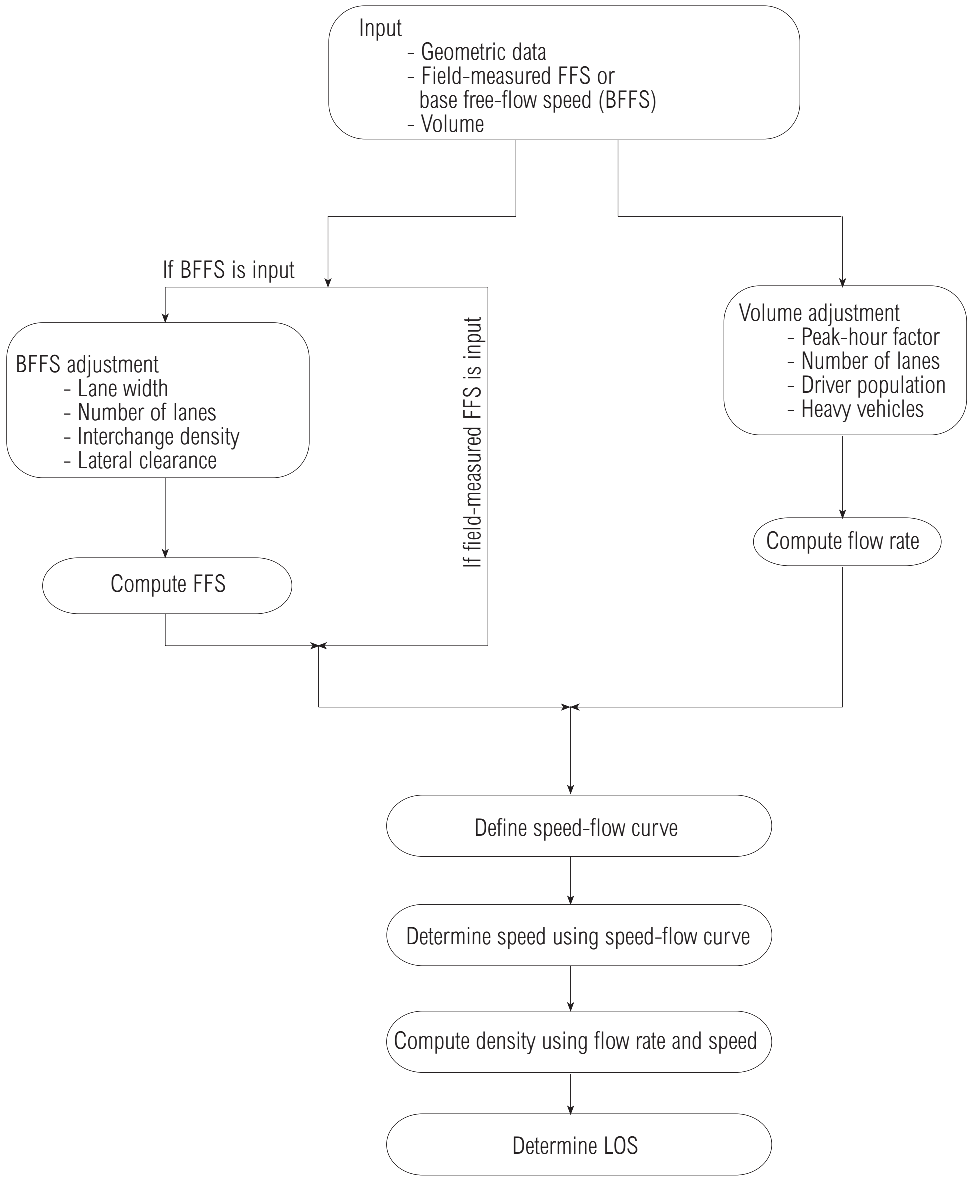
II. METHODOLOGY

The methodology described in this chapter is for the analysis of basic freeway segments. A method for analysis of extended lengths of freeway that comprise a combination of basic segments, weaving segments, and ramp junctions is found in Chapter 22. Exhibit 23-1 illustrates input to and the basic computation order of the method for basic freeway segments. The primary output of the method is LOS.

EXHIBIT 23-1. BASIC FREEWAY SEGMENT METHODOLOGY



LOS

A basic freeway segment can be 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 (v/c) ratio. Each of these measures is an indication of how well traffic flow is being accommodated by the freeway.

The measure used to provide an estimate of level of service is density. The three measures of speed, density, and flow or volume are interrelated. If values for two of these measures are known, the third can be computed.

Level-of-service thresholds for a basic freeway segment are summarized below.

Density is used to define LOS

LOS	Density Range (pc/km/ln)
A	0–7
B	> 7–11
C	> 11–16
D	> 16–22
E	> 22–28
F	> 28

Density greater than 28 pc/km/ln (LOS F) indicates a queue that extends into the segment

For any given level of service, the maximum allowable density is somewhat lower than that for the corresponding level of service on multilane highways. This reflects the higher quality of service drivers expect when using freeways as compared with surface multilane facilities. This does not imply that an at-grade multilane highway will perform better than a freeway with the same number of lanes under similar conditions. For any given density, a freeway will carry higher flow rates at higher speeds than will a comparable multilane highway.

The specification of maximum densities for LOS A through D is based on the collective professional judgment of the members of the Committee on Highway Capacity and Quality of Service of the Transportation Research Board. The upper value shown for LOS E (28 pc/km/ln) is the maximum density at which sustained flows at capacity are expected to occur.

LOS criteria for basic freeway segments are given in Exhibit 23-2 for free-flow speeds of 120 km/h or greater, 110 km/h, 100 km/h, and 90 km/h. To be within a given LOS, the density criterion must be met. In effect, under base conditions, these are the speeds and flow rates expected to occur at the density shown for each LOS.

EXHIBIT 23-2. LOS CRITERIA FOR BASIC FREEWAY SEGMENTS

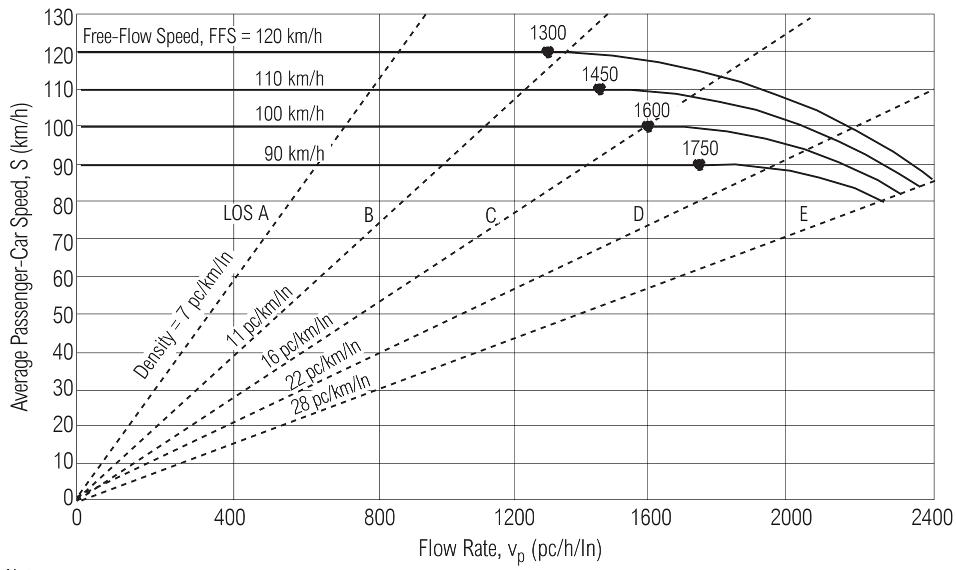
Criteria	LOS				
	A	B	C	D	E
FFS = 120 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	120.0	120.0	114.6	99.6	85.7
Maximum v/c	0.35	0.55	0.77	0.92	1.00
Maximum service flow rate (pc/h/ln)	840	1320	1840	2200	2400
FFS = 110 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	110.0	110.0	108.5	97.2	83.9
Maximum v/c	0.33	0.51	0.74	0.91	1.00
Maximum service flow rate (pc/h/ln)	770	1210	1740	2135	2350
FFS = 100 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	100.0	100.0	100.0	93.8	82.1
Maximum v/c	0.30	0.48	0.70	0.90	1.00
Maximum service flow rate (pc/h/ln)	700	1100	1600	2065	2300
FFS = 90 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	90.0	90.0	90.0	89.1	80.4
Maximum v/c	0.28	0.44	0.64	0.87	1.00
Maximum service flow rate (pc/h/ln)	630	990	1440	1955	2250

Note:
The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. The speed criterion is the speed at maximum density for a given LOS.

Failure, breakdown, congestion, and LOS F occur when queues begin to form on the freeway. Density tends to increase sharply within the queue and may be considerably higher than the maximum value of 28 pc/km/ln for LOS E. Further guidance on analysis of basic freeway segments with densities greater than 28 pc/km/ln is provided in Chapter 22.

Exhibit 23-3 shows the relationship between speed, flow, and density for basic freeway segments. It also shows the definition of the various LOS on the basis of density boundary values.

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS



Note:
Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 120, 110, 100, and 90 km/h, respectively.

For $90 \le FFS \le 120$ and for flow rate (v_p)
$(3100 - 15FFS) < v_p \le (1800 + 5FFS)$,

$$S = FFS - \left[\frac{1}{28}\left(23FFS - 1800\right)\left(\frac{v_p + 15FFS - 3100}{20FFS - 1300}\right)^{2.6}\right]$$

For $90 \le FFS \le 120$ and
$v_p \le (3100 - 15FFS)$,
$S = FFS$

DETERMINING FFS

Measure or estimate the FFS

FFS is the mean speed of passenger cars measured during low to moderate flows (up to 1,300 pc/h/ln). For a specific segment of freeway, speeds are virtually constant in this range of flow rates. Two methods can be used to determine the FFS of a basic freeway segment: field measurement and estimation with guidelines provided in this chapter. The field-measurement procedure is provided for users who prefer to gather these data directly. However, field measurements are not required for application of the method. If field-measured data are used, no adjustments are made to the free-flow speed.

Measurement of free-flow speed

The speed study should be conducted at a location that is representative of the segment when flows and densities are low (flow rates may be up to 1,300 pc/h/ln). Weekday off-peak hours are generally good times to observe low to moderate flow rates. The speed study should measure the speeds of all passenger cars or use a systematic sample (e.g., every 10th passenger car). The speed study should measure passenger-car speeds across all lanes. 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 speed studies may be used. Further guidance on the conduct of speed studies is found in standard traffic engineering publications, such as the *Manual of Traffic Engineering Studies* published by the Institute of Transportation Engineers.

The average of all passenger-car speeds measured in the field under low- to moderate-volume conditions can be used directly as the FFS of the freeway segment. This speed reflects the net effect of all conditions at the study site that influence speed, including those considered in this method (lane width, lateral clearance, interchange density, and number of lanes) as well as others such as speed limit and vertical and horizontal alignment. Speed data that include both passenger cars and heavy vehicles can be used for level terrain or moderate downgrades but should not be used for rolling or mountainous terrain.

Estimate free-flow speed if measurement is not possible

If field measurement of FFS is not possible, FFS can be estimated indirectly on the basis of the physical characteristics of the freeway segment being studied. The physical characteristics include lane width, number of lanes, right-shoulder lateral clearance, and interchange density. Equation 23-1 is used to estimate the free-flow speed of a basic freeway segment:

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \qquad (23\text{-}1)$$

where

FFS = free-flow speed (km/h);
$BFFS$ = base free-flow speed, 110 km/h (urban) or 120 km/h (rural);
f_{LW} = adjustment for lane width from Exhibit 23-4 (km/h);
f_{LC} = adjustment for right-shoulder lateral clearance from Exhibit 23-5 (km/h);
f_N = adjustment for number of lanes from Exhibit 23-6 (km/h); and
f_{ID} = adjustment for interchange density from Exhibit 23-7 (km/h).

BFFS

Estimation of FFS for an existing or future freeway segment is accomplished by adjusting a base free-flow speed downward to reflect the influence of four factors: lane width, lateral clearance, number of lanes, and interchange density. Thus, the analyst is required to select an appropriate BFFS as a starting point.

Adjustment for Lane Width

The base condition for lane width is 3.6 m or greater. When the average lane width across all lanes is less than 3.6 m, the base free-flow speed (e.g., 120 km/h) is reduced. Adjustments to reflect the effect of narrower average lane width are given in Exhibit 23-4.

EXHIBIT 23-4. ADJUSTMENTS FOR LANE WIDTH

Lane Width (m)	Reduction in Free-Flow Speed, f_{LW} (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Adjustment for Lateral Clearance

Base lateral clearance is 1.8 m or greater on the right side and 0.6 m or greater on the median or left side, measured from the edge of the paved shoulder to the nearest edge of the traveled lane. When the right-shoulder lateral clearance is less than 1.8 m, the BFFS is reduced. Adjustments to reflect the effect of narrower right-shoulder lateral clearance are given in Exhibit 23-5. No adjustments are available to reflect the effect of median lateral clearance less than 0.6 m. Lateral clearance less than 0.6 m on either the right or left side of a freeway is considered rare. Considerable judgment must be used in determining whether objects or barriers along the right side of a freeway present a true obstruction. Such obstructions may be continuous, such as retaining walls, concrete barriers, or guardrails, or may be noncontinuous, such as light supports or bridge abutments. In some cases, drivers may become accustomed to certain types of obstructions, in which case their influence on traffic flow may be negligible.

Adjustment for lateral clearance reflects only the right-shoulder width

EXHIBIT 23-5. ADJUSTMENTS FOR RIGHT-SHOULDER LATERAL CLEARANCE

	Reduction in Free-Flow Speed, f_{LC} (km/h)			
	Lanes in One Direction			
Right-Shoulder Lateral Clearance (m)	2	3	4	≥ 5
≥ 1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.7	0.3	0.2
1.2	1.9	1.3	0.7	0.4
0.9	2.9	1.9	1.0	0.6
0.6	3.9	2.6	1.3	0.8
0.3	4.8	3.2	1.6	1.1
0.0	5.8	3.9	1.9	1.3

Adjustment for Number of Lanes

Adjustment for number of lanes (not applicable to rural freeway segments)

Freeway segments with five or more lanes (in one direction) are considered as having base conditions with respect to number of lanes. When fewer lanes are present, the BFFS is reduced. Exhibit 23-6 provides adjustments to reflect the effect of number of lanes on BFFS. In determining number of lanes, only mainline lanes, both basic and auxiliary, should be considered. HOV lanes should not be included.

EXHIBIT 23-6. ADJUSTMENTS FOR NUMBER OF LANES

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (km/h)
≥ 5	0.0
4	2.4
3	4.8
2	7.3

Note: For all rural freeway segments, f_N is 0.0.

The adjustments in Exhibit 23-6 are based exclusively on data collected on urban and suburban freeways and do not reflect conditions on rural freeways, which typically carry two lanes in each direction. In using Equation 23-1 to estimate the FFS of a rural freeway segment, the value of the adjustment for number of lanes, f_N, should be 0.0.

Adjustment for Interchange Density

A 10-km segment is used to determine interchange density

The base interchange density is 0.3 interchanges per kilometer, or 3.3-km interchange spacing. Base free-flow speed is reduced when interchange density becomes greater. Adjustments to reflect the effect of interchange density are provided in Exhibit 23-7. Interchange density is determined over a 10-km segment of freeway (5 km upstream and 5 km downstream) in which the freeway segment is located. An interchange is defined as having at least one on-ramp. Therefore, interchanges that have only off-ramps would not be considered in determining interchange density. Interchanges considered should include typical interchanges with arterials or highways and major freeway-to-freeway interchanges.

EXHIBIT 23-7. ADJUSTMENTS FOR INTERCHANGE DENSITY

Interchanges per Kilometer	Reduction in Free-Flow Speed, f_{ID} (km/h)
≤ 0.3	0.0
0.4	1.1
0.5	2.1
0.6	3.9
0.7	5.0
0.8	6.0
0.9	8.1
1.0	9.2
1.1	10.2
1.2	12.1

DETERMINING FLOW RATE

The hourly flow rate must reflect the influence of heavy vehicles, the temporal variation of traffic flow over an hour, and the characteristics of the driver population. These effects are reflected by adjusting hourly volumes or estimates, typically reported in vehicles per hour (veh/h), to arrive at an equivalent passenger-car flow rate in passenger cars per hour (pc/h). The equivalent passenger-car flow rate is calculated using the heavy-vehicle and peak-hour adjustment factors and is reported on a per lane basis (pc/h/ln). Equation 23-2 is used to calculate the equivalent passenger-car flow rate.

Convert veh/h to pc/h using heavy-vehicle, peak-hour, and driver population factors

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p} \qquad (23\text{-}2)$$

where

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

Peak-Hour Factor

The peak-hour factor (PHF) represents the variation in traffic flow within an hour. Observations of traffic flow consistently indicate that the flow rates found in the peak 15-min period within an hour are not sustained throughout the entire hour. The application of the peak-hour factor in Equation 23-2 accounts for this phenomenon.

On freeways, typical PHFs range from 0.80 to 0.95. Lower PHFs are characteristic of rural freeways or off-peak conditions. Higher factors are typical of urban and suburban peak-hour conditions. Field data should be used, if possible, to develop PHFs representative of local conditions.

Heavy-Vehicle Adjustments

Freeway traffic volumes that include a mix of vehicle types must be adjusted to an equivalent flow rate expressed in passenger cars per hour per lane. This adjustment is made using the factor f_{HV}. Once the values of E_T and E_R are found, the adjustment factor, f_{HV}, is determined by using Equation 23-3.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (23\text{-}3)$$

where

E_T, E_R = passenger-car equivalents for trucks/buses and recreational vehicles (RVs) in the traffic stream, respectively;

P_T, P_R = proportion of trucks/buses and RVs in the traffic stream, respectively; and

f_{HV} = heavy-vehicle adjustment factor.

Adjustments for heavy vehicles in the traffic stream apply for three vehicle types: trucks, buses, and RVs. There is no evidence to indicate distinct differences in performance between trucks and buses on freeways, and therefore trucks and buses are treated identically.

In many cases, trucks will be the only heavy-vehicle type present in the traffic stream to a significant degree. Where the percentage of RVs is small compared with the percentage of trucks, it is sometimes convenient to consider all heavy vehicles to be trucks. It is generally acceptable to do this where the percentage of trucks and buses is at least five times the percentage of RVs.

The factor f_{HV} is found using a two-step process. First, the passenger-car equivalent for each truck/bus and RV is found for the traffic and roadway conditions under study. These equivalency values, E_T and E_R, represent the number of passenger cars that would use the same amount of freeway capacity as one truck/bus or RV, respectively, under prevailing roadway and traffic conditions. Second, using the values of E_T and E_R and the proportion of each type of vehicle in the traffic stream (P_T and P_R), the adjustment factor f_{HV} is computed.

The effect of heavy vehicles on traffic flow depends on grade conditions as well as traffic composition. Passenger-car equivalents can be selected for one of three conditions: extended freeway segments, upgrades, and downgrades.

Extended Freeway Segments

Extended segment—use when no one grade (3 percent or greater) is longer than 0.5 km. Use when no one grade (less than 3 percent) is longer than 1 km.

It is often appropriate to consider an extended length of freeway containing a number of upgrades, downgrades, and level segments as a single uniform segment. This is possible where no one grade is long enough or steep enough to have a significant effect on the operation of the overall segment. As a guideline, extended segment analysis can be used where no one grade of 3 percent or greater is longer than 0.5 km or where no one grade of less than 3 percent is longer than 1.0 km.

Specific Grades

Any grade less than 3 percent that is longer than 1.0 km or any grade of 3 percent or more that is longer than 0.5 km must be analyzed as a separate segment because of its significant effect on traffic flow.

Equivalents for Extended Freeway Segments

Whenever extended segment analysis is used, the terrain of the freeway must be classified as level, rolling, or mountainous.

Level Terrain

Level terrain is 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 includes short grades of no more than 2 percent.

Rolling Terrain

Rolling terrain is any combination of grades and horizontal or vertical alignment that causes heavy vehicles to reduce their speeds substantially below those 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 any grade is long enough, trucks will be forced to decelerate to the crawl speed, which they will then be able to maintain for extended distances. Appendix A contains truck performance curves illustrating crawl speed and length of grade.

Appendix A shows truck performance curves

Mountainous Terrain

Mountainous terrain is any combination of grades and horizontal or vertical alignment that causes heavy vehicles to operate at crawl speeds for significant distances or at frequent intervals.

Exhibit 23-8 gives passenger-car equivalents for extended freeway segments. Note that it is extremely difficult to have mountainous terrain as defined herein without violating the guidelines for using the general terrain methodology (i.e., having no grade greater than 3 percent longer than 0.5 km). To a lesser extent, the same statement may be made with respect to rolling terrain. The equivalence values shown in Exhibit 23-8 are most useful in the planning stage of analysis, when specific alignments are not known but approximate capacity computations are still needed.

EXHIBIT 23-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED FREEWAY SEGMENTS

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

Equivalents for Specific Grades

Any freeway grade of more than 1.0 km for grades less than 3 percent or 0.5 km for grades of 3 percent or more should be considered as a separate segment. Analysis of such segments must consider the upgrade and downgrade conditions and whether the grade is a single and isolated grade of constant percentage or part of a series forming a composite grade.

Several studies have indicated that freeway truck populations have an average weight-to-power ratio of between 75 and 90 kg/kW. These procedures adopt passenger-car equivalents calibrated for a mix of trucks/buses in this range. RVs vary considerably in both type and characteristics. These vehicles include everything from cars with trailers to self-contained mobile campers. In addition to the variability of the vehicles, the drivers are not professionals, and their degree of skill in handling such vehicles varies. Typical weight-to-power ratios of RVs range from 20 to 40 kg/kW.

Equivalents for Specific Upgrades

Exhibits 23-9 and 23-10 give values of E_T and E_R for upgrade segments. These factors vary with the percent of grade, length of grade, and the proportion of heavy vehicles in the traffic stream. The maximum values of E_T and E_R occur when there are only a few heavy vehicles. The equivalents decrease as the number of heavy vehicles increases, because these vehicles tend to form platoons and have operating characteristics that are more uniform as a group than those of passenger cars.

Establishing length of grade

The length of grade is generally taken from a profile of the highway in question and 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 percent of the length of the vertical curves at the beginning and end of the grade be included in the length of the grade. Where two consecutive upgrades are present, 50 percent of the length of the vertical curve between them is assigned to the length of each upgrade.

EXHIBIT 23-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UPGRADES

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

EXHIBIT 23-10. PASSENGER-CAR EQUIVALENTS FOR RVs ON UPGRADES

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

In analyzing upgrades, the point of interest is usually the end of the grade, where heavy vehicles presumably have the maximum effect on operations. This is not always the case, however. If a ramp junction is located midgrade, the point of the merge or diverge will also be a critical point for analysis. In the case of composite grades, the point at which heavy vehicles are traveling slowest is the critical point for analysis. If a 5 percent upgrade is followed by a 2 percent upgrade, it is reasonable to assume that the end of the 5 percent portion will be critical, since heavy vehicles would be expected to accelerate on the 2 percent portion of the grade.

Equivalents for Specific Downgrades

For RVs, downgrades may be treated as level terrain

There are few specific data on the effect of heavy vehicles on traffic flow on downgrades. In general, if the downgrade does not cause trucks to shift into a low gear, they may be treated as if they were level terrain segments, and passenger-car equivalents are selected accordingly. Where more severe downgrades occur, trucks must often use low gears to avoid gaining too much speed and running out of control. In such cases, their effect is greater than it would be on level terrain. Exhibit 23-11 gives values of E_T. For RVs, downgrades may be treated as level terrain.

EXHIBIT 23-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON DOWNGRADES

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

Equivalents for Composite Grades

The vertical alignment of most freeways results in a continuous series of grades. It is often necessary to determine the effect of a series of significant grades in succession. The most straightforward technique is to compute the average grade to the point in question. The average grade is defined as the total rise from the beginning of the composite grade divided by the length of the grade.

Appendix A gives a detailed composite grade technique

The average grade technique is an acceptable approach for grades in which all subsections are less than 4 percent or the total length of the composite grade is less than 1,200 m. For more severe composite grades, a detailed technique is presented in Appendix A. This technique uses vehicle performance curves and equivalent speeds to determine the equivalent simple grade for analysis.

Driver Population Factor

The traffic stream characteristics that are the basis of this methodology are representative of regular drivers in a substantially commuter traffic stream or in a stream in which most drivers are familiar with the facility. It is generally accepted that traffic streams with different characteristics (i.e., recreational drivers) use freeways less efficiently. Whereas 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 reduction in capacity (LOS E) extends to service volumes for other levels of service as well.

The adjustment factor f_p is used to reflect this effect. The values of f_p range from 0.85 to 1.00. In general, the analyst should select 1.00, which reflects commuter traffic (i.e., familiar users), unless there is sufficient evidence that a lower value should be applied. Where greater accuracy is needed, comparative field studies of commuter and recreational traffic flow and speeds are recommended.

DETERMINING LOS

The first step in determining LOS of a basic freeway segment is to define and segment the freeway facility as appropriate. Second, on the basis of estimated or field-measured FFS, an appropriate speed-flow curve of the same shape as the typical curves (Exhibit 23-3) is constructed. On the basis of the flow rate, v_p, and the constructed speed-flow curve, an average passenger-car speed is read on the y-axis of Exhibit 23-3. The next step is to calculate density using Equation 23-4.

$$D = \frac{v_p}{S} \qquad (23\text{-}4)$$

where

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

LOS of the basic freeway segment is then determined by comparing the calculated density with the density ranges in Exhibit 23-2.

SENSITIVITY OF RESULTS TO INPUT VARIABLES

Downstream conditions may cause backups that result in low speeds and low volumes. The basic freeway segment methodology cannot be applied in such circumstances.

Analysts will note that there is no direct way to calibrate the estimated capacity of the basic freeway segment with field conditions. The analyst must instead calibrate the estimated free-flow speed and demand adjustments with field conditions. Field measurements of density can be used to determine LOS directly.

The FFS for urban freeways is sensitive to the average interchange spacing and the number of lanes in one direction. The sensitivity increases with the number of lanes. Exhibit 23-12 can be used to determine the FFS given the number of lanes in one direction and the average distance between freeway interchanges.

EXHIBIT 23-12. URBAN FREEWAY FFS AND INTERCHANGE SPACING
(SEE FOOTNOTE FOR ASSUMED VALUES)

	Free-Flow Speed (km/h)			
	Interchange Spacing (km)			
Number of Lanes	1.00	1.25	2.00	3.00
2	94	97	101	103
3	96	99	103	105
4	98	102	106	108
5	99	104	108	110

Note:
Assumptions: BFFS = 110 km/h, lane width = 3.6 m, lateral clearance = 1.8 m.

The FFS for rural freeways is sensitive to the average interchange spacing for spacing under 1.0 km. Exhibit 23-13 can be used to determine the FFS for rural freeways given the average interchange spacing.