



Transportation Engineering

Highway Capacity (II)

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Learning Objectives

- To perform capacity analysis for multilane highways
- To perform capacity analysis for two-lane highways
- To distinguish differences in analysis methods for freeway/multilane highway/two-lane highway

(Chapter 7; HCM Ch23)

Practice Problem

- BFFS = 70 mph (LOS A or B)
- $N = 3$, $LC = 3\text{ft}$, $LW = 11\text{ft}$
- 1 interchange/mi
- $V = 3080$ veh/hr (1-dir)
- $PHF = 0.88$
- 154 Tr & Buses
- Level terrain
- All commuters
- Determine density (D) and LOS



Freeway Analysis Applications

- Operational analysis
 - Given geometric and traffic conditions, estimate speed, density, and LOS
- Design
 - Given forecasted demand volume and desired LOS, determine number of lanes needed
- Planning
 - Given forecasted AADT (annual average daily traffic), HV%, and terrain type, estimate operational and design parameters

Freeway Analysis Applications

- Planning (cont.)
 - First step: convert AADT to DDHV (directional design hour volume)

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

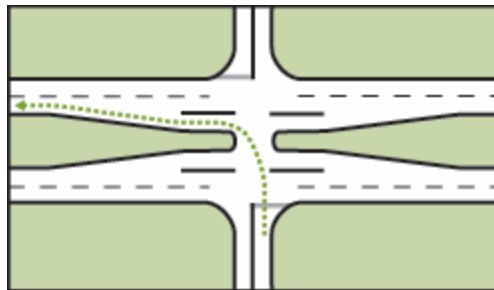
$$DDHV_{(veh/hr)} = AADT_{(veh/day)} \cdot K \cdot D$$

K: proportion of AADT occurring in peak hour
0.08-0.09 (urban), 0.15-0.20 (rural)

D: proportion of peak hour traffic in the heavier direction
0.52 (urban circumferential fwy),
0.55 (urban radial fwy), 0.75 (rural fwy)

Multilane Highways

- 4 to 6 lanes
- Often with physical medians or two-way left-turn lanes
- Posted speed limit of 40~55mph
- Flow not as efficient as freeways



Multilane Highways



Multilane Highway Analysis

- Minor differences in base conditions
 - Minimum lane widths of 12 ft
 - Objects no closer than 6 ft from the edge of the traveled pavement (at the roadside or median)
 - No direct access points
 - Divided highway
 - FFS of 60mph pr more
 - 100% passenger cars
 - Drivers primarily regulars
- Similar to freeways
 - Determine flow rate
 - Determine free flow speed
 - Determine level of service  defined by density

Determining Flow Rate

- Same as freeway analysis

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

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.

Determining FFS

- Two methods:
 - Direct measurement
 - Low-volume conditions (below 1400 pc/h/ln)
 - No adjustment needed
 - Use a baseline and adjust it
 - Use BFFS of 60 mph or estimate based on the 85th percentile speed

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

f_{LW} = adjustment for lane width (mph)

f_{LC} = adjustment for right-shoulder lateral clearance (mph)

f_M = adjustment for median type (mph)

f_A = adjustment for access points (mph)

Lane Width Adjustment (f_{LW})

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

- Base condition ($f_{LW} = 0$)
 - Average width of 12 ft. or wider across all 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

Same as Freeway LOS

Lateral Clearance Adjustment (f_{LC})

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

- Base condition ($f_{LC} = 0$)
– 12 ft or greater TLC

$$TLC = LC_R + LC_L$$

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/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:

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

Median Adjustment (f_M)

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

- Base condition ($f_M = 0$)
 - Divided highway

EXHIBIT 21-6. ADJUSTMENT FOR MEDIAN TYPE

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

Access-Point Density Adjustment (f_A)

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

- Base condition ($f_A = 0$)
 - 0 access points per mile
 - For $NAPM \leq 40$: $f_A = 0.25 \times \text{\#access point/mi}$
 - For $NAPM > 40$: $f_A = 10$
- Default density give by Table 7-15

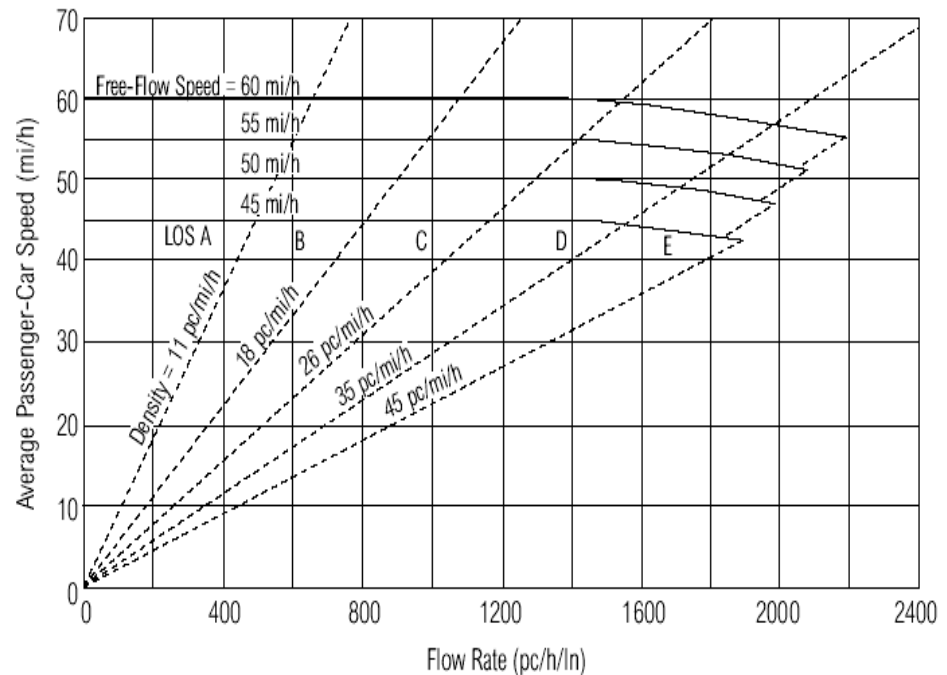
EXHIBIT 21-7. ACCESS-POINT DENSITY ADJUSTMENT

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

Table 7-14

Determining LOS

- Same procedure as for freeways
- Use v_p and FFS curve to find average passenger car speed (S)
- Calculate density $D = \frac{v_p}{S}$
- Compare calculated density with LOS Criteria for Basic Freeway Segments (Table 7-10) or speed-flow curve (figure 7-5)



Note:

Maximum densities for LOS E occur at a v/c ratio of 1.0. They are 40, 41, 43, and 45 pc/mi/ln at FFS of 60, 55, 50, and 45 mi/h, respectively. Capacity varies by FFS. Capacity is 2,200, 2,100, 2,000, and 1,900 pc/h/ln at FFS of 60, 55, 50, and 45 mi/h, respectively.

Figure 7-5

LOS Criteria for Multilane Highways

Free-Flow Speed	Criteria	LOS				
		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.

Table 7-10

Two-lane Highways



Two-lane Highways

- Undivided two-lane, two-way highways
- Class I
 - consistent high-speed operations and infrequent passing delays
 - Long-distance trips
 - LOS defined by % time-spent-following and avg. travel speed
- Class II
 - Short trips; accessibility
 - LOS defined by % time-spent-following only

Two-lane Highway Analysis

- Base conditions
 - Minimum lane widths of 12 ft
 - Shoulders at least 6 ft
 - No 'No Passing Zones' on the highway
 - No traffic control or turning vehicles
 - Level terrain
 - 100% passenger cars
 - 50/50 split
- Either as **two-way segments** with both directions combined or as **directional segments** with each direction considered separately

Two-way Segment Analysis

- Determine flow rate (iterative procedure)

$$v_p = \frac{V}{PHP \cdot f_G \cdot f_{HV}}$$

f_{HV} = Adjustment for heavy vehicle

Same equation, different tables (7-27, 7-28)

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

f_G = Adjustment for grade

Table 7-25 for speed estimation, 7-26 for %
time-spent-following estimation

Two-way Segment Analysis

- Determine free-flow speed: two methods
 - Direct measurement

$$FFS = S_{FM} + 0.00776 \frac{V_f}{f_{HV}}$$

- Use a baseline and adjust it

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

Two-way Segment Analysis

- Determine average travel speed

$$ATS = FFS + 0.00776 \cdot v_p - f_{np}$$

f_{np} = Adjustment for % of no-passing zones

- Determine PTSF

$$PTSF = BPTSF + f_{d/npA}$$
$$BPTSF = 100 \left(1 - e^{0.000879 v_p} \right)$$

$f_{d/np}$ = Adjustment for directional distribution and
% of no-passing zones

Two-way Segment Analysis

- Determine LOS

TABLE 7-20 LOS Criteria for Two-Lane Highways in Class I

LOS	Percent Time-Spent-Following	Average Travel Speed (mph)
A	≤ 35	> 55
B	$> 35-50$	$> 50-55$
C	$> 50-65$	$> 45-50$
D	$> 65-80$	$> 40-45$
E	> 80	≤ 40

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

Source: TRB, 2000

Two-way Segment Analysis

- Determine LOS

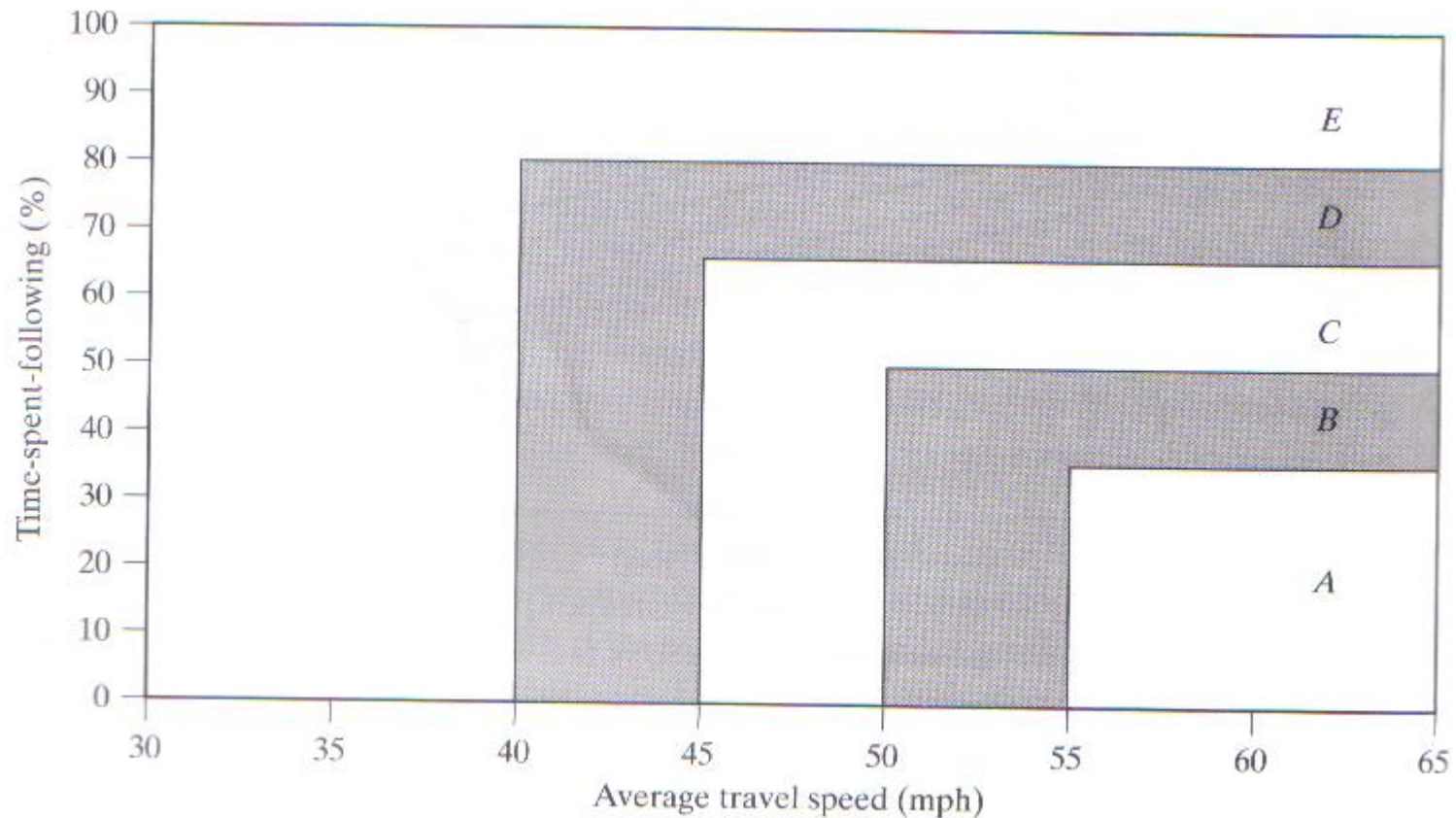


Figure 7-7 LOS Criteria (Graphical) for Two-Lane Highways in Class I (TRB, 2000).

Two-way Segment Analysis

- Determine LOS

TABLE 7-21 LOS Criteria for Two-Lane Highways in Class II

LOS	Percent Time-Spent-Following
A	≤ 40
B	$> 40-55$
C	$> 55-70$
D	$> 70-85$
E	> 85

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

Source: TRB, 2000.

Directional Segment Analysis

- Section 5.3 in chapter 7