CHAPTER 12

HIGHWAY CONCEPTS

CONTENTS

EXHIBITS

I. INTRODUCTION

This chapter introduces capacity and quality-of-service concepts for highway facilities with points of access that are not fully controlled. This chapter can be used in conjunction with Chapter 20, which provides a methodology for two-lane highways, and Chapter 21, which provides a methodology for multilane highways.

II. MULTILANE HIGHWAYS

Multilane highways generally have posted speed limits of 60 to 90 km/h. They usually have a total of four or six lanes, counting both directions, often with medians or two-way left-turn lanes (TWLTL); however, they also may be undivided.

Traffic signals spaced at 3.0 km or less create urban street conditions

Multilane highways typically are located in suburban communities, leading into central cities, or along high-volume rural corridors connecting two cities or two significant activities that generate a substantial number of daily trips. Such highways often have traffic signals; but traffic signals spaced at 3.0 km or less typically create urban street conditions.

Traffic volumes on multilane highways vary but might range from 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 all major crossings are grade separated.

Illustrations 12-1 through 12-4 show typical multilane highways.

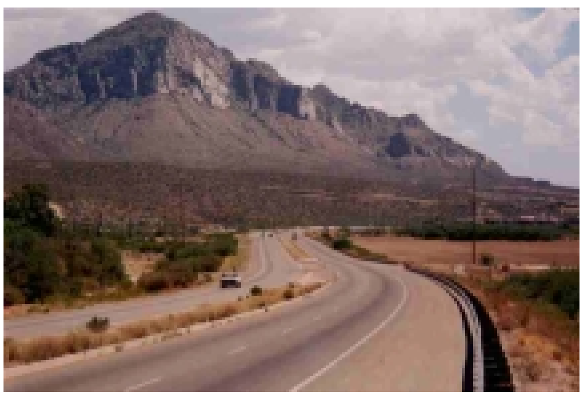


ILLUSTRATION 12-1. Divided multilane highway in a rural environment.

ILLUSTRATION 12-2. Divided multilane highway in a suburban environment.

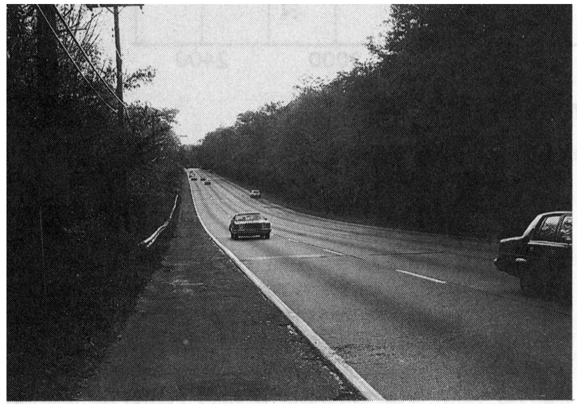


ILLUSTRATION 12-3. Undivided multilane highway in a rural environment.

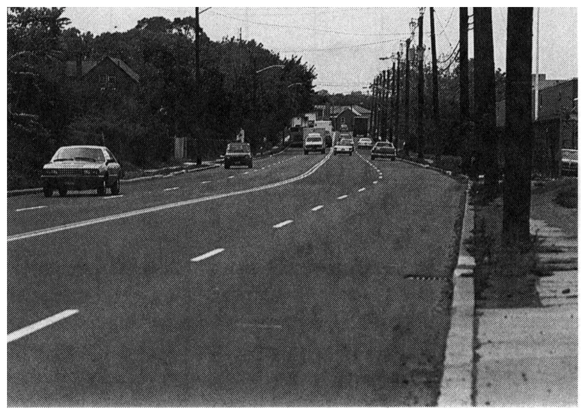


ILLUSTRATION 12-4. Undivided multilane highway in a suburban environment.

MULTILANE HIGHWAY CAPACITY

Multilane highways in suburban and rural settings have different operational characteristics from freeways, urban streets, and two-lane highways. Most notably, multilane highways are not completely access controlled—they can have at-grade intersections and occasional traffic signals.

Multilane highways can be similar to freeways or can approach urban street conditions

Friction caused by opposing vehicles on undivided highways and the access to roadside development contribute to a different operational setting from that of freeways. Multilane highways range from the uninterrupted flow of freeways to the flow conditions on urban streets, which are frequently interrupted by signals.

The capacity of a multilane highway is the maximum sustained hourly flow rate at which vehicles reasonably can be expected to traverse a uniform segment under prevailing roadway and traffic conditions.

FREE-FLOW SPEED

Free-flow speed (FFS) is the speed of traffic at low volume and low density. It is the speed at which drivers feel comfortable traveling under the physical, environmental, and traffic-control conditions on an uncongested section of multilane highway. Free-flow speeds will be lower on sections of highway with restricted vertical or horizontal alignments. FFS tend to be lower when posted speed limits are lower. The importance of

FFS is that it is the starting point for analyzing capacity and level of service (LOS) for uninterrupted-flow conditions.

Field studies of FFS

Field determination of FFS requires travel time studies during periods of low-to-moderate volume. Operating speed, as defined in previous capacity manuals and in documents produced by the American Association of State Highway and Transportation Officials, is similar to FFS under low-volume conditions. For multilane highways, the upper limit for low volume is 1,400 passenger cars per hour per lane (pc/h/ln).

The FFS for multilane highways is the mean speed of passenger cars under low-to-moderate traffic flow. The LOS for multilane highways is based on density, which is calculated by dividing per-lane flow by speed.

RELATIONSHIPS BETWEEN HIGHWAY TYPES

Certain characteristics distinguish multilane suburban and rural highways from freeways. Vehicles may enter or leave multilane highways at intersections and driveways, and they can encounter traffic signals.

Design standards for multilane highways tend to be lower than those for freeways, although a multilane highway approaches freeway conditions as its access points and turning volumes approach zero. Moreover, the visual setting and the developed frontage along multilane highways have a greater impact on drivers than they do along freeways.

The multilane highway is similar to urban streets in many respects, although it lacks the regularity of traffic signals and tends to have greater control on the number of access points per kilometer. Also, its design standards are generally higher than those for urban streets. The speed limits on multilane highways are often 10 to 20 km/h higher than speed limits on urban streets. Pedestrian activity, as well as parking, is minimal, unlike on urban streets.

Multilane highways differ substantially from two-lane highways, principally because a driver on a multilane highway is able to pass slower-moving vehicles without using lanes designated for oncoming traffic. Multilane highways also tend to be located near urban areas and often connect urban areas; they usually have better design features than two-lane highways, including horizontal and vertical curvature.

SPEED-FLOW AND DENSITY-FLOW RELATIONSHIPS

The speed-flow and density-flow relationships for a typical uninterrupted-flow segment on a multilane highway under either base or nonbase conditions in which the FFS is known are shown in Exhibits 12-1 and 12-2. Because drivers on multilane highways allow for potential conflicts with turning traffic—even when there are no access points in the immediate vicinity—the operating characteristics may be slightly less favorable than for a freeway.

As indicated in Exhibit 12-1, the speed of traffic on a multilane highway is not affected by traffic volume with a flow rate of less than 1,400 pc/h/ln. As the exhibit shows, the capacity of a multilane highway under base conditions is 2,200 pc/h/ln for highways with an FFS of 100 km/h. For flow rates of 1,400 to 2,200 pc/h/ln, the speed on a multilane highway with an FFS of 100 km/h drops by 12 km/h. Exhibit 12-2 shows that density varies continuously throughout the range of flow rates.

The capacity value of 2,200 pc/h/ln represents the maximum 15-min flow rate accommodated under base conditions for highways with an FFS of 100 km/h. Capacities on specific multilane highways may vary.

FACTORS AFFECTING FFS

Several traffic control, physical, and traffic conditions affect the FFS along a multilane highway. These conditions are described in the following sections.

EXHIBIT 12-1. SPEED-FLOW RELATIONSHIPS ON MULTILANE HIGHWAYS

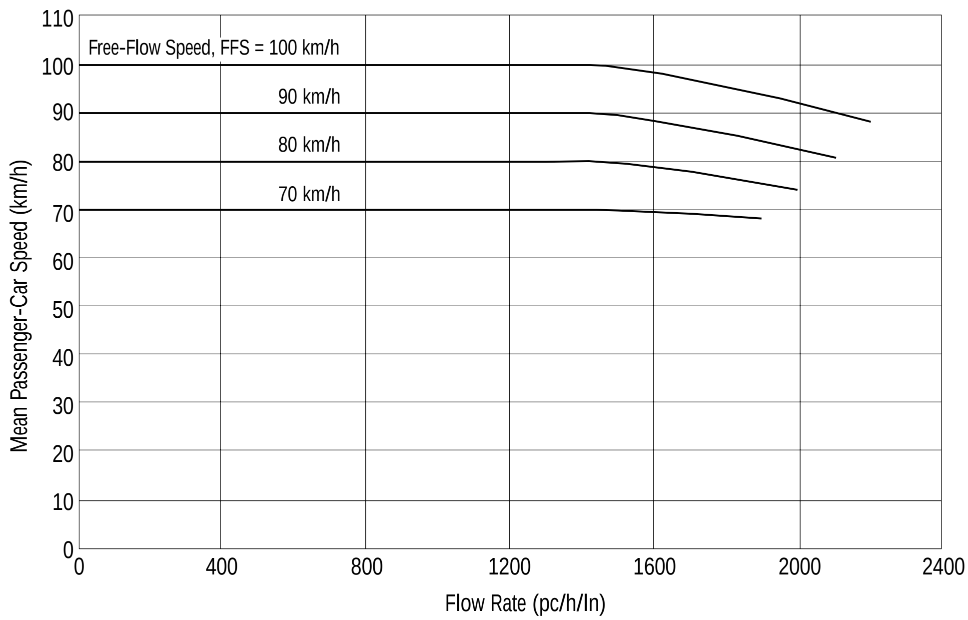
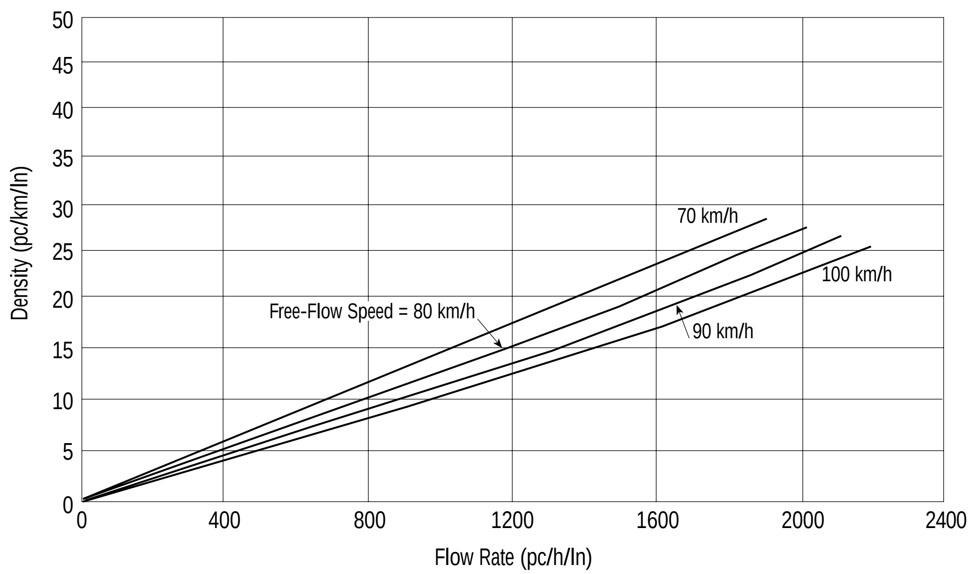


EXHIBIT 12-2. DENSITY-FLOW RELATIONSHIPS ON MULTILANE HIGHWAYS



Lane Width and Lateral Clearance

Two adjustments reflect the effect of a constricted cross section on free-flow speeds. The adjustments relate to the average width of lanes and the combined lateral clearance along the right side and the median of a multilane highway. Lane widths less than 3.6 m reduce travel speeds; however, widths of more than 3.6 m are not considered to increase speed above the base level.

For lateral clearance, a total clearance—that is, the left side plus the right side along one direction of roadway—of 3.6 m or more is considered the base condition. A combined lateral clearance of less than 3.6 m has a negative influence on travel speeds.

Roadside obstructions

Whether roadside and median objects and barriers present true obstructions is a matter of judgment. These obstructions might be continuous—such as a retaining wall—or not continuous—such as light supports or bridge abutments. In some cases, drivers become accustomed to certain types of obstructions, so that the effect on traffic flow becomes negligible. For example, continuous reinforced-concrete and W-beam barriers have little or no impact on speeds, even when less than 1.8 m from the travel lanes. Illustrations 12-5 through 12-8 show various types of roadside and median treatments that can affect the flow on multilane highways.

Median Type

Typically, there are three types of medians along multilane rural and suburban highways:

- Undivided medians composed of a striped centerline;
- TWLTL medians composed of a full-width lane; and
- Medians composed of a raised curb, barrier, or natural terrain or landscaping.

A raised curb in the median, even when interrupted with regular openings should be considered a raised median; however, short sections of raised or flush median (less than 150 m long) should not.

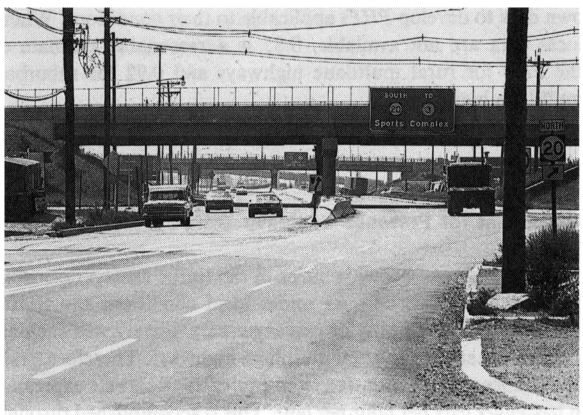


ILLUSTRATION 12-5. Bridge pier in center of normally undivided suburban multilane highway.

ILLUSTRATION 12-6. Inadequate shoulder width and other obstructions along multilane highway.

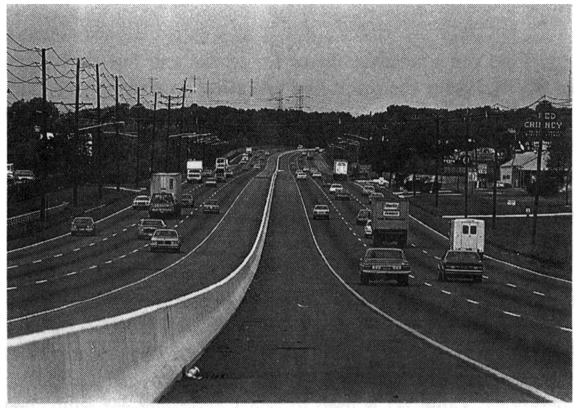


ILLUSTRATION 12-7. Divided multilane highway with high design standards.

ILLUSTRATION 12-8. Divided multilane highway with TWLTL and adequate shoulder width.

Access Points

An important influence on FFS is the number of access points along the right side of the roadway. The amount of activity at each point contributes to changes in travel speed, but drivers also adjust their travel speed simply because the access points are there.

The placement of intersections or driveways along a multilane highway therefore reduces travel speeds. For every six access points per kilometer in one direction, travel speed on a multilane highway decreases by 4.0 km/h (*1*).

Typically, only access points on the right of the roadway are taken into account. Intersections, driveways, or median openings on the opposite side that are expected to have a significant effect on traffic flow in the direction of interest may be included when determining access-point density.

Other Factors

The design speed of the principal physical elements of a multilane roadway—especially horizontal and vertical alignments—also can influence travel speeds. Design speed, however, is difficult to assess in the field; therefore several alternative methods for estimating FFS along a section of multilane highway are described in Chapter 21. The design speed, along with the associated horizontal and vertical alignments, is implicit in these methods. However, if a multilane highway has extreme horizontal or vertical conditions, FFS should be determined from field observation and field study.

Posted speed limits

Posted speed limits normally influence the FFS of passenger cars (*2*). Typically, the mean speed of passenger cars is above the posted speed limit for multilane highways.

The posted speed limit correlates significantly with the speed at which vehicles move along the highway. When no other estimate is available, the FFS can be calculated based on the posted speed limit.

Vehicular speeds, and the proportion of vehicles exceeding the speed limit, are affected by speed enforcement. However, several studies (*3–5*) have found that enforcement effects are limited, both temporally and spatially. The effect of enforcement depends on its type and duration. In general, a stationary enforcement activity affects no more than a 13 to 15 km of roadway; moreover, its effect decays exponentially downstream. Nonetheless, the speeds at the site may be affected for up to 2 to 3 days afterwards. If the roadway is located in a community that regularly enforces speed limits, local measurements can be used to calibrate the relationship between 85th-percentile speed and FFS. These measurements should be taken, therefore, when the average anticipated enforcement efforts are under way.

FACTORS AFFECTING FLOW RATE

The volume estimate is adjusted by factors relating to both the composition and fluctuation of traffic, so that all roadways can be compared with an equivalent measure of passenger cars per hour per lane (pc/h/ln).

Peak-hour factor

The basis for traffic volumes is a 15-min peak-period flow during a peak hour of the day. Therefore, volumes in two time periods are required: a peak-hour volume and the flow rate within the peak 15 min of the peak hour. The hourly volume divided by the peak-hour factor (PHF) yields a flow rate. The PHF is the ratio of total hourly volume to four times the highest 15-min volume within the peak hour.

Heavy Vehicles

The second adjustment to the volume relates to heavy vehicles—the number of trucks, buses, and recreational vehicles (RVs) are converted into an equivalent number of passenger cars. Two categories of heavy vehicles are used: trucks and RVs. For analysis purposes, buses on multilane highways are categorized as trucks.

Converting heavy vehicles to equivalent passenger cars is especially important when analyzing sections of highway with grades. On level terrain and for near-capacity conditions, trucks, buses, and RVs tend to operate like passenger cars, so that the equivalency factor approaches 1.

Driver Population

The base conditions for multilane highway flow include a driver population primarily of commuters. Studies have shown that commuter and noncommuter driver populations do not display the same characteristics. Capacities for recreational traffic can be up to 20 percent lower than for commuter traffic on the same highway; however, the FFS does not seem to be similarly affected. If this possible effect of driver population is taken into account, locally derived data should be obtained and used carefully, according to the methodology for multilane highways.

LOS

A multilane highway is characterized by three performance measures:

- Density, in terms of passenger cars per kilometer per lane;
- Speed, in terms of mean passenger car speed; and
- Volume to capacity ratio.

Each of these measures indicates how well the highway accommodates traffic flow.

Density defines LOS for multilane highways

Density is the assigned primary performance measure for estimating LOS. The three measures of speed, density, and flow or volume are interrelated. If the values of two of these measures are known, the remaining measure can be computed.

LOS A describes completely free-flow conditions. The operation of vehicles is virtually unaffected by the presence of other vehicles, and operations are constrained only by the geometric features of the highway and by driver preferences. Maneuverability within the traffic stream is good. Minor disruptions to flow are easily absorbed without a change in travel speed.

LOS B also indicates free flow, although the presence of other vehicles becomes noticeable. Average travel speeds are the same as in LOS A, but drivers have slightly less freedom to maneuver. Minor disruptions are still easily absorbed, although local deterioration in LOS will be more obvious.

In LOS C, the influence of traffic density on operations becomes marked. The ability to maneuver within the traffic stream is clearly affected by other vehicles. On multilane highways with an FFS above 80 km/h, the travel speeds reduce somewhat. Minor disruptions can cause serious local deterioration in service, and queues will form behind any significant traffic disruption.

At LOS D, the ability to maneuver is severely restricted due to traffic congestion. Travel speed is reduced by the increasing volume. Only minor disruptions can be absorbed without extensive queues forming and the service deteriorating.

LOS E represents operations at or near capacity, an unstable level. The densities vary, depending on the FFS. Vehicles are operating with the minimum spacing for maintaining uniform flow. Disruptions cannot be dissipated readily, often causing queues to form and service to deteriorate to LOS F. For the majority of multilane highways with FFS between 70 and 100 km/h, passenger-car mean speeds at capacity range from 68 to 88 km/h but are highly variable and unpredictable.

LOS F represents forced or breakdown flow. It occurs either when vehicles arrive at a rate greater than the rate at which they are discharged or when the forecast demand exceeds the computed capacity of a planned facility. Although operations at these points—and on sections immediately downstream—appear to be at capacity, queues form behind these breakdowns. Operations within queues are highly unstable, with vehicles experiencing brief periods of movement followed by stoppages. Travel speeds within queues are generally less than 48 km/h. Note that the term LOS F may be used to characterize both the point of the breakdown and the operating condition within the queue.

For a detailed discussion of flow breakdown on uninterrupted-flow facilities, see Chapter 13, "Freeway Concepts"

Although the point of breakdown causes the queue to form, operations within the queue generally are not related to deficiencies along the highway segment.

REQUIRED INPUT DATA AND ESTIMATED VALUES

Exhibit 12-3 lists the default values that may be used for input parameters in the absence of local data. However, taking field measurements for use as inputs to an analysis is the most reliable means of generating parameter values. Only when this is not feasible should default values be considered.

Lane Width and Lateral Clearance

Field inspection, aerial photos, as-built plans, and local highway operating agency policies are sources of information for existing facilities. The standard lane width for new highway construction in the United States is 3.6 m. The standard shoulder width is 1.8 m (*6*). These standards may be reduced to accommodate special historical, environmental, or topographical constraints. In Canada, the standard lane width is 3.7 m.

Default values of 3.6 m for lane widths and 1.8 m for lateral clearance may be used in the absence of field data or local data. If lane widths vary within a segment, either the segment should be split into subsegments of uniform widths or the distance-weighted average of the lane widths should be computed and used to determine the effects on FFS.

EXHIBIT 12-3. REQUIRED INPUT DATA FOR MULTILANE HIGHWAYS

Required Data	Default
Geometric Data	
Number of lanes	-
Lane width	3.6 m
Lateral clearance	1.8 m
Median (Yes/No)	-
Access-point density	Exhibit 12-4
Specific grade or general terrain	Level
Base FFS	100 km/h
Demand	
Length of analysis period	15 min
PHF	0.88 rural, 0.92 urban
Heavy vehicles (%)	10% rural, 5% urban
Driver population factor	1.00

The same weighted averaging method may be used if there are only minor variations in lane width within a segment, or for varying shoulder or median widths. However, if variations in lane or shoulder widths extend for 760 m or more, the segment should be divided into shorter segments with consistent physical features.

Median

Either a divided or undivided highway must be selected for analysis. In estimating FFS, there is no distinction among two-way left-turn lanes, unpaved medians, landscaped medians, and medians with barriers—all are considered divided highways. An undivided highway has an FFS about 3 km/h slower than that of a divided highway. The FFS affects the facility's estimated capacity.

Access-Point Density

Access-point density is the total number of active intersections and driveways on the right side of the road divided by the length of the facility. The density should be averaged over a minimum of 5 km if data are available. In the absence of local data, default values from Exhibit 12-4 may be used.

EXHIBIT 12-4. DEFAULT ACCESS-POINT DENSITY

Development Type	Default Value	Access Points/km (one side)
Rural	5	0–6
Low-Density Suburban	10	7–12
High-Density Suburban	15	≥ 13

Specific Grade or General Terrain

The general terrain type can be used instead of the specific grade, if there is no single grade on the segment that extends for more than 1.6 km or that exceeds 3 percent for more than 0.8 km.

The maximum extended grade for rural highways ranges between 5 percent and 8 percent (*6*) in mountainous terrain. Lower maximum grades of 3 percent to 5 percent are specified for highways in level terrain. The higher grades within each range typify lower-speed facilities with FFS less than 80 km/h.

If field measurement is not possible, and construction plans are not available, extended grades can be approximated using the analyst's general knowledge of the local terrain. In the absence of local data, default values of 3 percent may be used for an extended grade in otherwise level terrain, 5 percent for an extended grade in rolling terrain, and 7 percent for an extended grade in mountainous terrain.

Base FFS

If field measurements are unavailable, FFS can be estimated by applying adjustments to a base FFS. A base FFS of 100 km/h may be used for a rural or a suburban multilane highway. The base FFS must be reduced to account for the effects of lateral clearance at the shoulder and median, median type, lane width, and density of access points.

Length of Analysis Period

The planning, design, and analysis policies, and the available resources of an agency will determine the length of the analysis period or periods. The analyst may want to evaluate the peak hours occurring during the morning commute, midday, and evening commute on a typical weekday, or perhaps a peak hour during a Saturday or Sunday if the roadway segment carries a high volume of weekend recreational traffic. Within each hour analyzed, the highest 15-min volume is of primary interest. A PHF is applied to convert the hourly volume to a peak 15-min flow rate. Chapter 8 describes a procedure to compute peak direction and peak-hour demand from an average daily traffic volume.

PHF

The ratio of hourly demand to four times the peak 15-min demand typically ranges from 0.75 to 0.95. The higher values tend to occur as demand approaches capacity on the facility. Default values of 0.88 for rural areas and 0.92 for urban areas may be used in the absence of local data.

Percentage of Heavy Vehicles

The local Highway Performance Management System (HPMS) may be used to obtain local information on the percentage of heavy vehicles by facility and area type. If the relative proportions of RVs, trucks, and buses are not known, the heavy vehicles can be considered trucks when determining passenger-car equivalents and computing the heavy-vehicle adjustment factor. In the absence of local data, a default value of 5 percent heavy vehicles—including all types—may be used for urban areas, and 10 percent for rural areas.

Driver Population Factor

The reciprocal of the driver population factor is used to increase the flow rate to account for a driver population not familiar with the multilane highway. The factor should normally be 1.00 but can be reduced to 0.85 for the analysis of weekend conditions in a recreational area.

SERVICE VOLUME TABLE

Exhibit 12-5 can be used to estimate the number of lanes required to provide a desired LOS for default conditions. The impact of different FFS, the truck percentage, and the type of terrain also can be determined from this exhibit.

EXHIBIT 12-5. EXAMPLE SERVICE VOLUMES FOR MULTILANE HIGHWAYS
(SEE FOOTNOTE FOR ASSUMED VALUES)

FFS (km/h)	Number of Lanes	Terrain	Service Volumes (veh/h) A	B	C	D	E
100	2	Level	1200	1880	2700	3450	4060
		Rolling	1140	1800	2570	3290	3870
		Mountainous	1040	1640	2350	3010	3540
	3	Level	1800	2830	4050	5180	6100
		Rolling	1710	2700	3860	4940	5810
		Mountainous	1570	2470	3530	4520	5320
80	2	Level	960	1510	2190	2920	3520
		Rolling	910	1440	2090	2790	3360
		Mountainous	830	1310	1910	2550	3070
	3	Level	1440	2260	3290	4390	5290
		Rolling	1370	2160	3140	4180	5040
		Mountainous	1250	1970	2870	3830	4610

Notes:
Assumptions: highway with 100-km/h FFS has 5 access points/km; highway with 80-km/h FFS has 15 access points/km; lane width = 3.6 m; shoulder width > 1.8 m; divided highway; PHF = 0.88; 5 percent trucks; and regular commuters.

This table contains approximate values. It is meant for illustrative purposes only. The values are highly dependent on the assumptions and should not be used for operational analyses or final design. This table was derived from the assumed values listed in the footnote.

III. TWO-LANE HIGHWAYS

A two-lane highway is an undivided roadway with two lanes, one for use by traffic in each direction. Passing a slower vehicle requires use of the opposing lane as sight distance and gaps in the opposing traffic stream permit. As volumes and geometric restrictions increase, the ability to pass decreases and platoons form. Motorists in platoons are subject to delay because they are unable to pass. Illustration 12-9 shows a typical view of a two-lane, two-way rural highway.

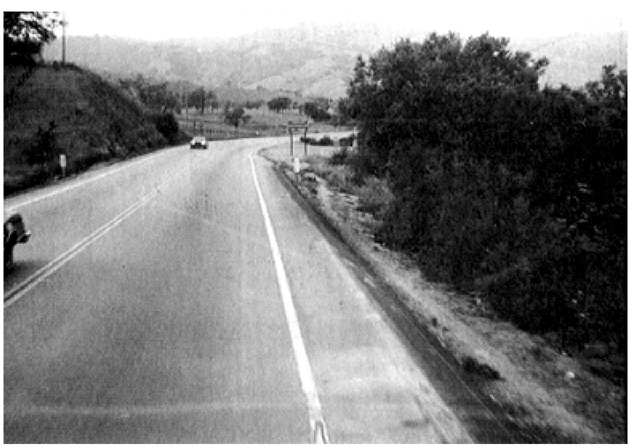


ILLUSTRATION 12-9. Typical two-lane, two-way highway in a rural environment.

Two-lane highways are a key element in the highway systems of most countries. They perform a variety of functions, are located in all geographic areas, and serve a wide range of traffic. Any consideration of operating quality must account for these disparate functions.

Traffic operations on two-lane, two-way highways differ from those on other uninterrupted-flow facilities. Lane changing and passing are possible only in the face of oncoming traffic in the opposing lane. Passing demand increases rapidly as traffic volumes increase, and passing capacity in the opposing lane declines as volumes increase. Therefore, on two-lane highways, unlike other types of uninterrupted-flow facilities, normal traffic flow in one direction influences flow in the other direction. Motorists must adjust their travel speeds as volume increases and the ability to pass declines.

Efficient mobility is the principal function of major two-lane highways that connect major traffic generators or that serve as primary links in state and national highway networks. These routes tend to serve long-distance commercial and recreational travelers, and long sections may pass through rural areas without traffic-control interruptions. Consistent high-speed operations and infrequent passing delays are desirable for these facilities.

Other paved, two-lane rural highways serve for accessibility. They provide all-weather access to an area, often for relatively low traffic volumes. Cost-effective access is the dominant consideration. Although beneficial, high speed is not the principal concern. Delay—as indicated by the formation of platoons—is more relevant as a measure of service quality.

Two-lane roads also serve scenic and recreational areas in which the vista and environment are meant to be experienced and enjoyed without traffic interruption or delay. A safe roadway is desired, but high-speed operation is neither expected nor desired. For these reasons, there are two performance measures to describe service quality for two-lane highways: percent time-spent-following and average travel speed.

Percent time-spent-following defined

Percent time-spent-following represents the freedom to maneuver and the comfort and convenience of travel. It is the average percentage of travel time that vehicles must travel in platoons behind slower vehicles due to the inability to pass. Percent time-spent-following is difficult to measure in the field. However, the percentage of vehicles traveling with headways of less than 3 s at a representative location can be used as a surrogate measure.

Car-following criterion is 3 s

Average travel speed defined

Average travel speed reflects the mobility on a two-lane highway: it is the length of the highway segment divided by the average travel time of all vehicles traversing the segment in both directions during a designated interval.

LOS criteria use both these performance measures. On major two-lane highways, for which efficient mobility is paramount, both percent time-spent-following and average travel speed define LOS. However, roadway alignments with reduced design speeds will limit the LOS that can be achieved. On highways for which accessibility is paramount and mobility less critical, LOS is defined only in terms of percent time-spent-following, without consideration of average travel speed.

CLASSIFICATION OF TWO-LANE HIGHWAYS

Two-lane highways are categorized into two classes for analysis:

Class I highways

- Class I—These are two-lane highways on which motorists expect to travel at relatively high speeds. Two-lane highways that are major intercity routes, primary arterials connecting major traffic generators, daily commuter routes, or primary links in state or national highway networks generally are assigned to Class I. Class I facilities most often serve long-distance trips or provide connecting links between facilities that serve long-distance trips.

Class II highways

- Class II—These are two-lane highways on which motorists do not necessarily expect to travel at high speeds. Two-lane highways that function as access routes to Class I facilities, serve as scenic or recreational routes that are not primary arterials, or pass through rugged terrain generally are assigned to Class II. Class II facilities most often serve relatively short trips, the beginning and ending portions of longer trips, or trips for which sightseeing plays a significant role.

The classes of two-lane roads closely relate to their functions—most arterials are considered Class I, and most collectors and local roads are considered Class II. However, the primary determinant of a facility's classification in an operational analysis is the motorist's expectations, which might not agree with the functional classification. For example, an intercity route that passes through rugged mountainous terrain might be described as Class II instead of Class I if motorists recognize that a high-speed route is not feasible in that corridor.

The LOS for Class I highways on which efficient mobility is paramount is defined in terms of both percent time-spent-following and average travel speed. On Class II highways, mobility is less critical, and LOS is defined only in terms of percent time-spent-following. Drivers generally tolerate higher levels of percent time-spent-following on a Class II facility than on a Class I facility, because Class II highways usually serve shorter trips and different trip purposes.

For Class I highways, two criteria define LOS: percent time-spent-following and average travel speed. For Class II highways, LOS is based only on percent time-spent-following.

BASE CONDITIONS

The base conditions for a two-lane highway are the absence of restrictive geometric, traffic, or environmental factors. Base conditions are not the same as typical or default conditions. The methodology in Chapter 20 accounts for the effects of geometric, traffic, or environmental conditions that are more restrictive than the base conditions. The base conditions include

- Lane widths greater than or equal to 3.6 m;
- Clear shoulders wider than or equal to 1.8 m;
- No no-passing zones;
- All passenger cars;
- No impediments to through traffic, such as traffic control or turning vehicles; and
- Level terrain.

For the analysis of two-way flow (i.e., both directions), a 50/50 directional split of traffic is also considered a base condition. Most directional distribution on rural two-lane highways ranges from 50/50 to 70/30. On recreational routes, the directional distribution may be as high as 80/20 or more during holiday or other peak periods. Some variation in speed and percent time-spent-following occurs with changing directional distribution and volume. For directional analysis (i.e., separate analysis of each direction), directional distribution is not a base condition.

Traffic can operate ideally only if lanes and shoulders are wide enough not to constrain speeds. Lane and shoulder widths less than the base values of 3.6 m and 1.8 m, respectively, are likely to reduce speeds and may increase percent time-spent-following.

The frequency of no-passing zones is used to characterize roadway design and to analyze expected traffic conditions along a two-lane highway. A no-passing zone is any zone marked for no passing or any section of road with a passing sight distance of 300 m or less. The average percentage of no-passing zones in both directions along a section is used for the analysis of two-way flow. The percentage of no-passing zones for a particular direction of travel is used in directional analysis.

No-passing zone

The sight distance value of 300 m is equivalent to that used by the Manual on Uniform Traffic Control Devices for passing and no-passing zones on highways with an 85th-percentile speed of 90 km/h

No-passing zones typically range from 20 to 50 percent of a rural two-lane highway. Values approaching 100 percent can be found on sections of winding, mountainous roads. No-passing zones have a greater effect in mountainous terrain than in level or rolling terrain. Heavy platoon formation along a highway section also can cause greater-than-expected operational problems on an adjacent downstream section with restricted passing opportunities.

BASIC RELATIONSHIPS

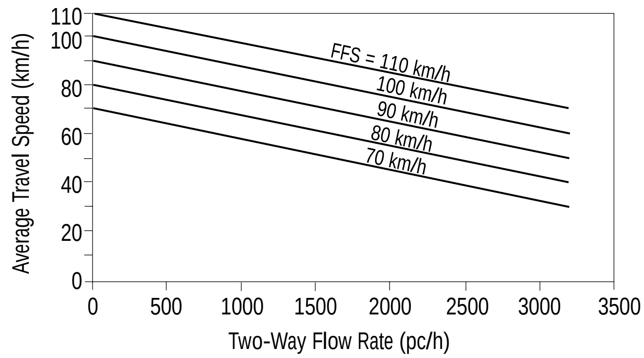
Exhibit 12-6 shows the relationship of flow rate, average travel speed, and percent time-spent-following for base conditions on an extended two-way facility (*7*).

Highway geometric features include a general description of longitudinal section characteristics and specific roadway cross-section information. Longitudinal section characteristics are described by the average percentage of the highway with no-passing zones in either direction. Roadway cross-section data include lane width and usable shoulder width. Geometric data and design speed are considered in estimating the FFS.

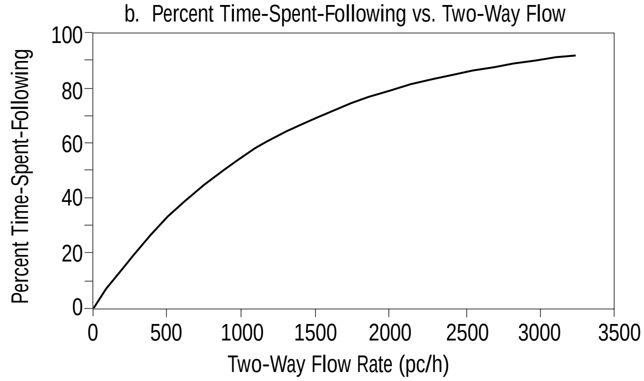
Analysis of two-way flow usually is performed on extended lengths; but directional analysis is applied to relatively short, uniform segments

EXHIBIT 12-6. SPEED-FLOW AND PERCENT TIME-SPENT-FOLLOWING FLOW RELATIONSHIPS FOR TWO-WAY SEGMENTS WITH BASE CONDITIONS

a. Average Travel Speed vs. Two-Way Flow



b. Percent Time-Spent-Following vs. Two-Way Flow

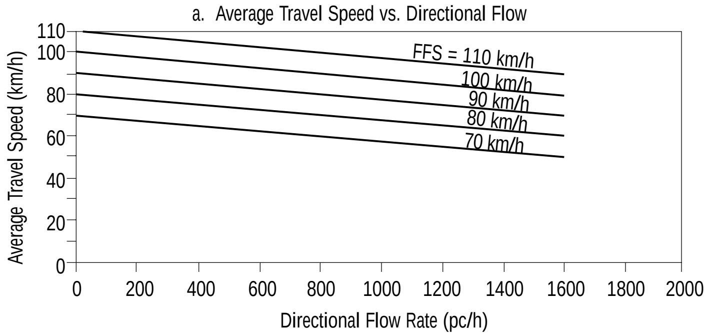


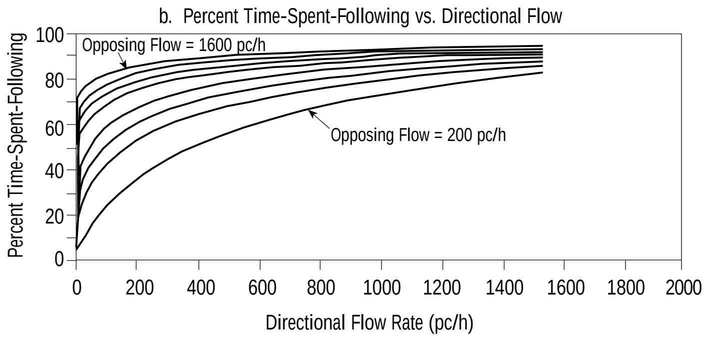
Two-way segments and directional segments

Two-lane highways can be analyzed either as two-way segments obtaining traffic performance measures for both directions of travel combined, or as directional segments, with each direction of travel considered separately. Separate analysis by direction is appropriate for steep grades and for segments with passing lanes.

Exhibit 12-7 illustrates the relationship of flow rate, average travel speed, and percent time-spent-following for base conditions of a directional segment of a two-way facility (*7*). These relationships are conceptually analogous to the relationships for the two-way segments in Exhibit 12-6; however, the relationships for directional segments incorporate the effect of the opposing flow rate on the average travel speed and percent time-spent-following. In Exhibit 12-7(a), the y-intercept represents the FFS in the analysis direction, incorporating the effect of the demand flow rate in the opposing direction. Exhibit 12-7(b) graphs the relationships between directional flow rate and percent time-spent-following when opposing flow rates range from 200 to 1,600 pc/h.

EXHIBIT 12-7. SPEED-FLOW AND PERCENT TIME-SPENT-FOLLOWING FLOW RELATIONSHIPS FOR DIRECTIONAL SEGMENTS WITH BASE CONDITIONS

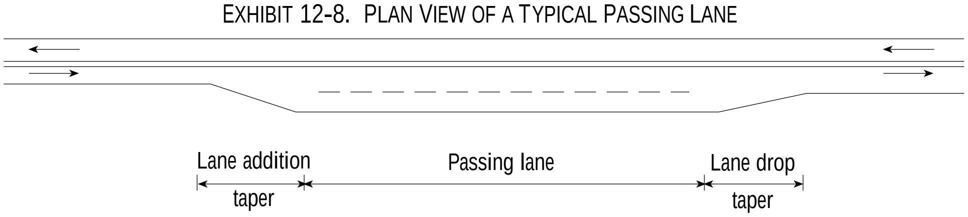




PASSING LANES ON TWO-LANE HIGHWAYS

A passing lane is a lane added in one direction of travel on a conventional two-lane highway to improve opportunities for passing. The addition of a passing lane to a two-lane highway provides a three-lane cross section with two lanes in one direction of travel and one lane in the other. Exhibit 12-8 illustrates a typical passing lane on a two-lane highway. Depending on local practice, traffic in the opposing direction may be prohibited from passing or may be permitted to pass if adequate sight distance is available, as shown in Exhibit 12-8. On some two-lane highways, passing lanes are provided intermittently or at intervals for each direction of travel. On other highways, added passing lanes alternate continuously between the two directions of travel. Passing lanes also can be provided in both directions of travel at the same location, resulting in a short section of four-lane undivided highway with improved passing opportunities in both directions.

EXHIBIT 12-8. PLAN VIEW OF A TYPICAL PASSING LANE



LOS

The primary measures of service quality for Class I two-lane highways are percent time-spent-following and average travel speed. For Class II two-lane highways, service quality is based only on percent time-spent-following. LOS criteria are defined for peak 15-min flow periods and are intended for application to segments of significant length.

LOS A describes the highest quality of traffic service, when motorists are able to travel at their desired speed. Without strict enforcement, this highest quality would result in average speeds of 90 km/h or more on two-lane highways in Class I. The passing frequency required to maintain these speeds has not reached a demanding level, so that passing demand is well below passing capacity, and platoons of three or more vehicles are rare. Drivers are delayed no more than 35 percent of their travel time by slow-moving vehicles. A maximum flow rate of 490 pc/h total in both directions may be achieved with base conditions. On Class II highways, speeds may fall below 90 km/h, but motorists will not be delayed in platoons for more than 40 percent of their travel time.

LOS B characterizes traffic flow with speeds of 80 km/h or slightly higher on level-terrain Class I highways. The demand for passing to maintain desired speeds becomes significant and approximates the passing capacity at the lower boundary of LOS B. Drivers are delayed in platoons up to 50 percent of the time. Service flow rates of 780 pc/h total in both directions can be achieved under base conditions. Above this flow rate, the number of platoons increases dramatically. On Class II highways, speeds may fall below 80 km/h, but motorists will not be delayed in platoons for more than 55 percent of their travel time.

LOS C describes further increases in flow, resulting in noticeable increases in platoon formation, platoon size, and frequency of passing impediments. The average speed still exceeds 70 km/h on level-terrain Class I highways, even though unrestricted passing demand exceeds passing capacity. At higher volumes the chaining of platoons and significant reductions in passing capacity occur. Although traffic flow is stable, it is susceptible to congestion due to turning traffic and slow-moving vehicles. Percent time-spent-following may reach 65 percent. A service flow rate of up to 1,190 pc/h total in both directions can be accommodated under base conditions. On Class II highways, speeds may fall below 70 km/h, but motorists will not be delayed in platoons for more than 70 percent of their travel time.

LOS D describes unstable traffic flow. The two opposing traffic streams begin to operate separately at higher volume levels, as passing becomes extremely difficult. Passing demand is high, but passing capacity approaches zero. Mean platoon sizes of 5 to 10 vehicles are common, although speeds of 60 km/h still can be maintained under base conditions on Class I highways. The proportion of no-passing zones along the roadway section usually has little influence on passing. Turning vehicles and roadside distractions cause major shock waves in the traffic stream. Motorists are delayed in platoons for nearly 80 percent of their travel time. Maximum service flow rates of 1,830 pc/h total in both directions can be maintained under base conditions. On Class II highways, speeds may fall below 60 km/h, but in no case will motorists be delayed in platoons for more than 85 percent of their travel time.

At LOS E, traffic flow conditions have a percent time-spent-following greater than 80 percent on Class I highways and greater than 85 percent on Class II. Even under base conditions, speeds may drop below 60 km/h. Average travel speeds on highways with less than base conditions will be slower, even down to 40 km/h on sustained upgrades. Passing is virtually impossible at LOS E, and platooning becomes intense, as slower vehicles or other interruptions are encountered.

The highest volume attainable under LOS E defines the capacity of the highway, generally 3,200 pc/h total in both directions. Operating conditions at capacity are unstable and difficult to predict. Traffic operations seldom reach near capacity on rural highways, primarily because of a lack of demand.

LOS F represents heavily congested flow with traffic demand exceeding capacity. Volumes are lower than capacity and speeds are highly variable.

REQUIRED INPUT DATA AND ESTIMATED VALUES

Exhibit 12-9 lists default values for input parameters that may be used in the absence of local data. However, taking field measurements for use as inputs to an analysis is the most reliable means of generating parameter values. Only when this is not feasible should the default values be considered.

EXHIBIT 12-9. REQUIRED INPUT DATA: TWO-LANE HIGHWAYS

Required Data	Default
Geometric Data	
Highway class	Exhibit 12-10
Lane width	3.6 m
Shoulder width	1.8 m
Access-point density	Exhibit 12-4
Specific grade or general terrain	Level
Percent no-passing	Exhibit 12-11
Base FFS	-
Length of passing lane	Exhibit 12-12
Demand	
Length of analysis period	15 min
PHF	0.88 rural, 0.92 urban
Directional split	Exhibit 12-13
Heavy vehicles percentages	Exhibit 12-14

Highway Classes

Two-lane highways are categorized into two classes. The general description of these classes is summarized in Exhibit 12-10.

EXHIBIT 12-10. SUMMARY OF TWO-LANE HIGHWAY CLASSES

Class	Description
I	Highways on which motorists expect to travel at relatively high speeds, including major intercity routes, primary arterials, and daily commuter routes
II	Highways on which motorists do not necessarily expect to travel at high speeds, including access routes, scenic and recreational routes that are not primarily arterials, and routes through rugged terrain

Lane Width and Shoulder Width

Refer to the description of lane width and lateral clearance under the required input data and estimated values for multilane highways.

Access-Point Density

Refer to the description of access-point density under the required input data and estimated values for multilane highways.

Specific Grade or General Terrain

Refer to the description of specific grade or general terrain under the required input data and estimated values for multilane highways.

Percentage of No-Passing Zones

The percentage of each segment length in which passing is prohibited should be estimated from local data. In the absence of such data, Exhibit 12-11 may be used.

EXHIBIT 12-11. DEFAULT VALUES FOR PERCENTAGE OF NO-PASSING ZONES

Terrain Type	No-Passing Zones (%)
Level	20
Rolling	50
Mountainous	80

Base FFS

The base FFS for a two-lane highway is observed at base conditions and ranges from 70 to 110 km/h, depending on the highway's characteristics.

Length of Passing Lane

Passing lanes on two-lane highways range in length from 0.3 to 5.0 km (*8*). Research has shown that the optimal lengths for passing lanes range from 0.8 to 3.2 km, depending on the traffic flow rate, as shown in Exhibit 12-12.

EXHIBIT 12-12. OPTIMAL LENGTHS OF PASSING LANES

Directional Flow Rate (pc/h)	Optimal Passing Lane Length (km)
100	≤ 0.80
200	> 0.80–1.20
400	> 1.20–1.60
≥ 700	> 1.60–3.20

Source: Harwood and St. John (*8*).

Length of Analysis Period

Refer to the description of the length of analysis period under the required data and estimated values for multilane highways.

PHF

When feasible, the PHF should be determined from local field data. If field data are not available, the factors presented in Exhibit 12-9 may be used for two-way and directional two-lane highway analysis. In general, lower PHFs are typical of rural or off-peak conditions, but higher PHFs are typical of urban or suburban peak-hour conditions. Default PHF values of 0.88 for rural areas and 0.92 for urban areas may be used in the absence of local data.

Directional Split

Directional distribution is defined as 50/50 for base conditions. Most directional distributions on rural two-lane highways range from 50/50 to 70/30. On recreational routes, the directional distribution may be as high as 80/20 or more during holiday or other peak periods. Exhibit 12-13 lists default directional splits that may be used if field-observed data are not available.

EXHIBIT 12-13. DEFAULT VALUES FOR DIRECTIONAL SPLIT ON TWO-LANE HIGHWAYS

Type	Directional Split
Rural Highways	60/40
Urban Highways	60/40
Recreational Highways	80/20

Percentage of Heavy Vehicles

The local HPMS may be used to obtain local information on the percentage of heavy vehicles by facility and area type. When estimates of the traffic mix are not available,

Exhibit 12-14 presents default values that may be used for primary routes. Recreational routes typically would have a higher proportion of RVs and often a lower proportion of trucks than shown in Exhibit 12-14.

EXHIBIT 12-14. DEFAULT HEAVY-VEHICLE PERCENTAGES ON TWO-LANE HIGHWAYS

Type of Heavy Vehicle	Rural (%)	Urban (%)
Trucks (including buses)	14	2
RVs	4	0

SERVICE VOLUME TABLE

An example service volume table for Class I highways is provided in Exhibit 12-15. From the exhibit, the hourly volume that can be accommodated at a given LOS, terrain, and FFS can be determined under specified conditions.

This table contains approximate values and is meant for illustrative purposes only. The values depend on the assumptions and should not be used for operational analyses or final design. This table was derived using assumed values listed in the footnote.

EXHIBIT 12-15. EXAMPLE SERVICE VOLUMES FOR A CLASS I TWO-LANE RURAL HIGHWAY (SEE FOOTNOTE FOR ASSUMED VALUES)

FFS (km/h)	Terrain	Service Volumes (veh/h)				
		A	B	C	D	E
110	Level	260	490	900	1570	2680
	Rolling	130	260	710	1490	2500
	Mountainous	40	160	310	610	1410
100	Level	260	490	900	1570	2680
	Rolling	130	260	710	1490	2500
	Mountainous	40	160	310	510	1410
90	Level	N/A	490	900	1570	2680
	Rolling	N/A	260	710	1490	2500
	Mountainous	N/A	160	310	510	1410
80	Level	N/A	N/A	490	1420	2680
	Rolling	N/A	N/A	280	1100	2500
	Mountainous	N/A	N/A	180	870	1410
70	Level	N/A	N/A	N/A	490	2680
	Rolling	N/A	N/A	N/A	280	2500
	Mountainous	N/A	N/A	N/A	180	1410

Note:
Assumptions: 60/40 directional split; 20-, 40-, and 60-percent no-passing zones for level, rolling, and mountainous terrain, respectively; 14 percent trucks; and 4 percent RVs.
N/A = not achievable for the given condition
Source: Harwood et al. (*7*).

IV. REFERENCES

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. Tignor, S.C. *Driver Speed Behavior on U.S. Streets and Highways*. Compendium of Technical Papers, Institute of Transportation Engineers, August 5–8, 1990.
3. Hool, J. N., S. Maghsoodloo, A. D. Veren, and D. D. Brown. Analysis of Selective Enforcement Strategy Effects on Rural Alabama Traffic Speeds. In *Transportation Research Record 910*, TRB, National Research Council, Washington, D.C., 1983, pp. 74–81.

4. Armour, M. The Effect of Police Presence on Urban Driving Speeds. *Australia Road Research*, Vol. 14, No. 3, Sept. 1984, pp. 142–148.
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6. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. Washington, D.C., 1990.
7. Harwood, D. W., A. D. May, I. B. Anderson, L. Leiman, and A. R. Archilla. *Capacity and Quality of Service of Two-Lane Highways*. Final Report, NCHRP Project 3-55(3), Midwest Research Institute, 1999 (forthcoming).
8. Harwood, D. W., and A. D. St. John. *Operational Effectiveness of Passing Lanes on Two-Lane Highways*. Report No. FHWA/RD-86/196, FHWA, U.S. Department of Transportation, Washington, D.C., 1986.