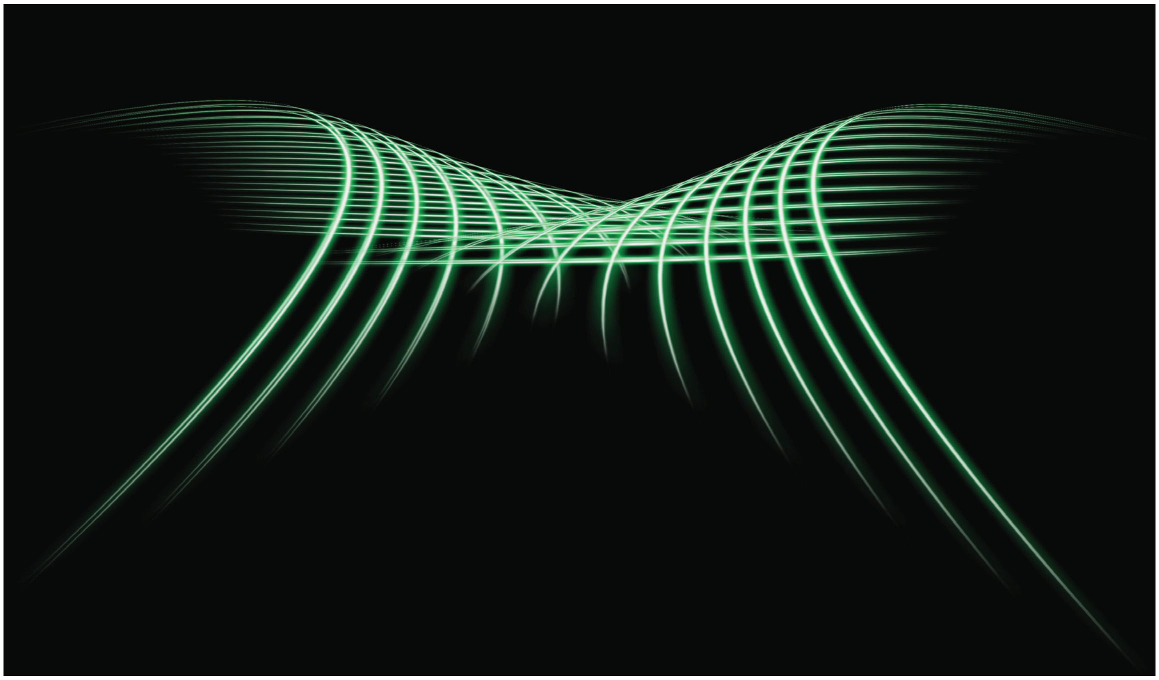
HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 14

MULTILANE HIGHWAYS

TRB TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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HCM2010

HIGHWAY CAPACITY MANUAL

The HCM 2010 significantly enhances how engineers and planners assess the traffic and environmental effects of highway projects by

- Providing an integrated multimodal approach to the analysis and evaluation of urban streets from the points of view of automobile drivers, transit passengers, bicyclists, and pedestrians;
- Addressing the proper application of microsimulation analysis and the evaluation of the results;
- Examining active traffic management in relation to demand and capacity; and
- Exploring specific tools and generalized service volume tables to assist planners in quickly sizing future facilities.

The HCM 2010 consists of four volumes:

Volume 1: Concepts;
Volume 2: Uninterrupted Flow;
Volume 3: Interrupted Flow; and
Volume 4: Applications Guide (electronic only).

The four-volume format provides information at several levels of detail, to help users more easily apply and understand the concepts, methodologies, and potential applications.

Volumes 1, 2, and 3 are issued as a boxed set. Volume 4 is electronic only, accessible to registered HCM users via the Internet, and includes four types of content: supplemental chapters on methodological details and emerging issues; interpretations, clarifications, and corrections; comprehensive case studies; and a technical reference library.

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CHAPTER 14
MULTILANE HIGHWAYS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

Chapter 14, Multilane Highways, addresses capacity and level-of-service (LOS) analysis for uninterrupted-flow segments of surface multilane highways. In general, uninterrupted flow may exist on a multilane highway if there are 2 mi or more between traffic signals. Where signals are more closely spaced, the facility should be analyzed as an urban street.

Many multilane highways will have periodic signalized intersections, even if the average signal spacing is well over 2 mi. In such cases, the multilane highway segments that are more than 2 mi away from any signalized intersections are analyzed by using the methodology of this chapter. Isolated signalized intersections should be analyzed with the methodology of Chapter 18, Signalized Intersections.

LOS procedures are provided for both automobiles and bicycles. The automobile methodology is based on the results of NCHRP Project 3-33 (*1*), and bicycle LOS is based on research conducted for the Florida Department of Transportation (*2*). The same methodology for bicycle LOS is used for both multilane and two-lane highways; readers interested in details of the bicycle methodology should refer to Chapter 15, Two-Lane Highways.

TYPES OF MULTILANE HIGHWAYS

Multilane highways generally have four to six lanes (in both directions) and posted speed limits between 40 and 55 mi/h. In some states, speed limits of 60 or 65 mi/h are used on some multilane highways. These highways may be divided by one of various median types, may be undivided (with only a centerline separating the directions of flow), or may have a two-way left-turn lane (TWLTL). They are typically located in suburban areas, leading into central cities, or along high-volume rural corridors, connecting two cities or two activity centers that generate a substantial number of daily trips. Exhibit 14-1 illustrates common types of multilane highways.

Traffic volumes on multilane highways vary widely but often have demand in the range of 15,000 to 40,000 veh/day. In some cases, volumes as high as 100,000 veh/day have been observed when access across the median is restricted and when major crossings are grade-separated. Bicycles are typically permitted on multilane highways, and multilane highways often serve as primary routes for both commuter cyclists (on suburban highways) and recreational cyclists (on rural highways).

BASE CONDITIONS

Base conditions include good weather, good visibility, and no incidents or accidents. These conditions are always assumed to exist.

The base conditions under which the full capacity of a multilane highway segment is achieved include good weather, good visibility, no incidents or accidents, no work zone activity, and no pavement defects that would affect operations. This chapter's methodology assumes that these conditions exist. If any of these conditions do not exist, the speed, LOS, and capacity of the multilane highway segment can be expected to be worse than the predictions by this methodology.

Exhibit 14-1
Multilane Highways

(a) Divided suburban multilane highway

(b) Undivided suburban multilane highway

(c) Suburban multilane highway with TWLTL

(d) Undivided rural multilane highway

Base conditions include the following conditions; the methodology can be adjusted to address situations in which these conditions do not exist:

Base conditions include 0% heavy vehicles and a driver population composed of regular users of the highway.

The methodology provides adjustments for situations in which these conditions do not apply.

- No heavy vehicles, such as trucks, buses, and recreational vehicles (RVs), in the traffic stream; and
- A driver population composed primarily of regular users who are familiar with the facility.

Characteristics such as lane width, total lateral clearance (TLC), median type, and access-point density will have an impact on the free-flow speed (FFS) of the facility. Curves describing operations under base conditions, however, account for differing FFSs.

FLOW CHARACTERISTICS UNDER BASE CONDITIONS

More severe geometric characteristics and the existence of access points are two key differences that result in lower multilane highway speeds and capacities than those of freeways with similar cross sections.

Uninterrupted flow on multilane highways is in most ways similar to that on basic freeway segments (Chapter 11). Several factors are different, however. Because side frictions are present in varying degrees from uncontrolled driveways and intersections as well as from opposing flows on undivided cross sections, speeds on multilane highways tend to be lower than those on similar basic freeway segments. The basic geometry of multilane highways also tends to be more severe than that of basic freeway segments because of the lower speed expectations. Last, isolated signalized intersections can exist along multilane highways. The overall result is that speeds and capacities on multilane highways are lower than those on basic freeway segments with similar cross sections.

Exhibit 14-2 shows speed–flow characteristics of multilane highway segments for various FFSs. Equations describing these curves are shown in Exhibit 14-3.

Curves are shown for FFSs between 45 mi/h and 60 mi/h. Because FFSs can vary widely, it is recommended that the FFS of a multilane highway segment be estimated to the nearest 5 mi/h, as follows:

The FFS of a multilane highway segment should be rounded to the nearest 5 mi/h.

42.5 mi/h ≤ FFS < 47.5 mi/h: use FFS = 45 mi/h,

47.5 mi/h ≤ FFS < 52.5 mi/h: use FFS = 50 mi/h,

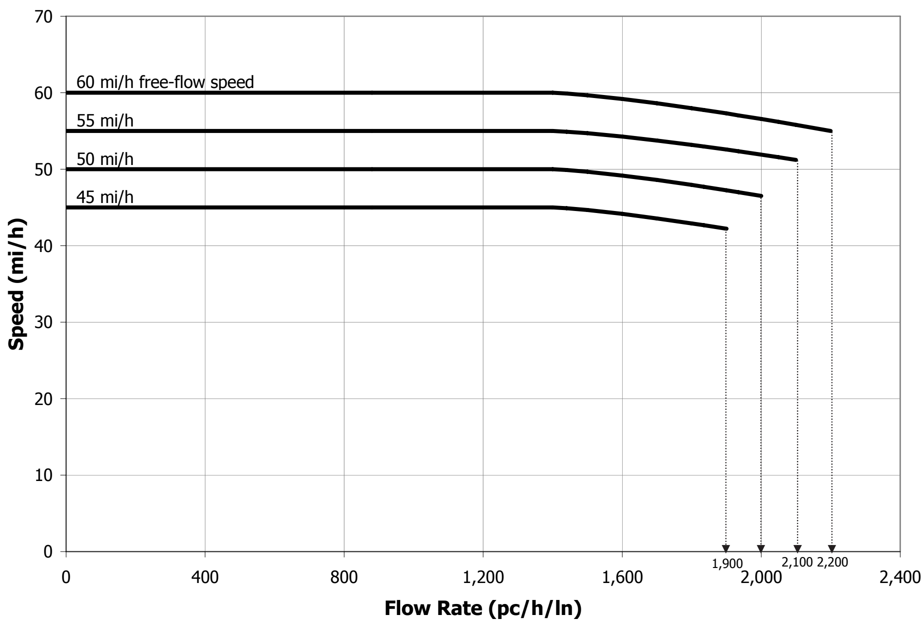
52.5 mi/h ≤ FFS < 57.5 mi/h: use FFS = 55 mi/h,

57.5 mi/h ≤ FFS < 62.5 mi/h: use FFS = 60 mi/h.

For multilane highway segments, speeds remain constant until they reach 1,400 pc/h/ln, after which speeds decline with further increases in flow rate.

Flow rates over 1,400 pc/h/ln result in speeds below the highway's FFS.

Exhibit 14-2
Speed–Flow Curves for Multilane Highways Under Base Conditions



Note: Maximum densities for LOS E occur at a *v/c* ratio of 1.00. These are 40, 41, 43, and 45 pc/mi/ln for FFSs of 60, 55, 50, and 45 mi/h, respectively.

Exhibit 14-3
Equations Describing Speed–Flow Curves in Exhibit 14-2

FFS (mi/h)	For $v_p \leq$ 1,400 pc/h/ln, S (mi/h)	For $v_p >$ 1,400 pc/h/ln, S (mi/h)
60	60	$60-\left[5.00\times\left(\frac{v_p-1400}{800}\right)^{1.31}\right]$
55	55	$55-\left[3.78\times\left(\frac{v_p-1400}{700}\right)^{1.31}\right]$
50	50	$50-\left[3.49\times\left(\frac{v_p-1400}{600}\right)^{1.31}\right]$
45	45	$45-\left[2.78\times\left(\frac{v_p-1400}{500}\right)^{1.31}\right]$

Multilane highways with higher FFSs will also have higher base capacities. As most highways do not operate under base conditions, observed capacities will usually be lower than the base capacity.

Capacities represent an average flow rate across all lanes. Individual lanes could have higher stable flows.

CAPACITY OF MULTILANE HIGHWAY SEGMENTS

The capacity of a multilane highway segment under base conditions varies with the FFS. For 60-mi/h FFS, the capacity is 2,200 pc/h/ln. For lesser FFSs, capacity diminishes. For 55-mi/h FFS, the capacity is 2,100 pc/h/ln; for 50-mi/h FFS, 2,000 pc/h/ln; and for 45-mi/h FFS, 1,900 pc/h/ln.

These values represent national norms. Capacity varies stochastically, and any given location could have a larger or smaller value. In addition, capacity refers to the average flow rate across all lanes. Thus, a two-lane (in one direction) multilane highway segment with a 60-mi/h FFS would have an expected capacity of 2 × 2,200 = 4,400 pc/h. This flow would not be uniformly distributed in the two lanes. Thus, one lane could have stable flows in excess of 2,200 pc/h/ln.

LOS FOR MULTILANE HIGHWAY SEGMENTS

Automobile Mode

Automobile LOS is defined by density.

Automobile LOS for multilane highway segments are defined in Exhibit 14-4. Because speeds are constant through a broad range of flow rates, LOS are defined on the basis of density, which is a measure of the proximity of vehicles to each other in the traffic stream.

Exhibit 14-4
Automobile LOS for Multilane Highway Segments

LOS	FFS (mi/h)	Density (pc/mi/ln)
A	All	>0–11
B	All	>11–18
C	All	>18–26
D	All	>26–35
E	60	>35–40
	55	>35–41
	50	>35–43
	45	>35–45
F	Demand Exceeds Capacity	
	60	>40
	55	>41
	50	>43
	45	>45

LOS thresholds for multilane highways are the same as those on freeways for LOS A–D. However, multilane highway capacity (the LOS E–F boundary) occurs at lower densities.

For LOS A through D, the criteria are the same as those for basic freeway segments. This classification is appropriate, since both represent multilane uninterrupted flow. The boundary between LOS E and F, however, represents capacity. For multilane highways, capacity occurs at varying densities, depending on the FFS. The density at capacity ranges from 40 pc/mi/ln for 60-mi/h FFS to 45 pc/mi/ln for 45-mi/h FFS.

LOS F is determined when the demand flow rate exceeds capacity. When this occurs, the methodology does not produce a density estimate. Thus, although density in such cases will be above the thresholds shown, specific values cannot be determined.

Exhibit 14-5 shows LOS thresholds in relation to the base speed–flow curves.

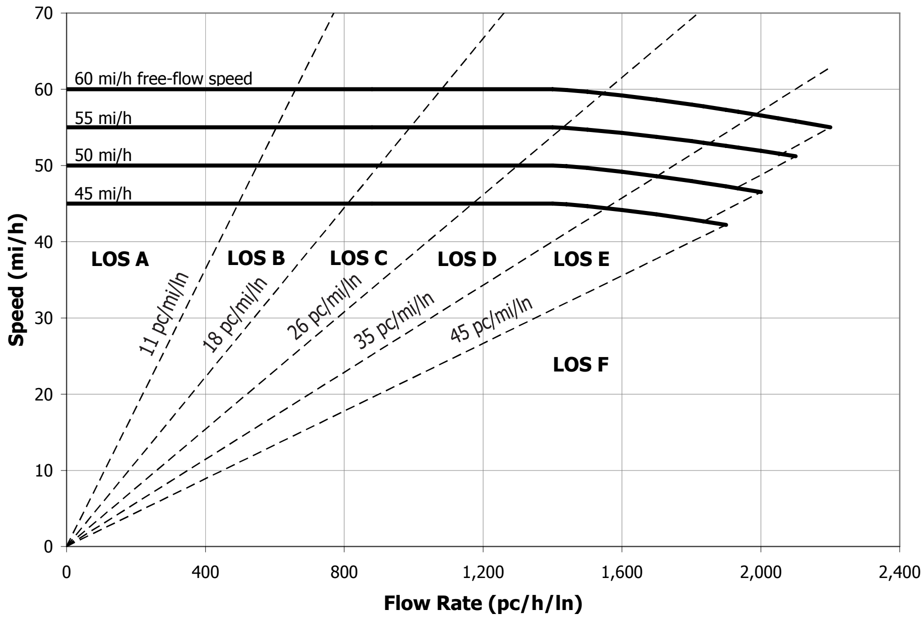


Exhibit 14-5
LOS on Base Speed–Flow Curves

Automobile LOS Described

The descriptions of LOS for basic freeway segments given in Chapter 11 are also generally applicable to multilane highways. Vehicles entering the highway from a direct access point are an additional factor on multilane highways; these vehicles are not present on basic freeway segments and could result in a breakdown of flow at high flow rates.

The LOS thresholds for multilane highways reflect the collective professional judgment of the members of the Transportation Research Board's Highway Capacity and Quality of Service Committee. The upper values shown for LOS F (40 to 45 pc/mi/ln, depending on the FFS) represent the maximum density at which sustained flows at capacity are expected to occur. Breakdown (LOS F) conditions on multilane highways occur whenever the highway's demand exceeds its capacity.

Bicycle Mode

Bicycle LOS for multilane highway segments are based on a bicycle LOS score, which is in turn based on a traveler-perception index. Chapter 15, Two-Lane Highways, provides details about this index, which is identical for two-lane highways and multilane highways. The LOS ranges for bicycles on multilane highways are given in Exhibit 14-6.

Bicycle LOS is based on a traveler-perception index score. Details are given in Chapter 15.

Exhibit 14-6
Bicycle LOS on Multilane Highways

LOS	Bicycle LOS Score
A	≤1.5
B	>1.5–2.5
C	>2.5–3.5
D	>3.5–4.5
E	>4.5–5.5
F	>5.5

REQUIRED INPUT DATA

Automobile Mode

Analysis of a multilane highway segment requires details concerning the geometric characteristics of the segment and the demand characteristics of the users of the segment. This section presents the required input data for the basic freeway segment methodology; specifics about individual parameters are given in Section 2, Methodology.

Data Describing Multilane Highway Segment

The following information concerning the geometric features of the multilane highway segment is needed to conduct an analysis:

- FFS: 45 to 60 mi/h;
- Number of lanes (one direction): two or three;
- Lane width: 10 ft to more than 12 ft;
- Right-side lateral clearance: 0 ft to more than 6 ft;
- Median- (left-) side lateral clearance: 0 ft to more than 6 ft;
- Access-point density: 0 to 40 points/mi;
- Terrain: level, rolling, or mountainous; or length and percent grade of specific grades; and
- Type of median: divided, TWLTL, or undivided.

Data Describing Demand

The following information is required concerning the users of the multilane highway segment:

- Demand during the analysis hour; or daily demand, *K*-factor, and *D*-factor;
- Heavy-vehicle presence (percent trucks and buses, percent RVs): 0%–100% in general terrain or 0%–25% for specific grades;
- Peak hour factor (PHF): up to 1.00; and
- Driver-population factor: 0.85–1.00.

Length of Analysis Period

The period for any multilane highway analysis is generally the critical 15-min period within the peak hour. The methodology can be applied to any 15-min period, however.

If demand volumes are used, demand flow rates are estimated through the use of the PHF. When 15-min volumes are directly measured, the worst analysis period within the hour is selected, and flow rates are the 15-min volumes multiplied by 4. For subsequent computations in the methodology, the PHF is set to 1.00.

Bicycle Mode

The following data are required to evaluate bicycle LOS on a multilane highway; the ranges of values used in the development of the bicycle LOS model (*2*) are also shown:

- Width of the outside through lane: 10 to 16 ft,
- Shoulder width: 0 to 6 ft,
- Motorized vehicle volumes: up to 36,000 annual average daily traffic (AADT),
- Number of directional through lanes,
- Posted speed: 45 to 50 mi/h,
- Heavy-vehicle percentage: 0% to 2%, and
- Pavement condition: present serviceability rating of 1 to 5.

2. METHODOLOGY

This methodology is used to analyze the capacity, LOS, lane requirements, and impacts of traffic and design features on uninterrupted-flow segments of rural and suburban multilane highways.

LIMITATIONS OF METHODOLOGY

Automobile Mode

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

- The negative impacts of poor weather conditions, traffic accidents or incidents, railroad crossings, or construction operations;
- Interference caused by parking on the shoulders of the multilane highway;
- The effect of lane drops and lane additions at the beginning or end of multilane highway segments;
- Possible queuing impacts when a multilane highway segment transitions to a two-lane highway segment;
- Differences between various types of median barriers and the difference between the impacts of a median barrier and a TWLTL;
- FFS below 45 mi/h or higher than 60 mi/h;
- Significant presence of on-street parking;
- Presence of bus stops that have significant use; and
- Significant pedestrian activity.

The last three factors are more representative of an urban or suburban arterial, but they may also exist on facilities with more than 2 mi between traffic signals. When the factors are present on uninterrupted-flow segments of multilane highways, the methodology does not deal with their impact on flow. In addition, this methodology cannot be applied to highways with a total of three lanes in both directions, which should be analyzed as two-lane highways with periodic passing lanes.

Uninterrupted-flow facilities that allow access solely through a system of on-ramps and off-ramps from grade separations or service roads should be analyzed as freeways.

Bicycle Mode

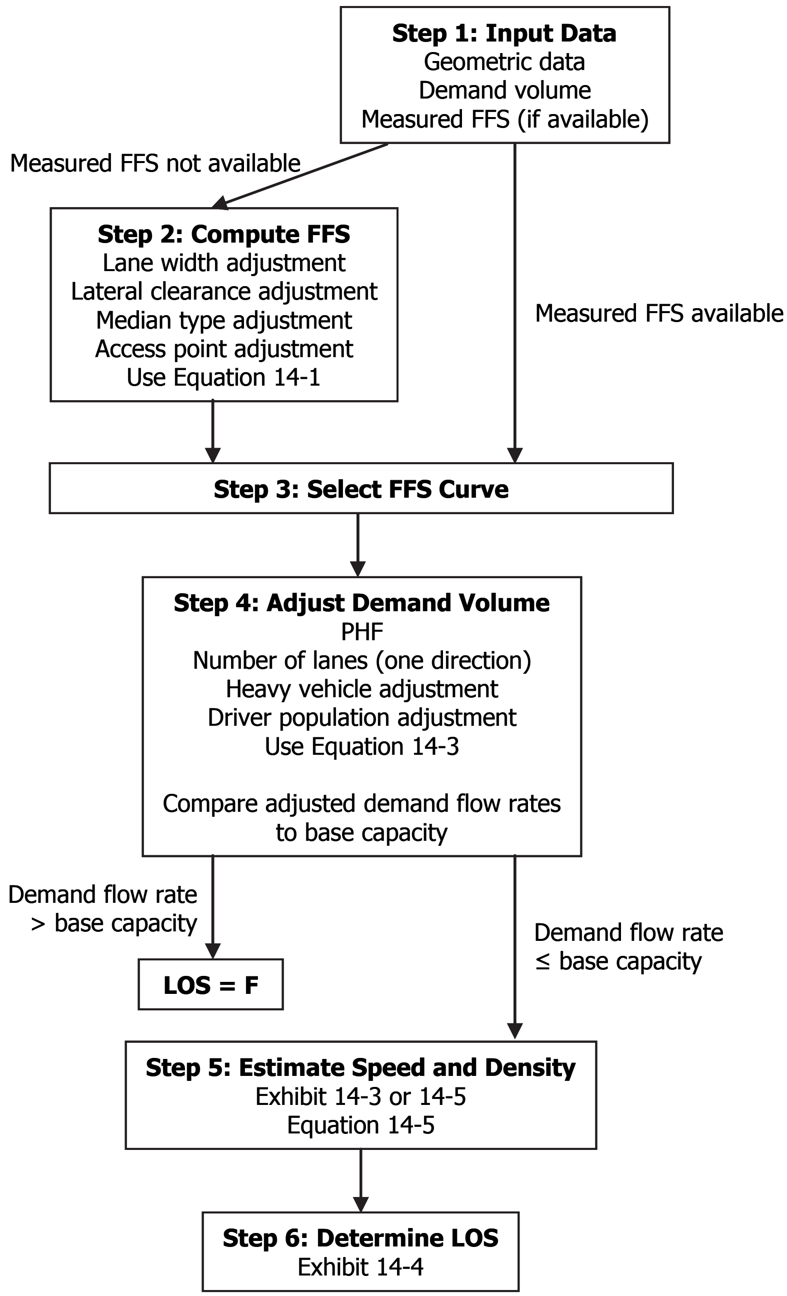
Although the bicycle LOS model has been successfully applied to rural multilane highways, users should be aware that conditions on many of those highways are outside the range of values used to develop the model.

The bicycle methodology was developed with data collected on urban and suburban streets, including facilities that would be defined as suburban multilane highways. Although the methodology has been successfully applied to rural multilane highways in different parts of the United States, users should be aware that conditions on many rural multilane highways (i.e., posted speeds of 55 mi/h or higher or heavy-vehicle percentages over 2%) will be outside the range of values used to develop the bicycle LOS model.

AUTOMOBILE MODE

Exhibit 14-7 provides an overview of this chapter's computational methodology for the automobile mode. It shows a typical operational analysis in which the LOS is determined for a specified set of geometric and traffic conditions. The methodology can also be used, as described in this chapter's Applications section, to determine the number of lanes needed to provide a target LOS, as well as to determine service flow rates, service volumes, and daily service volumes.

Exhibit 14-7
Overview of Multilane Highway Methodology for Automobile Mode



Step 1: Input Data

For a typical operational analysis, the analyst must specify (with either site-specific or default values) demand volume; number and width of lanes; right-side and median lateral clearance; type of median; roadside access points per mile; percent of heavy vehicles, such as trucks, buses, and RVs; PHF; terrain; and driver population factor.

Step 2: Compute FFS

FFS can be determined directly from field measurements or can be estimated as described below.

Field Measurement

FFS is the mean speed of passenger cars during periods of low to moderate flow.

FFS is the mean speed of passenger cars measured during periods of low to moderate flow (up to 1,400 pc/h/ln). For a specific multilane highway segment, speeds are virtually constant in this range of flow rates. If the FFS can be field measured, that determination is preferable. If the FFS is measured directly, no adjustments are applied to the measured value.

The speed study should be conducted at a location representative of the segment at a time when flow rates are less than 1,400 pc/h/ln. The speed study should measure the speeds of all passenger cars or use a systematic sample (e.g., every tenth car in each lane). A sample of at least 100 passenger-car speeds should be obtained. Any speed measurement technique that has been found acceptable for other types of traffic engineering applications may be used. Further guidance on the conduct of speed studies is provided in a standard traffic engineering publication (*3*).

Estimation

It is not possible to make field measurements for future facilities, and field measurement may not be possible or practical for all existing ones. In such cases, the segment's FFS may be estimated by using Equation 14-1, which is based on the physical characteristics of the segment under study:

Equation 14-1

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

where

$BFFS$ = base FFS for multilane highway segment (mi/h);

FFS = FFS of basic freeway segment (mi/h);

f_{LW} = adjustment for lane width, from Exhibit 14-8 (mi/h);

f_{LC} = adjustment for TLC, from Exhibit 14-9 (mi/h);

f_M = adjustment for median type, from Exhibit 14-10 (mi/h); and

f_A = adjustment for access-point density, from Exhibit 14-11 (mi/h).

Base FFS

This methodology covers multilane highway segments with FFS ranging from 45 mi/h to 60 mi/h. The most significant value in Equation 14-1 is the BFFS. There is not a great deal of information available to help establish a base value. In one sense, it is like the design speed—it represents the potential FFS based only on the horizontal and vertical alignment of the highway, not on the impacts of lane widths, lateral clearances, median type, and access points. The design speed may be used as the BFFS if it is available.

Although speed limits are not always uniformly set, the BFFS may be estimated, if necessary, as the posted or statutory speed limit plus 5 mi/h for speed limits 50 mi/h and higher and as the speed limit plus 7 mi/h for speed limits less than 50 mi/h.

Adjustment for Lane Width

Average lane widths less than 12 ft reduce the FFS.

The base condition for lane width is 12 ft or greater. When the average lane width across all lanes is less than 12 ft, the FFS is negatively affected. Adjustments to reflect the effect of narrow average lane widths are shown in Exhibit 14-8.

Exhibit 14-8
Adjustment to FFS for Average Lane Width

Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
≥11–12	1.9
≥10–11	6.6

Adjustment for Lateral Clearance

Clearance restrictions on either the right or left side of the highway reduce the FFS.

The adjustment for lateral clearance on multilane highway segments is based on TLC at the roadside (right side) and at the median (left side). 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 to be obstructions.

Right-side lateral clearance is measured from the right edge of the travel lanes to the nearest periodic or continuous roadside obstruction. If such obstructions are farther than 6 ft from the edge of the pavement, a value of 6 ft is used.

Left-side lateral clearance is measured from the left edge of the travel lanes to the nearest periodic or continuous obstruction in the median. If such obstructions are farther than 6 ft from the edge of the pavement, a value of 6 ft is used.

Use 6 ft as the left-side clearance for undivided highways and highways with TWLTLs.

Left-side lateral clearances are subject to some judgment. Many types of common median barriers do not affect driver behavior if they are no closer than 2 ft from the edge of the travel lane, including concrete and W-beam barriers. A value of 6 ft would be used in such cases. Also, when the multilane highway segment is undivided or has a TWLTL, no left-side lateral clearance restriction is assumed, and a value of 6 ft is applied because there is a separate adjustment for the type of median that accounts for the impact of an undivided highway on FFS.

Equation 14-2 is used to determine TLC:

Equation 14-2

$$TLC = LC_R + LC_L$$

where

TLC = total lateral clearance (ft) (maximum value 12 ft);

LC_R = right-side lateral clearance (ft) (maximum value 6 ft); and

LC_L = left-side lateral clearance (ft) (maximum value 6 ft).

Exhibit 14-9 shows the reduction in FFS due to lateral obstructions on the multilane highway.

Exhibit 14-9
Adjustment to FFS for Lateral Clearances

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	**Reduction in FFS (mi/h)**	**TLC (ft)**	**Reduction in FFS (mi/h)**
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Note: Interpolation to the nearest 0.1 is recommended.

Adjustment for Type of Median

The FFS is reduced on undivided highways.

The adjustment for type of median is given in Exhibit 14-10. Undivided multilane highways reduce the BFFS by 1.6 mi/h.

Exhibit 14-10
Adjustment to FFS for Median Type

Median Type	Reduction in FFS, f_M (mi/h)
Undivided	1.6
TWLTL	0.0
Divided	0.0

Adjustment for Access-Point Density

FFS is reduced as the access-point density increases.

Exhibit 14-11 presents the adjustment to FFS for various levels of access-point density. Studies indicate that for each access point per mile, the estimated FFS decreases by approximately 0.25 mi/h, regardless of the type of median.

The number of access points per mile is determined by dividing the total number of access points (i.e., driveways and unsignalized intersections) on the right side of the highway in the direction of travel by the length of the segment in miles. An intersection or driveway should only be included in the count if it influences traffic flow. Access points that go unnoticed by drivers, or with little activity, should not be used to determine access-point density.

Exhibit 14-11
Adjustment to FFS for Access-Point Density

Access-Point Density (access points/mi)	Reduction in FFS, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥40	10.0

Note: Interpolation to the nearest 0.1 is recommended.

Although the calibration of this adjustment did not include one-way multilane highway segments, it might be appropriate to include intersection approaches and driveways on both sides of the facility in determining the access-point density on one-way segments.

Step 3: Select FFS Curve

As noted previously, once the multilane highway segment's FFS is determined, one of the four base speed–flow curves from Exhibit 14-2 is selected for use in the analysis. Interpolating between curves is not recommended. Criteria for selecting an appropriate curve were given in the text preceding Exhibit 14-2.

Step 4: Adjust Demand Volume

The basic speed–flow curves of Exhibit 14-2 are based on flow rates in equivalent passenger cars per hour, with the driver population dominated by regular users of the multilane highway segment. Demand volumes expressed as vehicles per hour under prevailing conditions must be converted to this basis. Equation 14-3 is used for this adjustment:

Equation 14-3

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

where

- v_p = demand flow rate under equivalent base conditions (pc/h/ln);
- V = demand volume under prevailing conditions (veh/h);
- PHF = peak hour factor;
- N = number of lanes (one direction);
- f_{HV} = adjustment factor for presence of heavy vehicles in traffic stream, from Equation 14-4; and
- f_p = adjustment factor for atypical driver populations.

PHF

The 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 within an hour are not sustained throughout the entire hour. The application of the PHF in Equation 14-3 accounts for this phenomenon.

On multilane highways, typical PHFs range from 0.75 to 0.95. Lower values are typical of lower-volume conditions. Higher values are typical of urban and suburban peak-hour conditions. Field data should be used if possible to develop PHFs that represent local conditions.

Adjustment for Heavy Vehicles

A *heavy vehicle* is defined as any vehicle with more than four wheels on the ground during normal operation. Such vehicles are generally categorized as trucks, buses, or RVs. Trucks cover a wide variety of vehicles, from single-unit trucks with double rear tires to triple-unit tractor–trailer combinations. Small panel or pickup trucks with only four wheels are, however, classified as passenger cars. Buses include intercity buses, public transit buses, and school buses. Because buses are in many ways similar to single-unit trucks, both types of vehicles are considered in one category. RVs include a wide variety of vehicles from self-contained motor homes to cars and small trucks with trailers (for boats, all-terrain vehicles, or other items). The heavy-vehicle adjustment factor f_{HV} is computed by using Equation 14-4:

Equation 14-4

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

where

f_{HV} = heavy-vehicle adjustment factor,

P_T = proportion of trucks and buses in traffic stream,

P_R = proportion of RVs in traffic stream,

E_T = passenger-car equivalent (PCE) of one truck or bus in traffic stream, and

E_R = PCE of one RV in traffic stream.

The adjustment factor is found in a two-step process. First, the PCE for each truck, bus, and RV is found for the prevailing conditions under study. These equivalency values represent the number of passenger cars that would use the same amount of freeway capacity as one truck, bus, or RV under the prevailing conditions. Second, Equation 14-4 is used to convert the PCE values to the adjustment factor.

In many cases, trucks will be the only heavy vehicle present in the traffic stream. In others, the percentage of RVs will be small compared with trucks and buses. If the ratio of trucks and buses to RVs is 5:1 or greater, all heavy vehicles may be (but do not have to be) considered to be trucks.

The effect of heavy vehicles on traffic flow depends on terrain and grade conditions as well as traffic composition. PCEs can be selected for one of three conditions:

- Extended multilane highway segments in general terrain,
- Specific upgrades, or
- Specific downgrades.

Each of these conditions is more precisely defined and discussed below.

Equivalents for General Terrain Segments

General terrain can be applied where

Grades are ≤2%,

Grades are ≤0.25 mi long, or

Grades are >2% and <3%, and are ≤0.50 mi long.

General terrain refers to extended lengths of multilane highway containing a number of upgrades and downgrades where no single grade is long enough or steep enough to have a significant impact on the operation of the overall segment. As a guideline for this determination, extended-segment analysis can be applied where no one grade of 3% or more is longer than 0.25 mi, or where no single grade between 2% and 3% is longer than 0.50 mi.

There are three categories of general terrain:

- *Level terrain*: Any combination of grades and horizontal or vertical alignment that permits heavy vehicles to maintain the same speed as passenger cars. This type of terrain typically contains short grades of no more than 2%.
- *Rolling terrain*: Any combination of grades and horizontal or vertical alignment that causes heavy vehicles to reduce their speed substantially below that of passenger cars but that does not cause heavy vehicles to operate at crawl speeds for any significant length of time or at frequent intervals. *Crawl speed* is the maximum sustained speed that trucks can maintain on an extended upgrade of a given percent. If the grade is long enough, trucks will be forced to decelerate to the crawl speed, which they can maintain for extended distances. Appendix A of Chapter 11, Basic Freeway Segments, contains truck performance curves that provide truck speeds for various lengths and severities of grade. The same curves may be used for uninterrupted-flow segments on multilane highways.
- *Mountainous terrain*: Any combination of grades and horizontal and vertical alignment that causes heavy vehicles to operate at crawl speed for significant distances or at frequent intervals.

Mountainous terrain is relatively rare. Generally, in segments severe enough to cause the type of operation described for mountainous terrain, there will be individual grades that are longer and steeper than the criteria for general terrain analysis.

The mountainous terrain category is rarely used, because individual grades will typically be longer and steeper than the criteria for general terrain analysis.

Exhibit 14-12 shows PCEs for trucks and buses and RVs in general terrain segments.

Exhibit 14-12
PCEs for Heavy Vehicles in General Terrain Segments

Vehicle	PCE by Type of Terrain: Level	Rolling	Mountainous
Trucks and buses, E_T	1.5	2.5	4.5
RVs, E_R	1.2	2.0	4.0

Equivalents for Specific Upgrades

Any grade between 2% and 3% and longer than 0.5 mi, or 3% or greater and longer than 0.25 mi, should be considered to be a separate segment. The analysis of such segments must consider the upgrade conditions and the downgrade conditions separately, as well as whether the grade is a single, isolated grade of constant percentage or part of a series forming a composite grade. Appendix A of Chapter 11 discusses the analysis of composite grades.

Exhibit 14-13 and Exhibit 14-14 give values of E_T and E_R for trucks and buses and for RVs, respectively. These factors vary with the percent of grade, length of grade, and the proportion of heavy vehicles in the traffic stream. Maximum values occur when there are only a few heavy vehicles in the traffic stream. The equivalents decrease as the number of heavy vehicles increases because these vehicles tend to form platoons. Because heavy vehicles have more uniform operating characteristics, fewer large gaps are created in the traffic stream when they platoon, and the impact of a single heavy vehicle in a platoon is less severe than that of a single heavy vehicle in a stream primarily composed of passenger cars. The aggregate impact of heavy vehicles on the traffic stream, however, increases as the number and percentage of heavy vehicles increase.

Exhibit 14-13
PCEs for Trucks and Buses (E_T) on Upgrades

Percent Upgrade	Length (mi)	Proportion of Trucks and Buses 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2 – 3	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50 – 0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75 – 1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00 – 1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3 – 4	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50 – 0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75 – 1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00 – 1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
>4 – 5	0.00 – 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.50 – 0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75 – 1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
>5 – 6	0.00 – 0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30 – 0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50 – 0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	>0.75 – 1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
>6	0.00 – 0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.0
	>0.25 – 0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30 – 0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50 – 0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75 – 1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Note: Interpolation for percentage of trucks and buses is recommended to the nearest 0.1.

Exhibit 14-14
PCEs for RVs (E_R) on Upgrades

Percent Upgrade	Length (mi)	Proportion of RVs 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
>2 – 3	0.00 – 0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
>3 – 4	0.00 – 0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	>0.25 – 0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
>4 – 5	0.00 – 0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>0.25 – 0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
>5	0.00 – 0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	>0.25 – 0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	>0.50	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

Note: Interpolation for percentage of RVs is recommended to the nearest 0.1.

The grade length should include 25% of the length of the vertical curves at the start and end of the grade.

With two consecutive upgrades, 50% of the length of the vertical curve joining them should be included.

The length of the grade is generally taken from a highway profile. It typically includes the straight portion of the grade plus some portion of the vertical curves at the beginning and end of the grade. It is recommended that 25% of the length of the vertical curves at both ends of the grade be included in the length. Where two consecutive upgrades are present, 50% of the length of the vertical curve joining them is included in the length of each grade.

In the analysis of upgrades, the point of interest is generally at the end of the grade, where heavy vehicles have the maximum effect on operations. However, if a segment ends midgrade (because of a major access point, for example), the length of the grade to the end of the segment would be used.

The point of interest in an analysis of upgrades is usually the spot where heavy vehicles would have the greatest impact on operations: for example, the top of a grade or the top of the steepest grade in a series.

On composite grades, the relative steepness of segments is important. If a 5% upgrade is followed by a 2% upgrade, for example, the maximum impact of heavy vehicles is most likely at the end of the 5% segment. Heavy vehicles would be expected to accelerate after entering the 2% segment.

Equivalents for Specific Downgrades

Knowledge of specific impacts of heavy vehicles on operating conditions on downgrades is limited. In general, if the downgrade is not severe enough to cause trucks to shift into a lower gear (to engage engine braking), heavy vehicles may be treated as if they were on level terrain segments. Where a downgrade is severe, trucks must often use low gears to avoid gaining too much speed and running out of control. In such cases, their effect on operating conditions is more significant than on level terrain. Exhibit 14-15 gives values of E_T for this situation.

Exhibit 14-15
PCEs for Trucks and Buses (E_T) on Specific Downgrades

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

On downgrades, RVs are always treated as if they were on level terrain; E_R is therefore always 1.2 on downgrades regardless of the length or severity of the downgrade or the percentage of RVs in the traffic stream.

E_R is always 1.2 on downgrades.

Equivalents for Composite Grades

The vertical alignment of most multilane highways results in a continuous series of grades. It is often necessary to determine the effect of a series of grades in succession. The most straightforward technique is to compute the *average grade,* defined as the total rise from the beginning of the composite grade to the point of interest divided by the length of the grade (to the point of interest).

The average grade technique is an acceptable approach for grades in which all subsections are less than 4% or the total length of the grade is less than 4,000 ft. For more severe composite grades, a detailed technique is presented in Appendix A of Chapter 11, Basic Freeway Segments. This technique uses vehicle performance curves and equivalent speeds to determine the equivalent simple grade for analysis. It can be applied to composite grades on multilane highways.

The average grade can be used when all component grades are <4% or the total length of the grades is <4,000 ft.

Appendix A of Chapter 11 provides a method for addressing more severe composite grades.

Adjustment for Driver Population

The base traffic stream characteristics for multilane highway segments are representative of regular drivers in a traffic stream composed substantially of commuters, or drivers who are familiar with the facility. It is generally accepted that traffic streams composed of driver populations with different characteristics (e.g., recreational drivers) use freeways less efficiently. Although data are sparse and reported results vary substantially, significantly lower capacities have been reported on weekends, particularly in recreational areas. It may generally be assumed that the reduced capacity (LOS E) extends to service flow rates and service volumes for other LOS as well.

A f_p-value of 1.00 should generally be used, reflective of drivers who are regular users of the freeway.

The adjustment factor f_p is used to reflect the effect of driver population. The values of f_p usually range from 0.85 to 1.00, although lower values have been observed in some cases. In general, the analyst should use a value of 1.00, which reflects commuters or otherwise familiar drivers, unless there is sufficient evidence that a lower value should be used. Where greater accuracy is needed, comparative field studies of commuter and recreational traffic flow and speeds are recommended.

Does LOS F Exist?

At this point, the demand flow rate has been computed and is stated in units of passenger cars per hour per lane under equivalent base conditions. This demand flow rate must be compared with the base capacity (in the same units). If demand exceeds capacity, LOS F is assigned, and the analysis ends. If demand is less than capacity, LOS F does not exist, and the analysis continues.

Step 5: Estimate Speed and Density

At this point in the methodology, the following have been determined: (*a*) the FFS and appropriate FFS curve for use in the analysis, and (*b*) the demand flow rate expressed in passenger cars per hour per lane under equivalent base conditions. With this information, the estimated speed and density of the traffic stream may be determined.

With the equations specified in Exhibit 14-3, the expected mean speed of the traffic stream can be computed. A graphical solution using Exhibit 14-2 can also be performed.

With the estimated speed determined, Equation 14-5 is used to estimate the density of the traffic stream:

Equation 14-5

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

where

D = density (pc/mi/ln),

v_p = demand flow rate (pc/h/ln), and

S = mean speed of traffic stream (mi/h).

Step 6: Determine LOS

Exhibit 14-4 is entered with the density obtained from Equation 14-5 to determine the expected prevailing LOS.

BICYCLE MODE

The calculation of bicycle LOS on multilane and two-lane highways shares the same methodology, since multilane and two-lane highways operate in fundamentally the same manner for bicyclists and car drivers. Cyclists travel much more slowly than the prevailing traffic flow and stay as far to the right as possible, including using paved shoulders when available. This similarity indicates the need for only one model.

Follow the step-by-step description of the bicycle LOS method given in Chapter 15, Two-Lane Highways, when bicycle LOS on multilane highways is calculated.

The bicycle LOS model for multilane highways uses a traveler perception index calibrated by using a linear regression model. The model fits independent variables associated with roadway characteristics to the results of a user survey that rates the comfort of various bicycle facilities. The resulting bicycle LOS index computes a numerical LOS score, generally ranging from 0.5 to 6.5, which is stratified to produce a LOS A to F result by using Exhibit 14-6.

Full details on the bicycle LOS methodology and calculation procedures are given in Chapter 15, Two-Lane Highways.

3. APPLICATIONS

The analysis methodology for multilane highway segments is relatively straightforward. Thus, it can be directly used in any one of four applications:

1. *Operational analysis*: All traffic and roadway conditions are specified for an existing facility or a future facility with forecast conditions. The existing or expected LOS is determined.
2. *Design analysis*: A forecast demand volume is used, and key design parameters are specified (e.g., lane width and lateral clearance). The number of lanes required to deliver a target LOS is determined.
3. *Planning and preliminary engineering*: The basic scenario is the same as that for design analysis except that the analysis is conducted at a much earlier stage in the development process. Inputs include default values, and the demand volume is usually stated as an AADT.
4. *Service flow rates and service volumes*: The service flow rate, service volume, daily service volume, or all three are estimated for each LOS for an existing or future facility. All traffic and roadway conditions must be specified for this type of analysis.

Because the methodology and its algorithms are simple and do not involve iterations, all of the types of analysis cited can be completed without the iterative approach required by many other HCM methodologies.

DEFAULT VALUES

For this chapter's methodology, a range of input data is needed. Most of these data should be field measured or estimated values for the specific segment under consideration. When some of the data are not available, default values may be used. However, use of default values will affect the accuracy of the output. Exhibit 14-16 shows the data that are required to conduct an operational analysis and the recommended default values when site-specific data are unavailable (*4*).

Exhibit 14-16
Required Input Data and Default Values for Multilane Highway Segments

Required Data	Default Values
Geometric Data	
Number of lanes in one direction	2 or 3 (in one direction), must have site-specific value
Lane width	12 ft
TLC	12 ft
Access-point density	8 access points/mi (rural) 16 access points/mi (low-density suburban) 25 access points/mi (high-density suburban)
Terrain or specific grade (%, length)	No default, must have site-specific value
Base FFS	65 mi/h
Demand Data	
Length of analysis period	15 min
PHF	0.88, rural; 0.95, suburban
Percentage of heavy vehicles	10%, rural; 5%, urban*
Driver population factor	1.00

Note: *Alternative state-specific default values for percentage of heavy vehicles are given in Chapter 26, Freeway and Highway Segments: Supplemental.

The analyst may also replace the default values of Exhibit 14-16 with defaults that have been locally calibrated.

ESTABLISHING ANALYSIS BOUNDARIES

The methodology of this chapter applies to an uninterrupted-flow segment of multilane highway with uniform prevailing conditions. Thus, any point at which one or more of the prevailing conditions change should mark the beginning of a new analysis segment. The following conditions generally necessitate segmenting the highway:

Grade changes of 2% or more, changes in the highway's geometric characteristics, changes in speed limit, signal or STOP control of the highway, and major access points are places where multilane highways should be segmented.

- A change in the basic number of travel lanes on the highway;
- A change in the highway's median treatment;
- A change of grade of 2% or more or a constant upgrade longer than 4,000 ft;
- The presence of a traffic signal, STOP sign, or roundabout along the multilane highway;
- A significant change in the access-point density;
- A change in the speed limit;
- An access point at which a significant number or percentage of vehicles enters or leaves the highway; and
- The presence of a bottleneck condition.

In general, when analysis boundaries are established, the minimum length of a study segment should be 2,500 ft. The boundary of a study segment should be no closer than 0.25 mi to a traffic signal.

TYPES OF ANALYSIS

Operational Analysis

Operational analyses find the expected LOS for specified roadway and traffic conditions.

The operational analysis application was fully specified in the Methodology section of this chapter. Operational analysis begins with all input parameters specified and is used to find the expected LOS that would result from the prevailing roadway and traffic conditions.

Design Analysis

Design analyses find the number of lanes required for a target LOS, given a specified demand volume.

In design analysis, a known demand volume is used to determine the number of lanes needed to deliver a target LOS. Two modifications are required to the operational analysis methodology. First, since the number of lanes is to be determined, the demand volume is converted to a demand flow rate in passenger cars per hour, not passenger cars per hour per lane, by using Equation 14-6 instead of Equation 14-3:

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

Equation 14-6

where v is the demand flow rate in passenger cars per hour and all other variables are as previously defined.

Second, a maximum service flow rate for the target LOS is then selected from Exhibit 14-17. These values are selected from the base speed–flow curves of Exhibit 14-5 for each LOS.

Exhibit 14-17
Maximum Service Flow Rates (pc/h/ln) for Multilane Highway Segments Under Base Conditions

FFS (mi/h)	Target LOS A	B	C	D	E
60	660	1,080	1,550	1,980	2,200
55	600	990	1,430	1,850	2,100
50	550	900	1,300	1,710	2,000
45	290	810	1,170	1,550	1,900

Then the number of lanes required to deliver the target LOS can be found from Equation 14-7:

Equation 14-7

$$N = \frac{v}{MSF_i}$$

where N is the number of lanes required and MSF_i is the maximum service flow rate for LOS i from Exhibit 14-17. Equation 14-6 and Equation 14-7 can be conveniently combined as Equation 14-8:

Equation 14-8

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

where all variables are as previously defined.

All fractional values of N must be rounded up.

The value of N resulting from Equation 14-7 or Equation 14-8 will most likely be fractional. Because only integer numbers of lanes can be constructed, the result is always rounded to the next higher value. Thus, if the result is 2.1 lanes, 3 lanes must be provided. In effect, the minimum number of lanes needed to provide the target LOS is 2.1. If the result were rounded to 2, a poorer LOS than the target value would result.

Because only whole lanes can be built, it may not be possible to achieve the target LOS for a given demand volume.

This rounding-up process will occasionally produce an interesting result: it is possible that a target LOS (for example, LOS C) cannot be achieved for a given demand volume. If 2.1 lanes are required to produce LOS C, providing two lanes would drop the LOS, most likely to D. However, if three lanes are provided, the LOS might actually improve to B. Thus, some judgment may be required to interpret the results. In this case, two lanes might be provided even though they would result in a borderline LOS D. Economic considerations might lead a decision maker to accept a slightly lower operating condition than that originally targeted.

Planning and Preliminary Engineering

Planning and preliminary engineering applications also find the number of lanes required to deliver a target LOS but provide more generalized input values to the methodology.

The objective of planning or preliminary engineering is to get a general idea of the number of lanes that will be required to deliver a target LOS. The primary differences are that many default values will be used, and the demand volume will be usually expressed as an AADT. Thus, a planning and preliminary engineering analysis starts by converting the demand expressed as an AADT to an estimate of the directional peak-hour demand volume (DDHV), as shown in Equation 14-9.

$$V = DDHV = AADT \times K \times D$$

Equation 14-9

where K is the proportion of AADT occurring during the peak hour, D is the proportion of peak-hour volume traveling in the peak direction, and all other variables are as previously defined.

Chapter 3, Modal Characteristics, provides additional guidance on K- *and* D-*factors.*

Once the hourly demand volume is estimated, the methodology follows the same path as that for design analysis.

Service Flow Rates, Service Volumes, and Daily Service Volumes

This chapter's methodology can be easily manipulated to produce service flow rates, service volumes, or daily service volumes, or all three, for a multilane highway segment.

Exhibit 14-17 gives values of the maximum service flow rates MSF_i for each LOS for multilane highways of various FFSs. These values are given in terms of passenger cars per hour per lane under equivalent base conditions. A service flow rate SF_i is the maximum rate of flow that can exist while LOS i is maintained during the 15-min analysis period under prevailing conditions. It can be computed from the maximum service flow rate by using Equation 14-10:

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

Equation 14-10

where all variables are as previously defined.

A service flow rate can be converted to a service volume SV_i by applying a PHF , as shown in Equation 14-11. A service volume is the maximum hourly volume that can exist while LOS i is maintained during the worst 15-min period of the analysis hour.

$$SV_i = SF_i \times PHF$$

Equation 14-11

where all variables are as previously defined.

A daily service volume DSV_i is the maximum AADT that can be accommodated by the facility under prevailing conditions while LOS i is maintained during the worst 15-min period of the analysis day. It is estimated from Equation 14-12:

$$MSV_i = \frac{SV_i}{K \times D}$$

Equation 14-12

where all variables are as previously defined.

GENERALIZED DAILY SERVICE VOLUMES

Exhibit 14-18 and Exhibit 14-19 are generalized daily service volume tables for multilane highway segments or facilities. They are based on a set of specified typical conditions for rural and urban multilane highways:

- Percent HV = 10% (rural), 5% (urban);
- FFS = 60 mi/h;
- PHF = 0.88 (rural), 0.95 (urban); and
- Driver population factor f_p = 1.00.

Values of rural and urban daily service volumes are provided for four-lane and six-lane highways in level and rolling terrain. A range of *K*- and *D*-factors is provided. Users should enter Exhibit 14-18 and Exhibit 14-19 with local or regional values of these factors for the appropriate size of multilane highway in the appropriate terrain.

Exhibit 14-18
Generalized Daily Service Volumes for Rural Multilane Highways (1,000 veh/day)

K-Factor	*D*-Factor	Four-Lane Highways				Six-Lane Highways			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Level Terrain									
0.09	0.50	33.2	48.0	63.1	73.8	49.8	71.9	94.6	110.7
	0.55	30.2	43.6	57.4	67.1	45.3	65.4	86.0	100.6
	0.60	27.7	40.0	52.6	61.5	41.5	60.0	78.9	92.2
	0.65	25.5	36.9	48.5	56.8	38.3	55.3	72.8	85.1
0.10	0.50	29.9	43.2	56.8	66.4	44.8	64.8	85.2	99.6
	0.55	27.2	39.2	51.6	60.4	40.8	58.9	77.4	90.6
	0.60	24.9	36.0	47.3	55.3	37.4	54.0	71.0	83.0
	0.65	23.0	33.2	43.7	51.1	34.5	49.8	65.5	76.6
0.11	0.50	27.2	39.2	51.6	60.4	40.8	58.9	77.4	90.6
	0.55	24.7	35.7	46.9	54.9	37.0	53.5	70.4	82.3
	0.60	22.6	32.7	43.0	50.3	34.0	49.1	64.5	75.5
	0.65	20.9	30.2	39.7	46.4	31.3	45.3	59.6	69.7
0.12	0.50	24.9	36.0	47.3	55.3	37.4	54.0	71.0	83.0
	0.55	22.6	32.7	43.0	50.3	34.0	49.1	64.5	75.5
	0.60	20.8	30.0	39.4	46.1	31.1	45.0	59.2	69.2
	0.65	19.2	27.7	36.4	42.6	28.7	41.5	54.6	63.9
Rolling Terrain									
0.09	0.50	29.8	43.1	56.7	66.3	44.7	64.6	85.0	99.4
	0.55	27.1	39.2	51.5	60.3	40.7	58.8	77.3	90.4
	0.60	24.9	35.9	47.2	55.2	37.3	53.9	70.8	82.9
	0.65	22.9	33.1	43.6	51.0	34.4	49.7	65.4	76.5
0.10	0.50	26.8	38.8	51.0	59.7	40.3	58.2	76.5	89.5
	0.55	24.4	35.3	46.4	54.2	36.6	52.9	69.6	81.4
	0.60	22.4	32.3	42.5	49.7	33.6	48.5	63.8	74.6
	0.65	20.7	29.8	39.2	45.9	31.0	44.7	58.9	68.8
0.11	0.50	24.4	35.3	46.4	54.2	36.6	52.9	69.6	81.4
	0.55	22.2	32.0	42.2	49.3	33.3	48.1	63.2	74.0
	0.60	20.3	29.4	38.6	45.2	30.5	44.1	58.0	67.8
	0.65	18.8	27.1	35.7	41.7	28.2	40.7	53.5	62.6
0.12	0.50	22.4	32.3	42.5	49.7	33.6	52.9	63.8	74.6
	0.55	20.3	29.4	38.6	45.2	30.5	48.1	58.0	67.8
	0.60	18.6	26.9	35.4	41.4	28.0	44.1	53.1	62.1
	0.65	17.2	24.9	32.7	38.2	25.8	40.7	49.0	57.4

Note: Key assumptions: 12% trucks, 0.88 PHF, 60-mi/h FFS, driver population factor 1.0.

Exhibit 14-19
Generalized Daily Service Volumes for Urban Multilane Highways (1,000 veh/day)

K-Factor	D-Factor	Four-Lane Highways LOS B	Four-Lane Highways LOS C	Four-Lane Highways LOS D	Four-Lane Highways LOS E	Six-Lane Highways LOS B	Six-Lane Highways LOS C	Six-Lane Highways LOS D	Six-Lane Highways LOS E
Level Terrain									
0.08	0.50	48.3	69.3	88.5	98.4	72.4	104.0	132.8	147.5
	0.55	43.9	63.0	80.5	89.4	65.8	94.5	120.7	134.1
	0.60	40.2	57.8	73.8	82.0	60.4	86.6	110.7	123.0
	0.65	37.1	53.3	68.1	75.7	55.7	80.0	102.1	113.5
0.09	0.50	42.9	61.6	78.7	87.4	64.4	92.4	118.0	131.2
	0.55	39.0	56.0	71.5	79.5	58.5	84.0	107.3	119.2
	0.60	35.8	51.3	65.6	72.9	53.7	77.0	98.4	109.3
	0.65	33.0	47.4	60.5	67.3	49.5	71.1	90.8	100.9
0.10	0.50	38.6	55.4	70.8	78.7	57.9	83.2	106.2	118.0
	0.55	35.1	50.4	64.4	71.5	52.7	75.6	96.6	107.3
	0.60	32.2	46.2	59.0	65.6	48.3	69.3	88.5	98.4
	0.65	29.7	42.6	54.5	60.5	44.6	64.0	81.7	90.8
0.12	0.50	35.1	50.4	64.4	71.5	52.7	75.6	96.6	107.3
	0.55	31.9	45.8	58.5	65.0	47.9	68.7	87.8	97.6
	0.60	29.3	42.0	53.7	59.6	43.9	63.0	80.5	89.4
	0.65	27.0	38.8	49.5	55.0	40.5	58.2	74.3	82.5
Rolling Terrain									
0.08	0.50	44.8	64.4	82.2	91.3	67.3	96.5	123.3	137.0
	0.55	40.8	58.5	74.7	83.0	61.1	87.8	112.1	124.6
	0.60	37.4	53.6	68.5	76.1	56.0	80.4	102.8	114.2
	0.65	34.5	49.5	63.2	70.3	51.7	74.3	94.9	105.4
0.09	0.50	39.9	57.2	73.1	81.2	59.8	85.8	109.6	121.8
	0.55	36.2	52.0	66.4	73.8	54.4	78.0	99.6	110.7
	0.60	33.2	47.7	60.9	67.7	49.8	71.5	91.3	101.5
	0.65	30.7	44.0	56.2	62.5	46.0	66.0	84.3	93.7
0.10	0.50	35.9	51.5	65.8	73.1	53.8	77.2	98.6	109.6
	0.55	32.6	46.8	59.8	66.4	48.9	70.2	89.7	99.6
	0.60	29.9	42.9	54.8	60.9	44.8	64.4	82.2	91.3
	0.65	27.6	39.6	50.6	56.2	41.4	59.4	75.9	84.3
0.12	0.50	32.6	46.8	59.8	66.4	48.9	77.2	89.7	99.6
	0.55	29.6	42.5	54.4	60.4	44.5	70.2	81.5	90.6
	0.60	27.2	39.0	49.8	55.4	40.8	64.4	74.7	83.0
	0.65	25.1	36.0	46.0	51.1	37.6	59.4	69.0	76.6

Note: Key assumptions: 8% trucks, 0.93 PHF, 60-mi/h FFS, driver population factor 1.0.

Exhibit 14-18 and Exhibit 14-19 must be used with care. Because the characteristics of any given multilane highway may or may not be typical, the values should not be used in the analysis of a specific segment of multilane highway. The exhibits are intended to allow a general evaluation of many facilities within a given jurisdiction on a first-pass basis to identify those segments or facilities that might be in need of remediation. Any segments or facilities so identified should then be submitted to specific analysis by using this chapter's methodology and each segment's site-specific characteristics. Exhibit 14-18 and Exhibit 14-19 should not be used to make final decisions on which segments or facilities to upgrade or on the specific designs proposed for such upgrades.

Daily service volumes are computed with Equation 14-10 through Equation 14-12, which combined yield Equation 14-13:

$$DSV_i = \frac{MSF_i \times N \times f_{HV} \times f_p \times PHF}{K \times D}$$

Equation 14-13

where all variables are as previously defined. Values of *MSF* are selected from Exhibit 14-18 or Exhibit 14-19 for the typical FFS of 60 mi/h. Exhibit 14-18 and Exhibit 14-19 do not show LOS A, since this level is rarely of interest in assessing improvement programs.

For multilane highways, daily service volume tables are quite easy to construct by using localized typical values and local defaults. Equation 14-13 is easily applied. All of the variables in the equation simply have to be defined for a given FFS. The heavy-vehicle adjustment depends on PCEs, which are easily obtained for each of the terrain categories.

USE OF ALTERNATIVE TOOLS

Except for the effects of interaction with other facilities, the limitations of the methodology that were stated earlier in the chapter have minimal potential to be addressed by alternative tools. There is thus insufficient experience with alterative tools to support the development of useful guidance for their application to multilane highways.

4. EXAMPLE PROBLEMS

Exhibit 14-20
List of Example Problems

Problem Number	Description	Application
1	LOS on an undivided four-lane highway	Operational analysis
2	LOS on a five-lane highway with TWLTL	Operational analysis
3	Design cross section required to provide target LOS	Design analysis
4	Multilane highway modernization	Planning analysis
5	Future cross section required to provide target LOS	Planning analysis

EXAMPLE PROBLEM 1: LOS ON UNDIVIDED FOUR-LANE HIGHWAY

A 3.25-mi, undivided four-lane highway is primarily on level terrain. The highway does, however, contain one sustained grade of 2.5% that is 3,200 ft long. At what LOS is the highway expected to operate?

The Facts

- Level terrain; 3,200-ft, 2.5% grade included;
- Base FFS = 65 mi/h;
- Lane width: 11 ft;
- Clearance at roadside: 4 ft;
- Access points per mile: 20;
- Peak-hour volume: 1,900 veh/h;
- Traffic composition: 13% trucks, 2% RVs;
- PHF = 0.90; and
- Familiar facility users.

Comments

Three solutions will be needed in this case: (*a*) for the level terrain portion of the highway, (*b*) for the 2.5% upgrade portion of the highway, and (*c*) for the 2.5% downgrade portion of the highway. The factor that will vary for each of these is the heavy-vehicle adjustment factor.

Step 1: Input Data

All input data are specified in the example problem statement.

Step 2: Compute FFS

The FFS is estimated with Equation 14-1. The BFFS is given as 65 mi/h. Adjustments are needed for

- Lane width f_{LW} = 1.9 mi/h (Exhibit 14-8, with 11-ft lanes);
- Lateral clearance f_{LC} = 0.4 mi/h (Exhibit 14-9, with TLC = 4 + 6 = 10 ft, four lanes);
- Median type f_M = 1.6 mi/h (Exhibit 14-10, for undivided highways); and
- Access-point density f_A = 5.0 mi/h (Exhibit 14-11, with 20 access points/mi).

Then

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

$$FFS = 65.0 - 1.9 - 0.4 - 1.6 - 5.0 = 56.1 \text{ mi/h}$$

Step 3: Select FFS Curve

FFSs are all rounded to the nearest 5 mi/h. Therefore, the FFS used in the calculation will be 55 mi/h.

Step 4: Adjust Demand Volume

The demand volume, stated in vehicles per hour under prevailing conditions, must be converted to a demand flow rate in passenger cars per hour under base conditions by using Equation 14-3:

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

where

V = demand volume (veh/h) (1,900 veh/h, given),

PHF = peak hour factor (0.90, given), and

f_p = driver population factor (1.00, familiar users).

The heavy-vehicle adjustment factor is computed by using Equation 14-4:

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

Three sets of PCEs have to be determined: for level terrain, for 2.5% upgrade, and for 2.5% downgrade.

- Level terrain: E_T = 1.5 (Exhibit 14-12); E_R = 1.2 (Exhibit 14-12);
- Upgrade: E_T = 1.5 (Exhibit 14-13, with 13% trucks and a 2.5% grade; 3,200/5,280 = 0.61 mi); E_R = 3.0 (Exhibit 14-14 with 2% RVs and 2.5% grade for 0.61 mi); and
- Downgrade: E_T = 1.5 (Exhibit 14-15 with less than 4% grade and 13% trucks); E_R = 1.2 (from the text following Exhibit 14-15).

In this case, the equivalents are the same for the level terrain segments and the 2.5% downgrade. Consequently, there are only two different heavy-vehicle adjustment factors to work with:

$$f_{HV}\,(\text{level, down}) = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(1.2 - 1)} = 0.935$$

$$f_{HV}\,(\text{up}) = \frac{1}{1 + 0.13\,(1.5 - 1) + 0.02\,(3.0 - 1)} = 0.905$$

There are thus two values of flow rate in passenger cars per hour under base conditions:

$$v_p\,(\text{level, down}) = \frac{1{,}900}{0.90 \times 2 \times 0.935 \times 1} = 1{,}129 \text{ pc/h}$$

$$v_p\,(\text{up}) = \frac{1{,}900}{0.90 \times 2 \times 0.905 \times 1} = 1{,}166 \text{ pc/h}$$

Step 5: Estimate Speed and Density

Speed for the two demand levels can be estimated by using the equations in Exhibit 14-3 or graphically by using Exhibit 14-5. In this case, both demand flow rates, 1,129 pc/h and 1,166 pc/h, are less than 1,400 pc/h. From Exhibit 14-3, the speed for both of these situations is the FFS, or 55 mi/h.

The densities of the general-terrain and specific-grade segments are then computed with Equation 14-5:

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

$$D\,(\text{level, down}) = \frac{1{,}129}{55} = 20.5 \text{ pc/mi/ln}$$

$$D\,(\text{up}) = \frac{1{,}166}{55} = 21.2 \text{ pc/mi/ln}$$

Step 6: Determine LOS

As shown in Exhibit 14-4, the LOS for both densities is C.

Discussion

The multilane highway described here operates at LOS C throughout the entire study area, including the upgrade and the downgrade within it. In a sense, this problem involves a *facility* as opposed to a *segment*. The facility contains several component segments: level-terrain segments on either side of the 2.5%, 3,200-ft grade and the uphill and downhill portions of the 2.5% grade itself.

This chapter's methodology applies to uniform multilane highway segments. In this example problem, there were three segments, which together formed a facility of more than 3 mi. LOS C on all segments is very likely acceptable and would not generally call for immediate remediation.

EXAMPLE PROBLEM 2: LOS ON FIVE-LANE HIGHWAY WITH TWLTL

An 11,000-ft segment of a five-lane highway (two travel lanes in each direction plus a TWLTL) includes a 4% grade of 6,000 ft followed by 5,000 ft of level terrain. At what LOS is the facility expected to operate?

The Facts

- Lane width: 12 ft;
- Lateral clearance, both sides of the roadway: 12 ft;

- Traffic composition: 6% trucks, 0% RVs;
- Access points per mile on the level segment: eastbound, 10; westbound, 13;
- Access points per mile on the specific grade segment: eastbound, 10; westbound, 0;
- PHF = 0.90;
- Familiar users of the facility;
- Peak-hour demand: 1,500 veh/h;
- The upgrade occurs in the westbound direction; and
- Posted speed limit = 45 mi/h.

Comments

This problem is similar to Example Problem 1 in that there are three segments in the facility as described, each of which must be analyzed. The upgrade and downgrade on the 4% grade must be separately analyzed, as well as the level terrain segment. This case is a bit more complex, since not all characteristics of the segments are the same, particularly access points. Because no BFFS is given, it will be estimated as the speed limit plus 7 mi/h, or 45 + 7 = 52 mi/h.

Step 1: Input Data

All input data are given in the example problem statement.

Step 2: Compute FFS

The FFS is estimated by using Equation 14-1:

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

In this case, the BFFS is estimated to be 52 mi/h. The lane width is 12 ft, which is the base condition; therefore f_{LW} = 0.0 mi/h (Exhibit 14-8). The lateral clearance is 12 ft at each roadside, but a maximum value of 6 ft may be used. A TWLTL is considered to have a median lateral clearance of 6 ft. Thus, the TLC is 6 + 6 = 12 ft, which is also a base condition. Therefore, f_{LC} = 0.0 mi/h (Exhibit 14-9). The median type adjustment f_M is also 0.0 mi/h (Exhibit 14-10).

For this example problem, only the access-point density produces a nonzero adjustment to the BFFS. Both eastbound (EB) segments (level terrain, 4% downgrade) have 10 access points/mi. From Exhibit 14-11, the corresponding adjustment factor is 2.5 mi/h. The westbound (WB) level-terrain segment has 13 access points/mi, and an adjustment factor of 3.3 mi/h (by interpolation in Exhibit 14-11). The WB upgrade has 0 access points/mi and an adjustment factor of 0.0 mi/h. Therefore

$$FFS_{\text{EB,Level,Downgrade}} = 52.0 - 0.0 - 0.0 - 0.0 - 2.5 = 49.5 \text{ mi/h}$$

$$FFS_{\text{WB,Level}} = 52.0 - 0.0 - 0.0 - 0.0 - 3.3 = 48.7 \text{ mi/h}$$

$$FFS_{\text{WB,Upgrade}} = 52.0 - 0.0 - 0.0 - 0.0 - 0.0 = 52.0 \text{ mi/h}$$

Step 3: Select FFS Curve

Despite the fact that slight differences in FFS exist, all three segment analyses will use the 50-mi/h speed–flow curve.

Step 4: Adjust Demand Volume

Demand volume is adjusted by using Equation 14-3:

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

where

V = 1,500 veh/h (given),

PHF = 0.90 (given),

N = 2 lanes (given), and

f_p = 1.00 (familiar users, given).

To compute the heavy-vehicle adjustment factor (Equation 14-4), PCEs for trucks are needed for (*a*) level terrain, (*b*) a 4%, 6,000-ft upgrade, and (*c*) a 4%, 6,000-ft downgrade. The following values are obtained:

- Level terrain: 1.5 (Exhibit 14-12);
- Upgrade: 3.0 (Exhibit 14-13, with 6% trucks and a 4% grade, 6,000/5,280 = 1.14 mi); and
- Downgrade: 1.5 (Exhibit 14-15 with a 4% grade less than 4 mi long).

As in Example Problem 1, the downgrade equivalent is the same as the equivalent for level terrain. Therefore, there are only two heavy-vehicle adjustment factors (Equation 14-4):

$$f_{HV}\,(\text{level,down}) = \frac{1}{1 + 0.06(1.5 - 1)} = 0.971$$

$$f_{HV}\,(\text{up}) = \frac{1}{1 + 0.06(3.0 - 1)} = 0.893$$

and

$$v_p\,(\text{level, down}) = \frac{1500}{0.90 \times 2 \times 0.971 \times 1.0} = 858 \text{ pc/mi/ln}$$

$$v_p\,(\text{up}) = \frac{1500}{0.90 \times 2 \times 0.893 \times 1.0} = 933 \text{ pc/mi/ln}$$

Step 5: Estimate Speed and Density

Speed is estimated by using the equations of Exhibit 14-3 or the graph in Exhibit 14-5. With the equations of Exhibit 14-3, both demand flow rates are less than 1,400 pc/h/ln. Therefore, the speeds are equal to the FFSs, both of which are 50 mi/h.

Density is computed by using Equation 14-5:

$$D\ (\text{level, down}) = \frac{858}{50} = 17.1\ \text{pc/mi/ln}$$

$$D\ (\text{up}) = \frac{933}{50} = 18.7\ \text{pc/mi/ln}$$

Step 6: Determine LOS

The LOS is found by comparing the densities of the segments with the criteria in Exhibit 14-4. The level terrain and downgrade segments operate at LOS B. The upgrade segment operates at LOS C.

Discussion

Even though the upgrade technically operates at LOS C, it is very close to the LOS B boundary (18.0 pc/mi/ln). All segments of the multilane highway facility described operate well. No remediation would likely be needed.

EXAMPLE PROBLEM 3: DESIGN CROSS SECTION REQUIRED TO PROVIDE TARGET LOS

A new 2-mi segment of multilane highway will be built within a 150-ft right-of-way. Sixty feet of right-of-way will be reserved for clear zones; therefore, 90 ft of width will be available for travel lanes, shoulders, and median. How many travel lanes are needed to provide LOS D during the peak hour?

The Facts

- AADT = 60,000 veh/day;
- D = 0.10; K = 0.55;
- 50-mi/h speed limit;
- Rolling terrain;
- Traffic composition: 5% trucks, no RVs;
- PHF = 0.90;
- Access-point density = 10.0 access points/mi; and
- Familiar facility users.

Comments

This problem is potentially iterative. The exact cross section is unknown—not only the number of lanes but also the lateral clearances and median treatment. Thus, assumptions will be made and will have to be checked when the trial analysis is complete. To begin the solution, it will be assumed that 12-ft lanes will be provided and that 6-ft clearances at the roadside and median will also be provided (TLC = 6 + 6 = 12 ft). A divided highway will also be assumed for initial computations.

Step 1: Input Data

All input data are specified in the example problem statement.

Step 2: Compute FFS

No BFFS is given. It will be assumed that the BFFS will be 5 mi/h more than the posted speed limit, or 50 + 5 = 55 mi/h. FFS is estimated by using Equation 14-1. Given that the lane width, lateral clearance, and median treatments assumed are all base conditions, there is no adjustment for these. The only adjustment is for access-point density. On the basis of Exhibit 14-11 for 10 access points/mi, the adjustment is 2.5 mi/h. Therefore

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

$$FFS = 55.0 - 0.0 - 0.0 - 0.0 - 2.5 = 52.5 \text{ mi/h}$$

Step 3: Select FFS Curve

Following this chapter's guidelines, for a FFS of 52.5 mi/h, the 55-mi/h base speed–flow curve will be used in this analysis.

Step 4: Determine Number of Lanes Needed for LOS D

Step 4 has a number of intermediate computations. First, the demand volume is stated as an AADT. This volume must be converted to an estimated directional design-hour volume ($V = DDHV$) by using Equation 14-9:

$$V = DDHV = AADT \times K \times D$$

$$V = DDHV = 60{,}000 \times 0.10 \times 0.55 = 3{,}300 \text{ veh/h}$$

The number of lanes required to meet a target LOS is estimated with Equation 14-8:

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

where

MSF = 1,850 pc/h/ln (Exhibit 14-17, with LOS D and 55 mi/h);

PHF = 0.90 (given); and

f_p = 1.00 (familiar users).

The heavy-vehicle adjustment factor is estimated by using Equation 14-4 and the PCE for trucks in rolling terrain from Exhibit 14-12, which is 2.5. Then

$$f_{HV} = \frac{1}{1 + 0.05(2.5 - 1)} = 0.930$$

and

$$N = \frac{3{,}300}{1{,}850 \times 0.90 \times 0.93 \times 1.00} = 2.13 \text{ lanes}$$

This result means that to meet the criteria for LOS D within the peak hour, three lanes in each direction will have to be provided and the facility will be a six-lane multilane highway.

It is necessary to consider whether the assumed cross section (now known to be six lanes) can fit in the 90-ft available width. Lane widths are 12 ft, with 6-ft lateral clearances at both roadsides and in the median. If a 12-ft median is assumed, the total width becomes (6 × 12) + (6 × 2) + 12 = 72 + 12 + 12 = 96 ft, which is in excess of the 90-ft right-of-way.

The median treatment could be reconsidered. It is not necessary to have a 12-ft median with 6-ft clearances to the inside edges of the travel pavement to produce the desired operation. A concrete median barrier with 2-ft buffers on each side would occupy a total of only 6 ft and would not be expected to have any impact on driver behavior or the FFS. Then the total width required would be (6 × 12) + (6 × 2) + 6 = 90 ft. This is the design cross section. None of the calculations done to this point would be altered by this design.

It is likely that providing a six-lane highway will result in better operations than the minimums of LOS D. With the number of lanes known, the demand flow rate under base conditions can be computed with Equation 14-3:

$$v_p = \frac{3{,}300}{0.90 \times 3 \times 0.93 \times 1.00} = 1{,}314 \text{ pc/h/ln}$$

Step 5: Estimate Speed and Density

The speed of the traffic stream can be determined by using the equations of Exhibit 14-3 or the graph in Exhibit 14-5. On the basis of the equations, because the demand flow rate is less than 1,400 pc/h/ln, the speed is the FFS, or 55 mi/h in this case.

The density may now be computed by using Equation 14-5:

$$D = \frac{1{,}314}{55} = 23.9 \text{ pc/mi/ln}$$

Step 6: Determine LOS

From the criteria of Exhibit 14-4, the LOS provided is C, one grade better than the design target of LOS D.

Discussion

The design resulted in a six-lane cross section on a divided multilane highway with no clearance obstructions. The LOS provided is better than the design target, since three lanes were provided in each direction while only 2.13 lanes were necessary.

EXAMPLE PROBLEM 4: MULTILANE HIGHWAY MODERNIZATION

A 2.5-mi segment of a substandard multilane highway is to be improved by providing wider shoulders, widening the lanes to 12 ft, improving the alignment on a few sharp curves, restricting the number of roadside access points, and adding a median. These improvements will increase the FFS of the facility from 50 mi/h to 60 mi/h. How much additional traffic can be accommodated while the postimprovement LOS is maintained?

The Facts

- Demand flow rate = 1,400 pc/h/ln under base conditions.

Comments

This problem is relatively straightforward. Most of the steps in a standard analysis can be skipped, since the present and future FFS are given, and the demand flow rate has already been reduced to base conditions.

Step 1: Find Existing LOS

With the equations of Exhibit 14-3, the speed of vehicles in the existing configuration will be the FFS, or 50 mi/h. With Equation 14-5, the density is computed as

$$D = \frac{1{,}400}{50} = 28 \text{ pc/mi/ln}$$

From Exhibit 14-4, this is LOS D.

Step 2: Find Expected LOS After Improvement

With the equations of Exhibit 14-3, the speed of vehicles on the improved cross section will also be the FFS, or 60 mi/h. The density is computed with Equation 14-5:

$$D = \frac{1{,}400}{60} = 23.2 \text{ pc/mi/ln}$$

From Exhibit 14-4, this is LOS C.

Step 3: Find Additional Volume Under LOS C

From Exhibit 14-5, the maximum service flow rate for LOS C on a 60-mi/h multilane highway is 1,550 pc/h/ln. The existing demand flow rate is 1,400 pc/h/ln. The additional demand flow possible while LOS C is maintained is 1,550 – 1,400 = 150 pc/h/ln. Since there are three lanes in each direction, the demand flow rate can increase by 3 × 150 = 450 pc/h without slipping into LOS D.

Discussion

This example problem illustrates how the methodology can be adapted to different uses, in this case, evaluating the impact of a proposed improvement to a multilane highway. The LOS improves from D to C, and an additional peak-hour demand flow rate of 450 pc/h can be accommodated by the improved highway while LOS C is maintained.

EXAMPLE PROBLEM 5: FUTURE CROSS SECTION REQUIRED TO PROVIDE TARGET LOS

A new suburban multilane highway is being planned. The opening-day forecast AADT is 42,000 vehicles per day. How many lanes will be needed to provide for LOS C during the peak hour on opening day?

The Facts

Since this is a planning application, many details cannot be based on current information. As a result, some of the "facts" are forecasts, and default values based on regional data are used to complete the list of facts needed for the analysis.

- Demand = 42,000 veh/day;
- $K = 0.10$; $D = 0.60$;
- Traffic composition: 10% trucks, no RVs;
- Rolling terrain;
- Base FFS = 55 mi/h;
- Lane width: 12 ft; roadside lateral clearance: 6 ft;
- Undivided highway;
- Access-point density = 6 access points/mi;
- PHF = 0.90; and
- Commuter traffic.

Comments

The demand volume, given as an AADT, must be converted to a DDHV. Once this is done, the example becomes a design application to determine the number of lanes needed to deliver LOS C.

Step 1: Input Data

All input data for this problem are specified in the problem statement.

Step 2: Compute FFS

The FFS is computed by using Equation 14-1. The BFFS is given. Lane widths and lateral clearances conform to base conditions, and no adjustments will be necessary. Then

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

where

$BFFS$ = 55 mi/h (given);

f_{LW} = 0.0 mi/h (Exhibit 14-8, with 12-ft lanes);

f_{LC} = 0.0 mi/h (Exhibit 14-9, with 6-ft clearances);

f_M = 1.6 mi/h (Exhibit 14-10, undivided);

f_A = 1.5 mi/h (Exhibit 14-11, with 6 access points/mi, interpolated);

and

$$FFS = 55.0 - 0.0 - 0.0 - 1.6 - 1.5 = 51.9 \text{ mi/h}$$

Step 3: Select FFS Curve

On the basis of criteria given in the methodology section, the 50-mi/h FFS curve will be used for this solution.

Step 4: Determine Number of Lanes Needed to Provide LOS C

The number of lanes needed to deliver LOS C on opening day is estimated with Equation 14-8:

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

The demand volume must be converted to an hourly basis by using Equation 14-9:

$$V = DDHV = AADT \times K \times D$$

$$V = DDHV = 42{,}000 \times 0.10 \times 0.60 = 2{,}520 \text{ veh/h}$$

The value of MSF is selected from Exhibit 14-17 for a 50-mi/h highway and LOS C: 1,300 pc/h. The heavy-vehicle adjustment factor f_{HV} is computed by using Equation 14-4 with a PCE of 2.5 selected from Exhibit 14-12 for trucks in rolling terrain:

$$f_{HV} = \frac{1}{1 + 0.10(2.5 - 1)} = 0.870$$

Because the demand volume is composed primarily of commuters, the adjustment factor for driver population f_p is 1.00. The PHF was given as 0.90. Then

$$N = \frac{2{,}520}{1{,}300 \times 0.90 \times 0.87 \times 1.00} = 2.48 \text{ lanes}$$

This result implies that a six-lane cross section will have to be provided. Because this cross section is more than the minimum computed, the actual demand flow rate under base conditions should be computed by using Equation 14-3:

$$v_p = \frac{2{,}520}{0.90 \times 3 \times 0.87 \times 1.00} = 1{,}073 \text{ pc/mi/ln}$$

Step 5: Estimate Speed and Density

From the equations of Exhibit 14-3, the expected speed for the demand flow rate is the FFS of 50 mi/h. The density can now be computed with Equation 14-5:

$$D = \frac{1{,}073}{50} = 21.5 \text{ pc/mi/ln}$$

Step 6: Determine LOS

From Exhibit 14-4, the six-lane multilane highway will be expected to operate at LOS C, which was the design objective.

Discussion

In this case, the target LOS has been achieved with the six-lane cross section. The highway will, however, operate in the better portion of LOS C instead of at the boundary.

5. REFERENCES

Some of these references can be found in the Technical Reference Library in Volume 4.

1. Reilly, W., D. Harwood, J. Schoen, and M. Holling. *Capacity and LOS Procedures for Rural and Urban Multilane Highways*. NCHRP Project 3-33, Final Report. JHK & Associates, Tucson, Ariz., May 1990.
2. Landis, B. W., V. R. Vattikuti, and M. T. Brannick. Real-Time Human Perceptions: Toward a Bicycle Level of Service. In *Transportation Research Record 1578,* Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 119–126.
3. Robertson, H. D. (ed.). *Manual of Traffic Engineering Studies*. Institute of Transportation Engineers, Washington, D.C., 2000.
4. Zegeer, J. D., M. A. Vandehey, M. Blogg, K. Nguyen, and M. Ereti. *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses*. Transportation Research Board of the National Academies, Washington, D.C., 2008.