TOPIC 6

Highway Capacity and Level of Service

Traffic Flow Elements

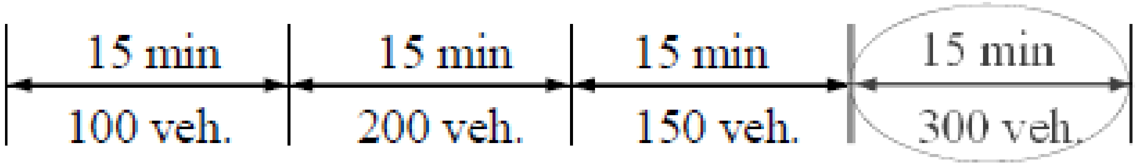
Volume (V):

❖ Total number of vehicles that pass a point on a highway or a lane during a given time interval (veh/h, veh/d, …)

Flow (q):

❖ Equivalent hourly rate at which vehicles pass a point on a highway/lane during a time period less than 1 hour (veh/h)

Difference between volume, flow and PHF.



Volume = $V = 100 + 200 + 150 + 300 = 750$ veh/h

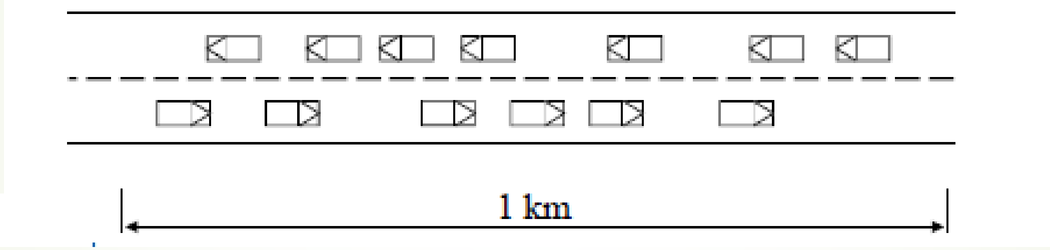
Flow = $q = 300 \times 4 = 1200$ veh/h

PHF = $$PHF = \frac{750}{1200} = 0.625$$

Traffic Flow Elements

Density (k):

❖ Number of vehicles traveling over a unit length of highway at an instant in time (veh/km)



Speed (u):

❖ Distance traveled by vehicles during unit of time (km/h), and is defined as:

i. Time-mean speed ($\bar{u}_t$) – Arithmetic mean of speeds of all vehicles passing a point during specified time interval

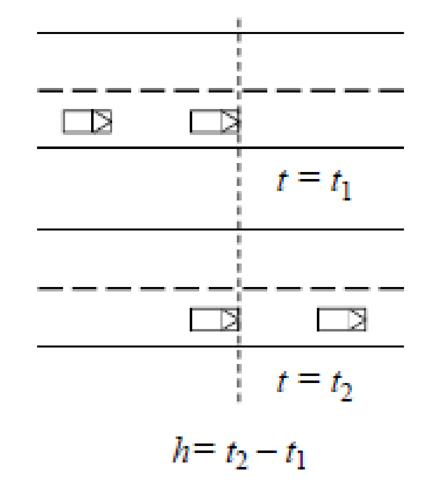
$$\bar{u}_t = \frac{\sum u_i}{n} = \frac{\sum {L}/{t_i}}{n}$$

Traffic Flow Elements

ii. Space-mean speed ($\bar{u}_s$):– Arithmetic mean of speeds of all vehicles occupying a relatively long section of the road at a given instant

$$\bar{u}_s = \frac{L}{\sum t_i/n} = \frac{nL}{\sum t_i}$$

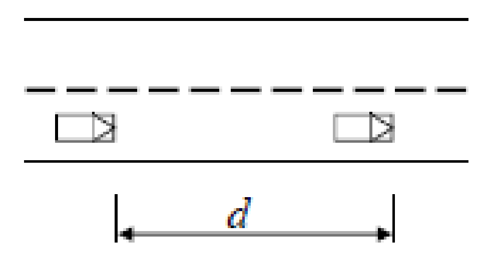
Time headway (h):



❖ Difference between the time the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives

Space headway (d):

❖ Distance between front of a vehicle and the front of the following vehicle



Flow-Density Relationships

- The general equation relating flow, density, and space mean speed is:

Flow = density * space-mean speed

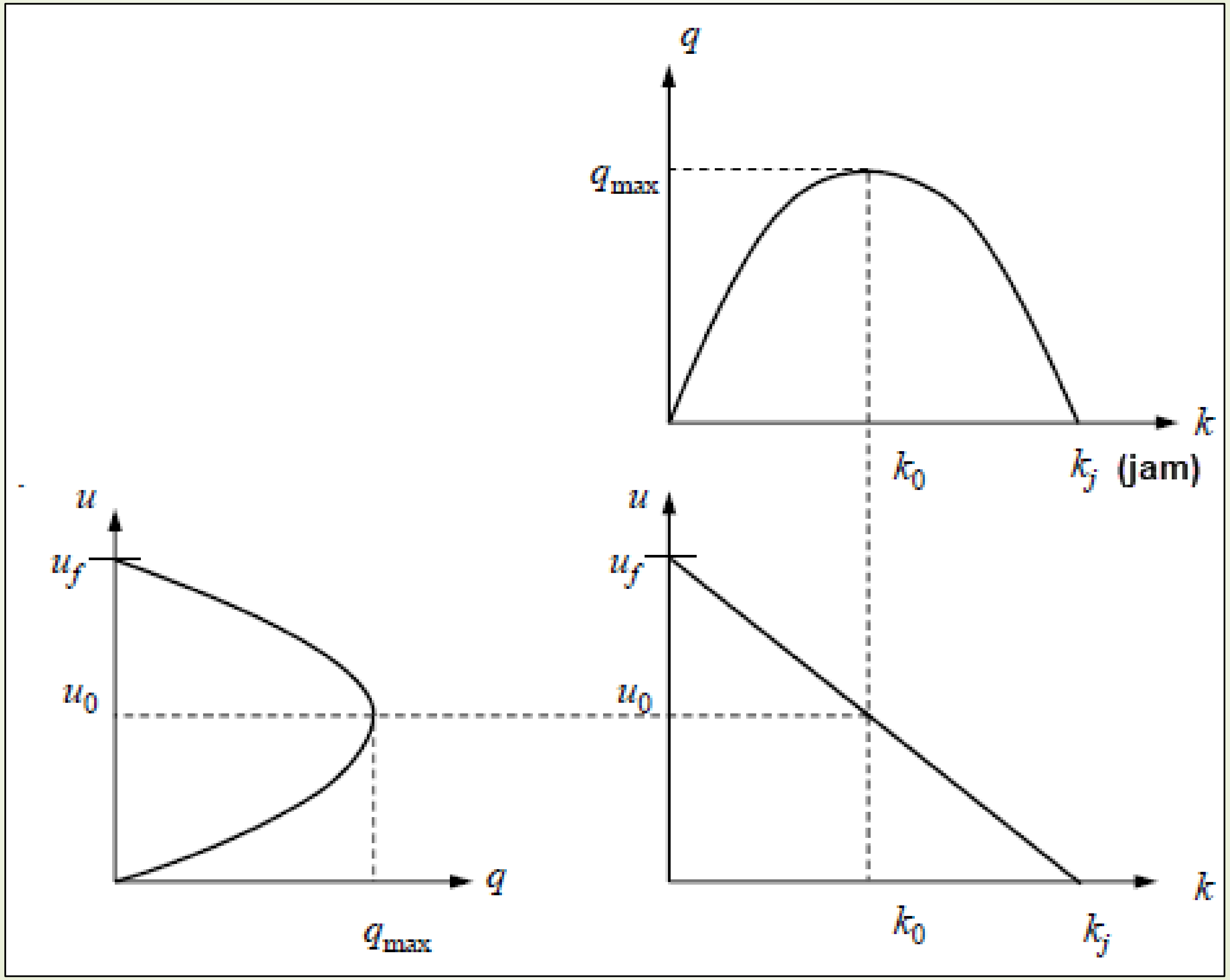
$$q = k \times \bar{u}_s$$

- Fundamental Diagram of flow:

When k = 0, q = 0

- As k increases, q increases to a maximum value qmax
- As k increases beyond k0 (critical density), q decreases
- At maximum k = kj (jam density), q = 0 as cars would line up

Flow-Density Relationships



Capacity and Level of Service

Capacity:

❖ The maximum hourly flow rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway under prevailing **roadway**, **traffic** and **control conditions**

- **Roadway conditions:**

– Associated with the geometric design of the road

– Examples: number of lanes, lane width, shoulder width, horizontal and vertical alignment, …

- **Traffic conditions:**

– Associated with characteristics of traffic stream

– Examples: traffic composition, directional distribution on two-lane highways, …

Capacity and Level of Service

- **Control conditions:**
  - Include traffic control devices, signal phasing, cycle length, …

❖ Capacity analysis involves the quantitative evaluation of the capability of a road section to carry traffic

Level of service (LOS):

❖ It is a qualitative measure of:

- The operating conditions within a traffic system, and

- How these conditions are perceived by drivers and passengers

Concept of LOS

- Six levels of service
  - A → highest
  - B
  - C
  - D
  - E
  - F → lowest

Concept of LOS

LOS Designations:

- **LOS A:**
  - Vehicles are completely unimpeded in their ability to manoeuvre
  - FFS prevails and effects of incidents and breakdowns are easily absorbed
- **LOS B:**
  - Reasonably free-flow conditions, and ability to manoeuvre is slightly restricted
  - Effects of minor incidents and breakdowns are easily absorbed
- **LOS C:**
  - Near free-flow speed, but freedom to manoeuvre is noticeably restricted
  - Substantial local deterioration in service due to minor incidents

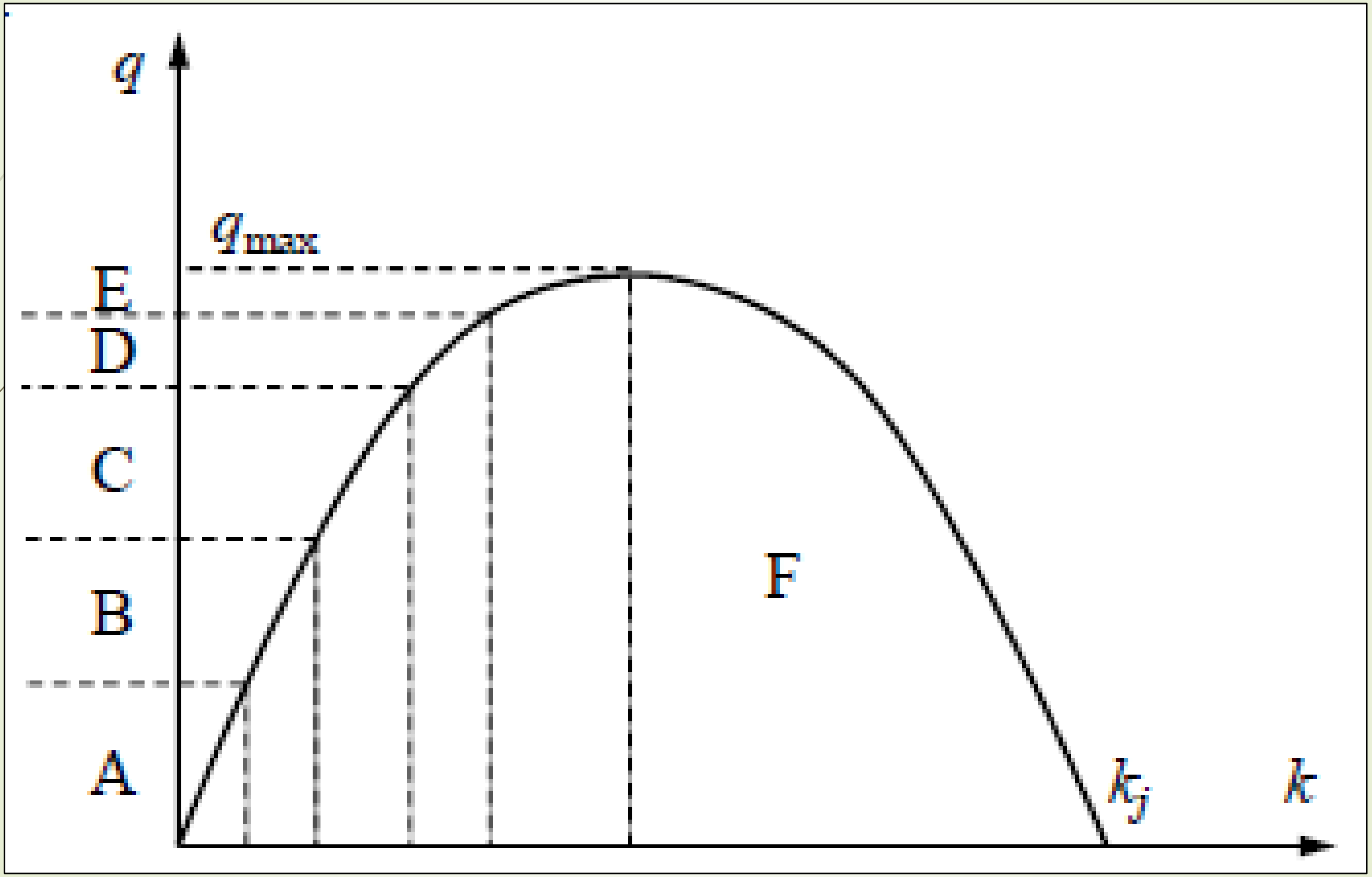
Concept of LOS

- **LOS D:**
  - Freedom to manoeuvre is more noticeably limited
  - Minor incidents can create queuing

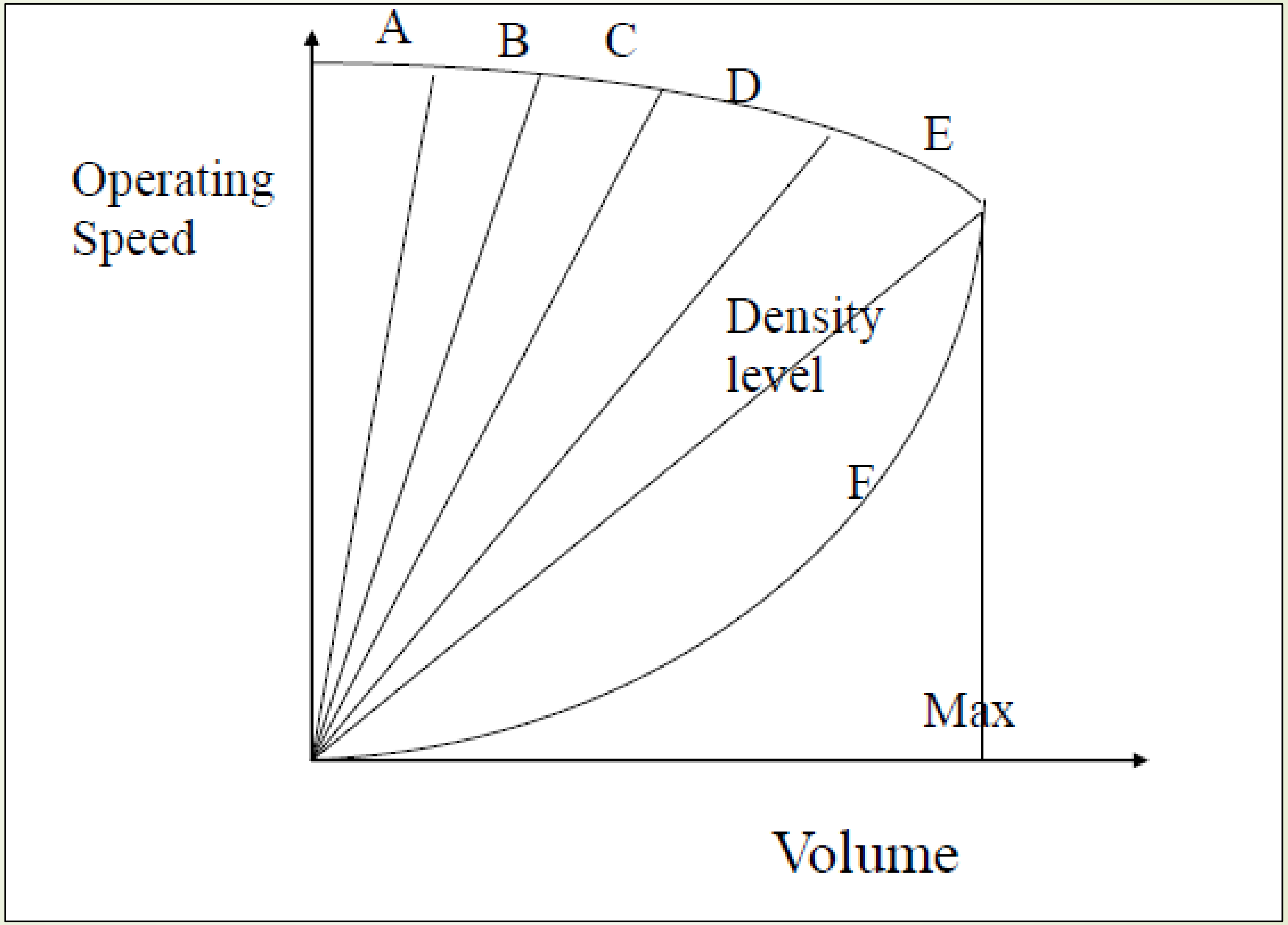
- **LOS E:**
  - Operation is near capacity
  - No useable gaps, and little room to manoeuvre
  - Minor incidents cause immediate and extensive queuing

- **LOS F:**
  - Breakdown in vehicular flow (forced-flow)
  - Number of cars arriving at a point > the number discharged

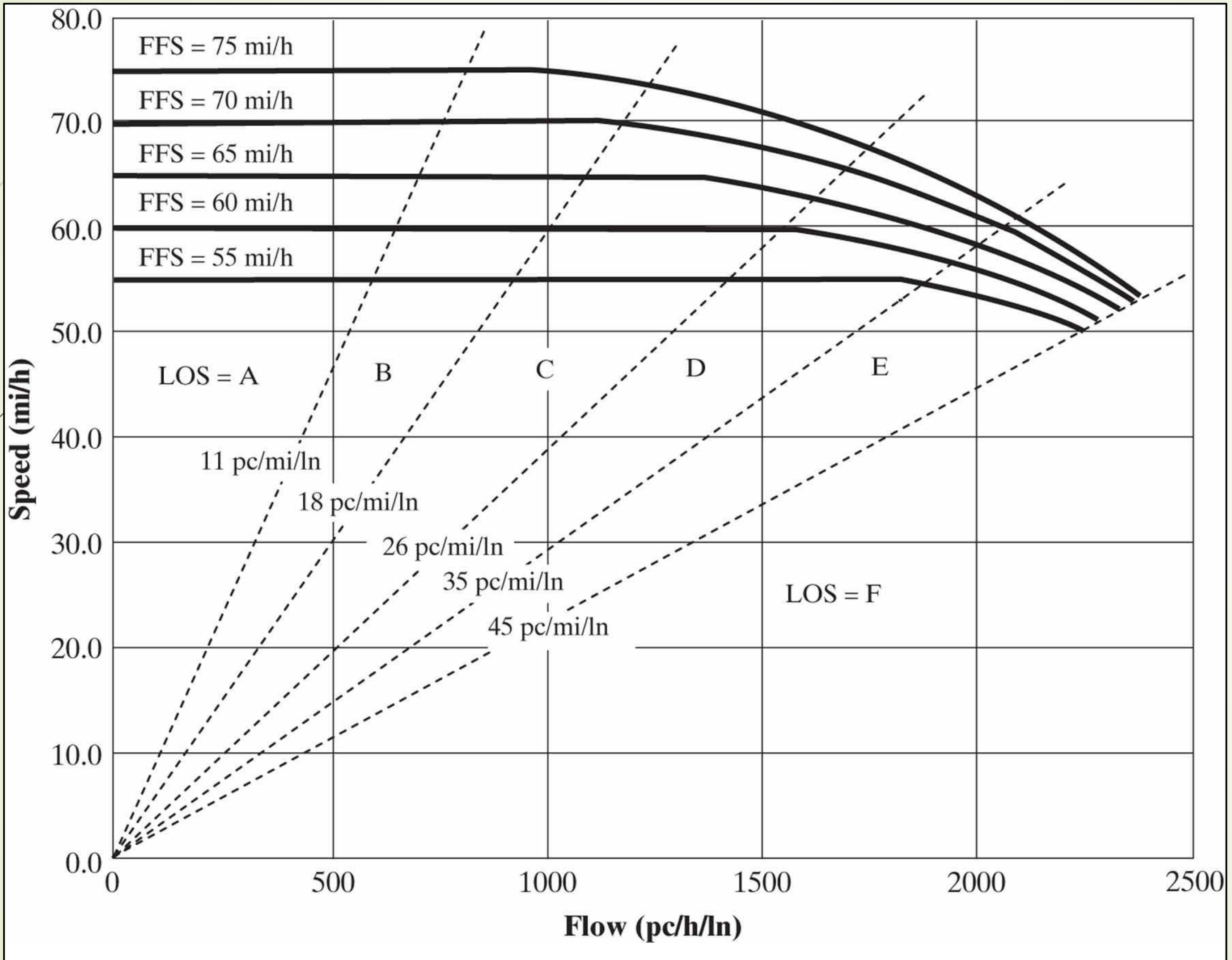
Concept of LOS



Concept of LOS



Concept of LOS



Concept of LOS

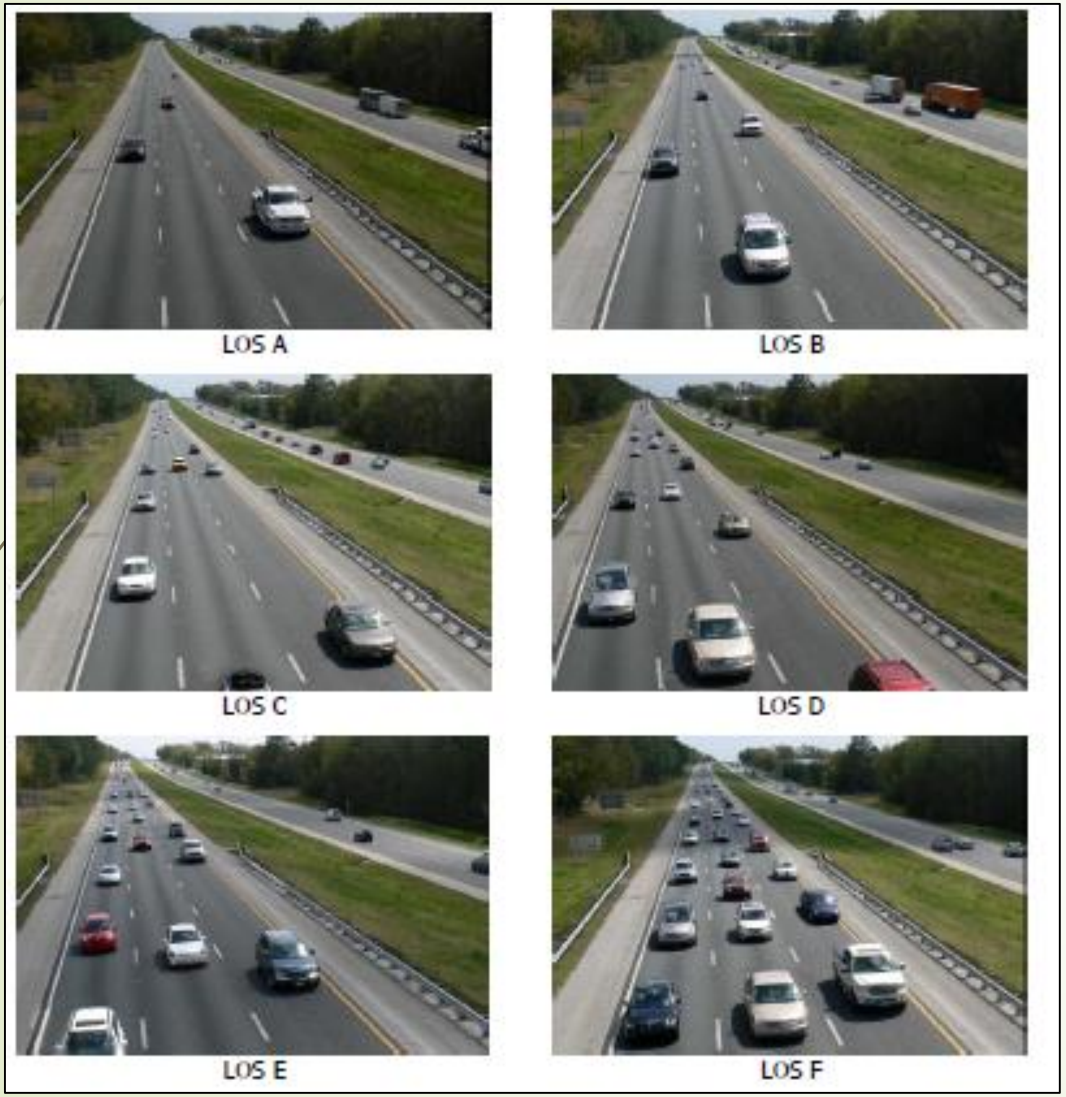


Figure 9.3b
(Garber & Hoel 2013)

Note:

We will study LOS for three types of road segments:

– Basic freeway segments
– Multi-lane highways
– Two-lane highways

Basic Freeway Segments

- A freeway is a divided highway with full access control and two or more lanes in each direction
- Opposing traffic is separated by a raised barrier, an at-grade median, or a raised traffic island

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

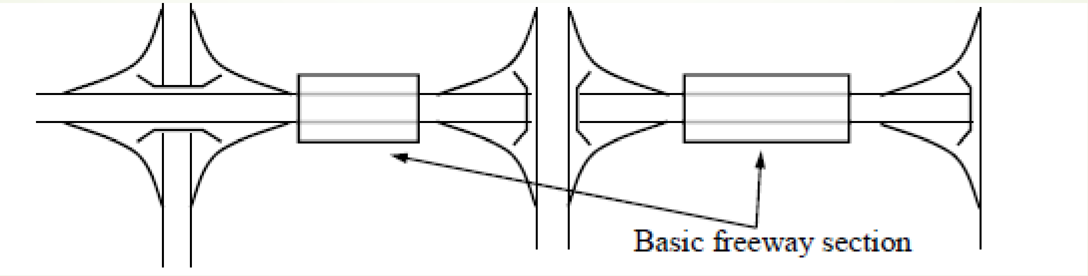
Basic Freeway Segments

❖ A freeway is composed of three elements:

i. **Ramp junctions**
– Merge influence area (1500 ft downstream an entrance)
– Diverge influence area (1500 ft upstream an exit)

ii. **Weaving areas**
– 500 ft upstream an entrance to 500 ft downstream following exit

iii. **Basic freeway segments**
– Segments outside the ramps or weaving influence areas



Basic Freeway Segments

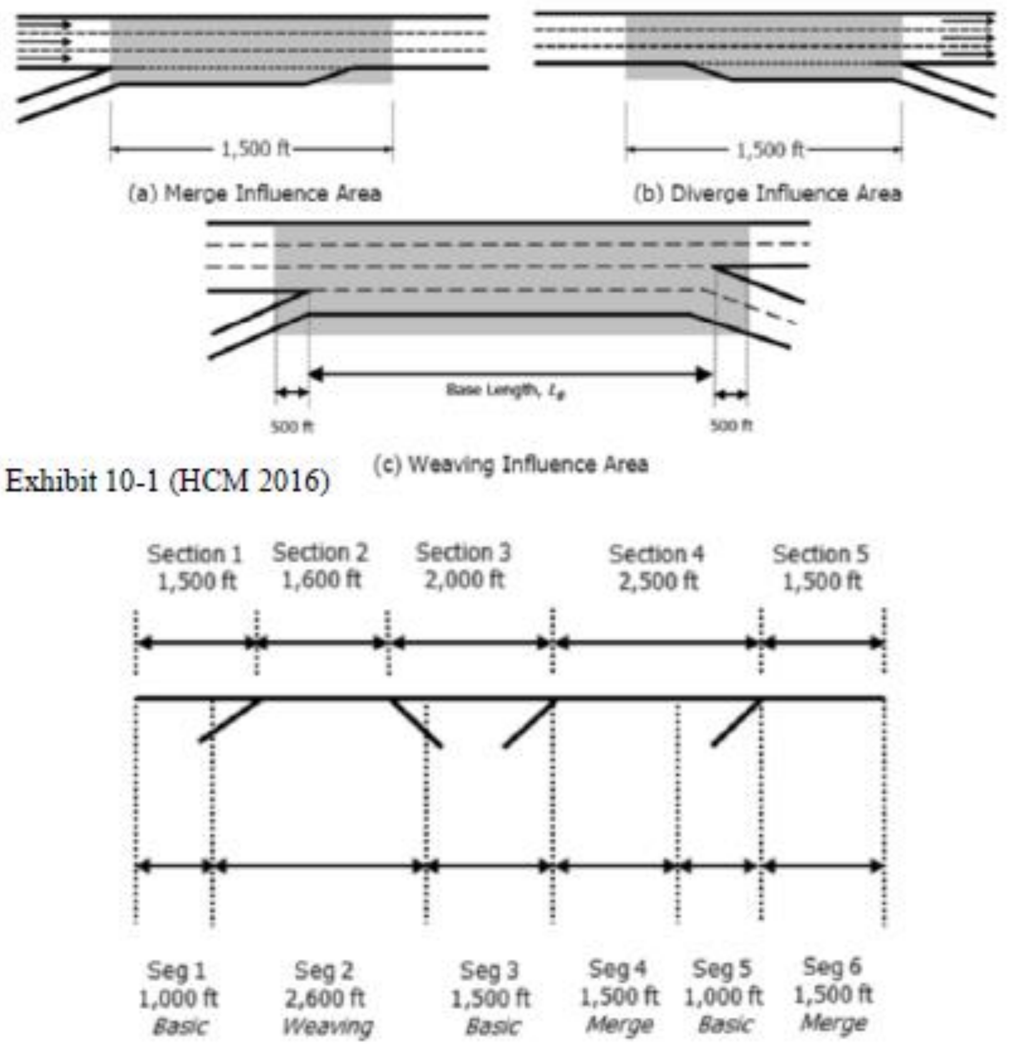
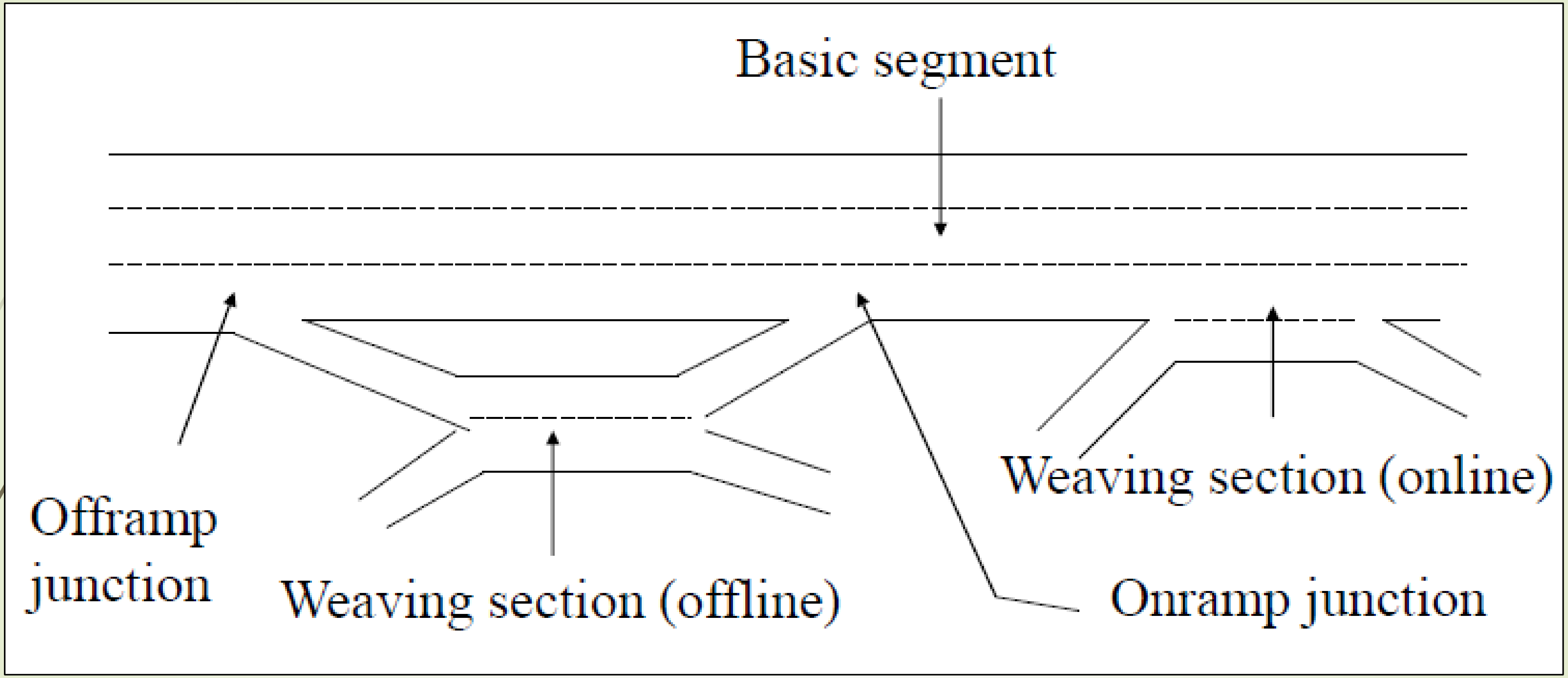


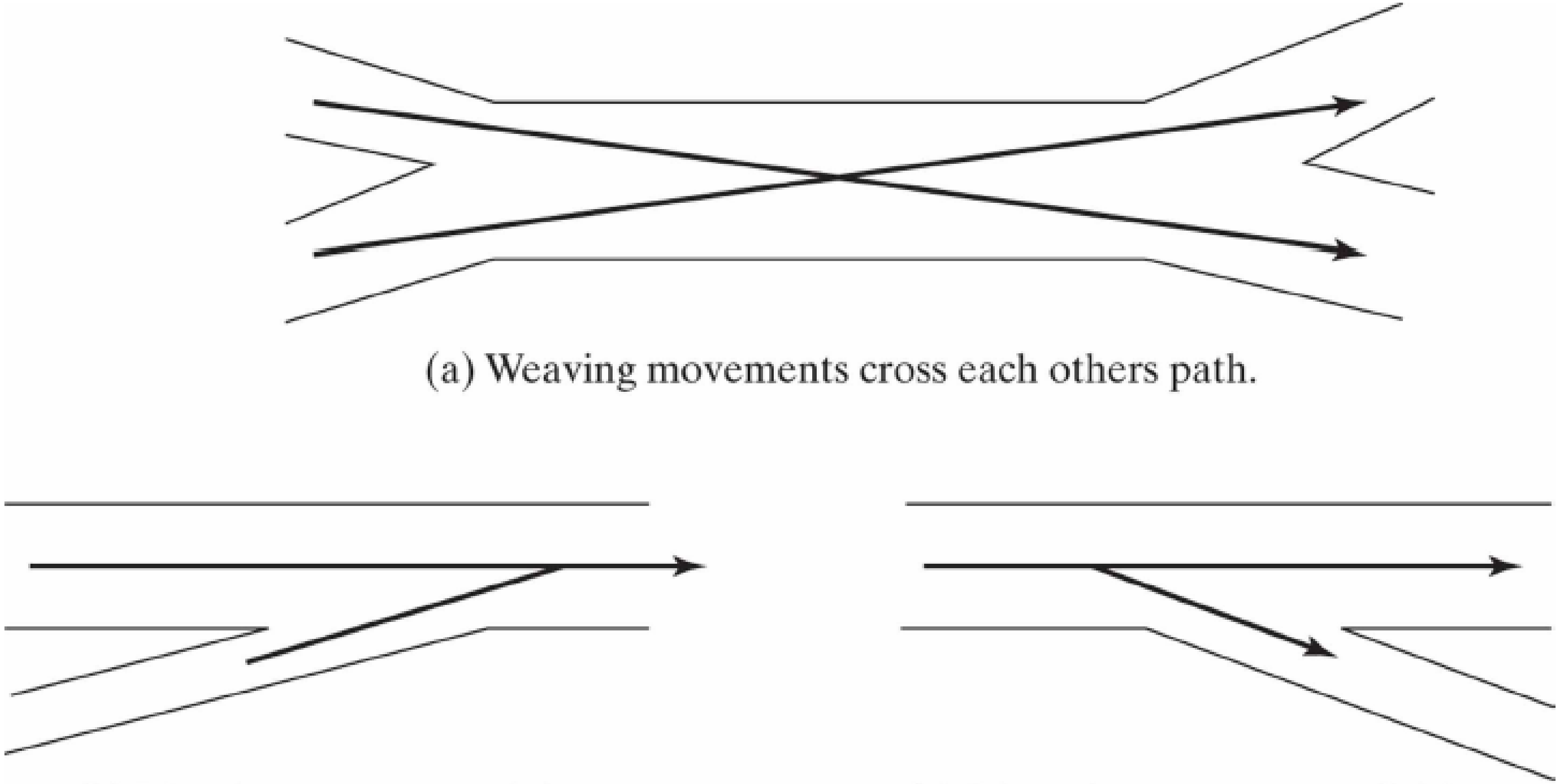
Exhibit 10-1 (HCM 2016)

Exhibit 10-2 (HCM 2016)

Basic Freeway Segments



Basic Freeway Segments



(a) Weaving movements cross each others path.

(b) Merging movements join to form a single traffic stream.

(c) Diverging movements divide to form separate traffic streams.

Basic Freeway Segments

Base conditions:

- Criteria to be satisfied for a basic freeway segment to operate at maximum capacity
- If any of the conditions is not met, segment's capacity is reduced

Conditions:

– No weather or visibility issues or incidents affecting traffic flow

– Traffic stream is all passenger cars; i.e. no trucks, buses, or RV's

– Lane width $\geq$ 12 ft (3.6 m)

– Lateral clearance (clearance between the body of the vehicle moving on the outermost lane to any of the way side installations like sign posts, signal tree etc)$\geq$ 6 ft (1.8 m)

Basic Freeway Segments

– All drivers are commuters; i.e. regular users and are familiar with the freeway

– Total ramp density is zero

– Ramp density = total number of on and off ramps per mile in one direction = number of on and off ramps within ± 3 miles divided by 6

– Traffic stream is not affected by upstream or downstream bottlenecks

– Level grade ($G \leq 2\%$)

Basic Freeway Segments

HCM procedure to estimate LOS:

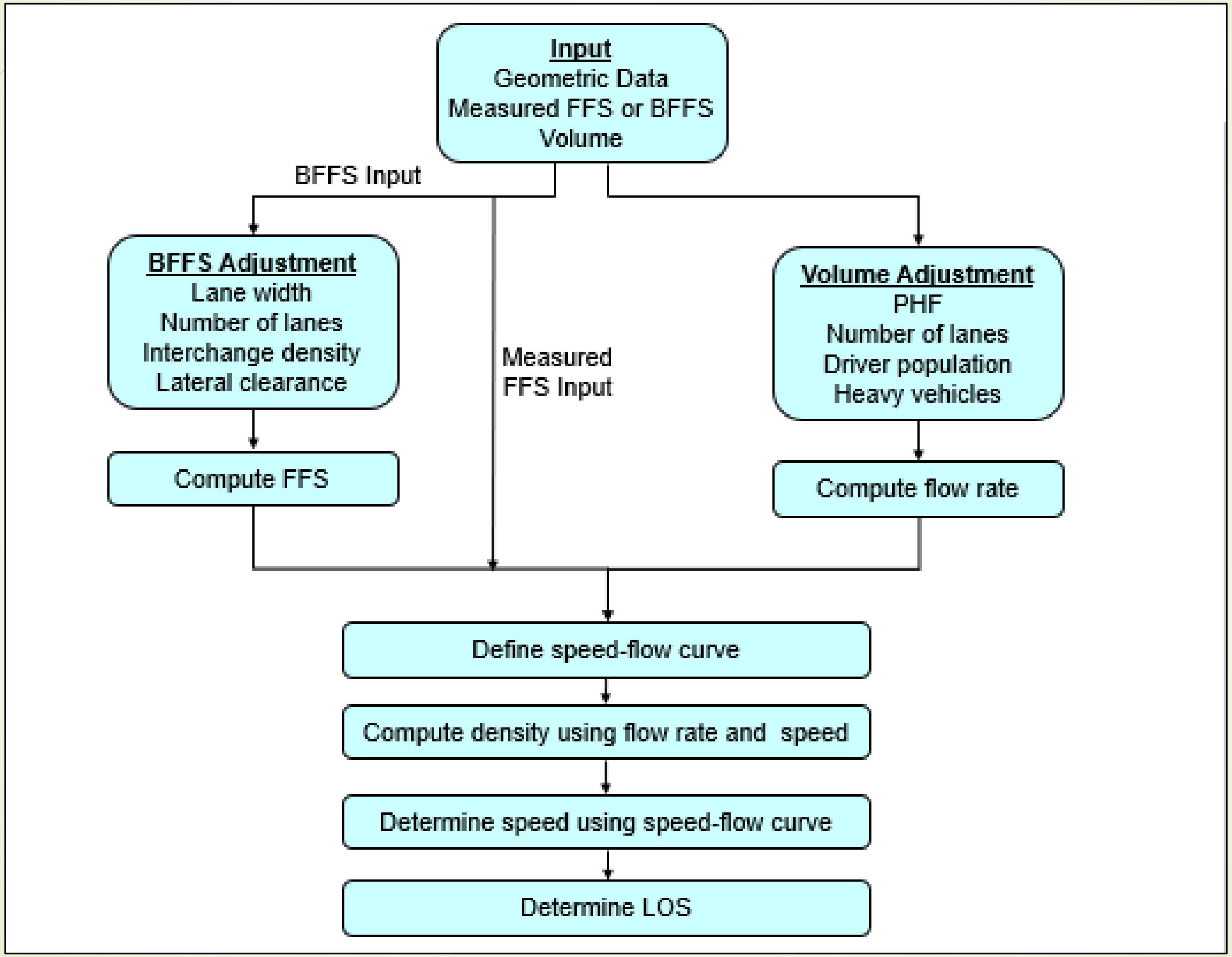
❖ LOS of basic freeway segments is estimated based on:

– Flow rate, v_p (pc/h/ln)

– Average car speed, S (mi/h)

– Density, D (pc/mi/ln)

Basic Freeway Segments



Basic Freeway Segments

Step 1: Specify input data

– Demand volume

– Number and width of lanes

– Right-side lateral clearance

– Total ramp density

– Percent of heavy vehicles (trucks, buses & RVs)

– Terrain (segment length & grade)

– Composition of driver population (commuters, regular users, …)

Basic Freeway Segments

Step 2: Compute free-flow speed (FFS)

– Mean speed of passenger cars under low to moderate traffic flows

– Can be measured in the field (flow rate < 1000 pc/h/ln) or computed as:

$$FFS = BFFS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84}$$

where

FFS = free-flow speed of the basic freeway segment (mi/h);

$BFFS$ = base FFS for the basic freeway segment (mi/h);

f_{LW} = adjustment for lane width, from Exhibit 12-20 (mi/h); **(HCM, 2016)**

f_{RLC} = adjustment for right-side lateral clearance, from Exhibit 12-21 (mi/h); **(HCM, 2016)** and

TRD = total ramp density (ramps/mi).

Basic Freeway Segments

Exhibit 12-20 : Adjustment to FFS for Average Lane Width for Basic Freeway and Multilane Highway Segments

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
≥11–12	1.9
≥10–11	6.6

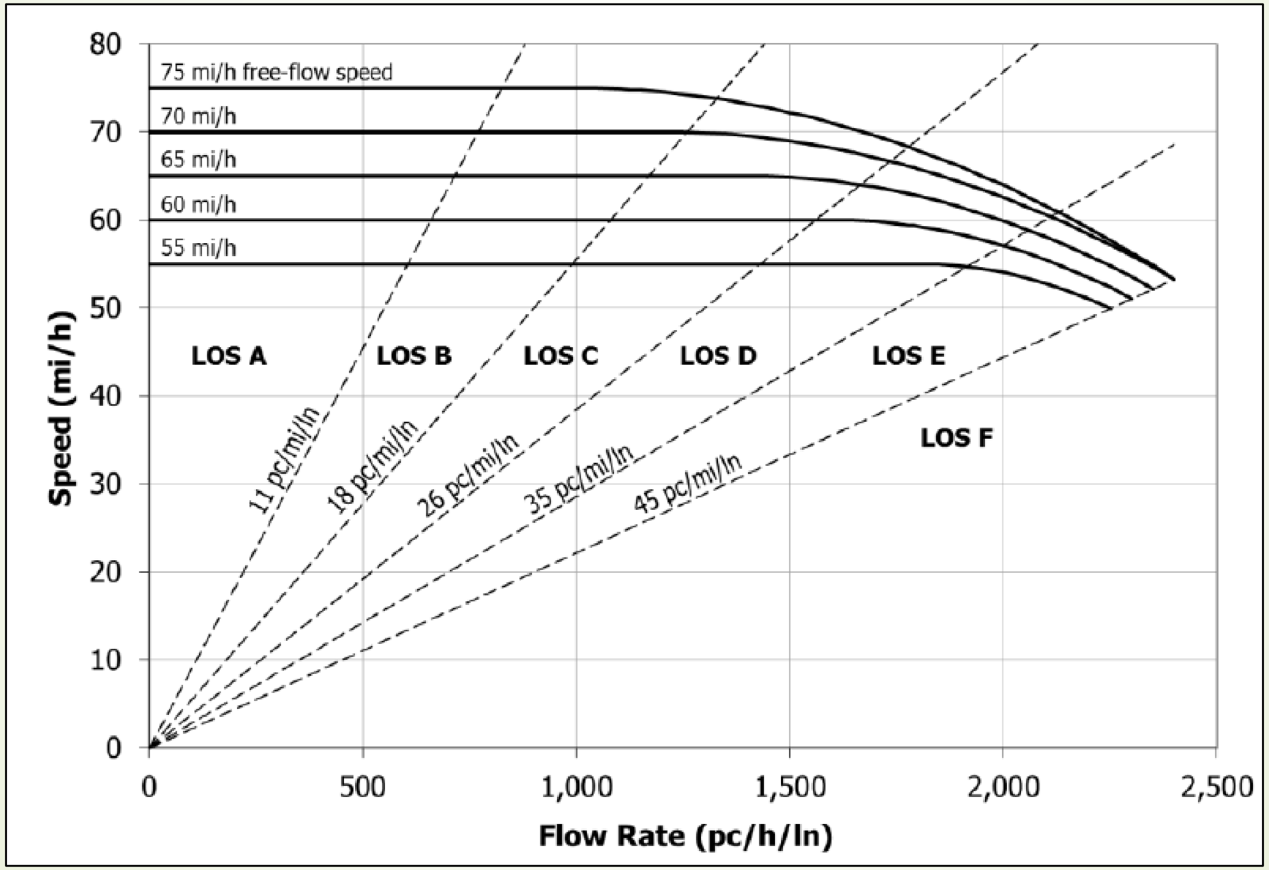
Exhibit 12-21 : Adjustment to FFS for Right-Side Lateral Clearance, f_{RLC} (mi/h), for Basic Freeway Segments

Right-Side Lateral Clearance (ft)	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	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Basic Freeway Segments

Step 3: Select FFS curve

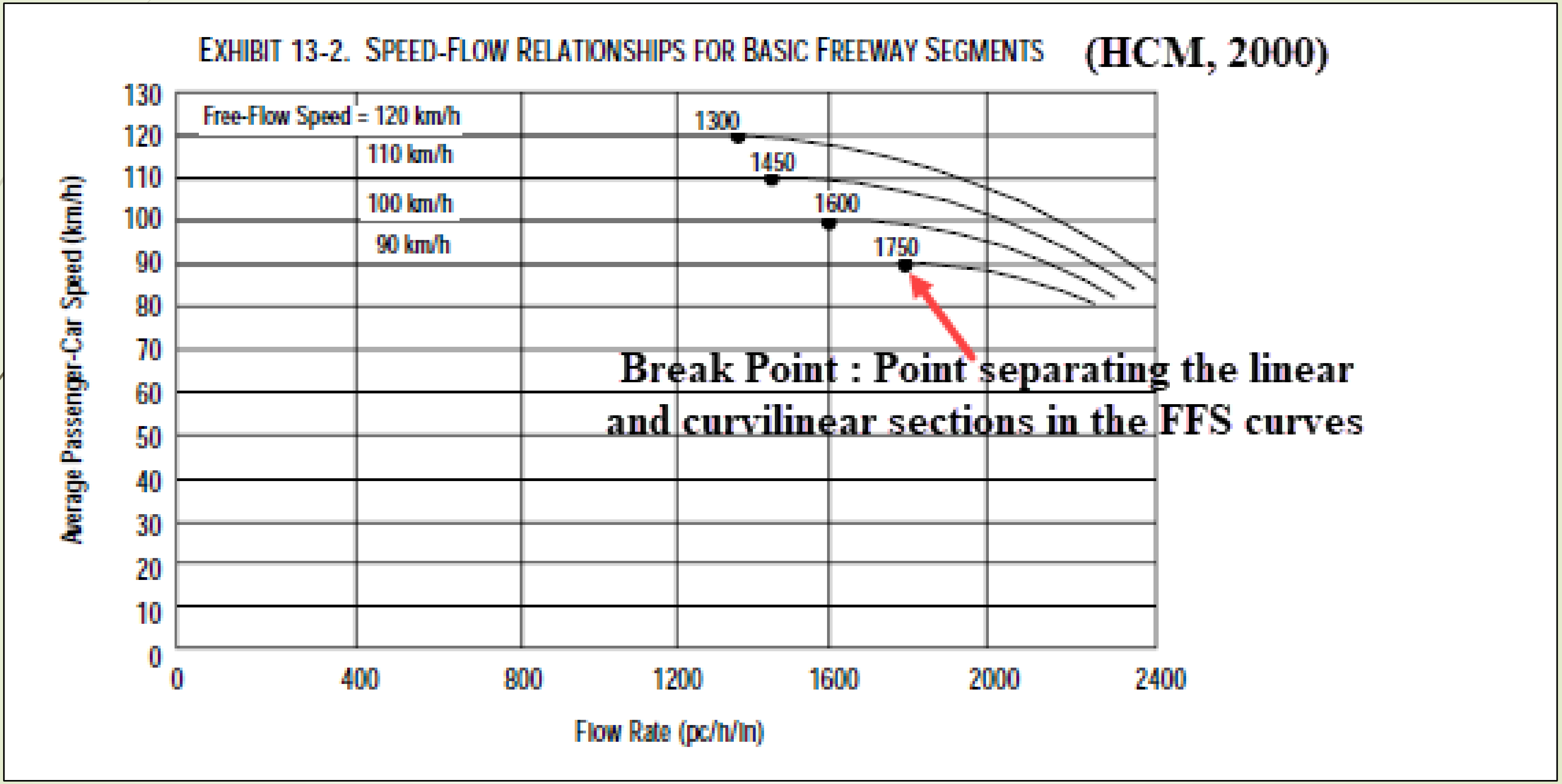
– Select based on the computed value of FFS (Exhibit 12-16, 2016 HCM)



– Do not interpolate between curves

Basic Freeway Segments

Step 3: Select FFS curve



Basic Freeway Segments

Step 4: Compute the demand flow rate (v_p) (HCM, 2000)

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

- V = demand hourly volume under prevailing conditions (veh/h)
- PHF = peak-hour factor
- N = number of lanes in the analysis direction
- f_p = adjustment factor for unfamiliar driver populations = 0.85–1.00
- f_{HV} = adjustment factor for presence of heavy vehicles

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

- Two cases for E_T and E_R
  - **Case 1: Extended general segment**
    - » *Not too long or too steep grades*
    - » *Area is level, rolling, or mountainous*
    - » *Use* ***Exhibit 21-8 (HCM, 2000)***
  - **Case 2: Specific grade**
    - » *$L > 0.25$ mi & $G > 3\%$ or $L > 0.5$ mi & $G = 2$-3%*
    - » *For upgrades: use* **Ex 21-9** *for E_T &* **Ex 21-10** *for E_R*
    - » *For downgrades: use* **Ex 21-11** *for E_T & E_R = E_R for level grade*

Basic Freeway Segments

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

Basic Freeway Segments

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

Basic Freeway Segments

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

Basic Freeway Segments

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

Basic Freeway Segments

Step 5: Estimate average passenger car speed (S)

– Equal to FFS at low flow rates (up to the breakpoint)

– Beyond the breakpoint, use the relevant equation:

FFS (mi/h)	Breakpoint (pc/h/ln)	Flow Rate Range: ≥0 ≤ Breakpoint	Flow Rate Range: >Breakpoint ≤ 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	$55 - 0.00002469\,(v_p - 1{,}800)^2$

Basic Freeway Segments

Step 5: Estimate average passenger car speed (S)

– Equal to FFS at low flow rates (up to the breakpoint of vp =1400 pc/h/ln):

– Beyond the breakpoint, use the relevant equation:

- $S_{BP-75} = 75 - 0.00001107(v_p - 1000)^2$
- $S_{BP-70} = 70 - 0.00001160(v_p - 1200)^2$
- $S_{BP-65} = 65 - 0.00001418(v_p - 1400)^2$
- $S_{BP-60} = 60 - 0.00001816(v_p - 1600)^2$
- $S_{BP-55} = 55 - 0.00002469(v_p - 1800)^2$

Basic Freeway Segments

Step 6: Compute the density (D)

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

Step 7: Estimate LOS

– If D > 45 pc/mi/ln, there are three posible options:

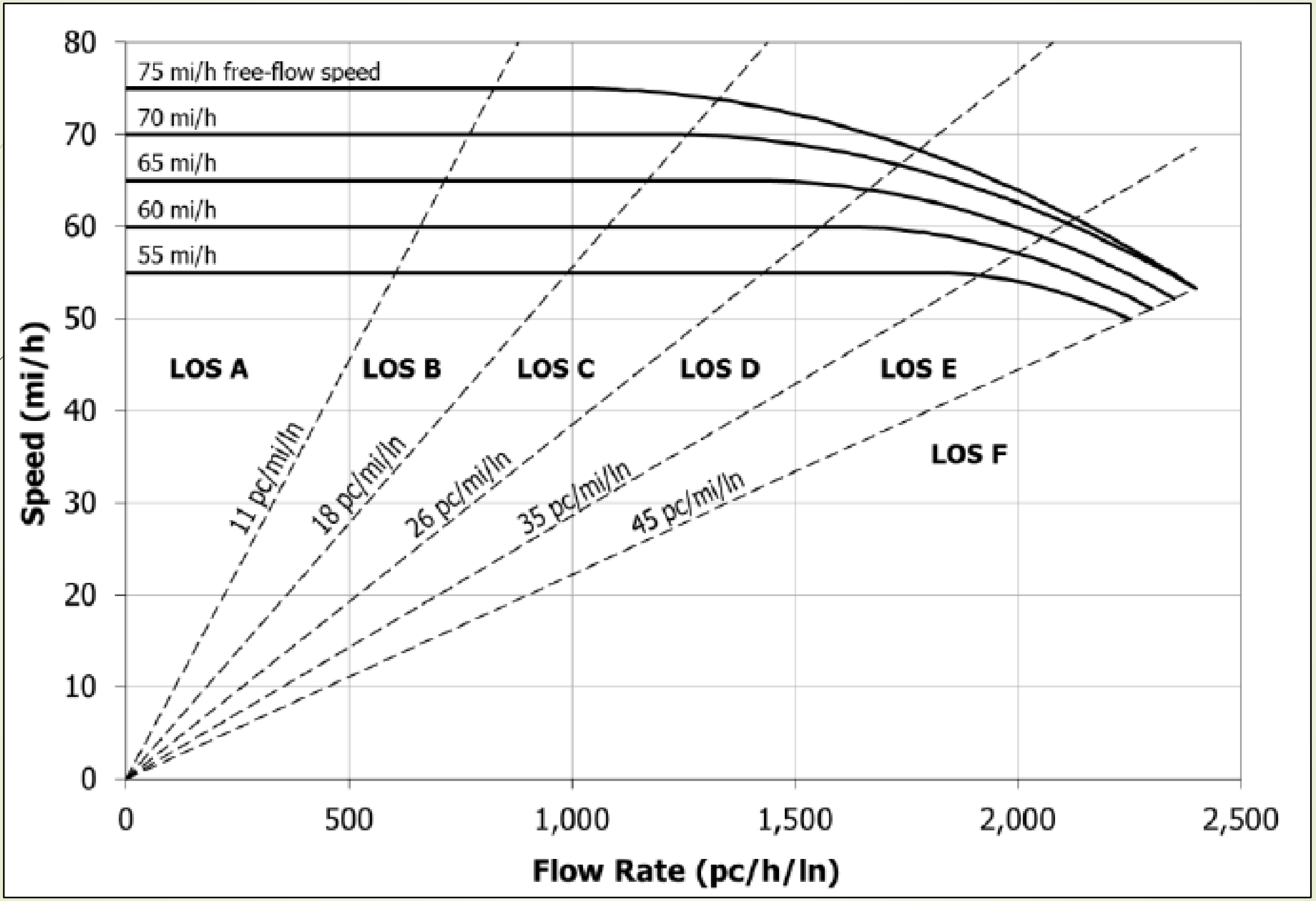
– **LOS = F**

– **Demand volume is greater than capacity**

– **Analysis procedure is not valid**

– Otherwise, determine LOS based on Exhibit 12-16 (HCM, 2016), Exhibit 11-5 (HCM, 2010) (Exhibit 12-15 in 2016 HCM)

Basic Freeway Segments



Basic Freeway Segments

LOS Criteria for Basic Freeway Segments (**Exhibit 11-5 HCM 2010)**

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

Basic Freeway Segments

LOS Criteria for Basic Freeway Segments

Criteria	LOS A	LOS B	LOS C	LOS D	LOS E
FFS = 75 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
Maximum v/c	0.34	0.56	0.76	0.90	1.00
Maximum service flow rate (pc/h/ln)	820	1350	1830	2170	2400
FFS = 70 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	70.0	70.0	68.2	61.5	53.3
Maximum v/c	0.32	0.53	0.74	0.90	1.00
Maximum service flow rate (pc/h/ln)	770	1260	1770	2150	2400
FFS = 65 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum v/c	0.27	0.44	0.64	0.85	1.00
Maximum service flow rate (pc/h/ln)	600	990	1430	1910	2250

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.

Basic Freeway Segments

Example 1: LOS – Basic Freeway Segments

Determine the LOS on a regular weekday on a 0.40-mi section of a six-lane urban freeway with a grade of 2 percent, using the following data:8

– Demand hourly volume, V = 3000 veh/h, PHF = 0.85

– Percentage trucks = 12%, percentage RV's = 2%

– Lane width = 11 ft, shoulder width = 6 ft

– Terrain = level

– Driver population adjustment factor fp = 0.9

– Ramp density: 4 diamond interchanges (2 ramps each) spaced 1.5 mi apart

Basic Freeway Segments

Solution:

Compute *FFS*:

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

– LW = 11 ft → Exbt 12-20 → $f_{LW} = 1.9$

– Sh.W. = 6 ft → Exbt 12-21 → $f_{LC} = 0$

– $TRD = \frac{2\times4}{6} = 1.33$ ramps/mi

$FFS = 75.4 - 1.9 - 0 - 3.22 \times (1.33)^{0.84} = 69.41\ mi/h$

Select FFS curve

– For FFS = 69.41 mi/h → use FFS curve = 70 mi/h; breakpoint = 1200 pc/h/ln

Compute v_p:

– $V = 3000$ veh/h, $PHF = 0.85$, $N = 3$, $f_p = 0.9$ (given)

– $P_T = 0.12$ & $P_R = 0.02$ (given)

– From Exbt 21- 8: $E_T = 1.5$ & $E_R = 1.2$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + 0.12(1.5 - 1) + 0.02(1.2 - 1)} = 0.94$$

$$v_p = \frac{V}{PHF \times N \times f_p \times f_{HV}} = \frac{3000}{0.85 \times 3 \times 0.9 \times 0.94} = 1391\ \text{pc/h/ln}$$

Basic Freeway Segments

Solution:

Estimate S:

– $v_p > 1200$ pc/h/ln

$S_{BP-70} = 70 - 0.00001160\,(1391 - 1200)^2 = 69.6$ mi/h

Compute D:

$$D = \frac{v_p}{S} = \frac{1391}{69.6} = 19.99 \text{ pc/mi/ln}$$

Determine LOS:

– D >18-26 pc/mi/ln → LOS = C

Basic Freeway Segments

Freeway Example 2

The Facts

- Demand volume = 75,000 veh/day,
- Proportion of AADT in the peak hour: 0.09,
- Directional distribution: 55/45,
- Rolling terrain, and
- Target LOS = D.

Given these, find number of lanes

Comments

In this planning and preliminary engineering application, several input variables are not specified, so default values will have to be used. With knowledge of local conditions and freeway design standards, the following default values will be used in the solution: FFS = 65 mi/h; 5% trucks, no RVs; PHF = 0.95; and f_p = 1.00.

Determining Opening-Day Directional Design-Hour Volume

Because the demand volume is given as an AADT, it must be converted to a directional design-hour volume (DDHV) by using Equation 11-8:

$$V = DDHV = AADT \times K \times D$$

$$V = DDHV = 75{,}000 \times 0.09 \times 0.55 = 3{,}713 \text{ veh/h}$$

Step 1: Input Data

All input data were specified.

Basic Freeway Segments

Freeway Example 2 (Cont.)

Step 2: Compute FFS

A default value of 65 mi/h will be used in this problem.

Step 3: Select FFS Curve

The 65-mi/h speed–flow curve will be used in this problem.

Step 4: Determine Number of Lanes Required

After estimating the demand volume on an hourly basis, the remainder of this solution follows the design application. The number of lanes needed is estimated by using Equation 11-7:

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

Next slide

The maximum service flow rate is selected from Exhibit 11-17 for LOS D on a 65-mi/h basic freeway segment: 2,030 pc/h/ln. The PHF is a default value: 0.95. The driver population factor is also a default value: 1.00. The freeway is in rolling terrain and is expected to have 5% trucks (another default value). From Equation 11-10, for rolling terrain, $E_T = 2.5$. See the following slides for Eq. 11-10

Basic Freeway Segments

Maximum Service Flow Rates in Passenger Cars per Hour per Lane for Basic Freeway Segments Under Base Conditions (Exhibit 11-17 HCM(2010)

FFS (mi/h)	Target 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.

Basic Freeway Segments

Freeway Example 2 (Cont.)

11-10, for rolling terrain, $E_T = 2.5$. Then

Eq.11.10

$$f_{HV} = \frac{1}{1+0.05(2.5-1)+0} = 0.930$$

$$N = \frac{3{,}713}{2{,}030 \times 0.95 \times 0.93 \times 1.00} = 2.07 \text{ lanes}$$

Because fractional lanes cannot be built, three lanes will have to be provided in each direction to ensure that LOS D is provided during the worst 15 min of the peak hour. Therefore, the resulting LOS may be better than the design target.

Step 5: Estimate Speed and Density

In order to determine the likely LOS resulting from a six-lane freeway, the speed and density should be estimated. Equation 11-2 is used to determine the actual demand flow rate for three lanes:

Basic Freeway Segments

Freeway Example 2 (Cont.)

Step 5: Estimate Speed and Density

In order to determine the likely LOS resulting from a six-lane freeway, the speed and density should be estimated. Equation 11-2 is used to determine the actual demand flow rate for three lanes:

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

$$v_p = \frac{3{,}713}{0.95 \times 3 \times 0.93 \times 1.00} = 1{,}401 \text{ pc/h/ln}$$

From Exhibit 11-3, for a 65-mi/h basic freeway segment with more than 1,400 pc/h/ln, the expected speed is

$$S = 65 - 0.00001418\left(v_p - 1{,}400\right)^2$$

$$S = 65 - 0.00001418\,(1{,}401 - 1{,}400)^2 = 65.0 \text{ mi/h}$$

Basic Freeway Segments

and the density is

$$D = \frac{v_p}{S} = \frac{1{,}401}{65.0} = 21.6 \text{ pc/mi/ln}$$

Step 6: Determine LOS

As shown in Exhibit 11-5, the expected LOS is C.

See previous slides for Exhibit 11-5.

Discussion

This problem illustrates an interesting point: given the parameters of this example problem, the target LOS of D cannot be achieved on opening day. If a four-lane freeway (two lanes in each direction) is built, LOS E will result. If a six-lane freeway (three lanes in each direction) is built, LOS C will result.

Multilane Highways

- Multilane highways differ from both two-lane highways and freeways
- They may exhibit some of the following characteristics:
  - – Posted speed limits are usually between 40 and 55 mi/h
  - – They may be undivided or include medians
  - – They are located in suburban areas or in high-volume rural corridors
  - – They may include a two-way left-turn median lane (TWLTL)
  - – Traffic volumes range from 15,000 to 40,000/day
  - – Volumes are up to 100,000/day with grade separations and no cross median access
  - – Traffic signals at major crossing points are possible
  - – There is partial control of access

Multilane Highways

Multilane Highways

HCM procedure to estimate LOS:

❖ Similar to basic freeway segments, LOS of multilane highways is estimated based on:

- Flow rate, v_p(pc/h/ln)
- Average car speed, S (mi/h)
- Density, D (pc/mi/ln)

Step 1: Specify input data

- Demand volume
- Number and width of lanes
- Right-side and median lateral clearance
- Roadside access points per miles
- Percent of heavy vehicles (trucks, buses & RVs)
- Terrain (segment length & grade)
- Composition of driver population (commuters, regular users, etc)

Multilane Highways

Step 2: Compute the value of free-flow speed (FFS)

– Can be measured in the field (flow rate < 1000 pc/h/ln) or computed as:

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

where

FFS = free-flow speed of the multilane highway segment (mi/h);

$BFFS$ = base FFS for the multilane highway segment (mi/h);

f_{LW} = adjustment for lane width, from Exhibit 12-20 (mi/h); **(HCM, 2016)**

f_{TLC} = adjustment for total lateral clearance, from Exhibit 12-22 (mi/h); **(HCM, 2016)**

f_M = adjustment for median type, from Exhibit 12-23 (mi/h); and **(HCM, 2016)**

f_A = adjustment for access point density, from Exhibit 12-24 (mi/h). **(HCM, 2016)**

Multilane Highways

Exhibit 12-20 : Adjustment to FFS for Average Lane Width for Basic Freeway and Multilane Highway Segments

Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
≥11–12	1.9
≥10–11	6.6

Multilane Highways

Exhibit 12-22 : Adjustment to FFS for Lateral Clearances for Multilane Highways

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)	TLC (ft)	Reduction in FFS, f_{TLC} (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

Note: Interpolation to the nearest 0.1 is recommended.

Multilane Highways

Exhibit 12-23 : Adjustment to FFS for Median Type for Multilane Highways

Median Type	Reduction in FFS, f_M (mi/h)
Undivided	1.6
TWLTL	0.0
Divided	0.0

Multilane Highways

Exhibit 12-24 : Adjustment to FFS for Access Point Density for Multilane Highways

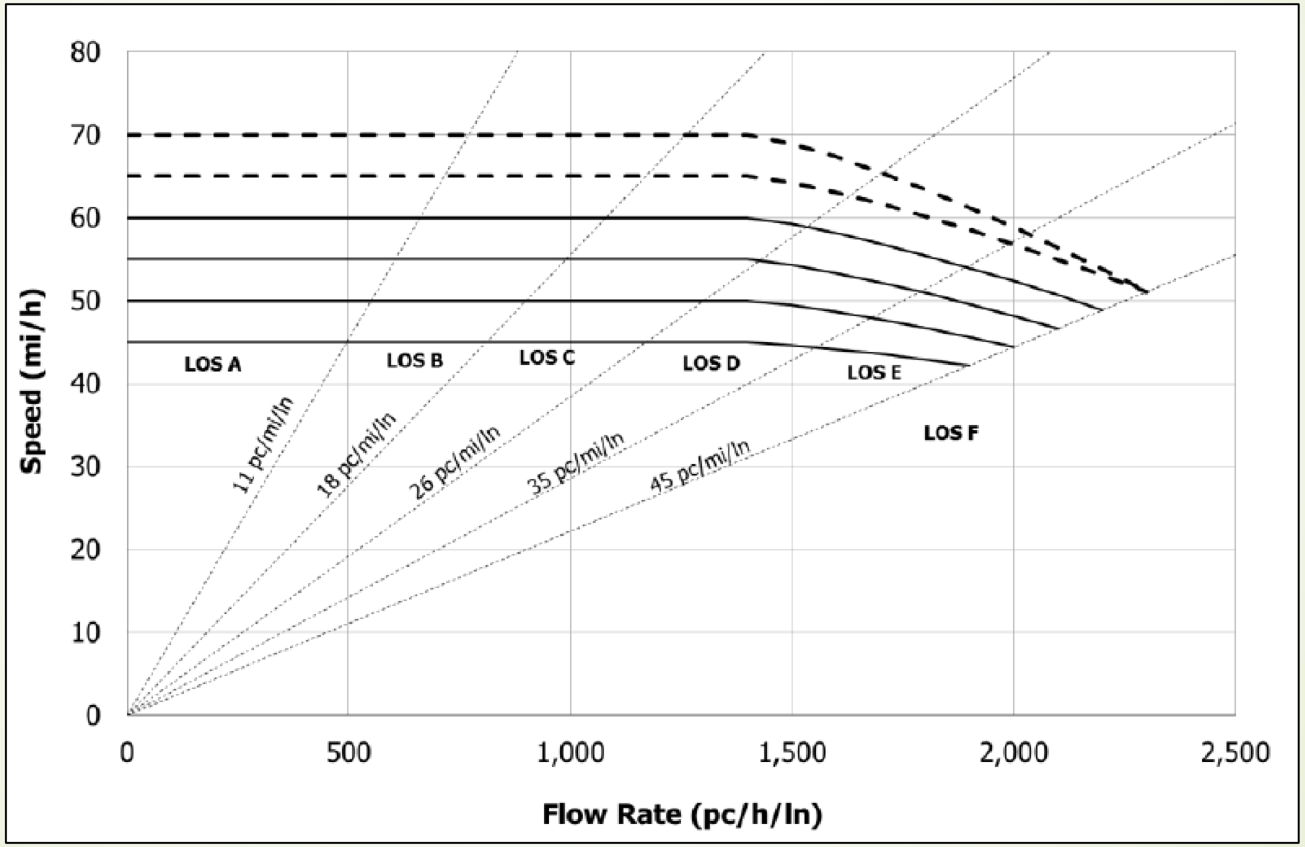
Access Point Density (access points/mi)	Reduction in FFS, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥40	10.0

Note: Interpolation to the nearest 0.1 is recommended.

Multilane Highways

Step 3: Select FFS curve

– Select based on the computed value of FFS (Exhibit 12-17, 2016 HCM)



– Do not interpolate between curves

Multilane Highways

Step 4: Compute the demand flow rate (v_p) (HCM, 2000)

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

- V = demand hourly volume under prevailing conditions (veh/h)
- PHF = peak-hour factor
- N = number of lanes in the analysis direction
- f_p = adjustment factor for unfamiliar driver populations = 0.85–1.00
- f_{HV} = adjustment factor for presence of heavy vehicles

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

- Two cases for E_T and E_R
  - **Case 1: Extended general segment**
    - *Not too long or too steep grades*
    - *Area is level, rolling, or mountainous*
    - *Use* ***Exhibit 21-8 (HCM, 2000)***
  - **Case 2: Specific grade**
    - *$L > 0.25$ mi & $G > 3\%$ or $L > 0.5$ mi & $G = 2$-3%*
    - *For upgrades: use* **Ex 21-9** *for E_T &* **Ex 21-10** *for E_R*
    - *For downgrades: use* **Ex 21-11** *for E_T & $E_R = E_R$ for level grade*

Multilane Highways

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

Multilane Highways

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

Multilane Highways

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

Multilane Highways

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

Multilane Highways

Step 5: Estimate average passenger car speed (S)

– Equal to FFS at low flow rates (up to the breakpoint of vp =1400 pc/h/ln):

– Beyond the breakpoint, use the relevant equation:

- $S_{BP-60} = 60 - \left[5.00 \times \left(\frac{v_p - 1400}{800}\right)^{1.31}\right]$
- $S_{BP-55} = 55 - \left[3.78 \times \left(\frac{v_p - 1400}{700}\right)^{1.31}\right]$
- $S_{BP-50} = 50 - \left[3.49 \times \left(\frac{v_p - 1400}{600}\right)^{1.31}\right]$
- $S_{BP-60} = 45 - \left[2.78 \times \left(\frac{v_p - 1400}{500}\right)^{1.31}\right]$

Multilane Highways

Step 6: Compute the density (D)

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

Step 7: Estimate LOS

– Threshold of LOS F changes with FFS:

– Begins with D = 40 pc/mi/ln for 60 mi/h and increases to 45pc/mi/ln for 45 mi/h

– Otherwise, LOS criteria are similar to those on basic freeway segments determine LOS based on Exhibit 11-5 (HCM, 2010)

Multilane Highways

LOS Criteria for Basic Freeway Segments (**Exhibit 11-5 HCM 2010**)

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

Multilane Highways

Example 1: LOS – Multilane Highways

A 3200 ft segment of 3.25 mi four-lane undivided multilane highway in a suburban area is at a 2.5% grade. The highway is in level terrain, and lane widths are 11 ft. The measured free-flow speed is 46.0 mi/h. The directional peak hour volume is 1900 veh/h, PHF is 0.9, and there are 13% trucks and 2% RV's. Determine the LOS on the upgrade and downgrade

Multilane Highways

For the downgrade:

- Compute FFS:
  - Measured value is FFS = 46.0 mi/h
- Select FFS curve
  - For FFS = 46.0 mi/h → <u>use</u> FFS curve = 45 mi/h
- Compute v_p:
  - V = 1900 veh/h, PHF = 0.90, N = 2 (given)
  - f_p = 1.00 (assume commuter drivers)
  - P_T = 0.13 & P_R = 0.02 (given)
  - L = 3200/5280 = 0.606 mi, G = 2.5%
    - **From Ex 21-9, E_T = 1.5**
    - **From Ex 21-8, (level terrain): E_R = 1.2**
  - $f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} = \frac{1}{1+0.13(1.5-1)+0.02(1.2-1)} = 0.935$

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} = \frac{1900}{0.90 \times 2 \times 0.935 \times 1} = 1129 \text{ pc/h /ln}$$

- Determine S:
  - Since v_p < 1400 pc/h/ln ⇒ $S = FFS$ = 45 mi/h **(Exhibit 12-17, 2016 HCM)**
- Compute D:
  - $D = \frac{v_p}{S} = \frac{1129}{45} = 25.09$ pc/mi/ln
- Determine LOS **(Exhibit 11-5, 2010 HCM)**
  - D >18-26 pc/mi/ln → <u>**LOS = C**</u>

Multilane Highways

For the upgrade:

- Compute FFS:
  - Measured value is FFS = 46.0 mi/h
- Select FFS curve
  - For FFS = 46.0 mi/h → use FFS curve = 45 mi/h
- Compute v_p:
  - V = 1900 veh/h, PHF = 0.90, N = 2 (given)
  - f_p = 1.00 (assumed)
  - P_T = 0.13 & P_R = 0.02 (given)
  - L = 0.606 mi, G = 2.5%
    - From Ex 21-9, $E_T = 1.5$
    - From Ex 21-10, $E_R = 3.0$
  - $f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} = \frac{1}{1+0.13(1.5-1)+0.02(3.0-1)} = 0.905$

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} = \frac{1900}{0.90 \times 2 \times 0.905 \times 1} = 1166 \text{ pc/h /ln}$$

- Determine S:
  - Since v_p < 1400 pc/h/ln ⇒ $S = FFS$ = 45 mi/h (Exhibit 12-17, 2016 HCM)
- Compute D:
  - $D = \frac{v_p}{S} = \frac{1166}{45} = 25.91$ pc/mi/ln
- Determine LOS (Exhibit 11-5, 2010 HCM)
  - D >18-26 pc/mi/ln → <u>LOS = C</u>

Two-lane highways

- For LOS analysis, two-lane highways are classified into three classes according to their function:

– Class I:

– Function is to serve as primary arterials, daily commuter routes, and links to other arterial highways

– Motorists' expectations are that travel will be at relatively high speeds

– Class II:

– Function is to serve as access to Class I highways, and scenic byways

– Average trip lengths are shorter than on Class I highways

– Motorists' expectation is slower travel speeds than on Class I highways

– Class III:

– Serve moderately developed areas. May be a portion of Class I or Class II highway passing through a small town or recreational area

– May be used by local traffic and number of unsignalized access points is higher than in rural areas

Two-lane highways

(a) Examples of Class I Two-Lane Highways

(b) Examples of Class II Two-Lane Highways

(c) Examples of Class III Two-Lane Highways

Figure 9.9 Two-Lane Highway Classification Illustrated

SOURCE: From *Highway Capacity Manual 2010*. Copyright, National Academy of Sciences, Washington, D.C. Reproduced with permission of the Transportation Research Board.

Two-lane highways

- Base conditions for two-lane highways:
  - No restrictive conditions due to geometric elements, traffic control, or environment
  - Level terrain
  - Lane width ≥ 12ft
  - Clear shoulders ≥ 6 ft
  - Passing permitted with PSD > 1000 ft
  - No restriction on through traffic due to control
  - All passenger cars in traffic stream
- Capacity of a two-lane highway under base conditions is:
  - 1700 pc/h for each direction of travel
  - Nearly independent of directional distribution
  - 3200 pc/h for the two directions of the extended segment
  - If one direction reaches 1700 pc/h, the other direction is limited to 1500 pc/h
  - 3200-3400 pc/h for short sections of two-lane highway, such as a tunnel or bridge

Two-lane highways

❖ Three measures to describe service quality:

– Percent time spent following another vehicle (PTSF):

– The average percentage of time that vehicles are traveling behind slower vehicles (time headway between consecutive vehicles is less than 3 s)

– Average travel speed (ATS):

– The space mean speed of vehicles in the traffic stream

– Percent of free-flow speed (PFFS):

– A measure of the ability of vehicles to travel at the posted speed limit

❖ LOS criteria (Exhibit 15-3, 2010 HCM):

– Class I highways: PTSF & ATS

– Class II highways: PTSF only ATS

– Class III highways: PFFS

Two-lane highways

Exhibit 15-3, 2010 HCM

LOS	Class I Highways ATS (mi/h)	Class I Highways PTSF (%)	Class II Highways PTSF (%)	Class III Highways PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50–55	>35–50	>40–55	>83.3–91.7
C	>45–50	>50–65	>55–70	>75.0–83.3
D	>40–45	>65–80	>70–85	>66.7–75.0
E	≤40	>80	>85	≤66.7

Two-lane highways

LOS Designations:

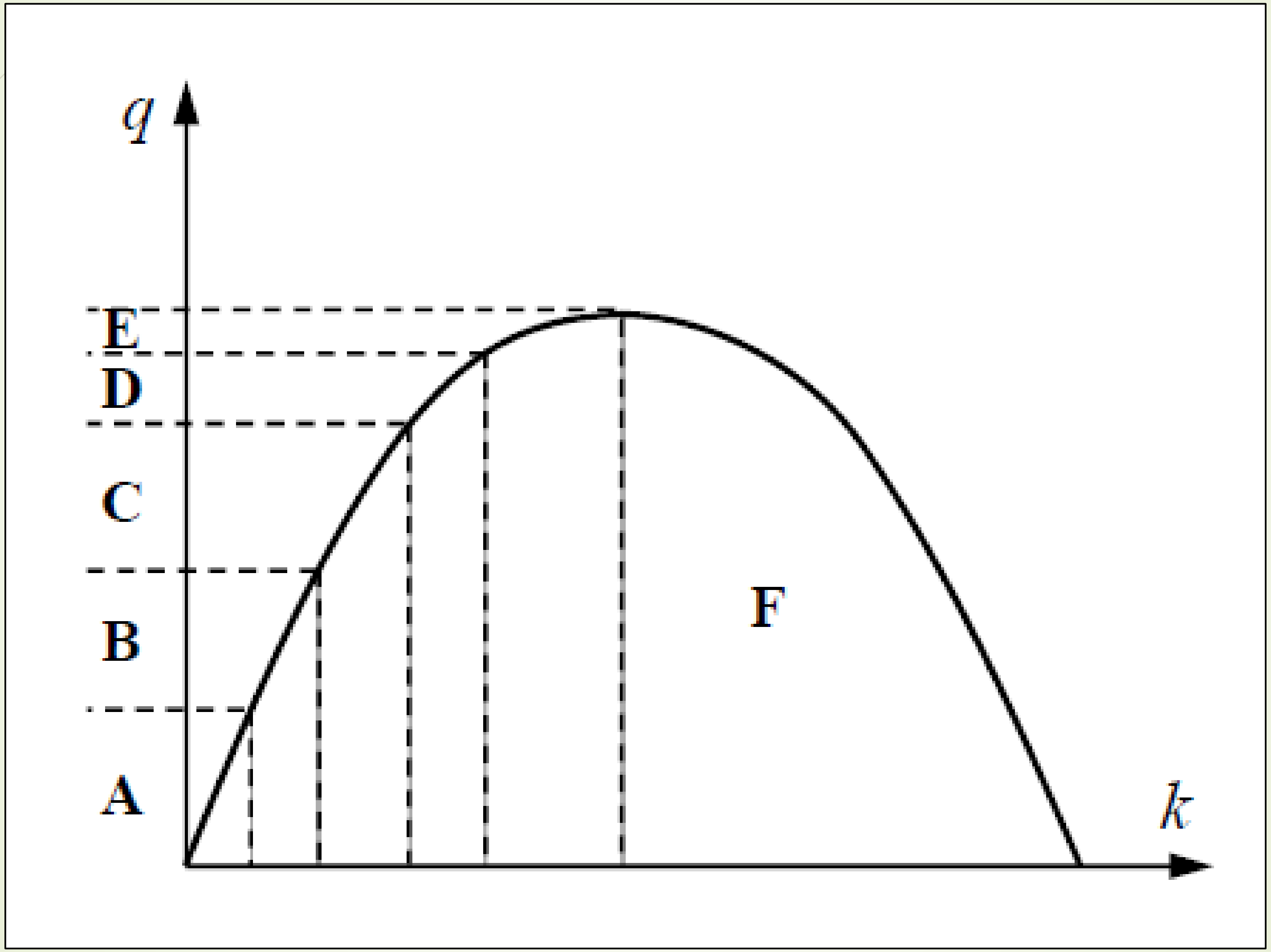
- LOS A:
  - – Class I: motorists travel at their desired speed; need for passing is below capacity
  - – Class II: speeds are controlled by road conditions; small amount of platooning is likely
  - – Class III: speeds close or equal to FFS
- LOS B:
  - – Class I: passing demand and capacity are balanced; some speed reduction is in evidence
  - – Class II: some degree of platooning is noticeable
  - – Class III: maintaining FFS operation is difficult; speed is noticeably reduced

Two-lane highways

LOS Designations:

- LOS C:
  - – All classes: most vehicles travel in platoons and speeds decrease
- LOS D:
  - – Platooning increases significantly
- LOS E:
  - – Demand is approaching capacity
  - – Class I&II: passing has become virtually impossible
  - – Class III: speeds are less than two-thirds of FFS
- LOS F:
  - – Congested flow
  - – Demand is greater than capacity in one direction

Two-lane highways



Two-lane highways

- LOS on each direction is analyzed separately

  – Procedure to compute PTSF applies to Class I & II highways
  – Procedure to compute ATS applies to Class I & III highways
  – Procedure to compute PFFS applies to Class III highways only

- Analysis can be carried out for:

  – Direction segments in general terrain (level or rolling)
  – Direction segments on specific grades (mountainous terrain or $G \geq 3\%$ & $L \geq 0.6$ mi)
  – Direction segments that include passing and truck climbing lanes

Two-lane highways

Procedures for LOS analysis:

- Develop input data: Class I, II & III
  - Geometry, volume, BFFS
- Estimate FFS: Class I & III
  - Direct field measurement (volume < 200 veh/h)
  - Field measurement with speed adjustment (volume > 200 veh/h)
  - Adjustments to BFFS (f_{LS}, f_A)
- Compute demand adjustments for ATS: Class I & III
  - PHF, $f_{HV,ATS}$, $f_{g,ATS}$

Two-lane highways

Procedures for LOS analysis:

- Compute demand adjustments for PTSF: Class I & II
  - PHF, $f_{HV,PTSF}$, $f_{g,PTSF}$
- Estimate PTSF: Class I & II
  - $f_{np,PTSF}$
- Estimate PFFS: Class III
- Determine LOS: Class I, II & III

Two-lane highways

Estimating FFS:

- Direct field measurement (volume < 200 veh/h)
- Field measurement with speed adjustment (volume > 200 veh/h)

$$FFS = S_{FM} + 0.00776 \frac{V}{f_{HV,ATS}}$$

  - S_{FM} = mean speed of sample (mi/h)
  - V = total demand flow rate, both directions, during speed measurement (veh/h)
  - $f_{HV,ATS}$ = heavy vehicle adjustment factor

- Adjustments to BFFS

$$FFS = BFFS - f_{LS} - f_A$$

  - FFS = estimated free-flow speed (mi/h)
  - BFFS = base free-flow speed (mi/h)
    - *Depends on local conditions*
    - *Should be estimated based on knowledge of the area and speeds on similar facilities*
    - *Range of BFFS is 45–65 mi/h*
    - *Posted speed limits may serve as surrogates for BFFS*
  - f_{LS} = adjustment factor for lane and shoulder width (Exhibit 20-5, 2000 HCM)
  - f_A = adjustment factor for number of access points per mile (Exhibit 20-6, 2000 HCM)

Two-lane highways

Estimating FFS:

EXHIBIT 20-5. ADJUSTMENT (f_{LS}) FOR LANE WIDTH AND SHOULDER WIDTH

Lane Width (m)	Reduction in FFS (km/h) — Shoulder Width (m) ≥ 0.0 < 0.6	≥ 0.6 < 1.2	≥ 1.2 < 1.8	≥ 1.8
2.7 < 3.0	10.3	7.7	5.6	3.5
≥ 3.0 < 3.3	8.5	5.9	3.8	1.7
≥ 3.3 < 3.6	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0.0

Two-lane highways

Estimating FFS:

EXHIBIT 20-6. ADJUSTMENT (f_A) FOR ACCESS-POINT DENSITY

Access Points per km	Reduction in FFS (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
≥ 24	16.0

Two-lane highways

Demand adjustment for ATS:

- Demand volume per direction (veh/h) is converted to flow rate (pc/h)

$$v_{i,ATS} = \frac{V_i}{PHF \times f_{g,ATS} \times f_{HV,ATS}}$$

  - $v_{i,ATS}$ = demand flow rate i for ATS estimation (pc/h)
  - $i = d$ (analysis direction) or o (opposing direction)
  - V_i = demand volume for direction i (veh/h)
  - $f_{g,ATS}$ = grade adjustment factor
    - Level or rolling terrain and downgrades (Exhibit 20-7, 2000 HCM)
    - Upgrades ($G \geq 3\%$ & $L \geq 0.6$ mi) (Exhibit 20-13, 2000 HCM)
  - $f_{HV,ATS}$ = heavy vehicles adjustment factor
    - For general terrain, upgrades, and downgrades where trucks do not travel at crawling speed

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

      - » P_T & P_R = *proportion of trucks (and buses) and RVs in traffic*
      - » E_T & E_R = *passenger car equivalent for trucks (and buses) and RVs in traffic* (Exhibit 20-9, Exhibit 20-15 and Exhibit 20-17, 2000 HCM)
    - For downgrades where trucks travel at crawling speed

$$f_{HV,ATS} = \frac{1}{1 + P_{TC} \times P_T(E_{TC} - 1) + (1 - P_{TC}) \times P_T(E_T - 1) + P_R(E_R - 1)}$$

      - » P_{TC} = *proportion of trucks operating at crawl speed*
      - » E_T = *passenger car equivalent of trucks operating at crawl speed* (Exhibit 20-18, 2000 HCM)

Two-lane highways

EXHIBIT 20-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS TO DETERMINE SPEEDS ON TWO-WAY AND DIRECTIONAL SEGMENTS

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
			Level	Rolling
Trucks, E_T	0–600	0–300	1.7	2.5
	> 600–1,200	> 300–600	1.2	1.9
	> 1,200	> 600	1.1	1.5
RVs, E_R	0–600	0–300	1.0	1.1
	> 600–1,200	> 300–600	1.0	1.1
	> 1,200	> 600	1.0	1.1

Two-lane highways

EXHIBIT 20-15. PASSENGER-CAR EQUIVALENTS FOR TRUCKS FOR ESTIMATING AVERAGE SPEED ON SPECIFIC UPGRADES

Grade (%)	Length of Grade (km)	Passenger-Car Equivalent for Trucks, E_T — Range of Directional Flow Rates, v_d (pc/h)		
		0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	2.5	1.9	1.5
	0.8	3.5	2.8	2.3
	1.2	4.5	3.9	2.9
	1.6	5.1	4.6	3.5
	2.4	6.1	5.5	4.1
	3.2	7.1	5.9	4.7
	4.8	8.2	6.7	5.3
	≥ 6.4	9.1	7.5	5.7
≥ 3.5 < 4.5	0.4	3.6	2.4	1.9
	0.8	5.4	4.6	3.4
	1.2	6.4	6.6	4.6
	1.6	7.7	6.9	5.9
	2.4	9.4	8.3	7.1
	3.2	10.2	9.6	8.1
	4.8	11.3	11.0	8.9
	≥ 6.4	12.3	11.9	9.7
≥ 4.5 < 5.5	0.4	4.2	3.7	2.6
	0.8	6.0	6.0	5.1
	1.2	7.5	7.5	7.5
	1.6	9.2	9.0	8.9
	2.4	10.6	10.5	10.3
	3.2	11.8	11.7	11.3
	4.8	13.7	13.5	12.4
	≥ 6.4	15.3	15.0	12.5
≥ 5.5 < 6.5	0.4	4.7	4.1	3.5
	0.8	7.2	7.2	7.2
	1.2	9.1	9.1	9.1
	1.6	10.3	10.3	10.2
	2.4	11.9	11.8	11.7
	3.2	12.8	12.7	12.6
	4.8	14.4	14.3	14.2
	≥ 6.4	15.4	15.2	15.0
≥ 6.5	0.4	5.1	4.8	4.6
	0.8	7.8	7.8	7.8
	1.2	9.8	9.8	9.8
	1.6	10.4	10.4	10.3
	2.4	12.0	11.9	11.8
	3.2	12.9	12.8	12.7
	4.8	14.5	14.4	14.3
	≥ 6.4	15.4	15.3	15.2

Two-lane highways

EXHIBIT 20-17. PASSENGER-CAR EQUIVALENTS FOR RVs FOR ESTIMATING AVERAGE TRAVEL SPEED ON SPECIFIC UPGRADES

Grade (%)	Length of Grade (km)	Passenger-Car Equivalent for RVs, E_R — Range of Directional Flow Rates, v_d (pc/h): 0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.1	1.0	1.0
	0.8	1.2	1.0	1.0
	1.2	1.2	1.0	1.0
	1.6	1.3	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.5	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 3.5 < 4.5	0.4	1.3	1.0	1.0
	0.8	1.3	1.0	1.0
	1.2	1.3	1.0	1.0
	1.6	1.4	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.4	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 4.5 < 5.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.5	1.0	1.0
	2.4	1.5	1.0	1.0
	3.2	1.5	1.0	1.0
	4.8	1.6	1.0	1.0
	≥ 6.4	1.6	1.0	1.0
≥ 5.5 < 6.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.2	1.0
	≥ 6.4	1.6	1.5	1.2
≥ 6.5	0.4	1.6	1.0	1.0
	0.8	1.6	1.0	1.0
	1.2	1.6	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.3	1.3
	≥ 6.4	1.6	1.5	1.4

Two-lane highways

EXHIBIT 20-18. PASSENGER-CAR EQUIVALENTS FOR ESTIMATING THE EFFECT ON AVERAGE TRAVEL SPEED OF TRUCKS THAT OPERATE AT CRAWL SPEEDS ON LONG STEEP DOWNGRADES

Difference Between FFS and Truck Crawl Speed (km/h)	Passenger-Car Equivalent for Trucks at Crawl Speeds, E_{TC}		
	Range of Directional Flow Rates, v_d (pc/h)		
	0–300	> 300–600	> 600
≤ 20	4.4	2.8	1.4
40	14.3	9.6	5.7
≥ 60	34.1	23.1	13.0

Two-lane highways

Estimating ATS:

$$ATS_d = FFS - 0.00776(v_{d,ATS} + v_{o,ATS}) - f_{np,ATS}$$

- ATS_d = average travel speed in the analysis direction (mi/h)
- FFS = free flow speed (mi/h)
- $v_{d,ATS}$ = demand flow rate for ATS determination in the analysis direction (pc/h)
- $v_{o,ATS}$ = demand flow rate for ATS determination in the opposite direction (pc/h)
- $f_{np,ATS}$ = adjustment factor for ATS determination for the percentage of no-passing zones in the analysis direction

(Exhibit 20-19, 2000 HCM)

Two-lane highways

Estimating ATS:

EXHIBIT 20-19. ADJUSTMENT (f_{np}) TO AVERAGE TRAVEL SPEED FOR PERCENTAGE OF NO-PASSING ZONES IN DIRECTIONAL SEGMENTS

Opposing Demand Flow Rate, v_o (pc/h)	No-Passing Zones (%) ≤ 20	40	60	80	100
FFS = 110 km/h					
≤ 100	1.7	3.5	4.5	4.8	5.0
200	3.5	5.3	6.2	6.5	6.8
400	2.6	3.7	4.4	4.5	4.7
600	2.2	2.4	2.8	3.1	3.3
800	1.1	1.6	2.0	2.2	2.4
1000	1.0	1.3	1.7	1.8	1.9
1200	0.9	1.3	1.5	1.6	1.7
1400	0.9	1.2	1.4	1.4	1.5
≥ 1600	0.9	1.1	1.2	1.2	1.3
FFS = 100 km/h					
≤ 100	1.2	2.7	4.0	4.5	4.7
200	3.0	4.6	5.9	6.4	6.7
400	2.3	3.3	4.1	4.4	4.6
600	1.8	2.1	2.6	3.0	3.2
800	0.9	1.4	1.8	2.1	2.3
1000	0.9	1.1	1.5	1.7	1.9
1200	0.8	1.1	1.4	1.5	1.7
1400	0.8	1.0	1.3	1.3	1.4
≥ 1600	0.8	1.0	1.1	1.1	1.2
FFS = 90 km/h					
≤ 100	0.8	1.9	3.6	4.2	4.4
200	2.4	3.9	5.6	6.3	6.6
400	2.1	3.0	3.8	4.3	4.5
600	1.4	1.8	2.5	2.9	3.1
800	0.8	1.1	1.7	2.0	2.2
1000	0.8	0.9	1.3	1.5	1.8
1200	0.8	0.9	1.2	1.4	1.6
1400	0.8	0.9	1.1	1.2	1.4
≥ 1600	0.8	0.8	0.9	0.9	1.1
FFS = 80 km/h					
≤ 100	0.3	1.1	3.1	3.9	4.1
200	1.9	3.2	5.3	6.2	6.5
400	1.8	2.6	3.5	4.2	4.4
600	1.0	1.5	2.3	2.8	3.0
800	0.6	0.9	1.5	1.9	2.1
1000	0.6	0.7	1.1	1.4	1.8
1200	0.6	0.7	1.1	1.3	1.6
1400	0.6	0.7	1.0	1.1	1.3
≥ 1600	0.6	0.7	0.8	0.8	1.0
FFS = 70 km/h					
≤ 100	0.1	0.6	2.7	3.6	3.8
200	1.5	2.6	5.0	6.1	6.4
400	1.5	0.8	3.2	4.1	4.3
600	0.7	0.5	2.1	2.7	2.9
800	0.5	0.5	1.3	1.8	2.0
1000	0.5	0.5	1.0	1.3	1.8
1200	0.5	0.5	1.0	1.2	1.6
1400	0.5	0.5	1.0	1.0	1.2
≥ 1600	0.5	0.5	0.7	0.7	0.9

Two-lane highways

Demand adjustment for PTSF:

- Similar procedure to ATS but different tables

$$v_{i,PTSF} = \frac{V_i}{PHF \times f_{g,PTSF} \times f_{HV,PTSF}}$$

- $v_{i,PTSF}$ = demand flow rate i for PTSF estimation (pc/h)
- $i = d$ (analysis direction) or o (opposing direction)
- V_i = demand volume for direction i (veh/h)
- $f_{g,PTSF}$ = grade adjustment factor
  - **Level or rolling terrain and downgrades** (Exhibit 20-8, 2000 HCM)
  - **Upgrades ($G \geq 3\%$ & $L \geq 0.6$ mi)** (Exhibit 20-14, 2000 HCM)
- $f_{HV,PTSF}$ = heavy vehicles adjustment factor

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

  - P_T & P_R = **proportion of trucks (and buses) and RVs in traffic**
  - E_T & E_R = **passenger car equivalent for trucks (and buses) and RVs in traffic** (Exhibit 20-10, Exhibit 20-16, 2000 HCM for Trucks)

NOTE : E_R is always = 1 for estimating PTSF

Two-lane highways

EXHIBIT 20-8. GRADE ADJUSTMENT FACTOR (f_G) TO DETERMINE PERCENT TIME-SPENT-FOLLOWING ON TWO-WAY AND DIRECTIONAL SEGMENTS

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0–600	0–300	1.00	0.77
> 600–1200	> 300–600	1.00	0.94
> 1200	> 600	1.00	1.00

Two-lane highways

EXHIBIT 20-10. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS TO DETERMINE PERCENT TIME-SPENT-FOLLOWING ON TWO-WAY AND DIRECTIONAL SEGMENTS

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
			Level	Rolling
Trucks, E_T	0–600	0–300	1.1	1.8
	> 600–1,200	> 300–600	1.1	1.5
	> 1,200	> 600	1.0	1.0
RVs, E_R	0–600	0–300	1.0	1.0
	> 600–1,200	> 300–600	1.0	1.0
	> 1,200	> 600	1.0	1.0

Two-lane highways

EXHIBIT 20-14. GRADE ADJUSTMENT FACTOR (f_G) FOR ESTIMATING PERCENT TIME-SPENT-FOLLOWING ON SPECIFIC UPGRADES

Grade (%)	Length of Grade (km)	Grade Adjustment Factor, f_G — Range of Directional Flow Rates, v_d (pc/h): 0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.00	0.92	0.92
	0.8	1.00	0.93	0.93
	1.2	1.00	0.93	0.93
	1.6	1.00	0.93	0.93
	2.4	1.00	0.94	0.94
	3.2	1.00	0.95	0.95
	4.8	1.00	0.97	0.96
	≥ 6.4	1.00	1.00	0.97
≥ 3.5 < 4.5	0.4	1.00	0.94	0.92
	0.8	1.00	0.97	0.96
	1.2	1.00	0.97	0.96
	1.6	1.00	0.97	0.97
	2.4	1.00	0.97	0.97
	3.2	1.00	0.98	0.98
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 4.5 < 5.5	0.4	1.00	1.00	0.97
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 5.5 < 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00

Two-lane highways

Estimating PTSF:

$$PTSF_d = BPTSF_d + f_{np,PTSF} \left\{ \frac{v_{d,PTSF}}{v_{d,PTSF} + v_{o,PTSF}} \right\}$$

- $PTSF_d$ = percent time spent following in the analysis direction
- $BPTSF_d$ = base percent time spent following in the analysis direction
- $f_{np,PTSF}$ = adjustment to PTSF for the percentage of no-passing zones in the analysis direction (Exhibit 20-20, 2000 HCM)
- $v_{d,PTSF}$ = demand flow rate in analysis direction for estimation of PTSF (pc/h)
- $v_{o,PTSF}$ = demand flow rate in opposite direction for estimation of PTSF (pc/h)

$$BPTSF = 100\left[1 - \exp\left(a\, v_d^b\right)\right]$$

- ***a* & *b* = constants from** (Exhibit 20-21, 2000 HCM)

Two-lane highways

Exhibit 20-20. Adjustment (f_{np}) to Percent Time-Spent-Following for Percentage of No-Passing Zones in Directional Segments

Opposing Demand Flow Rate, v_o (pc/h)	No-Passing Zones (%)				
	≤ 20	40	60	80	100
FFS = 110 km/h					
≤ 100	10.1	17.2	20.2	21.0	21.8
200	12.4	19.0	22.7	23.8	24.8
400	9.0	12.3	14.1	14.4	15.4
600	5.3	7.7	9.2	9.7	10.4
800	3.0	4.6	5.7	6.2	6.7
1000	1.8	2.9	3.7	4.1	4.4
1200	1.3	2.0	2.6	2.9	3.1
1400	0.9	1.4	1.7	1.9	2.1
≥ 1600	0.7	0.9	1.1	1.2	1.4
FFS = 100 km/h					
≤ 100	8.4	14.9	20.9	22.8	26.6
200	11.5	18.2	24.1	26.2	29.7
400	8.6	12.1	14.8	15.9	18.1
600	5.1	7.5	9.6	10.6	12.1
800	2.8	4.5	5.9	6.7	7.7
1000	1.6	2.8	3.7	4.3	4.9
1200	1.2	1.9	2.6	3.0	3.4
1400	0.8	1.3	1.7	2.0	2.3
≥ 1600	0.6	0.9	1.1	1.2	1.5
FFS = 90 km/h					
≤ 100	6.7	12.7	21.7	24.5	31.3
200	10.5	17.5	25.4	28.6	34.7
400	8.3	11.8	15.5	17.5	20.7
600	4.9	7.3	10.0	11.5	13.9
800	2.7	4.3	6.1	7.2	8.8
1000	1.5	2.7	3.8	4.5	5.4
1200	1.0	1.8	2.6	3.1	3.8
1400	0.7	1.2	1.7	2.0	2.4
≥ 1600	0.6	0.9	1.2	1.3	1.5
FFS = 80 km/h					
≤ 100	5.0	10.4	22.4	26.3	36.1
200	9.6	16.7	26.8	31.0	39.6
400	7.9	11.6	16.2	19.0	23.4
600	4.7	7.1	10.4	12.4	15.6
800	2.5	4.2	6.3	7.7	9.8
1000	1.3	2.6	3.8	4.7	5.9
1200	0.9	1.7	2.6	3.2	4.1
1400	0.6	1.1	1.7	2.1	2.6
≥ 1600	0.5	0.9	1.2	1.3	1.6
FFS = 70 km/h					
≤ 100	3.7	8.5	23.2	28.2	41.6
200	8.7	16.0	28.2	33.6	45.2
400	7.5	11.4	16.9	20.7	26.4
600	4.5	6.9	10.8	13.4	17.6
800	2.3	4.1	6.5	8.2	11.0
1000	1.2	2.5	3.8	4.9	6.4
1200	0.8	1.6	2.6	3.3	4.5
1400	0.5	1.0	1.7	2.2	2.8
≥ 1600	0.4	0.9	1.2	1.3	1.7

Two-lane highways

EXHIBIT 20-21. VALUES OF COEFFICIENTS USED IN ESTIMATING PERCENT TIME-SPENT-FOLLOWING FOR DIRECTIONAL SEGMENTS

Opposing Demand Flow Rate, v_o (pc/h)	a	b
≤ 200	–0.013	0.668
400	–0.057	0.479
600	–0.100	0.413
800	–0.173	0.349
1000	–0.320	0.276
1200	–0.430	0.242
1400	–0.522	0.225
≥ 1600	–0.665	0.199

Two-lane highways

Estimating PFFS:

$$PFFS = \frac{ATS_d}{FFS}$$

Determining LOS

LOS	Class I Highways ATS (mi/h)	Class I Highways PTSF (%)	Class II Highways PTSF (%)	Class III Highways PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50–55	>35–50	>40–55	>83.3–91.7
C	>45–50	>50–65	>55–70	>75.0–83.3
D	>40–45	>65–80	>70–85	>66.7–75.0
E	≤40	>80	>85	≤66.7

Two-lane highways

Example:

Determine the LOS for the following classes of two-lane highways:

a) Class I
b) Class II
c) Class III

Input data are as follows:

- Volume = 1600 veh/h (two-way)
- Percent trucks = 14%
- Percent RV's = 4%
- Peak hour factor = 0.95
- Rolling terrain
- Percent directional split = 50/50
- 50% no-passing zones in the analysis direction
- Number of access points = 20 per mi
- BFFS = 60 mi/h
- Segment length = 10 mi
- Lane width = 11 ft
- Shoulder width = 4 ft

Two-lane highways

Example:

Determine the LOS for the following classes of two-lane highways:

a) Class I
b) Class II
c) Class III

Input data are as follows:

- Volume = 1600 veh/h (two-way)
- Percent trucks = 14%
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- Peak hour factor = 0.95
- Rolling terrain
- Percent directional split = 50/50
- 50% no-passing zones in the analysis direction
- Number of access points = 20 per mi
- BFFS = 60 mi/h
- Segment length = 10 mi
- Lane width = 11 ft
- Shoulder width = 4 ft

Two-lane highways

Estimate FFS (Classes I, II & III):

$$FFS = BFFS - f_{LS} - f_A$$

- LW = 11 ft & Sh W = 4 ft → Exb 20-5 → $f_{LS} = 1.7$
- Access points = 20 per mi → Exb 20-6 → $f_A = 5.0$

$$FFS = 60 - 1.7 - 5.0 = 53.3$$

Compute demand adjustment for ATS (Classes I & III):

$$v_{i,ATS} = \frac{V_i}{PHF \times f_{g,ATS} \times f_{HV,ATS}}$$

- V_i = 800 veh/h
- PHF = 0.95
- For rolling terrain; $v = \frac{800}{0.95}$ = 842 veh/h → Exb 20-9 → $f_{g,ATS} = 0.99$
- $P_T = 0.14$ & $P_R = 0.04$
- For rolling terrain; v = 842 veh/h → Exb 20-15 &17 → $E_T = 1.4$ & $E_R = 1.1$

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

$$f_{HV,ATS} = \frac{1}{1 + 0.14(1.4 - 1) + 0.04(1.1 - 1)} = 0.943$$

$$v_{i,ATS} = \frac{800}{0.95 \times 0.99 \times 0.943} = 902 \text{ pc/h}$$

Two-lane highways

Estimate ATS (Class I & III):

- $ATS_d = FFS - 0.00776(v_{d,ATS} + v_{o,ATS}) - f_{np,ATS}$
  - %no-passing zones = 50%; $v_{o,ATS}$ = 902 pc/h → Exb 20-20 → $f_{np,ATS} = 0.7$
- $ATS_d = 53.3 - 0.00776(902 + 902) - 0.7 = 38.6$ mi/h

Compute demand adjustment for PTSF (Class I & II):

$$v_{i,PTSF} = \frac{V_i}{PHF \times f_{g,PTSF} \times f_{HV,PTSF}}$$

- $V_i = 1600 \times 0.5 = 800$ veh/h
- PHF = 0.95
- For rolling terrain; $v = 842$ veh/h → Exb 20-8 → $f_{g,PTSF} = 1.00$
- $P_T = 0.14$ & $P_R = 0.04$
- For rolling terrain; $v = 842$ veh/h → Exb 20-10 → $E_T = 1.0$ & $E_R = 1.0$

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

$$f_{HV,PTSF} = \frac{1}{1 + 0.14(1.0 - 1) + 0.04(1.0 - 1)} = 1.00$$

$$v_{i,PTSF} = \frac{800}{0.95 \times 1.00 \times 1.00} = 842 \text{ pc/h}$$

Two-lane highways

Estimate PTSF (Class I & II):

$$PTSF_d = BPTSF_d + f_{np,PTSF}\left\{\frac{v_{d,PTSF}}{v_{d,PTSF} + v_{o,PTSF}}\right\}$$

$$BPTSF = 100\left[1 - \exp\left(a\ v_d^b\right)\right]$$

– v_o= 842 pc/h → Exb 20-21 → a = -0.0046 & b = 0.832

$$BPTSF = 100[1 - \exp(-0.0046 \times 842^{0.832})] = 71.3\%$$

– %no-passing zones = 50%; directional split = 50/50; $v_d + v_o$= 1684 pc/h → Exb 20-20 → $f_{np,PTSF}$ = 21.0

$$PTSF_d = 71.3 + 21.0\left\{\frac{842}{842 + 842}\right\} = 81.8\%$$

Estimate PFFS (Class III):

$$PFFS = \frac{ATS_d}{FFS}$$

$$PFFS = \frac{38.6}{53.3} = 72.4\%$$

Two-lane highways

Determine LOS:

- From **Exhibit 15-3, 2010 HCM**
  - Class I:
    - **ATS = 38.6 → LOS_{ATS} = E**
    - **PTSF = 81.8% → LOS_{PTSF} = E**
    - **LOS = E**
  - Class II:
    - **PTSF = 81.8% → LOS_{PTSF} = D**
    - **LOS = D**
  - Class III:
    - **PFFS = 72.4% → LOS_{PFFS} = D**
    - **LOS = D**

Thank You!!!