CHAPTER 4
High way capacity
And
Level of Service

(Metric Unit)

CHAPTER 4

4.1. Introduction

One of the most critical needs in traffic engineering is a clear understanding of how much traffic a given facility can accommodate and under what operating conditions. These important issues are addressed in highway capacity and level-of-service analysis. The basis for all capacity and level-of-service analysis is a set of analytic procedures that relate demand or existing flow levels, geometric characteristics, and controls to measures of the resulting quality of operations.

Highway Capacity

The capacity of a facility defined as the maximum hourly flow rate at which the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under prevailing roadway, traffic and control conditions with a reasonable expectation of occurrence. For most cases, to analyze the capacity we used the peak 15 minutes of the peak hour.

Capacity is independent of the demand. It speaks about the physical amount of vehicles and passengers that a road can afford. It does not depend on the total number of vehicles demanding service. Generally the highway capacity depends on certain conditions as listed below;

1. **Road way characteristics**: This are associated with the geometric characteristics and design elements of the facility, which include type of facility, number of lanes, lane width, shoulder width, horizontal and vertical alignments, lateral clearance, design speed, and availability of queuing space at intersections. For example, a curved road has lesser capacity compared to a straight road.
2. **Traffic conditions**: Capacity is expressed in terms of units of some specific thing (car, people, etc.), so it also does depend on the traffic conditions. The traffic conditions are associated with the characteristics of the traffic stream on the segment of the highway. These include the distribution of the different types of vehicles in the traffic stream or traffic composition such as the mix of cars, trucks, buses etc. and the directional and lane distribution of the traffic volume on the highway segment. Furthermore it includes peaking characteristics, proportions of turning movements at intersections etc.
3. **Control conditions**: This primarily applies to surface facilities and includes the types of traffic control devices in operation, signal phasing, allocation of green time, cycle length, and the relationship with adjacent control measures.

Level of Service

The level-of-service concept was introduced in the 1965 HCM as a convenient way to describe the general quality of operations on a facility with defined traffic, roadway, and control conditions. Using a letter scale from A to F, a terminology for operational quality was created that has become an important tool in communicating complex issues to decision-makers and the general public. The HCM 2000 defines level of service as follows: "Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience."

A term level-of-service closely related to capacity and often confused with it is service volume. When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a qualitative measure. Service volume is the maximum number of vehicles, passengers, or the like, which can be accommodated by a given facility or system under given conditions at a given level of service.

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 with the physical characteristics of the highway and the different operating characteristics that can occur when the highway carries different traffic volumes. Speed-flow-density relationships are the principal factor affecting the level of service of a highway segment under ideal conditions.

For a given road or facility, capacity could be constant. But actual flow will be different for different days and different times in a day itself. The intention of LOS is to relate the traffic service quality to a given flow rate of traffic. It is a term that designates a range of operating conditions on a particular type of facility. Highway capacity manual (HCM) provides some procedure to determine level of service. It divides the quality of traffic into six levels ranging from level A to level F. Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed and level F represents the worst quality of traffic.

Service A: This represents free-flow conditions where traffic flow is virtually zero. Only the geometric design features of the highway may limit the speed of the car. Comfort and convenience levels for road users are very high as vehicles have almost complete freedom to maneuver.

Level of service A

Service B: Represents reasonable free-flow conditions. Comfort and convenience levels for road users are still relatively high as vehicles have only slightly reduced freedom to maneuver. Minor accidents are accommodated with ease although local deterioration in traffic flow conditions would be more discernible than in service A.

Level of service B

Service C: Delivers stable flow conditions. Flows are at a level where small increases will cause a considerable reduction in the performance or 'service' of the highway. There are marked restrictions in the ability to maneuver and care is required when changing lane. While minor incidents can still be absorbed, major incidents will result in the formation of queues. The speed chosen by the driver is substantially affected by that of the other vehicles. Driver comfort and convenience have decreased perceptibly at this level.

Level of service C

Service D: The highway is operating at high-density levels but stable flow still prevails. Small increases in flow levels will result in significant operational difficulties on the highway. There are severe restrictions on a driver's ability to maneuver, with poor levels of comfort and convenience.

Level of service D

Service E: Represents the level at which the capacity of the highway has been reached. Traffic flow conditions are best described as unstable with any traffic incident causing extensive queuing and even breakdown. Levels of Basic Elements of comfort and convenience are very poor and all speeds are low if relatively uniform.

Level of service E

Service F: Describes a state of breakdown or forced flow with flows exceeding capacity. The operating conditions are highly unstable with constant queuing and traffic moving on a 'stop-go' basis.

Level of service F

4.2. Factors affecting level of service

The factors affecting level of service (LOS) can be listed as follows:

i. Speed and travel time
ii. Traffic interruptions/restrictions
iii. Freedom to travel with desired speed
iv. Driver comfort and convenience
v. Operating cost.

Factors such as lane width, lateral obstruction, traffic composition, grade and driver population also affect the maximum flow on a given highway segment. The effect of each of these factors on flow is discussed.

- **Lane Width**. Traffic flow tends to be restricted when lane widths are narrower than 12 ft (3.65m). This is because vehicles have to travel closer together in the lateral direction, and motorists tend to compensate for this by driving more cautiously and by increasing the spacing between vehicles, thus reducing the maximum flow on the highway.
- **Lateral Obstruction.** In general, when roadside or median objects are located too close to the edge of the pavement, motorists in lanes adjacent to the object tend to shy away from the object, resulting in reduced lateral distances between vehicles. This lateral reduction in space also results in longer spacing's between vehicles and a reduction in the maximum flow on the highway. This effect is eliminated if the object is located at least 6ft (1.8m) from the edge of the roadway. Note, however, that lateral clearances are based mainly on safety considerations and not on flow consideration.
- **Traffic Composition**. 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.
- **Grade**. The effect of a grade depends on both the length and the slope of the grade. Traffic operations are significantly affected when grades of 3 percent or greater are longer than 1/4 mi (400m) and when grades are less than 3 percent and longer than l/2 mi (800m). The effect of heavy vehicles on such grades is much greater than that for passenger vehicles.
- **Speeds, Space mean speed,** are also used in level-of-service analysis because flow has a significant effect on speed.
- **Driver Population**. Under ideal conditions, a driver population consisting primarily of weekday commuters is assumed. However, it is known that other driver populations do not exhibit the same behavior.

Because these factors affect traffic operations on the highway, it is essential that they be considered in any LOS analysis. Highway Capacity Manual (HCM) used travel speed and volume by capacity ratio (v/c ratio) to distinguish between various levels of service. The value of v/c ratio can vary between 0 and 1. Depending upon the travel speed and v/c ratio, HCM has defined six levels of service as shown in the figure 1.

These operating conditions can be expressed graphically with reference to the basic speed-flow relationship. At the level of service A, speed is near its maximum value, restricted only by the geometry of the road, and flows are low relative to the capacity of the highway, given the small number of vehicles present. At the level of service D, flows are maximized, with speed at approximately 50% of its maximum value. Level of service F denotes the 'breakdown' condition at which both speeds and flow levels tend towards zero.

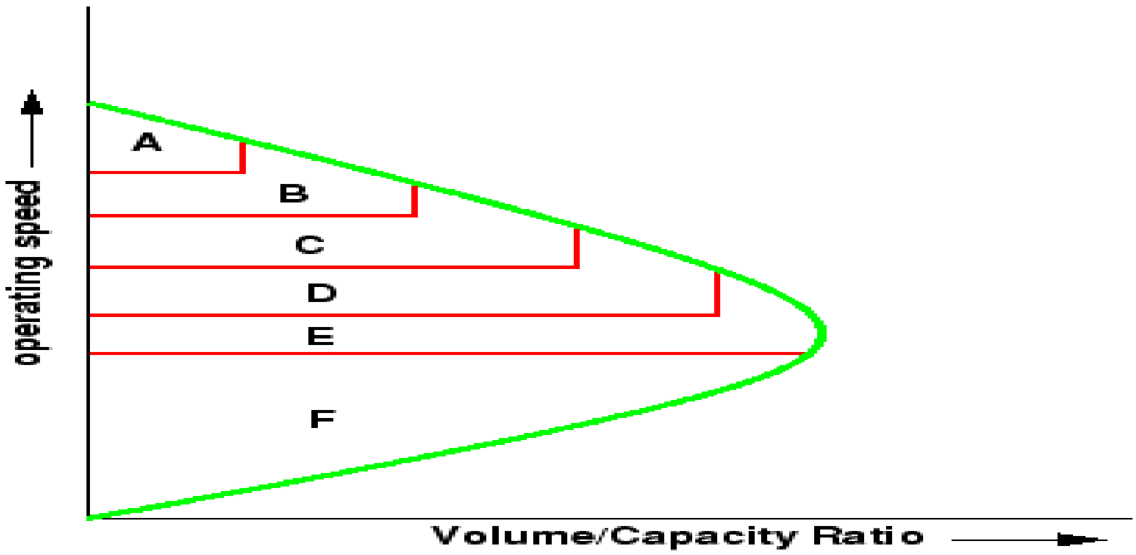

Figure 4.1 Linkage between level of service (LOS), speed and flow/capacity.

4.3. Determining the capacity and LOS of a highway

'Level of service' describes in a qualitative way the operational conditions for traffic from the viewpoint of the road user. It gauges the level of congestion on a highway in terms of variables such as travel time and traffic speed.

In order to determine a road's level of service, a comprehension of the relationship between hourly volume, peak hour factor and service flow is vital:

Hourly volume (V) The highest hourly volume within a 24-hour period

Peak-hour factor (PHF) The ratio of the hourly volume to the peak 15 minute flow (V_{15}) enlarged to an hourly value

$$PHF = V \div (V_{15} \times 4)$$

Service flow (SF) The peak 15 minute flow (V_{15}) enlarged to an hourly value

$$SF = V_{15} \times 4$$

4.3.1. Analysis method of Two-Lane Rural Highways Capacity

The capacity of a two-lane highway under base conditions is now established as 3200 pc/h in both directions, with a maximum of 1700 pc/h in one direction. The base conditions for which this capacity is defined include:

- 3.6m (or greater) lanes
- 1.8m (or greater) usable shoulders
- Level terrain
- No heavy vehicles
- 100% passing sight distance available (no "No Passing" zones)
- 50/50 directional split of traffic
- No traffic interruptions

Level of Service

Level of service for two-lane rural highways is defined in terms of two measures of effectiveness:

- Average travel speed (ATS)
- Percent time spent following (PTSF)

Average travel speed is the average speed of all vehicles traversing the defined analysis segment for the specified time period, usually the peak 15-minutes of a peak hour. When analysis of both directions is used, the average travel speed includes vehicles in both directions. When analysis of single direction is used, the average travel speed includes those vehicles in the analysis direction only.

Percent time spent following is similar to "percent time delay,”. It is the aggregate percentage of time that all drivers spend in queues, unable to pass, with the speed restricted by the queue leader. A substitute measure for PTSF is the percentage of vehicles following others at headways of 3.0 s or less.

Level of service criteria for two-lane rural highways is shown in Table 4.11. The criteria vary for Class I and Class II highways. Class II highways, where mobility is not a principal function; use only the PTSF criteria for determination of level of service. For Class I highways, the LOS is determined by the measure yielding the poorest result.

LOS	Percent Time-Spent-Following	Average Travel Speed (km/h)
A	≤ 35	> 90
B	> 35–50	> 80–90
C	> 50–65	> 70–80
D	> 65–80	> 60–70
E	> 80	≤ 60

Note:
LOS F applies whenever the flow rate exceeds the segment capacity.

Table 4.11: Level-of-Service Criteria for Two-Lane Rural Highways **Class I**

LOS	Percent Time-Spent-Following
A	≤ 40
B	> 40–55
C	> 55–70
D	> 70–85
E	> 85

Note:
LOS F applies whenever the flow rate exceeds the segment capacity.

Table 4.12: Level-of-Service Criteria for Two-Lane Rural Highways **Class II**

Types of Analysis

Generally two-direction and single-direction analysis with three distinct methodologies are provided to analyses two lane two way rural roads

- Two-directional analysis of general extended sections (≥3.22km) in level or rolling terrain
- Single-directional analysis of general extended sections (≥3.22km) in level or rolling terrain
- Single-direction analysis of specific grades

For specific grades, only single-direction analysis of the upgrade and downgrade is permitted, as these tend to differ significantly. In what is usually referred to as "mountainous" terrain, all analysis is on the basis of specific grades comprising that terrain. Any grade of 3% or more and at least 0.97kmi long must be addressed using specific grade procedures.

Free-Flow Speed

As was the case for multilane highways and freeways, the free-flow speed of a two-lane highway is a significant variable used in estimating expected operating conditions.

Field Measurement of Free-Flow Speed

The free-flow speed of a two-lane rural highway may be measured directly in the field. The speed study should be conducted at a representative site within the study section. Free-flow speeds may be directly measured as follows:

- A representative speed sample of 100 or more vehicles should be obtained.
- Total two-way traffic flow should be 200 pc/h or less.
- All vehicle speeds should be observed during the study period, or a systematic sampling (such as 1 vehicle out of every 10) should be applied.
- When two-direction analysis is contemplated, the speed sample should be selected from both directions of flow; when a one-direction analysis is contemplated, the speed sample should be selected only from the direction under study.

If field measurements must be made at total flow levels higher than 200 pc/h, the free-flow speed

$$FFS = S_{FM} + 0.0125\,\frac{V_f}{f_{HV}}$$

Where: FFS = free-flow speed for the facility, km/hr; S_m = mean speed of the measured sample (Where total flow> 200 pc/h), km/hr; V_f = observed flow rate for the period of the speed sample, veh/h and f_{HV} = heavy vehicle adjustment factor.

Estimating Free-Flow Speeds

If field observation of free-flow speed is not practical, free-flow speed on a two-way rural highway may be estimated as follows:

$$FFS = BFFS - f_{LS} - f_A$$

Where: FFS = free-flow speed for the facility, km/hr, BFFS =base free-flow speed for the facility, km/hr; f_{LS} = adjustment for lane and shoulder width, km/hr and

f_A = adjustment for access point density, km/hr

Most of the time BFFS is limited to a range of 72-105 km/h, with Class I highways usually in the 88-105 km/h range and Class II highways usually in the 72-80 km/h range. Sometimes the design speed, which represents the maximum safe speed for the horizontal and vertical alignment of the highway, is a reasonable substitute for the BFFS.

Adjustment factors for lane and shoulder width are shown in Table 4.13; adjustment factors for access point density are shown in Table 4.14. Access point density is computed by dividing the total number of driveways and intersections on both sides of the highway by the total length of the segment in miles.

Table 4.13: Free-Flow Speed Adjustments for Lane and Shoulder Width (f_{LS})

	Reduction in FFS (km/h)			
	Shoulder Width (m)			
Lane Width (m)	≥ 0.0 < 0.6	≥ 0.6 < 1.2	≥ 1.2 < 1.8	≥ 1.8
2.7 < 3.0	10.3	7.7	5.6	3.5
≥ 3.0 < 3.3	8.5	5.9	3.8	1.7
≥ 3.3 < 3.6	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0.0

Table 4.14: Free-Flow Speed Adjustments for Access Point Density (f_A)

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

Estimating Demand Flow Rate

As for most HCM 2000 methodologies, a critical computational step is the determination of a demand flow rate reflecting the base conditions for the facility type being analyzed. This requires that an hourly volume reflecting prevailing conditions be adjusted to reflect peak flow rates within the hour and base conditions. For two-lane rural highways, this adjustment is made as follows:

$$v_p = \frac{V}{PHF * f_G * f_{HV}} \qquad \text{…} \qquad ..4.15$$

Where: v = demand flow rate pc/h; V = hourly demand volume under prevailing conditions veh/h; PHF = peak hour factor; f_{HV} = adjustment for heavy vehicle presence f_G = adjustment for grades.

Determining Grade Adjustment Factors

For every computation, two grade adjustment factors will be required: one for the ATS determination and one for the PTSF determination. Selection of appropriate adjustment factors also depends upon the type of analysis being conducted. Grade adjustment factors are found as follows:

- f_G for Two-way and directional analysis of general terrain segments for ATS determinations: Table 4.20.
- f_G for Two-way and directional analysis of general terrain segments for PTSF determinations: Table 4.21.
- Specific upgrades for ATS determination: Table 4.22.
- Specific upgrades for PTSF determination: Table 4.23.

Table 4.20: Grade Adjustment Factor (f_G) for General Terrain Segments and Specific Downgrades **ATS** Determinations **two way and directional analysis**

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0–600	0–300	1.00	0.71
> 600–1200	> 300–600	1.00	0.93
> 1200	> 600	1.00	0.99

Table 4.21: Grade Adjustment Factor (f_G) for General Terrain Segments and Specific Downgrades **PTSF** Determinations **two way and directional analysis**

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0–600	0–300	1.00	0.77
> 600–1200	> 300–600	1.00	0.94
> 1200	> 600	1.00	1.00

Table 4.22: Grade Adjustment Factor (f_G) for Specific Upgrades: ATS Determinations

Grade (%)	Length of Grade (km)	Grade Adjustment Factor, f_G Range of Directional Flow Rates v_d (pc/h) 0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	0.81	1.00	1.00
	0.8	0.79	1.00	1.00
	1.2	0.77	1.00	1.00
	1.6	0.76	1.00	1.00
	2.4	0.75	0.99	1.00
	3.2	0.75	0.97	1.00
	4.8	0.75	0.95	0.97
	≥ 6.4	0.75	0.94	0.95
≥ 3.5 < 4.5	0.4	0.79	1.00	1.00
	0.8	0.76	1.00	1.00
	1.2	0.72	1.00	1.00
	1.6	0.69	0.93	1.00
	2.4	0.68	0.92	1.00
	3.2	0.66	0.91	1.00
	4.8	0.65	0.91	0.96
	≥ 6.4	0.65	0.90	0.96
≥ 4.5 < 5.5	0.4	0.75	1.00	1.00
	0.8	0.65	0.93	1.00
	1.2	0.60	0.89	1.00
	1.6	0.59	0.89	1.00
	2.4	0.57	0.86	0.99
	3.2	0.56	0.85	0.98
	4.8	0.56	0.84	0.97
	≥ 6.4	0.55	0.82	0.93
≥ 5.5 < 6.5	0.4	0.63	0.91	1.00
	0.8	0.57	0.85	0.99
	1.2	0.52	0.83	0.97
	1.6	0.51	0.79	0.97
	2.4	0.49	0.78	0.95
	3.2	0.48	0.78	0.94
	4.8	0.46	0.76	0.93
	≥ 6.4	0.45	0.76	0.93
≥ 6.5	0.4	0.59	0.86	0.98
	0.8	0.48	0.76	0.94
	1.2	0.44	0.74	0.91
	1.6	0.41	0.70	0.91
	2.4	0.40	0.67	0.91
	3.2	0.39	0.67	0.89
	4.8	0.39	0.66	0.88
	≥ 6.4	0.38	0.66	0.87

Table 4.23: Grade Adjustment Factor (f_G) for Specific Upgrades: PTSF Determinations

Grade (%)	Length of Grade (km)	Grade Adjustment Factor, f_G		
		Range of Directional Flow Rates, v_d (pc/h)		
		0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.00	0.92	0.92
	0.8	1.00	0.93	0.93
	1.2	1.00	0.93	0.93
	1.6	1.00	0.93	0.93
	2.4	1.00	0.94	0.94
	3.2	1.00	0.95	0.95
	4.8	1.00	0.97	0.96
	≥ 6.4	1.00	1.00	0.97
≥ 3.5 < 4.5	0.4	1.00	0.94	0.92
	0.8	1.00	0.97	0.96
	1.2	1.00	0.97	0.96
	1.6	1.00	0.97	0.97
	2.4	1.00	0.97	0.97
	3.2	1.00	0.98	0.98
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 4.5 < 5.5	0.4	1.00	1.00	0.97
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 5.5 < 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00

Determining the Heavy-Vehicle Adjustment Factor

The heavy-vehicle adjustment factors for ATS and PTSF determinations are found from passenger-car equivalents as follows:

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad \ldots\ldots\ldots\ldots\ldots 4.16$$

Where: f_{HV}= heavy-vehicle adjustment factor; P_T = proportion of trucks and buses in the traffic stream; P_R = proportion of recreational vehicles in the traffic stream E_T = passenger-car equivalent for trucks and buses E_R = passenger-car equivalent for recreational vehicles

As in multilane methodologies, the passenger-car equivalent is the number of passenger cars displaced by one truck (or RV) under the prevailing conditions on the analysis segment.

As in the determination of the grade-adjustment factor, values of E_T and E_R depend upon initial estimates of the demand flow rate and are therefore iterative.

Iteration rules are the same as described for the grade-adjustment factor. Passenger-car equivalents also depend upon which measure of effectiveness is being predicted (ATS or PTSF), and the type of analysis being applied. Passenger-car equivalents are found from the following tables:

Table 4.24a: Passenger-Car Equivalents for General Terrain Segments: ATS Determinations

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain: Level	Type of Terrain: Rolling
Trucks, E_T	0–600	0–300	1.7	2.5
	> 600–1,200	> 300–600	1.2	1.9
	> 1,200	> 600	1.1	1.5
RVs, E_R	0–600	0–300	1.0	1.1
	> 600–1,200	> 300–600	1.0	1.1
	> 1,200	> 600	1.0	1.1

Table 4.24b: Passenger-Car Equivalents for General Terrain Segments: PTSF Determinations

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain: Level	Type of Terrain: Rolling
Trucks, E_T	0–600	0–300	1.1	1.8
	> 600–1,200	> 300–600	1.1	1.5
	> 1,200	> 600	1.0	1.0
RVs, E_R	0–600	0–300	1.0	1.0
	> 600–1,200	> 300–600	1.0	1.0
	> 1,200	> 600	1.0	1.0

Table 4.25: Passenger-Car Equivalents of Trucks for Specific Upgrades: ATS Determination

Grade (%)	Length of Grade (km)	Passenger-Car Equivalent for Trucks, E_T — Range of Directional Flow Rates, v_d (pc/h): 0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	2.5	1.9	1.5
	0.8	3.5	2.8	2.3
	1.2	4.5	3.9	2.9
	1.6	5.1	4.6	3.5
	2.4	6.1	5.5	4.1
	3.2	7.1	5.9	4.7
	4.8	8.2	6.7	5.3
	≥ 6.4	9.1	7.5	5.7
≥ 3.5 < 4.5	0.4	3.6	2.4	1.9
	0.8	5.4	4.6	3.4
	1.2	6.4	6.6	4.6
	1.6	7.7	6.9	5.9
	2.4	9.4	8.3	7.1
	3.2	10.2	9.6	8.1
	4.8	11.3	11.0	8.9
	≥ 6.4	12.3	11.9	9.7
≥ 4.5 < 5.5	0.4	4.2	3.7	2.6
	0.8	6.0	6.0	5.1
	1.2	7.5	7.5	7.5
	1.6	9.2	9.0	8.9
	2.4	10.6	10.5	10.3
	3.2	11.8	11.7	11.3
	4.8	13.7	13.5	12.4
	≥ 6.4	15.3	15.0	12.5
≥ 5.5 < 6.5	0.4	4.7	4.1	3.5
	0.8	7.2	7.2	7.2
	1.2	9.1	9.1	9.1
	1.6	10.3	10.3	10.2
	2.4	11.9	11.8	11.7
	3.2	12.8	12.7	12.6
	4.8	14.4	14.3	14.2
	≥ 6.4	15.4	15.2	15.0
≥ 6.5	0.4	5.1	4.8	4.6
	0.8	7.8	7.8	7.8
	1.2	9.8	9.8	9.8
	1.6	10.4	10.4	10.3
	2.4	12.0	11.9	11.8
	3.2	12.9	12.8	12.7
	4.8	14.5	14.4	14.3
	≥ 6.4	15.4	15.3	15.2

Table 4.26: Passenger-Car Equivalents of RVs for Specific Upgrades: ATS Determination

		Passenger-Car Equivalent for RVs, E_R		
		Range of Directional Flow Rates, v_d(pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.1	1.0	1.0
	0.8	1.2	1.0	1.0
	1.2	1.2	1.0	1.0
	1.6	1.3	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.5	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 3.5 < 4.5	0.4	1.3	1.0	1.0
	0.8	1.3	1.0	1.0
	1.2	1.3	1.0	1.0
	1.6	1.4	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.4	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 4.5 < 5.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.5	1.0	1.0
	2.4	1.5	1.0	1.0
	3.2	1.5	1.0	1.0
	4.8	1.6	1.0	1.0
	≥ 6.4	1.6	1.0	1.0
≥ 5.5 < 6.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.2	1.0
	≥ 6.4	1.6	1.5	1.2
≥ 6.5	0.4	1.6	1.0	1.0
	0.8	1.6	1.0	1.0
	1.2	1.6	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.3	1.3
	≥ 6.4	1.6	1.5	1.4

Table 4.27: Passenger-Car Equivalents for Trucks and RV's on Specific Upgrades: PTSF Determination

Grade (%)	Length of Grade (km)	Passenger-Car Equivalent for Trucks, E_T — Range of Directional Flow Rates, v_d (pc/h): 0–300	> 300–600	> 600	RVs, E_R
≥ 3.0 < 3.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.0	1.0	1.0	1.0
	3.2	1.0	1.0	1.0	1.0
	4.8	1.4	1.0	1.0	1.0
	≥ 6.4	1.5	1.0	1.0	1.0
≥ 3.5 < 4.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.0	1.0	1.0
	3.2	1.4	1.0	1.0	1.0
	4.8	1.7	1.1	1.2	1.0
	≥ 6.4	2.0	1.5	1.4	1.0
≥ 4.5 < 5.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.2	1.2	1.0
	3.2	1.6	1.3	1.5	1.0
	4.8	2.3	1.9	1.7	1.0
	≥ 6.4	3.3	2.1	1.8	1.0
≥ 5.5 < 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.2	1.2	1.0
	2.4	1.5	1.6	1.6	1.0
	3.2	1.9	1.9	1.8	1.0
	4.8	3.3	2.5	2.0	1.0
	≥ 6.4	4.3	3.1	2.0	1.0
≥ 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.3	1.0
	1.6	1.3	1.4	1.6	1.0
	2.4	2.1	2.0	2.0	1.0
	3.2	2.8	2.5	2.1	1.0
	4.8	4.0	3.1	2.2	1.0
	≥ 6.4	4.8	3.5	2.3	1.0

Some specific downgrades are steep enough to require some trucks to shift into low gear and travel at crawl speeds to avoid loss of control. In such situations, the effect of trucks traveling at crawl speed may be taken into account by replacing with the following when computing the heavy vehicle adjustment factor, **f_{Hv}**, for ATS determination:

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

Where: P_{TC} = proportion of heavy vehicles forced to travel at crawl speeds; E_{TC} = passenger care equivalents for trucks at crawl speed Table 4.28

Note that P_{TC} is stated as a proportion of the truck population, not of the entire traffic stream. Thus, a P_{TC} of 0.50 means that 50% of the trucks are operating down the grade at crawl speeds. Note that for two-lane highways; all composite grades are treated using the average grade of the analysis section. The average grade for any segment is the total change in elevation (m) divided by the length of the segment (m).

Difference Between FFS and Truck Crawl Speed (km/h)	Passenger-Car Equivalent for Trucks at Crawl Speeds, E_{TC} — Range of Directional Flow Rates, v_d (pc/h)		
	0–300	> 300–600	> 600
≤ 20	4.4	2.8	1.4
40	14.3	9.6	5.7
≥ 60	34.1	23.1	13.0

Table 4.28: Passenger-Car Equivalents for Trucks Operating at Crawl Speeds on Specific Downgrades: ATS Determination

Estimating Average Travel Speed

Once the appropriate demand flow rate(s) are computed, the average travel speed in the section is estimated using Equation 4-18 for two-direction analysis and Equation 4-19 for single-direction analysis:

$$ATS = FFS - 0.0125v_p - f_{np} \quad \text{………………………….. (4.18)}$$

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np} \quad \text{………………(4.19)}$$

Where: ATS = average travel speed, both directions, km/hr, ATS_d = average travel speed in the direction of analysis, km/hr., FFS = free-flow speed, both directions, km/hr; FFS_d = free-flow speed in the direction of analysis, km/hr; v = demand flow rate, both directions, pc/h; V_d = demand flow rate in the direction of analysis, pc/h; V_o = demand flow rate in the opposing direction, pc/h; f_{np} = adjustment for the existence of "No Passing" zones in the study segment.

Values of the adjustment factor, f_{np} are given in Table 4.29 for two-direction analyses and in Table 4.30 for single-direction analyses. The adjustment is based on flow rates, the percentage of the analyses segment for which passing is prohibited, and (for single-direction analyses) the free-flow speed of the facility.

Table 4.29: Adjustment for Effect of "No Passing" Zones fnp) on ATS: Two-Direction Segments

Two-Way Demand Flow Rate, v_p (pc/h)	Reduction in Average Travel Speed (km/h)					
	No-Passing Zones (%)					
	0	20	40	60	80	100
0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	1.0	2.3	3.8	4.2	5.6
400	0.0	2.7	4.3	5.7	6.3	7.3
600	0.0	2.5	3.8	4.9	5.5	6.2
800	0.0	2.2	3.1	3.9	4.3	4.9
1000	0.0	1.8	2.5	3.2	3.6	4.2
1200	0.0	1.3	2.0	2.6	3.0	3.4
1400	0.0	0.9	1.4	1.9	2.3	2.7
1600	0.0	0.9	1.3	1.7	2.1	2.4
1800	0.0	0.8	1.1	1.6	1.8	2.1
2000	0.0	0.8	1.0	1.4	1.6	1.8
2200	0.0	0.8	1.0	1.4	1.5	1.7
2400	0.0	0.8	1.0	1.3	1.5	1.7
2600	0.0	0.8	1.0	1.3	1.4	1.6
2800	0.0	0.8	1.0	1.2	1.3	1.4
3000	0.0	0.8	0.9	1.1	1.1	1.3
3200	0.0	0.8	0.9	1.0	1.0	1.1

Table 4:30 Adjustment for Effect of "No Passing" Zones f_{np}) on ATS Single-Direction Segments

Opposing Demand Flow Rate, v_o (pc/h)	No-Passing Zones (%) ≤ 20	40	60	80	100
FFS = 110 km/h					
≤ 100	1.7	3.5	4.5	4.8	5.0
200	3.5	5.3	6.2	6.5	6.8
400	2.6	3.7	4.4	4.5	4.7
600	2.2	2.4	2.8	3.1	3.3
800	1.1	1.6	2.0	2.2	2.4
1000	1.0	1.3	1.7	1.8	1.9
1200	0.9	1.3	1.5	1.6	1.7
1400	0.9	1.2	1.4	1.4	1.5
≥ 1600	0.9	1.1	1.2	1.2	1.3
FFS = 100 km/h					
≤ 100	1.2	2.7	4.0	4.5	4.7
200	3.0	4.6	5.9	6.4	6.7
400	2.3	3.3	4.1	4.4	4.6
600	1.8	2.1	2.6	3.0	3.2
800	0.9	1.4	1.8	2.1	2.3
1000	0.9	1.1	1.5	1.7	1.9
1200	0.8	1.1	1.4	1.5	1.7
1400	0.8	1.0	1.3	1.3	1.4
≥ 1600	0.8	1.0	1.1	1.1	1.2
FFS = 90 km/h					
≤ 100	0.8	1.9	3.6	4.2	4.4
200	2.4	3.9	5.6	6.3	6.6
400	2.1	3.0	3.8	4.3	4.5
600	1.4	1.8	2.5	2.9	3.1
800	0.8	1.1	1.7	2.0	2.2
1000	0.8	0.9	1.3	1.5	1.8
1200	0.8	0.9	1.2	1.4	1.6
1400	0.8	0.9	1.1	1.2	1.4
≥ 1600	0.8	0.8	0.9	0.9	1.1
FFS = 80 km/h					
≤ 100	0.3	1.1	3.1	3.9	4.1
200	1.9	3.2	5.3	6.2	6.5
400	1.8	2.6	3.5	4.2	4.4
600	1.0	1.5	2.3	2.8	3.0
800	0.6	0.9	1.5	1.9	2.1
1000	0.6	0.7	1.1	1.4	1.8
1200	0.6	0.7	1.1	1.3	1.6
1400	0.6	0.7	1.0	1.1	1.3
≥ 1600	0.6	0.7	0.8	0.8	1.0
FFS = 70 km/h					
≤ 100	0.1	0.6	2.7	3.6	3.8
200	1.5	2.6	5.0	6.1	6.4
400	1.5	0.8	3.2	4.1	4.3
600	0.7	0.5	2.1	2.7	2.9
800	0.5	0.5	1.3	1.8	2.0
1000	0.5	0.5	1.0	1.3	1.8
1200	0.5	0.5	1.0	1.2	1.6
1400	0.5	0.5	1.0	1.0	1.2
≥ 1600	0.5	0.5	0.7	0.7	0.9

Determining Percent Time Spent Following

For two-direction analyses, and single-direction analyses Percent time spent following (PTSF) is determined using the following equation 4.20 and 4.21 respectively.

$$PTSF = BPTSF + f_{d/np}$$

$$BPTSF = 100\left(1 - e^{-0.000879 v_p}\right) \quad \text{.................. (4.20)}$$

$$PTSF_d = BPTSF_d + f_{np}$$

$$BPTSF_d = 100\left(1 - e^{a v_d^{\,b}}\right) \quad \text{......................(4.21)}$$

Where: **PTSF** = percent time spent following, two directions, %

$PTSF_d$ = percent time spent following, single direction, %

BPTSF = base percent time spent following, two directions,%

$BPTSF_d$ = base percent time spent following, single directions,%

Vp = demand flow rate, pc/h, both directions

V_d = demand flow rate in analysis direction, pc/h

$f_{d/np}$ = adjustment to PTSF for the combined effect of directional distribution and percent "No Passing" zones on two way analysis segments, %

f_{np} = adjustment to PTSF for the effect of percent "No Passing" zones on single-direction analysis segments,%

a, b = calibration constants based on opposing flow rate in single direction analysis

Adjustnient factor fd/np is found in Table 4.33. Adjustment factor f_{np} is found in Table 4.32 and calibration constants "a" and "b" are found in Table 4.31.

Table 4.31: Coefficients "a" and "b"

Opposing Demand Flow Rate, v_o (pc/h)	a	b
≤ 200	−0.013	0.668
400	−0.057	0.479
600	−0.100	0.413
800	−0.173	0.349
1000	−0.320	0.276
1200	−0.430	0.242
1400	−0.522	0.225
≥ 1600	−0.665	0.199

Table 4.32: Adjustment f_{np}) to PTSF for Percent "No Passing" Zones in Single-Direction Segments

Opposing Demand Flow Rate, v_o (pc/h)	No-Passing Zones (%)				
	≤ 20	40	60	80	100
			FFS = 110 km/h		
≤ 100	10.1	17.2	20.2	21.0	21.8
200	12.4	19.0	22.7	23.8	24.8
400	9.0	12.3	14.1	14.4	15.4
600	5.3	7.7	9.2	9.7	10.4
800	3.0	4.6	5.7	6.2	6.7
1000	1.8	2.9	3.7	4.1	4.4
1200	1.3	2.0	2.6	2.9	3.1
1400	0.9	1.4	1.7	1.9	2.1
≥ 1600	0.7	0.9	1.1	1.2	1.4
			FFS = 100 km/h		
≤ 100	8.4	14.9	20.9	22.8	26.6
200	11.5	18.2	24.1	26.2	29.7
400	8.6	12.1	14.8	15.9	18.1
600	5.1	7.5	9.6	10.6	12.1
800	2.8	4.5	5.9	6.7	7.7
1000	1.6	2.8	3.7	4.3	4.9
1200	1.2	1.9	2.6	3.0	3.4
1400	0.8	1.3	1.7	2.0	2.3
≥ 1600	0.6	0.9	1.1	1.2	1.5
			FFS = 90 km/h		
≤ 100	6.7	12.7	21.7	24.5	31.3
200	10.5	17.5	25.4	28.6	34.7
400	8.3	11.8	15.5	17.5	20.7
600	4.9	7.3	10.0	11.5	13.9
800	2.7	4.3	6.1	7.2	8.8
1000	1.5	2.7	3.8	4.5	5.4
1200	1.0	1.8	2.6	3.1	3.8
1400	0.7	1.2	1.7	2.0	2.4
≥ 1600	0.6	0.9	1.2	1.3	1.5
			FFS = 80 km/h		
≤ 100	5.0	10.4	22.4	26.3	36.1
200	9.6	16.7	26.8	31.0	39.6
400	7.9	11.6	16.2	19.0	23.4
600	4.7	7.1	10.4	12.4	15.6
800	2.5	4.2	6.3	7.7	9.8
1000	1.3	2.6	3.8	4.7	5.9
1200	0.9	1.7	2.6	3.2	4.1
1400	0.6	1.1	1.7	2.1	2.6
≥ 1600	0.5	0.9	1.2	1.3	1.6
			FFS = 70 km/h		
≤ 100	3.7	8.5	23.2	28.2	41.6
200	8.7	16.0	28.2	33.6	45.2
400	7.5	11.4	16.9	20.7	26.4
600	4.5	6.9	10.8	13.4	17.6
800	2.3	4.1	6.5	8.2	11.0
1000	1.2	2.5	3.8	4.9	6.4
1200	0.8	1.6	2.6	3.3	4.5
1400	0.5	1.0	1.7	2.2	2.8
≥ 1600	0.4	0.9	1.2	1.3	1.7

Table 4.33: Adjustment (fd/np) for the Combined Effect of Directional Distribution and Percent "No Passing" Zones on PTSF on Two-Way Segments

Two-Way Flow Rate, v_p (pc/h)	Increase in Percent Time-Spent-Following (%)					
	No-Passing Zones (%)					
	0	20	40	60	80	100
Directional Split = 50/50						
≤ 200	0.0	10.1	17.2	20.2	21.0	21.8
400	0.0	12.4	19.0	22.7	23.8	24.8
600	0.0	11.2	16.0	18.7	19.7	20.5
800	0.0	9.0	12.3	14.1	14.5	15.4
1400	0.0	3.6	5.5	6.7	7.3	7.9
2000	0.0	1.8	2.9	3.7	4.1	4.4
2600	0.0	1.1	1.6	2.0	2.3	2.4
3200	0.0	0.7	0.9	1.1	1.2	1.4
Directional Split = 60/40						
≤ 200	1.6	11.8	17.2	22.5	23.1	23.7
400	0.5	11.7	16.2	20.7	21.5	22.2
600	0.0	11.5	15.2	18.9	19.8	20.7
800	0.0	7.6	10.3	13.0	13.7	14.4
1400	0.0	3.7	5.4	7.1	7.6	8.1
2000	0.0	2.3	3.4	3.6	4.0	4.3
≥ 2600	0.0	0.9	1.4	1.9	2.1	2.2
Directional Split = 70/30						
≤ 200	2.8	13.4	19.1	24.8	25.2	25.5
400	1.1	12.5	17.3	22.0	22.6	23.2
600	0.0	11.6	15.4	19.1	20.0	20.9
800	0.0	7.7	10.5	13.3	14.0	14.6
1400	0.0	3.8	5.6	7.4	7.9	8.3
≥ 2000	0.0	1.4	4.9	3.5	3.9	4.2
Directional Split = 80/20						
≤ 200	5.1	17.5	24.3	31.0	31.3	31.6
400	2.5	15.8	21.5	27.1	27.6	28.0
600	0.0	14.0	18.6	23.2	23.9	24.5
800	0.0	9.3	12.7	16.0	16.5	17.0
1400	0.0	4.6	6.7	8.7	9.1	9.5
≥ 2000	0.0	2.4	3.4	4.5	4.7	4.9
Directional Split = 90/10						
≤ 200	5.6	21.6	29.4	37.2	37.4	37.6
400	2.4	19.0	25.6	32.2	32.5	32.8
600	0.0	16.3	21.8	27.2	27.6	28.0
800	0.0	10.9	14.8	18.6	19.0	19.4
≥1400	0.0	5.5	7.8	10.0	10.4	10.7

Example 1&2

4.3.2. Analysis Methodologies for Multilane Highways and Basic Freeway Sections

The characteristics and criteria described for freeways and multilane highways in the previous section apply to facilities with base traffic and roadway conditions.

In most cases, base conditions do not exist, and a methodology is required to address the impact of prevailing conditions on these characteristics and criteria.

Analysis methodologies are provided that account for the impact of a variety of prevailing conditions, including:

- Lane widths
- Lateral clearances
- Number of lanes (freeways)
- Type of median (multilane highways)
- Frequency of interchanges (freeways) or access points (multilane highways)
- Presence of heavy vehicles in the traffic stream
- Driver populations dominated by occasional or unfamiliar users of a facility

Some of these factors affect the free-flow speed of the facility, while others affect the equivalent demand flow rate on the facility.

Speed-Flow Characteristics

Capacity analysis procedures for freeways and multilane highways are based on calibrated speed-flow curves for sections with various free-flow speeds operating under base conditions. Base conditions for freeways and multilane highways indicated above.

Figures 4.3 show the standard curves calibrated for use in the capacity analysis of basic freeway sections and multilane highways. These exhibits also show the density lines that define levels of service for uninterrupted flow facilities. Modem drivers maintain high average speeds at relatively high rates of flow on freeways and multilane highways.

This is clearly indicated in Figures 4.4. For freeways, the free-flow speed is maintained until flows reach 1,300 to 1,750 pc/hr/ln. Multilane highway characteristics are similar. Thus, on most uninterrupted flow facilities, the transition from stable to unstable flow occurs very quickly and with relatively small increments in flow.

Multilane Highways

Levels of Service

For Multilane highways, the measure of effectiveness used to define levels of service is density. The use of density, rather than speed, is based primarily on the shape of the speed-flow relationships depicted in Figures 4.2 and 4.3. Because average speed remains constant through most of the range of flows and because the total difference between free-flow speed and the speed at capacity is relatively small, defining five level-of-service boundaries based on this parameter would be very difficult.

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

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

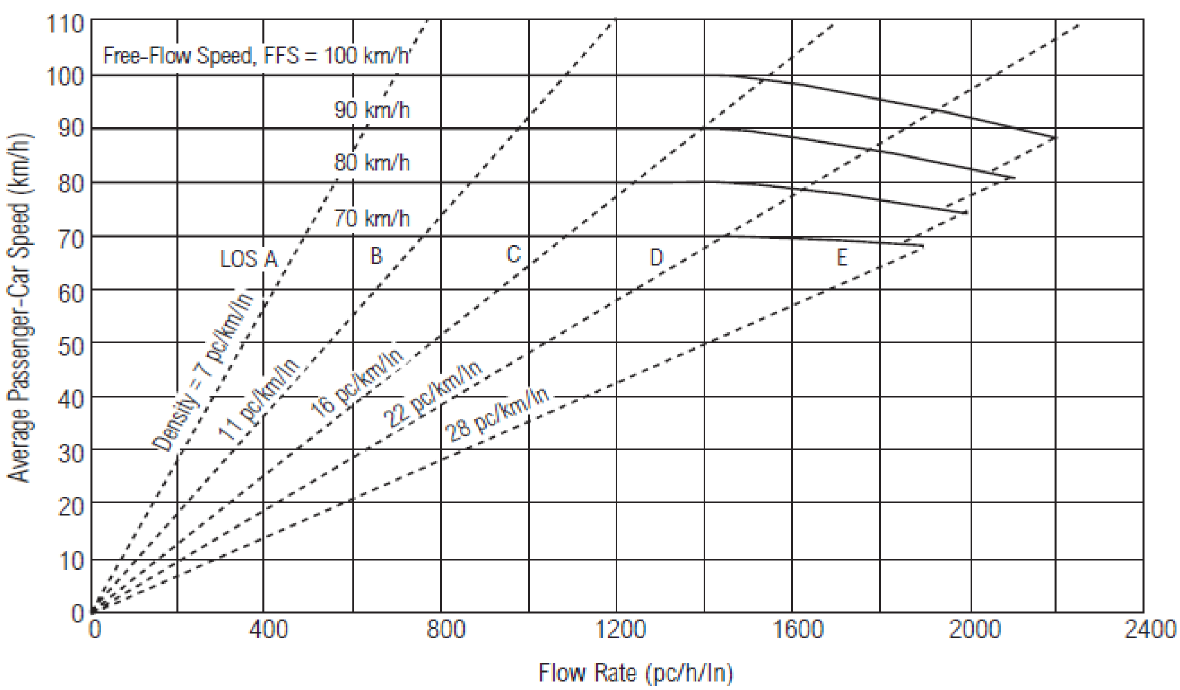

Fig 4.3 Speed-Flow Curves for Multilane Highway Sections

Types of Analysis

There are three types of analysis that can be conducted for basic freeway sections and multilane highways:

- Operational analysis
- Service flow rate and service volume analysis
- Design analysis

All forms of analysis require the determination of the free-flow speed of the facility in question. Field measurement and estimation techniques for making this determination are discussed in a later section.

Operational Analysis
Determination of flow rate

The most common form of analysis is operational analysis. In this form of analysis, all traffic, roadway, and control conditions are defined for an existing or projected highway section, and the expected level of service and operating parameters are determined.

The basic approach is to convert the existing or forecast demand volumes to an equivalent flow rate under ideal conditions:

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

Where:

$\mathbf{V_P}$ = demand flow rate under equivalent ideal conditions, pc/h/ln

PHF = peak-hour factor

N = number of lanes (in one direction) on the facility

$\mathbf{f_{Hv}}$ = adjustment factor for presence of heavy vehicles

$\mathbf{f_P}$ = adjustment factor for driver population presence of occasional or non-familiar users of a facility

This result is used to enter either the standard speed-flow curves of (multilane highways). Using the appropriate free-flow speed, the curves may be entered on the x-axis with the demand flow rate, V_P, to determine the level of service and the expected average speed.

Heavy Vehicle Adjustment Factor; $\mathbf{f_{HV}}$

The heavy-vehicle adjustment factor is based upon the concept of passenger-car equivalents. A passenger-car equivalent is the number of passenger cars displaced by one truck, bus, or RV in a given traffic stream under prevailing conditions. Given that two categories of heavy vehicle are used, two passenger car equivalent values are defined:

E_T = passenger car equivalent for trucks and buses in the traffic stream under prevailing conditions

E_R = passenger car equivalent for RV's in the traffic stream under prevailing conditions

The relationship between these equivalents and the heavy-vehicle adjustment factor is best illustrated by example:

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

Passenger-Car Equivalents for Extended Freeway and Multilane Highway Sections

A long section of roadway may be considered as a single extended section if no one grade of 3% or greater is longer than 0.25 miles, and if no grade of less than 3% is longer than 0.5 miles. Such general terrain sections are designated in one of three general terrain categories i.e level, rolling or Mountainous.

Table 4.34: Passenger-Car Equivalents for Trucks, Buses, and RVs on Extended General Terrain Sections of Freeways or Multilane Highways

	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

Passenger-Car Equivalents for Specific Grades on Freeways and Multilane Highways

Any grade of less than 3% that is longer than 0.50 miles and any grade of 3% or steeper that is longer than 0.25 miles must be considered as a specific grade. This is because a long grade may have a significant impact on both heavy-vehicle operation and the characteristics of the entire traffic stream.

Table 4.35: Passenger-Car Equivalents for Trucks and Buses on uniform Upgrades

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

Table 4.36: Passenger-Car Equivalents for RVs on Upgrades

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

Table 4.37: 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

Driver Population Factor

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

Determining the Free-Flow Speed (Multilane Highway)

The free-flow speed of a facility is best determined by field measurement. Given the shape of speed-flow relationships for freeways and multilane highways, an average speed measured when flow is less than or equal to 1,000 veh/h/ln may be taken to represent the free-flow speed.

It is not always possible, however, to measure the free-flow speed. When new facilities or redesigned facilities are under consideration, it is not possible to measure free-flow speeds. Even for existing facilities, the time and cost of conducting field studies may not be warranted.

The free-flow speed for a multilane highway may be estimated as:

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

Where: FFS = free-flow speed of the multilane highway, km/hr; BFFS =base free-flow speed; f_{LW} = adjustment for lane width, km/hr; f_{LC} = adjustment for lateral clearance, km/hr; f_M = adjustment for type of median, km/hr; f_A = adjustment for access points, km/hr

A base free-flow speed of 97 km/hr may be used for rural and suburban multilane highways, if no field data is available. It may also be estimated using the posted speed limit. The base free-flow speed is approximately 11 km/hr higher than the posted speed limit, for speed limits of 64 and 73 km/hr. and for speed limits of 80 and 89 km/hr, the base free-flow speed is approximately 8 km/hr higher than the limit.

Lane Width Adjustment The base lane width for multilane highways is 3.6m as was the case for freeways. For narrower lanes, the free-flow speed is reduced by the values shown in Table 4.38.

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

Table 4.38 Adjustment to Free-Flow Speed for Lane Width on a Multilane Highway

Lateral Clearance Adjustment For multilane highways, this adjustment is based on the total lateral clearance, which is the sum of the lateral clearances on the right side of the roadway and on the left (median) side of the roadway. While this seems like a simple concept, there are some details that must be observed:

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

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

Table 4.39: Adjustment to Total Lateral Clearance on a Multilane Highway

Median-Type Adjustment The median-type adjustment is shown in Table 4.40. A reduction of 2.6 km/hr is made for undivided configurations, while divided multilane highways, or multilane highways with two-way left-turn lanes, represent base conditions.

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

Table 4.40: Adjustment to Free-Flow Speed for Median Type on Multilane Highways

Access-Point Density Adjustment A critical adjustment to base free-flow speed is related to access-point density. Access-point density is the average number of unsignalized driveways or roadways per km that provide access to the multilane highway on the right side of the roadway (for the subject direction of traffic).

Driveways or other entrances with little traffic, or that, for other reasons, do not affect driver behavior, should not be included in the access-point density. Adjustments are shown in Table 4.41.

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

Table 4.41: Adjustment to Free-Flow Speed for Access-Point Density on a Multilane Highway

Example 3

Basic Freeways

Levels of Service

For basic freeway segment, the measure of effectiveness used to define levels of service is density.

The base conditions under which the full capacity of a basic freeway segment is achieved are good weather, good visibility, and no incidents or accidents. For the analysis procedures in this chapter, these base conditions are assumed to exist. If any of these conditions fails to exist, the speed, LOS, and capacity of the freeway segment all tend to be reduced. 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.

LOS criteria for basic freeway segments are given in table below 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.

Determination of flow rate

The same as the determination of flow rate of **multilane highway** analysis. The entire table used to determine flow rate in multilane used for basic freeway also.

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.

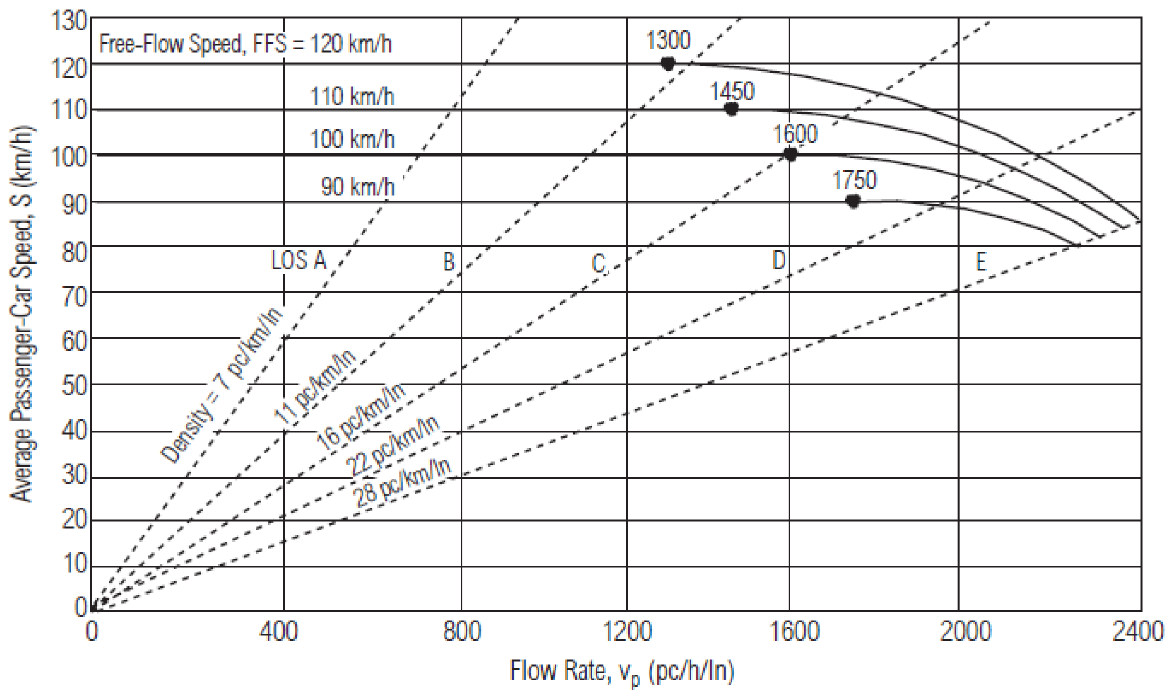

Fig 4.4 Speed-Flow Curves for Basic Freeway Sections

The free-flow speed of a freeway can be estimated as:

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

Where: FFS = free-flow speed of the freeway, km/hr; BFFS = base free-flow speed of the freeway (113 km/hr for urban and suburban freeways, 120 km/hr for rural freeways); f_{LW} = adjustment for lane width, km/hr; f_{LC} = adjustment for lateral clearance, km/hr; f_N = adjustment for number of lanes, km/hr; f_{ID} = adjustment for interchange density, km/hr

Lane Width Adjustment (f_{LW}): The base condition for lane width is an average width of 3.65m (12ft) or greater. For narrower lanes, the base free-flow speed is reduced by the factors shown in Table 4.42.

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

Table 4.42: Adjustment to Free-Flow Speed for Lane Width on a Freeway

Lateral Clearance Adjustment Base lateral clearance is 6 ft (1.83m) or greater on the right side and 2 ft (0.60m) or greater on the median or left side of the basic freeway section. Adjustments for right-side lateral clearances less than 6 ft (1.83m) are given in Table 4.43. There are no adjustments provided for median clearances less than 2 ft (0.6m), as such conditions are considered rare.

Care should be taken in assessing whether an "obstruction" exists on the right side of the freeway. Obstructions may be continuous, such as a guardrail or retaining wall, or they may be periodic, such as light supports and bridge abutments.

Right-Shoulder Lateral Clearance (m)	Reduction in Free-Flow Speed, f_{LC} (km/h)			
	Lanes in One Direction			
	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

Table 4.43: Adjustment to Free-Flow Speed for Lateral Clearance on a Freeway (f_{LC})

Right-side obstructions primarily influence driver behavior in the right lane. Drivers "shy away" from such obstructions, moving further to the left in the lane. Drivers in adjacent lanes may also shift somewhat to the left in response to vehicle placements in the right lane.

The overall affect is to cause vehicles to travel closer to each other laterally than would normally be the case, thus making flow less efficient. This is the same effect as for narrow lanes. Since the primary impact is on the right lane, the total impact on free-flow speed declines as the number of lanes increases.

Adjustment for Number of Lanes The base condition for number of lanes in one direction on a freeway is five or more lanes. The use of this size freeway as a base has been questioned, as it is a relatively rare occurrence. The adjustment for number of lanes is given in Table 4.44.

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.

Table 4.44: Adjustment to Free-Flow Speed for Number of Lanes on a Freeway

Interchange Density Adjustment Perhaps the most significant impact on freeway free-flow speed is the number and spacing of interchanges. Interchange density is defined as the average number of interchanges per km over a 10km section of the facility, taken as 5km upstream and 5km downstream of the point or section under consideration. Note that the interchange density is not based on the number of ramps. An interchange may consist of several ramp connections. A typical diamond interchange has four ramps, while a full cloverleaf interchange has eight. To qualify as an interchange, there must be at least one on-ramp. Thus, a junction with only off-ramps would not qualify as an interchange. The base condition for interchange density is 0.3 interchanges/km. Adjustments for interchange density are shown in Table 4.45.

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

Table 4.45: Adjustment to Free-Flow Speed for Interchange Density on a Freeway

Example 4

References

1. High way capacity manual 2000 **Metric Unit**
2. Traffic engineering third edition by Roess & Prasas, 2004
3. Highway Engineering , Martin rogers
4. Traffic and Highway Engineering, Nicholas J. Garber