Montogue

QUIZ GT501

Highway Capacity and Level of Service

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► PROBLEMS

PROBLEM 1 (Roess et al., 2010, w/ permission)

A freeway operating in generally rolling terrain has a traffic composition of 12% trucks and 3% RVs. If the observed peak hour volume is 3200 veh/h, what is the equivalent volume in pce/h?

A) V_{pce} = 3405 pce/h
B) V_{pce} = 3633 pce/h
C) V_{pce} = 3874 pce/h
D) V_{pce} = 4022 pce/h

PROBLEM 2 (Roess et al., 2010, w/ permission)

An existing six-lane divided freeway with a field-measured free-flow speed of 45 mi/h serves a peak-hour volume of 4000 veh/h, with 12% trucks and no RVs. The PHF is 0.88. The freeway has rolling terrain. What is the likely level of service for this section?

A) LOS B
B) LOS C
C) LOS D
D) LOS E

PROBLEM 3A (Roess et al., 2010, w/ permission)

Find the upgrade service flow rate for an eight-lane urban freeway with the following characteristics:

→ 11-ft lanes
→ 2-ft right-side lateral clearance
→ 4.2 ramps/mi
→ 4% trucks, no recreational vehicles
→ Driver population consisting of regular facility users

The section in question is on a 3.5% sustained grade of 1.5 mile. The *PHF* is 0.92.

A) *SF* = 3455 veh/h
B) *SF* = 3927 veh/h
C) *SF* = 4412 veh/h
D) *SF* = 4889 veh/h

PROBLEM 3B

Determine the service volume for the freeway considered in the previous problem.

A) *SV* = 3179 veh/h
B) *SV* = 3613 veh/h
C) *SV* = 4059 veh/h
D) *SV* = 4498 veh/h

PROBLEM 4 (Roess et al., 2010, w/ permission)

A long section of suburban freeway is to be designed on level terrain. A level section of 5 miles is, however, followed by a 5% grade, 2.0 mi in length. If the DDHV is 2500 veh/h with 10% trucks and 3% RVs, how many lanes will be needed on the upgrade to provide for a minimum of level of service C? Assume that base conditions of lane width and lateral clearance exist and that ramp density is 0.50/mi. The *PHF* = 0.92.

A) N_C = 2 lanes in each direction

B) N_C = 3 lanes in each direction

C) N_C = 4 lanes in each direction

D) N_C = 5 lanes in each direction

PROBLEM 5 (Mannering & Washburn, 2013, w/ permission)

A segment of four-lane freeway (two lanes in each direction) has a 3% upgrade that is 1500 ft long followed by a 1000-ft 4% upgrade. It has 12-ft lanes and 3-ft shoulders. The directional hourly traffic flow is 2000 vehicles with 5% large trucks and buses (no recreational vehicles). The total ramp density for this freeway segment is 2.33 ramps per mile. If the peak-hour factor is 0.90 and all of the drivers are regular users, what is the level of service of this compound-grade segment?

A) LOS A

B) LOS B

C) LOS C

D) LOS D

PROBLEM 6 (Mannering & Washburn, 2013, w/ permission)

A six-lane freeway (three lanes in each direction) in a scenic area has a measured free-flow speed of 55 mi/h. The peak-hour factor is 0.80, and there are 8% large trucks and 6% recreational vehicles in the traffic stream. One upgrade is 5% and 0.5 mi long. An analyst has determined that the freeway is operating at capacity on this upgrade during the peak hour. If the peak-hour traffic volume is 3900 vehicles, what value of the driver population factor was used?

A) f_p = 0.867

B) f_p = 0.911

C) f_p = 0.945

D) f_p = 0.982

PROBLEM 7 (Mannering & Washburn, 2013, w/ permission)

A four-lane freeway (two lanes in each direction) is located on rolling terrain and has 12-ft lanes, no lateral obstructions within 6 ft of the pavement edges, and there are two ramps within three miles upstream of the segment midpoint and three ramps within three miles downstream of the segment midpoint. The traffic stream consists of cars, buses, and large trucks (no recreational vehicles). A weekday directional peak-hour volume of 1800 vehicles (familiar users) is observed, with 700 arriving in the most congested 15-min period. If a level of service no worse than C is desired, determine the maximum number of trucks and buses that can be present in the peak-hour traffic stream.

A) n_T = 126 veh

B) n_T = 216 veh

C) n_T = 306 veh

D) n_T = 396 veh

PROBLEM 8A (Roess et al., 2010, w/ permission)

An old urban four-lane freeway on rolling terrain has a free flow speed of 60 mi/h. The traffic features a truck proportion of 7% and no RVs. The peak-hour factor *PHF* = 0.90. The present peak-hour demand on the facility is 2100 veh/h, and the anticipated growth is expected to be 3% per year. What will be the level of service of this road 10 years from now?

A) LOS A
B) LOS B
C) LOS C
D) LOS D

PROBLEM 8B

When will the road considered in the previous problem reach breakdown, that is, when will the freeway reach level of service F if no improvements or alternative routes are implemented?

A) t_{bd} = 19.6 years
B) t_{bd} = 24.5 years
C) t_{bd} = 29.4 years
D) t_{bd} = 34.3 years

PROBLEM 9 (Mannering & Washburn, 2013, w/ permission)

A 5% upgrade on a six-lane freeway (three lanes in each direction) is 1.25 mi long. On this segment of freeway, the directional peak-hour volume is 3800 vehicles with 2% large trucks and 4% buses (no recreational vehicles), the peak-hour factor is 0.90, and all drivers are regular users. The lanes are 12 ft wide, there are no lateral obstructions within 10 ft of the roadway, and the total ramp density is 1.0 ramp per mile. A bus strike eliminates all bus traffic, but it is estimated that for each bus removed from the roadway, seven additional passenger cars will be added as travelers seek other means of travel. True or false?

1.( ) The density of the segment increases by more than 10% after the beginning of the strike.
2.( ) The volume-to-capacity ratio after the strike begins is greater than 0.8.
3.( ) The level of service of the segment remains unchanged after the beginning of the strike.

PROBLEM 10 (Mannering & Washburn, 2013, w/ permission)

A Class I two-lane highway is on level terrain, has a measured free-flow speed of 65 mi/h, and has 50% no-passing zones. During the peak hour, the analysis direction flow rate is 182 veh/h, the opposing direction flow rate is 78 veh/h, and the *PHF* = 0.90. There are 15% large trucks and buses (no RVs). Determine the level of service.

A) LOS A
B) LOS B
C) LOS C
D) LOS D

PROBLEM 11 (Mannering & Washburn, 2013, w/ permission)

A Class I two-lane highway is on level terrain with passing permitted throughout. The hinghway has 11-ft lanes with 4-ft shoulders. There are 16 access points per mile. The base FFS is 60 mi/h. During the peak hour, 440 vehicles are traveling in the analysis direction and 360 vehicles are traveling in the opposing direction. If the PHF is 0.85 and there are 4% large trucks, 3% buses, and 2% recreational vehicles, determine the level of service.

A) LOS A
B) LOS B
C) LOS C
D) LOS D

PROBLEM 12 (Mannering & Washburn, 2013, w/ permission)

A Class III two-lane highway is on level terrain, has a measured free-flow speed of 45 mi/h, and has 100% no-passing zones. During the peak hour, the analysis direction flow rate is 150 veh/h, the opposing direction flow rate is 100 veh/h, and the PHF = 0.95. There are 5% large trucks and 10% recreational vehicles. Determine the level of service.

A) LOS A
B) LOS B
C) LOS C
D) LOS D

► ADDITIONAL INFORMATION

Figure 1 Freeway speed-flow curves and level-of-service criteria

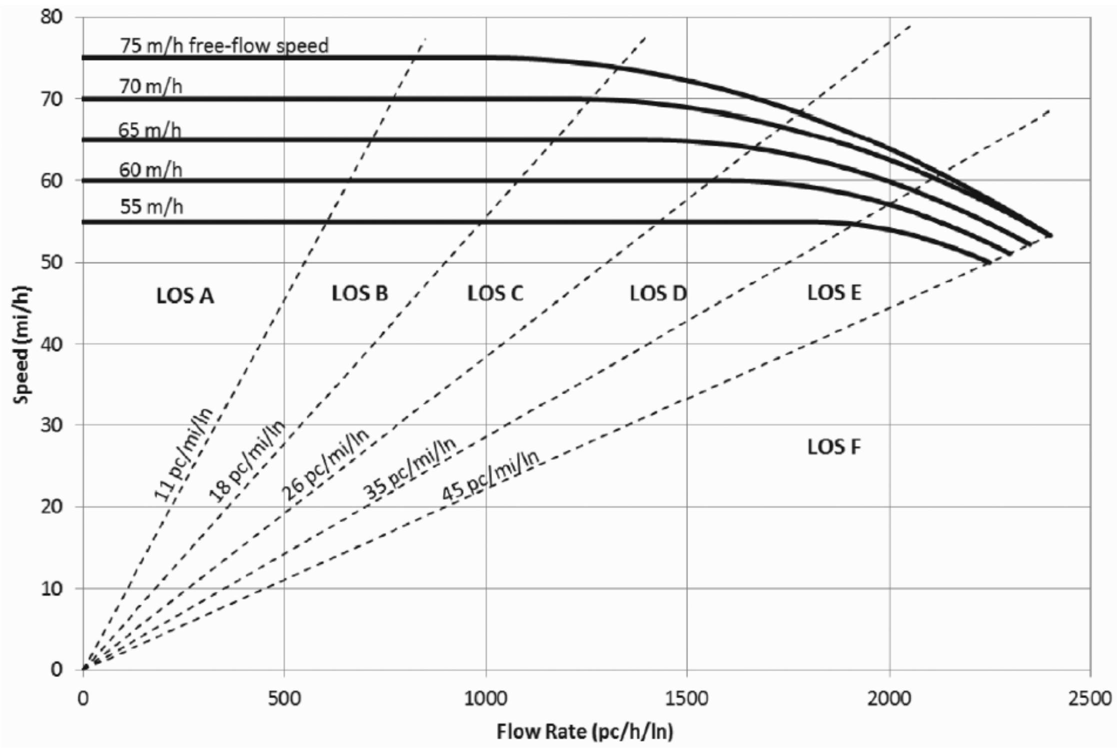

Figure 2 Multilane highway speed-flow curves and level-of-service criteria

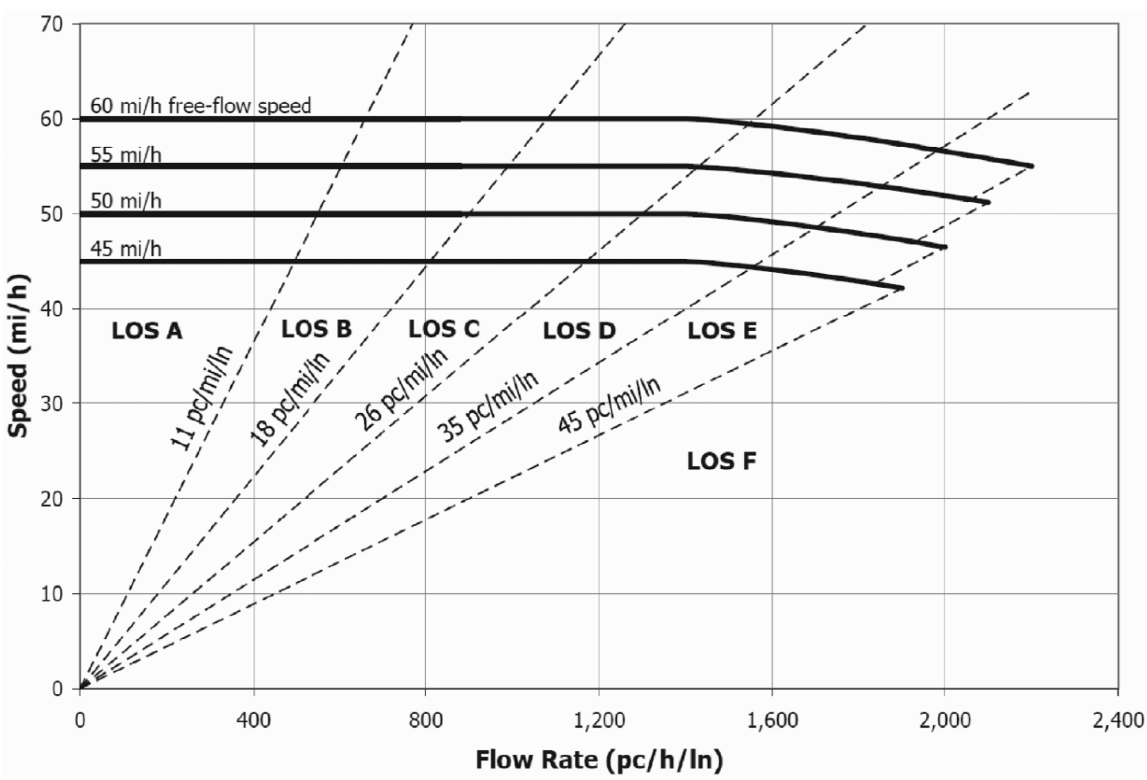

Table 1 Passenger-car equivalents for trucks, buses, and RVs

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T	1.5	2.5	4.5
E_R	1.2	2.0	4.0

Table 2 Adjustment to free-flow speed for lane width on a freeway

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

Table 3 Adjustment to free-flow speed for lateral clearance on a freeway

Right Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mi/h)			
	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	2.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Table 4 Selecting a speed-flow curve in Figures 1 and 2

Free-Flow Speed is: (mi/h)	Use Speed-Flow Curve for a *FFS* of: (mi/h)
≥72.5 < 77.5	75
≥67.5 < 72.5	70
≥62.5 < 67.5	65
≥57.5 < 62.5	60
≥52.5 < 57.5	55
≥47.5 < 52.5	50
≥42.5 < 47.5	45

Table 5 Passenger-car equivalents for trucks and buses on upgrades

Upgrade (%)	Length (mi)	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	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50–0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75–1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00–1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3–4	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50–0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75–1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00–1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
>4–5	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>050–0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75–1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	2.5	3.0	3.0	3.0
>5–6	0.00–0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30–0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50–0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	>0.75–1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
>6	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>0.25–0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30–0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50–0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75–1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Table 6 Passenger-car equivalents for RVs on upgrades

Grade (%)	Length (mi)	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	0.00–0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
>3–4	0.00–0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.25–0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
>4–5	0.00–0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	>0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
>5	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.5
	>0.25–50	6.0	4.0	4.0	4.0	3.5	3.0	2.5	2.5	2.0
	>0.50	6.0	4.5	4.0	4.0	4.0	3.5	3.0	2.5	2.0

Table 7 Passenger-car equivalents for trucks and buses on downgrades

Downgrade (%)	Length (mi)	E_T			
		Percentage Trucks and Buses (%)			
		5	10	15	≥20
< 4	All	1.5	1.5	1.5	1.5
≥4–5	≤4	1.5	1.5	1.5	1.5
	>4	2.0	2.0	2.0	1.5
>5–6	≤4	1.5	1.5	1.5	1.5
	>4	5.5	4.0	4.0	3.0
>6	≤4	1.5	1.5	1.5	1.5
	>4	7.5	6.0	5.5	4.5

Table 8 LOS criteria for basic freeway segments

Criterion	LOS				
	A	B	C	D	E
			FFS = 75 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	75.0	73.8	68.3	60.9	53.3
Maximum *v/c*	0.34	0.55	0.74	0.89	1.00
Maximum flow rate (pc/h/ln)	825	1330	1775	2130	2400
			FFS = 70 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	70.0	70.0	66.7	60.3	53.3
Maximum *v/c*	0.32	0.52	0.72	0.88	1.00
Maximum flow rate (pc/h/ln)	770	1260	1735	2110	2400
			FFS = 65 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	65.0	65.0	64.0	58.8	52.2
Maximum *v/c*	0.30	0.50	0.71	0.88	1.00
Maximum flow rate (pc/h/ln)	710	1170	1665	2060	2350
			FFS = 60 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	60.0	60.0	60.0	57.1	51.1
Maximum *v/c*	0.29	0.47	0.68	0.87	1.00
Maximum flow rate (pc/h/ln)	660	1080	1560	2000	2300
			FFS = 55 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average 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 flow rate (pc/h/ln)	605	990	1430	1915	2250

Table 9 Relationship between free-flow speed and capacity on basic freeway segments

Free-flow speed (mi/h)	Capacity (pc/h/ln)
75	2400
70	2400
65	2350
60	2300
55	2250

Table 10 Adjustment for access-point frequency (two-lane highways)

Access points/ mile	Reduction in free-flow speed (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

Table 11 Adjustment for lane width and shoulder width (two-lane highways)

	Reduction in free-flow speed (mi/h) Shoulder width (ft)			
Lane width (ft)	≥ 0 < 2	≥ 2 < 4	≥ 4 < 6	≥ 6
9 < 10	6.4	4.8	3.5	2.2
≥ 10 < 11	5.3	3.7	2.4	1.1
≥ 11 < 12	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

Table 12 Grade adjustment factor for Average Travel Speed (*ATS*) and Percent Time Spent Following (*PTSF*)

Directional demand flow rate (veh/h)	Average travel speed (mi/h)		Percent time spent following	
	Level terrain	Rolling terrain	Level terrain	Rolling terrain
≤ 100	1.00	0.67	1.00	0.73
200	1.00	0.75	1.00	0.80
300	1.00	0.83	1.00	0.85
400	1.00	0.90	1.00	0.90
500	1.00	0.95	1.00	0.96
600	1.00	0.97	1.00	0.97
700	1.00	0.98	1.00	0.99
800	1.00	0.99	1.00	1.00
≥ 900	1.00	1.00	1.00	1.00

Table 13 Passenger-car equivalents for heavy vehicles for Average Travel Speed (*ATS*) and Percent Time Spent Following (*PTSF*)

Vehicle type	Directional demand flow rate (veh/h)	Average travel speed (mi/h)		Percent time spent following	
		Level terrain	Rolling terrain	Level terrain	Rolling terrain
Trucks and buses, E_T	≤ 100	1.9	2.7	1.1	1.9
	200	1.5	2.3	1.1	1.8
	300	1.4	2.1	1.1	1.7
	400	1.3	2.0	1.1	1.6
	500	1.2	1.8	1.0	1.4
	600	1.1	1.7	1.0	1.2
	700	1.1	1.6	1.0	1.0
	800	1.1	1.4	1.0	1.0
	≥ 900	1.0	1.3	1.0	1.0
RVs, E_R	All flows	1.0	1.1	1.0	1.0

Table 14 Adjustment for no-passing zones on Average Travel Speed

Opposing flow rate, v_o (pc/h)	No-passing zones (%)				
	≤ 20	40	60	80	100
FFS ≥ 65 mi/h					
≤ 100	1.1	2.2	2.8	3.0	3.1
200	2.2	3.3	3.9	4.0	4.2
400	1.6	2.3	2.7	2.8	2.9
600	1.4	1.5	1.7	1.9	2.0
800	0.7	1.0	1.2	1.4	1.5
1000	0.6	0.8	1.1	1.1	1.2
1200	0.6	0.8	0.9	1.0	1.1
1400	0.6	0.7	0.9	0.9	0.9
≥ 1600	0.6	0.7	0.7	0.7	0.8
FFS = 60 mi/h					
≤ 100	0.7	1.7	2.5	2.8	2.9
200	1.9	2.9	3.7	4.0	4.2
400	1.4	2.0	2.5	2.7	3.9
600	1.1	1.3	1.6	1.9	2.0
800	0.6	0.9	1.1	1.3	1.4
1000	0.6	0.7	0.9	1.1	1.2
1200	0.5	0.7	0.9	0.9	1.1
1400	0.5	0.6	0.8	0.8	0.9
≥ 1600	0.5	0.6	0.7	0.7	0.7
FFS = 55 mi/h					
≤ 100	0.5	1.2	2.2	2.6	2.7
200	1.5	2.4	3.5	3.9	4.1
400	1.3	1.9	2.4	2.7	2.8
600	0.9	1.1	1.6	1.8	1.9
800	0.5	0.7	1.1	1.2	1.4
1000	0.5	0.6	0.8	0.9	1.1
1200	0.5	0.6	0.7	0.9	1.0
1400	0.5	0.6	0.7	0.7	0.9
≥ 1600	0.5	0.6	0.6	0.6	0.7
FFS = 50 mi/h					
≤ 100	0.2	0.7	1.9	2.4	2.5
200	1.2	2.0	3.3	3.9	4.0
400	1.1	1.6	2.2	2.6	2.7
600	0.6	0.9	1.4	1.7	1.9
800	0.4	0.6	0.9	1.2	1.3
1000	0.4	0.4	0.7	0.9	1.1
1200	0.4	0.4	0.7	0.8	1.0
1400	0.4	0.4	0.6	0.7	0.8
≥ 1600	0.4	0.4	0.5	0.5	0.5
FFS ≤ 45 mi/h					
≤ 100	0.1	0.4	1.7	2.2	2.4
200	0.9	1.6	3.1	3.8	4.0
400	0.9	0.5	2.0	2.5	2.7
600	0.4	0.3	1.3	1.7	1.8
800	0.3	0.3	0.8	1.1	1.2
1000	0.3	0.3	0.6	0.8	1.1
1200	0.3	0.3	0.6	0.7	1.0
1400	0.3	0.3	0.6	0.6	0.7
≥ 1600	0.3	0.3	0.4	0.4	0.6

Table 15 Adjustment for no-passing zones on Percent Time Spent Following

Two-way flow rate, $v_d + v_o$ (pc/h)	No-passing zones (%) 0	20	40	60	80	100
	Directional split = 50/50					
≤ 200	9.0	29.2	43.4	49.4	51.0	52.6
400	16.2	41.0	54.2	61.6	63.8	65.8
600	15.8	38.2	47.8	53.2	55.2	56.8
800	15.8	33.8	40.4	44.0	44.8	46.6
1400	12.8	20.0	23.8	26.2	27.4	28.6
2000	10.0	13.6	15.8	17.4	18.2	18.8
2600	5.5	7.7	8.7	9.5	10.1	10.3
3200	3.3	4.7	5.1	5.5	5.7	6.1
	Directional split = 60/40					
≤ 200	11.0	30.6	41.0	51.2	52.3	53.5
400	14.6	36.1	44.8	53.4	55.0	56.3
600	14.8	36.9	44.0	51.1	52.8	54.6
800	13.6	28.2	33.4	38.6	39.9	41.3
1400	11.8	18.9	22.1	25.4	26.4	27.3
2000	9.1	13.5	15.6	16.0	16.8	17.3
2600	5.9	7.7	8.6	9.6	10.0	10.2
	Directional split = 70/30					
≤ 200	9.9	28.1	38.0	47.8	48.5	49.0
400	10.6	30.3	38.6	46.7	47.7	48.8
600	10.9	30.9	37.5	43.9	45.4	47.0
800	10.3	23.6	28.4	33.3	34.5	35.5
1400	8.0	14.6	17.7	20.8	21.6	22.3
2000	7.3	9.7	15.7	13.3	14.0	14.5
	Directional split = 80/20					
≤ 200	8.9	27.1	37.1	47.0	47.4	47.9
400	6.6	26.1	34.5	42.7	43.5	44.1
600	4.0	24.5	31.3	38.1	39.1	40.0
800	4.8	18.5	23.5	28.4	29.1	29.9
1400	3.5	10.3	13.3	16.3	16.9	32.2
2000	3.5	7.0	8.5	10.1	10.4	10.7
	Directional split = 90/10					
≤ 200	4.6	24.1	33.6	43.1	43.4	43.6
400	0.0	20.2	28.3	36.3	36.7	37.0
600	-3.1	16.8	23.5	30.1	30.6	31.1
800	-2.8	10.5	15.2	19.9	20.3	20.8
1400	-1.2	5.5	8.3	11.0	11.5	11.9

Table 16 Coefficients for use with the *BPTSF* formula

Opposing Flow Rate, v_o (pc/h)	Coefficient a	Coefficient b
≤ 200	–0.0014	0.973
400	–0.0022	0.923
600	–0.0033	0.870
800	–0.0045	0.833
1000	–0.0049	0.829
1200	–0.0054	0.825
1400	–0.0058	0.821
≥ 1600	–0.0062	0.817

Table 17 LOS criteria for two-lane highways

	Class I		Class II	Class III
LOS	Percent time spent following (*PTSF*)	Average travel speed (*ATS*) mi/h	Percent time spent following (*PTSF*)	Percent free-flow speed (*PFFS*)
A	≤ 35	> 55	≤ 40	> 91.7
B	≤ 50	> 50	≤ 55	> 83.3–91.7
C	≤ 65	> 45	≤ 70	> 75.0–83.3
D	≤ 80	> 40	≤ 85	> 66.7–75.0
E	> 80	≤ 40	> 85	≤ 66.7

▶ SOLUTIONS

P.1 ■ Solution

The equivalent flow rate in pc/h is given by

$$V_{\text{pce}} = \frac{V_{\text{vph}}}{f_{HV}}$$

To proceed, we must compute the heavy vehicle factor f_{HV},

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

Since the freeway is on rolling terrain, factors E_T = 2.5 and E_R = 2.0 are taken from Table 1. Then, f_{HV} is determined as

$$f_{HV} = \frac{1}{1 + 0.12 \times \left(2.5 - 1\right) + 0.03 \times \left(2.0 - 1\right)} = 0.826$$

Lastly, V_{pce} becomes

$$V_{\text{pce}} = \frac{3200}{0.826} = \boxed{3874 \text{ pce/h}}$$

▶ The correct answer is **C**.

P.2 ■ Solution

The demand flow rate v_p is given by

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

To proceed, we require the heavy vehicle factor f_{HV}, which follows from the formula

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

Knowing that the highway has rolling terrain, factors E_T = 2.5 and E_R = 2.0 are taken from Table 1. The value of f_{HV} is then

$$f_{HV} = \frac{1}{1 + 0.12 \times \left(2.5 - 1\right) + 0 \times \left(2.0 - 1\right)} = 0.847$$

Substituting this and other data in the equation for v_p yields

$$v_p = \frac{4000}{0.88 \times 3 \times 0.847 \times 1.0} = 1789 \text{ pc/h/ln}$$

Entering this value of flow, along with the given FFS of 45 mi/h, into Figure 2, we conclude that the level of service for this section is E.

▶ The correct answer is **D**.

P.3 ■ Solution

Part A: The free-flow speed for such an urban freeway is given by

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

The correction f_{LW} for lane width, from Table 2, is 1.9 mi/h, while the correction f_{LC} for lateral clearance, from Table 3, is 0.8 mi/h. *TRD* = 4.2 ramps/mi is the ramp density. The value of *FFS* is then

$$FFS = 75.4 - 1.9 - 0.8 - 3.22 \times 4.2^{0.84} = 62 \text{ mi/h}$$

Table 4 indicates which speed-flow curve should be used in Figure 1. Since the *FFS* is between 57.5 and 62.5 mi/h, we shall use the speed-flow curve for a *FFS* of 60 mi/h. Now, the upgrade demand flow rate is determined with the equation

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

Use of this relation in turn requires the heavy vehicle factor f_{HV},

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

Here, E_T = 3.5 from Table 5. Therefore,

$$f_{HV} = \frac{1}{1 + 0.04 \times \left(3.5 - 1\right) + 0} = 0.909$$

Furthermore, Table 9 tells us that V = 2300 pc/h/ln. Backsubstituting this and other quantities in the equation for v_p, we obtain

$$v_p = \frac{2300}{0.92 \times 4 \times 0.909 \times 1.0} = 688 \text{ pc/h/ln}$$

Entering this flow rate into Figure 1 and referring to the curve for *FFS* = 60 mi/h, we see that the level of service for this freeway is B. At this point, we evoke the formula for service flow rate,

$$SF = MSF_B \times N \times f_{HV} \times f_p$$

From Table 8, the maximum service flow rate for this level of service and a speed of 60 mi/h is MSF_B = 1080 pc/h/ln. Therefore,

$$SF = 1080 \times 4 \times 0.909 \times 1.0 = \boxed{3927 \text{ veh/h}}$$

► The correct answer is **B**.

Part B: The service volume is the product of specific flow rate and the peak-hour factor; that is,

$$SV = SF \times PHF = 3927 \times 0.92 = \boxed{3613 \text{ veh/h}}$$

► The correct answer is **B**.

P.4 ■ Solution

The free-flow speed is easily determined as

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84} = 75.4 - 0 - 0 - 3.22 \times 0.5^{0.84} = 73.6 \text{ mi/h}$$

Following Table 4, this free-flow speed can be used in combination with the speed-flow curve for a FFS of 75 mi/h. From Table 8, we see that, for this FFS and a level of service C, the maximum service flow rate is 1775 pc/h/ln. The number N_C of lanes required for these conditions is given by

$$N_C = \frac{DDHV}{PHF \times f_{HV} \times f_p \times MSF_C}$$

Before proceeding, we require the heavy vehicle factor f_{HV}. From Tables 5 and 6, we take E_T = 2.5 and E_R = 4.0 respectively. Therefore,

$$f_{HV} = \frac{1}{1 + P_T\left(E_T - 1\right) + P_R\left(E_R - 1\right)} = \frac{1}{1 + 0.10 \times \left(2.5 - 1\right) + 0.03 \times \left(4.0 - 1\right)} = 0.806$$

Substituting this and other quantities into the equation for N_C, we find that

$$N_C = \frac{DDHV}{PHF \times f_{HV} \times f_p \times MSF_C} = \frac{2500}{0.92 \times 0.806 \times 1.0 \times 1775} = 1.9 \text{ lanes}$$

The nearest integer is 2. Thus, the number of lanes required to provide a LOC C on upgrade is 2 in each direction.

► The correct answer is **A**.

P.5 ■ Solution

The average grade of the road is

$$\text{Average grade} = \frac{1500 \times 0.03 + 1000 \times 0.04}{2500} = 3.4\%$$

The 15-min passenger car flow rate follows is found with the usual formula,

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

To proceed, we require the heavy vehicle factor. For a 3.4% upgrade and (1500 + 1000)/5280 = 0.473-mi segment, the passenger-car equivalent E_T = 2.0 from Table 5. It follows that

$$f_{HV} = \frac{1}{1 + 0.05 \times (2-1) + 0} = 0.952$$

Substituting these and other quantities in the relation for v_p, we see that

$$v_p = \frac{2000}{0.90 \times 2 \times 0.952 \times 1.0} = 1167 \text{ pc/h/ln}$$

Assessing the level of service of the freeway requires the density D, which is given by

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

where v_p = 1167 pc/h/ln as determined just now and S is the average passenger car speed, which we shall take as the free-flow speed. This, in turn, is calculated according to

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

where f_{LW} = 0 and f_{LC} = 1.8 mi/h from Tables 2 and 3, respectively, so that

$$FFS = 75.4 - 0 - 1.8 - 3.22 \times 2.33^{0.84} = 67.0 \text{ mi/h}$$

Consequently, the density D becomes

$$D = \frac{1167}{67.0} = 17.4 \text{ pc/mi/ln}$$

Finally, refer to Table 8. Since the density is greater than 11 but less than 18, we conclude that the level of service for this compound-grade segment is B.

► The correct answer is **B**.

P.6 ■ Solution

The driver population factor can be determined by adjusting the usual formula

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

Before proceeding, we need the heavy vehicle factor f_{HV}. This requires the passenger car equivalents E_T and E_R, which are determined to be 2.0 and 3.0 from Tables 5 and 6, respectively. It follows that

$$f_{HV} = \frac{1}{1 + 0.08 \times (2-1) + 0.06 \times (3-1)} = 0.833$$

In addition, the 15-min demand flow rate v_p for a freeway operating at capacity, that is, at a level of service E, is taken as v_p = 2250 pc/h/ln from Table 8. Substituting these and other quantities into the expression for f_p, we get

$$f_p = \frac{3900}{0.80 \times 3 \times 0.833 \times 2250} = \boxed{0.867}$$

► The correct answer is **A**.

P.7 ■ Solution

Knowing that f_{LW} = 0 (Table 2), f_{LC} = 0 (Table 3), and TRD = 5/6 = 0.833 ramps/mi, the free-flow speed for this freeway is

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22\text{TRD}^{0.84} = 75.4 - 3.22 \times 0.833^{0.84} = 72.6 \text{ mi/h}$$

The peak-hour factor is

$$PHF = \frac{V}{V_{15} \times 4} = \frac{1800}{700 \times 4} = 0.643$$

Now, the heavy vehicle adjustment factor can be determined by adjusting the equation for 15-min flow rate,

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

Here, the demand v_p that corresponds to a level of service *C* and a FFS of 72.6 mi/h can be determined by interpolating the maximum flow rates for 70 mi/h and 75 mi/h. From Table 8, the values in question are 1735 pc/h/ln for 70 mi/h and 1775 pc/h/ln for 75 mi/h. Interpolating, we get v_p = 1756 pc/h/ln. Substituting this and other data into the equation for f_{HV}, it follows that

$$f_{HV} = \frac{V}{PHF \times N \times v_p \times f_p} = \frac{1800}{0.643 \times 2 \times 1756 \times 1.0} = 0.797$$

Recall that f_{HV} is given by

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

From Table 1, E_T = 2.5 and E_R = 2.0 for rolling terrain. Since there are no recreational vehicles, P_R = 0. Substituting and solving for the proportion of trucks and buses, P_T, we get

$$0.797 = \frac{1}{1 + P_T \times (2.5 - 1) + 0} \rightarrow P_T = 0.17$$

It remains to determine the number of large trucks and buses, n_T,

$$n_T = V \times P_T = 1800 \times 0.17 = \boxed{306 \text{ veh}}$$

► The correct answer is **C**.

P.8 ■ Solution

Part A: We must first assess the corresponding service flow rate for each level of service. The formula in question is

$$SF_i = MSF_i \times N \times f_{HV} \times f_p$$

This in turn requires the heavy vehicle adjustment factor, which, with E_T = 2.5 (Table 1), becomes

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + 0.07 \times (2.5 - 1) + 0} = 0.905$$

We also require the maximum service flow rates (MSF) for each level of service, which can be taken from Table 8. For level of service *A*, for example, *MSF* = 660 pc/h/ln and

$$SF_A = 660 \times 2 \times 0.905 \times 1.0 = 1195 \text{ veh/h}$$

Given the peak-hour factor *PHF* = 0.90, the corresponding service volume is

$$SV_A = SF_A \times PHF = 1195 \times 0.90 = 1076 \text{ veh/h}$$

Calculations for each level of service are summarized below.

Level of Service	MSF	*N*	f_{HV}	f_p	SF (veh/h)	PHF	SV (veh/h)
A	660	2	0.905	1	1195	0.9	1075
B	1080	2	0.905	1	1955	0.9	1759
C	1560	2	0.905	1	2824	0.9	2541
D	2000	2	0.905	1	3620	0.9	3258
E	2300	2	0.905	1	4163	0.9	3747

The demand volume evolves in accordance with the equation

$$V(t) = 2100 \times 1.03^t$$

where *t* is time in years. We are interested in the demand volume ten years from now; that is,

$$V(10) = 2100 \times 1.03^{10} = 2822 \text{ veh/h}$$

Since this quantity is greater than 2541 but less than 3258 (see yellow column above), we conclude that the level of service after ten years will be *D*.

► The correct answer is **D**.

Part B: To establish the year at which breakdown occurs, we must equate *V(t)* to 3747 veh/h, which is the threshold value for the LOS to become *F*, and solve the ensuing equation for *t*; that is,

$$2100 \times 1.03^{t_{bd}} = 3747 \rightarrow \boxed{t_{bd} = 19.6 \text{ years}}$$

If no improvements or alternate routes are implemented, the facility will reach breakdown in about 19 and a half years.

► The correct answer is **A**.

P.9 ■ Solution

The solution begins with the computation of the free-flow speed, which is given by

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22\text{TRD}^{0.84} = 75.4 - 0 - 0 - 3.22 \times 1.0^{0.84} = 72.2 \text{ mi/h}$$

The 15-min passenger car flow rate before the strike is determined with the usual equation

$$v_{p,o} = \frac{V_o}{PHF \times N \times f_{HV,o} \times f_p}$$

Here, V_o = 3800 veh/h denotes the peak-hour volume before the strike and $f_{HV,o}$ denotes the heavy vehicle factor before the strike. The latter is determined with the relation

$$f_{HV,o} = \frac{1}{1 + P_{T,o}\left(E_{T,o} - 1\right) + P_R\left(E_R - 1\right)}$$

The proportion of trucks and buses is $P_{T,o}$ = 2 + 4 = 6%, and the passenger-car equivalent $E_{T,o}$ = 4.0 from Table 5, so that

$$f_{HV,o} = \frac{1}{1 + 0.06 \times (4.0 - 1) + 0} = 0.847$$

and, returning to the expression for $v_{p,o}$,

$$v_{p,o} = \frac{3800}{0.90 \times 3 \times 0.847 \times 1.0} = 1662 \text{ pc/h/ln}$$

We can now determine the density of the upgrade segment before the strike, D_o,

$$D_o = \frac{v_{p.o}}{S} = \frac{1662}{72.2} = 23.0 \text{ pc/mi/ln}$$

The volume-to-capacity ratio, in turn, is given by

$$\text{Volume-to-capacity ratio}\left(\text{bef. strike begins}\right) = \frac{v_{p,o}}{c}$$

where the capacity c = 2400 pc/h/ln, as per Table 9, with the result that

$$\text{Volume-to-capacity ratio (bef. strike begins)} = \frac{1662}{2400} = 0.693$$

Considering these data and referring to Table 8, we conclude that the level of service of the freeway before the strike is *C*. Now, let subscript 1 denote conditions *after* the strike begins. Once the strike begins, we must deduct the buses and add the seven vehicles that replace each bus. In mathematical terms,

$$V_1 = V_o - P_B \times V_o + 7 \times P_B \times V_o = 3800 - 0.04 \times 3800 + 7 \times 0.04 \times 3800 = 4712 \text{ veh/h}$$

Since the number of vehicles has changed, the proportion of trucks and buses will change accordingly. Its new value is

$$P_{T,1} = \frac{V_o \times P_T}{V_1} = \frac{3800 \times 0.02}{4712} = 0.016 = 1.6\%$$

The 15-min passenger car flow rate after the strike commences is given by

$$v_{p,1} = \frac{V_1}{PHF \times N \times f_{HV,1} \times f_p}$$

Here, $f_{HV,1}$ denotes the heavy vehicle factor after the strike, which is calculated as

$$f_{HV,1} = \frac{1}{1 + P_{T,1}\left(E_{T,1} - 1\right) + P_R\left(E_R - 1\right)}$$

The passenger-car equivalent $E_{T,1}$ = 5.0 (Table 5), so that

$$f_{HV,1} = \frac{1}{1 + 0.016 \times \left(5.0 - 1\right) + 0} = 0.940$$

Returning to the expression for $v_{p,1}$, we obtain

$$v_{p,1} = \frac{4712}{0.90 \times 3 \times 0.940 \times 1.0} = 1857 \text{ pc/h/ln}$$

The density of the segment after the strike begins is then

$$D_1 = \frac{v_{p,1}}{S} = \frac{1857}{72.2} = 25.7 \text{ pc/mi/ln}$$

which corresponds to an increase of about 11.7% relatively to conditions before the strike. The volume-to-capacity ratio, in turn, now becomes

$$\text{Volume-to-capacity ratio (aft. strike begins)} = \frac{1857}{2400} = 0.774$$

Considering these data and referring to Table 8, we conclude that the level of service of the freeway after the strike is between C and D. In the worst condition, we surmise that the level of service of the freeway after the strike becomes D.

► Statement **1** is true, while statements **2** and **3** are false.

P.10 ■ Solution

The flow rate in the analysis direction (denoted with the subscript *d*) is given by

$$v_d = \frac{V_d}{PHF \times f_G \times f_{HV}}$$

The grade adjustment factor for level terrain is f_G = 1.0 regardless of the flow rate (Table 10). The heavy vehicle factor, with E_T = 1.5 (Table 13), is

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + 0.15 \times (1.5 - 1) + 0} = 0.930$$

The value of v_d is then

$$v_d = \frac{182}{0.90 \times 1.0 \times 0.930} = 217 \text{ pc/h}$$

In a similar manner, the flow rate in the opposing direction is given by

$$v_o = \frac{V_o}{PHF \times f_G \times f_{HV}}$$

As before, f_G = 1.0. The heavy vehicle factor, with E_T = 1.9 (Table13), is

$$f_{HV} = \frac{1}{1 + 0.15 \times (1.9 - 1) + 0} = 0.881$$

so that

$$v_o = \frac{78}{0.90 \times 1.0 \times 0.881} = 98 \text{ pc/h}$$

The Average Travel Speed is calculated with the formula

$$ATS_d = FFS - 0.00776(v_d + v_o) - f_{np}$$

where adjustment factor f_{np}, interpolating from Table 14, is f_{np} = (2.2 + 2.8)/2 = 2.5. Hence,

$$ATS_d = 65 - 0.00776 \times (217 + 98) - 2.5 = 60.1 \text{ mi/h}$$

The Percent Time Spent Following is given by

$$PTSF_d = BPTSF_d + f_{np}\left(\frac{v_d}{v_d + v_o}\right)$$

Here, the base value $BPTSF_d$ is calculated as

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

Coefficients *a* = −0.0014 and *b* = 0.973 are taken from Table 16, so that

$$BPTSF_d = 100 \times \left[1 - \exp\left(-0.0014 \times 217^{0.973}\right)\right] = 23.1\%$$

In addition, adjustment factor f_{np} = 50% (Table 15). The $PTSF_d$ then becomes

$$PTSF_d = 23.1 + 50 \times \left(\frac{217}{217 + 98}\right) = 57.5\%$$

Finally, refer to Table 17. A Class I two-lane highway with an *ATS* > 55 in principle has a LOS A. However, a $PTSF_d$ between 50 and 65 places it in LOS C. Since the lower LOS governs, we conclude that the highway has Level of Service C.

► The correct answer is **C**.

P.11 ■ Solution

The free-flow speed may be estimated as

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

where *BFFS* = 60 mi/h, f_{LS} = 1.7 (Table 11) and f_A = 3.8 (Table 10), so that

$$FFS = 60 - 1.7 - 3.8 = 54.5 \text{ mi/h}$$

The flow rate in the analysis direction is determined with the equation

$$v_d = \frac{V_d}{PHF \times f_G \times f_{HV}}$$

The grade adjustment factor for level terrain is f_G = 1.0 for all flow rates (Table 12). The heavy vehicle factor, with E_T = 1.25 and E_R = 1.0 (Table 13), is

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + (0.04 + 0.03)\times(1.25 - 1) + 0.02 \times (1.0 - 1)} = 0.983$$

The value of v_d is then

$$v_d = \frac{440}{0.85 \times 1.0 \times 0.983} = 527 \text{ pc/h}$$

Next, the flow rate in the opposing direction is calculated as

$$v_o = \frac{V_o}{PHF \times f_G \times f_{HV}}$$

As before, f_G = 1.0. The heavy vehicle factor, with E_T = 1.35 and E_R = 1.0 (Table 13), is

$$f_{HV} = \frac{1}{1 + 0.07 \times (1.35 - 1) + 0.02 \times (1.0 - 1)} = 0.976$$

so that

$$v_o = \frac{360}{0.85 \times 1.0 \times 0.976} = 434 \text{ pc/h}$$

The Average Travel Speed is calculated with the formula

$$ATS_d = FFS - 0.00776(v_d + v_o) - f_{np}$$

where adjustment factor f_{np} = 0, with the result that

$$ATS_d = 54.5 - 0.00776 \times (527 + 434) - 0 = 47.0 \text{ mi/h}$$

The Percent Time Spent Following is given by

$$PTSF_d = BPTSF_d + f_{np}\left(\frac{v_d}{v_d + v_o}\right)$$

Here, the base value $BPTSF_d$ is calculated as

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

Coefficients a = −0.0024 and b = 0.948 are taken from Table 16, so that

$$BPTSF_d = 100 \times \left[1 - \exp\left(-0.0024 \times 527^{0.948}\right)\right] = 59.9\%$$

In addition, adjustment factor f_{np} = 0. The $PTSF_d$ then becomes

$$PTSF_d = 59.9 + 0 \times \left(\frac{527}{527 + 434} \right) = 59.9\%$$

Finally, refer to Table 17. A Class I two-lane highway with an *ATS* between 45 and 50 mi/h is associated with LOS C. Similarly, a $PTSF_d$ between 65 and 80 also implies that the road has LOS C. We conclude that the highway has Level of Service C.

► The correct answer is **C**.

P.12 ■ Solution

The flow rate in the analysis direction is given by

$$v_d = \frac{V_d}{PHF \times f_G \times f_{HV}}$$

The grade adjustment factor for level terrain is f_G = 1.0 regardless of the flow rate (Table 12). The heavy vehicle factor, knowing that E_T = (1.5 + 1.9)/2 = 1.7 and E_R = 1.0 (Table 13), is

$$f_{HV} = \frac{1}{1 + 0.05 \times (1.7 - 1) + 0.10 \times (1.0 - 1)} = 0.966$$

so that

$$v_d = \frac{150}{0.95 \times 1.0 \times 0.966} = 163 \text{ pc/h}$$

Likewise, the flow rate in the opposing direction is such that

$$v_o = \frac{V_o}{PHF \times f_G \times f_{HV}}$$

Again, f_G = 1.0. The heavy vehicle factor, with E_T = 1.9 and E_R = 1.0 (Table 13), is

$$f_{HV} = \frac{1}{1 + 0.05 \times (1.9 - 1) + 0.10 \times (1.0 - 1)} = 0.957$$

so that

$$v_o = \frac{V_o}{PHF \times f_G \times f_{HV}} = \frac{100}{0.95 \times 1.0 \times 0.957} = 110 \text{ pc/h}$$

We proceed to determine the Average Travel Speed,

$$ATS_d = FFS - 0.00776(v_d + v_o) - f_{np}$$

Here, factor f_{np} is 3.2 (Table 14). Therefore,

$$ATS_d = 45 - 0.00776 \times (163 + 110) - 3.2 = 39.7 \text{ mi/h}$$

The Percent Free-Flow Speed is then

$$PFFS_d = \frac{ATS_d}{FFS} = \frac{39.7}{45} = 0.882 = 88.2\%$$

Reading Table 17, we see that the Level of Service for this highway is B.

► The correct answer is **B**.

ANSWER SUMMARY

Problem 1		C
Problem 2		D
Problem 3	**3A**	B
	3B	B
Problem 4		A
Problem 5		B
Problem 6		A
Problem 7		C
Problem 8	**8A**	D
	8B	A
Problem 9		T/F
Problem 10		C
Problem 11		C
Problem 12		B

REFERENCES

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- ROESS, R., PRASSAS, E., and MCSHANE, W. (2010). *Traffic Engineering*. 4th edition. Upper Saddle River: Pearson.

Got any questions related to this quiz? We can help! Send a message to contact@montogue.com and we'll answer your question as soon as possible.