CHAPTER 21

MULTILANE HIGHWAYS

CONTENTS

EXHIBITS

I. INTRODUCTION

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

The procedures in this chapter are used to analyze the capacity, level of service (LOS), lane requirements, and impacts of traffic and design features of rural and suburban multilane highways.

The methodology in this chapter is based on the results of a National Cooperative Highway Research study (*1*). The study used additional references in developing the original methodology (*2–6*), which subsequently has been updated (*7*).

BASE CONDITIONS FOR MULTILANE HIGHWAYS

The procedures in this chapter determine the reduction in travel speed that occurs for less-than-base conditions. Under base conditions, the full speed and capacity of a multilane highway are achieved. These conditions include good weather, good visibility, and no incidents or accidents.

Studies of the flow characteristics of multilane highways have defined base conditions for developing flow relationships and adjustments to speed. The base conditions for multilane highways are as follows:

- 3.6-m minimum lane widths;
- 3.6-m minimum total lateral clearance in the direction of travel—this represents the total lateral clearances from the edge of the traveled lanes to obstructions along the edge of the road and in the median (in computations, lateral clearances greater than 1.8 m are considered in computations to be equal to 1.8 m);
- Only passenger cars in the traffic stream;
- No direct access points along the roadway;
- A divided highway; and
- Free-flow speed (FFS) higher than 100 km/h.

These base conditions represent the highest operating level of multilane rural and suburban highways.

LIMITATIONS OF THE METHODOLOGY

The methodology in this chapter does not take into account the following conditions:

- Transitory blockages caused by construction, accidents, or railroad crossings;
- Interference caused by parking on the shoulders (such as in the vicinity of a country store, flea market, or tourist attraction);
- Three-lane cross sections;
- The effect of lane drops and additions at beginning or end of segments;
- Possible queuing delays when transitions from a multilane segment into a two-lane segment are neglected;
- Differences between median barriers and two-way left-turn lanes; and
- FFS below 70 km/h or above 100 km/h.

II. METHODOLOGY

Methodology applies to signal spacing greater than 3.0 km

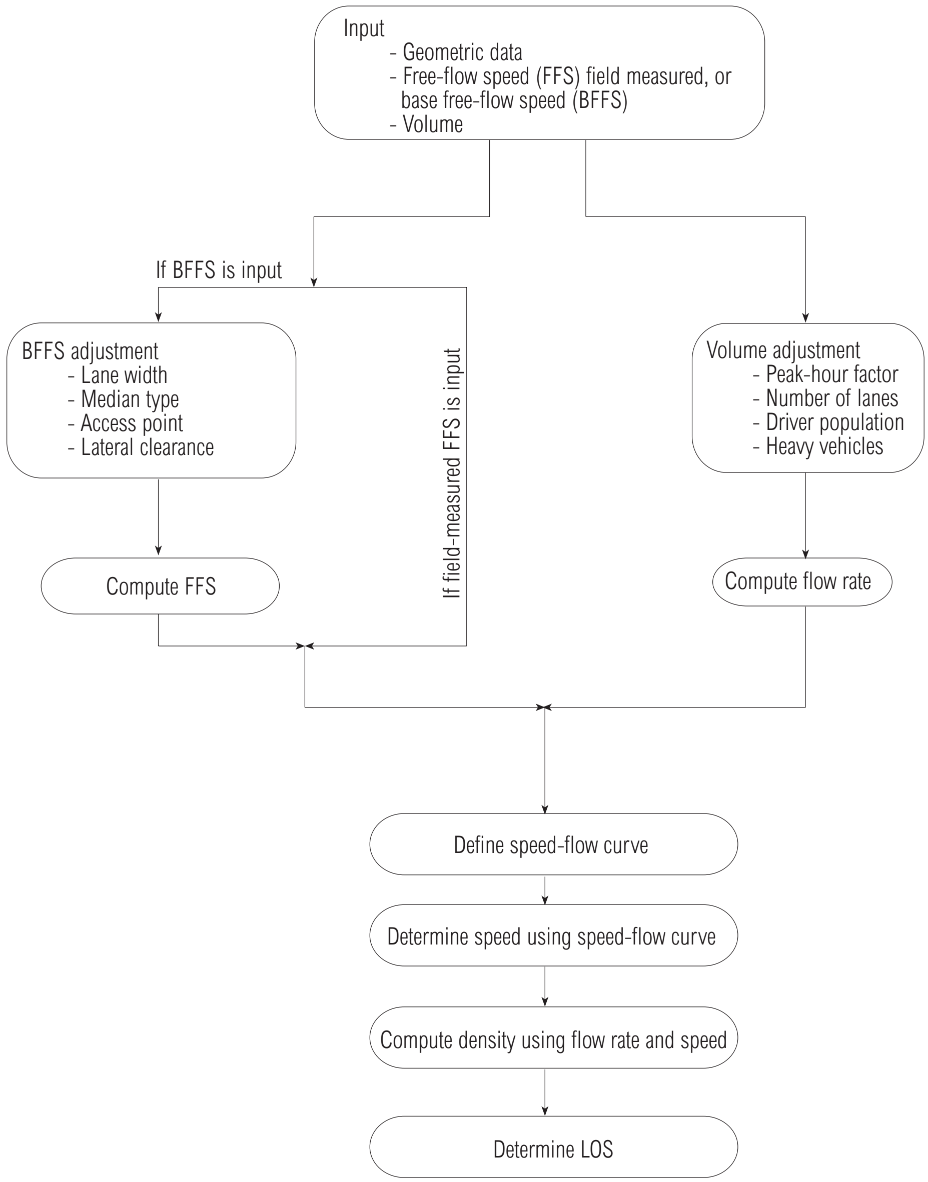
The methodology described in this chapter is intended for analysis of uninterrupted-flow highway segments. Chapter 15 presents the methodology for analyzing urban streets that have one or more of the following characteristics:

- Flow significantly influenced by other signals (i.e., a signal spacing less than or equal to 3.0 km),
- Significant presence of on-street parking,
- Presence of bus stops that have significant use, or
- Significant pedestrian activity.

Exhibit 21-1 illustrates the inputs and the basic computational order for the method described in this chapter. The primary output is LOS.

Uninterrupted-flow facilities that allow access solely through a system of on-ramps and off-ramps from grade separations or service roads are considered freeways and should be evaluated using the methodology presented in Chapter 23.

EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY



LOS

Although speed is a major concern of drivers, freedom to maneuver within the traffic stream and the proximity to other vehicles are also important. LOS criteria are listed in Exhibit 21-2. The criteria are based on the typical speed-flow and density-flow relationships shown in Exhibits 12-1 and 12-2. Exhibit 21-3 shows LOS boundaries as sloped lines, each corresponding to a constant value of density.

EXHIBIT 21-2. LOS CRITERIA FOR MULTILANE HIGHWAYS

		LOS				
Free-Flow Speed	Criteria	A	B	C	D	E
100 km/h	Maximum density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h)	100.0	100.0	98.4	91.5	88.0
	Maximum volume to capacity ratio (v/c)	0.32	0.50	0.72	0.92	1.00
	Maximum service flow rate (pc/h/ln)	700	1100	1575	2015	2200
90 km/h	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	90.0	90.0	89.8	84.7	80.8
	Maximum v/c	0.30	0.47	0.68	0.89	1.00
	Maximum service flow rate (pc/h/ln)	630	990	1435	1860	2100
80 km/h	Maximum density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h)	80.0	80.0	80.0	77.6	74.1
	Maximum v/c	0.28	0.44	0.64	0.85	1.00
	Maximum service flow rate (pc/h/ln)	560	880	1280	1705	2000
70 km/h	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	70.0	70.0	70.0	69.6	67.9
	Maximum v/c	0.26	0.41	0.59	0.81	1.00
	Maximum service flow rate (pc/h/ln)	490	770	1120	1530	1900

Note:
The exact mathematical relationship between density and volume to capacity ratio (v/c) has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.

The LOS criteria reflect the shape of the speed-flow and density-flow curves, particularly as speed remains relatively constant across LOS A to D but is reduced as capacity is approached. For FFS of 100, 90, 80, and 70 km/h, Exhibit 21-2 gives the average speed, the maximum value of v/c, the maximum density, and the corresponding maximum service flow rate for each LOS.

As with other LOS criteria, the maximum service flow rates in Exhibit 21-2 are stated in terms of flow rate based on the peak 15-min volume. Demand or forecast hourly volumes generally are divided by the peak-hour factor (PHF) to reflect a maximum hourly flow rate before comparison with the criteria of Exhibit 21-2. Using the basic speed-flow curves (see Exhibit 21-3), the relationships between LOS, flow, and speed can be analyzed.

DETERMINING FFS

FFS is measured using the mean speed of passenger cars operating in low-to-moderate flow conditions (up to 1,400 pc/h/ln). Mean speed is virtually constant across this range of flow rates. Field measurement and estimation with guidelines provided in this chapter are methods that can be used to determine FFS.

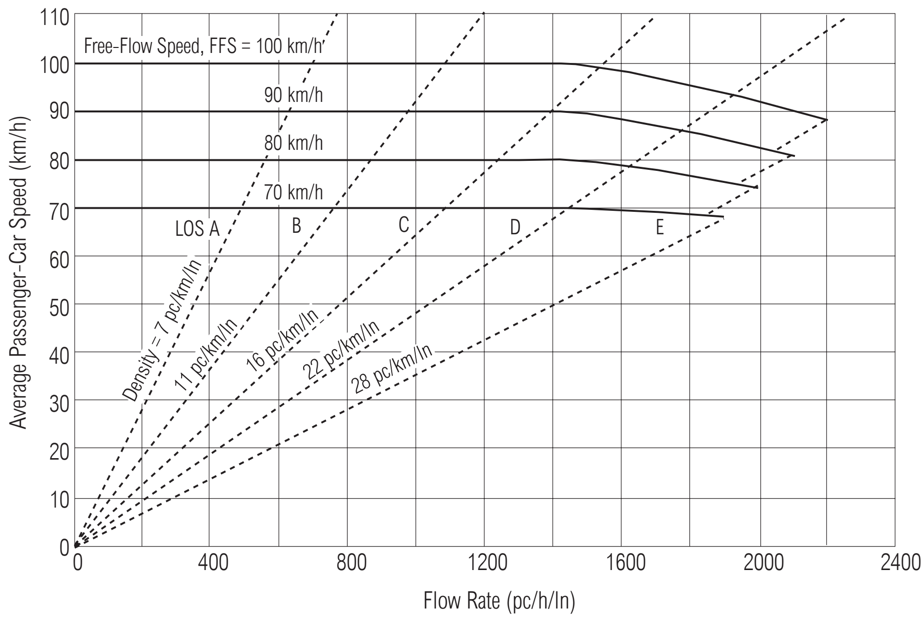
The field measurement procedure is for those who prefer to gather data directly or to incorporate the measurements into a speed-monitoring program. However, field measurements are not necessary to apply the method.

The FFS of a highway can be determined directly from a speed study conducted in the field. If field-measured data are used, no adjustments need to be made to FFS. The speed study should be conducted along a reasonable length of highway within the segment under evaluation; for example, an upgrade should not be selected within a site that is generally level. Any speed measurement technique acceptable for other types of traffic engineering speed studies can be used.

FFS occurs at flow rates ≤ 1,400 pc/h/ln

The field study should be conducted in the more stable regime of low-to-moderate flow conditions (up to 1,400 pc/h/ln). If the speed study must be conducted at a flow rate of more than 1,400 pc/h/ln, the FFS can be found by using the model speed-flow curve, assuming that data on traffic volumes are recorded at the same time.

EXHIBIT 21-3. SPEED-FLOW CURVES WITH LOS CRITERIA



Note:
Maximum densities for LOS E occur at a v/c ratio of 1.0. They are 25, 26, 27, and 28 pc/km/ln at FFS of 100, 90, 80, and 70 km/h, respectively. Capacity varies by FFS. Capacity is 2,200, 2,100, 2,000, and 1,900 pc/h/ln at FFS of 100, 90, 80, and 70 km/h, respectively.

For flow rate (v_p), v_p > 1400 and
$90 < FFS \le 100$ then

$$S = FFS - \left[\left(\frac{9.3}{25}FFS - \frac{630}{25}\right)\left(\frac{v_p - 1{,}400}{15.7FFS - 770}\right)^{1.31}\right]$$

For v_p > 1,400 and
$80 < FFS \le 90$ then

$$S = FFS - \left[\left(\frac{10.4}{26}FFS - \frac{696}{26}\right)\left(\frac{v_p - 1{,}400}{15.6FFS - 704}\right)^{1.31}\right]$$

For v_p > 1,400 and
$70 < FFS \le 80$ then

$$S = FFS - \left[\left(\frac{11.1}{27}FFS - \frac{728}{27}\right)\left(\frac{v_p - 1{,}400}{15.9FFS - 672}\right)^{1.31}\right]$$

For v_p > 1,400 and
FFS = 70 then

$$S = FFS - \left[\left(\frac{3}{28}FFS - \frac{75}{14}\right)\left(\frac{v_p - 1{,}400}{25FFS - 1{,}250}\right)^{1.31}\right]$$

For $v_p \le$ 1,400, then
S = FFS

The speed study should measure the speeds of all passenger cars or of a systematic sampling of passenger cars (e.g., of every 10th passenger car). The speed study not only should measure speeds for unimpeded vehicles but also should include representative numbers of impeded vehicles. A sample should obtain at least 100 passenger-car speeds. Further guidance on the conduct of speed studies available in standard traffic engineering publications, such as the *Manual of Traffic Engineering Studies*, published by the Institute of Transportation Engineers (*6*).

The average passenger-car speed under low-volume conditions can be used as the free-flow speed if the field measurements were made at flow rates at or below 1,400 pc/h/ln. This FFS reflects the net effects of all conditions at the site that influence speed, including those identified in this procedure (lane width, lateral clearance, type of median, and access points), as well as others, such as speed limit and vertical and horizontal alignment.

Highway agencies with ongoing speed-monitoring programs or with speed data on file might prefer to use those data rather than conduct a new speed study or use an indirect method to estimate speed. The data can be used directly if collected in accordance with the procedures presented above. Data including both passenger-car and heavy-vehicle speeds probably can be used for level terrain or moderate downgrades, but they should not be used for rolling or mountainous terrain.

ESTIMATING FFS

The FFS can be estimated indirectly when field data are not available.

$$FFS = BFFS - f_{LW} - f_{LC} - f_{M} - f_{A} \tag{21-1}$$

where

$BFFS$ = base FFS (km/h);
FFS = estimated FFS (km/h);
f_{LW} = adjustment for lane width, from Exhibit 21-4 (km/h);
f_{LC} = adjustment for lateral clearance, from Exhibit 21-5 (km/h);
f_{M} = adjustment for median type, from Exhibit 21-6 (km/h); and
f_{A} = adjustment for access points, from Exhibit 21-7 (km/h).

Base FFS

When it is not possible to use data from a similar roadway, an estimate might be necessary, based on available data, experience, and consideration of the variety of factors that have an identified effect on FFS. The speed limit is one factor that affects FFS. Recent research suggests that FFS on multilane highways under base conditions is approximately 11 km/h higher than the speed limit for 65 and 70 km/h speed limits, and it is 8 km/h higher for 80 and 90 km/h speed limits. Chapter 12 provides default values for base FFS.

Adjustment for Lane Width

Base conditions for multilane highways require 3.6-m lane widths. Exhibit 21-4 presents the adjustment to modify the estimated FFS to account for narrower lanes. Exhibit 21-4 shows that 3.0 m and 3.3 m lanes reduce free-flow speeds by 10.6 km/h and 3.1 km/h, respectively. For Exhibit 21-4, lane widths greater than 3.6 m are considered 3.6 m. There are no research data for lane widths less than 3.0 m.

EXHIBIT 21-4. ADJUSTMENT FOR LANE WIDTH

Lane Width (m)	Reduction in FFS (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

For undivided highways and highways with two-way left-turn lanes (TWLTL), the left edge lateral clearance equals 1.8 m

Adjustment for Lateral Clearance

Exhibit 21-5 lists the speed reductions caused by the lateral clearance for fixed obstructions on the roadside or in the median. Fixed obstructions with lateral clearance effects include light standards, signs, trees, abutments, bridge rails, traffic barriers, and retaining walls. Standard raised curbs are not considered obstructions. Exhibit 21-5 shows the appropriate reduction in FFS based on the total lateral clearance, which is defined as

$$TLC = LC_R + LC_L \tag{21-2}$$

where

TLC = total lateral clearance (m),

LC_R = lateral clearance (m), from the right edge of the travel lanes to roadside obstructions (if greater than 1.8 m, use 1.8 m), and

LC_L = lateral clearance (m), from the left edge of the travel lanes to obstructions in the roadway median (if the lateral clearance is greater than 1.8 m, use 1.8 m). For undivided roadways, there is no adjustment for left-side lateral clearance. The undivided design is taken into account by the median adjustment. To use Exhibit 21-5 for undivided highways, the lateral clearance on the left edge is always 1.8 m. Lateral clearance in the median of roadways with two-way left-turn lanes (TWLTLs) is considered to be 1.8 m.

EXHIBIT 21-5. ADJUSTMENT FOR LATERAL CLEARANCE

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)	Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)
3.6	0.0	3.6	0.0
3.0	0.6	3.0	0.6
2.4	1.5	2.4	1.5
1.8	2.1	1.8	2.1
1.2	3.0	1.2	2.7
0.6	5.8	0.6	4.5
0.0	8.7	0.0	6.3

Note:
a. Total lateral clearance is the sum of the lateral clearances of the median (if greater than 1.8 m, use 1.8 m) and shoulder (if greater than 1.8 m, use 1.8 m). Therefore, for purposes of analysis, total lateral clearance cannot exceed 3.6 m.

Thus, a total lateral clearance of 3.6 m is used for a completely unobstructed roadside and median; however, the actual value is used when obstructions are located closer to the roadway. The adjustment for lateral clearance on six-lane highways is slightly less than for four-lane highways because lateral obstructions have a minimal effect on traffic operations in the center lane of a three-lane roadway.

Median Type

The values in Exhibit 21-6 indicate that the average FFS should be decreased by 2.6 km/h for undivided highways to account for the friction caused by opposing traffic in an adjacent lane.

EXHIBIT 21-6. ADJUSTMENT FOR MEDIAN TYPE

Median Type	Reduction in FFS (km/h)
Undivided highways	2.6
Divided highways (including TWLTLs)	0.0

Adjustment for Access-Point Density

Exhibit 21-7 presents the adjustment to FFS for various levels of access-point density. The data indicate that for each access point per kilometer the estimated FFS decreases by approximately 0.4 km/h, regardless of the type of median. The access-point density on a divided roadway is determined by dividing the total number of access points (i.e., intersections and driveways) on the right side of the roadway in the direction of travel by the segment's total length 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 in determining access-point density.

EXHIBIT 21-7. ACCESS-POINT DENSITY ADJUSTMENT

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

Guidelines for one-way highways

Although the access-point adjustments do not include data for one-way multilane highways, it might be appropriate to include intersections and driveways on both sides of a one-way roadway to determine the total number of access points per kilometer.

DETERMINING FLOW RATE

Two adjustments must be made to hourly volume counts or estimates to arrive at the equivalent passenger-car flow rate used in LOS analyses. These adjustments are the PHF and the heavy vehicle adjustment factor. The number of lanes also is used so that the flow rate can be expressed on a per-lane basis. These adjustments are applied in the following manner using Equation 21-3.

$$v_p = \frac{V}{PHF \ * N \ * f_{HV} \ * f_p} \tag{21-3}$$

where

- v_p = 15-min passenger-car equivalent flow rate (pc/h/ln),
- V = hourly volume (veh/h),
- PHF = peak-hour factor,
- N = number of lanes,
- f_{HV} = heavy-vehicle adjustment factor, and
- f_p = driver population factor.

PHF

PHF represents the variation in traffic flow within an hour. Observations of traffic flow consistently indicate that the flow rates found in the peak 15-min period within an hour are not sustained throughout the entire hour. The application of PHF in Equation 21-3 accounts for this phenomenon.

Heavy-Vehicle Adjustments

The presence of heavy vehicles in the traffic stream decreases the FFS because base conditions allow a traffic stream of passenger cars only. Therefore, traffic volumes must be adjusted to reflect an equivalent flow rate expressed in passenger cars per hour per lane (pc/h/ln). This is accomplished by applying the heavy-vehicle factor (f_{HV}). Once values for E_T and E_R have been determined, the adjustment factor for heavy vehicles may be computed as shown in Equation 21-4.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \qquad (21\text{-}4)$$

where

E_T and E_R = passenger-car equivalents for trucks and buses and for recreational vehicles (RVs), respectively;

P_T and P_R = proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction); and

f_{HV} = adjustment factor for heavy vehicles.

Adjustment for heavy vehicles in the traffic stream applies to three types of vehicles: trucks, RVs, and buses. No evidence indicates any distinct differences in the performance characteristics of trucks and buses on multilane highways; therefore, buses are considered trucks in this method. Finding the heavy-vehicle adjustment factor requires two steps. First, find an equivalent truck factor (E_T) and RV factor (E_R) for prevailing operating conditions. Second, using E_T and E_R, compute an adjustment factor for all heavy vehicles in the traffic stream.

Extended General Highway Segments

Passenger-car equivalents can be selected for two conditions: extended general highway segments and specific grades. Values of passenger-car equivalents are selected from Exhibits 21-8 through 21-11. For long segments of highway in which no single grade has a significant impact on operations, Exhibit 21-8 is used to select passenger-car equivalents for trucks and buses (E_T) and for RVs (E_R).

EXHIBIT 21-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED GENERAL HIGHWAY SEGMENTS

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

A long multilane highway segment can be classified as an extended general highway segment if no grade exceeding 3 percent is longer than 0.8 km, and if grades of 3 percent or less do not exceed 1.6 km.

Specific Grade

Any grade of 3 percent or less that is longer than 1.6 km or a grade greater than 3 percent that is longer than 0.8 km should be treated as an isolated, specific grade. In addition, the upgrade and downgrade must be treated separately, because the impact of heavy vehicles differs substantially in each.

Equivalents for Extended General Highway Segments

For an extended general segment analysis, the terrain of the highway must be classified as level, rolling, or mountainous. These three classifications are discussed below.

Level Terrain

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

Rolling Terrain

Rolling terrain is any combination of horizontal and vertical alignment that causes heavy vehicles to reduce their speeds substantially below those of passenger cars. However, the terrain does not cause heavy vehicles to operate at crawl speeds for any significant length of time or at frequent intervals.

Mountainous Terrain

Mountainous terrain is any combination of horizontal and vertical alignment that causes heavy vehicles to operate at crawl speeds for significant distances or at frequent intervals. For these general highway segments, values of E_T and E_R are selected from Exhibit 21-8.

Equivalents for Specific Grades

Any highway grade of more than 1.6 km for grades less than 3 percent or of 0.8 km for grades of 3 percent or more should be considered a separate segment. Analysis of such segments must consider the upgrade and downgrade conditions and whether the grade is single and isolated, with a constant percentage of change, or part of a series forming a composite grade.

Equivalents for Specific Upgrades

Exhibits 21-9 and 21-10 give passenger-car equivalents for trucks and buses (E_T) and for RVs (E_R), respectively, on uniform upgrades on four- and six-lane highways. Exhibit 21-9 is based on an average weight-to-power ratio of 100 kg/kW, which is typical of trucks on multilane highways in the United States.

Weight-to-power ratio for trucks

Equivalents for Specific Downgrades

Downgrade conditions for trucks and buses on four- or six-lane highways are analyzed using equivalents from Exhibit 21-11. For all downgrades less than 4 percent and for steeper downgrades less than or equal to 3.2 km long, use the passenger-car equivalents for trucks and buses in level terrain, given in Exhibit 21-8. For grades of at least 4 percent and longer than 3.2 km, use the specific values shown in Exhibit 21-11. For all cases of RVs on downgrades, use the passenger-car equivalents for level terrain, given in Exhibit 21-8.

Equivalents for Composite Grades

When several consecutive grades of different steepness form a composite grade, an average, uniform grade is computed and used in analysis. The average grade is commonly computed as the total rise from the beginning of the grade divided by the total horizontal distance over which the rise occurs.

The composite grade technique is reasonably accurate for segment lengths of 1200 m or less, or for grades of 4 percent or less. For steeper grades and longer segment lengths, a more exact technique is described in Appendix A of Chapter 23. If a large change in grade occurs for a significant length, the analyst should consider segmenting the roadway to apply the composite grade technique.

Generally, an average grade can be used to represent consecutive grades, but for a more detailed method, see Appendix A of Chapter 23

Sometimes a single, steep grade creates a critical effect that might not be identified in a length of highway to be analyzed; in this case, the composite grade technique can be supplemented by a specific grade analysis.

EXHIBIT 21-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UNIFORM UPGRADES

Upgrade (%)	Length (km)	E_T Percentage of Trucks and Buses 2	4	5	6	8	10	15	20	25
<2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥ 2–3	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.8–1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 1.2–1.6	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.6–2.4	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 2.4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3–4	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8–1.2	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 1.2–1.6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.6–2.4	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 2.4	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4–5	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.8–1.2	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 1.2–1.6	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.6	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5–6	0.0–0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.5	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.5–0.8	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.8–1.2	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.2–1.6	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.6	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.4–0.5	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.5–0.8	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.8–1.2	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 1.2–1.6	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.6	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

EXHIBIT 21-10. PASSENGER-CAR EQUIVALENTS FOR RVS ON UNIFORM UPGRADES

Grade (%)	Length (km)	E_R Percentage of RVs 2	4	5	6	8	10	15	20	25
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2–3	0.0–0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3–4	0.0–0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.4–0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
> 4–5	0.0–0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
> 5	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	> 0.4–0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.5	3.5	3.0	3.0	2.5	2.0

EXHIBIT 21-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS ON DOWNGRADES

Downgrade (%)	Length (km)	E_T			
		Percentage of Trucks			
		5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4–5	≤ 6.4	1.5	1.5	1.5	1.5
4–5	> 6.4	2.0	2.0	2.0	1.5
> 5–6	≤ 6.4	1.5	1.5	1.5	1.5
> 5–6	> 6.4	5.5	4.0	4.0	3.0
> 6	≤ 6.4	1.5	1.5	1.5	1.5
> 6	> 6.4	7.5	6.0	5.5	4.5

Driver Population Factor

The adjustment factor f_p reflects the effect weekend recreational and perhaps even midday drivers have on the facility. The values for f_p range from 0.85 to 1.00. Typically, the analyst should select 1.00, which reflects weekday commuter traffic (i.e., users familiar with the highway), unless there is sufficient evidence that a lesser value, reflecting more recreational or weekend traffic characteristics, should be applied. When greater accuracy is needed, comparative field studies of weekday and weekend traffic flow and speeds are recommended.

DETERMINING LOS

The LOS on a multilane highway can be determined directly from Exhibit 21-3 on the basis of the FFS and the service flow rate (v_p) in pc/h/ln. The procedure is as follows:

- Step 1. Define and segment the highway as appropriate.
- Step 2. On the basis of the measured or estimated FFS, construct an appropriate speed-flow curve of the same shape as the typical curves shown in Exhibit 21-3. The curve should intercept the y-axis at the FFS.
- Step 3. Based on the flow rate v_p, read up to the FFS curve identified in Step 2 and determine the average passenger-car speed and LOS corresponding to that point.
- Step 4. Determine the density of flow according to Equation 21-5.

$$D = \frac{v_p}{S} \qquad (21\text{-}5)$$

where

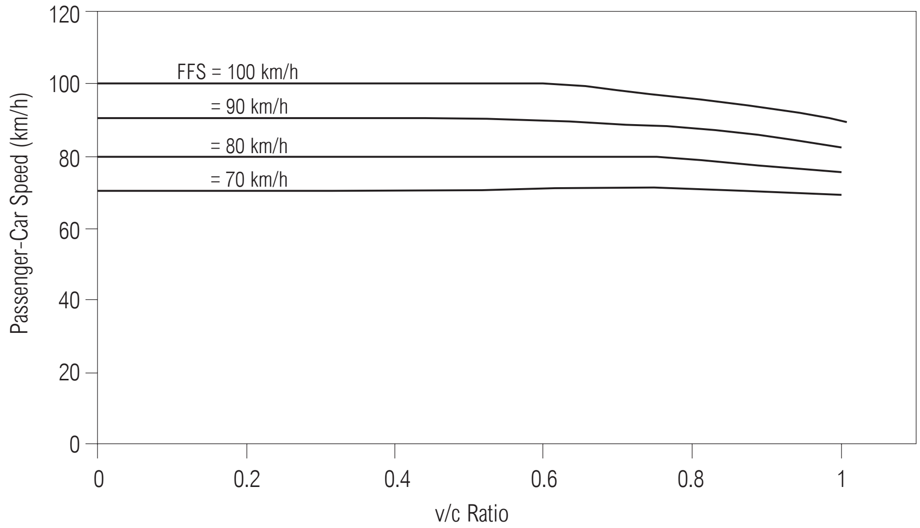
D = density (pc/km/ln),
v_p = flow rate (pc/h/ln), and
S = average passenger-car travel speed (km/h).

The LOS also can be determined by comparing the computed density with the density ranges provided in Exhibit 21-2.

SENSITIVITY OF RESULTS TO INPUT VARIABLES

Exhibit 21-12 shows the impact of v/c ratios on passenger-car speed for multilane highways. Note that speed is insensitive to demand until demand is at least 70 percent of capacity; also note that the mean speed on lower-speed segments is not sensitive to demand until the demand reaches at least 90 percent of capacity.

EXHIBIT 21-12. EFFECT OF v/c RATIO ON MEAN SPEED



III. APPLICATIONS

For guidelines on required inputs and estimated values, see Chapter 12, "Highway Concepts"

The methodology of this chapter can be used to analyze the capacity and LOS of multilane highways. The analyst must address two fundamental questions. First, the primary output must be identified. Primary outputs typically solved for in a variety of applications include LOS, number of lanes required (N), and flow rate achievable (v_p). Performance measures related to density (D) and speed (S) are also achievable but are considered secondary outputs.

Second, the analyst must identify the default values or estimated values for use in the analysis. Basically, the analyst has 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 outputs, both primary and secondary.

A common application of the method is to compute the LOS of an existing segment or of a changed segment in the near term or distant future. This type of application is often termed operational, and its primary output is LOS, with secondary outputs for density and speed. Another application is to check the adequacy or to recommend the required number of lanes for a multilane highway given the volume or flow rate and LOS goal. This is termed a design application since its primary output is the number of lanes required to serve the assumed conditions. Other outputs from this application include speed and density. Finally, the achievable flow rate v_p can be calculated as a primary output. This analysis requires stating a LOS goal and a number of lanes as inputs. This analysis typically estimates the point at which a flow rate will cause the highway to operate at an unacceptable LOS.

Another general type of analysis can be termed planning. These analyses use estimates, *Highway Capacity Manual* (HCM) default values, and local default values as inputs in the calculation. As outputs, LOS, number of lanes, or flow rate can be determined, along with the secondary outputs of density and speed. The difference between planning analysis and operational or design analysis is that most or all of the input values in planning come from estimates or default values, but the operational and design analyses tend to use field measurements or known values for most or all of the input variables. Note that for each of the analyses, FFS, either measured or estimated, is required as an input for the computation.

SEGMENTING THE HIGHWAY

The procedures described in this chapter are best applied to homogeneous segments of roadway, for which the variables affecting travel speeds are constant. Therefore, it is often necessary for the analyst to divide a section of highway into separate segments for analysis. The following conditions generally necessitate segmenting the highway:

- A change in the basic number of travel lanes along the highway,
- A change in the median treatment along the highway,
- A change of grade of 2 percent or more or a constant upgrade over 1220 m,
- The presence of a traffic signal or a stop sign along the multilane highway,
- A significant change in the density of access points,
- A change in speed limits, and
- The presence of a bottleneck condition.

Study segments should be at least 760 m long and 0.4 km from a signal

In general, when segmenting a highway for analysis, the minimum length of a study segment should be 760 m. Also, the limits of study segments should be no closer than 0.4 km to a signalized intersection. The procedures in this chapter are based on average conditions observed over an extended highway segment with generally consistent physical characteristics.

COMPUTATIONAL STEPS

The multilane highways worksheet for computations is shown in Exhibit 21-13. For all applications, the analyst provides general information and site information.

Operational (LOS) analysis

For operational (LOS) analysis, all speed and flow data are entered as inputs. Equivalent flow is then computed with the aid of the exhibits for passenger-car equivalencies. FFS is estimated by adjusting a base FFS. Finally, LOS is determined by entering (with v_p) the speed-flow graph at the top of the worksheet and intersecting the specific curve that has been selected or constructed for the highway segment.

This point of intersection identifies the LOS and, on the vertical axis of the graph, the estimated speed S. If the analyst requires a value for density D, it is calculated as v_p/S.

Design (N) analysis

The key to design analysis for number of lanes N is establishing an hourly volume. All information, with the exception of number of lanes, can be entered in the flow input and speed input portion of the worksheet (see Exhibit 21-13). An FFS, either computed or measured directly, is entered on the worksheet. The appropriate curve representing the FFS is established on the graph. The required or desired LOS is also entered. Then, the analyst assumes N and computes flow v_p with the aid of the exhibits for passenger-car equivalencies. LOS is determined by entering the speed-flow graph with v_p at the top of the worksheet. The derived LOS is compared with the desired LOS. This process is then repeated, adding one lane to the previously assumed number of lanes, until the determined LOS matches or is better than the desired LOS. Density is calculated using v_p and S.

Design (v_p) analysis

The objective of design analysis for flow rate v_p is to estimate the flow rate in pc/h/ln given a set of traffic, roadway, and FFS conditions. A desired LOS is entered on the worksheet. Then, the FFS of the segment is established using either the base FFS and the four adjustment factors or an FFS measured in the field. Once this segment speed-flow curve is established, the analyst can determine what flow rate is achievable with the given LOS. This would be considered the maximum flow rate achievable or allowable for the given level. Also directly available from the graph is the average passenger-car speed. Finally, if required, a value for density can be calculated, using v_p and S.

PLANNING APPLICATIONS

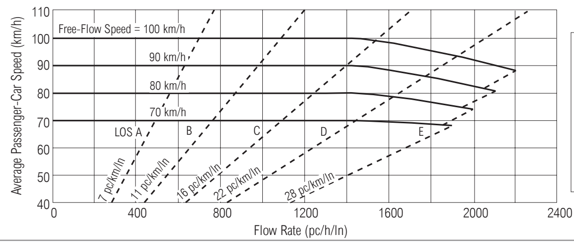
Planning (LOS), Planning (v_p), and Planning (N) applications

The three planning applications—planning for LOS, flow rate v_p, and number of lanes N—correspond directly to the procedures described for operations and design. The primary criterion categorizing these as planning applications is the use of estimates, HCM default values, and local default values for inputs into the calculations. The use of annual average daily traffic (AADT) to estimate directional design-hour volume (DDHV) also characterizes a planning application. (For guidelines on computing DDHV, refer to Chapter 8.)

To perform planning applications, the analyst typically has few, if any, of the required input values. Chapter 12 contains more information on the use of default values.

EXHIBIT 21-13. MULTILANE HIGHWAYS WORKSHEET

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst ____________
Agency or Company ____________
Date Performed ____________
Analysis Time Period ____________

Site Information

Highway/Direction of Travel ____________
From/To ____________
Jurisdiction ____________
Analysis Year ____________

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

Flow Inputs

Volume, V ____________veh/h
Annual avg. daily traffic, AADT ____________veh/day
Peak-hour proportion of AADT, K ____________
Peak-hour direction proportion, D ____________
DDHV = AADT * K * D ____________veh/h
Driver type
❑ Commuter/Weekday ❑ Recreational/Weekend

Peak-hour factor, PHF ____________
% Trucks and buses, P_T ____________
% RVs, P_R ____________
General terrain
❑ Level ❑ Rolling ❑ Mountainous
Grade: Length ______km Up/Down ______%
Number of lanes ____________

Calculate Flow Adjustments

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

Speed Inputs

Lane width, LW ____________m
Total lateral clearance, TLC ____________m
Access points, A ____________A/km
Median type, M ❑ Undivided ❑ Divided
FFS (measured) ____________km/h
Base free-flow Speed, BFFS ____________km/h

Calculate Speed Adjustments and FFS

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

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
S ____________km/h
$D = v_p / S$ ____________pc/km/ln
LOS ____________

Design (v_p) or Planning (v_p)
LOS ____________
v_p ____________pc/h/ln
$V = v_p * PHF * N * f_{HV} * f_p$ ____________veh/h
S ____________km/h
$D = v_p/S$ ____________pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration
N ____________assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
LOS ____________

Design (N) or Planning (N) 2nd Iteration
N ____________assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
LOS ____________
S ____________km/h
$D = v_p / S$ ____________pc/km/ln

Glossary

N - Number of lanes
V - Hourly volume
v_p - Flow rate
LOS - Level of service
DDHV - Directional design-hour volume
S - Speed
D - Density
FFS - Free-flow speed
BFFS - Base free-flow speed

Factor Location

E_T - Exhibit 21-8, 21-9, 21-11
E_R - Exhibit 21-8, 21-10
f_p - Page 21-11
LOS, S, FFS, v_p - Exhibit 21-2, 21-3
f_{LW} - Exhibit 21-4
f_{LC} - Exhibit 21-5
f_M - Exhibit 21-6
f_A - Exhibit 21-7

ANALYSIS TOOLS

The multilane highways worksheet shown in Exhibit 21-13 and provided in Appendix A can be used to perform all applications, including operational for LOS; design for flow rate v_p and number of lanes N; and planning for LOS, v_p, and N.

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Find LOS on an undivided four-lane highway	Operational (LOS)
2	Find LOS on a five-lane highway with TWLTL	Operational (LOS)
3	Find the cross section required within a right-of-way to achieve desired LOS	Planning (N)
4	Find how much additional traffic can be accommodated by grade separation of a signalized intersection on a highway segment	Planning (v_p)
5	Find opening-day volume and number of lanes on a new suburban highway facility	Planning (N)

EXAMPLE PROBLEM 1 (PART I)

The Highway A 5.23-km undivided four-lane highway on level terrain. A 975-m segment with 2.5 percent grade also is included in the study.

The Question What are the peak-hour LOS, speed, and density for the level terrain portion of the highway?

The Facts

√ Level terrain,
√ 74.0-km/h field-measured FFS,
√ 3.4-m lane width,
√ 1,900-veh/h peak-hour volume,
√ 13 percent trucks and buses,
√ 2 percent RVs, and
√ 0.90 PHF.

Outline of Solution All input parameters are known. Demand will be computed in terms of pc/h/ln, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

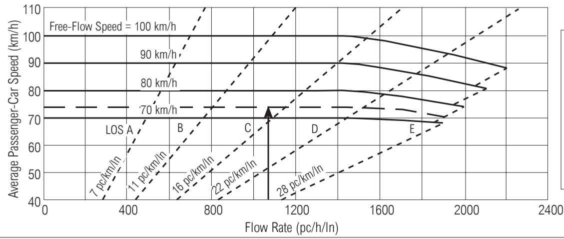
1. Find f_{HV} (use Exhibit 21-8 and Equation 21-4)	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(1.2 - 1)}$ $f_{HV} = 0.935$
2. Find v_p (use Equation 21-3)	$v_p = \frac{V}{PHF * N * f_{HV} * f_p}$ $v_p = \frac{1,900}{0.90 * 2 * 0.935 * 1.00}$ $v_p = 1,129$ pc/h/ln
3. Determine LOS (use Exhibit 21-3)	LOS C

The Results

- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.3 pc/km/ln.

Example Problem 1 (Part I)

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	AM

Site Information

Highway/Direction of Travel	US 80 (East)
From/To	MP 17 - MP 20
Jurisdiction	M. County
Analysis Year	1999

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

Flow Inputs

Volume, V	1,900 veh/h	Peak-hour factor, PHF	0.90
Annual avg. daily traffic, AADT	___ veh/day	% Trucks and buses, P_T	13
Peak-hour proportion of AADT, K	___	% RVs, P_R	2
Peak-hour direction proportion, D	___	General terrain	☒ Level ☐ Rolling ☐ Mountainous
DDHV = AADT * K * D	___ veh/h	Grade: Length ___ km	Up/Down ___ %
Driver type: ☒ Commuter/Weekday ☐ Recreational/Weekend		Number of lanes	2

Calculate Flow Adjustments

f_p	1.00	E_R	1.2
E_T	1.5	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.935

Speed Inputs

Lane width, LW	3.4 m
Total lateral clearance, TLC	___ m
Access points, A	___ A/km
Median type, M	☒ Undivided ☐ Divided
FFS (measured)	74.0 km/h
Base free-flow Speed, BFFS	___ km/h

Calculate Speed Adjustments and FFS

f_{LW}	___ km/h
f_{LC}	___ km/h
f_A	___ km/h
f_M	___ km/h
$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$	___ km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1129 pc/h/ln
S	74.0 km/h
$D = v_p/S$	15.3 pc/km/ln
LOS	C

Design (v_p) or Planning (v_p)

LOS	___
v_p	___ pc/h/ln
$V = v_p * PHF * N * f_{HV} * f_p$	___ veh/h
S	___ km/h
$D = v_p/S$	___ pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	___ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	___ pc/h/ln
LOS	___

Design (N) or Planning (N) 2nd Iteration

N	___ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	___ pc/h/ln
LOS	___
S	___ km/h
$D = v_p/S$	___ pc/km/ln

Glossary

- N - Number of lanes
- V - Hourly volume
- v_p - Flow rate
- LOS - Level of service
- DDHV - Directional design-hour volume
- S - Speed
- D - Density
- FFS - Free-flow speed
- BFFS - Base free-flow speed

Factor Location

- E_T - Exhibit 21-8, 21-9, 21-11
- E_R - Exhibit 21-8, 21-10
- f_p - Page 21-11
- LOS, S, FFS, v_p - Exhibit 21-2, 21-3
- f_{LW} - Exhibit 21-4
- f_{LC} - Exhibit 21-5
- f_M - Exhibit 21-6
- f_A - Exhibit 21-7

EXAMPLE PROBLEM 1 (PART II)

The Highway A 5.23-km undivided four-lane highway on level terrain. A 975-m segment with 2.5 percent grade also is included in the study.

The Question What are peak-hour LOS, speed, and density of traffic on the 2.5 percent grade? Does this operation still meet the minimum required LOS D?

The Facts

- √ 2.5 percent grade (upgrade and downgrade),
- √ 74.0-km/h field-measured FFS,
- √ 3.4-m lane width,
- √ 1,900-veh/h peak-hour volume,
- √ 13 percent trucks and buses,
- √ 2 percent RVs, and
- √ 0.90 PHF.

Comments

- √ For the 2.5 percent downgrade, trucks, buses, and RVs all operate as though on level terrain. Therefore, results obtained in Part I are applicable for downgrade results of the 2.5 percent grade segment.
- √ Assume FFS of 74.0 km/h applies to both upgrade and downgrade segments.

Outline of Solution All input parameters are known. Demand will be computed in terms of pc/h/ln, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

1. Find f_{HV} (use Exhibits 21-9 and 21-10).	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(3.0 - 1)}$ $f_{HV} = 0.905$
2. Find v_p.	$v_p = \frac{V}{PHF * N * f_{HV} * f_p}$ $v_p = \frac{1,900}{0.90 * 2 * 0.905 * 1.00}$ $v_p = 1,166$ pc/h/ln
3. Determine LOS (use Exhibit 21-3).	LOS C (upgrade) LOS C (downgrade)

The Results

Downgrade:

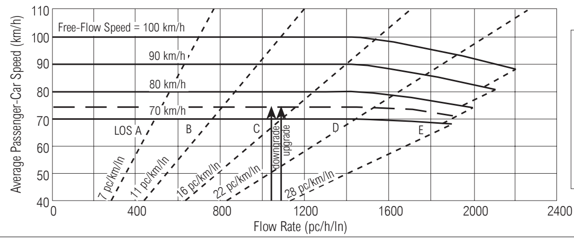
- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.3 pc/km/ln.

Upgrade:

- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.8 pc/km/ln.

Example Problem 1 (Part II)

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	AM

Site Information

Highway/Direction of Travel	US 80 (East)
From/To	MP 17 - MP 20
Jurisdiction	M. County
Analysis Year	1999

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

Flow Inputs

Volume, V	1,900 veh/h	Peak-hour factor, PHF	0.90
Annual avg. daily traffic, AADT	____ veh/day	% Trucks and buses, P_T	13
Peak-hour proportion of AADT, K		% RVs, P_R	2
Peak-hour direction proportion, D		General terrain	❑ Level ❑ Rolling ❑ Mountainous
DDHV = AADT * K * D	____ veh/h	Grade: Length 0.975 km	Up/Down 2.5 (up) %
Driver type: ☒ Commuter/Weekday ❑ Recreational/Weekend		Number of lanes	2

Calculate Flow Adjustments

f_p	1.00	E_R	3.0
E_T	1.5	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.905

Speed Inputs

Lane width, LW	3.4 m
Total lateral clearance, TLC	____ m
Access points, A	____ A/km
Median type, M	☒ Undivided ❑ Divided
FFS (measured)	74.0 km/h
Base free-flow Speed, BFFS	____ km/h

Calculate Speed Adjustments and FFS

f_{LW}	____ km/h
f_{LC}	____ km/h
f_A	____ km/h
f_M	____ km/h
FFS = $BFFS - f_{LW} - f_{LC} - f_A - f_M$	____ km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1166 pc/h/ln
S	74.0 km/h
D = v_p/S	15.8 pc/km/ln
LOS	C

Design (v_p) or Planning (v_p)

LOS	
v_p	____ pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p	____ veh/h
S	____ km/h
D = v_p/S	____ pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	____ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	____ pc/h/ln
LOS	

Design (N) or Planning (N) 2nd Iteration

N	____ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	____ pc/h/ln
LOS	
S	____ km/h
D = v_p/S	____ pc/km/ln

Glossary

N - Number of lanes
V - Hourly volume
v_p - Flow rate
LOS - Level of service
DDHV - Directional design-hour volume
S - Speed
D - Density
FFS - Free-flow speed
BFFS - Base free-flow speed

Factor Location

E_T - Exhibit 21-8, 21-9, 21-11
E_R - Exhibit 21-8, 21-10
f_p - Page 21-11
LOS, S, FFS, v_p - Exhibit 21-2, 21-3
f_{LW} - Exhibit 21-4
f_{LC} - Exhibit 21-5
f_M - Exhibit 21-6
f_A - Exhibit 21-7

EXAMPLE PROBLEM 2 (PART I)

The Highway A 3.4-km segment of an east-west five-lane highway with two travel lanes in each direction separated by a two-way left-turn lane (TWLTL). The highway includes a 4 percent grade, 1830-m in length, followed by level terrain of 1570 m.

The Question What is the LOS of the highway on level terrain during the peak hour?

The Facts

√ Level terrain,
√ 3.6-m lane width,
√ 6 percent trucks and buses,
√ 6 access points/km (eastbound),
√ 3.6-m and greater lateral clearance for westbound and eastbound,
√ 83.0-km/h 85th-percentile speed,
√ 1,500-veh/h peak-hour volume,
√ 8 access points/km (westbound), and
√ 0.90 PHF.

Comments

√ Assume base FFS to be 3.0 km/h less than 85th-percentile speed.
BFFS = 83.0 – 3.0 = 80.0 km/h
√ Assume no RVs, since none is indicated.

Outline of Solution All input parameters are known. Demand will be computed in terms of pc/h/ln, an FFS estimate, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

1. Find f_{HV} (EB and WB) (use Exhibit 21-8).	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.06(1.5 - 1) + 0}$ $f_{HV} = 0.971$
2. Find v_p (EB and WB) (use Equation 21-3).	$v_p = \frac{V}{PHF * N * f_{HV} * f_p}$ $v_p = \frac{1{,}500}{0.90 * 2 * 0.971 * 1.00}$ $v_p = 858$ pc/h/ln
3. Compute EB and WB free-flow speeds (use Exhibits 21-4, 21-5, 21-6, 21-7, and Equation 21-1).	$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$ FFS = 80 – 0.0 – 0.0 – 4.0 – 0.0 FFS = 76.0 km/h (EB) FFS = 80 – 0.0 – 0.0 – 5.3 – 0.0 FFS = 74.7 km/h (WB)
4. Determine LOS (use Exhibit 21-3).	LOS C (EB and WB)

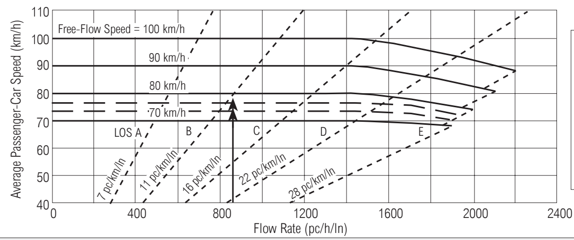
The Results

Eastbound:
- LOS C,
- Speed = 76.0 km/h, and
- Density = 11.3 pc/km/ln.

Westbound:
- LOS C,
- Speed = 74.7 km/h, and
- Density = 11.5 pc/km/ln.

Example Problem 2 (Part I)

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	PM

Site Information

Highway/Direction of Travel	Buckeye Rd. (EB/WB)
From/To	50th - 58th St.
Jurisdiction	N. County
Analysis Year	1999

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

Flow Inputs

Volume, V	1,500 veh/h
Annual avg. daily traffic, AADT	veh/day
Peak-hour proportion of AADT, K	
Peak-hour direction proportion, D	
DDHV = AADT * K * D	veh/h
Driver type	☒ Commuter/Weekday ☐ Recreational/Weekend

Peak-hour factor, PHF	0.90
% Trucks and buses, P_T	6
% RVs, P_R	0
General terrain	☒ Level ☐ Rolling ☐ Mountainous
Grade: Length ____ km	Up/Down ____ %
Number of lanes	2

Calculate Flow Adjustments

f_p	1.00
E_T	1.5
E_R	
$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.971

Speed Inputs

Lane width, LW	3.6 m
Total lateral clearance, TLC	> 3.6 m
Access points, A	6/8 A/km
Median type, M	☐ Undivided ☒ Divided
FFS (measured)	km/h
Base free-flow Speed, BFFS	80 km/h

Calculate Speed Adjustments and FFS

f_{LW}	km/h
f_{LC}	km/h
f_A	4.0/5.3 km/h
f_M	km/h
FFS = BFFS − f_{LW} − f_{LC} − f_A − f_M	76.0/74.7 km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	858 pc/h/ln
S	76.0/74.7 km/h
D = v_p/S	11.3/11.5 pc/km/ln
LOS	C/C

Design (v_p) or Planning (v_p)

LOS	
v_p	pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p	veh/h
S	km/h
D = v_p/S	pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	pc/h/ln
LOS	

Design (N) or Planning (N) 2nd Iteration

N	assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	pc/h/ln
LOS	
S	km/h
D = v_p/S	pc/km/ln

Glossary

- N - Number of lanes
- V - Hourly volume
- v_p - Flow rate
- LOS - Level of service
- DDHV - Directional design-hour volume
- S - Speed
- D - Density
- FFS - Free-flow speed
- BFFS - Base free-flow speed

Factor Location

- E_T - Exhibit 21-8, 21-9, 21-11
- E_R - Exhibit 21-8, 21-10
- f_p - Page 21-11
- LOS, S, FFS, v_p - Exhibit 21-2, 21-3
- f_{LW} - Exhibit 21-4
- f_{LC} - Exhibit 21-5
- f_M - Exhibit 21-6
- f_A - Exhibit 21-7

EXAMPLE PROBLEM 2 (PART II)

The Highway A 3.4-km segment of an east-west five-lane highway with two travel lanes in each direction separated by a TWLTL. The highway characteristics include a 4 percent grade, 1830 m in length, followed by level terrain of 1570 m.

The Question What is the LOS of the 4 percent grade segment during the peak hour?

Additional Facts

- √ 4.0 percent grade (EB downgrade, WB upgrade),
- √ 87.0-km/h eastbound 85th-percentile speed,
- √ 77.0-km/h westbound 85th-percentile speed,
- √ 3.6-m lane width,
- √ 6 access points/km (EB), and
- √ 0 access points (WB).

Comments

- √ Assume base FFS to be 3.0 km/h less than 85th-percentile speed.
  BFFS (EB) = 87.0 – 3.0 = 84.0 km/h
- √ BFFS (WB) = 77.0 – 3.0 = 74.0 km/h
- √ Assume no RVs, since none indicated.

Outline of Solution All input parameters are known. Demand will be computed in terms of pc/h/ln, an FFS estimate, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

1. Find f_{HV} (EB and WB) (use Exhibits 21-9 and 21-11).	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.06(1.5 - 1) + 0} = 0.971$ (EB) $f_{HV} = \frac{1}{1 + 0.06(3.0 - 1) + 0} = 0.893$ (WB)
2. Find v_p (EB and WB).	$v_p = \frac{V}{PHF * N * f_{HV} * f_p}$ $v_p = \frac{1,500}{0.90 * 2 * 0.971 * 1.00} = 858$ pc/h/ln (EB) $v_p = \frac{1,500}{0.90 * 2 * 0.893 * 1.00} = 933$ pc/h/ln (WB)
3. Compute EB and WB FFS (use Exhibits 21-4, 21-5, 21-6, and 21-7).	$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$ FFS = 84.0 – 0.0 – 0.0 – 4.0 – 0.0 = 80.0 km/h (EB) FFS = 74.0 – 0.0 – 0.0 – 0.0 – 0.0 = 74.0 km/h (WB)
4. Determine LOS (use Exhibit 21-3).	LOS B (EB) LOS C (WB)

The Results

Eastbound:

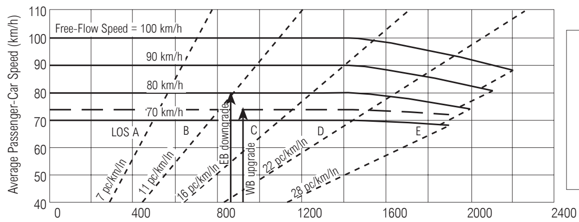
- LOS B,
- Speed = 80.0 km/h, and
- Density = 10.7 pc/km/ln.

Westbound:

- LOS C,
- Speed = 74.0 km/h, and
- Density = 12.6 pc/km/ln.

Example Problem 2 (Part II)

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	PM

Site Information

Highway/Direction of Travel	Buckeye Rd. (EB/WB)
From/To	50th - 58th St.
Jurisdiction	N. County
Analysis Year	1999

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

Flow Inputs

Volume, V	1,500 veh/h	Peak-hour factor, PHF	0.90
Annual avg. daily traffic, AADT	veh/day	% Trucks and buses, P_T	6
Peak-hour proportion of AADT, K		% RVs, P_R	0
Peak-hour direction proportion, D		General terrain	
DDHV = AADT * K * D	veh/h	☐ Level ☐ Rolling ☐ Mountainous	
Driver type		Grade: Length 1.830 km	Up/Down 4 %
☒ Commuter/Weekday ☐ Recreational/Weekend		Number of lanes	2

Calculate Flow Adjustments

f_p	1.00	E_R	
E_T	1.5/3.0	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.971/0.893

Speed Inputs

Lane width, LW	3.6 m
Total lateral clearance, TLC	> 3.6 m
Access points, A	6/0 A/km
Median type, M	☐ Undivided ☒ Divided
FFS (measured)	km/h
Base free-flow Speed, BFFS	84.0/74.0 km/h

Calculate Speed Adjustments and FFS

f_{LW}	km/h
f_{LC}	km/h
f_A	4.0/0.0 km/h
f_M	km/h
FFS = BFFS – f_{LW} – f_{LC} – f_A – f_M	80.0/74.0 km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{\text{V or DDHV}}{\text{PHF} * N * f_{HV} * f_p}$	858/933 pc/h/ln
S	80.0/74.0 km/h
D = v_p/S	10.7/12.6 pc/km/ln
LOS	B/C

Design (v_p) or Planning (v_p)

LOS	
v_p	pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p	veh/h
S	km/h
D = v_p/S	pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	assumed
$v_p = \frac{\text{V or DDHV}}{\text{PHF} * N * f_{HV} * f_p}$	pc/h/ln
LOS	

Design (N) or Planning (N) 2nd Iteration

N	assumed
$v_p = \frac{\text{V or DDHV}}{\text{PHF} * N * f_{HV} * f_p}$	pc/h/ln
LOS	
S	km/h
D = v_p/S	pc/km/ln

Glossary

- N - Number of lanes
- V - Hourly volume
- v_p - Flow rate
- LOS - Level of service
- DDHV - Directional design-hour volume
- S - Speed
- D - Density
- FFS - Free-flow speed
- BFFS - Base free-flow speed

Factor Location

- E_T - Exhibit 21-8, 21-9, 21-11
- E_R - Exhibit 21-8, 21-10
- f_p - Page 21-11
- LOS, S, FFS, v_p - Exhibit 21-2, 21-3
- f_{LW} - Exhibit 21-4
- f_{LC} - Exhibit 21-5
- f_M - Exhibit 21-6
- f_A - Exhibit 21-7

EXAMPLE PROBLEM 3

The Highway A new 3.2-km segment of multilane highway with right-of-way width of 27.4 m.

The Question What is the cross section required to meet the design criterion of LOS D? What is the expected travel speed for passenger cars?

The Facts

√ 60,000 annual average daily traffic,
√ 80.0-km/h speed limit,
√ Peak-hour volume is 10 percent of daily traffic,
√ Peak-hour traffic has 55/45 directional split,
√ Rolling terrain,
√ 5 percent trucks,
√ 6 access points/km, and
√ 0.90 peak-hour factor.

Comments

√ This solution assumes that the given AADT is for the design year and that the other factors, although current, are accepted as representative of expected design year conditions.
√ Assume base FFS to be 8.0 km/h greater than the posted speed.
BFFS = 80.0 + 8.0 = 88.0 km/h

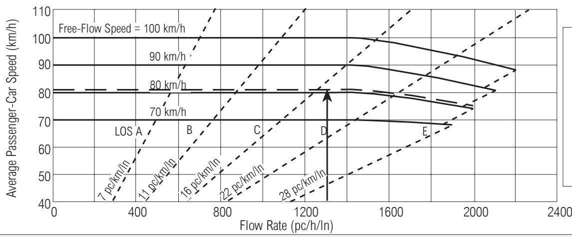
Steps

1. Convert AADT to design-hour volume.	DDHV = AADT * K * D DDHV = 60,000 * 0.10 * 0.55 = 3,300 veh/h
2. Find f_{HV} (use Exhibit 21-8). $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	$f_{HV} = \frac{1}{1 + 0.05(2.5 - 1) + 0} = 0.930$
3. Compute free-flow speed (use Exhibits 21-4, 21-5, 21-6, and 21-7).	$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$ FFS = 88.0 – 0.0 – 0.0 – 4.0 – 0.0 = 84.0 km/h
4. Determine maximum v_p (use Exhibit 21-3).	v_p = 1,775 pc/h/ln
5. Determine minimum N required.	$N = \frac{V}{PHF * v_p * f_{HV} * f_p}$ $N = \frac{3,300}{0.90 * 1,775 * 0.930 * 1.00}$ = 2.2 (use 3)
6. Compute v_p using minimum N required.	$v_p = \frac{3,300}{0.90 * 3 * 0.930 * 1.00}$ = 1,314 pc/h/ln
7. Determine if base conditions will fit within available right-of-way with a 3.6-m median to accommodate left-turn bays in the future.	Median width = 3.6 m Lane width = 3.6 m Lateral clearance (shoulder) = 1.8 m Total required width = 3.6 + 6 * 3.6 + 2 * 1.8 = 28.8 m (greater than available width)
8. Assume different design to fit available right-of-way. Use 1.8-m median and do not use shoulder at median.	Median width = 1.8 m (raised) Lane width = 3.6 m Lateral clearance (shoulder) = 1.8 m Total required width = 1.8 + 21.6 + 2 * 1.8 = 27.0 m (fits within available 27.4 m)
9. Compute FFS (use Exhibits 21-4, 21-5, 21-6, and 21-7).	FFS = 88.0 – 0.0 – 0.0 – 4.0 – 0.0 = 84.0 km/h
10. Determine LOS (use Exhibit 21-3).	LOS D

The Results A six-lane highway with lane widths of 3.6 m, a 1.8-m median, and lateral clearances of 1.8 m on the right will meet the operational objective of LOS D during the peak-hour period. The passenger-car speed of 84.0 km/h and density of 15.6 pc/km/ln are computed.

Example Problem 3

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	PM

Site Information

Highway/Direction of Travel	US 6 (N/E)
From/To	31st to 156th St.
Jurisdiction	M. County
Analysis Year	1999

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

Flow Inputs

Volume, V	____ veh/h	Peak-hour factor, PHF	0.90
Annual avg. daily traffic, AADT	60,000 veh/day	% Trucks and buses, P_T	5
Peak-hour proportion of AADT, K	0.10	% RVs, P_R	0
Peak-hour direction proportion, D	55/45	General terrain	
DDHV = AADT * K * D	3300 veh/h	❑ Level ☒ Rolling ❑ Mountainous	
Driver type		Grade: Length ____ km	Up/Down ____ %
☒ Commuter/Weekday ❑ Recreational/Weekend		Number of lanes	____

Calculate Flow Adjustments

f_p	1.00	E_R	0
E_T	2.5	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.930

Speed Inputs

Lane width, LW	3.6/3.6 m
Total lateral clearance, TLC	3.6 m
Access points, A	6 A/km
Median type, M	❑ Undivided ☒ Divided
FFS (measured)	____ km/h
Base free-flow Speed, BFFS	88.0 km/h

Calculate Speed Adjustments and FFS

f_{LW}	0.0/0.0 km/h
f_{LC}	0.0/0.0 km/h
f_A	4.0/4.0 km/h
f_M	0.0 km/h
FFS = BFFS − f_{LW} − f_{LC} − f_A − f_M	84.0/84.0 km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	____ pc/h/ln
S	____ km/h
D = v_p /S	____ pc/km/ln
LOS	____

Design (v_p) or Planning (v_p)

LOS	____
v_p	____ pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p	____ veh/h
S	____ km/h
D = v_p/S	____ pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	2.2 assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1,775 pc/h/ln
LOS	D

Design (N) or Planning (N) 2nd Iteration

N	3 assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1,314 pc/h/ln
LOS	C
S	84.0 km/h
D = v_p /S	15.6 pc/km/ln

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design-hour volume	

Factor Location

E_T - Exhibit 21-8, 21-9, 21-11	f_{LW} - Exhibit 21-4
E_R - Exhibit 21-8, 21-10	f_{LC} - Exhibit 21-5
f_p - Page 21-11	f_M - Exhibit 21-6
LOS, S, FFS, v_p - Exhibit 21-2, 21-3	f_A - Exhibit 21-7

EXAMPLE PROBLEM 4

The Highway A 4.0-km segment of a six-lane highway in a growing urban area to be improved.

The Question What is the estimated LOS for the existing and improved roadway? How much additional traffic can be added and still maintain the improved LOS?

The Facts

√ 1,400 pc/h/ln flow rate,
√ Free-flow travel time is 180 s, and
√ Improved free-flow travel time is 150 s.

Comments

This problem involves upgrading the design of a substandard section of multilane highway. The substandard highway has a measured FFS of 80 km/h. It is proposed to upgrade the design to a 96-km/h FFS through wider shoulders, widening the lanes to current standards, straightening the alignment on a few critical curves, restricting access to fronting properties and constructing a median.

Outline of Solution Using given peak-hour volume and FFS, determine LOS for improved and for current conditions. Determine additional volume that can be accommodated while still maintaining the improved LOS.

Steps

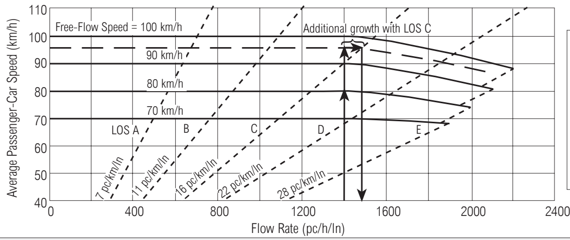
1. Determine LOS and speed of existing highway (use Exhibit 21-3).	v_p = 1,400 pc/h/ln, S = 80.0 km/h, LOS D
2. Determine maximum allowable flow at improved LOS and FFS (use Exhibit 21-3).	v_p = 1,400 pc/h/ln, FFS = 96.0 km/h, LOS C, Speed = 96.0 km/h
3. Compute additional volume.	Additional volume = 1,536 – 1,400 = 136 pc/h/ln

The Results

- Currently LOS D,
- Improved LOS C,
- Additional volume = 136 pc/h/ln,
- Speed = 96.0 km/h, and
- Density = 14.6 pc/km/ln.

Example Problem 4

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	PM

Site Information

Highway/Direction of Travel	Georgia Dr.
From/To	Meno to Woodstock
Jurisdiction	M. County
Analysis Year	1999

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

Flow Inputs

Volume, V ________ veh/h
Annual avg. daily traffic, AADT ________ veh/day
Peak-hour proportion of AADT, K ________
Peak-hour direction proportion, D ________
DDHV = AADT * K * D ________ veh/h
Driver type
☐ Commuter/Weekday ☐ Recreational/Weekend

Peak-hour factor, PHF ________
% Trucks and buses, P_T ________
% RVs, P_R ________
General terrain
☒ Level ☐ Rolling ☐ Mountainous
Grade: Length ________ km Up/Down ________ %
Number of lanes 3

Calculate Flow Adjustments

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

Speed Inputs

Lane width, LW ________ m
Total lateral clearance, TLC ________ m
Access points, A ________ A/km
Median type, M ☐ Undivided ☒ Divided
FFS (measured) 96.0 km/h
Base free-flow Speed, BFFS ________ km/h

Calculate Speed Adjustments and FFS

f_{LW} ________ km/h
f_{LC} ________ km/h
f_A ________ km/h
f_M ________ km/h
$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$ ________ km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ________ pc/h/ln
S ________ km/h
$D = v_p/S$ ________ pc/km/ln
LOS ________

Design (v_p) or Planning (v_p)

LOS ________
v_p 1,536 - 1,400 = 136 pc/h/ln
$V = v_p * PHF * N * f_{HV} * f_p$ ________ veh/h
S 96.0 km/h
$D = v_p/S$ 14.6 pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N ________ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ________ pc/h/ln
LOS ________

Design (N) or Planning (N) 2nd Iteration

N ________ assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ________ pc/h/ln
LOS ________
S ________ km/h
$D = v_p/S$ ________ pc/km/ln

Glossary

N - Number of lanes
V - Hourly volume
v_p - Flow rate
LOS - Level of service
DDHV - Directional design-hour volume
S - Speed
D - Density
FFS - Free-flow speed
BFFS - Base free-flow speed

Factor Location

E_T - Exhibit 21-8, 21-9, 21-11
E_R - Exhibit 21-8, 21-10
f_p - Page 21-11
LOS, S, FFS, v_p - Exhibit 21-2, 21-3
f_{LW} - Exhibit 21-4
f_{LC} - Exhibit 21-5
f_M - Exhibit 21-6
f_A - Exhibit 21-7

EXAMPLE PROBLEM 5

The Highway New suburban facility under planning with an opening-day AADT forecast of 42,000 veh/day.

The Question For opening-day volumes, how many lanes will be needed to provide LOS C during the peak hour?

The Facts

√ 42,000 veh/day,
√ Rolling terrain, and
√ 10 percent trucks.

Comments

√ Several input variables are not given. Reasonable default values based on the traffic engineer's knowledge of local conditions are selected as 10 percent trucks, 0 percent RVs, lane width of 3.6 m, undivided highway, K = 0.10, directional split of 60/40, BFFS = 90.0 km/h, access-point density of 4 access points/km, PHF = 0.90, and shoulder width of 1.8 m.
√ Assume commuter traffic (f_p = 1.00).

Outline of Solution Using the multilane highways worksheet (Appendix A), determine required lane configuration.

Steps

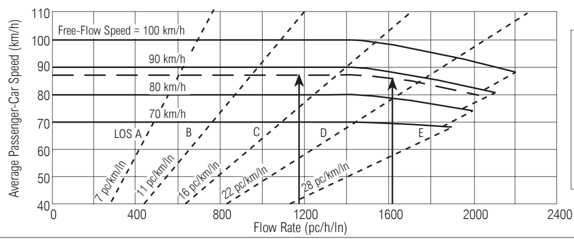
1. Convert AADT to directional design-hour volume (DDHV).	DDHV = AADT * K * D DDHV = 42,000 * 0.10 * 0.60 DDHV = 2,520 veh/h
2. Find f_{HV} (use Exhibit 21-8).	$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \frac{1}{1 + 0.1(2.5 - 1) + 0} = 0.870$
3. Compute free-flow speed (use Exhibits 21-4, 21-5, 21-6, and 21-7).	$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$ FFS = 90.0 – 0.0 – 0.0 – 2.7 – 2.6 = 84.7 km/h
4. Assume four-lane highway and compute v_p (use Equation 21-3).	$v_p = \frac{2,520}{0.90 * 0.870 * 2 * 1.00} = 1,609$ pc/h/ln
5. Determine LOS (use Exhibit 21-3).	LOS D
6. Assume six-lane highway and compute v_p (use Equation 21-3).	$v_p = \frac{2,520}{0.90 * 0.870 * 3 * 1.00} = 1,073$ pc/h/ln
7. Determine LOS (use Exhibit 21-3).	LOS C

The Results

- A 6-lane freeway is needed,
- LOS C,
- Speed = 84.7 km/h, and
- D = 12.7 pc/km/h.

Example Problem 5

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst	JMYE
Agency or Company	EHI
Date Performed	5/16/99
Analysis Time Period	PM

Site Information

Highway/Direction of Travel	
From/To	
Jurisdiction	M. County
Analysis Year	1999

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

Flow Inputs

Volume, V		veh/h
Annual avg. daily traffic, AADT	42,000	veh/day
Peak-hour proportion of AADT, K	0.10	
Peak-hour direction proportion, D	0.60	
DDHV = AADT * K * D	2520	veh/h

Driver type
☒ Commuter/Weekday ☐ Recreational/Weekend

Peak-hour factor, PHF	0.90
% Trucks and buses, P_T	10
% RVs, P_R	0

General terrain
☐ Level ☒ Rolling ☐ Mountainous

Grade: Length ______ km Up/Down ______ %

Number of lanes ______

Calculate Flow Adjustments

f_p	1.00
E_T	2.5
E_R	
$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	0.870

Speed Inputs

Lane width, LW	3.6	m
Total lateral clearance, TLC	3.6	m
Access points, A	4	A/km
Median type, M	☒ Undivided ☐ Divided	
FFS (measured)		km/h
Base free-flow Speed, BFFS	90	km/h

Calculate Speed Adjustments and FFS

f_{LW}	0.0	km/h
f_{LC}	0.0	km/h
f_A	2.7	km/h
f_M	2.6	km/h
$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M$	84.7	km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$		pc/h/ln
S		km/h
$D = v_p/S$		pc/km/ln
LOS		

Design (v_p) or Planning (v_p)

LOS		
v_p		pc/h/ln
$V = v_p * PHF * N * f_{HV} * f_p$		veh/h
S		km/h
$D = v_p/S$		pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N	2	assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1,609	pc/h/ln
LOS	D	

Design (N) or Planning (N) 2nd Iteration

N	3	assumed
$v_p = \frac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$	1,073	pc/h/ln
LOS	C	
S	84.7	km/h
$D = v_p/S$	12.7	pc/km/ln

Glossary

N - Number of lanes
V - Hourly volume
v_p - Flow rate
LOS - Level of service
DDHV - Directional design-hour volume
S - Speed
D - Density
FFS - Free-flow speed
BFFS - Base free-flow speed

Factor Location

E_T - Exhibit 21-8, 21-9, 21-11
E_R - Exhibit 21-8, 21-10
f_p - Page 21-11
LOS, S, FFS, v_p - Exhibit 21-2, 21-3
f_{LW} - Exhibit 21-4
f_{LC} - Exhibit 21-5
f_M - Exhibit 21-6
f_A - Exhibit 21-7

V. REFERENCES

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3. Armour, M. The Effect of Police Presence on Urban Driving Speeds. *Australian Road Research*, Vol. 14, No. 3, Sept. 1984, pp. 142–148.
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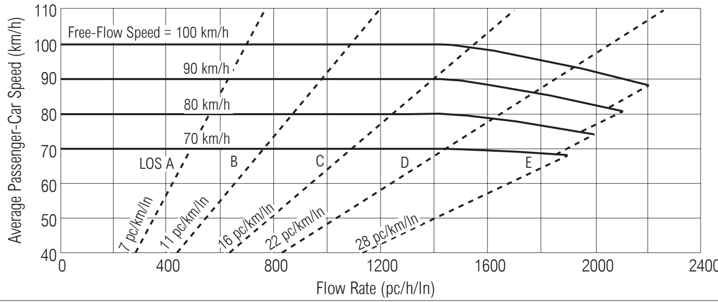
APPENDIX A. WORKSHEET

MULTILANE HIGHWAYS WORKSHEET

MULTILANE HIGHWAYS WORKSHEET



Application	Input	Output
Operational (LOS)	FFS, N, v_p	LOS, S, D
Design (N)	FFS, LOS, v_p	N, S, D
Design (v_p)	FFS, LOS, N	v_p, S, D
Planning (LOS)	FFS, N, AADT	LOS, S, D
Planning (N)	FFS, LOS, AADT	N, S, D
Planning (v_p)	FFS, LOS, N	v_p, S, D

General Information

Analyst ____________
Agency or Company ____________
Date Performed ____________
Analysis Time Period ____________

Site Information

Highway/Direction of Travel ____________
From/To ____________
Jurisdiction ____________
Analysis Year ____________

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

Flow Inputs

Volume, V ____________veh/h
Annual avg. daily traffic, AADT ____________veh/day
Peak-hour proportion of AADT, K ____________
Peak-hour direction proportion, D ____________
DDHV = AADT * K * D ____________veh/h
Driver type
❑ Commuter/Weekday ❑ Recreational/Weekend

Peak-hour factor, PHF ____________
% Trucks and buses, P_T ____________
% RVs, P_R ____________
General terrain
❑ Level ❑ Rolling ❑ Mountainous
Grade: Length ________km Up/Down ________%
Number of lanes ____________

Calculate Flow Adjustments

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

Speed Inputs

Lane width, LW ____________m
Total lateral clearance, TLC ____________m
Access points, A ____________A/km
Median type, M ❑ Undivided ❑ Divided
FFS (measured) ____________km/h
Base free-flow Speed, BFFS ____________km/h

Calculate Speed Adjustments and FFS

f_{LW} ____________km/h
f_{LC} ____________km/h
f_A ____________km/h
f_M ____________km/h
FFS = BFFS – f_{LW} – f_{LC} – f_A – f_M ____________km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \dfrac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
S ____________km/h
D = v_p /S ____________pc/km/ln
LOS ____________

Design (v_p) or Planning (v_p)

LOS ____________
v_p ____________pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p ____________veh/h
S ____________km/h
D = v_p/S ____________pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N ____________assumed
$v_p = \dfrac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
LOS ____________

Design (N) or Planning (N) 2nd Iteration

N ____________assumed
$v_p = \dfrac{V \text{ or } DDHV}{PHF * N * f_{HV} * f_p}$ ____________pc/h/ln
LOS ____________
S ____________km/h
D = v_p /S ____________pc/km/ln

Glossary

N - Number of lanes
V - Hourly volume
v_p - Flow rate
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