CHAPTER 20

TWO-LANE HIGHWAYS

CONTENTS

EXHIBITS

I. INTRODUCTION

This chapter presents a comprehensive study of two-lane highway operation (*1*). The development of the methodology used microscopic simulation, field data, and theoretical concepts. Analytical procedures are provided for two applications, operational and planning. Chapter 12, "Highway Concepts," presents definitions of basic parameters and important concepts related to the methodology. Appendix A also covers design treatments not addressed by the methodology.

For background and concepts, see Chapter 12, "Highway Concepts"

SCOPE OF THE METHODOLOGY

The analysis can consider two directions combined or only one direction

This chapter presents operational analysis for two-way and directional segments of two-lane highways. Two-way segments may include longer sections of two-lane highway with homogeneous cross sections and relatively constant demand volumes and vehicle mixes over the length of the segment. Two-way segments may be located in level or rolling terrain. Two-lane highways in mountainous terrain or with grades of 3 percent or more for lengths of 1.0 km or more cannot be analyzed as two-lane segments. Instead, they are analyzed as specific upgrades or downgrades. Performance measures for the two-way segment methodology apply to both directions of travel combined.

Directional segments carry one direction of travel on a two-lane highway with homogeneous cross sections and relatively constant demand volume and vehicle mix. Any roadway segment can be evaluated with the directional segment procedure, but separate analysis by direction of travel is particularly appropriate for steep grades and for segments containing passing lanes.

The types of directional segments addressed by the operational applications include directional segments in level or rolling terrain, specific upgrades, and specific downgrades. When only one direction of travel on a two-way segment is analyzed, the procedure for directional segments in level and rolling terrain is used. All directional segments in mountainous terrain and all grades of 3 percent or more with a length of 1.0 km or more must be analyzed as specific upgrades or downgrades.

For analysis of specific upgrades or downgrades, the length of grade is its tangent length plus a portion of the vertical curves at its beginning and end. About one-fourth of the length of the vertical curves at the beginning and end of a grade are included. If two grades (in the same direction) are joined by a vertical curve, one-half the length of the curve is included in each grade segment. The performance measures determined by the directional segment methodology apply only to the direction of travel being analyzed. However, the traffic performance measures for the analysis direction are influenced by the flow rate and traffic characteristics in the opposing direction.

The objective of operational analysis is to determine the level of service (LOS) for an existing or proposed facility operating under current or projected traffic demand. Operational analysis also may be used to determine the capacity of a two-lane highway segment, or the service flow rate that can be accommodated at any given LOS.

LIMITATIONS OF THE METHODOLOGY

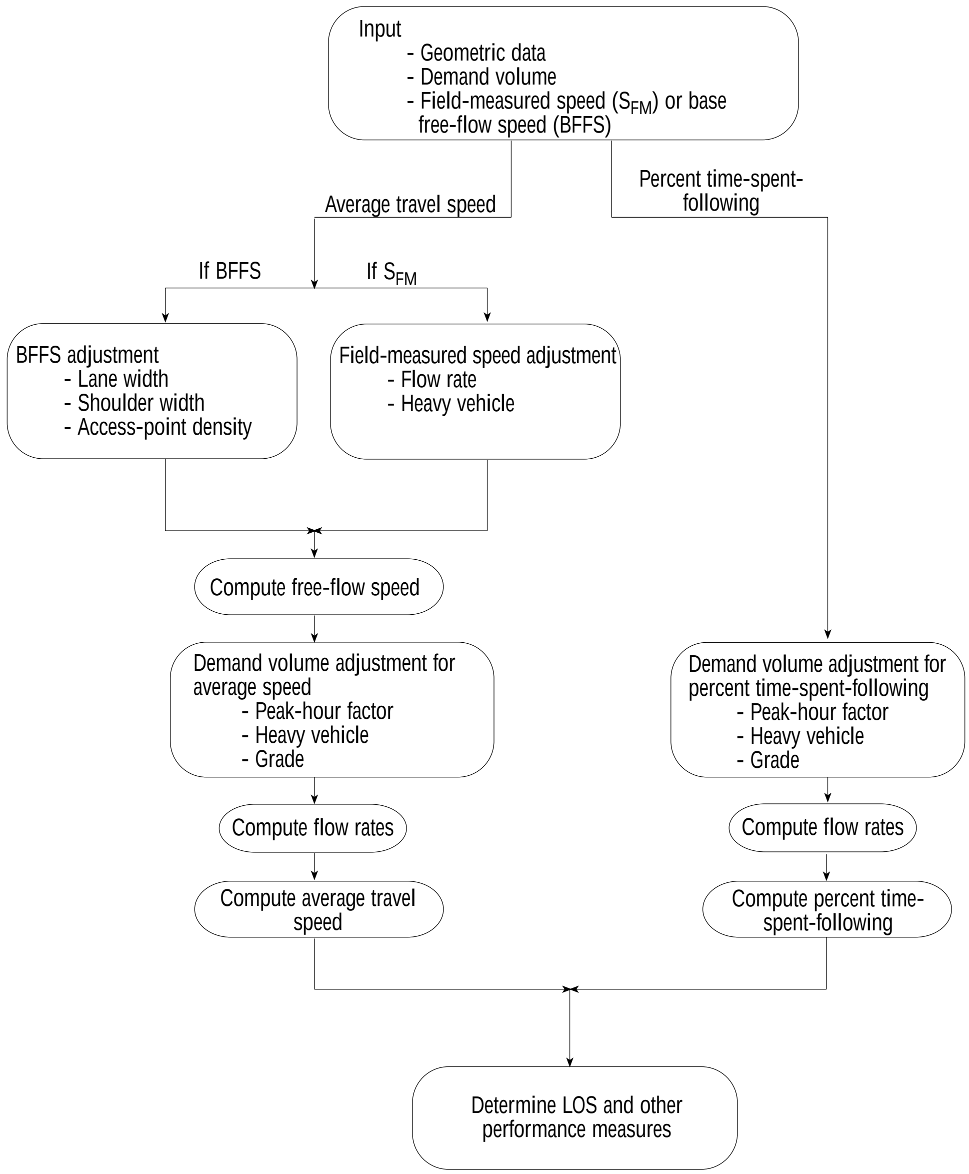
Some two-lane highways—particularly those that involve interactions among several passing or climbing lanes—are too complex to be addressed with the procedures of this chapter. For analytical problems beyond the scope of this chapter, see Part V of this manual, which describes the application of simulation modeling to two-lane highway analyses. Several design treatments discussed in Appendix A are not accounted for by the methodology.

The operational analysis methodologies in this chapter do not address two-lane highways with signalized intersections. Isolated signalized intersections on two-lane highways can be evaluated with the methodology in Chapter 16, "Signalized Intersections." Two-lane highways in urban and suburban areas with multiple signalized intersections at spacings of 3.2 km or less can be evaluated with the methodology of Chapter 15, "Urban Streets."

II. METHODOLOGY

The following discussion presents estimates of two-lane highway capacity, defines the LOS for two-lane highways, and documents the methodology for operational and for planning applications. Exhibit 20-1 summarizes the basic methodology for two-lane highways.

EXHIBIT 20-1. TWO-LANE HIGHWAY METHODOLOGY



CAPACITY

The capacity of a two-lane highway is 1,700 pc/h for each direction of travel. The capacity is nearly independent of the directional distribution of traffic on the facility, except that for extended lengths of two-lane highway, the capacity will not exceed 3,200 pc/h for both directions of travel combined. For short lengths of two-lane highway—such as tunnels or bridges—a capacity of 3,200 to 3,400 pc/h for both directions of travel combined may be attained but cannot be expected for an extended length.

Capacity = 1,700 pc/h for each direction, and 3,200 for both directions combined

LEVELS OF SERVICE

The service measures for a two-lane highway are defined in Chapter 12, "Highway Concepts." On Class I highways, efficient mobility is paramount, and LOS is defined in terms of both percent time-spent-following and average travel speed. On Class II highways, mobility is less critical, and LOS is defined only in terms of percent time-spent-following, without consideration of average travel speed. Drivers will tolerate higher levels of percent time-spent-following on a Class II facility than on a Class I facility, because Class II facilities usually serve shorter trips and different trip purposes.

For definitions of the service measures for two-lane highways, percent time-spent-following, and average travel speed, see Chapter 12, "Highway Concepts"

LOS criteria for two-lane highways in Classes I and II are presented in Exhibits 20-2, 20-3, and 20-4. Exhibit 20-2 reflects the maximum values of percent time-spent-following and average travel speed for each LOS for Class I highways. A segment of a Class I highway must meet the criteria for both the percent time-spent-following and the average travel speed shown in Exhibit 20-2 to be classified in any particular LOS. Exhibit 20-3 illustrates the LOS criteria for Class I highways. For example, a Class I two-lane highway with percent time-spent-following equal to 45 percent and an average travel speed of 65 km/h would be classified as LOS D based on Exhibit 20-2. However, a Class II highway with the same conditions would be classified as LOS B based on Exhibit 20-4. The difference between these LOS assessments represents the difference in motorist expectations for Class I and II facilities.

For definitions of Class I and II highways, also see Chapter 12

The LOS criteria in Exhibits 20-2 through 20-4 apply to all types of two-lane highways, including extended two-way segments, extended directional segments, specific upgrades, and specific downgrades.

TWO-WAY SEGMENTS

The two-way segment methodology estimates measures of traffic operation along a section of highway, based on terrain, geometric design, and traffic conditions. Terrain is classified as level or rolling, as described below. Mountainous terrain is addressed in the operational analysis of specific upgrades and downgrades, presented below. This methodology typically is applied to highway sections of at least 3.0 km.

Traffic data needed to apply the two-way segment methodology include the two-way hourly volume, a peak-hour factor (PHF), and the directional distribution of traffic flow. The PHF may be computed from field data, or appropriate default values may be selected from the tabulated values presented in Chapter 12. Traffic data also include the proportion of trucks and recreational vehicles (RVs) in the traffic stream. The operational analysis of extended two-way segments for a two-lane highway involves several steps, described in the following sections.

EXHIBIT 20-2. LOS CRITERIA FOR TWO-LANE HIGHWAYS IN CLASS I

LOS	Percent Time-Spent-Following	Average Travel Speed (km/h)
A	≤ 35	> 90
B	> 35–50	> 80–90
C	> 50–65	> 70–80
D	> 65–80	> 60–70
E	> 80	≤ 60

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

EXHIBIT 20-3. LOS CRITERIA (GRAPHICAL) FOR TWO-LANE HIGHWAYS IN CLASS I

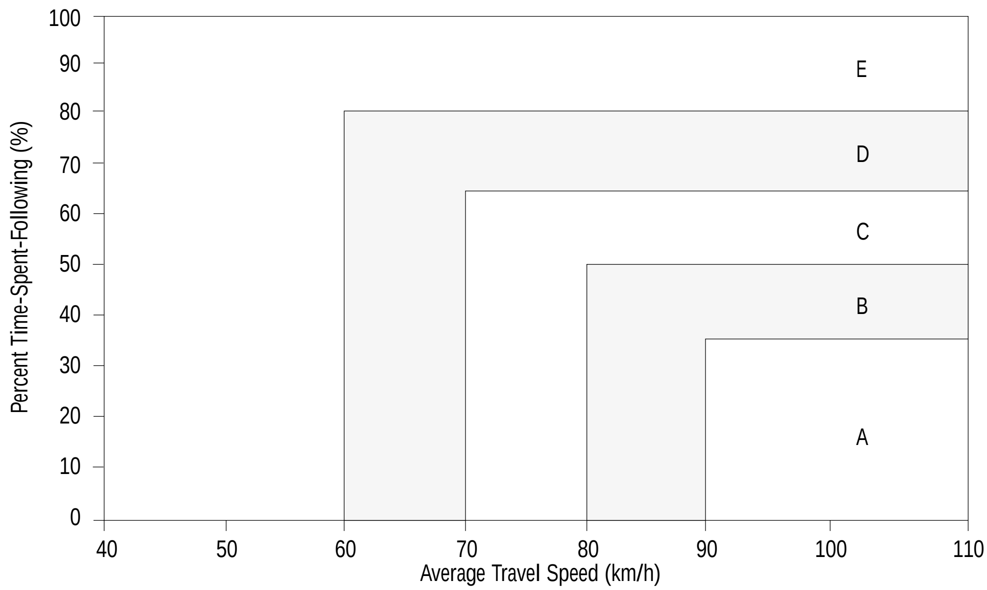


EXHIBIT 20-4. LOS CRITERIA FOR TWO-LANE HIGHWAYS IN CLASS II

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

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

Determining Free-Flow Speed

Free-flow speed occurs at two-way flows of 200 pc/h or less

A key step in the assessment of the LOS of a two-lane highway is to determine the free-flow speed (FFS). The FFS is measured using the mean speed of traffic under low flow conditions (up to two-way flows of 200 pc/h). If field measurements must be made with two-way flow rates of more than 200 pc/h, a volume adjustment must be made in determining FFS. This volume adjustment is discussed below.

Two general methods can be used to determine the FFS for a two-lane highway: field measurement and estimation with the guidelines provided in this chapter. The field-measurement procedure assists in gathering these data directly or incorporating the measurements into a speed monitoring program. However, field measurements are not necessary for an operational analysis—the FFS can be estimated from field data and user knowledge of conditions on the highway.

Field Measurement

The FFS of a highway can be determined directly from a speed study conducted in the field. No adjustments are made to the field-measured data. The speed study should be conducted at a representative location within the highway segment being evaluated; for example, a site on a short upgrade should not be selected within a segment that is generally level. Any speed measurement technique acceptable for other types of traffic engineering speed studies may be used. The field study should be conducted in periods of low traffic flow (up to a two-way flow of 200 pc/h) and should measure the speeds of all vehicles or of a systematic sampling (e.g., of every 10th vehicle). A representative sample of the speeds of at least 100 vehicles, impeded or unimpeded, should be obtained. Further guidance on speed studies is found in standard traffic engineering texts such as the *Manual of Transportation Engineering Studies* (*2*).

Speed measurements taken at flows exceeding 200 pc/h can be adjusted to FFS

If the speed study must be conducted at a two-way flow rate of more than 200 pc/h, the FFS can be found by using the speed-flow relationships shown in Chapter 12, assuming that data on traffic volumes are recorded at the same time. The FFS can be computed based on field data as shown in Equation 20-1.

$$FFS = S_{FM} + 0.0125 \frac{V_f}{f_{HV}} \qquad (20\text{-}1)$$

where

FFS = estimated free-flow speed (km/h),
S_{FM} = mean speed of traffic measured in the field (km/h),
V_f = observed flow rate for the period when field data were obtained (veh/h), and
f_{HV} = heavy-vehicle adjustment factor, determined as shown in Equation 20-4.

If field measurement of the highway is not feasible, data taken at a similar facility may be used. The surrogate roadway should be similar with respect to the variables affecting FFS, which are identified in this chapter.

Highway agencies with ongoing speed-monitoring programs or with speed data on file may prefer to use those rather than conducting a new speed study or using indirect speed estimates. However, these data should be used directly only if collected in accordance with the previously described procedures.

Estimating FFS

The FFS can be estimated indirectly if field data are not available. This is a greater challenge on two-lane highways than on other types of uninterrupted-flow facilities because the FFS of a two-lane highway can range from 70 to 110 km/h. To estimate FFS, the analyst must characterize the operating conditions of the facility in terms of a base free-flow speed (BFFS) that reflects the character of traffic and the alignment of the facility. Because of the broad range of speed conditions on two-lane highways and the importance of local and regional factors that influence driver-desired speeds, no guidance on estimating the BFFS is provided. Estimates of BFFS can be developed based on speed data and local knowledge of operating conditions on similar facilities. The design speed and posted speed limit of the facility may be considered in determining the BFFS; however, the design speeds and speed limits for many facilities are not based on current operating conditions. Once BFFS is estimated, adjustments can be made for the influence of lane width, shoulder width, and access-point density. The FFS is estimated using Equation 20-2.

$$FFS = BFFS - f_{LS} - f_A \qquad (20\text{-}2)$$

where

FFS = estimated FFS (km/h);
$BFFS$ = base FFS (km/h);
f_{LS} = adjustment for lane width and shoulder width, from Exhibit 20-5; and
f_A = adjustment for access points, from Exhibit 20-6.

The first adjustment to the estimated FFS relates to the effects of lane and shoulder widths. Base conditions for a two-lane highway require 3.6-m lane widths and 1.8-m shoulder widths. Exhibit 20-5 lists the adjustments to the estimated FFS for narrower lanes and shoulders. The data in Exhibit 20-5 indicate, for example, that a two-lane highway with 3.3-m lanes and full shoulder widths has an FFS that is 0.7 km/h less than a highway with base lane and shoulder widths. Similarly, a two-lane highway with 3.6-m lanes and 0.6-m shoulders has an FFS 4.2 km/h less than a highway with base lane and shoulder widths.

EXHIBIT 20-5. ADJUSTMENT (f_{LS}) FOR LANE WIDTH AND SHOULDER WIDTH

	Reduction in FFS (km/h)			
	Shoulder Width (m)			
Lane Width (m)	≥ 0.0 < 0.6	≥ 0.6 < 1.2	≥ 1.2 < 1.8	≥ 1.8
2.7 < 3.0	10.3	7.7	5.6	3.5
≥ 3.0 < 3.3	8.5	5.9	3.8	1.7
≥ 3.3 < 3.6	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0.0

Exhibit 20-6 lists the adjustments for access-point density. The data indicate that each access point per kilometer decreases the estimated FFS by about 0.4 km/h. The access-point density is found by dividing the total number of intersections and driveways on both sides of the roadway segment by the length of the segment in kilometers. An intersection or driveway should only be included if it influences traffic flow; access points unnoticed by the driver or with little activity should not be included.

EXHIBIT 20-6. ADJUSTMENT (f_A) FOR ACCESS-POINT DENSITY

Access Points per km	Reduction in FFS (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
≥ 24	16.0

When data on the number of access points on a two-lane highway segment are unavailable (e.g., when the highway has not yet been constructed), the guidelines in Chapter 12 may be used.

If a highway segment contains sharp horizontal curves with design speeds substantially below the rest of the segment, it may be desirable to determine the FFS separately for curves and tangents and compute a weighted-average FFS for the segment as a whole.

The data for the FFS relationships in this chapter include both commuter and noncommuter traffic. There were no significant differences between the two. However, it is expected that commuters or other regular drivers will use a facility more efficiently than recreational users and other occasional drivers. If the effect of a driver population is a concern, the FFS should be measured in the field. If field measurements cannot be made, an FFS should be selected to reflect the anticipated effect of the driver population. Care should be taken not to underestimate the BFFS of a highway by overstating the effect of a given driver population.

Determining Demand Flow Rate

Three adjustments must be made to hourly demand volumes, whether based on traffic counts or estimates, to arrive at the equivalent passenger-car flow rate used in LOS analysis. These adjustments are the PHF, the grade adjustment factor, and the heavy-vehicle adjustment factor. These adjustments are applied according to Equation 20-3.

$$v_p = \frac{V}{PHF * f_G * f_{HV}} \tag{20-3}$$

where

v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h),
V = demand volume for the full peak hour (veh/h),
PHF = peak-hour factor,
f_G = grade adjustment factor, and
f_{HV} = heavy-vehicle adjustment factor.

PHF

PHF represents the variation in traffic flow within an hour. Two-lane highway analysis is based on demand volumes for a peak 15-min period within the hour of interest—usually the peak hour. For operational analysis, the full-hour demand volumes must be converted to flow rates for the peak 15 min, as shown in Equation 20-3.

Grade Adjustment Factor

The grade adjustment factor, f_G, accounts for the effect of the terrain on travel speeds and percent time-spent-following, even if no heavy vehicles are present. The values of the grade adjustment factor are listed in Exhibit 20-7 for estimating average travel speeds and in Exhibit 20-8 for estimating percent time-spent-following.

EXHIBIT 20-7. GRADE ADJUSTMENT FACTOR (f_G) TO DETERMINE 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

EXHIBIT 20-8. 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

Adjustment for Heavy Vehicles

The presence of heavy vehicles in the traffic stream decreases the FFS, because at base conditions the traffic stream is assumed to consist only of passenger cars—a rare occurrence. Therefore, traffic volumes must be adjusted to an equivalent flow rate expressed in passenger cars per hour. This adjustment is accomplished by using the factor f_{HV}.

Adjustment for the presence of heavy vehicles in the traffic stream applies to two types of vehicles: trucks and RVs. Buses should not be treated as a separate type of heavy vehicle but should be included with trucks. The heavy-vehicle adjustment factor requires two steps. First, the passenger-car equivalency factors for trucks (E_T) and RVs (E_R) for the prevailing operating conditions must be found. Then, using these values, an adjustment factor must be computed to correct for all heavy vehicles in the traffic stream.

Heavy-vehicle adjustment considers trucks and RVs. Buses are included with trucks.

Passenger-car equivalents for extended two-way segments are determined from Exhibit 20-9 for estimating speeds and from Exhibit 20-10 for estimating percent time-spent-following. The terrain of extended two-way segments should be categorized as level or rolling.

EXHIBIT 20-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS 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

EXHIBIT 20-10. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS 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

Level Terrain

Level terrain is any combination of horizontal and vertical alignment permitting heavy vehicles to maintain approximately the same speed as passenger cars; this generally includes short grades of no more than 1 or 2 percent.

Rolling Terrain

Rolling terrain is any combination of horizontal and vertical alignment causing heavy vehicles to reduce their speeds substantially below those of passenger cars, but not to operate at crawl speeds for any significant length of time or at frequent intervals; generally, this includes short- and medium-length grades of no more than 4 percent. Segments with substantial lengths of more than a 4 percent grade should be analyzed with the specific grade procedure for directional segments.

Heavy-Vehicle Adjustment Factor

Once values for E_T and E_R have been determined, the adjustment factor for heavy vehicles is computed using Equation 20-4.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (20\text{-}4)$$

where

P_T = proportion of trucks in the traffic stream, expressed as a decimal;
P_R = proportion of RVs in the traffic stream, expressed as a decimal;

E_T = passenger-car equivalent for trucks, obtained from Exhibit 20-9 or Exhibit 20-10; and
E_R = passenger-car equivalent for RVs, obtained from Exhibit 20-9 or Exhibit 20-10.

Iterative Computations

Exhibits 20-7 through 20-10—the grade adjustment factor f_G and the passenger-car equivalents for trucks (E_T) and RVs (E_R)—are stratified by flow rates expressed in passenger cars per hour. However, until Equation 20-3 is applied, the flow rate in passenger cars per hour is not known. Therefore, an iterative approach must be applied to determine the passenger-car equivalent flow rate v_p, and from that, either average travel speed or percent time-spent-following.

First, determine the flow rate, in vehicles per hour, as V/PHF. Second, select values of f_G, E_T, and E_R appropriate for that flow rate from the tables. Then, determine the v_p from those values using Equations 20-3 and 20-4. If the computed value of v_p is less than the upper limit of the selected flow-rate range for which f_G, E_T, and E_R were determined, then the computed value of v_p should be used. If the v_p is higher than the upper limit of the selected flow-rate range, repeat the process for successively higher ranges until an acceptable value of v_p is found. Because the highest range includes all flow rates greater than 1,200 pc/h in both directions of travel combined, it can be used if a computed value exceeds the upper limit of both lower flow-rate ranges.

Determining Average Travel Speed

The average travel speed is estimated from the FFS, the demand flow rate, and an adjustment factor for the percentage of no-passing zones. The demand flow rate for estimating average travel speed is determined with Equation 20-3 using the value of f_{HV} computed with the passenger-car equivalents in Exhibit 20-9. Average travel speed is then estimated using Equation 20-5.

$$ATS = FFS - 0.0125v_p - f_{np} \qquad (20\text{-}5)$$

where

ATS = average travel speed for both directions of travel combined (km/h),
f_{np} = adjustment for percentage of no-passing zones (see Exhibit 20-11), and
v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h).

The FFS used in Equation 20-5 is the value estimated with Equation 20-1 or Equation 20-2. The adjustment for the effect of the percentage of no-passing zones on average travel speed (f_{np}) is listed in Exhibit 20-11. The exhibit shows that the effect of no-passing zones on average travel speed increases to a maximum at a two-way flow rate of 400 pc/h and then decreases at higher volumes. The maximum value of f_{np} is 7.3 km/h.

Determining Percent Time-Spent-Following

The percent time-spent-following is estimated from the demand flow rate, the directional distribution of traffic, and the percentage of no-passing zones. The demand flow rate (v_p) for estimating percent time-spent-following is determined with Equation 20-3 using the value of f_{HV} computed with passenger-car equivalents from Exhibit 20-10. Percent time-spent-following is then estimated using Equation 20-6. Appropriate values of base percent-time-spent following can be determined from Equation 20-7.

$$PTSF = BPTSF + f_{d/np} \qquad (20\text{-}6)$$

where

$PTSF$ = percent-time-spent following,

BPTSF = base percent time-spent-following for both directions of travel combined (use Equation 20-7), and

$f_{d/np}$ = adjustment for the combined effect of the directional distribution of traffic and of the percentage of no-passing zones on percent time-spent-following.

$$BPTSF = 100\left(1 - e^{-0.000879 v_p}\right) \quad (20\text{-}7)$$

An adjustment representing the combined effect of directional distribution of traffic and percentage of no-passing zones ($f_{d/np}$) is presented in Exhibit 20-12.

EXHIBIT 20-11. ADJUSTMENT (f_{np}) FOR EFFECT OF NO-PASSING ZONES ON AVERAGE TRAVEL SPEED ON TWO-WAY SEGMENTS

	Reduction in Average Travel Speed (km/h)					
	No-Passing Zones (%)					
Two-Way Demand Flow Rate, v_p (pc/h)	0	20	40	60	80	100
0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	1.0	2.3	3.8	4.2	5.6
400	0.0	2.7	4.3	5.7	6.3	7.3
600	0.0	2.5	3.8	4.9	5.5	6.2
800	0.0	2.2	3.1	3.9	4.3	4.9
1000	0.0	1.8	2.5	3.2	3.6	4.2
1200	0.0	1.3	2.0	2.6	3.0	3.4
1400	0.0	0.9	1.4	1.9	2.3	2.7
1600	0.0	0.9	1.3	1.7	2.1	2.4
1800	0.0	0.8	1.1	1.6	1.8	2.1
2000	0.0	0.8	1.0	1.4	1.6	1.8
2200	0.0	0.8	1.0	1.4	1.5	1.7
2400	0.0	0.8	1.0	1.3	1.5	1.7
2600	0.0	0.8	1.0	1.3	1.4	1.6
2800	0.0	0.8	1.0	1.2	1.3	1.4
3000	0.0	0.8	0.9	1.1	1.1	1.3
3200	0.0	0.8	0.9	1.0	1.0	1.1

Determining LOS

The first step in determining LOS is to compare the passenger-car equivalent flow rate (v_p) to the two-way capacity of 3,200 pc/h. If v_p is greater than the capacity, then the roadway is oversaturated and the LOS is F. Similarly, if the demand flow rate in either direction of travel—as determined from the two-way flow rate and the directional split—is greater than 1,700 pc/h, then the roadway is oversaturated and the LOS is F. In LOS F, percent time-spent-following is nearly 100 percent and speeds are highly variable and difficult to estimate.

When a segment of a Class I facility has a demand less than its capacity, the LOS is determined by locating a point on Exhibit 20-3 that corresponds to the estimated percent time-spent-following and average travel speed. If a segment of a Class II facility has a demand less than its capacity, the LOS is determined by comparing the percent time-spent-following with the criteria in Exhibit 20-4. The analysis should include the LOS and the estimated values of percent time-spent-following and average travel speed. Although average travel speed is not considered in the LOS determination for a Class II highway, the estimate may be useful in evaluating the quality of service of two-lane highway facilities, highway networks, or systems including the segment.

EXHIBIT 20-12. 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

Other Traffic Performance Measures

The v/c ratio for an extended two-way segment can be computed using Equation 20-8.

$$v/c = \frac{v_p}{c} \qquad (20\text{-}8)$$

where

v/c = volume to capacity ratio;
c = two-way segment capacity—normally 3,200 pc/h for two-way segment and 1,700 for a directional segment; and
v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h).

The total travel on the extended two-way segment during the peak 15-min period is computed using Equation 20-9.

$$VkmT_{15} = 0.25\left(\frac{V}{PHF}\right)L_t \qquad (20\text{-}9)$$

where

$VkmT_{15}$ = total travel on the analysis segment during the peak 15-min period (veh-km), and
L_t = total length of the analysis segment (km).

The total travel on the two-way segment during the peak hour is computed using Equation 20-10.

$$VkmT_{60} = V * L_t \qquad (20\text{-}10)$$

where

$VkmT_{60}$ = total travel on the analysis segment during the peak hour (veh-km).

Equation 20-11 can be used to compute the total travel time during the peak 15-min period using Equations 20-5 and 20-9.

$$TT_{15} = \frac{VkmT_{15}}{ATS} \qquad (20\text{-}11)$$

where

TT_{15} = total travel time for all vehicles on the analyzed segment during the peak 15-min period (veh-h).

DIRECTIONAL SEGMENTS

The methodology addresses three types of directional segments: extended directional segments, specific upgrades, and specific downgrades. The methodology for directional segments is analogous to the two-way segment methodology, except that it estimates traffic performance measures and LOS for one direction of travel at a time. However, the operational assessment of one direction of travel on a two-lane highway necessarily considers the opposing traffic volume. There is a strong interaction between the directions of travel on a two-lane highway because passing opportunities are reduced and eventually eliminated as the opposing traffic increases.

Directional analyses usually are applied to segments ≥3 km, or to grades ≥3 percent and ≥1 km in length

The directional segment methodology applies on level or rolling terrain, usually to highway sections of at least 3.0 km. Any grade of 3 percent or more and at least 1.0 km long must be addressed with the procedures for specific upgrades and downgrades. Mountainous terrain is addressed through an analysis of individual upgrades and downgrades. The specific upgrade and downgrade procedures differ from the extended segment procedure primarily in the handling of heavy-vehicle effects.

The basic directional segment methodology applies to segments on highways with one lane in each direction. However, there is a supplementary procedure to estimate the operational effect of an added passing lane within a directional segment. The operational analysis of a directional segment on a two-lane highway involves several steps, described below.

Determining FFS

The first step in the analysis of a directional segment is to determine FFS, using either of the methods for extended two-way segments. These methods should be applied on a directional basis rather than to both directions combined. If the FFS for a particular direction of travel is determined in the field, it should be under conditions of low traffic flow in both directions.

Determining Demand Flow Rate

The demand flow rate for the peak 15-min period in the direction analyzed is determined with Equation 20-12, which is analogous to Equation 20-3.

$$v_d = \frac{V}{PHF * f_G * f_{HV}} \quad (20\text{-}12)$$

where

- v_d = passenger-car equivalent flow rate for the peak 15-min period in the direction analyzed (pc/h),
- V = demand volume for the full peak hour in the direction analyzed (veh/h),
- f_G = grade adjustment factor, and
- f_{HV} = heavy-vehicle adjustment factor.

This demand flow rate should be based on the PHF, the traffic composition, and the terrain or actual grade in the specific direction of travel. As in the two-way segment procedure, different values of v_d are used for estimating average travel speed and percent time-spent-following, because the value of f_{HV} will differ for these applications.

Directional analysis also requires consideration of the demand flow rate in the opposing direction. The opposing demand flow rate is computed using Equation 20-13, which is analogous to Equation 20-12.

$$v_o = \frac{V_o}{PHF * f_G * f_{HV}} \quad (20\text{-}13)$$

where

- v_o = passenger-car equivalent flow rate for the peak 15-min period in the opposing direction of travel, and
- V_o = demand volume for the full peak hour in the opposing direction of travel.

The values of PHF and f_{HV} used in Equation 20-13 also should apply to the opposing direction of travel.

PHF

The PHF used in the directional segment procedure should be the same as that applied to a single direction of travel. If possible, the PHF should be determined from local field data, but if field data are not available, the default values given in Chapter 12 can be used.

Adjustments for Grade and Heavy Vehicles

The adjustment for the presence of heavy vehicles in directional segments is analogous to that for two-way segments in that the passenger-car equivalents for trucks (E_T) and RVs (E_R) are determined and used together with the proportions of trucks and RVs in Equation 20-4. However, the procedures for determining the values of E_T and E_R differ for extended directional segments, specific upgrades, and specific downgrades.

The values of E_T and E_R for an extended directional segment in level or rolling terrain are determined from Exhibits 20-9 and 20-10, based on the methodology for two-

Analysis of upgrades is only for segments with grades ≥ 3 percent and ≥ 0.4 km in length

way segments. For directional segments, the value of the grade adjustment factor, f_G, is given in Exhibits 20-7 and 20-8.

Any upgrade of 3 percent or more and a length of 0.4 km or more may be analyzed as a specific upgrade; however, any upgrade of 3 percent or more and a length of 1.0 km or more must be analyzed as a specific upgrade. This includes all upgrades on directional segments in mountainous terrain. If the grade varies, it should be analyzed as a single composite, using an average computed by dividing the total change in elevation by the total length of grade and expressing the result as a percentage.

The values of the grade adjustment factor f_G, used in estimating average travel speed for specific upgrades, are presented in Exhibit 20-13. The f_G for estimating percent time-spent-following on specific upgrades is presented in Exhibit 20-14. The grade adjustment factor accounts for the effect of the grade on average travel speeds and percent time-spent-following in a traffic stream composed entirely of passenger cars.

Passenger-car equivalents (E_T) for trucks used in estimating average travel speed and percent time-spent-following are presented in Exhibits 20-15 and 20-16, respectively. These factors account for the effect of trucks on average travel speed and percent time-spent-following on the specific upgrade, over and above the effect of the grade on passenger cars.

Exhibit 20-17 presents passenger-car equivalents (E_R) for RVs for estimating average travel speed on a specific upgrade. For estimating percent time-spent-following on specific upgrades, E_R is always 1.0, as shown in Exhibit 20-16.

Analysis of downgrades

Any downgrade of 3 percent or more and a length of 1.0 km or more must be analyzed as a specific downgrade. This includes all downgrades on directional segments in mountainous terrain. If the grade of a downgrade varies, it should be analyzed as a single composite using an average computed by dividing the total change in elevation by the total length of grade and expressing the result as a percentage. Because the definitions of specific upgrades and downgrades are similar, the opposing direction of any specific upgrade should be analyzed as a specific downgrade.

For most specific downgrades, the grade adjustment factor f_G is 1.0, and the heavy-vehicle adjustment factor f_{HV} is determined with passenger-car equivalencies from Exhibits 20-9 and 20-10. Some specific downgrades are long and steep enough that some heavy vehicles must travel at crawl speeds to avoid loss of control. This, of course, impedes other vehicles, increases percent time-spent-following, and decreases average travel speed. When this occurs, the heavy-vehicle adjustment factor f_{HV}, used to determine average travel speed, should be based on Equation 20-14 rather than on Equation 20-4.

$$f_{HV} = \frac{1}{1 + P_{TC} * P_T (E_{TC} - 1) + (1 - P_{TC}) P_T (E_T - 1) + P_R (E_R - 1)} \qquad (20\text{-}14)$$

where

P_{TC} = proportion (expressed as a decimal) of all trucks in the traffic stream using crawl speeds on the specific downgrade, and

E_{TC} = passenger-car equivalent for trucks using crawl speeds, obtained from Exhibit 20-18.

In applying Equation 20-14, the passenger-car equivalent for trucks that use crawl speeds (E_{TC}) should be determined from Exhibit 20-18, based on the directional flow rate and the difference between the FFS and the truck crawl speed. The passenger-car equivalents for other trucks (E_T) and RVs (E_R) should be the values for level terrain in Exhibit 20-9. If more specific data are not available, the proportion of all trucks that use crawl speeds can be estimated as equal to the proportion of all trucks that are tractor-trailer combinations.

EXHIBIT 20-13. 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 (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	0.81	1.00	1.00
	0.8	0.79	1.00	1.00
	1.2	0.77	1.00	1.00
	1.6	0.76	1.00	1.00
	2.4	0.75	0.99	1.00
	3.2	0.75	0.97	1.00
	4.8	0.75	0.95	0.97
	≥ 6.4	0.75	0.94	0.95
≥ 3.5 < 4.5	0.4	0.79	1.00	1.00
	0.8	0.76	1.00	1.00
	1.2	0.72	1.00	1.00
	1.6	0.69	0.93	1.00
	2.4	0.68	0.92	1.00
	3.2	0.66	0.91	1.00
	4.8	0.65	0.91	0.96
	≥ 6.4	0.65	0.90	0.96
≥ 4.5 < 5.5	0.4	0.75	1.00	1.00
	0.8	0.65	0.93	1.00
	1.2	0.60	0.89	1.00
	1.6	0.59	0.89	1.00
	2.4	0.57	0.86	0.99
	3.2	0.56	0.85	0.98
	4.8	0.56	0.84	0.97
	≥ 6.4	0.55	0.82	0.93
≥ 5.5 < 6.5	0.4	0.63	0.91	1.00
	0.8	0.57	0.85	0.99
	1.2	0.52	0.83	0.97
	1.6	0.51	0.79	0.97
	2.4	0.49	0.78	0.95
	3.2	0.48	0.78	0.94
	4.8	0.46	0.76	0.93
	≥ 6.4	0.45	0.76	0.93
≥ 6.5	0.4	0.59	0.86	0.98
	0.8	0.48	0.76	0.94
	1.2	0.44	0.74	0.91
	1.6	0.41	0.70	0.91
	2.4	0.40	0.67	0.91
	3.2	0.39	0.67	0.89
	4.8	0.39	0.66	0.88
	≥ 6.4	0.38	0.66	0.87

EXHIBIT 20-14. 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 (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.00	0.92	0.92
	0.8	1.00	0.93	0.93
	1.2	1.00	0.93	0.93
	1.6	1.00	0.93	0.93
	2.4	1.00	0.94	0.94
	3.2	1.00	0.95	0.95
	4.8	1.00	0.97	0.96
	≥ 6.4	1.00	1.00	0.97
≥ 3.5 < 4.5	0.4	1.00	0.94	0.92
	0.8	1.00	0.97	0.96
	1.2	1.00	0.97	0.96
	1.6	1.00	0.97	0.97
	2.4	1.00	0.97	0.97
	3.2	1.00	0.98	0.98
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 4.5 < 5.5	0.4	1.00	1.00	0.97
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 5.5 < 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00

EXHIBIT 20-15. PASSENGER-CAR EQUIVALENTS FOR TRUCKS FOR ESTIMATING AVERAGE SPEED ON SPECIFIC UPGRADES

		Passenger-Car Equivalent for Trucks, E_T		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	2.5	1.9	1.5
	0.8	3.5	2.8	2.3
	1.2	4.5	3.9	2.9
	1.6	5.1	4.6	3.5
	2.4	6.1	5.5	4.1
	3.2	7.1	5.9	4.7
	4.8	8.2	6.7	5.3
	≥ 6.4	9.1	7.5	5.7
≥ 3.5 < 4.5	0.4	3.6	2.4	1.9
	0.8	5.4	4.6	3.4
	1.2	6.4	6.6	4.6
	1.6	7.7	6.9	5.9
	2.4	9.4	8.3	7.1
	3.2	10.2	9.6	8.1
	4.8	11.3	11.0	8.9
	≥ 6.4	12.3	11.9	9.7
≥ 4.5 < 5.5	0.4	4.2	3.7	2.6
	0.8	6.0	6.0	5.1
	1.2	7.5	7.5	7.5
	1.6	9.2	9.0	8.9
	2.4	10.6	10.5	10.3
	3.2	11.8	11.7	11.3
	4.8	13.7	13.5	12.4
	≥ 6.4	15.3	15.0	12.5
≥ 5.5 < 6.5	0.4	4.7	4.1	3.5
	0.8	7.2	7.2	7.2
	1.2	9.1	9.1	9.1
	1.6	10.3	10.3	10.2
	2.4	11.9	11.8	11.7
	3.2	12.8	12.7	12.6
	4.8	14.4	14.3	14.2
	≥ 6.4	15.4	15.2	15.0
≥ 6.5	0.4	5.1	4.8	4.6
	0.8	7.8	7.8	7.8
	1.2	9.8	9.8	9.8
	1.6	10.4	10.4	10.3
	2.4	12.0	11.9	11.8
	3.2	12.9	12.8	12.7
	4.8	14.5	14.4	14.3
	≥ 6.4	15.4	15.3	15.2

EXHIBIT 20-16. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS 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 (km)	0–300	> 300–600	> 600	RVs, E_R
≥ 3.0 < 3.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.0	1.0	1.0	1.0
	3.2	1.0	1.0	1.0	1.0
	4.8	1.4	1.0	1.0	1.0
	≥ 6.4	1.5	1.0	1.0	1.0
≥ 3.5 < 4.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.0	1.0	1.0
	3.2	1.4	1.0	1.0	1.0
	4.8	1.7	1.1	1.2	1.0
	≥ 6.4	2.0	1.5	1.4	1.0
≥ 4.5 < 5.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.2	1.2	1.0
	3.2	1.6	1.3	1.5	1.0
	4.8	2.3	1.9	1.7	1.0
	≥ 6.4	3.3	2.1	1.8	1.0
≥ 5.5 < 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.2	1.2	1.0
	2.4	1.5	1.6	1.6	1.0
	3.2	1.9	1.9	1.8	1.0
	4.8	3.3	2.5	2.0	1.0
	≥ 6.4	4.3	3.1	2.0	1.0
≥ 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.3	1.0
	1.6	1.3	1.4	1.6	1.0
	2.4	2.1	2.0	2.0	1.0
	3.2	2.8	2.5	2.1	1.0
	4.8	4.0	3.1	2.2	1.0
	≥ 6.4	4.8	3.5	2.3	1.0

EXHIBIT 20-17. PASSENGER-CAR EQUIVALENTS FOR RVS 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 (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.1	1.0	1.0
	0.8	1.2	1.0	1.0
	1.2	1.2	1.0	1.0
	1.6	1.3	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.5	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 3.5 < 4.5	0.4	1.3	1.0	1.0
	0.8	1.3	1.0	1.0
	1.2	1.3	1.0	1.0
	1.6	1.4	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.4	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 4.5 < 5.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.5	1.0	1.0
	2.4	1.5	1.0	1.0
	3.2	1.5	1.0	1.0
	4.8	1.6	1.0	1.0
	≥ 6.4	1.6	1.0	1.0
≥ 5.5 < 6.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.2	1.0
	≥ 6.4	1.6	1.5	1.2
≥ 6.5	0.4	1.6	1.0	1.0
	0.8	1.6	1.0	1.0
	1.2	1.6	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.3	1.3
	≥ 6.4	1.6	1.5	1.4

EXHIBIT 20-18. PASSENGER-CAR EQUIVALENTS FOR ESTIMATING THE EFFECT ON AVERAGE TRAVEL SPEED OF TRUCKS THAT OPERATE AT CRAWL SPEEDS ON LONG STEEP DOWNGRADES

Difference Between FFS and Truck Crawl Speed (km/h)	Passenger-Car Equivalent for Trucks at Crawl Speeds, E_{TC}		
	Range of Directional Flow Rates, v_d (pc/h)		
	0–300	> 300–600	> 600
≤ 20	4.4	2.8	1.4
40	14.3	9.6	5.7
≥ 60	34.1	23.1	13.0

Iterative Computations

As with the two-way segment procedure, Equations 20-12 and 20-13 must be applied iteratively in some situations to determine appropriate values of v_d and v_o. This iterative process for directional segments is analogous to that for two-way segments, but with the following differences:

- For extended segments in level and rolling terrain and for specific downgrades, the directional flow rates from Exhibits 20-7 through 20-10 are used instead of the two-way rates;
- For specific upgrades, Exhibits 20-13 through 20-17 are used instead of Exhibits 20-7 through 20-10; and
- For specific downgrades on which some trucks travel at crawl speeds, Equation 20-14 is used instead of Equation 20-4.

Determining Average Travel Speed

The average travel speed is estimated from the FFS, the demand flow rate, the opposing flow rate, and an adjustment factor for the percentage of no-passing zones in the analysis direction. Average travel speed is then estimated using Equation 20-15.

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np} \tag{20-15}$$

where

ATS_d = average travel speed in the analysis direction (km/h),
FFS_d = free-flow speed in the analysis direction (km/h),
v_d = passenger-car equivalent flow rate for the peak 15-min period in the analysis direction (pc/h),
v_o = passenger-car equivalent flow rate for the peak 15-min period in the opposing direction (pc/h), determined from Equation 20-13; and
f_{np} = adjustment for percentage of no-passing zones in the analysis direction (see Exhibit 20-19).

The term containing v_d and v_o in Equation 20-15 represents the relationship between average travel speed and the directional and opposing flow rates presented in Chapter 12. The adjustment f_{np} accounts for the effect of the percentage of no-passing zones in the analysis direction. As shown in Exhibit 20-19, this effect is greatest when opposing flow rates are low; as the opposing flow rates increase, the effect decreases to zero, since passing and no-passing zones become irrelevant if the opposing flow allows no opportunities to pass.

EXHIBIT 20-19. ADJUSTMENT (f_{np}) TO AVERAGE TRAVEL SPEED 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 = 110 km/h					
≤ 100	1.7	3.5	4.5	4.8	5.0
200	3.5	5.3	6.2	6.5	6.8
400	2.6	3.7	4.4	4.5	4.7
600	2.2	2.4	2.8	3.1	3.3
800	1.1	1.6	2.0	2.2	2.4
1000	1.0	1.3	1.7	1.8	1.9
1200	0.9	1.3	1.5	1.6	1.7
1400	0.9	1.2	1.4	1.4	1.5
≥ 1600	0.9	1.1	1.2	1.2	1.3
FFS = 100 km/h					
≤ 100	1.2	2.7	4.0	4.5	4.7
200	3.0	4.6	5.9	6.4	6.7
400	2.3	3.3	4.1	4.4	4.6
600	1.8	2.1	2.6	3.0	3.2
800	0.9	1.4	1.8	2.1	2.3
1000	0.9	1.1	1.5	1.7	1.9
1200	0.8	1.1	1.4	1.5	1.7
1400	0.8	1.0	1.3	1.3	1.4
≥ 1600	0.8	1.0	1.1	1.1	1.2
FFS = 90 km/h					
≤ 100	0.8	1.9	3.6	4.2	4.4
200	2.4	3.9	5.6	6.3	6.6
400	2.1	3.0	3.8	4.3	4.5
600	1.4	1.8	2.5	2.9	3.1
800	0.8	1.1	1.7	2.0	2.2
1000	0.8	0.9	1.3	1.5	1.8
1200	0.8	0.9	1.2	1.4	1.6
1400	0.8	0.9	1.1	1.2	1.4
≥ 1600	0.8	0.8	0.9	0.9	1.1
FFS = 80 km/h					
≤ 100	0.3	1.1	3.1	3.9	4.1
200	1.9	3.2	5.3	6.2	6.5
400	1.8	2.6	3.5	4.2	4.4
600	1.0	1.5	2.3	2.8	3.0
800	0.6	0.9	1.5	1.9	2.1
1000	0.6	0.7	1.1	1.4	1.8
1200	0.6	0.7	1.1	1.3	1.6
1400	0.6	0.7	1.0	1.1	1.3
≥ 1600	0.6	0.7	0.8	0.8	1.0
FFS = 70 km/h					
≤ 100	0.1	0.6	2.7	3.6	3.8
200	1.5	2.6	5.0	6.1	6.4
400	1.5	0.8	3.2	4.1	4.3
600	0.7	0.5	2.1	2.7	2.9
800	0.5	0.5	1.3	1.8	2.0
1000	0.5	0.5	1.0	1.3	1.8
1200	0.5	0.5	1.0	1.2	1.6
1400	0.5	0.5	1.0	1.0	1.2
≥ 1600	0.5	0.5	0.7	0.7	0.9

Determining Percent Time-Spent-Following

The percent time-spent-following is estimated from the demand flow rate, the opposing flow rate, and an adjustment factor for the percentage of no-passing zones in the analysis direction. Percent time-spent-following is estimated using Equation 20-16.

$$PTSF_d = BPTSF_d + f_{np} \qquad (20\text{-}16)$$

where

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

$BPTSF_d$ = base percent time-spent-following in the direction analyzed, and

f_{np} = adjustment for percentage of no-passing zones in the analysis direction (see Exhibit 20-20).

The percent time-spent-following for base conditions under actual traffic volumes in the direction analyzed in Equation 20-16 is estimated by Equation 20-17.

$$BPTSF_d = 100\left(1 - e^{av_d^{\,b}}\right) \qquad (20\text{-}17)$$

The values of the coefficients a and b in Equation 20-17 are determined from the flow rate in the opposing direction of travel, as shown in Exhibit 20-21.

The adjustment f_{np} in Equation 20-16 accounts for the effect of the percentage of no-passing zones in the analysis direction. This effect, shown in Exhibit 20-20, is greatest at low opposing flow rates and decreases as the opposing flow rate increases, since passing and no-passing zones become irrelevant if the opposing flow rate is so high that there are no opportunities to pass.

Determining LOS

The first step in determining level of service is to compare the passenger-car equivalent flow rate (v_d) to the roadway capacity of 1,700 pc/h. If v_d is greater than the capacity, then the roadway is oversaturated and the LOS is F. In LOS F, percent time-spent-following is nearly 100 percent and speeds are highly variable and difficult to estimate.

For a segment on a Class I facility with demand less than capacity, the LOS is determined by locating the point corresponding to the estimated percent time-spent-following and average travel speed in Exhibit 20-3. For a segment on a Class II facility with demand less than capacity, the LOS is determined by comparing the directional percent time-spent-following to the criteria in Exhibit 20-4. The reported results of the analysis should include the LOS and the estimated values of percent time-spent-following and average travel speed. Although average travel speed is not considered in the LOS determination for a Class II roadway, the estimate of average travel speed may be useful in evaluating the quality of service of two-lane highway facilities, highway networks, or systems of which the roadway segment is a part.

Other Traffic Performance Measures

Other traffic performance measures, including v/c ratio, total travel, and total travel time, can be determined from Equations 20-8 through 20-11, but using directional volumes, flow rates, and speeds, rather than their two-way equivalents.

DIRECTIONAL SEGMENTS WITH PASSING LANES

The procedure should not be applied to mountainous terrain or specific upgrades

Providing a passing lane on a two-lane highway in level or rolling terrain has an effect on its LOS; an operational analysis procedure allows this effect to be estimated. This procedure, however, does not address added lanes in mountainous terrain or on specific upgrades, which are known as climbing lanes. A separate operational analysis procedure for climbing lanes is presented later in this chapter.

EXHIBIT 20-20. ADJUSTMENT (f_{np}) TO PERCENT TIME-SPENT-FOLLOWING FOR PERCENTAGE OF NO-PASSING ZONES IN DIRECTIONAL SEGMENTS

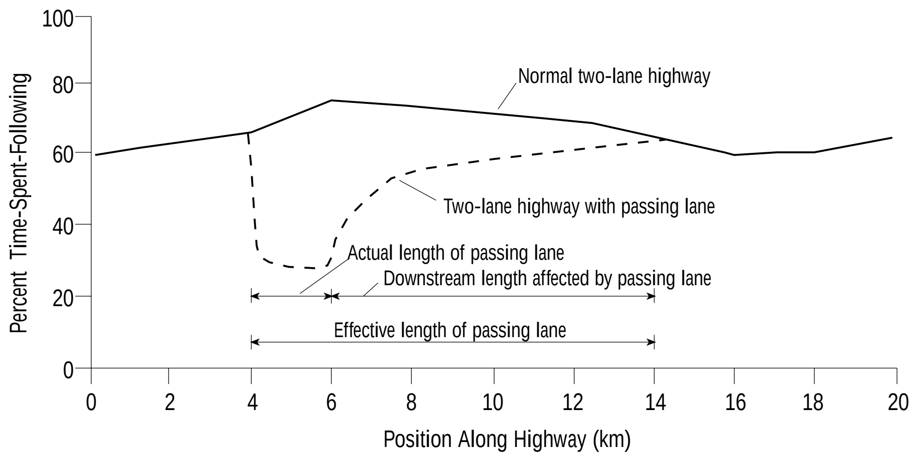
Opposing Demand Flow Rate, v_o (pc/h)	No-Passing Zones (%)				
	≤ 20	40	60	80	100
FFS = 110 km/h					
≤ 100	10.1	17.2	20.2	21.0	21.8
200	12.4	19.0	22.7	23.8	24.8
400	9.0	12.3	14.1	14.4	15.4
600	5.3	7.7	9.2	9.7	10.4
800	3.0	4.6	5.7	6.2	6.7
1000	1.8	2.9	3.7	4.1	4.4
1200	1.3	2.0	2.6	2.9	3.1
1400	0.9	1.4	1.7	1.9	2.1
≥ 1600	0.7	0.9	1.1	1.2	1.4
FFS = 100 km/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 = 90 km/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
FFS = 80 km/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 = 70 km/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

EXHIBIT 20-21. VALUES OF COEFFICIENTS 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	0.199

Exhibit 20-22 illustrates the operational effect of a passing lane on percent time-spent-following. The figure shows that installation of a passing lane provides operational benefits for some distance downstream before percent time-spent-following returns to its former level. Thus, the effective length of a passing lane is greater than its actual length. Exhibit 20-23 shows how the traffic flow rate on a downstream length of a two-lane highway benefits from a passing lane in terms of both percent time-spent-following and average travel speed.

EXHIBIT 20-22. OPERATIONAL EFFECT OF A PASSING LANE ON PERCENT TIME-SPENT-FOLLOWING



Source: Harwood and Hoban (*3*).

EXHIBIT 20-23. DOWNSTREAM LENGTH OF ROADWAY AFFECTED BY PASSING LANES ON DIRECTIONAL SEGMENTS IN LEVEL AND ROLLING TERRAIN

Directional Flow Rate (pc/h)	Downstream Length of Roadway Affected, L_{de} (km)	
	Percent Time-Spent-Following	Average Travel Speed
≤ 200	20.9	2.8
400	13.0	2.8
700	9.1	2.8
≥ 1000	5.8	2.8

For complex systems of passing lanes, consider use of a computer simulation model

The operational analysis procedures presented here for passing lanes in level or rolling terrain are applicable to directional segments of two-lane highways that include the entire passing lane. Sections of two-lane highway upstream and downstream of the passing lane also may be included. Whenever possible, the directional segment should include not only the passing lane but also its full effective downstream length, as indicated in Exhibit 20-23. There are special procedures for directional segments that include only part of the effective downstream length of the passing lane (e.g., when an analysis segment must end because of the proximity of a small town or due to a change in the demand volume). The effects of providing another passing lane in the same direction of travel within the effective length of the first passing lane are too complex to evaluate. In such situations, an evaluation with a traffic simulation model is recommended. The operational analysis procedures for passing lanes in level or rolling terrain are described below.

Analysis of a Directional Segment with a Passing Lane

The first step in the operational analysis of a passing lane is to apply the procedure for directional segments in level or rolling terrain to the normal cross section without the passing lane. The data required are the demand volume in the analysis direction, demand volume in the opposing direction, vehicle mix, lane width, shoulder width, and percentage of no-passing zones. The result is the percent time-spent-following and the average travel speed for the normal two-lane cross section.

Dividing the Segment into Regions

The next step is to divide the analysis segment into four regions. These regions are

1. Upstream of the passing lane,
2. The passing lane,
3. Downstream of the passing lane but within its effective length, and
4. Downstream of the passing lane but beyond its effective length.

These four lengths must add up to the total length of the analysis segment. The analysis regions and their lengths will differ for estimations of percent time-spent-following and average travel speed, because the downstream lengths for these measures differ, as shown in Exhibit 20-23.

For constraints on applicable lengths of lane additions see Chapter 12, "Highway Concepts"

The length of the passing lane, L_{pl}, used in the analysis, is either the length of the passing lane as constructed or its planned length. The passing lane length should include the lengths of the lane addition and lane drop tapers. The analysis procedure is calibrated for passing lanes within the optimal ranges of length shown in Chapter 12. Passing lane lengths substantially shorter or longer than the optimum may provide less operational benefit than predicted by this procedure.

The length of the conventional two-lane highway segment upstream of the passing lane, L_u, is determined by the actual or planned placement of the passing lane within the analysis section. The length of the downstream highway segment within the effective length of the passing lane, L_{de}, is determined from Exhibit 20-23. Any remaining length within the analysis segment downstream of the passing lane is included in L_d as shown in Equation 20-18.

$$L_d = L_t - \left(L_u + L_{pl} + L_{de}\right) \tag{20-18}$$

where

L_d	=	length of two-lane highway downstream of the passing lane and beyond its effective length (km),
L_t	=	total length of analysis segment (km),
L_u	=	length of two-lane highway upstream of the passing lane (km),
L_{pl}	=	length of the passing lane including tapers (km), and
L_{de}	=	downstream length of two-lane highway within the effective length of the passing lane (km) (from Exhibit 20-23).

Determining Percent Time-Spent-Following

Percent time-spent-following within lengths L_u and L_d is assumed to be equal to $PTSF_d$, as predicted by the directional segment procedure. Within the passing lane, percent time-spent-following is generally equal to 58 to 62 percent of its upstream value. This effect varies as a function of the directional flow rate, as shown in Exhibit 20-24. Within the downstream length, L_{de}, percent time-spent-following is assumed to increase linearly with distance from the passing-lane value to its normal upstream value. Thus, the average percent time-spent-following with the passing lane in place can be computed using Equation 20-19.

$$PTSF_{pl} = \frac{PTSF_d\left[L_u + L_d + f_{pl}L_{pl} + \left(\frac{1+f_{pl}}{2}\right)L_{de}\right]}{L_t} \qquad (20\text{-}19)$$

where

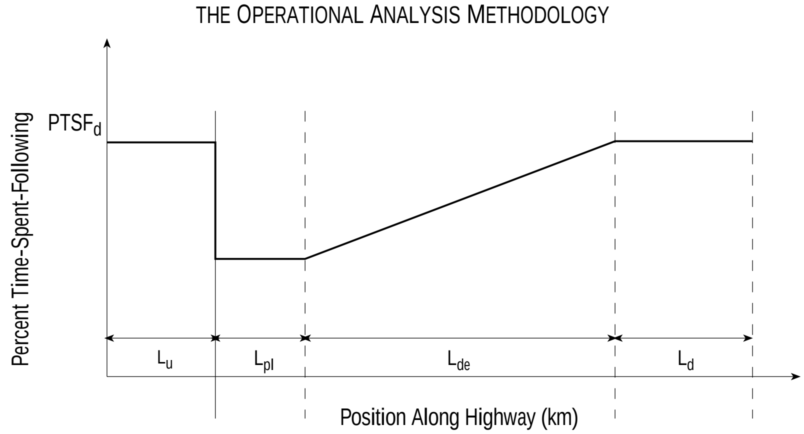
- $PTSF_{pl}$ = percent time-spent-following for the entire segment including the passing lane,
- $PTSF_d$ = percent time-spent-following for the entire segment without the passing lane from Equation 20-16, and
- f_{pl} = factor for the effect of a passing lane on percent time-spent-following (see Exhibit 20-24).

The variations in percent time-spent-following are shown in Exhibit 20-25.

EXHIBIT 20-24. FACTORS (f_{pl}) FOR ESTIMATION OF 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

EXHIBIT 20-25. EFFECT OF A PASSING LANE ON PERCENT TIME-SPENT-FOLLOWING AS REPRESENTED IN THE OPERATIONAL ANALYSIS METHODOLOGY



Special case: downstream effective length is truncated

If the analysis section is truncated by a town or a major intersection before the full downstream effective length of the passing lane has been reached, then distance L_d is not used and the actual downstream length within the analysis segment, L'_{de}, is less than the value of L_{de} tabulated in Exhibit 20-23. In this case, Equation 20-19 should be replaced by Equation 20-20. Equation 20-20 applies whenever distance, L_d, computed with Equation 20-8, is negative.

$$PTSF_{pl} = \frac{PTSF_d \left[L_u + f_{pl} L_{pl} + f_{pl} L'_{de} + \left(\frac{1 - f_{pl}}{2} \right) \left(\frac{(L'_{de})^2}{L_{de}} \right) \right]}{L_t} \tag{20-20}$$

where

L'_{de} = actual distance from end of passing lane to end of analysis segment (km). L'_{de} must be less than or equal to the value of L_{de} from Exhibit 20-23.

Determining Average Travel Speed

Average travel speed within lengths L_u and L_d is assumed to equal ATS_d, as predicted by the directional segment procedure. Within the passing lane, average travel speed is generally 8 to 11 percent higher than its upstream value. This effect varies as a function of directional flow rate, as shown in Exhibit 20-24. Within the downstream length, L_{de}, average travel speed is assumed to decrease linearly with distance from the within-passing-lane value to its normal upstream value. Thus, the average travel speed with the passing lane in place can be computed using Equation 20-21.

$$ATS_{pl} = \frac{ATS_d * L_t}{L_u + L_d + \frac{L_{pl}}{f_{pl}} + \frac{2L_{de}}{1 + f_{pl}}} \tag{20-21}$$

where

ATS_{pl} = average travel speed for the entire segment including the passing lane (km/h),

ATS_d = average travel speed for the entire segment without the passing lane from Equation 20-15 (km/h), and

f_{pl} = factor for the effect of a passing lane on average travel speed (see Exhibit 20-23).

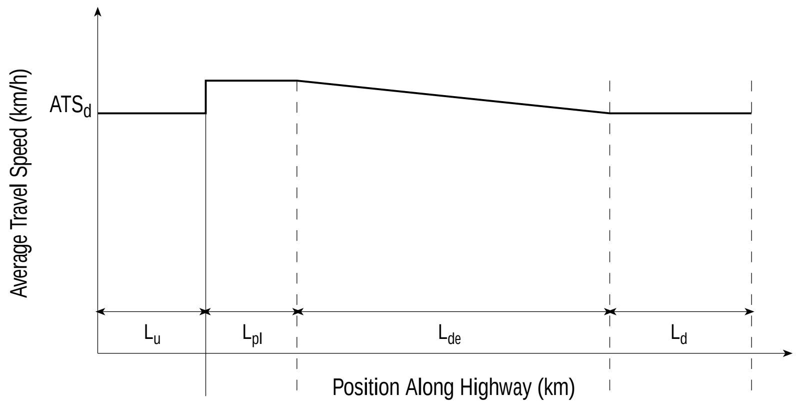
The variations in average travel speed are shown in Exhibit 20-26. If the analysis section is truncated by the presence of a town or a major intersection before the full downstream effective length of the passing lane has been reached, then distance L_d is not used and the actual downstream length within the analysis segment, L'_{de}, is less than the value of L_{de} tabulated in Exhibit 20-23. In this case, Equation 20-21 should be replaced by Equation 20-22. Equation 20-22 applies whenever distance, L_d, computed with Equation 20-18, is negative.

$$ATS_{pl} = \frac{ATS_d * L_t}{L_u + \frac{L_{pl}}{f_{pl}} + \frac{2L'_{de}}{\left[1 + f_{pl} + (f_{pl} - 1)\frac{L_{de} - L'_{de}}{L_{de}} \right]}} \tag{20-22}$$

Determining LOS

Determining LOS for a directional segment with a passing lane is similar to determining LOS for a directional segment without a passing lane; however, for the passing lane, the values of $PTSF_{pl}$ and ATS_{pl} are used instead of $PTSF_d$ and ATS_d. The LOS for a Class I highway segment with a passing lane is determined by locating the point corresponding to $PTSF_{pl}$ and AST_{pl} in Exhibit 20-3. The LOS for a Class II highway segment with a passing lane is determined by comparing $PTSF_{pl}$ to the LOS thresholds in Exhibit 20-4. If the directional demand flow rate, v_d, exceeds 1,700 pc/h, the roadway is oversaturated, and the LOS is F. Although a passing lane section with two lanes in the same direction can serve more than 1,700 pc/h, the sections with a single directional lane between passing lanes will be oversaturated and will become bottlenecks.

EXHIBIT 20-26. EFFECT OF A PASSING LANE ON AVERAGE TRAVEL SPEED AS REPRESENTED IN THE OPERATIONAL ANALYSIS METHODOLOGY



Effects of Passing Lanes on Opposing Traffic

If the installation of a passing lane on a directional segment changes the percentage of no-passing zones for the opposing direction of travel, the directional analysis for the opposing direction must be revised. This can occur, for example, if a highway agency routinely prohibits passing in the opposing direction of travel to a passing lane. However, if passing is permitted in the opposing direction of travel, the passing lane may have little effect on the LOS for the opposing direction. It is possible that a passing lane, by breaking up platoons in one direction of travel, may reduce passing opportunities for the other direction. However, this effect has not been quantified and is not reflected in the operational analysis procedure.

When passing lanes are provided in both directions of travel, the operational analyses for the two directions can proceed independently, unless the addition of the passing lane in one direction substantially changes the percentage of no-passing zones outside the passing lane in the other direction.

DIRECTIONAL SEGMENTS WITH CLIMBING LANES ON UPGRADES

The operational analysis procedure does not address traffic operations on the roadway downstream of a climbing lane beyond the top of the grade. Consider use of a computer simulation model of two-lane highway operations to analyze such segments.

A climbing lane is a passing lane added on an upgrade to allow traffic to pass heavy vehicles whose speeds are reduced. According to the American Association of State Highway and Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets* (*4*), climbing lanes on two-lane highway upgrades are warranted when

- The directional flow rate on the upgrade exceeds 200 veh/h,
- The directional flow rate for trucks on the upgrade exceeds 20 veh/h, and
- Any of the following conditions apply: a speed reduction of 15 km/h for a typical heavy truck, LOS E or F on the grade, or a reduction of two or more levels of service from the approach segment to the grade.

The AASHTO policy on climbing lanes directly refers to the LOS determined with the HCM operational analysis procedures. Operational analysis of climbing lanes on specific upgrades can be performed with the same procedures for passing lanes in level and rolling terrain, with two major differences. First, in applying the directional segment procedure to the roadway without the added lane, the grade adjustment factor, f_G, and the heavy-vehicle adjustment factor, f_{HV}, should be the values for specific upgrades. If the grade on which the lane is added is not sufficiently long or steep to be analyzed as a specific upgrade, then it should be analyzed as a passing lane rather than a climbing lane. Second, the values of the adjustment factors for average travel speed and percent time-spent-following in Exhibit 20-27 should be used instead of those in Exhibit 20-24.

EXHIBIT 20-27. FACTORS (f_{pl}) FOR ESTIMATION OF 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

Because climbing lanes are analyzed as part of a specific upgrade, the lengths L_u and L_d used in Equations 20-19 through 20-22 generally equal zero. The downstream effective length, L_{de}, also generally equals zero unless the climbing lane ends before the top of the grade. In this case, a value of L_{de} shorter than the values shown in Exhibit 20-23 should be considered.

LOS ASSESSMENT FOR DIRECTIONAL TWO-LANE FACILITIES

A directional two-lane highway facility is a series of contiguous directional two-lane highway segments. If an operational analysis has been conducted for each segment in the series, the results can be combined to obtain an operational assessment of the facility as a whole. The same approach can be used to combine operational results from directional segments in the opposing directions of travel on a two-lane highway. In either case, the applicable LOS criteria are shown in Exhibits 20-3 and 20-4 for Class I and II highways, respectively.

The combined percent time-spent-following for several directional segments can be determined by Equation 20-23.

$$PTSF_c = \frac{TT_1 * PTSF_1 + TT_2 * PTSF_2 + \ldots + TT_n * PTSF_n}{TT_1 + TT_2 + \ldots + TT_n} \qquad (20\text{-}23)$$

where

- $PTSF_c$ = percent time-spent-following for all segments combined,
- TT_x = total travel time (veh-h) for Segment x (determined from Equation 20-11), and
- $PTSF_x$ = percent time-spent-following for Segment x.

The combined average travel speed for several directional segments can be determined using Equation 20-24.

$$ATS_c = \frac{VkmT_1 + VkmT_2 + \ldots + VkmT_n}{TT_1 + TT_2 + \ldots + TT_n} \qquad (20\text{-}24)$$

where

- ATS_c = average travel speed for all segments combined (km/h) and
- $VkmT_x$ = total travel for Segment x, determined from Equation 20-9 (veh-km).

LOS ASSESSMENT FOR UNINTERRUPTED-FLOW FACILITIES AND CORRIDORS WITH TWO-LANE HIGHWAYS

Results from individual segments may be combined

A directional analysis procedure has been provided in this chapter so that operational analysis results for directional segments on two-lane facilities can be combined readily with results for interrupted-flow facilities, including multilane highways (see Chapter 21) and basic freeway segments (see Chapter 23). Operational analysis across different types of uninterrupted-flow facilities should be based solely on average travel speed, because percent time-spent-following generally is a consideration only for two-lane highways. Equations 20-20, 20-21, and 20-22 can be used to combine estimates of average travel speed from segments on different types of facilities.

III. APPLICATIONS

Guidelines on required inputs and estimated values are in Chapter 12, “Highway Concepts”

The methodology of this chapter can be used to analyze the capacity and LOS of two-lane highways. The analyst must address two fundamental questions. First, what is the primary output? Primary outputs typically solved for in a variety of applications include LOS and achievable flow rate (v_p). Performance measures related to average travel speed (ATS) and percent time-spent-following (PTSF) are also achievable but are secondary.

Second, what are the default values or estimated values for use in the analysis? Basically, there are three sources of input data:

1. Default values found in this manual,
2. Estimates and locally derived default values developed by the user, and
3. Values derived from field measurements and observation.

For each of the input variables, a value must be supplied to calculate the primary and secondary outputs.

A common application of the method is to compute the LOS of a current or a changed facility in the near term or in the future. This type of application is often termed operational, and its primary output is LOS, with secondary outputs for ATS and PTSF. The achievable flow rate, v_p, can be solved for as the primary output. This analysis requires a LOS goal and geometric data as inputs for estimating when a flow rate will be exceeded, causing the highway to operate at an unacceptable LOS. Using the methodology to determine the number of lanes required (known as a design application in this manual) is of course not necessary for two-lane highways. Modifications to grade, alignment, and cross section, however, can improve the operational efficiency of a two-lane facility. Computational examples are provided for two design-related applications—the addition of a passing or climbing lane to a two-lane highway and the addition of through lanes to convert a two-lane highway to a four-lane highway. The latter example involves a comparison of results obtained from this chapter with results obtained from Chapter 21, “Multilane Highways.”

Another general type of analysis is the planning analysis, which uses estimates, HCM default values, and local default values as inputs. As outputs, LOS or flow rate can be determined along with the secondary outputs of average travel speed and percent time-spent-following. The difference between this type of analysis and operational analysis is that most or all of the input values come from estimates or default values, while the operational analyses use field-measured values or known values.

COMPUTATIONAL STEPS

The worksheet for two-way, two-lane highway segment computations is shown in Exhibit 20-28. The worksheets for directional two-lane highway segments with or without a passing lane are included in Appendix B. For all applications, the analyst provides general information and site information.

Operational (LOS) analysis

For operational (LOS) analysis, the analyst inputs all the required data. For estimating average travel speed, equivalent flow is computed with the aid of exhibits for passenger-car equivalencies. FFS is estimated by applying adjustments to the base FFS. Then average travel speed is estimated. Similarly, equivalent flow is estimated by using passenger-car equivalency exhibits to estimate percent time-spent-following. Percent time-spent-following is estimated by adjusting the base percent time-spent-following value for the percentage of no-passing zones. Finally, LOS is determined by average travel speed, percent time-spent-following, or both, depending on the highway classification.

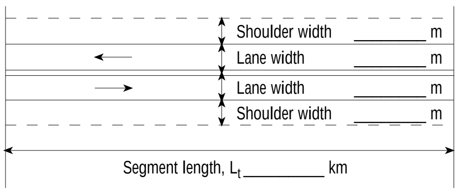
EXHIBIT 20-28. TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

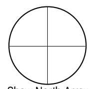
TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		**Site Information**	
Analyst	____________	Highway	____________
Agency or Company	____________	From/To	____________
Date Performed	____________	Jurisdiction	____________
Analysis Time Period	____________	Analysis Year	____________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data





❑ Class I highway ❑ Class II highway
Terrain ❑ Level ❑ Rolling
Two-way hourly volume ________ veh/h
Directional split ______ /_____
Peak-hour factor, PHF ________
% Trucks and buses, P_T ________ %
% Recreational vehicles, P_R ________ %
% No-passing zone ________ %
Access points/km ________/km

Average Travel Speed	
Grade adjustment factor, f_G (Exhibit 20-7)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-9)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-9)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	
Free-Flow Speed from Field Measurement	Estimated Free-Flow Speed
Field measured speed, S_{FM} ____________ km/h Observed volume, V_f ____________ veh/h Free-flow speed, FFS ____________ km/h $FFS = S_{FM} + 0.0125\left(\frac{V_f}{f_{HV}}\right)$	Base free-flow speed, BFFS ____________ km/h Adj. for lane width and shoulder width, f_{LS} (Exhibit 20-5) _____ km/h Adj. for access points, f_A (Exhibit 20-6) ____________ km/h Free-flow speed, FFS ____________ km/h $FFS = BFFS - f_{LS} - f_A$
Adj. for no-passing zones, f_{np} (km/h) (Exhibit 20-11)	
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	

Percent Time-Spent-Following	
Grade adjustment factor, f_G (Exhibit 20-8)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-10)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-10)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	
Base percent time-spent-following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879v_p})$	
Adj. for directional distribution and no-passing zone, $f_{d/np}$ (%) (Exhibit 20-12)	
Percent time-spent-following, PTSF (%) $PTSF = BPTSF + f_{d/np}$	

Level of Service and Other Performance Measures	
Level of service, LOS (Exhibit 20-3 for Class I or 20-4 for Class II)	
Volume to capacity ratio, v/c $v/c = \frac{v_p}{3{,}200}$	
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right)$	
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V * L_t$	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS}$	

Notes

1. If $v_p \geq 3{,}200$ pc/h, terminate analysis—the LOS is F.
2. If highest directional split $v_p \geq 1{,}700$ pc/h, terminate analysis—the LOS is F.

Design (v_p) analysis

The objective of design (v_p) analysis is to estimate the flow rate in passenger cars per hour given a set of traffic, roadway, and FFS conditions. A desired LOS is stated and entered in the worksheet. Then a flow rate is assumed and the procedure for operational (LOS) analysis is performed. This computed LOS is then compared with the desired LOS. If the desired LOS is not met, another flow rate is assumed. This iteration continues until the maximum flow rate for the desired LOS is achieved.

PLANNING APPLICATIONS

Planning (LOS) and planning (v_p) analyses

The two planning applications, planning for LOS and for v_p, correspond directly to the procedures for operational and design analyses. The criterion that categorizes these as planning applications is the use of estimates, HCM default values, and local default values as inputs. Another characteristic of a planning application is the use of annual average daily traffic (AADT) to estimate directional design-hour volume (DDHV). For guidelines in computing DDHV, see Chapter 8. Chapter 12 also lists the required data and estimated values to perform a planning application.

ANALYSIS TOOLS

Worksheets for two-way, directional, and directional with passing lane segments are provided in Appendix B. These worksheets can be used to perform operational (LOS), design (v_p), planning (LOS), and planning (v_p) analyses.

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Find the two-way LOS of a Class I two-lane highway	Operational (LOS)
2	Find the two-way LOS of a Class II two-lane highway	Operational (LOS)
3	Find the directional LOS of a Class I two-lane highway	Operational (LOS)
4	Find the directional LOS of a Class I two-lane highway including a passing lane	Operational (LOS)

EXAMPLE PROBLEM 1

The Highway A Class I two-lane highway segment.

The Question What is the two-way segment LOS for the peak hour?

The Facts

- √ 1,600 veh/h (two-way volume),
- √ 14 percent trucks and buses,
- √ 0.95 PHF,
- √ Rolling terrain,
- √ 1.2-m shoulder width,
- √ 50 percent no-passing zones,
- √ 50/50 directional split,
- √ 4 percent RVs,
- √ 100-km/h base FFS,
- √ 3.4-m lane width,
- √ 10-km length, and
- √ 12 access points/km.

Outline of Solution Two-way average travel speed and percent time-spent-following will be determined, and from these parameters, the LOS.

Steps

1.	Determine grade adjustment factor for average travel speed (use Exhibit 20-7).	$f_G = 0.99$
2.	Compute f_{HV} for average travel speed (use Exhibit 20-9 and Equation 20-4).	$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)}$ $f_{HV} = \frac{1}{1+0.14(1.5-1)+0.04(1.1-1)} = 0.931$
3.	Compute v_p (use Equation 20-3).	$v_p = \frac{V}{PHF * f_G * f_{HV}}$ $v_p = \frac{1,600}{(0.95)(0.99)(0.931)} = 1,827$ pc/h
4.	Calculate highest directional flow rate.	v_p * 0.50 = 1,827 * 0.50 = 914 pc/h
5.	Check the highest directional flow rate and two-way flow rate against capacity values of 1,700 pc/h and 3,200 pc/h, respectively.	914 pc/h < 1,700 pc/h 1,827 pc/h < 3,200 pc/h
6.	Compute the FFS (use Exhibits 20-5 and 20-6 and Equation 20-2).	FFS = BFFS – f_{LS} – f_A FFS = 100 – 2.8 – 8.0 = 89.2 km/h
7.	Compute the average travel speed (use Exhibit 20-11 and Equation 20-5).	ATS = FFS – 0.0125v_p – f_{np} ATS = 89.2 – 0.0125(1827) – 1.3 = 65.1 km/h
8.	Determine grade adjustment factor for percent time-spent-following (use Exhibit 20-8).	$f_G = 1.00$
9.	Compute f_{HV} for time-spent-following (use Exhibit 20-10 and Equation 20-4).	$f_{HV} = \frac{1}{1+0.14(1.0-1)+0.04(1.0-1)} = 1.000$
10.	Compute v_p (use Equation 20-3).	$v_p = \frac{1,600}{(0.95)(1.000)(1.00)} = 1,684$ pc/h
11.	Calculate the highest directional flow rate.	$v_p * 0.50 = 1,684 * 0.50 = 842$ pc/h
12.	Check the highest directional flow rate and two-way flow rate against the capacity values of 1,700 pc/h and 3,200 pc/h, respectively.	842 pc/h < 1,700 pc/h 1,684 pc/h < 3,200 pc/h

13. Compute base percent time-spent-following (use Equation 20-7).	$BPTSF = 100\left(1 - e^{-0.000879v_p}\right)$ $BPTSF = 100\left[1 - e^{-0.000879(1,684)}\right] = 77.2\%$
14. Compute percent time-spent-following (use Exhibit 20-12 and Equation 20-6).	PTSF = BPTSF + $f_{d/np}$ PTSF = 77.2 + 4.8 = 82.0%
15. Determine LOS (use Exhibit 20-3).	ATS = 65.1 km/h and PTSF = 82.0% LOS E

Results The two-lane highway operates at LOS E.

Other Performance Measures

$$v/c = \frac{v_p}{3,200} = \frac{1,827}{3,200} = 0.57$$

$$VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right) = 0.25(10)\left(\frac{1,600}{0.95}\right) = 4,211 \text{ veh-km}$$

$$VkmT_{60} = V * L_t = (1,600)(10) = 16,000 \text{ veh-km}$$

$$TT_{15} = \frac{VkmT_{15}}{ATS} = \frac{4,211}{65.1} = 64.7 \text{ veh-h}$$

Example Problem 1

TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		Site Information	
Analyst	*M.E.*	Highway	*US 391*
Agency or Company	*CEI*	From/To	*SR-33/Adams Rd.*
Date Performed	*5/20/99*	Jurisdiction	
Analysis Time Period		Analysis Year	*1999*

☒ Operational (LOS) ☐ Design (v_p) ☐ Planning (LOS) ☐ Planning (v_p)

Input Data

Shoulder width *1.2* m
Lane width *3.4* m
Lane width *3.4* m
Shoulder width *1.2* m
Segment length, L_t *10* km

Show North Arrow

☒ Class I highway ☐ Class II highway
Terrain ☐ Level ☒ Rolling
Two-way hourly volume *1,600* veh/h
Directional split *50* / *50*
Peak-hour factor, PHF *0.95*
% Trucks and buses, P_T *14* %
% Recreational vehicles, P_R *4* %
% No-passing zone *50* %
Access points/km *12* /km

Average Travel Speed

Grade adjustment factor, f_G (Exhibit 20-7)	*0.99*
Passenger-car equivalents for trucks, E_T (Exhibit 20-9)	*1.5*
Passenger-car equivalents for RVs, E_R (Exhibit 20-9)	*1.1*
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*0.931*
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	*1,827*
v_p * highest directional split proportion[2] (pc/h)	*914*

Free-Flow Speed from Field Measurement		Estimated Free-Flow Speed	
Field measured speed, S_{FM}	km/h	Base free-flow speed, BFFS	*100* km/h
Observed volume, V_f	veh/h	Adj. for lane width and shoulder width, f_{LS} (Exhibit 20-5)	*2.8* km/h
Free-flow speed, FFS	km/h	Adj. for access points, f_A (Exhibit 20-6)	*8.0* km/h
$FFS = S_{FM} + 0.0125\left(\frac{V_f}{f_{HV}}\right)$		Free-flow speed, FFS	*89.2* km/h
		$FFS = BFFS - f_{LS} - f_A$	

Adj. for no-passing zones, f_{np} (km/h) (Exhibit 20-11)	*1.3*
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	*65.1*

Percent Time-Spent-Following

Grade adjustment factor, f_G (Exhibit 20-8)	*1.00*
Passenger-car equivalents for trucks, E_T (Exhibit 20-10)	*1.0*
Passenger-car equivalents for RVs, E_R (Exhibit 20-10)	*1.0*
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*1.000*
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	*1,684*
v_p * highest directional split proportion[2] (pc/h)	*842*
Base percent time-spent-following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879v_p})$	*77.2*
Adj. for directional distribution and no-passing zone, $f_{d/np}$ (%) (Exhibit 20-12)	*4.8*
Percent time-spent-following, PTSF (%) $PTSF = BPTSF + f_{d/np}$	*82.0*

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 for Class I or 20-4 for Class II)	*E*
Volume to capacity ratio, v/c $v/c = \frac{v_p}{3{,}200}$	*0.57*
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right)$	*4,211*
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V * L_t$	*16,000*
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS}$	*64.7*

Notes

1. If $v_p \geq 3{,}200$ pc/h, terminate analysis—the LOS is F.
2. If highest directional split $v_p \geq 1{,}700$ pc/h, terminate analysis—the LOS is F.

EXAMPLE PROBLEM 2

The Highway A Class II two-lane highway segment on a scenic and recreational route.

The Question What is the two-way segment LOS?

The Facts

- √ 1,050 veh/h (two-way volume),
- √ 5 percent trucks and buses,
- √ 0.85 PHF,
- √ Rolling terrain,
- √ 0.6-m shoulder width,
- √ 60 percent no-passing zones,
- √ 70/30 directional split,
- √ 7 percent RVs,
- √ 90-km/h base FFS,
- √ 3.0-m lane width,
- √ 10-km roadway length, and
- √ 6 access points/km.

Outline of Solution Two-way average travel speed and percent time-spent-following will be determined, and with these parameters, the LOS. Since V/PHF = 1,050/0.85 = 1,235, select truck equivalencies and grade adjustment factors for flow rates greater than 1,200 pc/h.

Steps

1. Determine grade adjustment factor for average travel speed (use Exhibit 20-7).	$f_G = 0.99$
2. Compute f_{HV} for average travel speed (use Exhibit 20-9 and Equation 20-4).	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.05(1.5 - 1) + 0.07(1.1 - 1)} = 0.969$
3. Compute v_p (use Equation 20-3).	$v_p = \frac{V}{PHF * f_G * f_{HV}}$ $v_p = \frac{1{,}050}{(0.85)(0.99)(0.969)} = 1{,}288$ pc/h
4. Calculate the highest directional flow rate.	v_p * 0.70 = 1,288 * 0.70 = 902 pc/h
5. Check the highest directional flow rate and two-way flow rate against capacity values of 1,700 pc/h and 3,200 pc/h, respectively.	902 pc/h < 1,700 pc/h 1,288 pc/h < 3,200 pc/h
6. Compute FFS (use Exhibit 20-5 and 20-6 and Equation 20-2).	FFS = BFFS – f_{LS} – f_A FFS = 90 – 5.9 – 4.0 = 80.1 km/h
7. Compute ATS (use Exhibit 20-11 and Equation 20-5).	ATS = FFS – 0.0125v_p – f_{np} ATS = 80.1 – 0.0125(1288) – 2.3 = 61.7 km/h
8. Determine grade adjustment factor of percent time-spent-following (use Exhibit 20-8).	$f_G = 1.00$
9. Compute f_{HV} for percent time-spent-following (use Exhibit 20-10 and Equation 20-4).	$f_{HV} = \frac{1}{1 + 0.05(1.0 - 1) + 0.07(1.0 - 1)} = 1.000$
10. Compute v_p (use Equation 20-3).	$v_p = \frac{1{,}050}{(0.85)(1.000)(1.00)} = 1{,}235$ pc/h
11. Calculate the highest directional flow rate.	v_p * 0.70 = 1,235 * 0.70 = 865 pc/h

12. Check the highest directional flow rate and two-way flow rate against the capacity values of 1,700 pc/h and 3,200 pc/h, respectively.	865 pc/h < 1,700 pc/h 1,235 pc/h < 3,200 pc/h
13. Compute base percent time-spent-following (use Equation 20-7).	$BPTSF = 100\left(1 - e^{-0.000879v_p}\right)$ $BPTSF = 100\left[1 - e^{-0.000879(1,235)}\right] = 66.2\%$
14. Compute percent time-spent-following (use Exhibit 20-12 and Equation 20-6).	$PTSF = BPTSF + f_{d/np}$ PTSF = 66.2 + 9.0 = 75.2%
15. Determine LOS (use Exhibit 20-4).	PTSF = 75.2% LOS D

Results The two-lane highway operates at LOS D.

Other Performance Measures

$$v/c = \frac{v_p}{3,200} = \frac{1,288}{3,200} = 0.40$$

$$VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right) = 0.25(10)\left(\frac{1,050}{0.85}\right) = 3,088 \text{ veh-km}$$

$$VkmT_{60} = V * L_t = (1,050)(10) = 10,500 \text{ veh-km}$$

$$TT_{15} = \frac{VkmT_{15}}{ATS} = \frac{3,088}{61.7} = 50.0 \text{ veh-h}$$

Example Problem 2

TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		Site Information	
Analyst	*M.E.*	Highway	*State Highway 34*
Agency or Company	*CEI*	From/To	*US 24/Creek Rd.*
Date Performed	*5/20/99*	Jurisdiction	
Analysis Time Period		Analysis Year	*1999*

☒ Operational (LOS) ☐ Design (v_p) ☐ Planning (LOS) ☐ Planning (v_p)

Input Data

Shoulder width *0.6* m
Lane width *3.0* m
Lane width *3.0* m
Shoulder width *0.6* m
Segment length, L_t *10* km

Show North Arrow

☐ Class I highway ☒ Class II highway
Terrain ☐ Level ☒ Rolling
Two-way hourly volume *1,050* veh/h
Directional split *70* / *30*
Peak-hour factor, PHF *0.85*
% Trucks and buses, P_T *5* %
% Recreational vehicles, P_R *7* %
% No-passing zone *60* %
Access points/km *6* /km

Average Travel Speed

Grade adjustment factor, f_G (Exhibit 20-7)	*0.99*
Passenger-car equivalents for trucks, E_T (Exhibit 20-9)	*1.5*
Passenger-car equivalents for RVs, E_R (Exhibit 20-9)	*1.1*
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*0.969*
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	*1,288*
v_p * highest directional split proportion[2] (pc/h)	*902*

Free-Flow Speed from Field Measurement	Estimated Free-Flow Speed
Field measured speed, S_{FM} ____ km/h	Base free-flow speed, BFFS *90* km/h
Observed volume, V_f ____ veh/h	Adj. for lane width and shoulder width, f_{LS} (Exhibit 20-5) *5.9* km/h
Free-flow speed, FFS ____ km/h	Adj. for access points, f_A (Exhibit 20-6) *4.0* km/h
$FFS = S_{FM} + 0.0125\left(\frac{V_f}{f_{HV}}\right)$	Free-flow speed, FFS *80.1* km/h
	$FFS = BFFS - f_{LS} - f_A$

Adj. for no-passing zones, f_{np} (km/h) (Exhibit 20-11)	*2.3*
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	*61.7*

Percent Time-Spent-Following

Grade adjustment factor, f_G (Exhibit 20-8)	*1.00*
Passenger-car equivalents for trucks, E_T (Exhibit 20-10)	*1.0*
Passenger-car equivalents for RVs, E_R (Exhibit 20-10)	*1.0*
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*1.000*
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	*1,235*
v_p * highest directional split proportion[2] (pc/h)	*865*
Base percent time-spent-following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879v_p})$	*66.2*
Adj. for directional distribution and no-passing zone, $f_{d/np}$ (%) (Exhibit 20-12)	*9.0*
Percent time-spent-following, PTSF (%) $PTSF = BPTSF + f_{d/np}$	*75.2*

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 for Class I or 20-4 for Class II)	*D*
Volume to capacity ratio, v/c $v/c = \frac{v_p}{3{,}200}$	*0.40*
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right)$	*3,088*
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V * L_t$	*10,500*
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS}$	*50.0*

Notes

1. If $v_p \geq 3{,}200$ pc/h, terminate analysis—the LOS is F.
2. If highest directional split $v_p \geq 1{,}700$ pc/h, terminate analysis—the LOS is F.

EXAMPLE PROBLEM 3

The Highway A Class I two-lane highway segment.

The Question What is the LOS of the peak direction?

The Facts

- √ 1,200 veh/h (analysis direction volume),
- √ 14 percent trucks and buses,
- √ 4 percent RVs,
- √ 100-km/h base FFS,
- √ 3.3-m lane width,
- √ 10-km roadway length,
- √ 12 access points/km,
- √ 400 veh/h (opposing direction volume),
- √ 0.95 PHF,
- √ Rolling terrain,
- √ 1.2-m shoulder width, and
- √ 50 percent no-passing zones.

Outline of Solution Analysis direction average travel speed and percent time-spent-following will be determined, and with these parameters, the LOS.

Steps

1. Determine the grade adjustment factor, f_G, for average travel speed for the analysis direction (use Exhibit 20-7).	$f_G = 0.99$
2. Compute f_{HV} and v_d for average travel speed in the analysis direction (use Exhibit 20-9 and Equations 20-4 and 20-12).	$f_{HV} = \frac{1}{1 + 0.14(1.5 - 1) + 0.04(1.1 - 1)} = 0.931$ $v_d = \frac{1{,}200}{(0.95)(0.99)(0.931)} = 1{,}370 \text{ pc/h}$
3. Determine the grade adjustment factor, f_G, for average travel speed for the opposing direction (use Exhibit 20-7).	$f_G = 0.93$
4. Compute f_{HV} and v_o for average travel speed in the opposing direction (use Exhibit 20-9 and Equations 20-4 and 20-13).	$f_{HV} = \frac{1}{1 + 0.14(1.9 - 1) + 0.04(1.1 - 1)} = 0.885$ $v_o = \frac{400}{(0.95)(0.93)(0.885)} = 512 \text{ pc/h}$
5. Check v_d and v_o with the capacity value of 1,700 pc/h.	1,370 pc/h < 1,700 pc/h 512 pc/h < 1,700 pc/h
6. Compute FFS (use Exhibits 20-5 and 20-6, and Equation 20-2).	$FFS = BFFS - f_{LS} - f_A$ FFS = 100 – 2.8 – 8.0 = 89.2 km/h
7. Compute average travel speed (use Exhibit 20-19 and Equation 20-15).	$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np}$ $ATS_d = 89.2 - 0.0125(1370 + 512) - 2.7 =$ 63.0 km/h
8. Determine the grade adjustment factor, f_G, for percent time-spent-following for the analysis direction (use Exhibit 20-8).	$f_G = 1.00$
9. Compute f_{HV} and v_d for percent time-spent-following in the analysis direction (use Exhibit 20-10 and Equations 20-4 and 20-12).	$f_{HV} = \frac{1}{1 + 0.14(1.0 - 1) + 0.04(1.0 - 1)} = 1.000$ $v_d = \frac{1{,}200}{(0.95)(1.00)(1.000)} = 1{,}263 \text{ pc/h}$
10. Determine the grade adjustment factor, f_G, for percent time-spent-following for the opposing direction (use Exhibit 20-8).	$f_G = 0.94$

11. Compute f_{HV} and v_o for percent time-spent-following in the opposing direction (use Exhibit 20-10 and Equations 20-4 and 20-14).	$f_{HV} = \dfrac{1}{1+0.14(1.5-1)+0.04(1.0-1)} = 0.935$ $v_o \dfrac{400}{(0.95)(0.94)(0.935)} = 479$ pc/h
12. Check v_d and v_o against the capacity value of 1,700 pc/h.	1,263 pc/h < 1,700 pc/h 479 pc/h < 1,700 pc/h
13. Compute base percent time-spent-following the analysis direction (use Exhibit 20-21 and Equation 20-17).	$BPTSF_d = 100\left(1 - e^{av_d^b}\right)$ $BPTSF_d = 100\left[1 - e^{(-0.074)(1{,}263)^{0.453}}\right] = 84.7\%$
14. Compute percent time-spent-following for the analysis direction (use Exhibit 20-20 and Equation 20-16).	$PTSF_d = BPTSF_d + f_{np}$ $PTSF_d = 84.7 + 11.7 = 96.4\%$
15. Determine LOS (use Exhibit 20-3).	$ATS_d = 63.0$ km/h and $PTSF_d = 96.4\%$ LOS E

Results The two-lane highway operates at LOS E in the analysis direction.

Other Performance Measures

$$v/c = \frac{v_d}{1{,}700} = \frac{1{,}370}{1{,}700} = 0.81$$

$$VkmT_{15} = 0.25L_t\left(\frac{V_d}{PHF}\right) = 0.25(10)\left(\frac{1{,}200}{0.95}\right) = 3{,}158 \text{ veh-km}$$

$$VkmT_{60} = V_d * L_t = (1{,}200)(10) = 12{,}000 \text{ veh-km}$$

$$TT_{15} = \frac{VkmT_{15}}{ATS_d} = \frac{3{,}158}{63.0} = 50.1 \text{ veh-h}$$

Example Problem 3

DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		Site Information	
Analyst	*M.E.*	Highway/Direction of Travel	*State Highway 45*
Agency or Company	*CEI*	From/To	*RD 20/RD 35*
Date Performed	*5/20/99*	Jurisdiction	
Analysis Time Period		Analysis Year	*1999*

☒ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data

Shoulder width *1.2* m
Opposing direction — Lane width *3.3* m
Analysis direction — Lane width *3.3* m
Shoulder width *1.2* m
Segment length, L_t *10* km

Show North Arrow

☒ Class I highway ❑ Class II highway
Terrain ❑ Level ☒ Rolling
Grade Length ____km Up/down ____%
Peak-hour factor, PHF *0.95*
% Trucks and buses, P_T *14* %
% Recreational vehicles, P_R *4* %
% No-passing zone *50* %
Access points/km *12* /km

Analysis direction volume, V_d *1,200* veh/h Opposing direction volume, V_o *400* veh/h

Average Travel Speed

	Analysis Direction (d)	Opposing Direction (o)
Passenger-car equivalent for trucks, E_T (Exhibit 20-9 or 20-15)	*1.5*	*1.9*
Passenger-car equivalent for RVs, E_R (Exhibit 20-9 or 20-17)	*1.1*	*1.1*
Heavy-vehicle adjustment factor,[5] f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*0.931*	*0.885*
Grade adjustment factor,[1] f_G (Exhibit 20-6 or 20-12)	*0.99*	*0.93*
Directional flow rate,[2] v_i (pc/h) $v_i = \frac{V_i}{PHF * f_{HV} * f_G}$	*1,370*	*512*

Free-Flow Speed from Field Measurement		Estimated Free-Flow Speed	
Field measured speed,[3] S_{FM}	___ km/h	Base free-flow speed,[3] BFFS	*100* km/h
Observed volume,[3] V_f	___ veh/h	Adj. for lane width and shoulder width,[3] f_{LS} (Exh. 20-5)	*2.8* km/h
Free-flow speed, FFS_d	___ km/h	Adj. for access points,[3] f_A (Exhibit 20-6)	*8.0* km/h
$FFS_d = S_{FM} + 0.0125 \left(\frac{V_f}{f_{HV}}\right)$		Free-flow speed, FFS_d	*89.2* km/h
		$FFS_d = BFFS - f_{LS} - f_A$	

Adjustment for no-passing zones, f_{np} (km/h) (Exhibit 20-19)	*2.7*
Average travel speed, ATS_d (km/h) $ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np}$	*63.0*

Percent Time-Spent-Following

	Analysis Direction (d)	Opposing Direction (o)
Passenger-car equivalent for trucks, E_T (Exhibit 20-10 or 20-16)	*1.0*	*1.5*
Passenger-car equivalent for RVs, E_R (Exhibit 20-10 or 20-16)	*1.0*	*1.0*
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	*1.000*	*0.935*
Grade adjustment factor,[1] f_G (Exhibit 20-8 or 20-14)	*1.0*	*0.94*
Directional flow rate,[2] v_i (pc/h) $v_i = \frac{V_i}{PHF * f_{HV} * f_G}$	*1,263*	*479*

Base percent time-spent-following,[4] $BPTSF_d$ (%) $BPTSF_d = 100(1 - e^{av_d^b})$	*84.7*
Adjustment for no-passing zone, f_{np} (Exhibit 20-20)	*11.7*
Percent time-spent-following, $PTSF_d$ (%) $PTSF_d = BPTSF_d + f_{np}$	*96.4*

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 or 20-4)	*E*
Volume to capacity ratio, v/c $v/c = \frac{V_d}{1700}$	*0.81*
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V_d}{PHF}\right)$	*3,158*
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V_d * L_t$	*12,000*
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS_d}$	*50.1*

Notes

1. If the highway is extended segment (level) or rolling terrain, $f_G = 1.0$
2. If v_i (v_d or v_o) ≥ 1,700 pc/h, terminate analysis—the LOS is F.
3. For the analysis direction only.
4. Exhibit 20-21 provides factors a and b.
5. Use alternative Equation 20-14 if some trucks operate at crawl speeds on a specific downgrade.

EXAMPLE PROBLEM 4

The Highway A Class I two-lane highway segment described in Example Problem 3. In this analysis, a 2-km passing lane is to be added beginning at a location 2 km downstream from the beginning of the 10-km two-lane highway in the analysis direction.

The Question What is the LOS in the peak direction including the passing lane?

The Facts

- √ All input parameters listed in Example Problem 3,
- √ 2-km length of two-lane highway upstream of the passing lane, and
- √ 2-km length of passing lane including tapers.

Outline of Solution The length of roadway expected to be affected downstream of the passing lane will be determined. These lengths will be applied to the average travel speed and percent time-spent-following without a passing lane to compute the average travel speed and percent time-spent-following with the passing lane. Using these parameters, the LOS will be determined.

Steps

1. Compute L_d for average travel speed (use Exhibit 20-23 and Equation 20-18).	$L_d = L_t – (L_u + L_{pl} + L_{de})$ $L_d = 10 – (2 + 2 + 2.8) = 3.2$ km
2. Compute average travel speed of the analysis direction including passing lane (use Exhibit 20-24 and Equation 20-21).	$ATS_{pl} = \dfrac{ATS_d * L_t}{L_u + L_d + \dfrac{L_{pl}}{f_{pl}} + \dfrac{2L_{de}}{1+f_{pl}}}$ $ATS_{pl} = \dfrac{63.0(10)}{2 + 3.2 + \left(\dfrac{2}{1.11}\right) + \dfrac{2(2.8)}{1+1.11}} = 65.2$ km/h
3. Compute L_d for percent time-spent-following (use Exhibit 20-23 and Equation 20-18).	$L_d = L_t – (L_u + L_{pl} + L_{de})$ $L_d = 10 – (2 + 2 + 5.8) = 0.2$ km
4. Compute percent time-spent-following of the analysis direction including passing lane (use Exhibit 20-24 and Equation 20-19).	$PTSF_{pl} = \dfrac{PTSF_d\left[L_u + L_d + f_{pl}L_{pl} + \left(\dfrac{1+f_{pl}}{2}\right)L_{de}\right]}{L_t}$ $PTSF_{pl} = \dfrac{96.4\left[2 + 0.2 + 0.62(2) + \left(\dfrac{1+0.62}{2}\right)5.8\right]}{10} =$ 78.5%
5. Determine LOS (use Exhibit 20-3).	$ATS_{pl} = 65.2$ km/h and $PTSF_{pl} = 78.5\%$ LOS D

Results The two-lane highway operates at LOS D in the analysis direction with the passing lane as compared to LOS E without the passing lane (from Example Problem 3).

Other Performance Measures

$$v/c = \frac{v_d}{1,700} = \frac{1,370}{1,700} = 0.81$$

$$VkmT_{15} = 0.25L_t\left(\frac{V_d}{PHF}\right) = 0.25(10)\left(\frac{1,200}{0.95}\right) = 3,158 \text{ veh-km}$$

$$VkmT_{60} = V_d * L_t = (1,200)(10) = 12,000 \text{ veh-km}$$

$$TT_{15} = \frac{VkmT_{15}}{ATS_{pl}} = \frac{3,158}{65.2} = 48.4 \text{ veh-h}$$

Example Problem 4

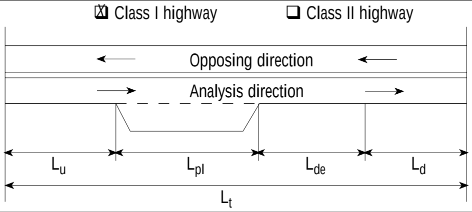
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WITH PASSING LANE WORKSHEET

General Information		Site Information	
Analyst	*M.E.*	Highway/Direction of Travel	*State Highway 45*
Agency or Company	*CEI*	From/To	*RD 20/RD 35*
Date Performed	*5/20/99*	Jurisdiction	
Analysis Time Period		Analysis Year	*1999*

☒ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data

☒ Class I highway ❑ Class II highway



Total length of analysis segment, L_t (km)	*10*
Length of two-lane highway upstream of the passing lane, L_u (km)	*2*
Length of passing lane including tapers, L_{pl} (km)	*2*
Average travel speed, ATS_d (from Directional Two-Lane Highway Segment Worksheet)	*63.0*
Percent time-spent-following, $PTSF_d$ (from Directional Two-Lane Highway Segment Worksheet)	*96.4*
Level of service,[1] LOS_d (from Directional Two-Lane Highway Segment Worksheet)	*E*
Average Travel Speed	
Downstream length of two-lane highway within effective length of passing lane for average travel speed, L_{de} (km) (Exhibit 20-23)	*2.8*
Length of two-lane highway downstream of effective length of the passing lane for average travel speed, L_d (km) $L_d = L_t - (L_u + L_{pl} + L_{de})$	*3.2*
Adj. factor for the effect of passing lane on average speed, f_{pl} (Exhibit 20-24)	*1.11*
Average travel speed including passing lane,[2] ATS_{pl} $ATS_{pl} = \frac{ATS_d * L_t}{L_u + L_d + \frac{L_{pl}}{f_{pl}} + \frac{2L_{de}}{1 + f_{pl}}}$	*65.2*
Percent Time-Spent-Following	
Downstream length of two-lane highway within effective length of passing lane for percent time-spent-following, L_{de} (km) (Exhibit 20-23)	*5.8*
Length of two-lane highway downstream of effective length of the passing lane for percent time-spent-following, L_d (km) $L_d = L_t - (L_u + L_{pl} + L_{de})$	*0.2*
Adj. factor for the effect of passing lane on percent time-spent-following, f_{pl} (Exhibit 20-24)	*0.62*
Percent time-spent-following including passing lane,[3] $PTSF_{pl}$ (%) $PTSF_{pl} = \frac{PTSF_d\left[L_u + L_d + f_{pl}L_{pl} + \left(\frac{1 + f_{pl}}{2}\right)L_{de}\right]}{L_t}$	*78.5*
Level of Service and Other Performance Measures [4]	
Level of service including passing lane, LOS_{pl} (Exhibits 20-3 or 20-4)	*D*
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS_{pl}}$	*48.4*

Notes

1. If LOS_d = F, passing lane analysis cannot be performed.
2. If $L_d < 0$, use alternative Equation 20-22.
3. If $L_d < 0$, use alternative Equation 20-20.
4. v/c, $VkmT_{15}$, and $VkmT_{60}$ are calculated on Directional Two-Lane Highway Segment Worksheet.

V. REFERENCES

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4. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. Washington, D.C., 1994.

APPENDIX A. DESIGN AND OPERATIONAL TREATMENTS

Two-lane highways comprise approximately 80 percent of all paved rural highways in the United States but carry only about 30 percent of all traffic. For the most part, two-lane highways carry light volumes and experience few operational problems. Some two-lane highways, however, periodically experience significant operational and safety problems due to a variety of traffic, geometric, and environment causes. Such highways may require design or operation improvements to alleviate congestion.

When traffic operational problems occur on a two-lane highway, many highway agencies consider widening the highway to four lanes. Another effective method for alleviating operational problems on two-lane highways is to provide passing lanes at intervals in each direction of travel or to provide climbing lanes on steep upgrades. Passing and climbing lanes cannot increase the capacity of a two-lane highway but can improve its level of service. Short sections of four-lane highway can function as a pair of passing lanes in opposite directions of travel. Operational analysis procedures for passing and climbing lanes on two-lane highways are included in this chapter.

There are a number of other design and operational treatments that are effective in alleviating operational congestion on two-lane highways. These include

- Turnouts,
- Shoulder use,
- Wide cross sections,
- Intersection turn lanes, and
- Two-way left-turn lanes.

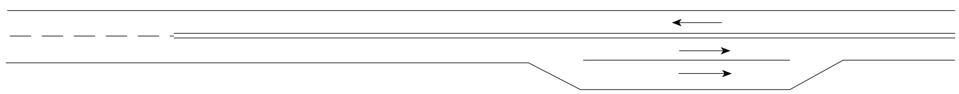
No calculation methodologies are provided in this chapter for these treatments; however, the treatments are discussed below to indicate their potential for improving traffic operations on two-lane highways.

TURNOUTS

A turnout is a widened, unobstructed shoulder area on a two-lane highway that allows slow-moving vehicles to pull out of the through lane so that vehicles following may pass. Turnouts are relatively short, generally less than 190 m. At a turnout, the driver of a slow-moving vehicle that is delaying one or more following vehicles is expected to pull out of the through lane, allowing the vehicles to pass. The driver of the slow-moving vehicle is expected to remain in the turnout only long enough for the following vehicles to pass and then should return to the through lane. When there are only one or two following vehicles, this maneuver usually can be completed smoothly and there is no need for the vehicle to stop in the turnout. When there are three or more following vehicles, however, the vehicle in the turnout will usually need to stop so that all of the following vehicles may pass. Signs inform motorists of the turnout's location and reinforce the legal requirements concerning turnout use.

Turnouts have been used in several countries to provide additional passing opportunities on two-lane highways. In the United States, turnouts have been used most extensively in the western states. Exhibit A20-1 illustrates a typical turnout.

EXHIBIT A20-1. TYPICAL TURNOUT TO INCREASE PASSING OPPORTUNITIES ON A TWO-LANE HIGHWAY



Turnouts may be used on nearly any type of two-lane highway that offers limited passing opportunities. Most often they appear on lower-volume highways in level or rolling terrain, on which long platoons are rare, and on difficult terrain with steep grades or with isolated slow-moving vehicles because the construction of a passing or climbing lane may not be cost-effective. To avoid confusing drivers, turnouts and passing lanes should not be intermixed on the same highway.

A single well-designed and well-located turnout can be expected to provide 20 to 50 percent of the number of passes that would occur in a 1.6-km passing lane in level terrain (*1, 2*). Turnouts have been found to operate safely—according to safety researchers turnout accidents occur at a rate of only 1 per 80,000 to 400,000 users (*2–4*).

SHOULDER USE

The primary purpose of the shoulder on a two-lane highway is to provide a stopping and recovery area for disabled or errant vehicles. However, paved shoulders also may be used to increase passing opportunities on a two-lane highway.

In some parts of the United States and Canada, if the paved shoulders are adequate, there is a longstanding custom for slower vehicles to move to the shoulder when another vehicle approaches from the rear and then return to the travel lane once the passing vehicle has cleared. This custom is regarded as a courtesy and requires little or no sacrifice in speed by either motorist. In this way, paved shoulders can function as continuous turnouts. A few highway agencies encourage drivers of slow-moving vehicles to use the shoulder in this way because it improves the LOS of two-lane highways without the expense of adding passing lanes or widening the highway. On the other hand, many highway agencies discourage this practice because their shoulders are not designed for frequent use by heavy vehicles.

One highway agency in the western United States generally does not permit shoulder use by slow-moving vehicles but designates specific sections on which the shoulder may be used by slow-moving vehicles. These shoulder-use sections range in length from 0.3 to 5.0 km and are identified by traffic signs.

Research has shown that a shoulder-use section is about 20 percent as effective in reducing platoons as a passing lane of comparable length (*1, 2*).

WIDE CROSS SECTIONS

Two-lane highways with lanes about 50 percent wider than normal have been used in several European countries as a less expensive alternative to passing lanes. Sweden, for example, has built approximately 800 km of roadways with two 5.5-m travel lanes and relatively narrow 1.0-m shoulders. The wider lane permits faster vehicles to pass slower vehicles while encroaching only slightly on the opposing lane of traffic. Opposing vehicles must move toward the shoulder to permit such maneuvers. Roadway sections with wider lanes can be provided at intervals, like passing lanes, to increase passing opportunities on two-lane highways.

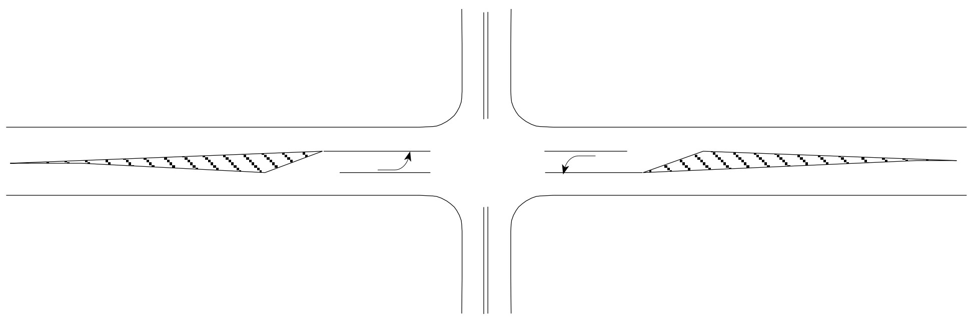
Research has found that speeds at low traffic volumes tend to increase on wider lanes, but the effect on speeds at higher volumes varies (*5*). More than 70 percent of drivers indicated that they appreciate the increased passing opportunities on the wider lanes. No safety problems have been associated with the wider lanes (*5*).

Formal procedures have not yet been established for evaluating the traffic operational effectiveness of wider lanes in increasing the passing opportunities on a two-lane highway. It is reasonable to estimate the traffic operational performance of a directional two-lane highway segment containing a section with widened lanes as midway between the same segment with and without a passing lane of comparable length.

INTERSECTION TURN LANES

Intersection turn lanes are desirable at selected locations on two-lane highways to reduce delays to through vehicles caused by turning vehicles and to reduce accidents related to turning. Separate right-turn and left-turn lanes may be provided, as appropriate, to remove turning vehicles from the through-travel lanes. Left-turn lanes, in particular, provide a protected location for turning vehicles to wait for a gap in opposing traffic. This reduces the potential for collisions from the rear and also may encourage drivers of left-turning vehicles to wait for an adequate gap in opposing traffic before turning. Exhibit A20-2 shows a typical two-lane highway intersection with left-turn lanes.

EXHIBIT A20-2. TYPICAL TWO-LANE HIGHWAY INTERSECTION WITH LEFT-TURN LANES

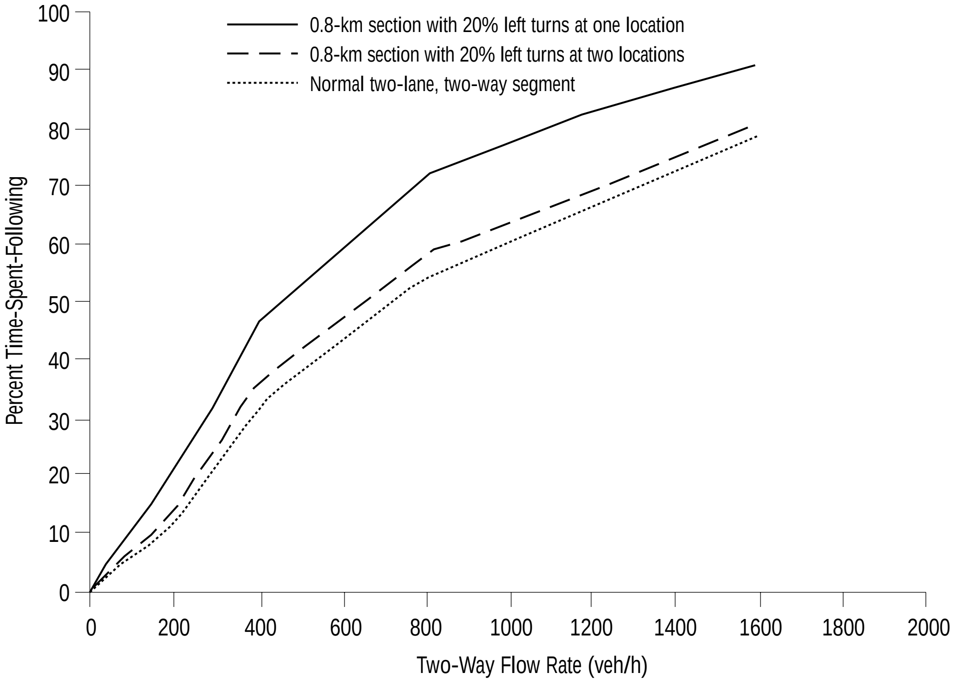


Research recommends specific traffic operational warrants for left-turn lanes at intersections on two-lane highways based on the directional volumes and the percentage of left turns (*6*). Intersection analysis with the methodologies of Chapter 16 for signalized intersections and Chapter 17 for unsignalized intersections can be used to quantify the effects of intersection turn lanes on delay at the intersection. There is no general methodology for estimating the effect of intersection turn lanes in increasing speed or reducing delay on the two-lane highway downstream. However, modeling of intersection delays shows the relative magnitude of likely effects of turning delays on percent time-spent-following (*7*); the results are shown in Exhibit A20-3. The top line in the exhibit shows that turning vehicles can increase percent time-spent-following substantially over a short road section. However, when these effects are averaged over a longer road section, the increase in percent time-spent-following is greatly reduced, as indicated by the dashed line in the exhibit. Provision of intersection turn lanes has the potential to minimize these delays.

Several highway agencies in the United States provide shoulder bypass lanes at three-leg intersections as a low-cost alternative to a left-turn lane. As shown in Exhibit A20-4, a portion of the paved shoulder opposite the minor-road leg may be marked as a lane for through traffic to bypass vehicles that are slowing or stopped to make a left turn. Shoulder bypass lanes may be appropriate for intersections that do not have volumes high enough to warrant a left-turn lane.

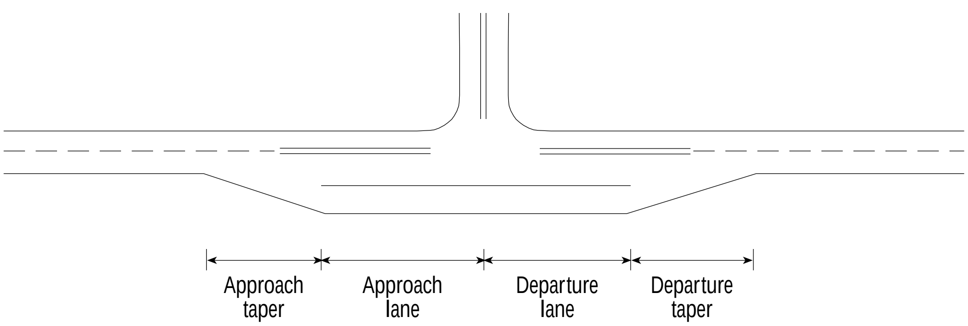
The delay reduction benefits of shoulder bypass lanes have not been quantified, but field studies have indicated that 97 percent of drivers who need to avoid delay will make use of an available shoulder bypass lane. One state has reported a marked decrease in rear-end collisions after shoulder bypass lanes were provided (*8*).

EXHIBIT A20-3. EFFECT OF TURNING DELAYS AT INTERSECTIONS ON PERCENT TIME-SPENT-FOLLOWING IN A TWO-LANE HIGHWAY



Source: Hoban (*7*).

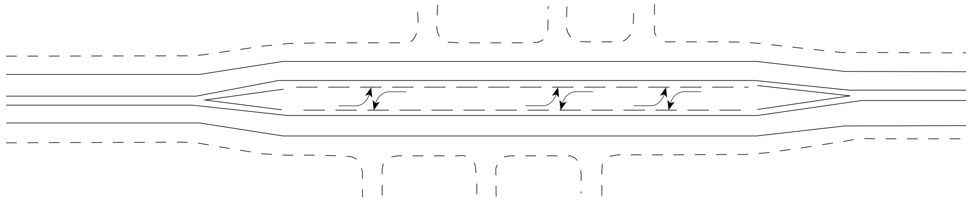
EXHIBIT A20-4. TYPICAL SHOULDER BYPASS LANE AT A THREE-LEG INTERSECTION ON A TWO-LANE HIGHWAY



TWO-WAY LEFT-TURN LANES

A two-way left-turn lane (TWLTL) is a paved area in the highway median that extends continuously along a roadway section and is marked to provide a deceleration and storage area, for vehicles traveling in either direction and making left turns at intersections and driveways. TWLTLs have been used for many years on urban and suburban streets with high driveway densities and turning demands to improve safety and reduce delays to through vehicles. TWLTLs also can be used on two-lane highways in rural and urban fringe areas to obtain these same types of operational and safety benefits. Exhibit A20-5 illustrates a typical TWLTL on a two-lane highway.

EXHIBIT A20-5. TYPICAL TWO-WAY LEFT-TURN LANE ON A TWO-LANE HIGHWAY

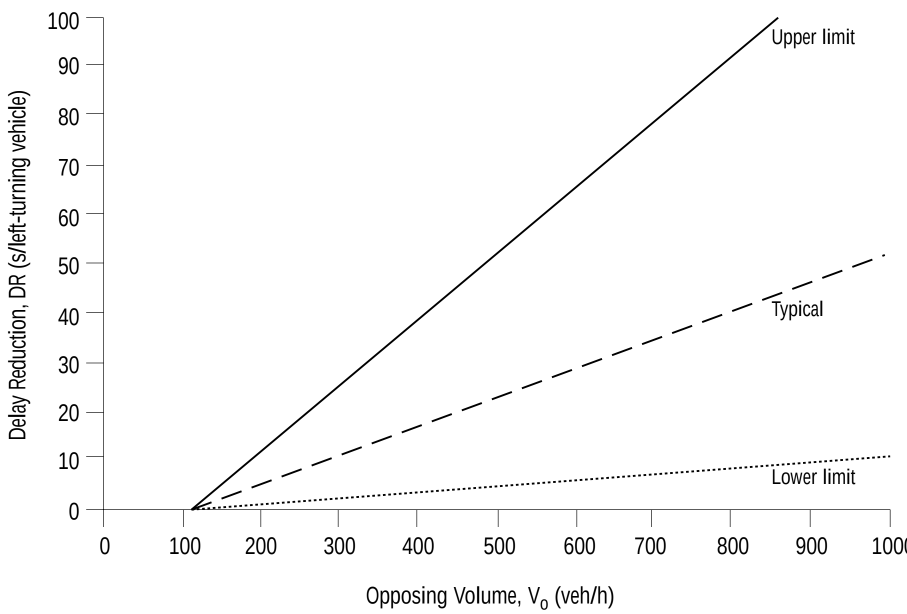


There is no formal methodology for evaluating the traffic operational effectiveness of TWLTLs on two-lane highways. Research has found that the delay reduction provided by a TWLTL depends on both the left-turn demand and the opposing traffic volume (*2*). Without a TWLTL or other left-turn treatment, vehicles that are slowing or stopped to make a left turn may create delays for following through vehicles. A TWLTL minimizes these delays and makes the roadway section operate more like two-way and directional segments with 100 percent no-passing zones. These research results apply to sites that do not have paved shoulders available for following vehicles to bypass turning vehicles. Paved shoulders may alleviate as much of the delay as a TWLTL.

Research has found little delay reduction at rural TWLTL sites with traffic volumes below 300 veh/h in one direction of travel (*2*). At several low-volume sites, no reduction was observed. The highest delay reduction observed was 3.4 s per left-turning vehicle. At low-volume rural sites, therefore, TWLTLs generally should be considered for reducing accidents but should not be expected to increase the operational performance of the highway.

At higher-volume urban fringe sites, greater delay reduction was found with TWLTLs on a two-lane highway. Exhibit A20-6 shows the expected delay reduction per left-turning vehicle as a function of opposing volume. As the delay reduction increases, a TWLTL can be justified for improving both traffic operation and safety.

EXHIBIT A20-6. ESTIMATED DELAY REDUCTION WITH A TWO-WAY LEFT-TURN LANE ON A TWO-LANE HIGHWAY WITHOUT PAVED SHOULDERS



Note:
$DR = -6.87 + 0.058V_o$
Source: Harwood and St. John (*2*).

REFERENCES

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5. Bergh, T. *A2+1 Roads with Cable Barrier for Improved Traffic Safety*. Proceedings of the Third International Symposium on Highway Capacity, Road Directorate, Ministry of Transport, Denmark, June 1998.
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APPENDIX B. WORKSHEETS

TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WORKSHEET

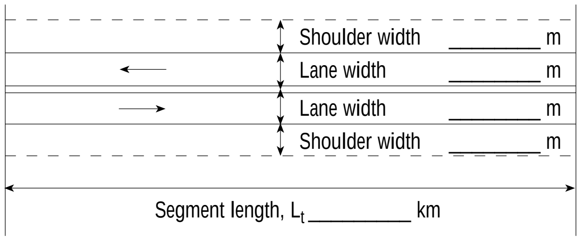
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WITH PASSING LANE WORKSHEET

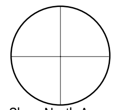
TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		Site Information	
Analyst	________	Highway	________
Agency or Company	________	From/To	________
Date Performed	________	Jurisdiction	________
Analysis Time Period	________	Analysis Year	________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data




Show North Arrow

❑ Class I highway ❑ Class II highway
Terrain ❑ Level ❑ Rolling
Two-way hourly volume ________ veh/h
Directional split ______ /_____
Peak-hour factor, PHF ________
% Trucks and buses, P_T ________ %
% Recreational vehicles, P_R ________ %
% No-passing zone ________ %
Access points/km ________/km

Average Travel Speed

Grade adjustment factor, f_G (Exhibit 20-7)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-9)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-9)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	
Free-Flow Speed from Field Measurement	Estimated Free-Flow Speed
Field measured speed, S_{FM} ________km/h Observed volume, V_f ________veh/h Free-flow speed, FFS ________km/h $FFS = S_{FM} + 0.0125\left(\frac{V_f}{f_{HV}}\right)$	Base free-flow speed, BFFS ________km/h Adj. for lane width and shoulder width, f_{LS} (Exhibit 20-5) _____km/h Adj. for access points, f_A (Exhibit 20-6) ________km/h Free-flow speed, FFS ________km/h $FFS = BFFS - f_{LS} - f_A$
Adj. for no-passing zones, f_{np} (km/h) (Exhibit 20-11)	
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	

Percent Time-Spent-Following

Grade adjustment factor, f_G (Exhibit 20-8)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-10)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-10)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	
Base percent time-spent-following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879v_p})$	
Adj. for directional distribution and no-passing zone, $f_{d/np}$ (%) (Exhibit 20-12)	
Percent time-spent-following, PTSF (%) $PTSF = BPTSF + f_{d/np}$	

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 for Class I or 20-4 for Class II)	
Volume to capacity ratio, v/c $v/c = \frac{v_p}{3,200}$	
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V}{PHF}\right)$	
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V * L_t$	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS}$	

Notes

1. If $v_p \geq 3,200$ pc/h, terminate analysis—the LOS is F.
2. If highest directional split $v_p \geq 1,700$ pc/h, terminate analysis—the LOS is F.

DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information		Site Information	
Analyst	____________	Highway/Direction of Travel	____________
Agency or Company	____________	From/To	____________
Date Performed	____________	Jurisdiction	____________
Analysis Time Period	____________	Analysis Year	____________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data

Shoulder width ________ m
Opposing direction — Lane width ________ m
Analysis direction — Lane width ________ m
Shoulder width ________ m
Segment length, L_t ________ km

Show North Arrow

❑ Class I highway ❑ Class II highway
Terrain ❑ Level ❑ Rolling
Grade Length ____km Up/down ____%
Peak-hour factor, PHF ________
% Trucks and buses, P_T ________ %
% Recreational vehicles, P_R ________ %
% No-passing zone ________ %
Access points/km ________/km

Analysis direction volume, V_d ______veh/h Opposing direction volume, V_o _____veh/h

Average Travel Speed

	Analysis Direction (d)	Opposing Direction (o)
Passenger-car equivalent for trucks, E_T (Exhibit 20-9 or 20-15)		
Passenger-car equivalent for RVs, E_R (Exhibit 20-9 or 20-17)		
Heavy-vehicle adjustment factor,[5] f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$		
Grade adjustment factor,[1] f_G (Exhibit 20-6 or 20-12)		
Directional flow rate,[2] v_i (pc/h) $v_i = \frac{V_i}{PHF * f_{HV} * f_G}$		

Free-Flow Speed from Field Measurement	Estimated Free-Flow Speed
Field measured speed,[3] S_{FM} ____________km/h	Base free-flow speed,[3] BFFS ____________km/h
Observed volume,[3] V_f ____________veh/h	Adj. for lane width and shoulder width,[3] f_{LS} (Exh. 20-5) ______km/h
Free-flow speed, FFS_d ____________km/h	Adj. for access points,[3] f_A (Exhibit 20-6) ____________km/h
$FFS_d = S_{FM} + 0.0125\left(\frac{V_f}{f_{HV}}\right)$	Free-flow speed, FFS_d ____________km/h
	$FFS_d = BFFS - f_{LS} - f_A$

Adjustment for no-passing zones, f_{np} (km/h) (Exhibit 20-19)	
Average travel speed, ATS_d (km/h) $ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np}$	

Percent Time-Spent-Following

	Analysis Direction (d)	Opposing Direction (o)
Passenger-car equivalent for trucks, E_T (Exhibit 20-10 or 20-16)		
Passenger-car equivalent for RVs, E_R (Exhibit 20-10 or 20-16)		
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$		
Grade adjustment factor,[1] f_G (Exhibit 20-8 or 20-14)		
Directional flow rate,[2] v_i (pc/h) $v_i = \frac{V_i}{PHF * f_{HV} * f_G}$		

Base percent time-spent-following,[4] $BPTSF_d$ (%) $BPTSF_d = 100(1 - e^{av_d^b})$	
Adjustment for no-passing zone, f_{np} (Exhibit 20-20)	
Percent time-spent-following, $PTSF_d$ (%) $PTSF_d = BPTSF_d + f_{np}$	

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 or 20-4)	
Volume to capacity ratio, v/c $v/c = \frac{V_d}{1700}$	
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t\left(\frac{V_d}{PHF}\right)$	
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V_d * L_t$	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS_d}$	

Notes

1. If the highway is extended segment (level) or rolling terrain, $f_G = 1.0$
2. If v_i (v_d or v_o) ≥ 1,700 pc/h, terminate analysis—the LOS is F.
3. For the analysis direction only.
4. Exhibit 20-21 provides factors a and b.
5. Use alternative Equation 20-14 if some trucks operate at crawl speeds on a specific downgrade.

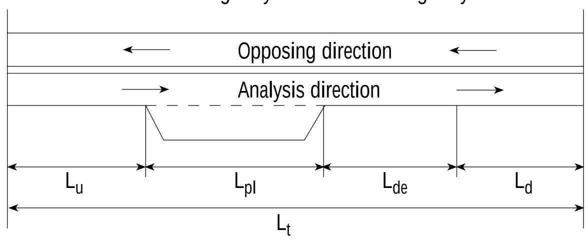
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WITH PASSING LANE WORKSHEET

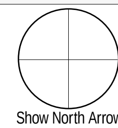
General Information		Site Information	
Analyst	____________	Highway/Direction of Travel	____________
Agency or Company	____________	From/To	____________
Date Performed	____________	Jurisdiction	____________
Analysis Time Period	____________	Analysis Year	____________

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data

❑ Class I highway ❑ Class II highway





Total length of analysis segment, L_t (km)	
Length of two-lane highway upstream of the passing lane, L_u (km)	
Length of passing lane including tapers, L_{pl} (km)	
Average travel speed, ATS_d (from Directional Two-Lane Highway Segment Worksheet)	
Percent time-spent-following, $PTSF_d$ (from Directional Two-Lane Highway Segment Worksheet)	
Level of service,[1] LOS_d (from Directional Two-Lane Highway Segment Worksheet)	

Average Travel Speed

Downstream length of two-lane highway within effective length of passing lane for average travel speed, L_{de} (km) (Exhibit 20-23)	
Length of two-lane highway downstream of effective length of the passing lane for average travel speed, L_d (km) $L_d = L_t - (L_u + L_{pl} + L_{de})$	
Adj. factor for the effect of passing lane on average speed, f_{pl} (Exhibit 20-24)	
Average travel speed including passing lane,[2] ATS_{pl} $ATS_{pl} = \dfrac{ATS_d * L_t}{L_u + L_d + \dfrac{L_{pl}}{f_{pl}} + \dfrac{2L_{de}}{1 + f_{pl}}}$	

Percent Time-Spent-Following

Downstream length of two-lane highway within effective length of passing lane for percent time-spent-following, L_{de} (km) (Exhibit 20-23)	
Length of two-lane highway downstream of effective length of the passing lane for percent time-spent-following, L_d (km) $L_d = L_t - (L_u + L_{pl} + L_{de})$	
Adj. factor for the effect of passing lane on percent time-spent-following, f_{pl} (Exhibit 20-24)	
Percent time-spent-following including passing lane,[3] $PTSF_{pl}$ (%) $PTSF_{pl} = \dfrac{PTSF_d\left[L_u + L_d + f_{pl}L_{pl} + \left(\dfrac{1 + f_{pl}}{2}\right)L_{de}\right]}{L_t}$	

Level of Service and Other Performance Measures [4]

Level of service including passing lane, LOS_{pl} (Exhibits 20-3 or 20-4)	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \dfrac{VkmT_{15}}{ATS_{pl}}$	

Notes

1. If LOS_d = F, passing lane analysis cannot be performed.
2. If $L_d < 0$, use alternative Equation 20-22.
3. If $L_d < 0$, use alternative Equation 20-20.
4. v/c, $VkmT_{15}$, and $VkmT_{60}$ are calculated on Directional Two-Lane Highway Segment Worksheet.