Two-Lane Two Way

A two – lane highway is an undivided highway with two lanes, one for use by traffic in each direction of travel.

Lane changing and passing is possible only in the phase of oncoming traffic in the opposing traffic

As traffic volume increase, the ability to pass will decrease

There are two performance measures to describe service quality for two lane two way highways:

-Percent time spent following (PTSF)

- Average travel speed (ATS)

-Percent time spent following (PTSF)

- Percent time spent following represent the freedom to maneuver and comfort and convenience of travel.

  It is the average percentage of travel time that vehicle must travel in platoons behind slower vehicles due to inability to pass.

-Average travel speed (ATS)

ATS reflects the mobility on a two lane highway. It is calculated as the length of the highway segment divided by the average travel time of all vehicles travelling the segment in both directions during a designated interval

-Types of two way two lanes

Two classes of two-lane highways are analyzed. They are defined according to their function in the following manner.

Class I. Two-lane highways that function 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. Two-lane highways where the expectation of motorists is that **travel speeds will be lower than for Class I** roads. These highways may **serve as access to Class I** two-lane highways; they may serve as scenic byways or may be used by motorists for sightseeing. They also may be located in rugged terrain. Average trip lengths on Class II highways are shorter than on Class I highways.

-Base conditions for two way two lanes

Base conditions exist for the following characteristics:

- Level terrain
- Lane widths 12 ft or greater
- Clear shoulders 6 ft wide or greater
- Passing permitted with absence of no-passing zones
- No impediments to through traffic due to traffic control or turning vehicles
- Passenger cars only in the traffic stream
- Equal volume in both directions (for analysis of two-way flow)

Capacity and LOS of a two-lane highway

Capacity of a two-lane highway is 1700 passenger cars per hour (pc/h) for each direction of travel

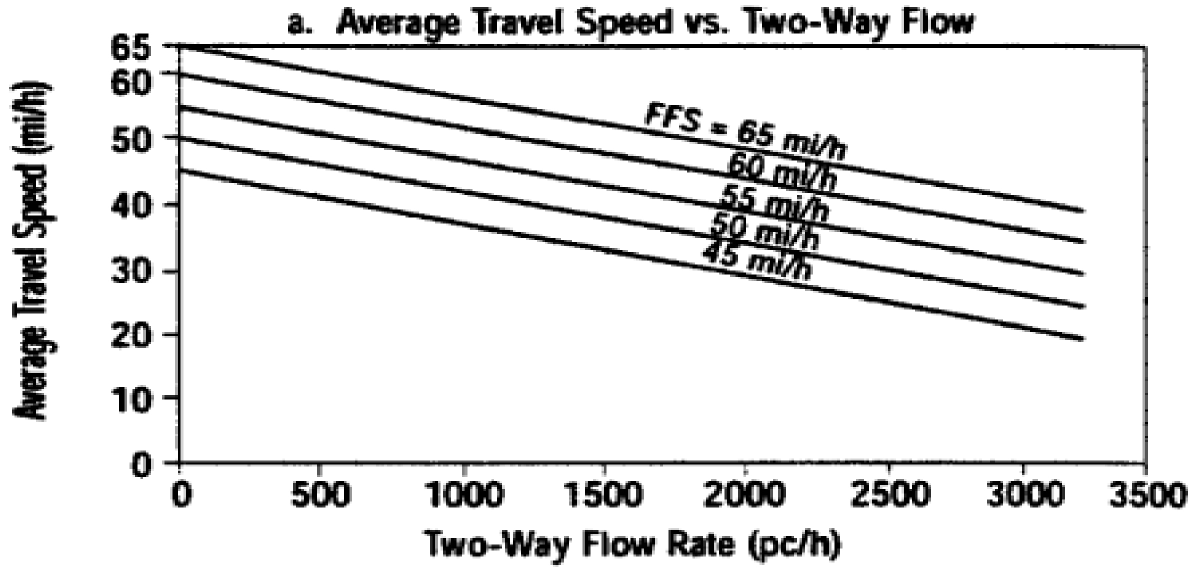
Capacity of two directions is 3200 pc / hr

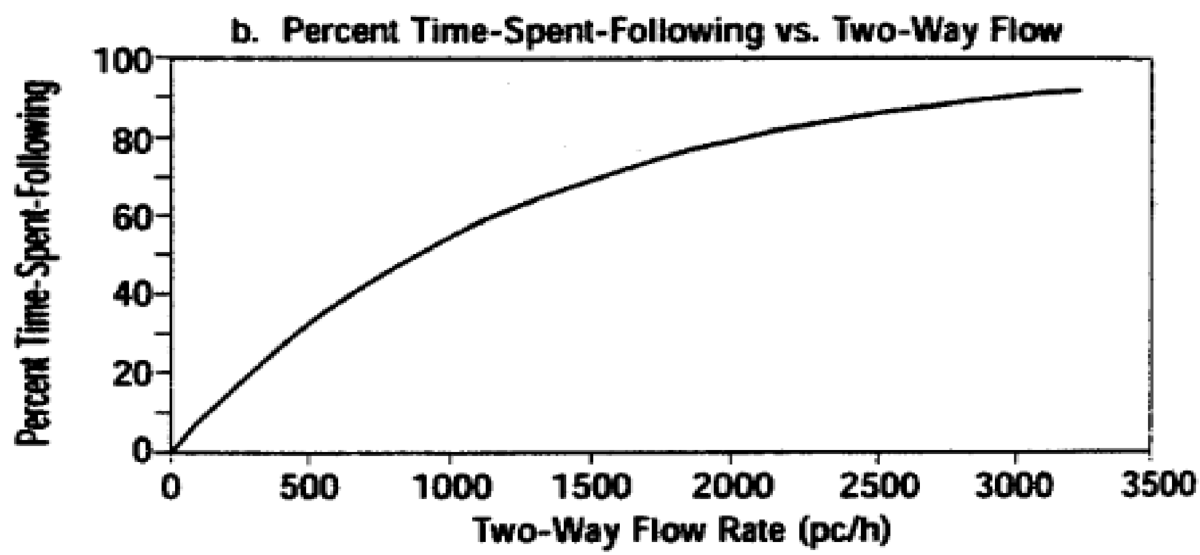
Level of Service (LOS) expresses the performance of a highway at traffic volumes less than capacity.

LOS for Class I highways is based on two measures: PTSF and ATS.

LOS for Class II highways is based on a single measure: PTSF

Speed-Flow and Percent Time-Spent-Following -Flow Relationships for Two-Way Segments with Base Conditions





Procedures for Determining Level of Service

The procedures for determining the LOS of a two-lane highway are carried out separately for the following cases:

Two-way segments *located in level or rolling terrain. Grades are 1 to 2 percent,* and heavy vehicles maintain the same speed as passenger cars.

Directional segments *for which the LOS is determined for traffic in a single direction.*

Any segment can be analyzed as a directional segment. The procedure is used to analyze extended directional segments, specific upgrades or downgrades defined as two-lane highways located in mountainous terrain or with grades that exceed 3 percent in segments exceeding lengths of 0.6 m and passing lanes for relatively short uniform segments.

Two-Way Segments

The analysis of two-lane roads for two-way segments is usually performed on extended lengths when the segment length is at least 2.0 mi and the segment is located in level or rolling terrain.

1. **Level terrain** segments contain flat grades of 2 percent or less. Heavy vehicles are able to maintain the same speed as passenger cars throughout the segment.

2. **Rolling terrain:** segments contain short or medium length grades of 4 percent or less. Heavy truck speeds are lower than passenger cars but are not at crawl speed.

Calculating the Value of PTSF for Two-Way Segments

- The percent time spent following (PTSF) for a two-way segment is computed using the following equation:

$$PTSF = BPTSF + f_{d/np}$$

BPTSF = the base percent time spent following for both directions and is computed using the following equation

$$BPTSF = 100[1 - e^{-0.000879 v_p}]$$

$f_{d/np}$ = adjustment in PTSF to account for the combined effect of:

(1) percent of directional distribution of traffic and

(2) percent of no-passing zones. (Table 9.3)

Table 9.3 Adjustment ($f_{d/np}$) for Combined Effect of Directional Distribution of Traffic and Percentage of No-Passing Zones on Percent Time-Spent-Following on Two-Way Segments

Two-Way Flow Rate, v_p (pc/h)	Increase in Percent Time-Spent-Following (%)					
	No-Passing Zones (%)					
	0	20	40	60	80	100
Directional Split = 50/50						
≤ 200	0.0	10.1	17.2	20.2	21.0	21.8
400	0.0	12.4	19.0	22.7	23.8	24.8
600	0.0	11.2	16.0	18.7	19.7	20.5
800	0.0	9.0	12.3	14.1	14.5	15.4
1400	0.0	3.6	5.5	6.7	7.3	7.9
2000	0.0	1.8	2.9	3.7	4.1	4.4
2600	0.0	1.1	1.6	2.0	2.3	2.4
3200	0.0	0.7	0.9	1.1	1.2	1.4
Directional Split = 60/40						
≤ 200	1.6	11.8	17.2	22.5	23.1	23.7
400	0.5	11.7	16.2	20.7	21.5	22.2
600	0.0	11.5	15.2	18.9	19.8	20.7
800	0.0	7.6	10.3	13.0	13.7	14.4
1400	0.0	3.7	5.4	7.1	7.6	8.1
2000	0.0	2.3	3.4	3.6	4.0	4.3
≥ 2600	0.0	0.9	1.4	1.9	2.1	2.2
Directional Split = 70/30						
≤ 200	2.8	13.4	19.1	24.8	25.2	25.5
400	1.1	12.5	17.3	22.0	22.6	23.2
600	0.0	11.6	15.4	19.1	20.0	20.9
800	0.0	7.7	10.5	13.3	14.0	14.6
1400	0.0	3.8	5.6	7.4	7.9	8.3
≥ 2000	0.0	1.4	4.9	3.5	3.9	4.2
Directional Split = 80/20						
≤ 200	5.1	17.5	24.3	31.0	31.3	31.6
400	2.5	15.8	21.5	27.1	27.6	28.0
600	0.0	14.0	18.6	23.2	23.9	24.5
800	0.0	9.3	12.7	16.0	16.5	17.0
1400	0.0	4.6	6.7	8.7	9.1	9.5
≥ 2000	0.0	2.4	3.4	4.5	4.7	4.9
Directional Split = 90/10						
≤ 200	5.6	21.6	29.4	37.2	37.4	37.6
400	2.4	19.0	25.6	32.2	32.5	32.8
600	0.0	16.3	21.8	27.2	27.6	28.0
800	0.0	10.9	14.8	18.6	19.0	19.4
≥ 1400	0.0	5.5	7.8	10.0	10.4	10.7

v_p = passenger-car equivalent flow rate for the peak 15-min period and is computed using Eq. 9.3.

$$v_p = \frac{V}{(PHF)(f_G)(f_{HV})} \tag{9.3}$$

V = demand volume for the entire peak hour, veh/h
PHF = peak hour factor, $V/(4)$ (peak 15-min volume)
f_G = grade adjustment factor for level or rolling terrain (Table 9.4)
f_{HV} = adjustment factor to account for heavy vehicles in the traffic stream and is computed using Eq. 9.4

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \tag{9.4}$$

PT and PR the decimal portion of trucks (and buses) and RVs in the traffic stream.

ET and ER the passenger-car equivalent for trucks and RVs respectively. Values are provided in Table 9.5.

Table 9.4 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

Table 9.5 Passenger-Car Equivalents for Trucks (E_T) and RVs (E_R) 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

iterative process to calculate Vp

Since the values of *ET and ER are functions of two-way flow rates in pc/h, an iterative* process is required in which a trial value of v_p *is based on the PHF only. Then a* new value of *vp is computed using appropriate values of ET and ER. If the second value* of v_p *is within the range used to determine truck and RV equivalents, the computed* value is correct. If not, a second iteration is required using the next higher range of flow rate.

Example 9.2 Computing the Value of Percent Time-Spent-Following (PTSF) for a Two-Way, Two-Lane Highway

Determine the value of PTSF for a 6-mile two-lane highway in rolling terrain. Traffic data are as follows. (Similar problems are solved using a tabular format in HCM 2000.)

Volume = 1600 veh/h (two-way)
Percent trucks = 14
Percent RVs = 4
Peak hour factor = 0.95
Percent directional split = 50 – 50
Percent no-passing zones = 50

Solution:

Step 1. Compute peak 15-min hourly passenger car equivalent v_p.

Trail value for v_p is V/PHF = 1600/0.95 = 1684 pc/h
Determine f_G = 1.00 (Table 9.4)
Determine E_T = 1.00 and E_R = 1.00 (Table 9.5)

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

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

$$v_p = \frac{v}{(PHF)(f_G)(f_{HV})} = \frac{1600}{(0.95)(1.00)(1.00)} = 1684 \text{ pc/h}$$

Note: Since 1684 < 3200, this section is operating below capacity.

Step 2. Compute base percent time-spent-following (BPTSF)

$$BPTSF = 100[1 - e^{-0.000879 v_p}] = 100[1 - e^{-0.000879(1684)}] = 77.2\%$$

Step 3. Compute percent time-spent-following (PTSF)

$$PTSF = BPTSF + f_{d/np}$$

$$f_{d/np} = 4.8 \text{ (by interpolation from Table 9.3)}$$

$$PTSF = 77.2 + 4.8 = 82.0\%$$

Calculating the Value of ATS for Two-Way Segments

The average travel speed (ATS) for a two-way segment is completed using

$$ATS = FFS - 0.0776v_p - f_{np}$$

where

ATS *average travel speed for both directions of travel combined (mi/h)*

FFS *free-flow speed, the mean speed at low flow when volumes are* 200 pc/h

f_{np} *adjustment for the percentage of no-passing zones (Table 9.6)*

v_p *passenger-car equivalent flow rate for the peak 15-min period*

(Equation 9.3 is used to compute *vp with values of* f_G *from Table 9.7 and ET and ER from Table 9.8.)*

Table 9.6 Adjustment (f_{np}) for Effect of No-Passing Zones on Average Travel Speed on Two-Way Segments

Two-Way Demand Flow Rate, v_p (pc/h)	*Reduction in Average Travel Speed (mi/h)*					
	No-Passing Zones (%)					
	0	*20*	*40*	*60*	*80*	*100*
0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	0.6	1.4	2.4	2.6	3.5
400	0.0	1.7	2.7	3.5	3.9	4.5
600	0.0	1.6	2.4	3.0	3.4	3.9
800	0.0	1.4	1.9	2.4	2.7	3.0
1000	0.0	1.1	1.6	2.0	2.2	2.6
1200	0.0	0.8	1.2	1.6	1.9	2.1
1400	0.0	0.6	0.9	1.2	1.4	1.7
1600	0.0	0.6	0.8	1.1	1.3	1.5
1800	0.0	0.5	0.7	1.0	1.1	1.3
2000	0.0	0.5	0.6	0.9	1.0	1.1
2200	0.0	0.5	0.6	0.9	0.9	1.1
2400	0.0	0.5	0.6	0.8	0.9	1.1
2600	0.0	0.5	0.6	0.8	0.9	1.0
2800	0.0	0.5	0.6	0.7	0.8	0.9
3000	0.0	0.5	0.6	0.7	0.7	0.8
3200	0.0	0.5	0.6	0.6	0.6	0.7

Table 9.7 Grade Adjustment Factor (f_G) to Determine Average Travel Speeds 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	0.71
> 600–1200	> 300–600	1.00	0.93
> 1200	> 600	1.00	0.99

Table 9.8 Passenger-Car Equivalents for Trucks (E_T) and RVs (E_R) 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

The determination of free-flow speed can be completed in three ways:

- Field measurements at volumes < 200 pc/h, S_{FM}.
- Field measurements at volumes > 200 pc/h, computed using Eq. 9.6.

$$FFS = S_{FM} + 0.00776 \frac{V_f}{f_{HV}} \tag{9.6}$$

where

S_{FM} mean speed of traffic measured in the field (mi/h)

V_f observed flow rate, veh/h for the period when speed data were obtained

f_{HV} heavy-vehicle adjustment factor

- Indirect estimation, when field data are unavailable, is computed using Eq. 9.7.

$$FFS = BFFS - f_{LS} - f_A \tag{9.7}$$

Where

BFFS base free-flow speed (mi/h)

f_{LS} adjustment for lane and shoulder width (Table 9.9)

f_A adjustment for number of access points per mi (Table 9.10)

Table 9.9 Adjustment (f_{LS}) for Lane Width and Shoulder Width

	Reduction in FFS (mi/h)			
	Shoulder Width (ft)			
Lane Width (ft)	$\geq 0 < 2$	$\geq 2 < 4$	$\geq 4 < 6$	≥ 6
$9 < 10$	6.4	4.8	3.5	2.2
$\geq 10 < 11$	5.3	3.7	2.4	1.1
$\geq 11 < 12$	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

Table 9.10 Adjustment (f_A) for Access-Point Density

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

Example 9.3 Computing the Value of Average Travel Speed for a Two-Directional, Two-Lane Highway

Use the data provided in Example 9.2 to estimate the average travel speed (ATS). Assume that the base free-flow speed (BFFS) is the posted speed of 60 mi/h. The section length is 6 mi, lane width is 11 ft, shoulder width is 4 ft, and there are 20 access points per mi.

Solution:

Step 1. Compute the free-flow speed under the given conditions using Eq. 9.7.

$$FFS = BFFS - f_{LS} - f_A$$
$$f_{LS} = 1.7 \text{ (Table 9.9)}$$
$$f_A = 5.0 \text{ (Table 9.10)}$$
$$FFS = 60 - (1.7) - (5.0) = 53.3 \text{ mi/h}$$

Step 2. Compute average travel speed using Eq. 9.5.

$$ATS = FFS - 0.00776\, v_p - f_{np}$$
$$FFS = 53.3 \text{ mi/h}$$

Calculate v_p using Eq. 9.3.

$$v_p = \frac{v}{(PHF)(f_G)(f_{HV})} = \frac{1600}{(0.95)(0.99)(0.931)} = 1827 \text{ pc/h}$$

Determine the value of f_{hv} using Eq. 9.4.

$$f_G = 0.99 \text{ (Table 9.7, since } v > 1200\text{, rolling terrain)}$$

$$E_T = 1.5$$

$$E_R = 1.1 \text{ (Table 9.8, since } v > 1200\text{, rolling terrain)}$$

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

$$f_{HV} = \frac{1}{1 + (0.14)(1.5 - 1.0) + (0.04)(1.1 - 1.0)} = 0.931$$

$$f_{np} = 0.8 \text{ (Table 9.6, since } v_p = 1827 \text{ and percent no-passing zones} = 50)$$

$$ATS = 53.3 - 0.00776(1827) - 0.8 = 53.3 - 14.2 - 0.8 = 38.3 \text{ mi/h}$$

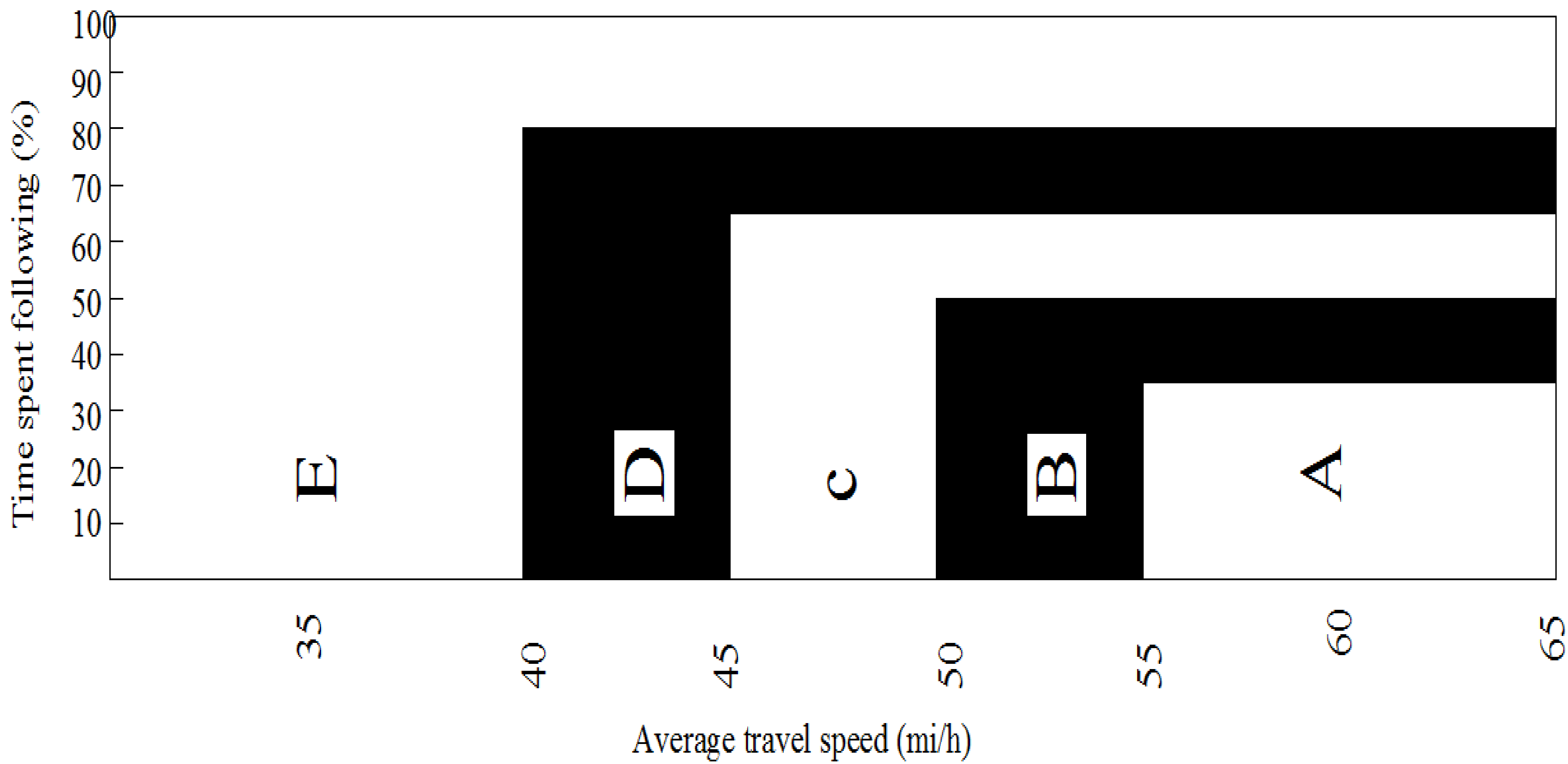
Table 9.1 Level-of-Service Criteria for Two-Lane Highways in Class I

LOS	*Percent Time-Spent-Following*	*Average Travel Speed (mi/h)*
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.

Table 9.2 Level-of-Service Criteria for Two-Lane Highways in Class II

LOS	*Percent Time-Spent-Following*
A	≤ 40
B	$40 < \text{PTSF} \leq 55$
C	$55 < \text{PTSF} \leq 70$
D	$70 < \text{PTSF} \leq 85$
E	> 85


Time spent following (%)
100
90
80
70
60
50
40
30
20
10
E
D
C
B
A
35
40
45
50
55
60
65
Average travel speed (mi/h)

DIRECTIONAL SEGMENTS

Three categories of directional segments are considered. They are:

• **Extended segments** located in level or rolling terrain with a length of at least 2 miles

• **Specific upgrades or downgrades** located in mountainous terrain or with grades of at least 3 percent for segment lengths of at least 0.6 mi long

• **A passing lane** added within a section in level or rolling terrain or as a truck climbing lane

Calculating the Value of PTSF for Directional Segments

- Calculating the Value of PTSF for Directional Segments in Level or Rolling Terrain can be done as follows:

$$PTSF_d = BPTSF_d + f_{np} \tag{9.12}$$

BPTSF is computed by using Eq. 9.13.

$$BPTSF_d = 100(1 - e^{a v_d^b}) \tag{9.13}$$

where

$PTSF_d$ = percent time-spent-following in the direction analyzed

$BPTSF_d$ = base percent time-spent-following in the direction analyzed (Eq. 9.13)

f_{np} = adjustment for percentage of no-passing zones in the analysis direction (Table 9.11)

v_d = passenger-car equivalent flow rate for the peak 15 minute period, in the analysis direction pc/h

a,b = coefficients based on peak 15-minute passenger-car equivalent opposing flow rate, v_o, (Table 9.12)

Table 9.11 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 = 65 mi/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 = 60 mi/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 = 55 mi/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

Table 9.11 Adjustment (f_{np}) to Percent Time-Spent-Following for Percentage of No-Passing Zones in Directional Segments (*continued*)

Opposing Demand Flow Rate, v_o (pc/h)	*No-Passing Zones (%)* ≤ 20	40	60	80	100
FFS = 50 mi/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 = 45 mi/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

Table 9.12 Values of Coefficients (a, b) 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	0.119

Example 9.5 Computing the Value of Percent Time-Spent-Following (PTSF) for the Peak Direction on a Two-Lane Highway

During the peak hour on a Class I two-lane highway in rolling terrain, volumes northbound are 1200 veh/h and volumes southbound are 400 veh/h. The PHF is 0.95, and there are 14% trucks/buses and 4% RVs. Lane widths are 11 ft, and shoulder widths are 4 ft. The roadway section is 5 mi in length, and there are 20 access points per mi. There are 50% no-passing zones and the base free-flow speed is 60 mi/h. Determine the percent time-spent-following in the peak direction of travel.

Solution:

Step 1. Compute peak 15-min hourly passenger-car equivalent in the peak direction, v_d and in the opposite direction v_o.

Trial value for v_d is $v_d/PHF = 1200/0.95 = 1263$ veh/h
Determine $f_G = 1.00$ (Table 9.4)
Determine $E_T = 1.00$ and $E_R = 1.00$ (Table 9.5)

Compute f_{HV}.

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

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

Compute v_d.

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})} = \frac{1200}{(0.95)(1.00)(1.00)} = 1263 \text{ pc/h}$$

Trial value for v_o is $v_o/PHF = 400/0.95 = 421$ veh/h
Determine $f_G = 0.94$ (Table 9.4)
Determine $E_T = 1.5$ and $E_R = 1.0$ (Table 9.5)

Compute f_{HV}.

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

$$f_{HV} = \frac{1}{1 + (0.14)(1.5 - 1.0) + (0.04)(1.0 - 1.0)} = 0.935$$

Compute v_o.

$$v_o = \frac{v}{(PHF)(f_G)(f_{HV})} = \frac{400}{(0.95)(0.95)(0.935)} = 479 \text{ pc/h}$$

Step 2. Compute base percent time-spent-following (BPTSF) using Eq. 9.13.

$$BPTSF_d = 100(1 - e^{av_d^b})$$

Determine the values a and b from Table 9.12 by interpolation.

$$a = -\{0.057 + (0.043)(79/200)\} = -0.074$$
$$b = 0.479 - (0.066)(79/200) = -0.453$$
$$BPTSF_d = 100(1 - e^{(-0.074)(1263)^{0.453}}) = 84.7 \text{ percent}$$

Step 3. Compute percent time-spent-following (PTSF) using Eq. 9.12.

$$PTSF_d = BPTSF_d + f_{np}$$

Use Table 9.11 to determine f_{np}.

f_{np} v_o	50% no-passing and FFS 60 mi/h
400	$(12.1 + 14.8)/2 = 13.45$
600	$(7.5 + 9.6)/2 = 8.55$
479	$(13.45 - (79/200)(4.90)) = 11.5$

$$PTSF_d = BPTSF_d + f_{np} = 84.7 + 11.5 = 96.2\%$$

Calculating the Value of ATS for Directional Segments in Level or Rolling Terrain

The average travel speed (ATS) for a two-way segment is computed by using Eq. 9.14.

$$ATS_d = FFS_d - 0.00776(v_d + v_o) - f_{np} \quad (9.14)$$

where

ATS_d = average travel speed in the analysis direction of travel (mi/h)
f_{np} = adjustment for the percentage of no-passing zones in the analysis direction (Table 9.13)
FFS_d = free-flow speed in the analysis direction

Table 9.13 Adjustment (f_{np}) to Average Travel Speed for Effect of 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 = 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	2.9
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	0.5	0.6	0.6	0.7

Table 9.13 Adjustment (f_{np}) to Average Travel Speed for Effect of Percentage of No-Passing Zones in Directional Segments (*continued*)

Opposing Demand Flow Rate, V_o (pc/h)	*No-Passing Zones (%)* ≤20	40	60	80	100
			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	0.6
			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

Example 9.6 Computing the Value of Average Travel Time (ATS) for the Peak Direction on a Two-Lane Highway

Use the data provided in Example 9.5 to estimate the average travel speed (ATS).

Solution:

Step 1. Compute the free-flow speed under the given conditions using Eq. 9.7.

$$FFS = BFFS - f_{LS} - f_A$$
$$f_{LS} = 1.7 \text{ (Table 9.9)}$$
$$f_A = 5.0 \text{ (Table 9.10)}$$
$$FFS = 60 - (1.7) - (5.0) = 53.3 \text{ mi/h}$$

Step 2. Compute the average travel speed using Eq. 9.14.

$$ATS_d = FFS_d - 0.00776\,(v_d + v_o) - f_{np}$$

Compute v_d.

$$f_G = 0.99 \text{ (Table 9.7, since } v > 600\text{, rolling terrain)}$$
$$E_T = 1.5;\ E_R = 1.1 \text{ (Table 9.8, since } v > 600\text{, rolling terrain)}$$

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

$$f_{HV} = \frac{1}{1 + (0.14)(1.5 - 1.0) + (0.04)(1.1) - 1.0)} = 0.931$$

$$v_d = \frac{V}{(PHF)(f_G)(f_{HV})} = \frac{1200}{(0.95)(0.99)(0.931)} = 1370 \text{ pc/h}$$

Compute v_o.

$$f_G = 0.93 \text{ (Table 9.7 since } v > 300\text{–}600\text{, rolling terrain)}$$
$$E_T = 1.9;\ E_R = 1.1 \text{ (Table 9.8, since } v > 300\text{–}600\text{, rolling terrain)}$$

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

$$f_{HV} = \frac{1}{1 + (0.14)(1.9 - 1.0) + 0.04(1.1 - 1.0)} = 0.884$$

$$v_o = \frac{V}{(PHF)(f_G)(f_{HV})} = \frac{400}{(0.95)(0.93)(0.884)} = 512 \text{ pc/h}$$

Note: Both v_d and v_o are less than 1700—the capacity of a one-way segment. $f_{np} = 1.6$, using Table 9.13 by interpolation, since $v_o = 512$ pc/h, FFS = 53.3 mi/h, and percent no-passing zones = 50.

$$ATS_d = 53.3 - 0.00776(1370 + 512) - 1.6 = 53.3 - 14.6 - 1.6 = 37 \text{ mi/h}$$

. The level of service if the segment is a Class I highway from Examples 9.5 and 9.6 is

$$PTSF = 96.2\%$$
$$ATS = 37.1 \text{ mi/h}$$
$$LOS = E \text{ (Table 9.1)}$$

The level of service if the segment is a Class II highway is

$$PTSF = 96.2\%$$
$$LOS = E \text{ (Table 9.2)}$$

Calculating the Value of PTSF and ATS for Directional Segments on Specific Upgrades

•**Any grade** of 3 percent or more and at least 0.6 mi in length must be analyzed as **a specific upgrade**.

•Lengths of 0.25 miles or more and **upgrades** of 3 percent or more may be analyzed, Segments in mountainous terrain are analyzed as specific upgrades.

•When grades vary within the section, a composite grade is computed as the total change in elevation divided by the total length expressed as a percentage.

Calculating the Value of PTSF and ATS for Directional Segments on Specific Upgrades

- The procedure described in the preceding section for computing PTSF and ATS of directional segments is followed for specific upgrades and downgrades. The difference is only on the effect of heavy vehicles

To Calculate PTSF:

1. Determine f_G *using Table 9.14.*
2. Determine E_T *and ER using Table 9.15.*
3. Compute f_{HV} *using Eq. 9.4.*

To Calculate ATS:

1. Determine f_G *using Table 9.16.*
2. Determine E_T *and ER using Tables 9.17 and 9.18.*
3. Compute f_{HV} *using Eq. 9.4.*

Table 9.14 Grade Adjustment Factor (f_G) for Estimating Percent Time-Spent-Following on Specific Upgrades

		Grade Adjustment Factor, f_G		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	Length of Grade (mi)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.25	1.00	0.92	0.92
	0.50	1.00	0.93	0.93
	0.75	1.00	0.93	0.93
	1.00	1.00	0.93	0.93
	1.50	1.00	0.94	0.94
	2.00	1.00	0.95	0.95
	3.00	1.00	0.97	0.96
	≥ 4.00	1.00	1.00	0.97
≥ 3.5 < 4.5	0.25	1.00	0.94	0.92
	0.50	1.00	0.97	0.96
	0.75	1.00	0.97	0.96
	1.00	1.00	0.97	0.97
	1.50	1.00	0.97	0.97
	2.00	1.00	0.98	0.98
	3.00	1.00	1.00	1.00
	≥ 4.00	1.00	1.00	1.00
≥ 4.5 < 5.5	0.25	1.00	1.00	0.97
	0.50	1.00	1.00	1.00
	0.75	1.00	1.00	1.00
	1.00	1.00	1.00	1.00
	1.50	1.00	1.00	1.00
	2.00	1.00	1.00	1.00
	3.00	1.00	1.00	1.00
	≥ 4.00	1.00	1.00	1.00
≥ 5.5 < 6.5	0.25	1.00	1.00	1.00
	0.50	1.00	1.00	1.00
	0.75	1.00	1.00	1.00
	1.00	1.00	1.00	1.00
	1.50	1.00	1.00	1.00
	2.00	1.00	1.00	1.00
	3.00	1.00	1.00	1.00
	≥ 4.00	1.00	1.00	1.00
≥ 6.5	0.25	1.00	1.00	1.00
	0.50	1.00	1.00	1.00
	0.75	1.00	1.00	1.00
	1.00	1.00	1.00	1.00
	1.50	1.00	1.00	1.00
	2.00	1.00	1.00	1.00
	3.00	1.00	1.00	1.00
	≥ 4.00	1.00	1.00	1.00

Table 9.15 Passenger-Car Equivalents for Trucks (E_T) and RVs (E_R) for Estimating Percent Time-Spent-Following on Specific Upgrades

		Passenger-Car Equivalent for Trucks, E_T			
		Range of Directional Flow Rates, v_d (pc/h)			
Grade (%)	*Length of Grade (mi)*	*0–300*	*> 300–600*	*> 600*	*RVs, E_R*
≥ 3.0 < 3.5	0.25	1.0	1.0	1.0	1.0
	0.50	1.0	1.0	1.0	1.0
	0.75	1.0	1.0	1.0	1.0
	1.00	1.0	1.0	1.0	1.0
	1.50	1.0	1.0	1.0	1.0
	2.00	1.0	1.0	1.0	1.0
	3.00	1.4	1.0	1.0	1.0
	≥ 4.00	1.5	1.0	1.0	1.0
≥ 3.5 < 4.5	0.25	1.0	1.0	1.0	1.0
	0.50	1.0	1.0	1.0	1.0
	0.75	1.0	1.0	1.0	1.0
	1.00	1.0	1.0	1.0	1.0
	1.50	1.1	1.0	1.0	1.0
	2.00	1.4	1.0	1.0	1.0
	3.00	1.7	1.1	1.2	1.0
	≥ 4.00	2.0	1.5	1.4	1.0
≥ 4.5 < 5.5	0.25	1.0	1.0	1.0	1.0
	0.50	1.0	1.0	1.0	1.0
	0.75	1.0	1.0	1.0	1.0
	1.00	1.0	1.0	1.0	1.0
	1.50	1.1	1.2	1.2	1.0
	2.00	1.6	1.3	1.5	1.0
	3.00	2.3	1.9	1.7	1.0
	≥ 4.00	3.3	2.1	1.8	1.0
≥ 5.5 < 6.5	0.25	1.0	1.0	1.0	1.0
	0.50	1.0	1.0	1.0	1.0
	0.75	1.0	1.0	1.0	1.0
	1.00	1.0	1.2	1.2	1.0
	1.50	1.5	1.6	1.6	1.0
	2.00	1.9	1.9	1.8	1.0
	3.00	3.3	2.5	2.0	1.0
	≥ 4.00	4.3	3.1	2.0	1.0
≥ 6.5	0.25	1.0	1.0	1.0	1.0
	0.50	1.0	1.0	1.0	1.0
	0.75	1.0	1.0	1.3	1.0
	1.00	1.3	1.4	1.6	1.0
	1.50	2.1	2.0	2.0	1.0
	2.00	2.8	2.5	2.1	1.0
	3.00	4.0	3.1	2.2	1.0
	≥4.00	4.8	3.5	2.3	1.0

Table 9.16 Grade Adjustment Factor (f_G) for Estimating Average Travel Speed on Specific Upgrades

		Grade Adjustment Factor, f_G		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	Length of Grade (mi)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.25	0.81	1.00	1.00
	0.50	0.79	1.00	1.00
	0.75	0.77	1.00	1.00
	1.00	0.76	1.00	1.00
	1.50	0.75	0.99	1.00
	2.00	0.75	0.97	1.00
	3.00	0.75	0.95	0.97
	≥ 4.00	0.75	0.94	0.95
≥ 3.5 < 4.5	0.25	0.79	1.00	1.00
	0.50	0.76	1.00	1.00
	0.75	0.72	1.00	1.00
	1.00	0.69	0.93	1.00
	1.50	0.68	0.92	1.00
	2.00	0.66	0.91	1.00
	3.00	0.65	0.91	0.96
	≥ 4.00	0.65	0.90	0.96
≥ 4.5 < 5.5	0.25	0.75	1.00	1.00
	0.50	0.65	0.93	1.00
	0.75	0.60	0.89	1.00
	1.00	0.59	0.89	1.00
	1.50	0.57	0.86	0.99
	2.00	0.56	0.85	0.98
	3.00	0.56	0.84	0.97
	≥ 4.00	0.55	0.82	0.93
≥ 5.5 < 6.5	0.25	0.63	0.91	1.00
	0.50	0.57	0.85	0.99
	0.75	0.52	0.83	0.97
	1.00	0.51	0.79	0.97
	1.50	0.49	0.78	0.95
	2.00	0.48	0.78	0.94
	3.00	0.46	0.76	0.93
	≥ 4.00	0.45	0.76	0.93
≥ 6.5	0.25	0.59	0.86	0.98
	0.50	0.48	0.76	0.94
	0.75	0.44	0.74	0.91
	1.00	0.41	0.70	0.91
	1.50	0.40	0.67	0.91
	2.00	0.39	0.67	0.89
	3.00	0.39	0.66	0.88
	≥ 4.00	0.38	0.66	0.87

Table 9.17 Passenger-Car Equivalents for Trucks (E_T) for Estimating Average Travel Speed on Specific Upgrades

		Passenger-Car Equivalent for Trucks, E_T		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	*Length of Grade (mi)*	*0–300*	*> 300–600*	*> 600*
≥ 3.0 < 3.5	0.25	2.5	1.9	1.5
	0.50	3.5	2.8	2.3
	0.75	4.5	3.9	2.9
	1.00	5.1	4.6	3.5
	1.50	6.1	5.5	4.1
	2.00	7.1	5.9	4.7
	3.00	8.2	6.7	5.3
	≥ 4.00	9.1	7.5	5.7
≥ 3.5 < 4.5	0.25	3.6	2.4	1.9
	0.50	5.4	4.6	3.4
	0.75	6.4	6.6	4.6
	1.00	7.7	6.9	5.9
	1.50	9.4	8.3	7.1
	2.00	10.2	9.6	8.1
	3.00	11.3	11.0	8.9
	≥ 4.00	12.3	11.9	9.7
≥ 4.5 < 5.5	0.25	4.2	3.7	2.6
	0.50	6.0	6.0	5.1
	0.75	7.5	7.5	7.5
	1.00	9.2	9.0	8.9
	1.50	10.6	10.5	10.3
	2.00	11.8	11.7	11.3
	3.00	13.7	13.5	12.4
	≥ 4.00	15.3	15.0	12.5
≥ 5.5 < 6.5	0.25	4.7	4.1	3.5
	0.50	7.2	7.2	7.2
	0.75	9.1	9.1	9.1
	1.00	10.3	10.3	10.2
	1.50	11.9	11.8	11.7
	2.00	12.8	12.7	12.6
	3.00	14.4	14.3	14.2
	≥ 4.00	15.4	15.2	15.0
≥ 6.5	0.25	5.1	4.8	4.6
	0.50	7.8	7.8	7.8
	0.75	9.8	9.8	9.8
	1.00	10.4	10.4	10.3
	1.50	12.0	11.9	11.8
	2.00	12.9	12.8	12.7
	3.00	14.5	14.4	14.3
	≥ 4.00	15.4	15.3	15.2

Table 9.18 Passenger-Car Equivalents for RVs (E_R) for Estimating Average Travel Speed on Specific Upgrades

		Passenger-Car Equivalent for RVs, E_R		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	*Length of Grade (mi)*	*0–300*	*> 300–600*	*> 600*
≥ 3.0 < 3.5	0.25	1.1	1.0	1.0
	0.50	1.2	1.0	1.0
	0.75	1.2	1.0	1.0
	1.00	1.3	1.0	1.0
	1.50	1.4	1.0	1.0
	2.00	1.4	1.0	1.0
	3.00	1.5	1.0	1.0
	≥ 4.00	1.5	1.0	1.0
≥ 3.5 < 4.5	0.25	1.3	1.0	1.0
	0.50	1.3	1.0	1.0
	0.75	1.3	1.0	1.0
	1.00	1.4	1.0	1.0
	1.50	1.4	1.0	1.0
	2.00	1.4	1.0	1.0
	3.00	1.4	1.0	1.0
	≥ 4.00	1.5	1.0	1.0
≥ 4.5 < 5.5	0.25	1.5	1.0	1.0
	0.50	1.5	1.0	1.0
	0.75	1.5	1.0	1.0
	1.00	1.5	1.0	1.0
	1.50	1.5	1.0	1.0
	2.00	1.5	1.0	1.0
	3.00	1.6	1.0	1.0
	≥ 4.00	1.6	1.0	1.0
≥ 5.5 < 6.5	0.25	1.5	1.0	1.0
	0.50	1.5	1.0	1.0
	0.75	1.5	1.0	1.0
	1.00	1.6	1.0	1.0
	1.50	1.6	1.0	1.0
	2.00	1.6	1.0	1.0
	3.00	1.6	1.2	1.0
	≥ 4.00	1.6	1.5	1.2
≥ 6.5	0.25	1.6	1.0	1.0
	0.50	1.6	1.0	1.0
	0.75	1.6	1.0	1.0
	1.00	1.6	1.0	1.0
	1.50	1.6	1.0	1.0
	2.00	1.6	1.0	1.0
	3.00	1.6	1.3	1.3
	≥ 4.00	1.6	1.5	1.4

Calculating the Value of PTSF and ATS for Directional Segments on Specific Downgrades

•Any downgrade of 3 percent or more and at least 0.6 miles in length is analyzed as a specific downgrade, as are all downgrade segments in mountainous terrain.

•The opposing direction of travel to a specific upgrade should be analyzed as a specific downgrade.

For specific downgrades that are long and steep, such that heavy vehicles must travel at crawl speeds to avoid losing control of the vehicle, the value of f_{HV} is computed by using Eq. 9.15.

For most downgrades, $f_G = 1.0$.

$$f_{HV} = \frac{1}{1 + P_{TC}P_T(E_{TC} - 1) + (1 - P_{TC})P_T(E_T - 1) + P_R(E_R - 1)} \quad (9.15)$$

where

P_{TC} = decimal proportion of trucks in the traffic stream that travel at crawl speeds on the analysis segment. In the absence of other information, the percentage of tractor-trailer combinations is used in this calculation.

E_{TC} = passenger-car equivalent for trucks in the traffic stream that travel at crawl speeds on the analysis segment. See Table 9.19.

Table 9.19 Passenger-Car Equivalents (E_{TC}) for Estimating the Effect on Average Travel Speed of Trucks that Operate at Crawl Speeds on Long Steep Downgrades

	Passenger-Car Equivalent for Trucks at Crawl Speeds, E_{TC}		
	Range of Directional Flow Rates, v_d (pc/h)		
Difference Between FFS and Truck Crawl Speeds (mi/h)	*0–300*	*> 300–600*	*> 600*
≤ 15	4.4	2.8	1.4
25	14.3	9.6	5.7
≥ 40	34.1	23.1	13.0

Example 9.8 Computing Volumes on Directional Segments for Specific Upgrades and Downgrades

Repeat Examples 9.5 and 9.6 if the grade in the peak direction is above 4.75 percent.

- Determine the values of v_d and v_o that are needed to compute PTSF and ATS. The data are reproduced here for a Class I two-lane highway.

Volumes northbound (peak direction) are 1200 veh/h

Volumes southbound are 400 veh/h

PHF is 0.95

14% trucks/buses, of which 15% are semi-trailers and 4% RVs

Lane widths are 11 ft

Shoulder widths are 4 ft

Roadway section is 5 mi in length

20 access points per mi

50% no-passing zones

Base free-flow speed is 60 mi/h

The difference between free-flow speed and crawl speed is 25 mi/h

Solution:

- Compute the value of v_d and v_o for PTSF and v_d *for a specific upgrade.*
- Determine f_G using Table 9.14.

$$f_G = 1.00$$

- Determine f_{HV} using Table 9.15.

$$E_T = 1.8 \qquad E_R = 1.0$$

- Compute f_{HV} using Eq. 9.4.

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

$$f_{HV} = \frac{1}{1 + (0.14)(1.8 - 1) + (0.04)(1 - 1)} = 0.899$$

- Compute v_d using Eq. 9.3.

$$v_d = \frac{V_d}{(PHF)(f_G)(f_{HV})} = \frac{1200}{(0.95)(1.00)(0.899)} = 1405 \text{ pc/h}$$

Compute v_o *for a specific downgrade.*

Determine f_G on downgrades.

$$f_G = 1.00$$

Determine E_{TC} using Table 9.19.

$$E_{TC} = 5.7$$

Determine E_T and E_R using Table 9.5.

$$E_T = 1.1 \qquad E_R = 1.0$$

Compute f_{HV} using Eq. 9.4.

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

$$f_{HV} = \frac{1}{1 + (0.15)(0.14)(5.7 - 1) + (1 - 0.15)(0.14)(1.1 - 1) + (0.04)(1 - 1)}$$
$$= 0.90$$

Compute v_o using Eq. 9.3.

$$v_o = \frac{V_o}{(PHF)(f_G)(f_{HV})} = \frac{400}{(0.95)(1.00)(0.900)} = 468 \text{ pc/h}$$

A similar procedure is followed in computing the value of v_d and v_o for ATS. The procedures to determine *PTSF* and *ATS* are as described in Examples 9.5 and 9.6.