General Intro.

Freeway : Divided multi-lane highway

↳ fully access Controlled along its Right of Way.

Expressway : Partial access Control.

Freeway — it continous un-interrupted flow.

↳ design spee about 135 kmph (70mph)

↳ its aim is to Connect high population cities.

↳ the drivers are not expected to stop in the freeway.

↳ there is NO STOP sign nor any controls like signalized I/S etc.

↳ Freeway ≃ 1% in length of all the roads ≃ 20% of all traffic.

Design features.

Acces Control.

→ entry & exit is by Ramps

→ no at grade I/S

→ no parking

→ no bus stop

→ no driveway

→ merging - entry

↳ diversion - exit.

Components.

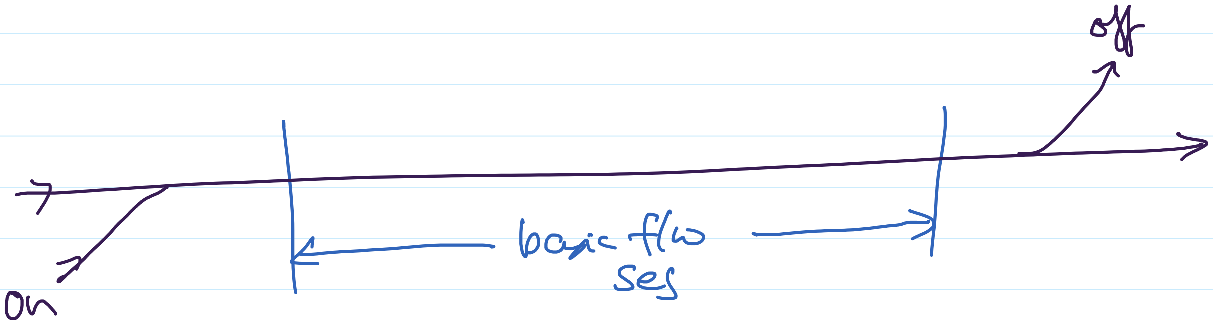
(1) Basic freeway

Components:

(i) Basic freeway

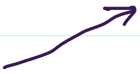
(ii) Ramp (on & off)

(iii) Weaving section.



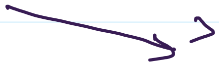
ramps

isolated on ramp



isolated off ramp

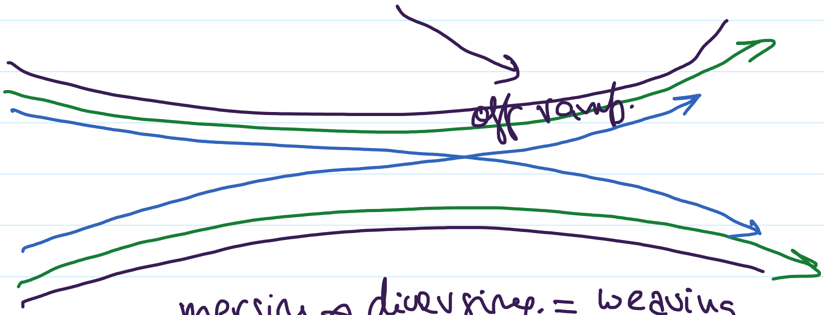
Consecutive on ramps



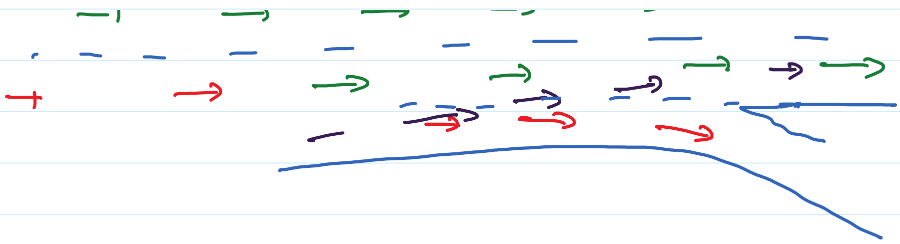
Consecutive off ramps.

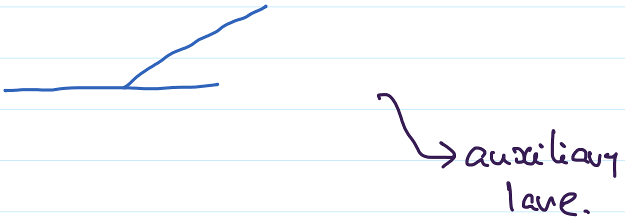
on ramp followed by

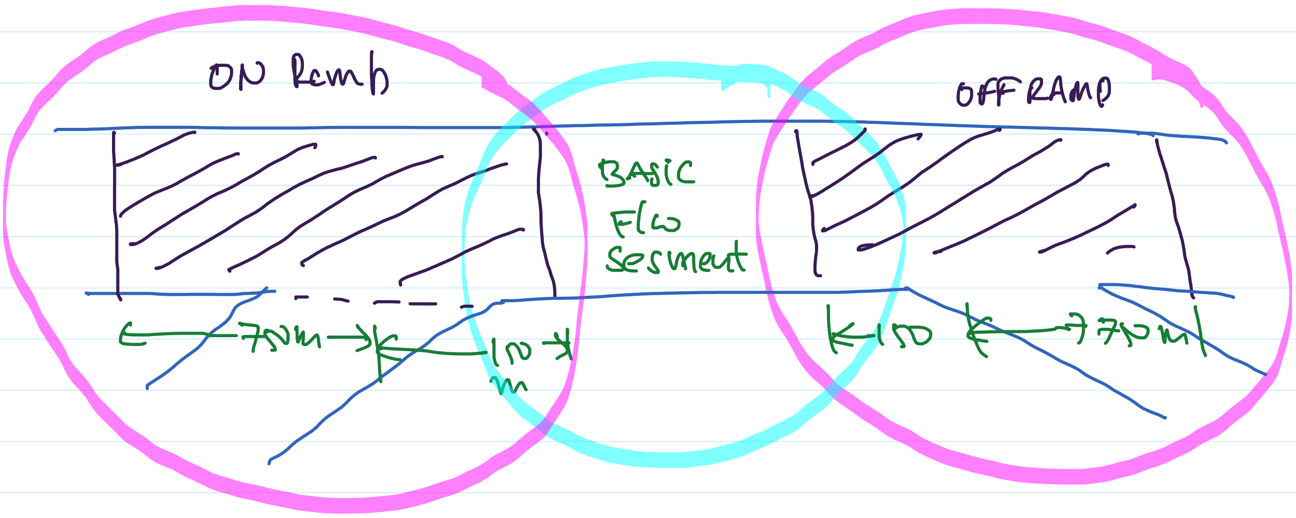
Weaving Section

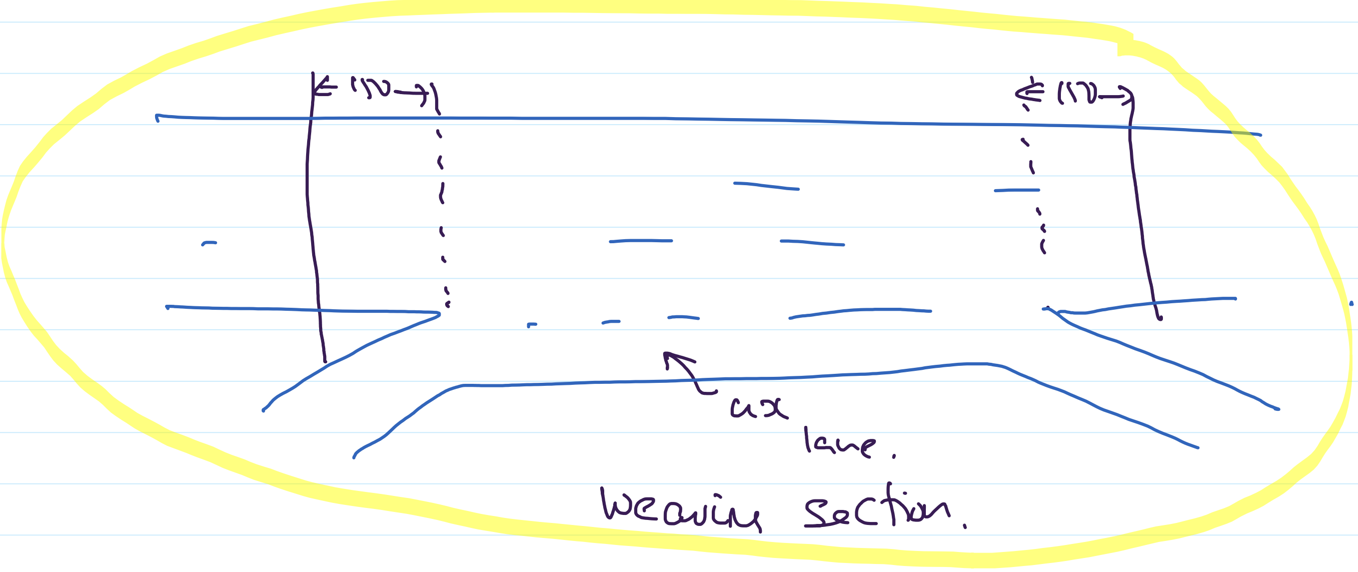


merging & diverging. = weaving.









Basic Freeway Segment

Purpose to analyze capacity
LoS

Purpose to analyze capacity
LoS

⇒ lanes that's required
↳ design

Basic Condition

↳ to achieve freeway Cap c_i

→ good weather
→ " visibility
→ no incidents
→ only pc
→ 3 km interchange spacing
→ driver population familiar with the facility

→ 3.6m lane width
→ 1.8 m shoulder clearance
→ 0.6 m wide median
→ 5 plus lanes in urban area
→ 2% max. grade & level terrain

⇒ FFS ≥ 110 kmph

Ignores

→ no HOV lane
→ truck lanes
→ climbing lanes
→ bridges / tunnel
→ speed limit
→ ITS, route guidance system

→ no toll plaza
→ FFS < 90 kmph FFS > 120 kmph
→ demand > capacity
→ influence of downstream queue
→ police enforcement
→ Ramp metering for cap. enhancement

LoS

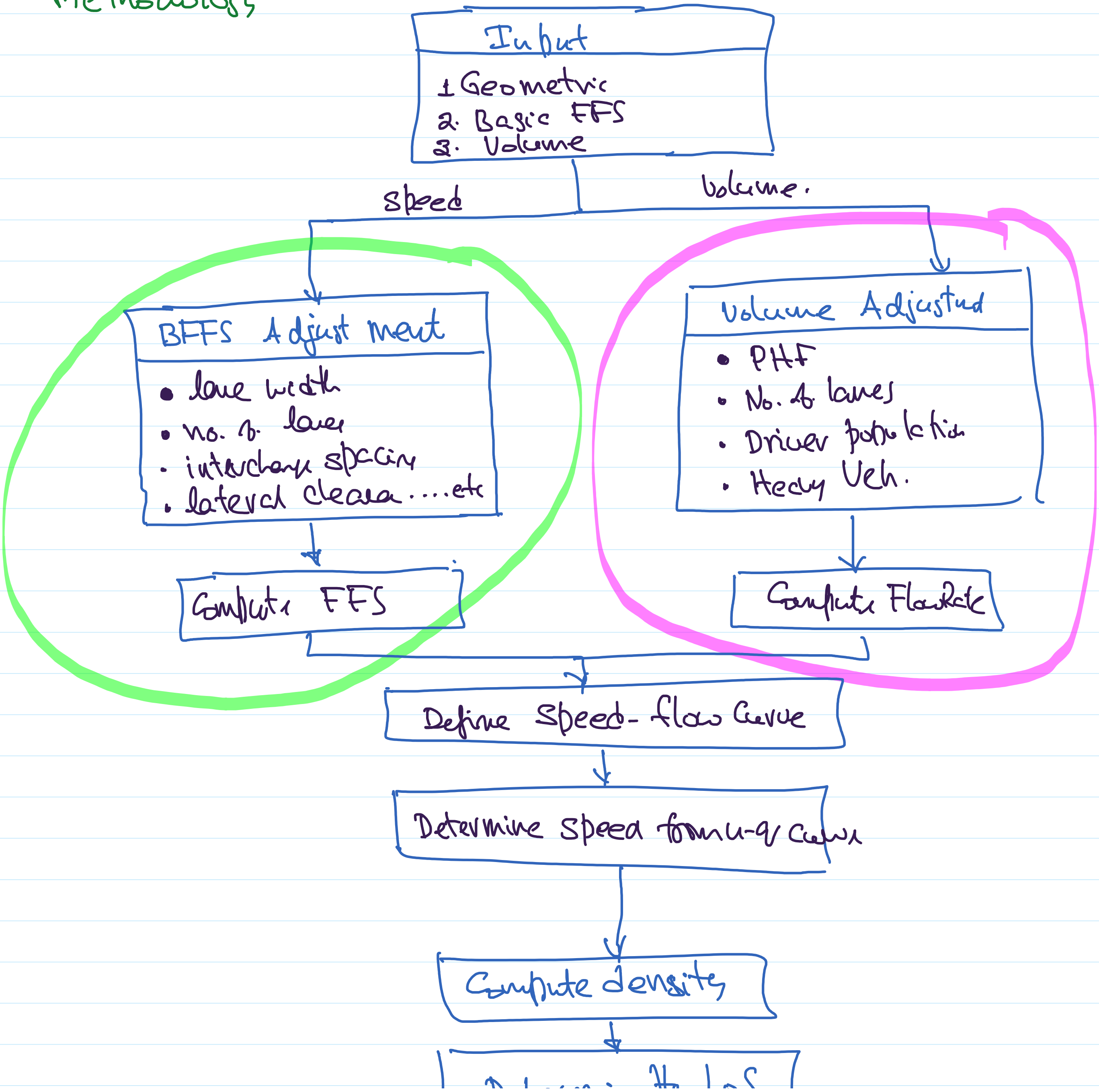
characterized by → density pc/km/l
↳ mean speed
↳ v/c ratio

↳ mean speed

↳ v/c ratio

LoS	Density pc/km/lane
	0-7
	7–11
	11–16
	16–22
	22-28
	>28

Methodology



Determine the LoS

LoS Criteria Expected speed and flowrate

HCM 2000

EXHIBIT 23-2. LOS CRITERIA FOR BASIC FREEWAY SEGMENTS

Criteria	LOS A	B	C	D	E
FFS = 120 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	120.0	120.0	114.6	99.6	85.7
Maximum v/c	0.35	0.55	0.77	0.92	1.00
Maximum service flow rate (pc/h/ln)	840	1320	1840	2200	2400
FFS = 110 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	110.0	110.0	108.5	97.2	83.9
Maximum v/c	0.33	0.51	0.74	0.91	1.00
Maximum service flow rate (pc/h/ln)	770	1210	1740	2135	2350
FFS = 100 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	100.0	100.0	100.0	93.8	82.1
Maximum v/c	0.30	0.48	0.70	0.90	1.00
Maximum service flow rate (pc/h/ln)	700	1100	1600	2065	2300
FFS = 90 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	90.0	90.0	90.0	89.1	80.4
Maximum v/c	0.28	0.44	0.64	0.87	1.00
Maximum service flow rate (pc/h/ln)	630	990	1440	1955	2250

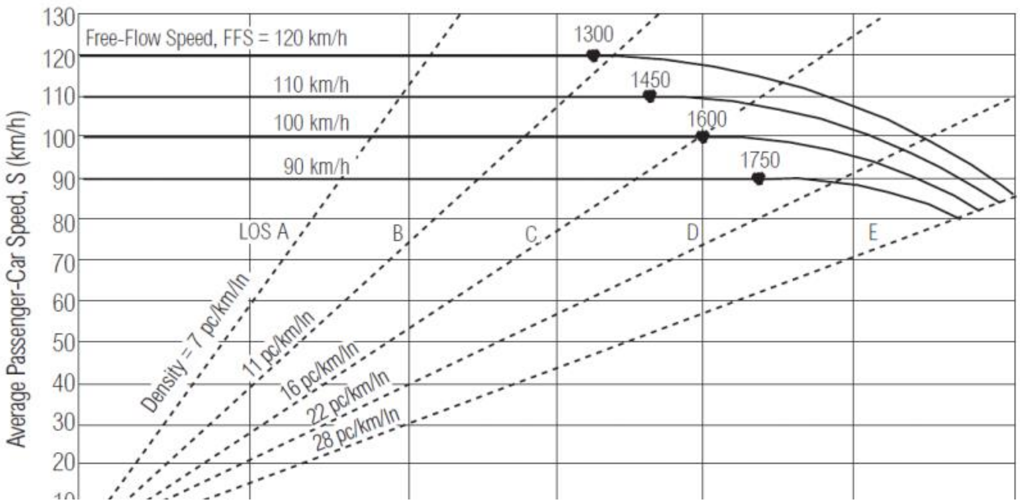
Operating Speed

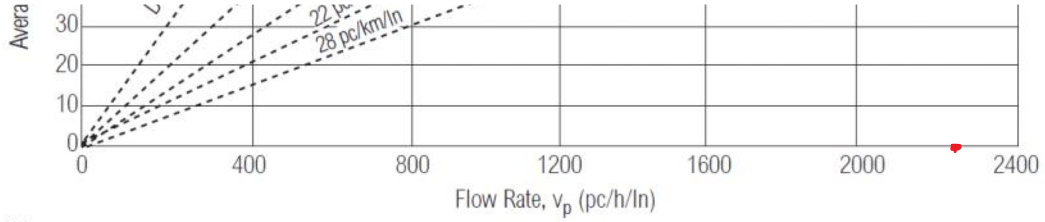
```
if ($90 \le FFS \le 120$)
{
    if ($(3100 - 15FFS) < V_p \le (1800 + 5FFS)$)
    {
        $S = FFS - \left\{ \frac{23FFS - 1800}{28} \times \left( \frac{V_p + 15FFS - 3100}{20FFS - 1300} \right)^{2.6} \right\}$
    }
    else if ($V_p \le (3100 - 15FFS)$)

        $S = FFS$

}
```

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS





Note:
Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 120, 110, 100, and 90 km/h, respectively.

Determining the Free Flow Speed.

FFS → speed that is measured at low to moderate flow (ie up to 1300 pc/hr/lane).

$$\boxed{FFS = BFFS - f_{LW} - f_{LC} - f_{N} - f_{ID}}$$

Basic free flow speed (120, 110, 100, 90 kmph)

f_{LW} → Adj factor for lane width.

LW (m)	f_{LW}
	0.0
	1.0
	8.1
	10.6

f_{LC}

LC (m)	f_{LC}			
	N=2	N=3	N=4	N >5
≥ 1.8	0	0	0	0
1.5	1.0	0.7	0.3	0.2

	4.8	-	-	1.1
0.0	5.8	-	-	1.3

f_N ⇒ Adj. factor for no of lanes.

N	f_N
>5	0
4	2.4
3	4.8
2	7.3

f_{ID} Adj. factor for Interchange Density.

ID $\frac{Int}{km}$	f_{ID}
≤ 0.3	0
0.4	1.1
0.5	2.1
⋮	
1.0	9.2
1.1	10.2
1.2	12.1

Determining the Flow Rate.

Factors influence flowrate
→ Hourly Variation
→ No. of lanes present there
→ Ch. of driver population.

$$V_p = \frac{V}{PHF \times N \times f \times f}$$

V ← hourly Volume

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

f_p → Adj. factor for driver population.

in veh/hr

15 mts pass. car. equivalent flowrate in pc/hr/lane.

Peak Hour Factor

no. of

Adj. Factor

PHF → 0.8 rural or off peak

→ 0.9 urban or peak

→ field data can be used.

$$PHF = \frac{\text{peak 15 min flowrate}}{\text{One Hour Flow}}$$

Heavy Vehicle Adj. Factor. f_{HV}

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

P_T: proportion of truck/buses

E_T: PCE of bus/truck

P_R: proportion Rec. Vehicle

E_R: → PCE of Vehi. Rec.

Extended freeway segment

→ if the grades and length are small

i.e. grade > 3% and less than 0.5 km or

grade < 3% and longer than 1.0 km.

then extended freeway segment will be used.

Factor.	Level g<2%	Rolling	Hilly
E_T (truck/bus)	1.5	2.5	4.5
E_R (RC. Veh)	1.2	2.0	4.0

Equivalent → Extended f/w < T/B, RV

→ Upgrade < Truck/Buses, RV

→ Down grade < Truck/Bus, RV

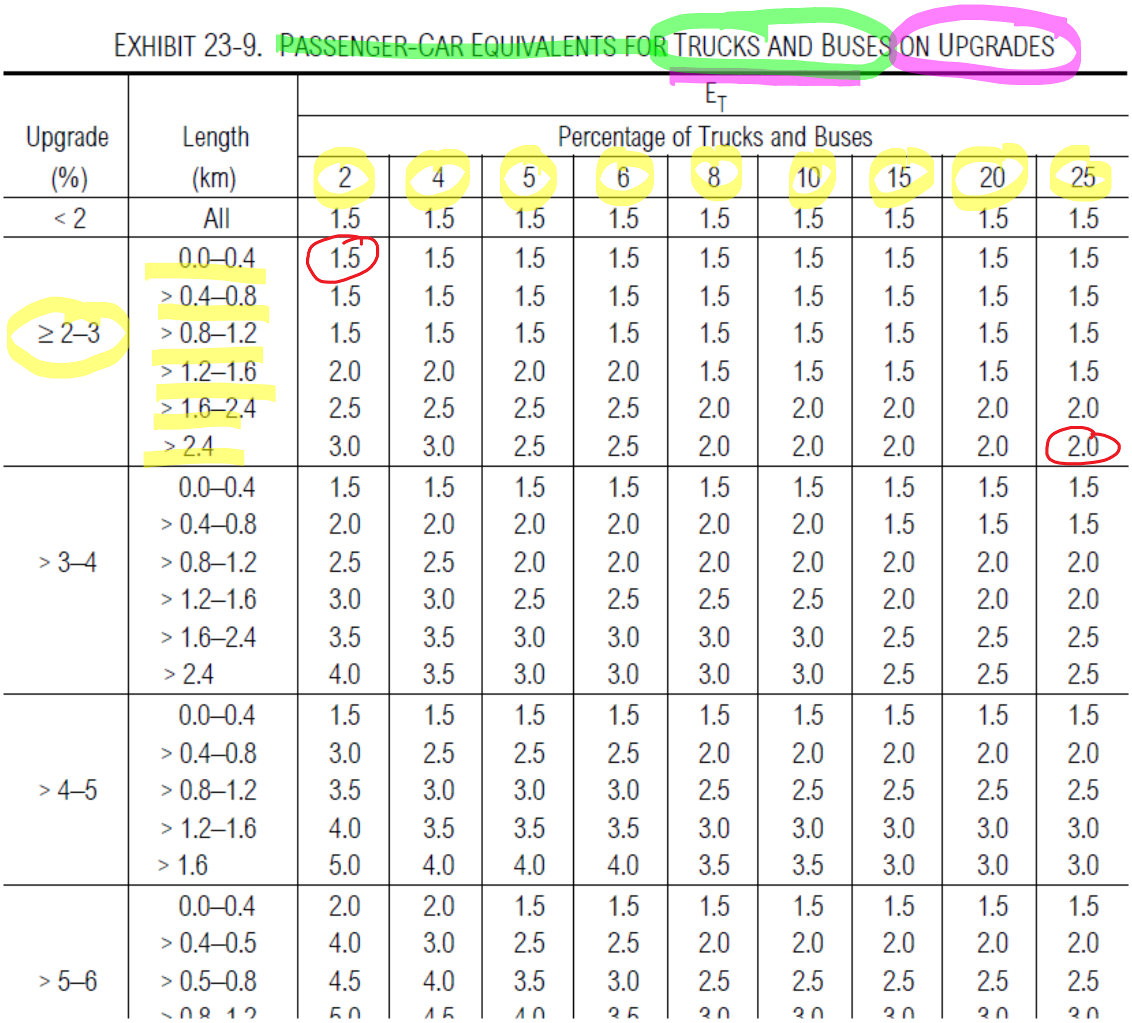


EXHIBIT 23-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UPGRADES

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

> 5–6	> 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

Driver Population Factor

$$f_p = \begin{cases} 1 & \text{for familiar drivers} \\ 0.85 & \text{for unfamiliar/recreational.} \end{cases}$$

Determine LoS

Steps

① Define the basic freeway segment

② Determine FFS

③ Determine service flow rate

④ Construct speed-flow curve

⑤ Calculate density = $D = \frac{V_p}{S}$ $\frac{\text{pc/hr/l}}{\text{km/hr.}}$

Numerical Example 1.

Find the LoS during peak hours for a basic freeway.

Given:
(i) Rural area (ii) four-lane road
(iii) Rolling terrain (iv) 110 kmph is the speed limit
(v) two lanes in each dir (vi) 3.3 m lanewidth
(v) 0.6 m lateral clearance (vi) all commuter traffic
(vii) Peak hour volume: 2000 veh/hr in one direction
(viii) 5% trucks (ix) PHF = 0.92

(vii) Peak hour volume: 2000 veh/hr in one direction.

(viii) 5% truck (ix) PHF = 0.92

(x) 0.6 interchge/km (xi) Bus & RV = 0%.

(xii) BFFS = 120 kmph.

Soln:

$$\begin{tikzcd} \text{Los} \arrow[r] & \text{Density.} \arrow[l, bend left] \end{tikzcd} = \frac{\text{flow}}{\text{speed}} \quad \frac{\leftarrow \text{adjusted flow}}{\leftarrow \text{adjusted spee}}$$

Step 1 Find free Flow Speed.

HCM 2000

Eq 23.1

$$FFS = BFFS - f_{LW} - f_{LC} - f_{N} - f_{ID}$$

$$= 120 - \underset{\substack{\downarrow \\ \text{Ex 23.4} \\ 3.3\text{m}}}{3.1} - \underset{\substack{\downarrow \\ \text{Ex 23.5} \\ 0.6\text{m}}}{3.9} - \underset{\substack{\downarrow \\ \text{Ex 23.6} \\ 2}}{0.0} - \underset{\substack{\downarrow \\ \text{Ex 23.7} \\ 6.6}}{3.9}$$

$$= 109.1 \text{ kmph.}$$

Step 2. Find Service Flow Rate V_p

Eq: 23.3.

a. $$f_{HV} = \frac{1}{1+P_T(E_T-1)} = \frac{1}{1+0.05\,(2.5-1)} = 0.930$$

b. $f_p = 1 \Leftarrow$ all drivers a commuters.

Eq: 23.2

c. $$V_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} = \frac{2000}{0.92 \times 2 \times 0.93 \times 1.0} = 1169$$

c. $v_p = \frac{\quad}{PHF \times N \times f_{HV} \times f_p} = \frac{\quad}{0.92 \times 2 \times 0.93 \times 1.0} = 1169$

Step 3 Finding Density.

$$D = \frac{V}{FFS} = \frac{1169}{109.1} = 10.7 \text{ veh/km/lane.}$$

Step 4 LOS corresponding to D.

$\therefore$ HCM 2000, Ch: 23.

$$\boxed{LOS = B}$$

Numerical Example 2

How many lanes are needed for a basic freeway segment at LOS D during peak hour?

Given: ① Suburban area ② 4000 veh/hr per direction ③ 15% truck ④ 3.6 m lane width ⑤ 0.85 PHF ⑥ 0.9 in the interchange density ⑦ 3% RV ⑧ 1.8 m LC ⑨ all are commuter traffic ⑩ BFS = 120 kmph ⑪ level terrain, ⑫ No. of lanes affect the FFS (Suburban).

Solution

I. Four lane

$N = 2$

Step 1 $FFS = \underset{\downarrow}{BFFS} - f_{LW} - f_{LC} - f_N - f_{ID}$

$= 120 - \underset{\substack{\downarrow \\ 3.6}}{0.0} - \underset{\substack{\downarrow \\ 1.8}}{0.0} - \underset{\substack{\downarrow \\ N=2}}{7.3} - \underset{\substack{\downarrow \\ 0.9}}{8.1}$

$\downarrow$ 3.6 $\quad\downarrow$ 1.8 $\quad\downarrow$ N=2 $\quad\downarrow$ 0.9

$= 104.6$

Step 2 ⓐ $$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_{RV}(E_{RV}-1)}$$

$$= \frac{1}{1+0.15(2.5-1)+0.03(2.2-1)}$$

$E_T = 2.5$, $E_{RV} = 2.2$ } HCM 2000

$\downarrow$

$= 0.925$

ⓑ $f_p = 1.0$ (all commuter traffic)

ⓒ $$V_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} = \frac{4000}{0.85 \times 2 \times 0.925 \times 1}$$

$= 2544$ veh/hr/lane. > 2400 veh/hr/lane.

③ Density $= \frac{V_p}{FFS} = \frac{2544}{104.6} = 24.32$ veh/km/lane.

④ LOS = E (HCM 2000 Ch: 23).

∴ Not acceptable.

II. Glane Road
N=3.

① FFS = BFF . . . . .

$= 120 - 0.0 - 0.0 - 4.8 - 8.1$

$\downarrow$ N=3

$= 107.1$ kmph.

$n = 3$

$= 107.1 \text{ kmph.}$

② V_p.

2a ⇒ $f_{HV} = 0.925$

2b ⇒ $f_p = 1.0$

$$V_p = \frac{4000}{0.85 \times 3 \times 0.925 \times 1} = 1696 \text{ pc/hr/lane.}$$

③ $$D = \frac{V_p}{FFS} = \frac{1696}{107.1} = 15.75 \text{ veh/km/lane.}$$

④ HCM 2000/ ch 23. for $D = 15.75$

LoS → LoS **C**

This is acceptable.