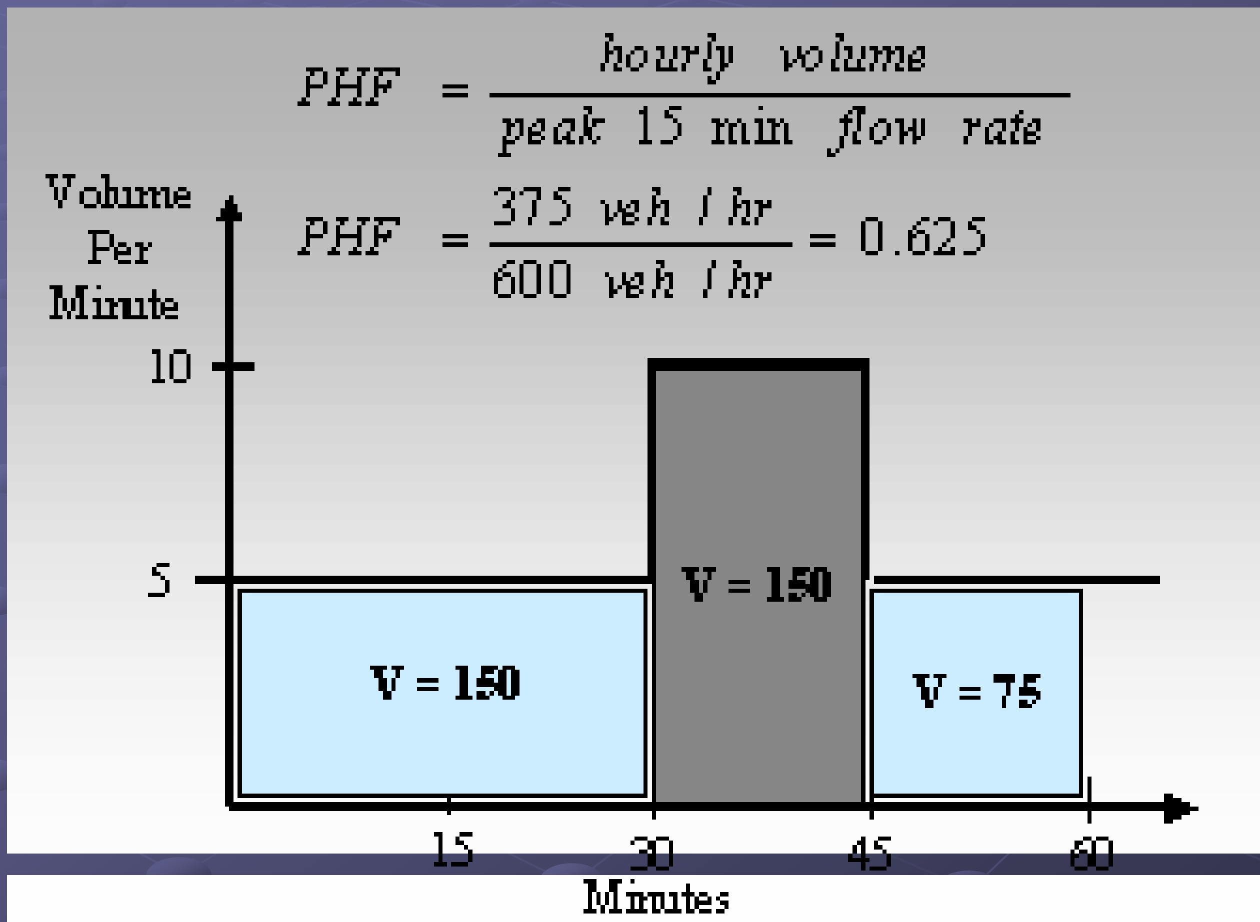
Peak Hour Factor (PHF)

$$PHF = \frac{\text{peak-hour volume}}{4(\text{peak 15-min volume})}$$

Flow is not uniform throughout an hour

HCM considers operating conditions during most congested 15-minute period of the hour to determine service level for the hour as a whole

Peak Hour Factor



Heavy Vehicle Adjustment

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

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (2$$

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.

f(hv) 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 ½ mile or grade more than 3% is more than ¼ mile)

EXHIBIT 21-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED GENERAL HIGHWAY SEGMENTS

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

Example: for 10% heavy trucks on rolling terrain, what is F_{hv}?

For rolling terrain, $E_T = 2.5$

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

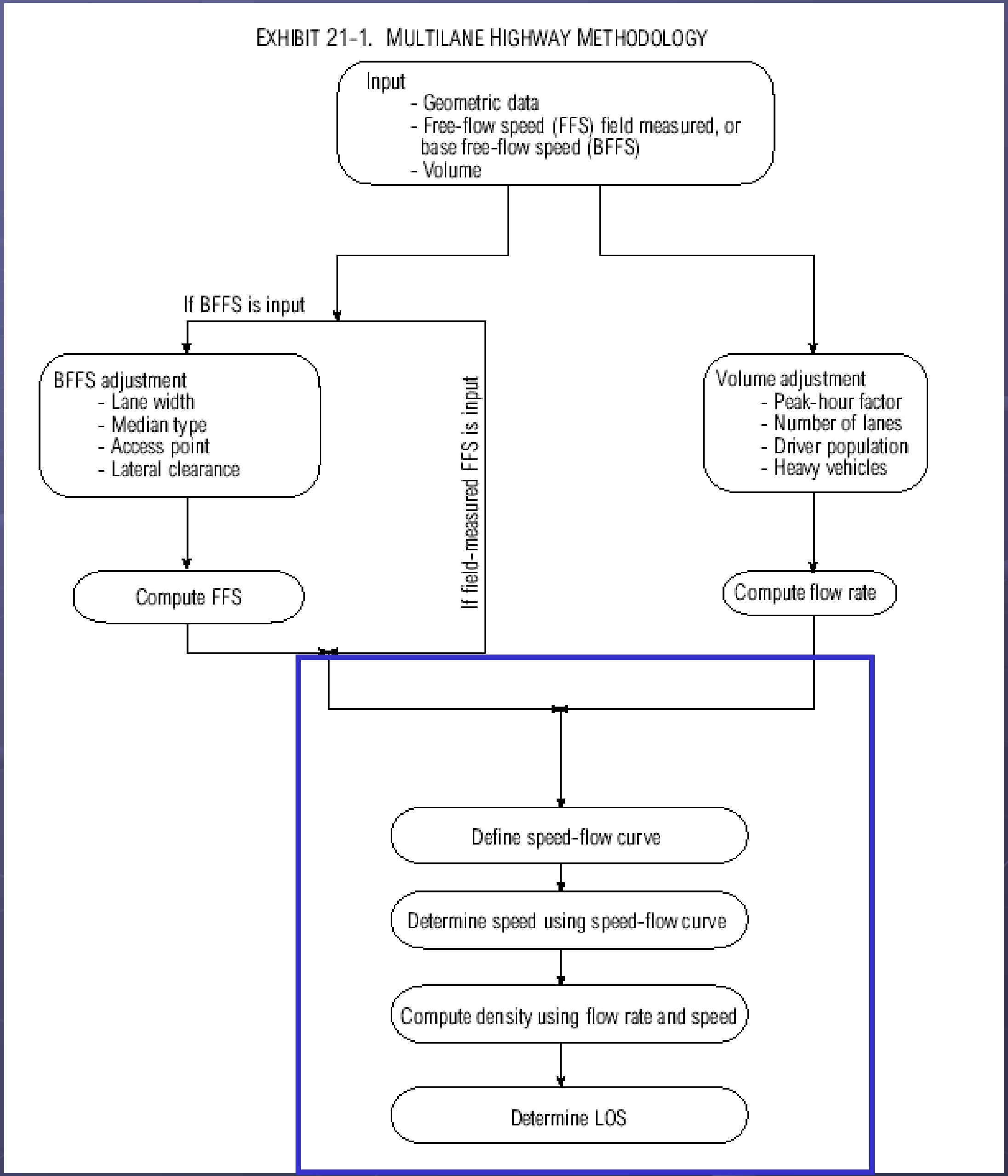
$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

Driver Population Factor (f_p)

- Non-familiar users affect capacity
- $f_p = 1$, familiar users
- $1 > f_p >= 0.85$, unfamiliar users

Step 3: Determine LOS

Demand Vs. Supply



Source: HCM, 2000

- Calculate v_p

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

- **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

$$D = \frac{v_p}{S} \qquad (21\text{-}5)$$

where

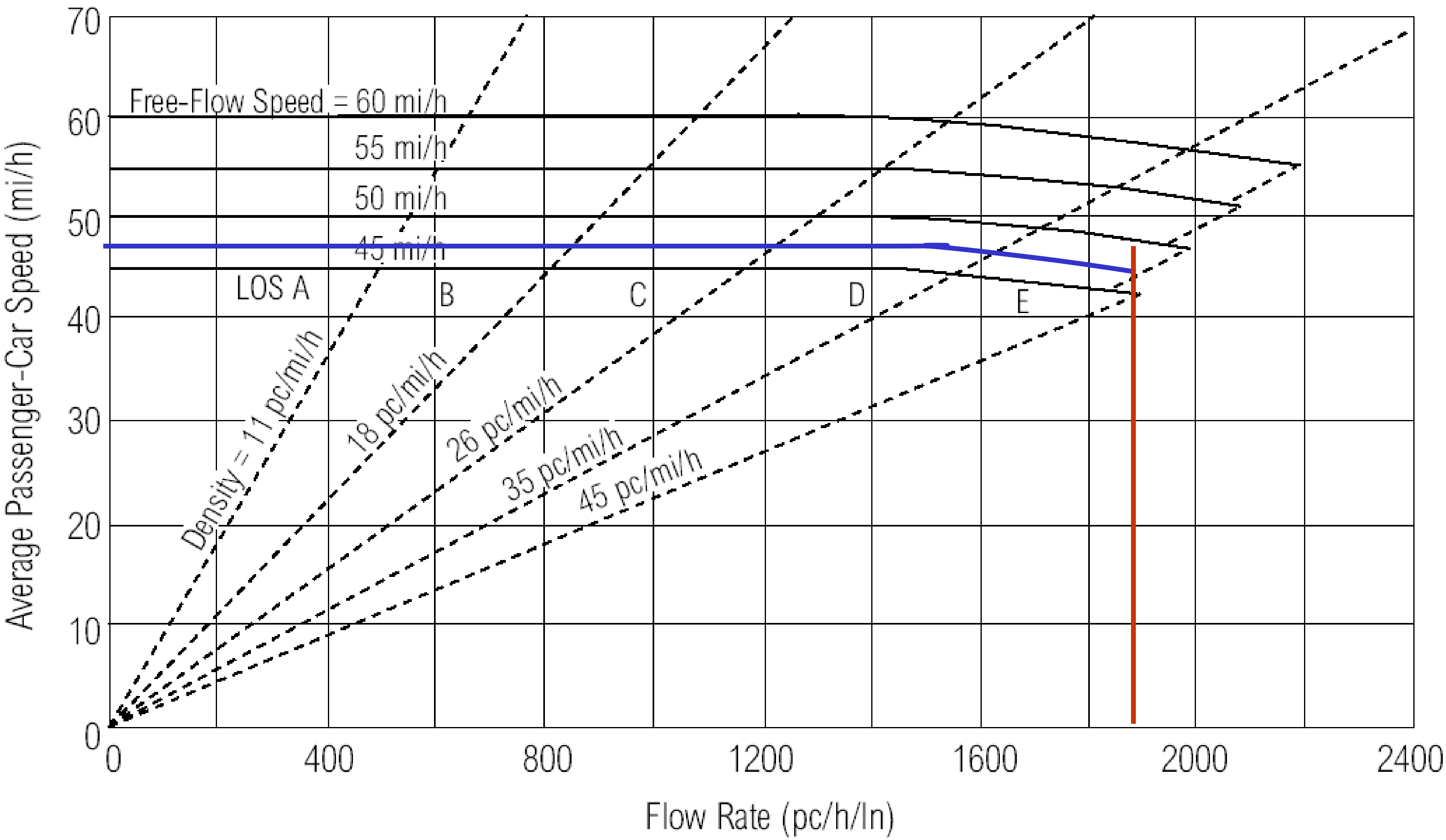
D = density (pc/mi/ln),
v_p = flow rate (pc/h/ln), and
S = average passenger-car travel speed (mi/h).

Example: for previous

$$D = \frac{1878 \text{ vph}}{48 \text{ mph}} = \mathbf{39.1\ pc/mi/lane}$$

EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA

LOS = E



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