Capacity and Level of Service for Highway Segments

1. Freeways

A freeway is a divided highway with full access control and two or more lanes in each direction for the exclusive use of moving traffic. Signalized or stop-controlled, at grade intersections or direct access to adjacent land use are not permitted in order to ensure the uninterrupted flow of vehicles. Opposing traffic is separated by a raised barrier, an at-grade median, or a raised traffic island. A freeway is composed of three elements: basic freeway sections, weaving areas, and ramp junctions.
Basic freeway sections are segments of the freeway that are outside of the influence area of ramps or weaving areas. Merging or diverging occurs where on- or off-ramps join the basic freeway section. Weaving occurs when vehicles cross each other’s path while traveling on freeway lanes. Figure below illustrates a basic freeway section.

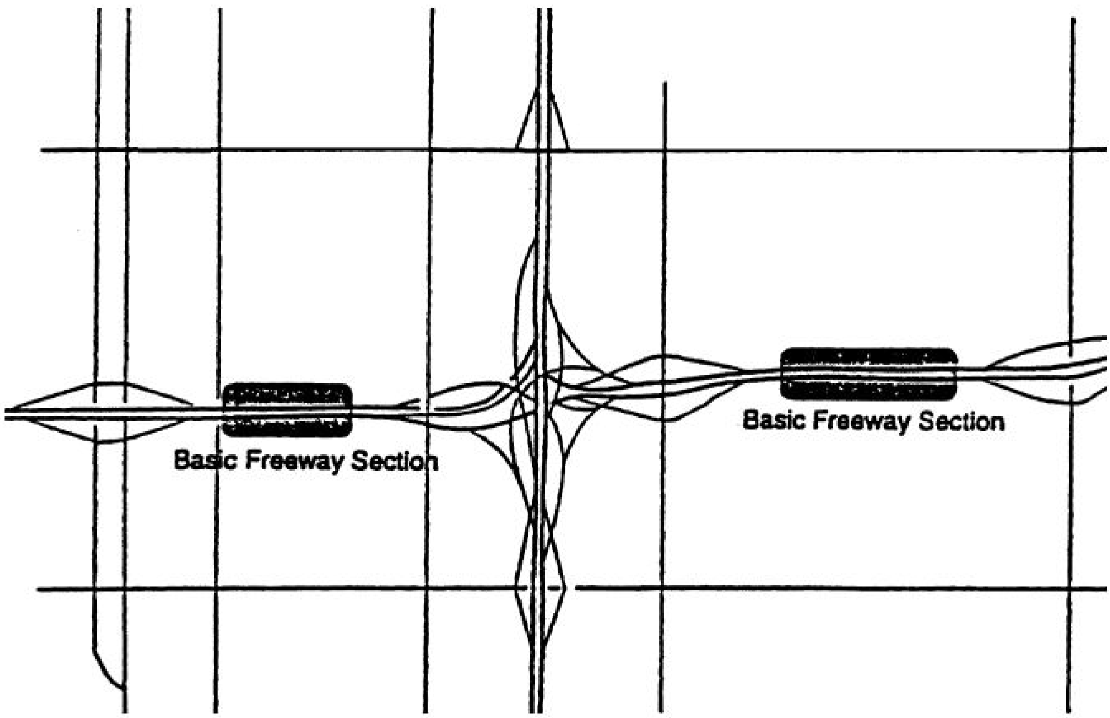


Figure: Example of Basic Freeway Section.

The exact point at which a basic freeway section begins or ends—that is, where the influence of weaving areas and ramp junctions has dissipated—depends on local conditions, particularly the level of service operating at the time. If traffic flow is light, the influence may be negligible, whereas under congested conditions, queues may be extensive.

The speed-flow-density relationship existing on a basic freeway section illustrated in Figure below depends on the prevailing traffic and roadway conditions. Base free-flow conditions include the following freeway characteristics:

- Lanes are 12 ft wide
- Lateral clearance between the edge of a right lane and an obstacle is 6 ft or greater
- There are no trucks, buses, or RVs in the traffic stream
- Urban freeways are five lanes in each direction
- Interchanges are spaced at least 2 mi apart
- Grades do not exceed 2%
- Drivers are familiar with the freeway

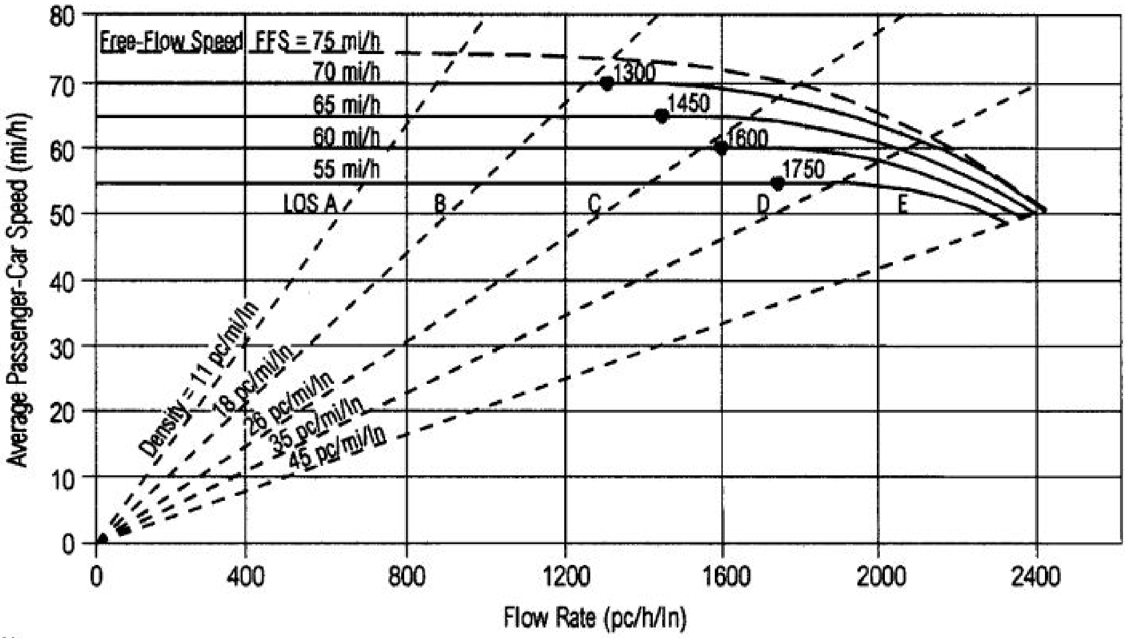


Figure: Speed-Flow Curves and Level-of-Service for Basic Freeway Segments.

The capacity of a freeway is the maximum sustained 15-minute rate of flow, expressed in passenger cars per hour per lane (pc/h/ln), which can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction. The roadway conditions are the geometric characteristics of the freeway segment under study, which include number and width of lanes, right-shoulder lateral clearance, interchange spacing, and grade. The traffic conditions are flow characteristics, including the percentage composition of vehicle types and the extent to which drivers are familiar with the freeway segment. Conditions of free-flow speed occur when flow rates are low to moderate (less than 1300 pc/h/ln at 70 mi/h). As flow rates increase beyond 1300, the mean speed of passenger cars in the traffic stream decreases.

Level of Service for Freeway Segments

Level of service (LOS) qualitatively measures both the operating conditions within a traffic system and how these conditions are perceived by drivers and passengers. It is related to the physical characteristics of the highway and the different operating characteristics that can occur when the highway carries different traffic volumes. Although speed-flow-density relationships are the principal factors affecting the level of service of a highway segment under ideal conditions, factors such as lane width, lateral obstruction, traffic composition, grade, speed, and driver population also affect the maximum flow on a given highway segment. The effects of each of these factors on flow are briefly discussed.

Lane Width. Traffic flow tends to be restricted when lane widths are narrower than 12 ft. This is because vehicles have to travel closer together in the lateral direction, and motorists tend to compensate for this by reducing their travel
speed.

Lateral Clearance. When roadside or median objects are located too close to the edge of the pavement, motorists in lanes adjacent to the objects tend to shy away from them, resulting in reduced lateral distances between vehicles, a result similar to lane reduction. Drivers compensate by reducing speed. The effect of lateral clearance is more pronounced for the right shoulder than for the median. Figure below illustrates how vehicles shy away from both roadside and median barriers.

Vehicle Equivalents. The presence of vehicles other than passenger cars such as trucks, buses, and recreational vehicles in a traffic stream reduces the maximum flow on the highway because of their size, operating characteristics, and interaction with other vehicles. Because freeway capacity is measured in terms of pc/h/ln, the number of heavy vehicles in the traffic stream must be converted into an equivalent number of passenger cars. Figure below illustrates the effect of trucks and other heavy vehicles on freeway traffic.

Grade. The effect of a grade depends on both the length and slope of the grade. Traffic operations are significantly affected when grades of 3 percent or greater are longer than one-quarter mi and when grades are less than 3 percent and longer than one-half mi. The effect of heavy vehicles on such grades is much greater than that of passenger vehicles.
Speed. Space mean speed, defined in Chapter 6, is used in level-of-service analysis.

Driver Population. Under ideal conditions, the driver population consists primarily of commuters. However, it is known that other driver populations do not exhibit the same characteristics. For example, recreational traffic capacities can be as much as 20 percent lower than for commuter traffic.

(a) Note how vehicles shy away from both roadside and median barriers, driving as close to the lane marking as possible. The existence of narrow lanes compounds the problem, making it difficult for two vehicles to travel alongside each other.

(b) In this case, vehicles shy away from the roadside barrier. This causes the placement of vehicles in each lane to be skewed toward the median. This is also an indication that the median barrier illustrated here does not present an obstruction to drivers.

Figure: Effect of Lane Width and Lateral Clearance on Traffic Flow.

(a) Note the formation of large gaps in front of slow-moving trucks climbing the upgrade.

(b) Even on relatively level terrain, the appearance of large gaps in front of trucks or other heavy vehicles is unavoidable.

Figure: Effect of Trucks and Other Heavy Vehicles on Traffic Flow.

Interchange Spacing. Short freeway sections, as found in urban areas, operate at lower free-flow speeds than longer ones, where interchanges are less frequent. The ideal spacing is 2 miles or more (0.5 interchanges per mi). The minimum average interchange spacing is 0.5 mi (2 interchanges per mi).

Any two of the following three performance characteristics can describe the level of service (LOS) for a basic freeway section:
v_p: Flow rate (pc/h/ln)
S: Average passenger car speed (mi/h)
D: Density defined as number of cars per mi (pc/mi/ln)
The relationship between the three performance characteristics is as noted in Eq. below.

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

Previous Table lists the level-of-service criteria for basic freeway sections in terms of free-flow speed and density, and Figure below illustrates each level of service (LOS) regime. The definition of level of service A through F is as follows.

Level of Service A: Free-flow operations in which vehicles are completely unimpeded in their ability to maneuver. Under these conditions, motorists experience a high level of physical and psychological comfort, and the effects of incidents or point breakdowns are easily absorbed.

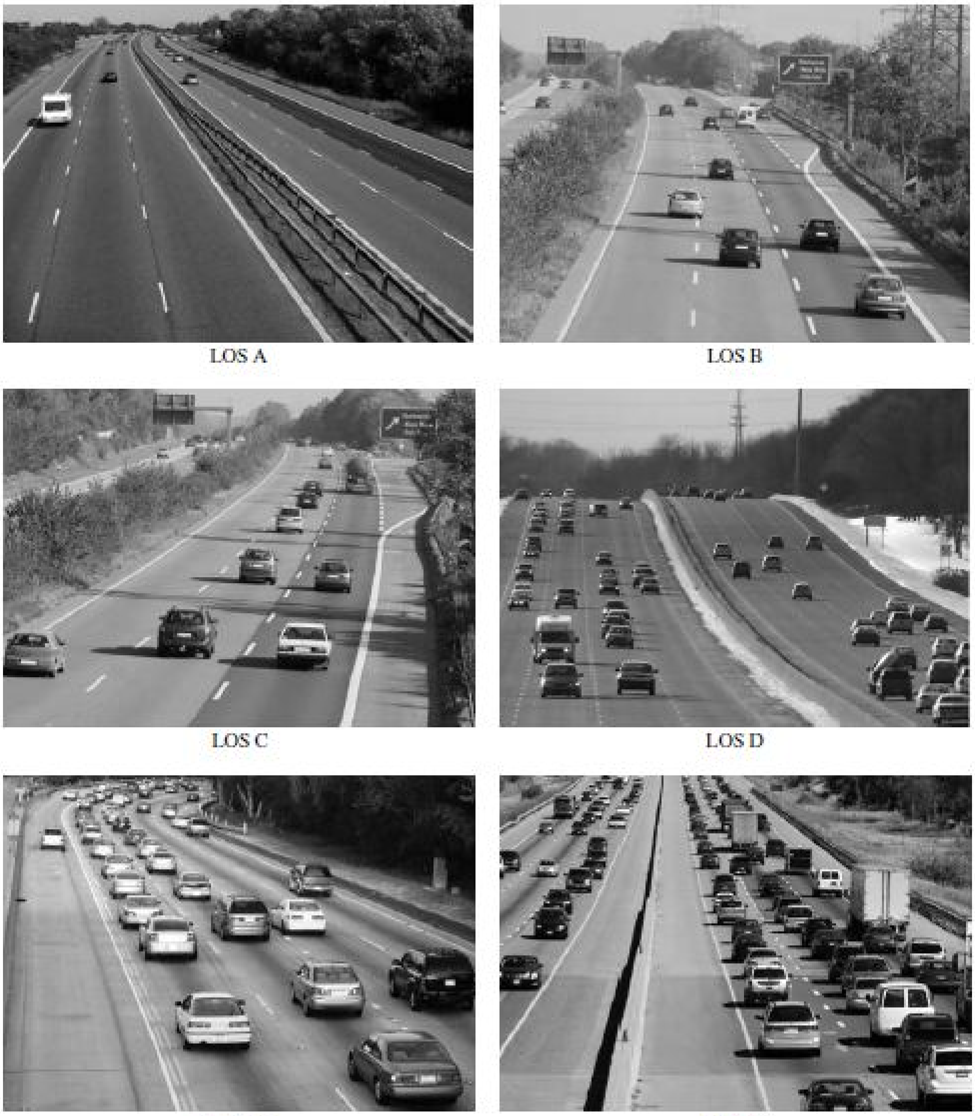
Level of Service B: Traffic is moving under reasonably free-flow conditions, and free-flow speeds are sustained. The ability to maneuver within the traffic stream is only slightly restricted. A high level of physical and psychological comfort is provided and the effects of minor incidents and point breakdowns are easily absorbed.

Level of Service C: Speeds are at or near the free-flow speed, but freedom to maneuver is noticeably restricted. Lane changes require more care and vigilance by the driver. When minor incidents occur, local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage.

Level of Service D: Speeds can begin to decline slightly and density increases more quickly with increasing flows. Freedom to maneuver is more noticeably limited, and drivers experience reduced physical and psychological comfort. Vehicle spacings average 165 ft (8 car lengths) and maximum density is 35 pc/mi/ln. Because there is so little space to absorb disruptions, minor incidents can be expected to create queuing.

Level of Service E: Operations are volatile because there are virtually no useable gaps. Maneuvers such as lane changes or merging of traffic from entrance ramps will result in a disturbance of the traffic stream. Minor incidents result in immediate and extensive queuing. Capacity is reached at its highest density value of 45 pc/mi/ln.

Level of Service F: Operation is under breakdown conditions in vehicular flow. These conditions prevail in queues behind freeway sections experiencing temporary or long-term reductions in capacity. The flow conditions are such that the number of vehicles that can pass a point is less than the number of vehicles arriving upstream of the point or at merging or weaving areas where the number of vehicles arriving is greater than the number discharged. Breakdown occurs when the ratio of forecasted demand to capacity exceeds 1.00.



LOS A LOS B
LOS C LOS D
LOS E LOS F

Figure: Levels of Service for Freeways.

Calculating the Flow Rate for a Basic Freeway Section

The formula for the flow rate in passenger pc/h/ln for a basic freeway section is:

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

where

v_p = 15 min passenger-car equivalent flow rate (pc/h/ln).
V = hourly peak vehicle volume, in one direction (veh/h).
PHF = peak hour factor.
N = number of travel lanes in one direction.
f_p = driver population factor with a range of 0.85 to 1.00 and use 1.00 for commuter traffic. If there is significant recreational or weekend traffic, the value is reduced.
f_{HV} = heavy vehicle adjustment factor.

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

The flow rate obtained from Eq. above will be achieved only if good pavement and weather conditions exist and there are no incidents on the freeway segments. If these conditions do not exist, the actual flow that will be achieved may be less.

The heavy-vehicle volumes in a traffic stream must be converted to an equivalent flow rate expressed in passenger cars (pc/h/ln). First, the passenger car equivalent (PCE) of each truck/bus (E_T) or recreational vehicle (E_R) is determined for the prevailing traffic and roadway conditions from previous Table. These numbers represent the number of passenger cars that would use up the same space on the highway as one truck, bus, or recreational vehicle under prevailing conditions. Trucks and buses are treated identically because it has been determined that their traffic flow characteristics are similar. Second, E_T and E_R are used with the proportions of each type of vehicle, P_T and P_R, to compute the adjustment factor, f_{HV}, using Eq. above.

The extent to which the presence of a truck affects the traffic stream also depends on the grade of the segment being considered. PCEs for trucks can be determined for three grade conditions: extended general freeway segments, specific upgrades, and specific downgrades.

Extended General Freeway Segments

These occur when a single grade is not too long or steep to have significant impact on capacity. Instead, upgrades, downgrades, and level sections are all considered to be extended general freeway segments. Grades of at least 3 percent and less than one quarter mi, or grades less than 3 percent and less than one-half mi, are included. The PCEs for these conditions are given in Table below. PCE values are affected by the type of terrain, which is classified as level, rolling, or mountainous.

Table: Passenger-Car Equivalents for Trucks and Buses (ET) and RVs (ER) on General Highway Segments: Multilane Highways and Basic Freeway Sections.

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

Freeway segments are considered to be on level terrain if the combination of grades and horizontal alignment permits heavy vehicles to maintain the same speed as passenger cars. Grades are generally short and not greater than 2 percent.

Freeway segments are considered to be on rolling terrain if the combination of grades and horizontal alignment causes heavy vehicles to reduce their speeds to values substantially

below those of passenger cars but not to travel at crawl speeds for any significant length of time.
Freeway segments are considered to be in mountainous terrain if the combination of grades and horizontal alignment causes heavy vehicles to operate at crawl speeds for a significant distance or at frequent intervals. Crawl speed is the maximum sustained speed that trucks can maintain on an extended upgrade of a given percent.

PCEs for Specific Upgrades

Any freeway grade of 3 percent or more and longer than one-quarter mi, or a grade of less than 3 percent and longer than one-half mi, should be considered as a separate segment. Specific grades are analyzed individually for downgrade and upgrade conditions.
The segment is considered either as a grade of constant percentage or as a series of grades.
The variety of trucks and recreational vehicles with varying characteristics results in a wide range of performance capabilities on specific grades. The truck population on freeways has an average weight-to-horsepower ratio of 125 to 150 lb/hp, and this range is used in determining PCEs for trucks and buses on specific upgrades. Recreational vehicles vary considerably in both type and characteristics and range from cars pulling trailers to large self-contained mobile homes. Further, unlike trucks, they are not driven by professionals, and the skill levels of recreational vehicle drivers greatly vary. Typical weight-to-horsepower ratios for recreational vehicles range between 30 to 60 lb/hp.

Tables below give PCE values for trucks/buses (ET) and for recreational vehicles, (ER) respectively, traveling on specific upgrades for different grades and different percentages of heavy vehicles within the traffic stream. For example, the effect on other traffic of a truck or bus traveling up a grade is magnified with increasing segment length and grade because the vehicle slows down. The PCEs selected should be associated with the point on the freeway where the effect is greatest, which is usually at the end of the grade, although a ramp junction at midgrade could be a critical point.
It has been suggested that the grade length be obtained from a profile of the road, including the tangent portion, plus one-fourth of the length of the vertical curves at the beginning and end of the grade. Where two consecutive upgrades are connected by a vertical curve, half the vertical curve length is added to each portion of the grade.
However, this guideline may not apply for some specific conditions. For example, to determine the effect of an on-ramp at an upgrade section of a freeway, the length used is that up to the ramp junction.

Table: Passenger-Car Equivalents for Trucks and Buses (E_T) on Upgrades, Multilane Highways, and Basic Freeway Sections.

		E_T								
		Percentage of Trucks and Buses								
Upgrade (%)	*Length (mi)*	*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	2.0
	> 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

Table : Passenger-Car Equivalents for RVs (E_R) on Uniform Upgrades, Multilane Highways, and Basic Freeway Segments.

		E_R								
		Percentage of RVs								
Grade (%)	*Length (mi)*	*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	4.5	3.5	3.0	3.0	2.5	2.0

PCEs for Specific Downgrades

If the downgrade is not so severe as to cause trucks to shift into low gear, they may be treated as if they were on level segments. Where grades are severe and require that trucks downshift, the effect on car equivalents (E_T) is greater, as shown in Table below. For recreational vehicles, a downgrade is treated as if it were level.

Table: Passenger-Car Equivalents for Trucks (E_T) on Downgrades, Multilane Highways, and Basic Freeway Segments.

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

Composite Grades

When a segment of freeway consists of two or more consecutive upgrades with different slopes, the PCE of heavy vehicles is determined by using one of two techniques.

One technique determines the average grade of the segment by finding the total rise in elevation and dividing it by the total horizontal distance. This average grade is then used with previous Tables. The average grade technique is valid for conditions where grades in all subsections are less than 4 percent or the total length of the composite grade is less than 4000 ft.

The second technique for determining the PCE of heavy vehicles on consecutive upgrades is to estimate the value of an equivalent continuous grade GE that would result in the final speed for trucks that is the same as that which would result from the actual series of consecutive grades of the same length. This technique should be used if any single portion of the consecutive grade exceeds 4 percent or if the total length of grade (measured horizontally) exceeds 4000 ft.

Truck acceleration/deceleration curves are used based on a vehicle with an average weight-to-horsepower ratio of 200 lb/hp, which represents a somewhat heavier vehicle than the "typical" truck of 125 to 150 lb/hp used to determine PCE values. This is a conservative approach that accounts for the greater influence heavier vehicles have over light vehicles in operation. Figure below is a performance curve for a standard 200 lb/hp truck, depicting the relationship between speed (mi/h) and length of grade for upgrades ranging from 1 to 8 percent and downgrades of 0 to 5 percent

for an entry speed of 55 mi/h. For example, at a 5 percent grade, a truck will slow to a crawl speed of 27 mi/h in a distance of 5000 ft.

Figure below can be used to determine the single constant grade GE for a series of consecutive grades of length L_{CG}. The procedure, illustrated in the following example, requires that the speed V_{EG} of a truck at the end of the consecutive grades be determined. Then, knowing the length of the composite grade, L_{CG}, and the truck speed at the end of the grade, V_{EG}, determine an equivalent grade GE.

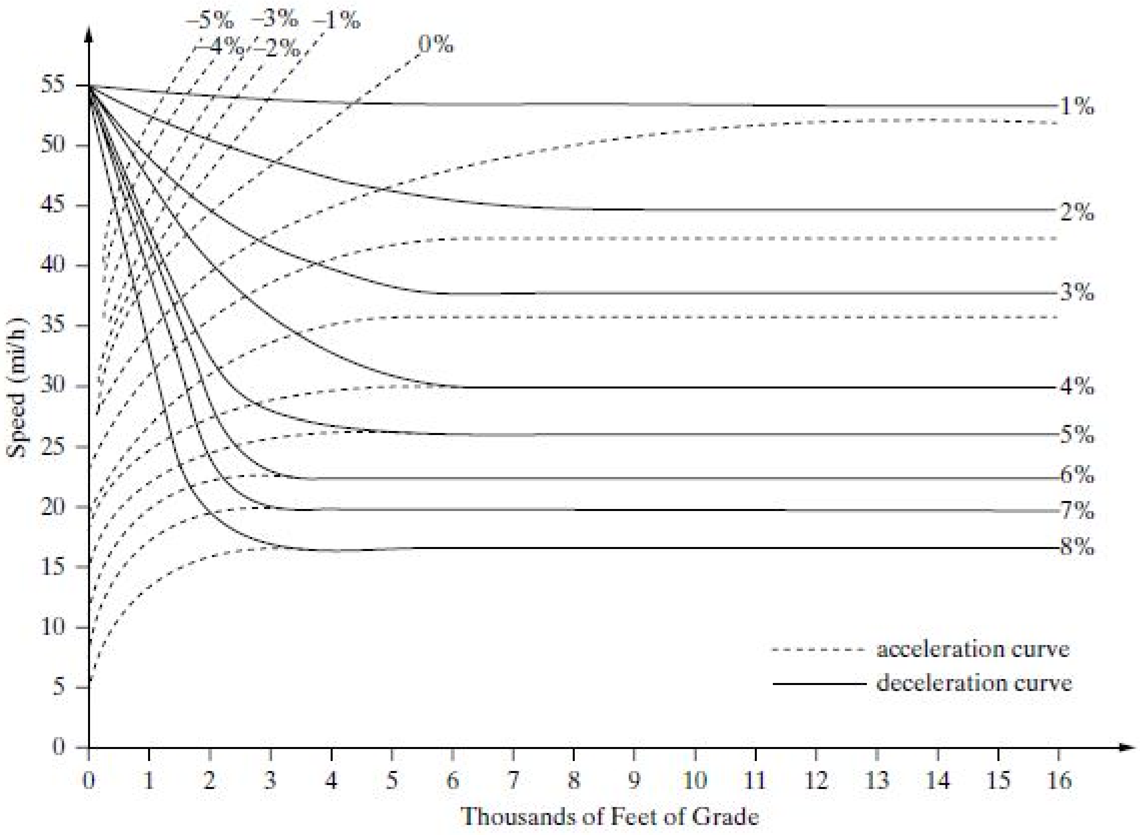


Figure: Performance Curves for Standard Trucks (200 lb/hp).

Calculating the Average Passenger Car Speed (S), Density (D), and Level of Service (LOS) for a Basic Freeway Section

Average passenger car speed (S) is depicted in Figure 9.8 and is one of three variables that can be used to determine the level of service. As shown in the figure, the value of APCS is a constant equal to the free-flow speed (FFS) up to a value of 1300 pc/h/ln at a FFS of 70 mi/h. In order to conduct a capacity analysis, compute v_p and obtain the
average passenger car speed (S) from the formulas used in the Highway Capacity Manual which is the basis for previous Figure. Compute the density using previous Eq. . The LOS is found in previous Table. Four types of problems are solved by capacity analysis:

Type I. Given highway volume, number of lanes, and free-flow speed, determine level of service.

Type II. Given highway volume, level of service, and free-flow speed, determine the average speed.

Type III. Given the level of service and free-flow speed, determine the hourly flow rate.

<u>Type IV</u>. Given the highway volume, free-flow speed, and the desired level of service, determine the number of freeway lanes required.

To solve these problems, it is necessary to determine the free-flow speed under prevailing physical and geometric conditions. Free-flow speed is the mean speed of passenger cars measured when the equivalent hourly flow rate is not greater than 1300 pc/h/ln. The free-flow speed can be measured in the field with a speed study, using procedures described in Chapter 4. If speed-study data are not available, the free-flow speed can be determined on the basis of specific characteristics of the freeway section including lane width, number of lanes, right shoulder lateral clearance, and interchange density. Equation below is used to compute the free-flow speed. We have:

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$

<u>where:</u>
FFS = free-flow speed (mi/h)
BFFS = base free-flow speed (mi/h) 70 mi/h (urban) or 75 mi/h (rural)
f_{LW} = adjustment for lane width (Table below)
f_{LC} = adjustment for right-shoulder lateral clearance (Table below)
f_N = adjustment for number of lanes (Table below)
f_{ID} = adjustment for interchange density (Table below)

Table: Adjustment (f_{LW}) for Lane Width.

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

Table: Adjustment (f_{LC}) for Right-Shoulder Lateral Clearance.

	Reduction in Free-Flow Speed, f_{LC} (mi/h)			
	Lanes in One Direction			
Right-Shoulder Lateral Clearance (ft)	*2*	*3*	*4*	*≥ 5*
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Table: Adjustment (f_N) for Number of Lanes.

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (mi/h)
≥ 5	0.0
4	1.5
3	3.0
2	4.5

Table: Adjustment (f_{ID}) for Interchange Density.

Interchanges per Mile	Reduction in Free-Flow Speed f_{ID} (mi/h)
≤ 0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

Average passenger car speed (S) can be calculated once the value of FFS has been determined. Previous Figure can provide an approximate value for S. When $v_p \leq$ 3400 _30FFS, then S = FFS, as seen in previous Figure, when the flow rates are low enough such that the average speed of traffic is not less than the free-flow speed. However, when:

v_p > 3400 - 30FFS, the flow rates are high enough such that the average speed begins to decrease. In this case, an estimate of S can be obtained using expressions for S, one for values greater than 70 mi/h and the other for values equal or less than 70 mi/h.
The term: 3400 _30FFS, is the equation of a line that connects the breakpoints on the curves in Figure 9.8 for the values 55, 60, 65, 70, and 75 mi/h.
The following expression is used for values of FFS greater than 70 mi/h.

The following expression is used for values of FFS greater than 70 mi/h.

$$S = FFS - \left[\left(FFS - \frac{160}{3} \right) \left(\frac{v_p + 30FFS - 3400}{30FFS - 1000} \right)^{2.6} \right]$$

The following expression is used for values of FFS equal to or less than 70 mi/h.

$$S = FFS - \left[\frac{1}{9}(7FFS - 340) \left(\frac{v_p + 30FFS - 3400}{40FFS - 1700} \right)^{2.6} \right]$$

Adjustment for Lane Width

When the average lane width of the freeway (or multilane highway) is less than the ideal value of 12 ft, the free-flow speed of 70 or 75 mi/h will be reduced. Previous Table provides the values of speed reduction in mi/h for lane widths of 10 and 11 ft.

Adjustment for Right-Shoulder Lateral Clearance

The ideal clearance conditions are 6 ft on the right (shoulder) side of the freeway and 2 ft on the left (median) side. When right-shoulder clearances have been reduced, free-flow speed will diminish by the values shown in Table 9.30. For example, if the right-shoulder clearance is 4 ft on a two-lane freeway section in one direction, the free-flow speed is reduced by 1.2 mi/h.

Adjustment for Number of Lanes

If the number of freeway lanes in one direction is less than five, the free-flow speed is reduced on urban and suburban highways, as shown in previous Table. Rural freeways are usually two lanes in one direction, and the speed reduction value is zero.

Adjustment for Interchange Density

The ideal interchange spacing is 2 mi or greater or 0.5 interchanges per mi. When the number of interchanges per mi increases, there is a corresponding decrease in free flow speed, as shown in previous Table . Interchanges are defined as having one or more on-ramps. Interchange spacing for the basic freeway section is determined by the number of interchanges within a distance of 3 mi upstream and 3 mi downstream of the section, and dividing this number by 6.

2. Multilane Highway

The procedures developed are used to analyze the capacity and level of service (LOS) for multilane highways. The results can be used in the planning and design phase to determine lane requirements necessary to achieve a given LOS and to consider the impacts of traffic and design features in rural and suburban environments. Multilane highways differ from two-lane highways by virtue of the number of lanes and from freeways by virtue of the degree of access. They span the range between freeway-like conditions of limited access to urban street conditions with frequent traffic-controlled intersections. Illustrations of the variety of multilane highway configurations are provided in Figure below. Multilane highways may exhibit some of the following characteristics:

- Posted speed limits are usually between 40 and 55 mi/h
- They may be undivided or include medians
- They are located in suburban areas or in high-volume rural corridors
- They may include a two-way, left-turn median lane (TWLTL)
- Traffic volumes range from 15,000 to 40,000/day
- Volumes are up to 100,000/day with grade separations and no cross-median access
- Traffic signals at major crossing points are possible
- There is partial control of access

(a) Divided multilane highway in a rural environment.

(b) Divided multilane highway in a suburban environment.

(c) Undivided multilane highway in a rural environment.

(d) Undivided multilane highway in a suburban environment.

Figure: Typical Multilane Highways.

<u>Level of Service for Multilane Highways</u>

Any two of the following three performance characteristics can describe the level of service (LOS) for a multilane highway:

V_p : Flow rate (pc/h/ln)

S: Average passenger car speed (mi/h)

D: Density defined as number of cars per mi (pc/mi/ln)

The relationship between the three performance characteristics can be computed using Eq. below:

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

Table below lists the level-of-service criteria for multilane highways in terms of maximum density, average speed, and maximum volume-to-capacity ratio. Figure below illustrates the level-of-service regimes. The definition of each level of service, A through F, is as follows:

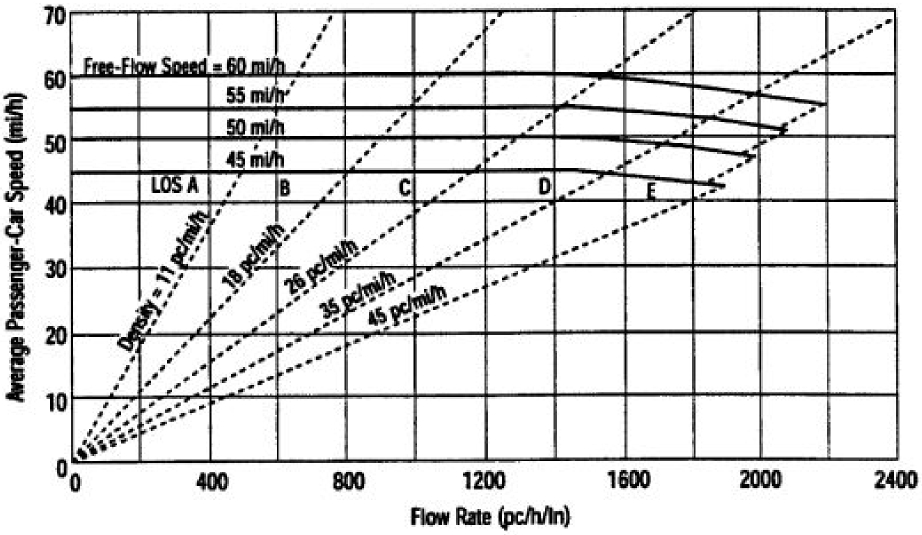


Figure: Speed-Flow Curves with Level-of-Service Criteria for Multilane Highways.

<u>Level of Service A</u>: Travel conditions are completely free flow. The only constraint on the operation of vehicles lies in the geometric features of the roadway and individual driver preferences. Maneuverability within the traffic stream is good, and minor disruptions to traffic are easily absorbed without an effect on travel speed.

<u>Level of Service B</u>: Travel conditions are at free flow. The presence of other vehicles is noticed but is not a constraint on the operation of vehicles as are the geometric features of the roadway and individual driver preferences. Minor disruptions are easily absorbed, although localized reductions in LOS are noted.

<u>Level of Service C</u>: Traffic density begins to influence operations. The ability to maneuver within the traffic stream is affected by other vehicles. Travel speeds show some reduction when free-flow speeds exceed 50 mi/h. Minor disruptions may be expected to cause serious local deterioration in service, and queues may begin to form.

<u>Level of ServiceD</u> :The ability to maneuver is severely restricted due to congestion. Travel speeds are reduced as volumes increase. Minor disruptions may be expected to cause serious local deterioration in service, and queues may begin to form.

<u>Level of Service E</u>: Operations are unstable and at or near capacity. Densities vary depending on the free-flow speed. Vehicles operate at the minimum spacing for which uniform flow can be maintained. Disruptions cannot be easily dissipated and usually result in the formation of queues and the deterioration of service.

<u>Level of Service F</u>: A forced breakdown of flow occurs at the point where the number of vehicles that arrive at a point exceeds the number of vehicles discharged or when forecast demand exceeds capacity. Queues form at the breakdown point while at sections downstream they may appear to be at capacity. Operations are highly unstable.

Calculating the Flow Rate for a Multilane Highway

Calculating the Flow Rate for a Multilane Highway

The flow rate in pc/h/ln for a multilane highway is computed using Eq. below:

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

where

v_p = 15-minute passenger-car equivalent flow rate (pc/h/ln)
V = hourly peak vehicle volume (veh/h) in one direction
N = number of travel lanes in one direction (2 or 3)
f_p = driver population factor with a range of 0.85 to 1.00. Use 1.00 for commuter traffic.
If there is significant recreational or weekend traffic, the value is reduced.
f_{HV} = heavy-vehicle adjustment factor.

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

where:

P_T and P_R = decimal portion of trucks/buses and recreational vehicles in the traffic stream
E_T and E_R = passenger car equivalents. Number of cars using the same space as a truck/bus or a recreational vehicle.

There are two situations that must be considered:

- **Extended general segments** in which the terrain is level, rolling or mountainous. The values of E_T and E_R are obtained from previous Table for heavy vehicles adjustment factor .
- **Specific grades**. These are defined as segments that are:

Upgrades: The values of E_T and E_R are obtained from previous Tables .
Downgrades: The value of E_T is obtained from previous Table. RVs are treated as if they were on level terrain.
To determine the grade of the highway profile for the analysis section, three situations are possible, each involving a different computational technique.
1. Highway profile is a constant grade, computed using Eq. below:

$$G = (100)\frac{H}{L}$$

where:

G = grade in percent
H= difference in elevation between the beginning and end of the section, ft.
L= horizontal distance between the beginning and end of the analysis section, ft.
Highway profile consists of two or more segments of different grades. The value of the grade for an analysis segment is determined for two possible conditions.
2. Segment length is < 4000 ft or grade is <4%. Use Eq. above to compute an average grade.
3. Segment length is > 4000 ft and/or grade > 4%.

Calculating the Average Passenger Car Speed (S), Density (D), and Level of Service (LOS) for a Multilane Highway

Average passenger car speed is depicted in Figure 9.15 and is one of three variables that can be used to determine the level of service. As shown in the figure, the value of (S) is a constant equal to the free-flow speed (FFS) up to a flow rate of 1400 pc/h/ln.
The following steps are used to calculate average passenger car speed:

Step 1. Compute the Value of Free-Flow Speed. Use Eq. below to estimate FFS:

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

where:
FFS = estimated free-flow speed (mi/h).
BFFS = base free-flow speed (mi/h). In the absence of field data, a default.
value of 60 mi/h is used for rural/suburban multilane highways.
f_{LW} = adjustment for lane width.
f_{LC} = adjustment for lateral clearance .
f_M = adjustment for median type.
f_A= adjustment for access-point density.

Step 2. Compute the value of flow rate, v, pc/h/ln.
Step 3. Construct a Speed-Flow Curve of the same shape as shown in Figure below. Interpolate between two curves that span the value of FFS obtained in Step 1
Step 4. Determine the value of average passenger car speed, S. Read up from the value of flow rate v, obtained in Step 2, to the intersection of the FFS curve. (Note that if v is 1400 pc/h/ln or less, the value of S is the same as that of FFS.)
Step 5. Compute the density, pc/mi/ln.
Step 6. Determine the LOS. Use the value of computed density.

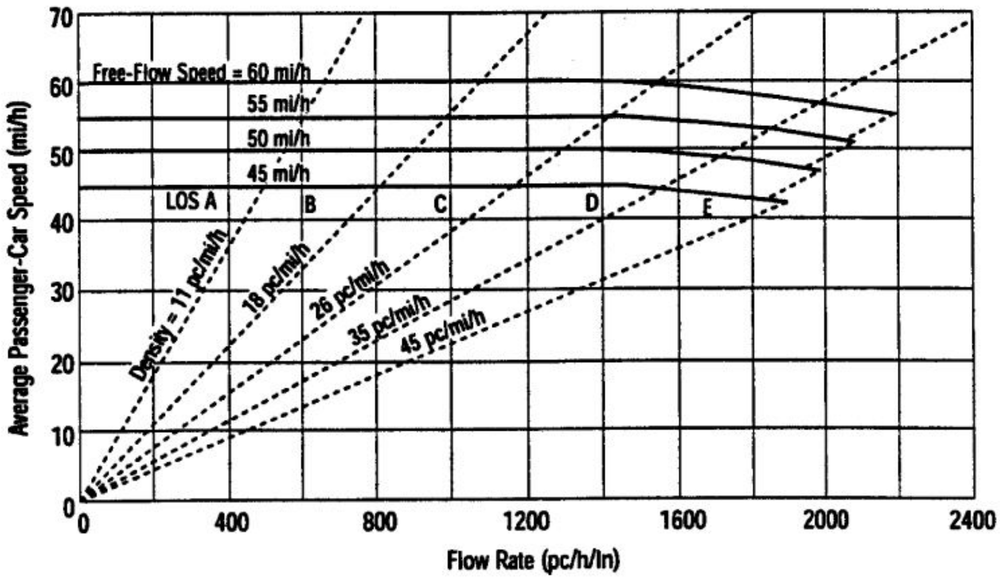


Figure: Speed-Flow Curves with Level-of-Service Criteria for Multilane Highways.