Capacity and Level of Service for Highway Segments

1. Introduction

The fundamental diagram of traffic flow which is used to illustrate the relationship between flow and density. It was shown that traffic flows reasonably well when the flow rate is less than at capacity, but excessive delay and congestion can occur when the flow rate is at or near capacity. This phenomenon is a primary consideration in the planning and design of highway facilities, because a main objective is to design or plan facilities that will operate at flow rates below their optimum rates. This objective can be achieved when a good estimate of the optimum flow of a facility can be made. Capacity analysis therefore involves the quantitative evaluation of the capability of a road section to carry traffic, and it uses a set of procedures to determine the maximum flow of traffic that a given section of highway will carry under prevailing roadway traffic and control conditions.

As the interaction among vehicles increases, motorists are increasingly influenced by the actions of others. Individual drivers find it more difficult to achieve their desired speeds and perceive a deterioration in the quality of flow as the density (veh/mi) increases, the level of operating performance changes with traffic density. The measure of quality of flow is the "level of service" (LOS), a qualitative measure, ranging from A to F, that characterizes both operational conditions within a traffic stream and highway users' perception. This lecture presents procedures for determining the level of service and other performance measures of uniform road segments on two-lane and multilane highways and freeways.

2. Two -Lane Highway

The procedures developed for two-lane highway segments provide the basis to evaluate level of service and capacity. For highway segments, there are two levels of analysis:

(1) operational and
(2) planning applications. Planning applications correspond directly to the procedures used for operational analysis but use estimates and default values in calculations.

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.

At an operational level of analysis, level of service is determined based on existing or future traffic conditions and specific roadway characteristics. The Highway Capacity Manual (HCM) procedure is designed to analyze two-lane highway segments for (1) two-way traffic, (2) for a specific direction, or (3) for a directional segment with a passing lane. If the terrain is mountainous or if the segment length to be analyzed is greater than 0.6 mi and the grade is at least 3 percent, two-lane highways are analyzed as specific upgrades or downgrades. Figure below depicts a two-lane, two way highway in a rural environment.

Figure: Typical Two-Lane, Two-Way Highway in a Rural Environment.

At a planning level of analysis, operational procedures are followed but with estimates, HCM default values, and/or local default values. Annual average traffic (AADT) values are used to estimate directional design hour volume (DDHV).

There are two measures used to describe the service quality of a two-lane highway. These are
(1) percent time following another vehicle and
(2) average travel speed.

1. Percent time-spent-following another vehicle (PTSF) is the average percentage of time that vehicles are traveling behind slower vehicles. When the time between consecutive vehicles (called the "headway") is less than three seconds, the trailing vehicle is considered to be following the lead vehicle. PTSF is a measure of the quality of service provided by the highway.

2. Average travel speed (ATS) is the space mean speed of vehicles in the traffic stream. Space mean speed is the segment length divided by average time for all vehicles to traverse the segment in both directions during a designated interval. ATS is a measure of the degree in which the highway serves its function of providing efficient mobility.

The relationships shown in these figures are for base conditions defined as the absence of restrictive geometric, traffic, or environmental factors.
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)

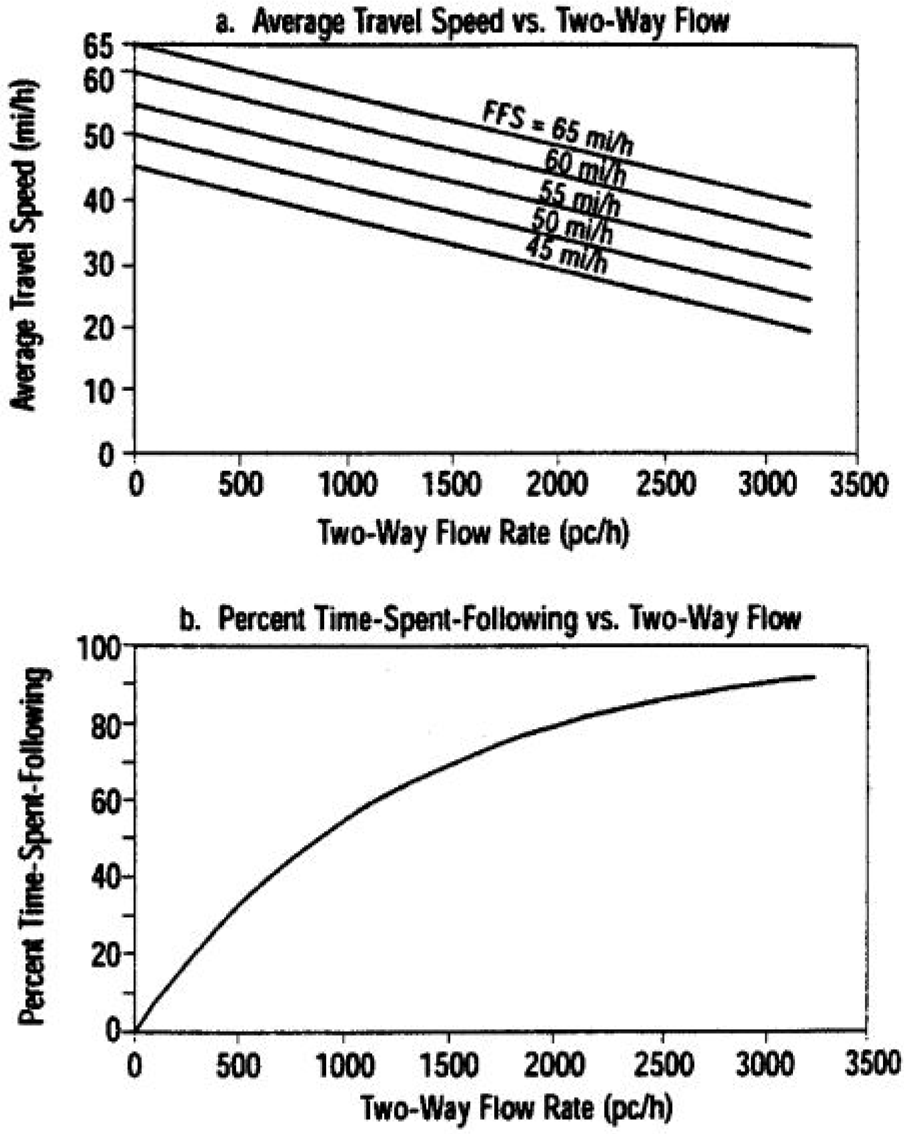

Figure: Speed-Flow and Percent Time-Spent-Following Flow Relationships for Two-Way Segments with Base Conditions.

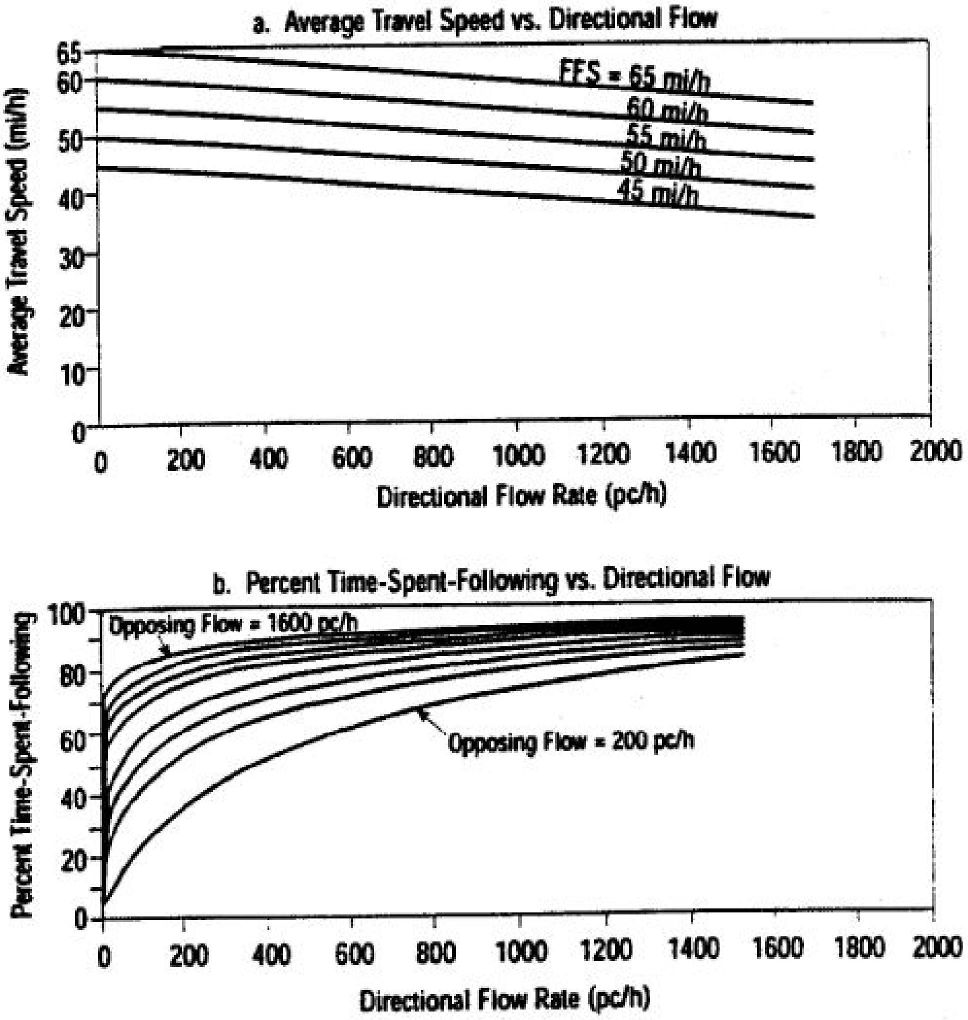

Figure: Speed-Flow and Percent Time-Spent-Following Flow Relationships for Directional Segments with Base Conditions.

Capacity of a two-lane highway is 1700 passenger cars per hour (pc/h) for each direction of travel and is nearly independent of the directional distribution of traffic. For extended segments, the capacity of a two-lane highway will not exceed a combined total of 3200 pc/h. Short sections of two-lane highway, such as a tunnel or bridge, may reach a capacity of 3200 to 3400 pc/h.

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. Level-of-service criteria are applied to travel during the peak 15 minutes of travel and on highway segments of significant length. Level-of-service designations are from A (highest) to F (lowest). Definitions of LOS and appropriate ranges for PTSF and ATS values are as follows:

Level of Service A: This is the highest quality of service that can be achieved. Motorists are able to travel at their desired speed. The need for passing other vehicles is well below the capacity for passing and few (if any) platoons of three or more cars are observed. Class I highway average travel speed (ATS) is 55 mi/h or greater, and travel delays (PTSF) occur no more than 35 percent of the time. Class II highway maximum delay (PTSF) is 40 percent of the time. Maximum service flow rate (two-way) under base conditions is 490 pc/h.

Level of Service B: At this level of service, if vehicles are to maintain desired speeds, the demand for passing other vehicles increases significantly. At the lower level of LOS B range, the passing demand and passing capacity are approximately equal.
Class I highway average travel speeds (ATS) are 50 to 55 mi/h. Travel delays (PTSF) occur between 35 and 50 percent of the time. Class II highway maximum delay (PTSF) is 40 to 55 percent of the time. Maximum service flow rate (two-way) under base conditions is 780 pc/h.

Level of Service C: Further increases in flow beyond the LOS B range results in a noticeable increase in the formation of platoons and an increase in platoon size. Passing opportunities are severely decreased. Class I highway average travel speeds (ATS) are 45 to 50 mi/h, and travel delays (PTSF) occur between 50 and 65 percent of the time. **Class II** highway maximum delay (PTSF) is 55 to 70 percent of the time. Maximum service flow rate (two-way) under base conditions is 1190 pc/h.

Level of Service D: Flow is unstable and passing maneuvers are difficult, if not impossible, to complete. Since the number of passing opportunities is approaching zero as passing desires increase, each lane operates essentially independently of the opposing lane. It is not uncommon that platoons will form that are 5 to 10 consecutive vehicles in length. Class I highway average travel speeds (ATS) are 40 to 45 mi/h, and travel delays (PTSF) occur between 65 and 80 percent of the time. Class II highway maximum delay (PTSF) is 70 to 85 percent of the time. Maximum service flow rate (two way) under base conditions is 1830 pc/h.

Level of Service E: Passing has become virtually impossible. Platoons are longer and more frequent as slower vehicles are encountered more often. Operating conditions are unstable and are difficult to predict. Class I highway average travel speeds (ATS) are 40 mi/h or less and travel delays (PTSF) occur more than 80 percent of the time.
Class II highway maximum delay (PTSF) is greater than 85 percent of the time. Maximum service flow rate (two-way) under base conditions is 3200 pc/h, a value seldom encountered on rural highways (except during summer holiday periods) due to lack of demand.

Level of Service F: Traffic is congested with demand exceeding capacity. Volumes are lower than capacity and speeds are variable.

Table below summarizes the ranges in values of PTSF and ATS for each level of service category for Class I two-lane roads. Table below summarizes the ranges in values of PTSF for each level of service category for Class II two-lane roads. For Class I highways, two criteria apply: (1) percent time-spent-following (PTSF), and (2) average travel speed (ATS). For Class II highways, a single criterion is used: percent time-spent-following (PTSF).

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

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

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

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. Definitions of level and rolling terrain are as follows:

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.

If the grade exceeds 4 percent, the two-way segment procedure cannot be used but must be analyzed using the specific grade procedure for directional segments.

Calculating the Value of PTSF for Two-Way Segments

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

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

where:

BPTSF = the base percent time spent following for both directions and is computed using Equation below:

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

$f_{d/np}$ = 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)

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

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

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 below)

f_{HV} = adjustment factor to account for heavy vehicles in the traffic stream and is computed using Eq. below:

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

P_T and P_R = the decimal portion of trucks (and buses) and RVs in the traffic stream.

For example, if there are 22 percent trucks in the traffic stream, then P_T = 0.22

E_T and E_R = the passenger-car equivalent for trucks and RVs respectively.

Values are provided in Table below.

Since the values of E_T and E_R 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 v_p is computed using appropriate values of E_T and E_R. 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.

Table: 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

Table: 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: 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	Type of Terrain: 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

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

<u>Calculating the Value of ATS for Two-Way Segments</u>

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

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

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 below)

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

Table: 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

Compute v_p with values of f_G and E_T and E_R from Tables below:

Table: 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: Passenger-Car Equivalents for Trucks (E_T) and RVs (E_R) to Determine Speeds on Two-Way and Directional Segments.

			Type of Terrain	
Vehicle Type	*Range of Two-Way Flow Rates (pc/h)*	*Range of Directional Flow Rates (pc/h)*	*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. below.

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

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. below:

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

where
FFS = estimated free-flow speed (mi/h)
BFFS = base free-flow speed (mi/h)
f_{LS} = adjustment for lane and shoulder width (Table below)
f_A = adjustment for number of access points per mi (Table below)

The base free-flow speed (BFFS) depends upon local conditions regarding the desired speeds of drivers. The transportation engineer estimates BFFS based on knowledge of the area and the speeds on similar facilities. The range of BFFS is 45 to 65 mi/h. Posted speed limits or design speeds may serve as surrogates for BFFS.

Table: 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: 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

Calculating Other Traffic Performance Measures for Two-Way, Two-Lane Highways

Additional measures that can be computed are as follows:

v/c = volume-to-capacity ratio

VMT_{15} = total number of vehicle-miles traveled during the peak 15-minute period

VMT_{60} = Total number of vehicle-miles traveled during the peak hour

TT_{15} = Total travel time, vehicle-hour, during the peak 15-minute period

The formula for each performance measure is:

$$v/c = \frac{v_p}{c}$$

where:

v_p/c =volume-to-capacity ratio.

c =two-way segment capacity (3200 for a two-directional segment, 1700 for a directional segment).

v_p =passenger car equivalent flow rate for peak 15 minute period (pc/h).

$$VMT_{15} = 0.25\left(\frac{V}{PHF}\right)L$$

where:

VMT_{15}=total travel on the analysis segment during the peak 15-minute (veh/mi).

L_t =total length of the analysis segment (mi).

V = hourly volume (veh/h).
PHF= Peak hour factor =V/(4) (peak 15-minute volume).

$$VMT_{60} = V(L_t)$$

$$TT_{15} = \frac{VMT_{15}}{ATS}$$

Directional Split

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 in Level or Rolling Terrain
The percent time-spent-following (PTSF) for a directional segment is computed by using Eq. below.

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

BPTSF is computed by using Eq. below:

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

where:
$PTSF_d$ = percent time-spent-following in the direction analyzed
$BPTSF_d$ = base percent time-spent-following in the direction analyzed
f_{np} = adjustment for percentage of no-passing zones in the analysis direction (Table below)
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 below)

Table: 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: 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: 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

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. below:

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

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 below)

FFS_d = free-flow speed in the analysis direction

Table: 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 : 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

<u>Calculating the Value of PTSF and ATS for Directional</u>
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. The procedure described in the preceding section for computing PTSF and ATS of directional segments is followed for specific upgrades and downgrades. However, the effect of heavy vehicles, as described by the grade adjustment factor, f_G, and the heavy vehicle factor, f_{HV}, used in previous Eq. are determined based on the average segment grade and segment length.

<u>To Calculate PTSF</u>:
1. Determine f_G
2. Determine E_T and E_R using .
3. Compute f_{HV} .

<u>To Calculate ATS:</u>
1. Determine f_G using .
2. Determine E_T and E_R.
3. Compute f_{HV}.

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

4. Determine v_d using Eq. below:

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

<u>where:</u>
v_d = passenger car equivalent flow rate for the peak 15-minute period in the direction analyzed (pc/h).
V_d = demand volume for the full peak hour in the direction analyzed (veh/h).

5. Determine v_o using Eq. below:

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

where:
v_o = passenger car equivalent flow rate for the peak 15-minute period in the opposing direction of travel (pc/h)
V_o = demand volume for the full peak hour in the opposing direction of travel (veh/h)
When computing v_o, the values used for f_{HV} and PHF should apply to the opposing direction of travel.

6. Compute PTSF and ATS following procedures used for directional analysis as described for level and rolling terrain.

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 most downgrades, f_G = 1.0. E_T and E_R are determined from previous Table for level terrain. 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. below.

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

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 below.

Table: 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: 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: 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

Calculating Percent Time-Spent-Following (PTSF) for Directional Segments when a Passing Lane has been Added within an Analysis Section in Level or Rolling Terrain

A passing lane is added to a two-lane highway to provide the motorist with additional opportunities to overtake slower vehicles. By adding a lane in one direction of travel, the percentage of time-spent-following can be reduced in the widened section and in a portion of the section that follows.

The net effect of a passing lane is to reduce the overall percent time-spent-following for the segment being analyzed. The greatest effect would result if the passing lane were as long as the entire length of the segment. The effect decreases as the length of the passing lane is reduced. Figure below depicts a plan view of a typical passing lane. The length includes tapers on both ends. Passing lanes are provided in a variety of formats. They may be exclusively for a single direction of traffic, or opposing traffic may be permitted its use. Passing lanes may be provided intermittently or at fixed intervals for each direction of travel. They also may be provided for both directions of travel at the same location, resulting in a short section of four-lane undivided highway.

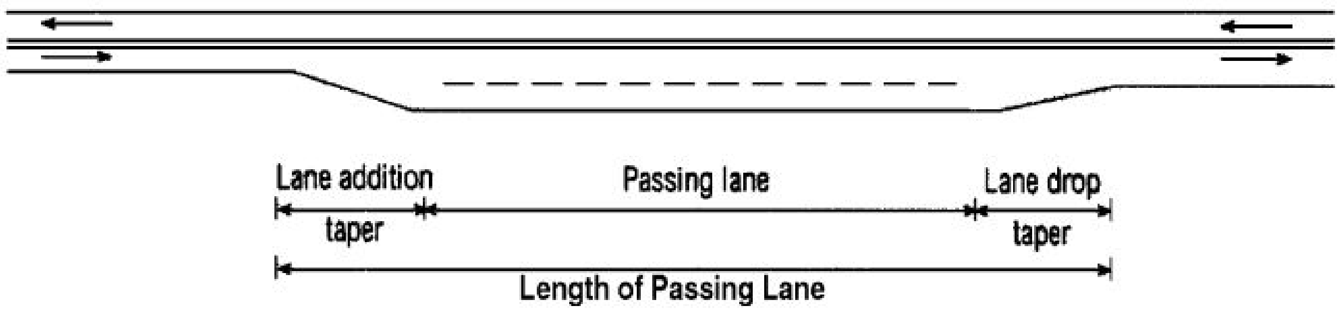

Figure: Plan View of a Typical Passing Lane.

Figure below illustrates conceptually how a passing lane through the analysis segment influences the PTSF. As illustrated, there are four regions where changes occur to the value of PTSF.

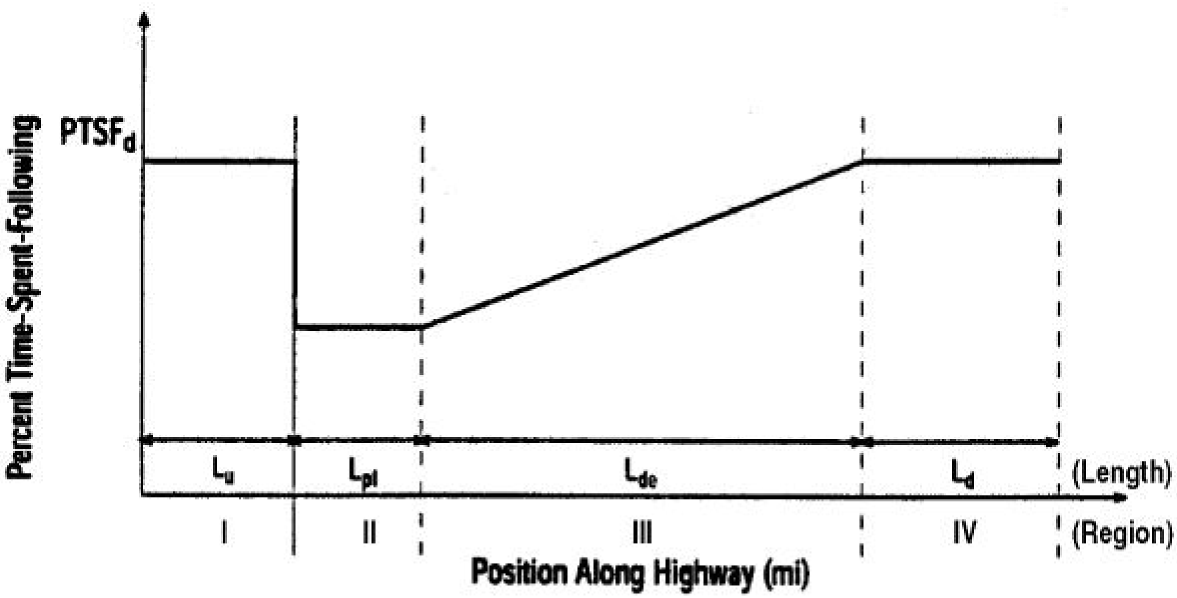

Figure: Effect of a Passing Lane on Percent Time-Spent-Following as Represented in the Operational Analysis Methodology.

<u>Region I.</u>

The PTSF in the immediate region preceding the passing lane (upstream of the passing lane) of length Lu will be $PTSF_d$–the value computed as described earlier for a directional segment. The length of Region I is determined by deciding where the planned or actual passing lane should be placed relative to the beginning point of the analysis segment.

<u>Region II</u>.

The passing lane of length L_{pl} is the constructed or planned length including tapers. This section will experience a sudden reduction in PTSF, as shown in Figure above. The extent of the reduction f_{pl} in PTSF ranges between 0.58 and 0.62, depending on the directional flow rate v_{d}, as shown in Table below. The optimal length of Region II is determined from Table below and ranges from 0.50 to 2.0 mi, depending on the directional flow rate.

Table: 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	> 300–000	> 000
≥ 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 : 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

Table : 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

Region III.

The region immediately downstream of the passing lane of length L_{de} benefits from the effect of the passing lane as the PTSF gradually increases to its original value. This region is considered to be within the effective length of the passing lane, and it is assumed that the value of PTSF increases linearly throughout its length. The length of Region III, L_{de}, is determined from Table below as a function of the directional flow rate.

Region IV.

This is the remaining downstream region within the segment, and its length is Ld. This section is beyond the effective length of the passing lane and the value $PTSF_d$ is equal to that of the upstream section of length Lu. The length of this region is the difference between the total segment length L_v and the sum of the lengths of Regions I, II, and III. Thus,

Ld = Lt - (Lu + Lpl + Ldc).

Table: Factors (f_{pl}) for Estimating the Average Travel Speed and Percent Time-Spent-Following within a Passing Lane.

Directional Flow Rate (pc/h)	*Average Travel Speed*	*Percent Time-Spent-Following*
0–300	1.08	0.58
> 300–600	1.10	0.61
> 600	1.11	0.62

Table: Optimal Lengths (L_{pl}) of Passing Lanes.

Directional Flow Rate (pc/h)	*Optimal Passing Lane Length (mi)*
100	≤ 0.50
200	> 0.50–0.75
400	> 0.75–1.00
≥ 700	> 1.00–2.00

Table : Downstream Length (L_{de}) of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain.

	Downstream Length of Roadway Affected L_{de} (mi)	
Directional Flow Rate (pc/h)	*Percent Time-Spent-Following*	*Average Travel Speed*
≤ 200	13.0	1.7
400	8.1	1.7
700	5.7	1.7
≥ 1000	3.6	1.7

Table: Factors (f_{pl}) for Estimating the Average Travel Speed and Percent Time-Spent-Following within a Climbing Lane.

Directional Flow Rate (pc/h)	*Average Travel Speed*	*Percent Time-Spent-Following*
0–300	1.02	0.20
> 300–600	1.07	0.21
> 600	1.14	0.23

The average value of percent time-spent-following for the entire analysis segment with a passing lane in place is $PTSF_{pl}$. The value is determined as the weighted average of the PTSF values in each region weighted by the region length, and computed by using Eq. below.

$$PTSF_{pl} = \frac{PTSF_d\left[L_u + (f_{pl})(L_{pl}) + \left(\frac{f_{pl}+1}{2}\right)(L_{de}) + L_d\right]}{L_t}$$

where:
$PTSF_{pl}$ = percent time-spent-following for the entire segment including the passing lane
$PTSF_d$ = percent time-spent-following for the entire segment without the passing lane from previous Equation.
f_{pl} = factor for the effect of a passing lane on percent-time-spent following from previous Table.

If the full downstream length is not reached because a traffic signal or a town interrupts the analysis section, then L_{de}' is replaced by a shorter length, . In this instance, Eq. above is modified as follows.

$$PTSF_{pl} = \frac{PTSF_d\left[L_u + (f_{pl})(L_{pl}) + f_{pl}L'_{de}\left(\frac{1-f_{pl}}{2}\right)\frac{(L'_{de})^2}{L_{de}}\right]}{L_t}$$

where :
L'_{de} : actual distance from end of passing lane to end of analysis segment in miles.

Note: L'_{de} must be less than or equal to the value of (obtained from previous Table).

Calculating Average Travel Speed (ATS) for Directional Segments when a Passing Lane has been Added within an Analysis Section in Level or Rolling Terrain
Figure below illustrates the changes in the value of average travel speed (ATS) that occur within each of the four regions when a passing lane has been added. The values are:

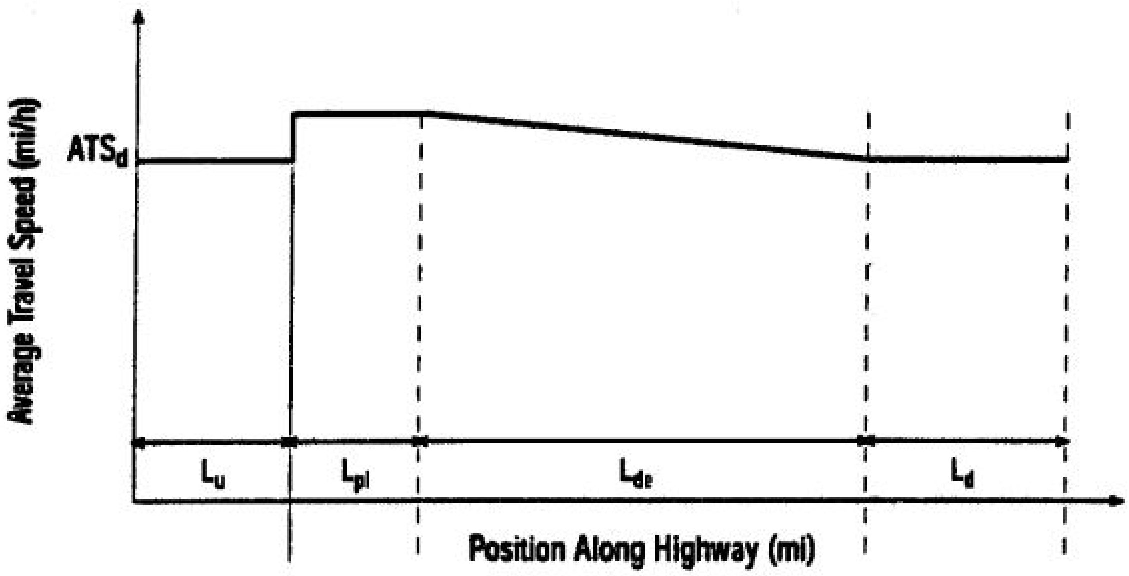

Figure: Effect of a Passing Lane on Average Travel Speed as Represented in the Operational Analysis Methodology.

Region I.
Average travel speed in the upstream region is ATS_d for length Lu.
Region II.
Average travel speed in the passing lane increases by a factor f_{pl} provided in previous Table. Values range from 1.08 to 1.11, depending on the directional flow rate v_d.
Region III.
Average travel speed within the downstream length decreases linearly from the value in Region II to ATSd. L_{de} = 1.7 mi, as shown in previous Table.

Region IV.

Average travel speed in the downstream region is ATS_d for length L_d. To compute the average speed for the analysis section, it is first necessary to compute the individual travel time within regions t_I, t_{II}, t_{III}, and t_{IV}. The average travel speed is the total analysis length Lt divided by the sum of the four travel times. The derivation below produced Eq. below, the value of ATS_{pl}, which is the effect on the average travel speed in the analysis section as the result of adding a passing lane:

$$ATS_{pl} = \frac{L_t}{t_I + t_{II} + t_{III} + t_{IV}}$$

$$= \frac{L_t}{\frac{L_u}{ATS_d} + \frac{L_{pl}}{(f_{pl})(ATS_d)} + \frac{(L_{de})}{\frac{(f_{pl})(ATS_d) + (ATS_d)}{2}} + \frac{L_d}{ATS_d}}$$

$$ATS_{pl} = \frac{(ATS_d)(L_t)}{L_u + \frac{L_{pl}}{f_{pl}} + \frac{2L_{de}}{f_{pl} + 1} + L_d}$$

Calculating Average Travel Speed (ATS) for Directional Segments when a Climbing Lane has been Added within an Analysis Section on an Upgrade

Climbing lanes are provided on long upgrade sections to provide an opportunity for faster moving vehicles to pass heavy trucks whose speed has been reduced. Climbing lanes are warranted on two-lane highways when one of the following conditions is met:

- Directional flow rate on the upgrade _200 veh/h
- Directional flow rate for trucks on the upgrade _20 veh/h, and when any of the

following conditions apply:

Speed reduction for trucks is 10 mi/h for a typical heavy truck LOS is E or F on the grade
LOS on the upgrade is two or more levels of service values higher than the approach grade

Operational analysis of climbing lanes follows the same procedural steps as described earlier for computing PTSF and ATS in level and rolling terrain. When applying the directional procedure to the direction without a passing lane, previous Tables should be used to determine the grade adjustment factor, f_G, and the heavy vehicle factor, f_{HV}. If the climbing lane is not long or steep enough to be analyzed as a specific upgrade, it is analyzed as a passing lane. Values for the adjustment factors f_{pl} for percent time-spent-following (PTSF) and average travel speed (ATS) are shown in Table previous. Furthermore, L_u and L_d are zero because climbing lanes are analyzed as part of a specific upgrade. L_{de} is usually zero unless the climbing lane ends before the top of the grade. If the lane does end before the top of grade, L_{de} is a lower value than shown in previous Table .

Computing the Combined Value of PTSF and ATS for Contiguous Directional Analysis Segments

A directional two-lane highway facility is composed of a series of contiguous directional segments, each analyzed separately as previously described. A combined value for PTSF and ATS that can be used to determine the overall LOS is computed by using Eqs below.

$$PTSF_c = \frac{\sum_{i=1}^{n}(TT_i)(PTSF_i)}{\sum_{i=1}^{n}(TT_i)}$$

$$ATS_c = \frac{\sum_{i=1}^{n}(VMT_i)}{\sum_{i=1}^{n}(TT_i)}$$

where:

n = the number of analysis segments.

TT_i= total travel time for all vehicles on analysis segment (veh/h).

$PTSF_i$= percent time-spent-following for segment i.

$PTSF_c$= percent time-spent-following for all segments combined.

ATS_c = average travel speed for all segments combined.

VMT_i = total travel on analysis segment i, (veh/mi).