BASIC FREEWAY CAPACITY STUDIES

Definitions

A freeway is a divided highway facility having two or more lanes in each direction for the exclusive use of traffic with full control of access and egress.

Freeway is the only facility that provides completely uninterrupted flow.

Composed of three subcomponents:

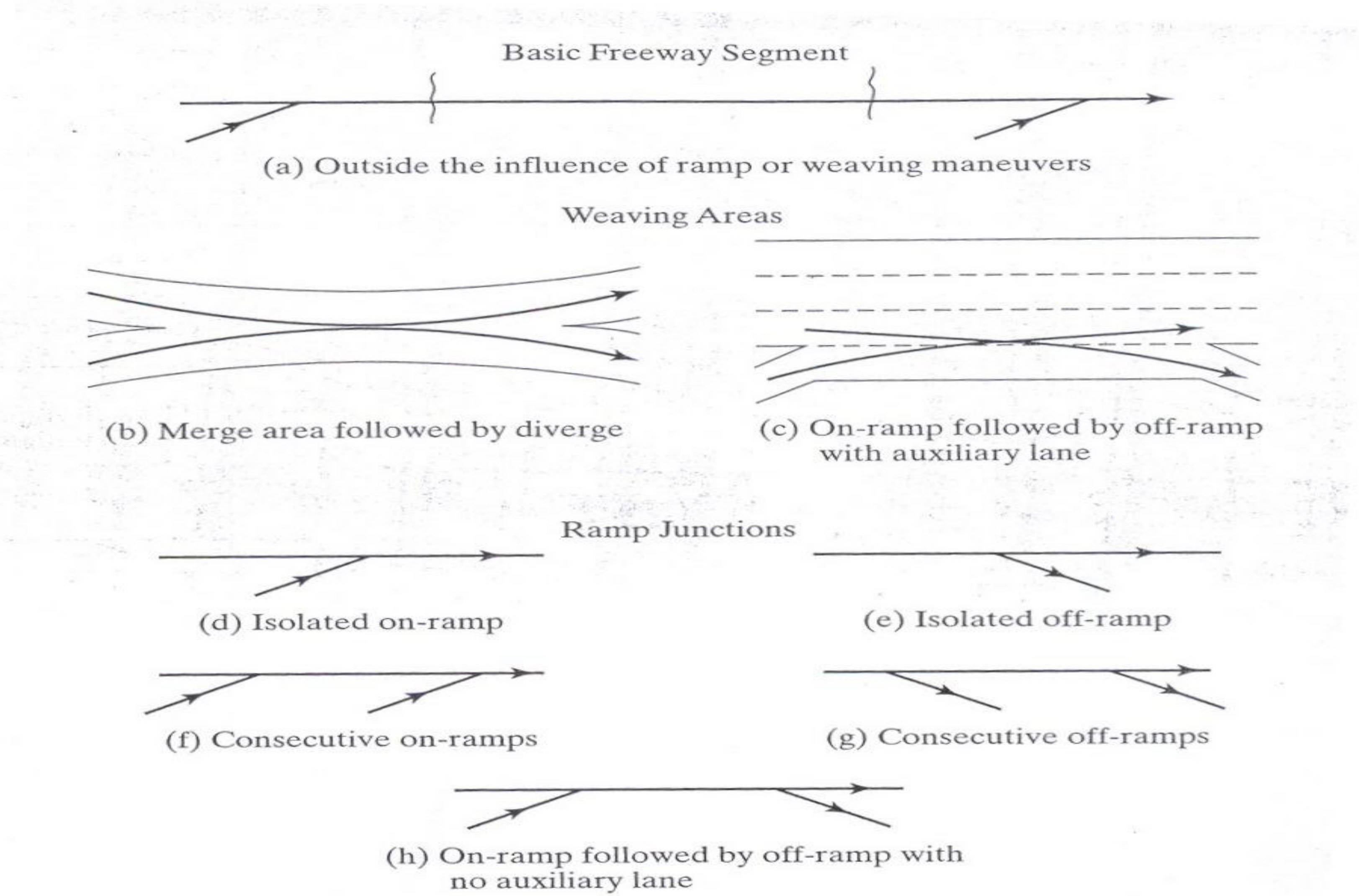
Basic freeway segments

Weaving areas

Ramp junctions

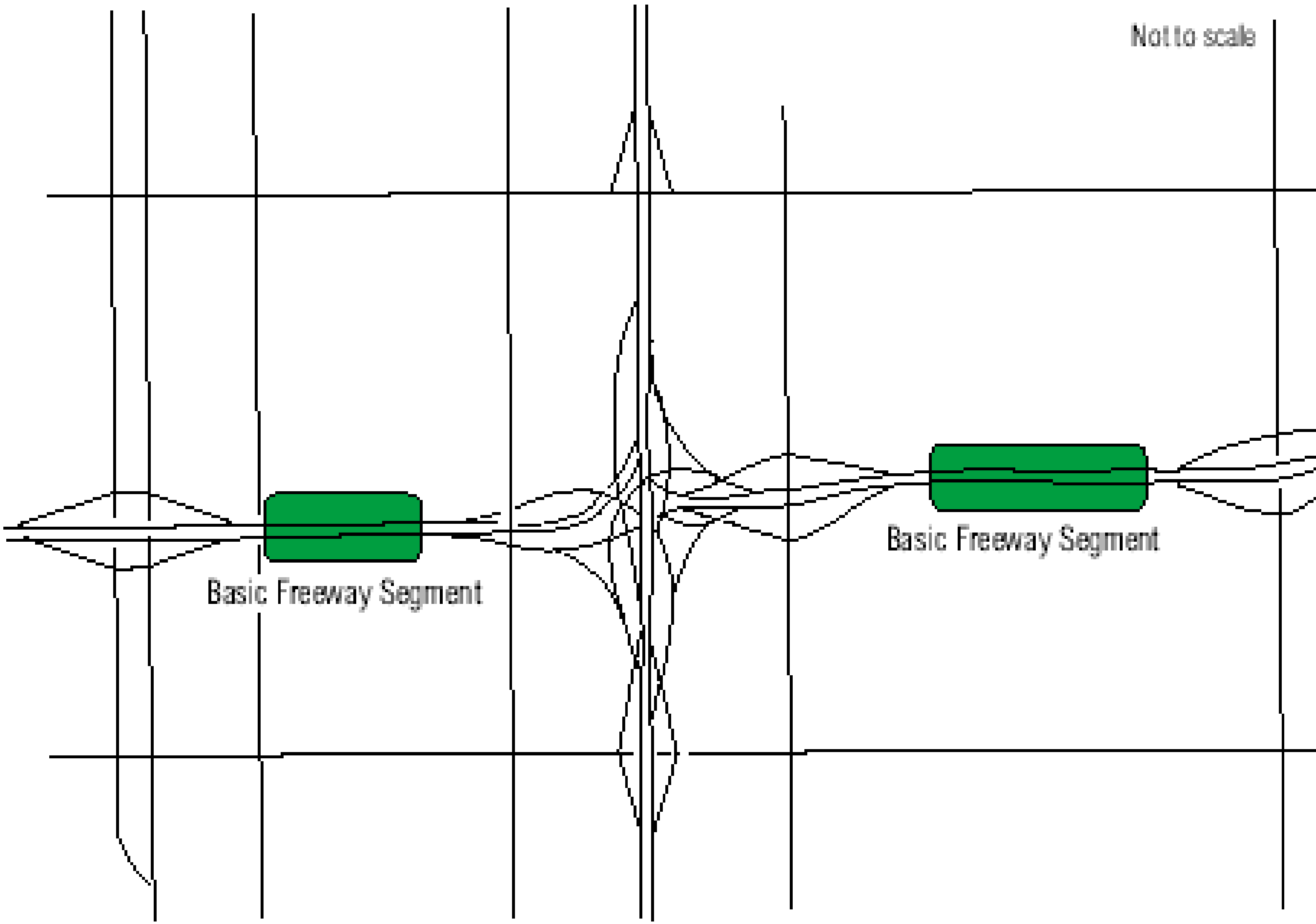
BASIC FREEWAY CAPACITY STUDIES

Definitions



BASIC FREEWAY CAPACITY STUDIES

Definitions



BASIC FREEWAY CAPACITY STUDIES

Definitions

Freeway capacity is the maximum (15 minutes) rate of flow, expressed in vehicles per hour, at which traffic can pass a point or uniform segment of freeway under existing roadway and traffic conditions.

BASIC FREEWAY CAPACITY STUDIES

Freeway Flow Characteristics

Traffic flow within a basic freeway segment can be generally described in three flow types:

1. Under saturated flow- low to moderate flows, not affected by upstream and downstream conditions.

2. Queue discharge flow- represents traffic flow after passage through a bottleneck.

3. Oversaturated flow- represents traffic flow that is influenced by the effects of a downstream bottleneck.

BASIC FREEWAY CAPACITY STUDIES

Freeway Flow Characteristics

A set of base (ideal) conditions for basic freeway segments are:

- 12-ft minimum lane widths
- 6-ft minimum right shoulder lateral clearance;
- 2-ft minimum median lateral clearance
- All passenger cars in the traffic stream
- 10 or more lanes
- Interchanges spacing of 2 miles or greater
- Level terrain, with grades no greater than 2%
- Driver population composed primarily of regular users of the facility

BASIC FREEWAY CAPACITY STUDIES

Free-Flow Speed

- Free-flow speed is the average speed of vehicles on a facility when drivers tend to drive at their desired speeds.

- It can be measured as the mean speed of passenger cars during low to moderate flows (up to 1300 pc/h/ln)

BASIC FREEWAY CAPACITY STUDIES

Free-Flow Speed

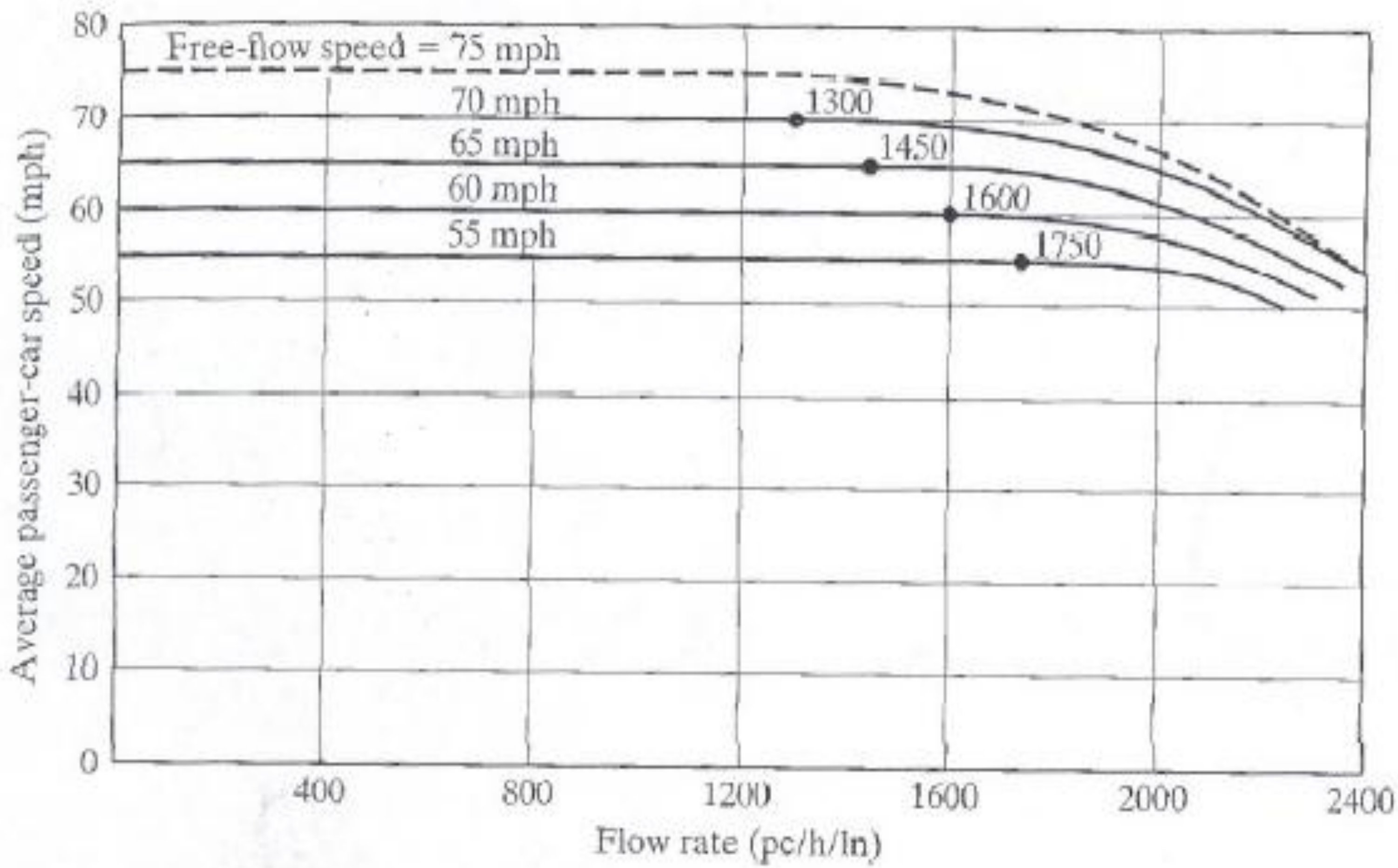


Figure 7-2 Speed-Flow Relationships for Basic Freeway Segments (TRB, 2000).

BASIC FREEWAY CAPACITY STUDIES

Level of Service (LOS)

- Speed is not a better measure of effectiveness since it remains nearly constant over a wide range of flow.

- Density increases throughout the range of flows up to capacity and provides a better measure of effectiveness.

Level of Service	Density Range (pc/mi/ln)
A	0–11
B	12–18
C	19–26
D	27–35
E	36–45
F	> 45

BASIC FREEWAY CAPACITY STUDIES

Level of Service (LOS)

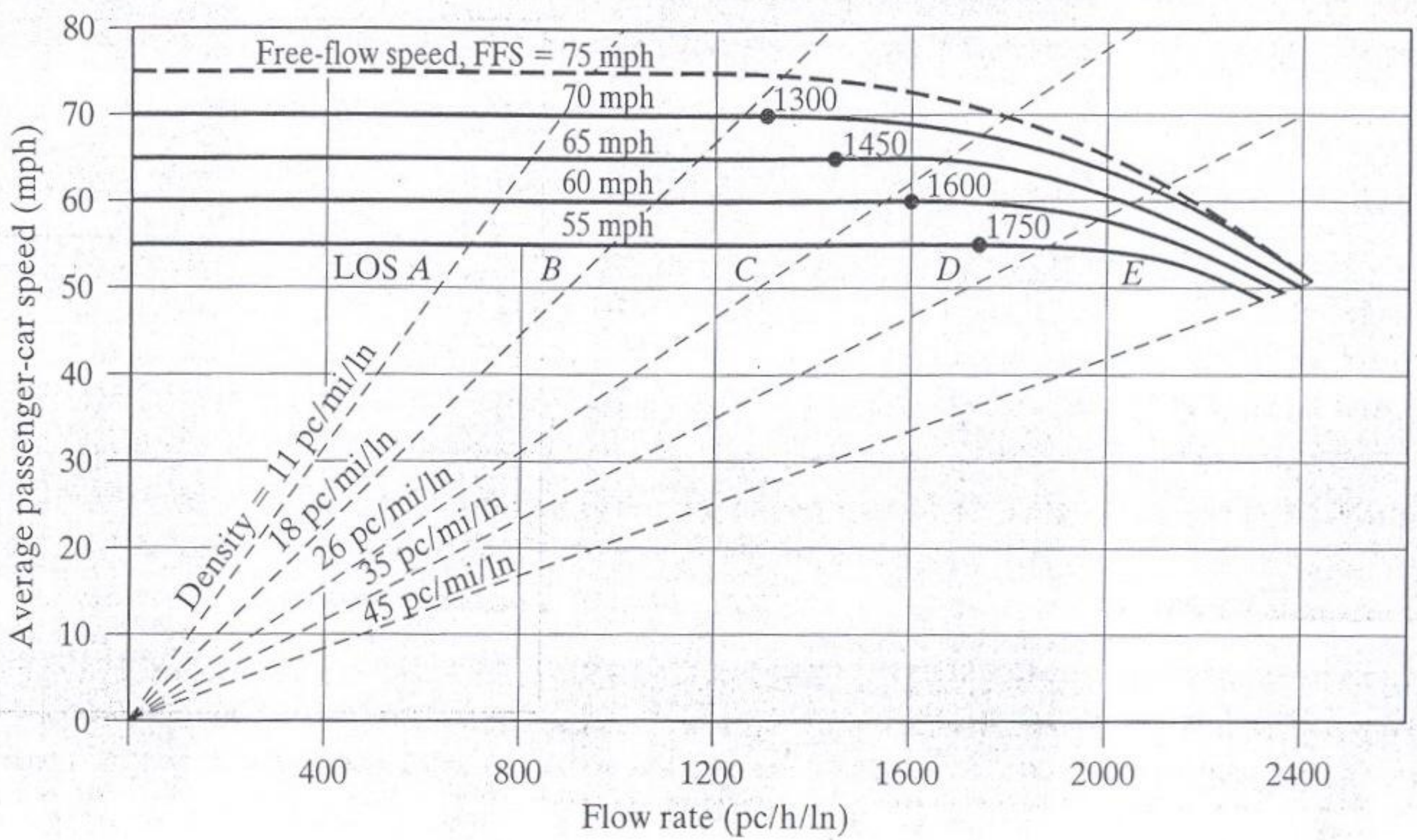


Figure 7-3 Speed-Flow Curves and LOS for Basic Freeway Segments (TRB, 2000).

BASIC FREEWAY CAPACITY STUDIES

Level of Service (LOS)

TABLE 7-1 LOS Criteria for Basic Freeway Segments

Criteria	LOS				
	A	B	C	D	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.

Source: TRB, 2000.

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

The determination of level of service (LOS) for a basic freeway section generally involves the determination of three components:

- Flow rate
- Free-flow speed, and
- Level of service

Once the flow-rate and free-flow speed are determined, then the LOS can be obtained using Table 7-1 or Figure 7-3.

BASIC FREEWAY CAPACITY STUDIES

Flow rate V_p

The flow-rate can be calculated using the following equation:

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

Where,

v_p = 15-min passenger-car flow rate (pc/h/ln)

V = hourly volume (veh/h)

PHF = peak-hour factor

N = number of lane (in one direction)

f_{HV} = heavy-vehicle adjustment factor, and

f_p = driver population factor

BASIC FREEWAY CAPACITY STUDIES

Flow rate V_p

The heavy-vehicle adjustment factor can be calculated using the following equation:

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

Where,

P_T, P_R = proportion of bus/truck, and proportion of RVs, respectively in the traffic stream

E_T, E_R =passenger car equivalent for truck/bus, and RVs, respectively

BASIC FREEWAY CAPACITY STUDIES

Flow rate V_p

- Extended Freeway Segments" mean that no one grade of 3% or greater is longer than 0.25 mile or no one grade of less than 3% is longer than 0.50 mile.

TABLE 7-2 Passenger-Car Equivalents on Extended Freeway 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

Source: TRB, 2000.

BASIC FREEWAY CAPACITY STUDIES

Flow rate V_p

- If these conditions do not exist then the following tables (7-3, 7-4, and 7-5) should be used for passenger car equivalents. The analysis of "Specific Grades"

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
	> 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 23-10. PASSENGER-CAR EQUIVALENTS FOR RVs ON UPGRADES

Upgrade (%)	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 23-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES 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 CAPACITY STUDIES

Free Flow Speed FFS

Now, if we like to use Table 7-1 or Figure 7-3, we must know the free-flow speed of the facility we are going to analyze.

The free-flow speed of a basic freeway section depends on the followings:

- Lane width
- Lateral clearance (i.e., shoulder width)
- Number of lanes, and
- Interchange density

BASIC FREEWAY CAPACITY STUDIES

Free Flow Speed FFS

The free-flow speed can be determined using the following equation:

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

where

FFS = estimated free-flow speed (mph)
BFFS = base free-flow speed, 70 mph (urban) or 75 mph (rural)
f_{LW} = adjustment for lane width from Table 7-6 (mph)
f_{LC} = adjustment for right-shoulder lateral clearance from Table 7-7 (mpl
f_N = adjustment for number of lanes from Table 7-8 (mi/h)
f_{ID} = adjustment for interchange density for Table 7-9 (mi/h).

BASIC FREEWAY CAPACITY STUDIES

Free Flow Speed FFS

TABLE 7-6 Adjustments for Lane Width

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

Source: TRB, 2000.

EXHIBIT 23-6. ADJUSTMENTS FOR NUMBER OF LANES

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (km/h)
≥ 5	0.0
4	2.4
3	4.8
2	7.3

Note: For all rural freeway segments, f_N is 0.0.

BASIC FREEWAY CAPACITY STUDIES

Free Flow Speed FFS

TABLE 7-9 Adjustments for Interchange Density

Interchanges per Mile	Reduction in Free-Flow Speed, f_{ID} (mph)
0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

Source: TRB, 2000.

TABLE 7-7 Adjustments for Right-Shoulder Lateral Clearance

Right-Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mph) — 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

Source: TRB, 2000.

BASIC FREEWAY CAPACITY STUDIES
Use of Highway Capacity Manual

<u>Example</u>

At a rural segment of a freeway, free-flow speed is observed as 66 mph through field measurement. Determine the level of service of this section when the flow rate is 2350 pc/h/ln.

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

- Draw a free-flow speed curve for 66 mph on Figure 7-3. Then use the given flow-rate of 2350 pc/h/ln to find the LOS. From the Figure, LOS = E

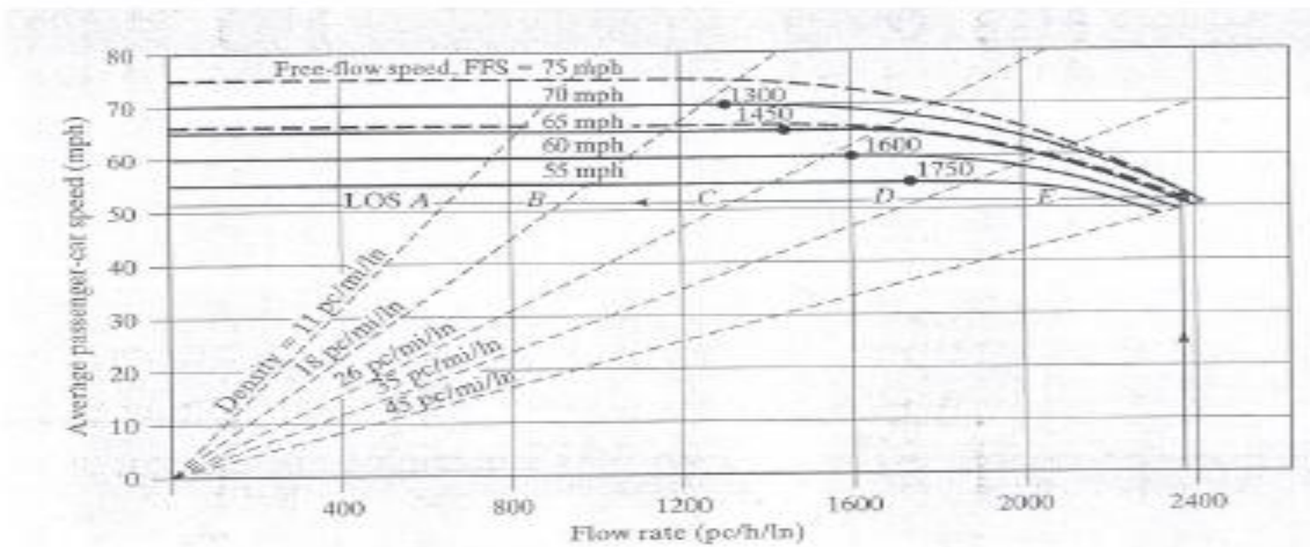


Figure 7-E1 Example Graphic Solution Using Speed-Flow Curves.

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

Example 2

Given:

- 4-lane urban freeway
- Interchange density 1.5/mile
- Directional peak flow 1950 veh/hr
- 5% trucks; PHF= 0.90; 11-ft lanes
- Obstructions 4 ft from right edge; rolling terrain

Determine

- (a) LOS, and (b) how much additional traffic could be accommodated before reaching capacity.

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

- Calculate service flow rate

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

$$v_p = \frac{1950}{0.90 \times 2 \times 0.93 \times 1} = 1165 \text{ pc/h/ln}$$

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

where, $P_T = 0.05$, $E_T = 2.5$ (rolling terrain; Table 7-2)

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

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

- Find the free-flow speed:

$$FFS = 70 - f_{LW} - f_{LC} - f_N - f_{ID}$$

$$f_{LW} = 1.9 \text{ mph (11 ft lanes; Table 7-6)}$$

$$f_{LC} = 1.2 \text{ mph (4 ft clearance; Table 7-7)}$$

$$f_N = 4.5 \text{ mph (2 lanes/direction; Table 7-8)}$$

$$f_{ID} = 5.0 \text{ mph (1.5 interchange/mile; Table 7-9)}$$

$$FFS = 70 - 1.9 - 1.2 - 4.5 - 5.0 = 57.4 \text{ mph}$$

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

- For v_p = 1165 pc/h/ln and FFS = 57.4 mph (from Figure 7-3), LOS = C.

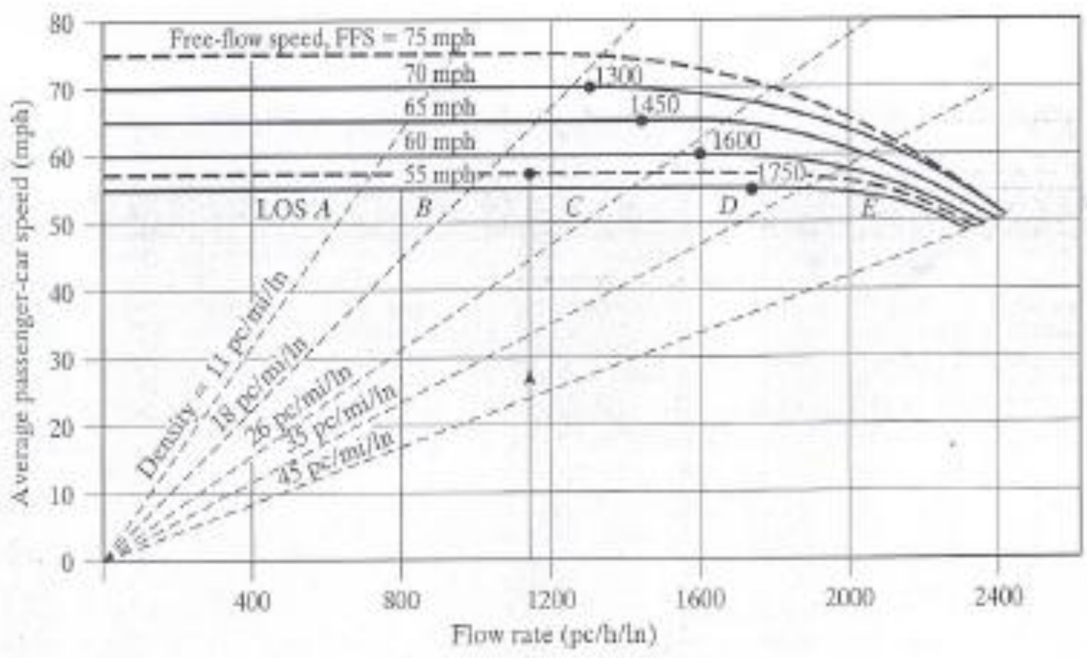


Figure 7-E2 Graphic Solution Using Speed-Flow Curves—Example 2.

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

b) <u>Additional traffic to reach capacity:</u>

Capacity corresponds to LOS E

Maximum service flow rate at LOS E = 2270 pc/h/ln

(from Fig. 7-3 or Table 7-1)

Therefore, additional traffic

= 2270 – 1165

= 1105 pc/h/ln

(Remember this value is the peak 15-minute flow rate.)

BASIC FREEWAY CAPACITY STUDIES

Use of Highway Capacity Manual

- ➔ Convert the peak rate of flow to hourly volume

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

$$V = 1105 \times 0.90 \times 2 \times 0.93 \times 1 = 1850 \text{ veh/hr}$$

- ✓ Therefore, additional traffic volume of 1850 veh/hr can be accommodated before reaching capacity.