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.

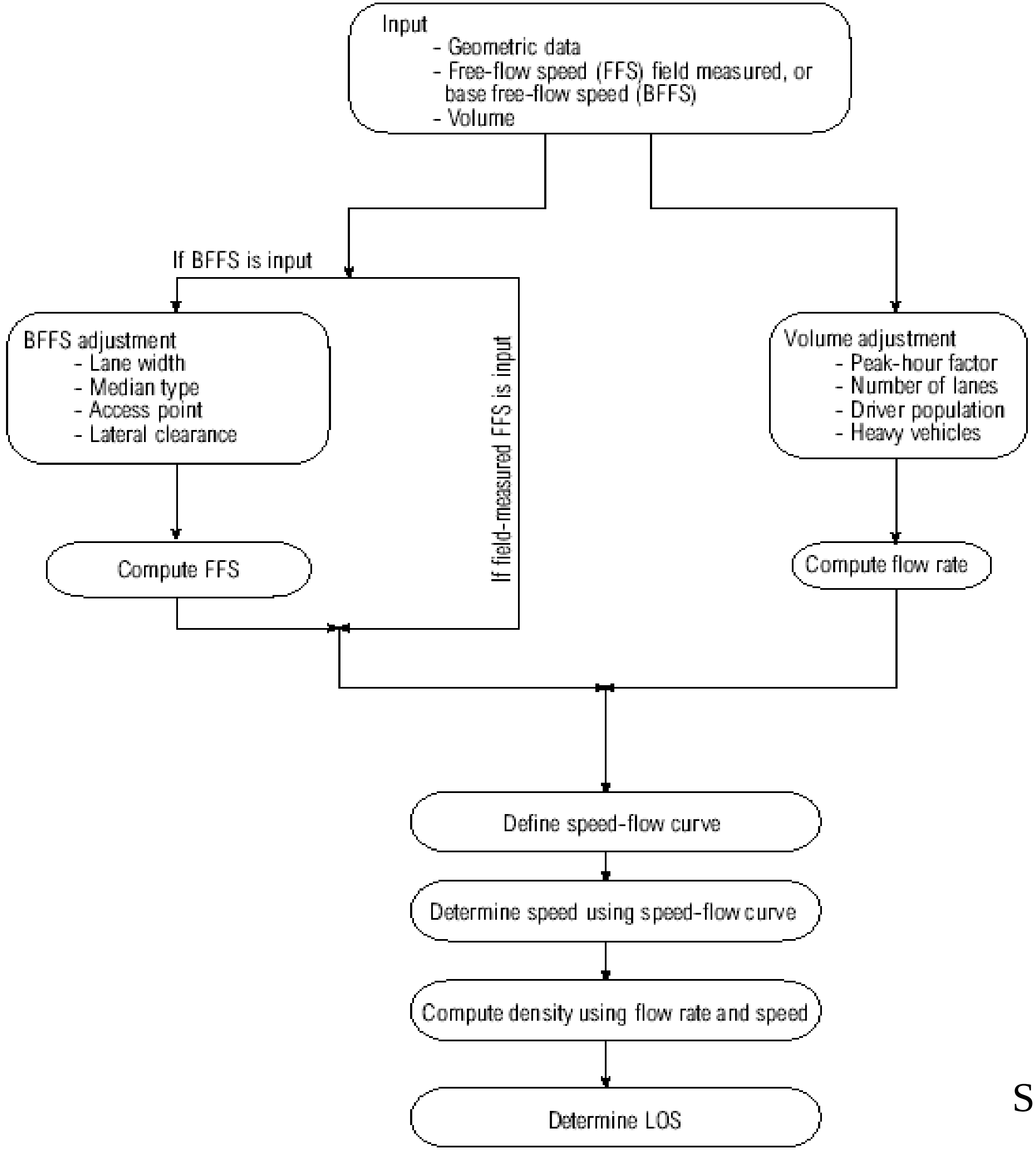
Multilane Highways

- 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

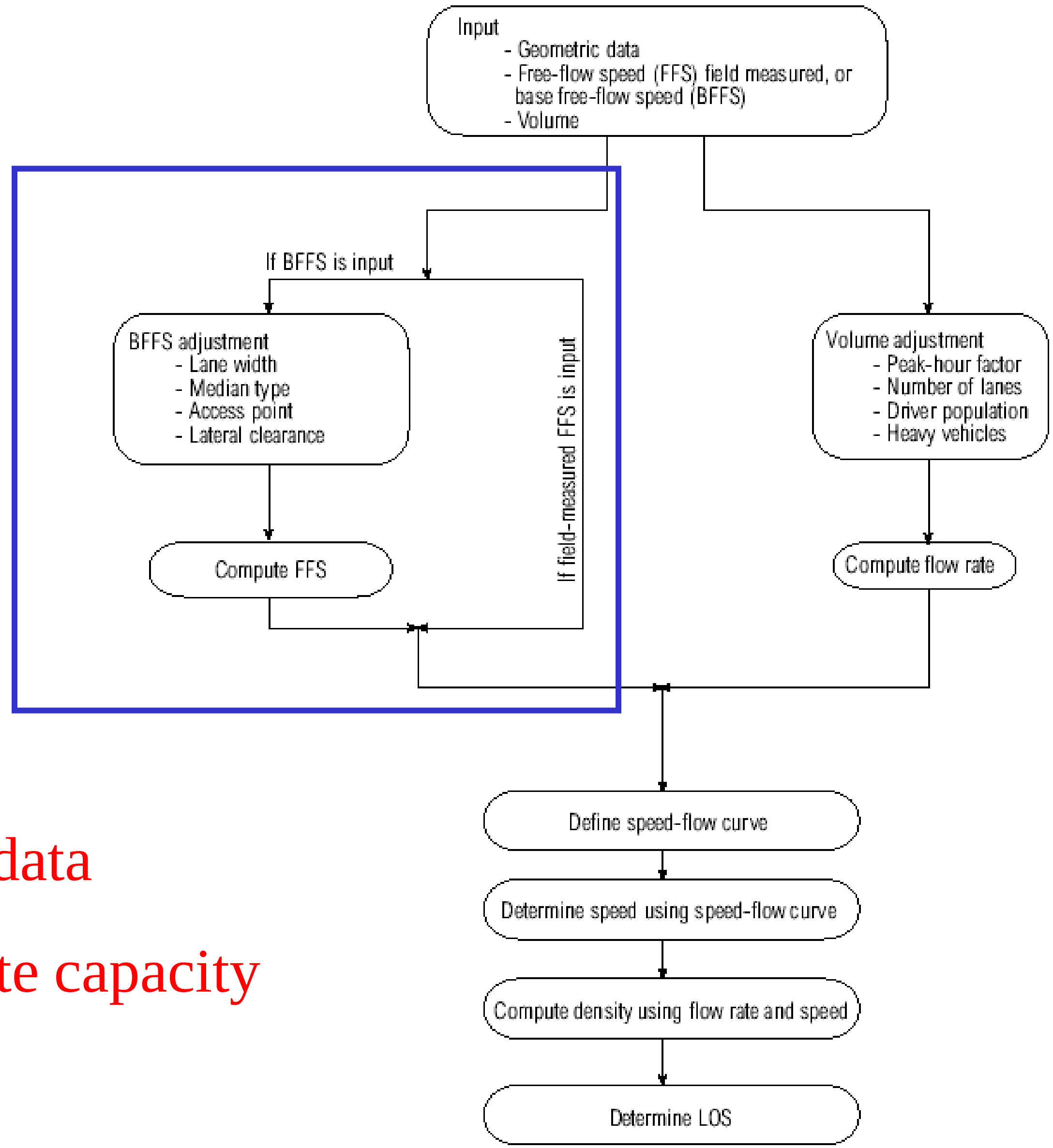
- Intended for analysis of uninterrupted-flow highway segments
  - Signal spacing > 2.0 miles
  - No on-street parking
  - No significant bus stops
  - No significant pedestrian activities

EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY



Source: HCM, 2000

EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY



Step 1: Gather data

Step 2: Calculate capacity (Supply)

Source: HCM, 2000

EXHIBIT 21-2. LOS CRITERIA FOR MULTILANE HIGHWAYS

		LOS				
Free-Flow Speed	Criteria	A	B	C	D	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.

Sourc

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

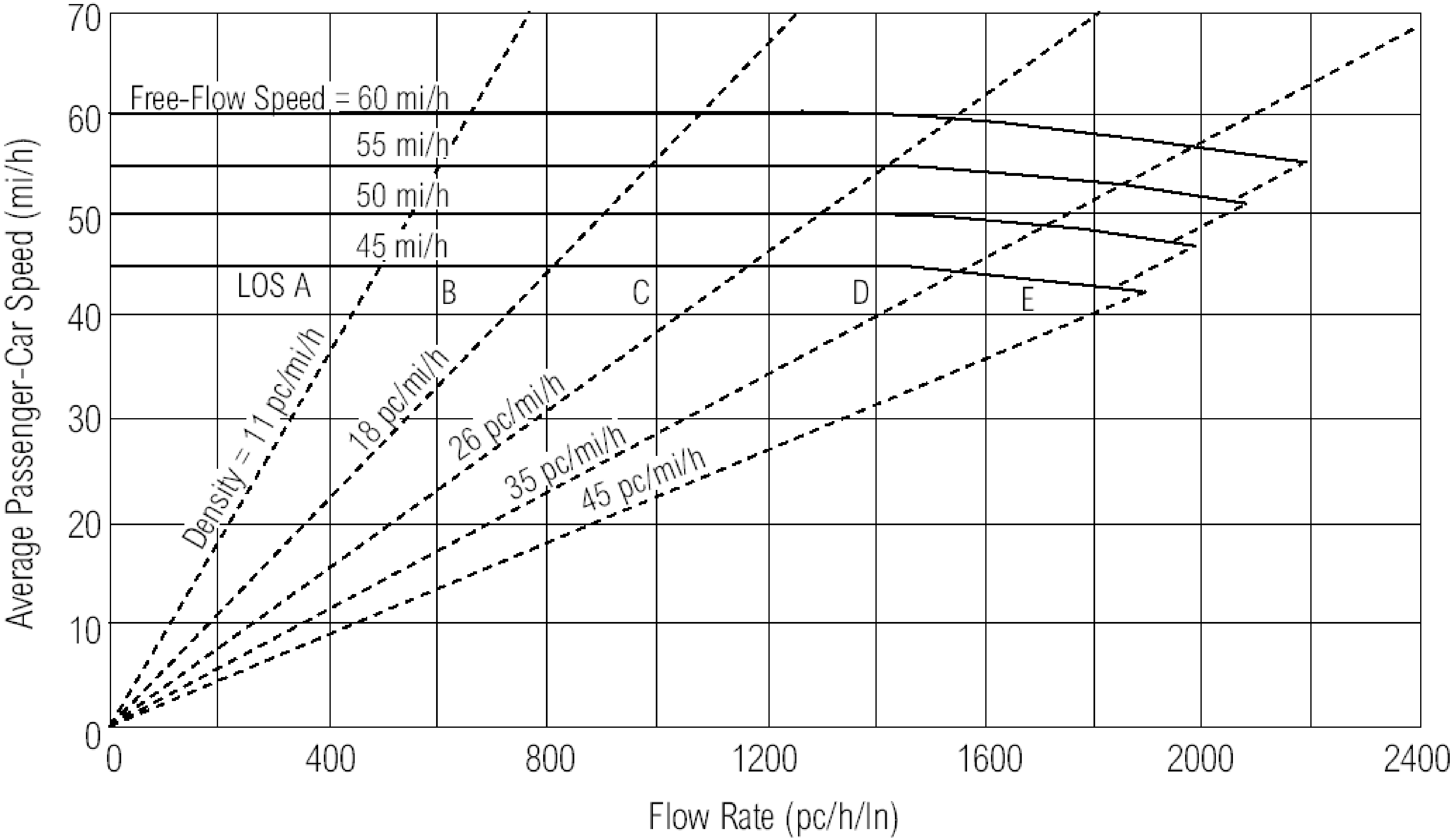
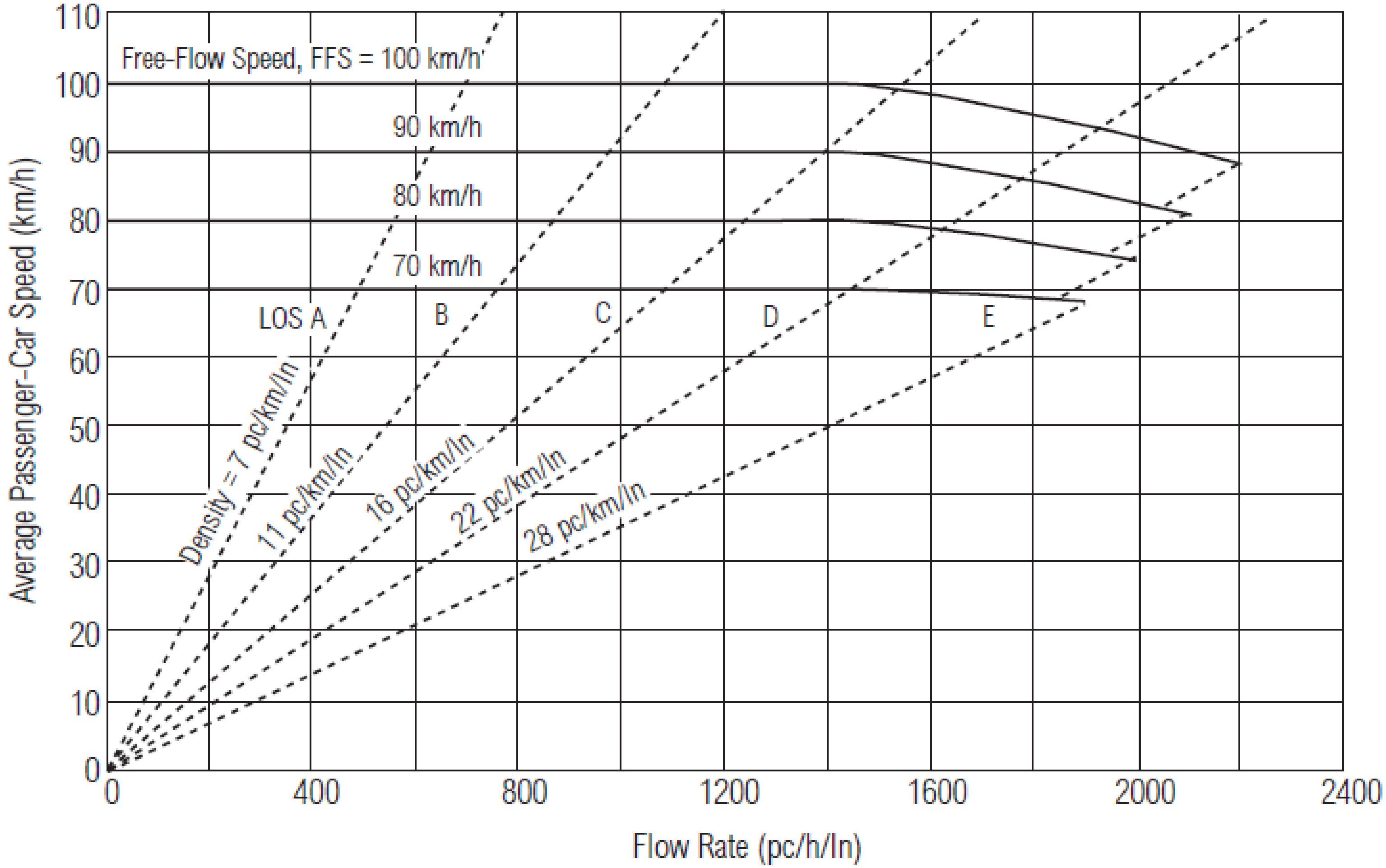


EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA



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
$90 < FFS \leq 100$ then

Source

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

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

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

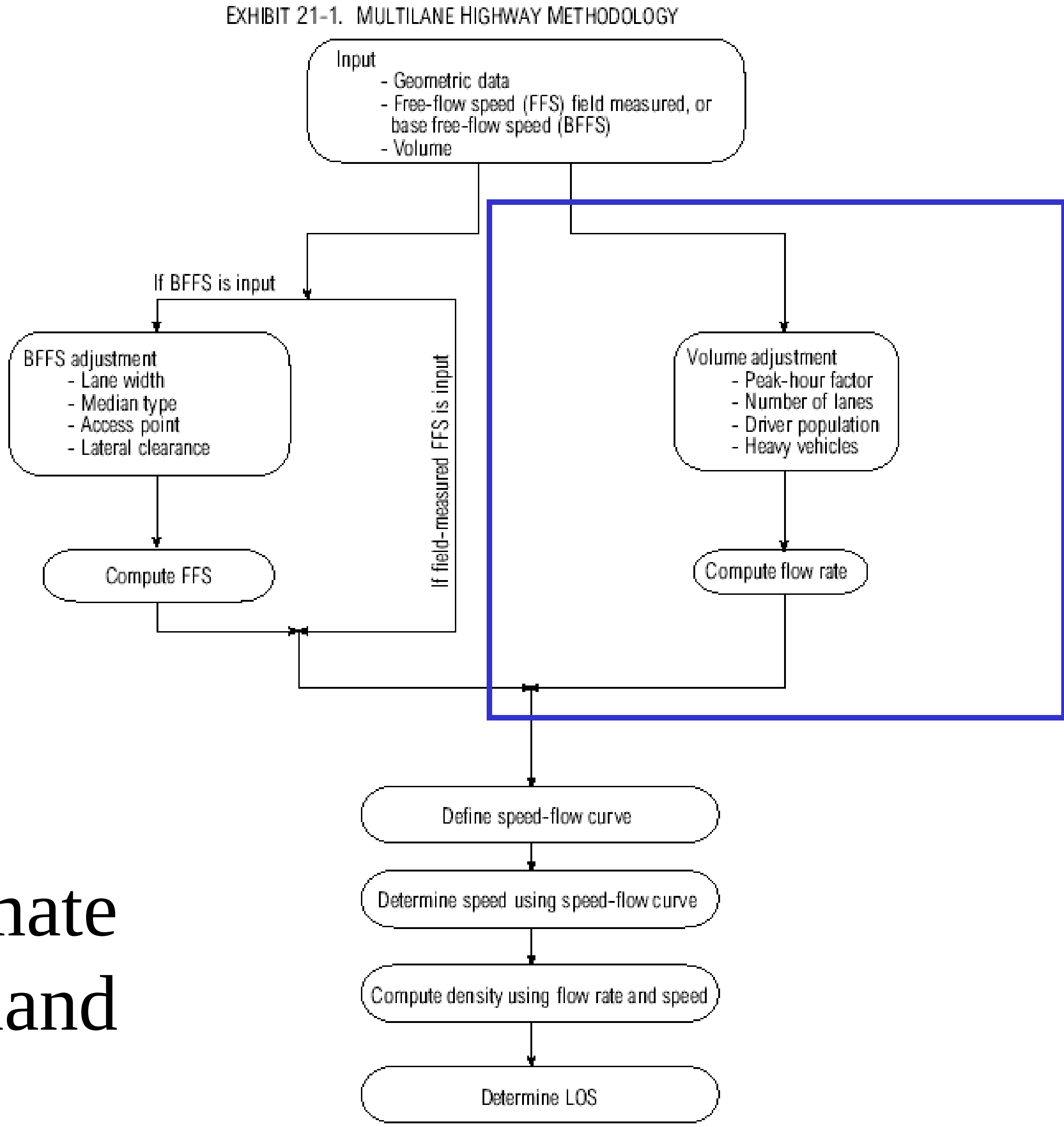
$BFFS$	=	base FFS (mi/h);
FFS	=	estimated FFS (mi/h);
f_{LW}	=	adjustment for lane width, from Exhibit 21-4 (mi/h);
f_{LC}	=	adjustment for lateral clearance, from Exhibit 21-5 (mi/h);
f_M	=	adjustment for median type, from Exhibit 21-6 (mi/h); and
f_A	=	adjustment for access points, from Exhibit 21-7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

BFFS = free flow under ideal conditions

FFS = free flow adjusted for actual conditions

From previous examples:

FFS = 60 mph – 6.6 mph - 0.4 mph – 0 – 5.0 mph = 48 mph (reduction of 12 mph)



Step 3: Estimate demand

Source: HCM, 2000

Multilane highway

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.

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 1 mile or grade more than 3% is more than 0.5 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, $E_T = 2.5$

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

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

EXHIBIT 21-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UNIFORM UPGRADES

Upgrade (%)	Length (km)	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	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.8–1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 1.2–1.6	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.6–2.4	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 2.4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3–4	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8–1.2	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 1.2–1.6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.6–2.4	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 2.4	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4–5	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.8–1.2	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 1.2–1.6	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.6	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5–6	0.0–0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.5	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.5–0.8	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.8–1.2	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.2–1.6	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.6	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.4–0.5	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.5–0.8	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.8–1.2	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 1.2–1.6	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.6	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

EXHIBIT 21-10. PASSENGER-CAR EQUIVALENTS FOR RVS ON UNIFORM UPGRADES

Grade (%)	Length (km)	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	0.0–0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3–4	0.0–0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.4–0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
> 4–5	0.0–0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
> 5	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	> 0.4–0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.5	3.5	3.0	3.0	2.5	2.0

EXHIBIT 21-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS ON DOWNGRADES

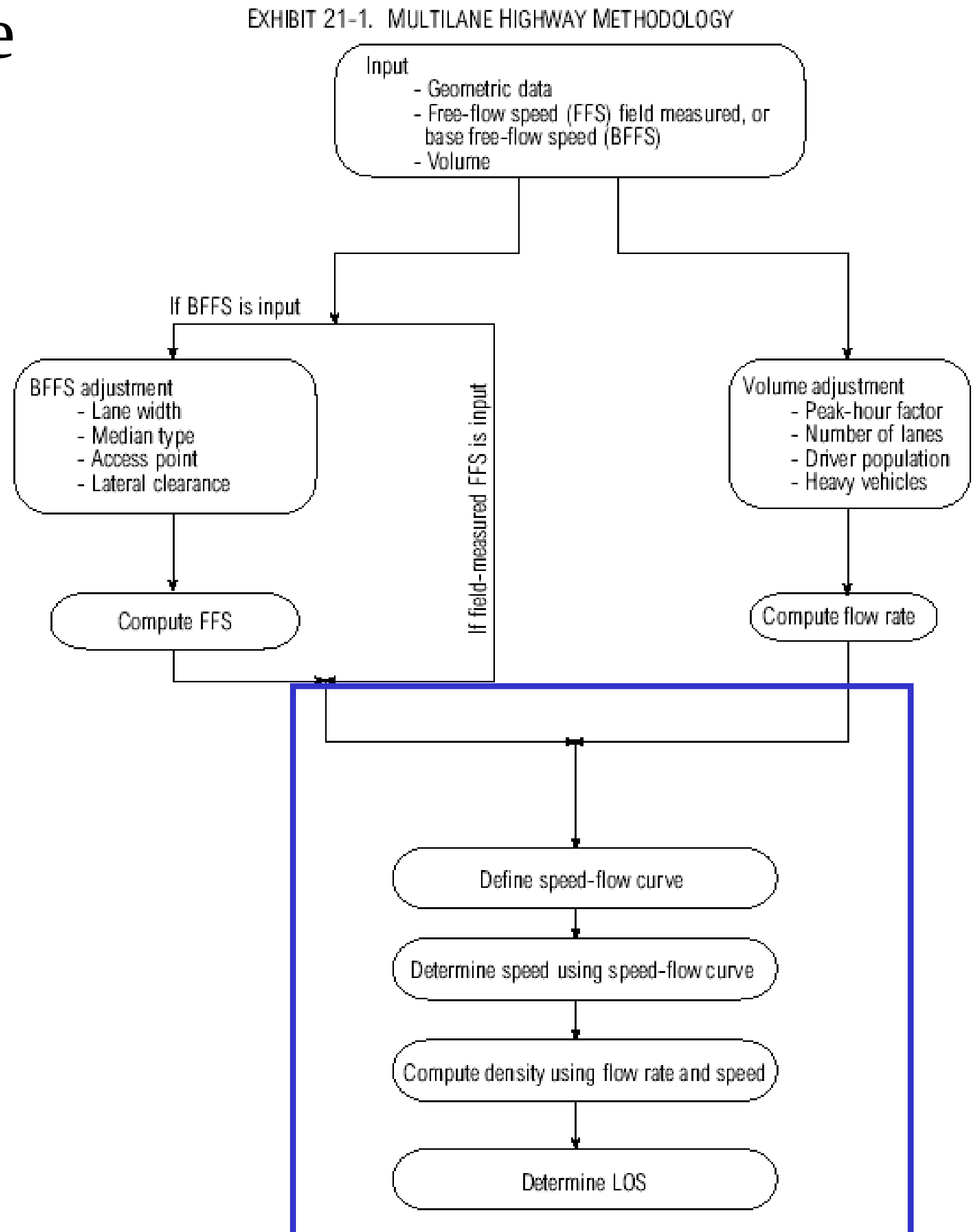
Downgrade (%)	Length (km)	E_T Percentage of Trucks 5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4–5	≤ 6.4	1.5	1.5	1.5	1.5
4–5	> 6.4	2.0	2.0	2.0	1.5
> 5–6	≤ 6.4	1.5	1.5	1.5	1.5
> 5–6	> 6.4	5.5	4.0	4.0	3.0
> 6	≤ 6.4	1.5	1.5	1.5	1.5
> 6	> 6.4	7.5	6.0	5.5	4.5

Driver Population Factor (f_p)

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

Step 4: 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

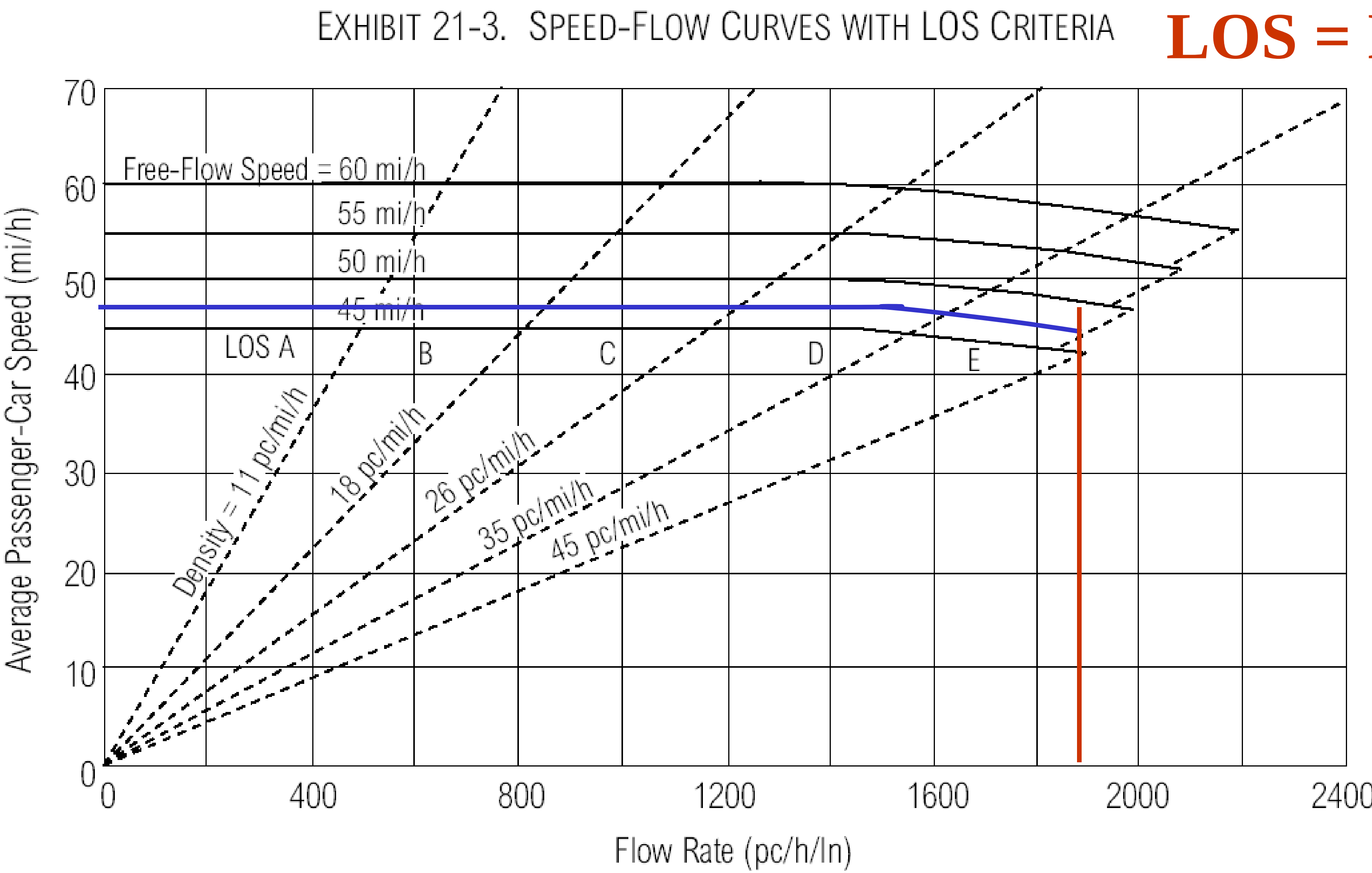
$$D = \frac{v_p}{S} \quad (21\text{-}5)$$

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

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



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

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

Recalculate Density

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

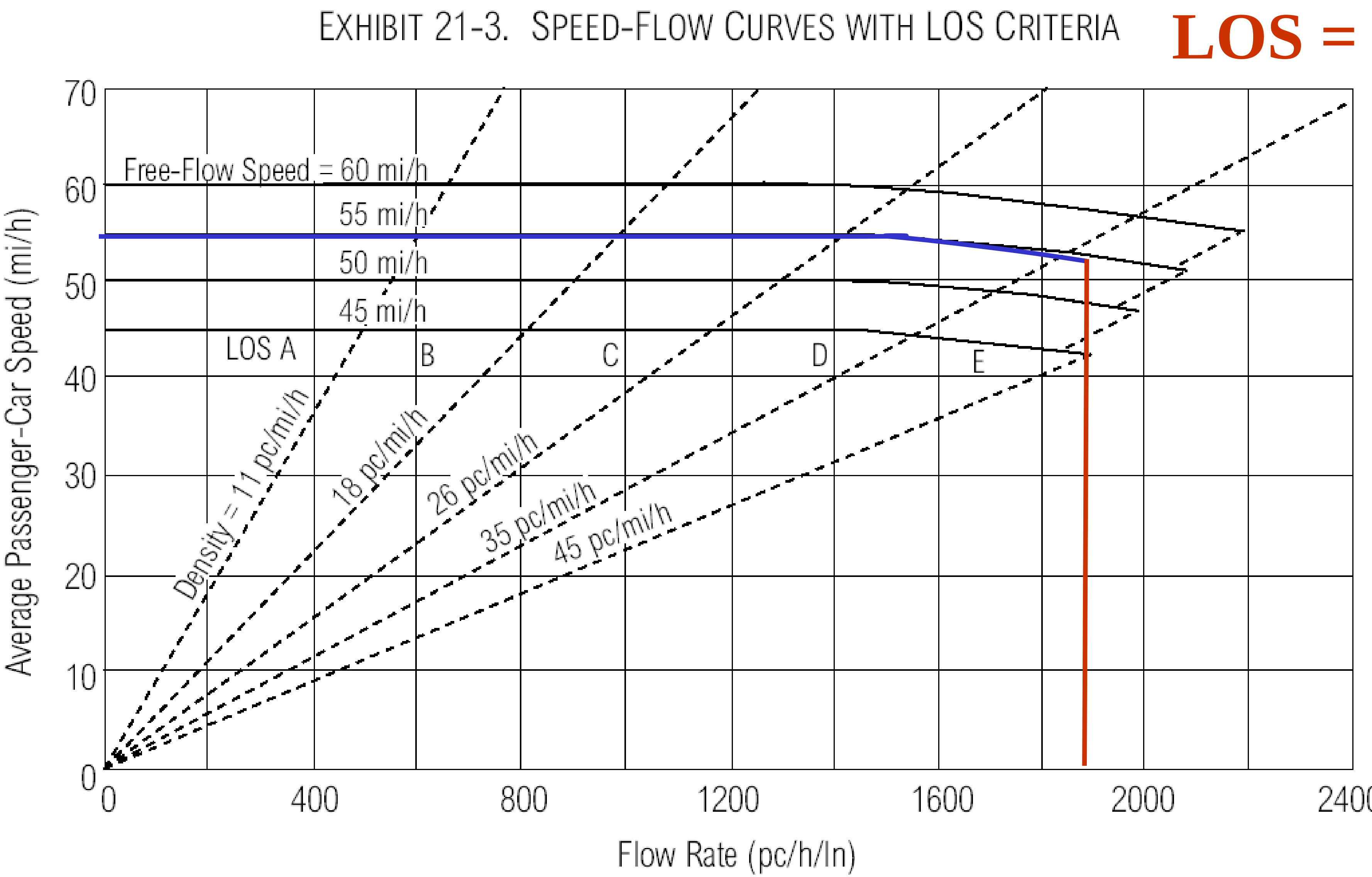
where

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

Example: for previous (but with wider lanes)

$$D = \frac{1878 \text{ vph}}{55 \text{ mph}} = \mathbf{34.1\ pc/mi/lane}$$

LOS = E



Now D = 34.1 pc/mi/ln, on border of LOS E

- Recalculate v_p, while adding a lane

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

- **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

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

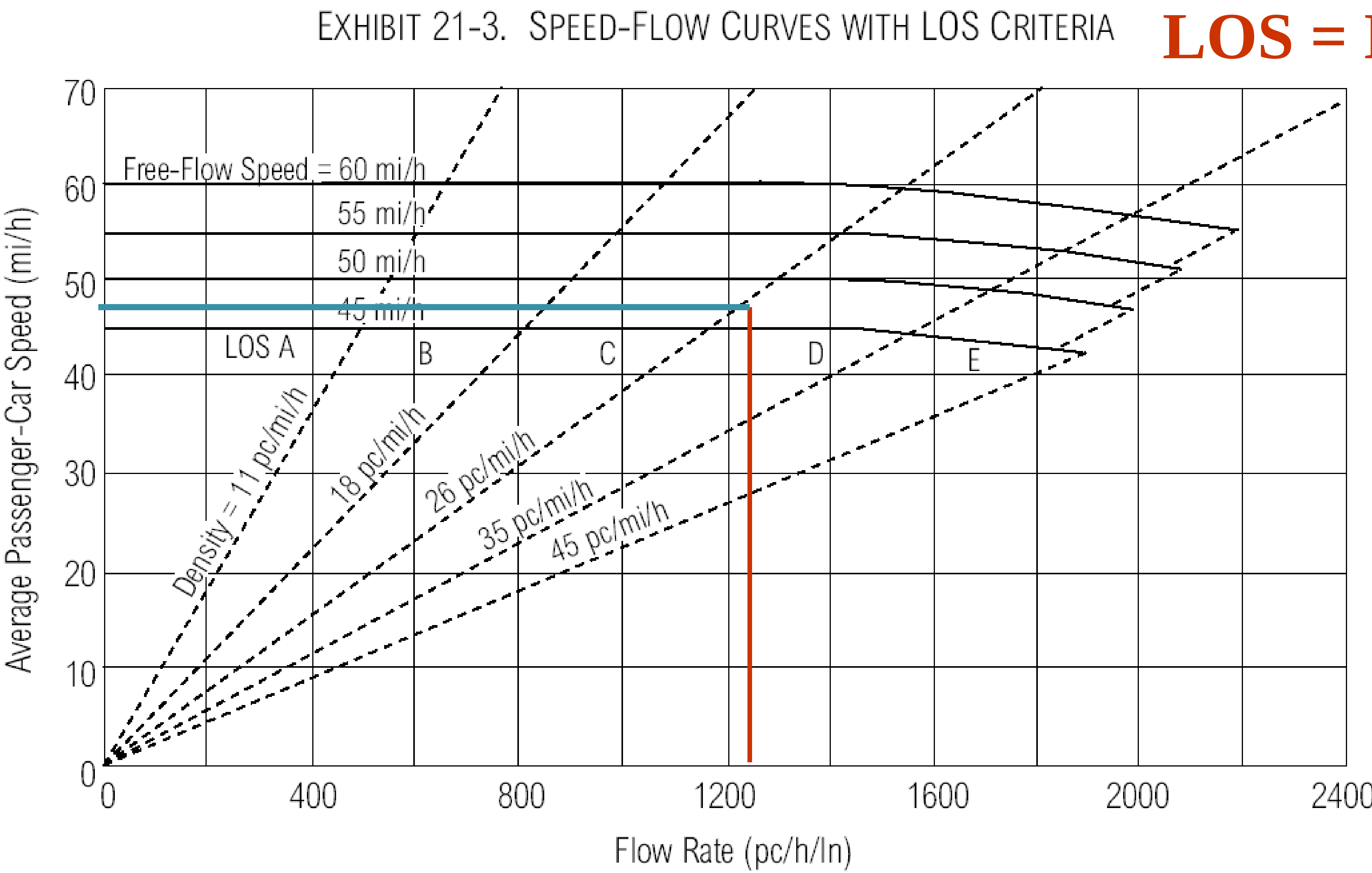
where

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

Example: for previous

$$D = \frac{1252 \text{ vph}}{48 \text{ mph}} = \mathbf{26.1\ pc/mi/lane}$$

LOS = D



Now D = 26.1 pc/mi/ln, 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 mph F_{lc} = 0.4 mph (LC = 4+6=10) F_M = 0.0 mph (divided)

$F_{A\ South}$= 2.5 mph (10 access points/mile) $F_{A\ North}$= 1.0 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

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

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.

V = 2300 vph   Rolling terrain   10% truck   PHF = 0.9   N =2

F_{hv} = 1/(1+ 0.1 (2.5 -1) = 0.870

Vp = 2300 / (0.9 * 2 * 0.87 * 1) = 1469 pc/h/ln

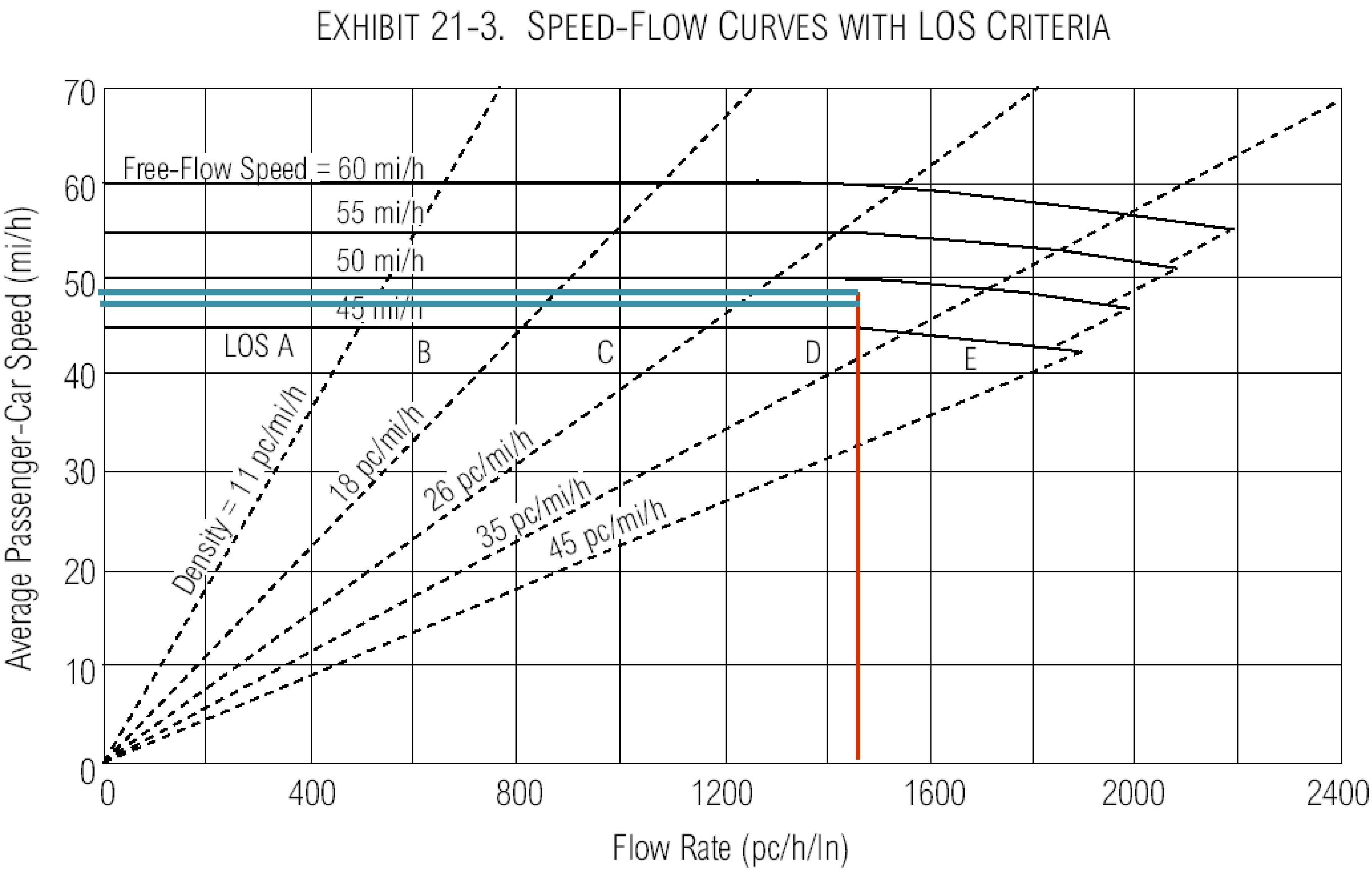


EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA
Free-Flow Speed = 60 mi/h
55 mi/h
50 mi/h
45 mi/h
LOS A
B
C
D
E
Density = 11 pc/mi/h
18 pc/mi/h
26 pc/mi/h
35 pc/mi/h
45 pc/mi/h
Average Passenger-Car Speed (mi/h)
Flow Rate (pc/h/ln)
0
10
20
30
40
50
60
70
0
400
800
1200
1600
2000
2400

LOS = D