CHAPTER 6

HIGHWAY CAPACITY AND LEVEL-OF-SERVICE ANALYSIS

The objective of applied traffic analysis is to provide a practical method of quantifying the **degree of traffic congestion** and to relate this to the overall **traffic-related performance of the roadway.**

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.**
- 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.
- Capacity analysis is a **quantitative assessment** of the ability of a traffic facility to handle vehicles or people for which it is designed.
- What is the performance level of the system at various operating conditions. Or in other words, **how good is the operation of the traffic facility.**

  Level of Service analysis tries to answer this question which is essentially a qualitative analysis.
- **The level-of-service** concept was introduced in the as a convenient way to describe the general quality of operations on a facility with defined traffic, roadway, and control conditions.

INTRODUCTION

- Transportation facilities can be classified into two categories of flow: **uninterrupted** and **interrupted**.
- **Interrupted flow: a** category of traffic facilities characterized by traffic signals, stop signs, or other fixed causes of periodic delay or interruption to the traffic stream.
- **Flow rate (Vp):** the equivalent hourly rate at which vehicles, bicycles, or persons pass a point on a lane, roadway, or other trafficway

  The peak 15 minute flow (V15) enlarged to an hourly value
- **Capacity or maximum service flow rate:** the maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions

  usually expressed as vehicles per hour, passenger cars per hour, or persons per hour.
- **Service volume (v)** 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.

  The highest hourly volume within a 24-hour period

HIGHWAY CAPACITY

- For most cases, to analyze the capacity we used the peak 15 minutes of the peak hour.
- Facilities generally operate poorly at or near capacity; they are rarely planned to operate in this range.
- Capacity analysis also estimates the maximum amount of traffic that a facility can accommodate while maintaining its prescribed level of operation.

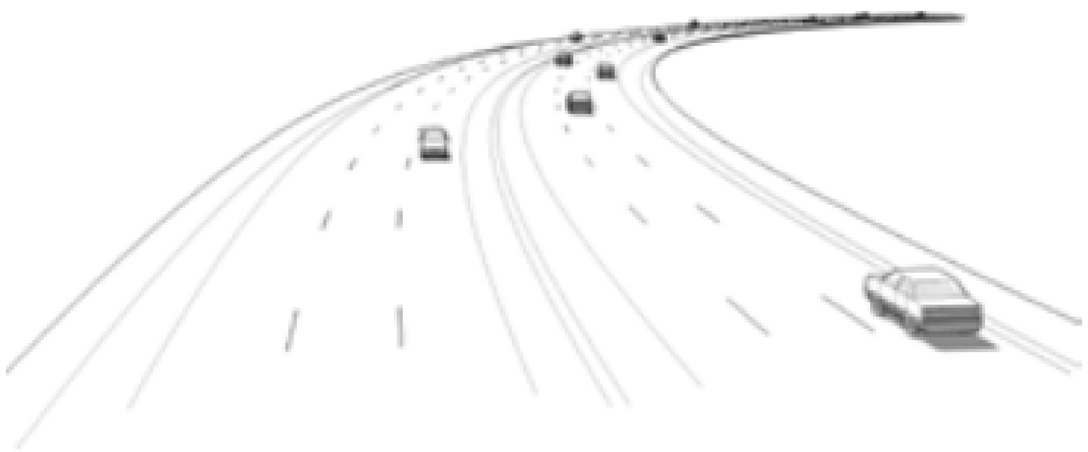
- Generally the highway capacity depends on certain conditions as listed below:
  - **Road way characteristics:** this are associated with the geometric characteristics and design elements of the facility
    - Including, type of facility, number of lanes, horizontal and vertical alignments
    - For example, a curved road has lesser capacity compared to a straight road.
  - **Traffic conditions:** are associated with the characteristics of the traffic stream on the segment of the highway such as 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
  - **Control conditions:** primarily applied to surface facilities and includes the types of traffic control devices in operation, signal phasing, allocation of green time, cycle length.
- Prevailing roadway, traffic, and control conditions define capacity; these conditions should be reasonably uniform for any section of facility analyzed. Any change in the prevailing conditions changes the capacity of the facility.

LEVEL OF SERVICE

- The level-of-service concept describes the general **quality of operations** on a facility with defined traffic, roadway, and control conditions.
- When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a **qualitative measure.**
- Level of service (LOS) qualitatively measures both the operating conditions within a traffic system and how these conditions are perceived by drivers and passengers.
- **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.
- Highway capacity manual (HCM) 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.

LEVEL OF SERVICE

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.



Level of Service A

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 B

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

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.

Level of 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 D

: The highway is operating at high density levels but stable flow still prevails.Small increases in flow levels will result insignificant 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

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.

Level of Service E

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 F

Describes a state of breakdown o forced flow with flows exceeding capacity.The operating conditions are highly unstable with constant queuing and traffic moving on a ‘stop-go’ basis.

DESIGN TRAFFIC VOLUMES

DESIGN TRAFFIC VOLUMES

- Daily volumes, while useful for planning purposes, cannot be used alone for design or operational analysis purposes.
- Volume varies considerably over the 24 hours of the day, with periods of maximum flow occurring during morning or evening rush hours.
- Traffic volume is an important basis for determining what improvements, if any, are required on a highway or street facility.
- Undefined Traffic volume studies are conducted to collect data on the number of vehicles and/or pedestrians that pass a point on a highway facility during a specified time period.
- Traffic Volumes can be expressed in terms of annual, daily, hourly, or sub-hourly periods. Traffic volume could be expressed as:
  - **Average daily traffic (ADT):** is the average of 24-hour counts collected over a number of days greater than one but less than a year.
  - **Average annual daily traffic (AADT)**: is the average of 24-hour counts collected every day of the year.

  Average weekday traffic (AWT)

  Average annual weekday traffic (AAWT)

$$\text{ADT} = \frac{Total\ volume\ of\ a\ given\ period}{Time\ period\ (Days)}$$

$$\text{AADT} = \frac{Total\ volume\ of\ one\ year}{365\ Day}$$

$$\text{AWT} = \frac{Total\ weekday\ volume\ of\ a\ given\ period}{No\ of\ weekday\ on\ the\ time\ period}$$

$$\text{AAWT} = \frac{Total\ weekday\ volume\ of\ one\ year}{260\ Day}$$

DESIGN TRAFFIC VOLUMES

Illustration of Daily Volume Parameters

1. Month	2. No. of Weekdays in Month (days)	3. Total Days in Month (days)	4. Total Monthly Volume (vehs)	5. Total Weekday Volume (vehs)	6. AWT 5/2 (veh/day)	7. ADT 4/3 (veh/day)
Jan	22	31	425,000	208,000	9,455	13,710
Feb	20	28	410,000	220,000	11,000	14,643
Mar	22	31	385,000	185,000	8,409	12,419
Apr	22	30	400,000	200,000	9,091	13,333
May	21	31	450,000	215,000	10,238	14,516
Jun	22	30	500,000	230,000	10,455	16,667
Jul	23	31	580,000	260,000	11,304	18,710
Aug	21	31	570,000	260,000	12,381	18,387
Sep	22	30	490,000	205,000	9,318	16,333
Oct	22	31	420,000	190.000	8,636	13,548
Nov	21	30	415,000	200,000	9,524	13,833
Dec	22	31	400,000	210,000	9,545	12,903
Total	**260**	**365**	**5,445,000**	**2,583,000**	—	—

AADT = 5,445,000/365 = 14,918 veh/day

AAWT = 2,583,000/260 = 9,935 veh/day

DESIGN TRAFFIC VOLUMES

Design hourly volume (DHV)

- Is the number of vehicles that travel through a segment of roadway during the design hour.
- The DHV is used for making roadway structural and capacity design decisions because traffic volume varies by hour and from day to day throughout the year.

K Factors

K is the percentage of ADT representing the 30th highest hourly volume in the design year. For typical main rural highways, K-factors generally range from 12 to 18 percent. For urban facilities, K factors are typically somewhat lower, ranging from 8 to 12 percent.

Directional design hour volume (DDHV)

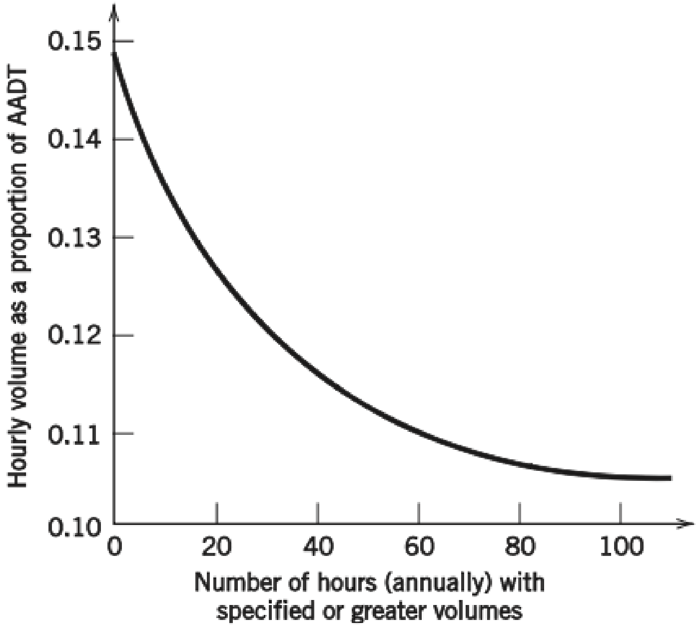
The directional design hour volume (DDHV) is the one-way volume in the predominant direction of travel in the design hour, expressed as a percentage of the two-way DHV.

Directional distribution factor (D)

D factor reflects the proportion of peak-hour traffic traveling in the peak direction and it is often there is much more traffic in one direction than the other. For rural and suburban roads, the directional distribution factor (D) ranges from 55 to 80 percent. A factor of approximately 50 percent is used for urban highways. Keep in mind that the directional distribution can change during the day.

$$DHV = K \times AADT$$

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



EXAMPLE

Consider the case of a rural highway that has a 20-year forecast of AADT of 30,000 veh/day, for given highway, the K factor ranges from 0.15 to 0.25, and the D factor ranges from 0.65-0.80. Determine DDHV

DDHV (low) = 30,000 × 0.15 × 0.65 = 2,925 veh/h

DDHV (high) = 30,000 × 0.25 × 0.80 = 6,000 veh/h

Table 5.2: General Ranges for K and D Factors

Facility Type	Normal Range of Values	
	K-Factor	***D*-Factor**
Rural	0.15–0.25	0.65–0.80
Suburban	0.12–0.15	0.55–0.65
Urban:		
Radial Route	0.07–0.12	0.55–0.60
Circumferential Route	0.07–0.12	0.50–0.55

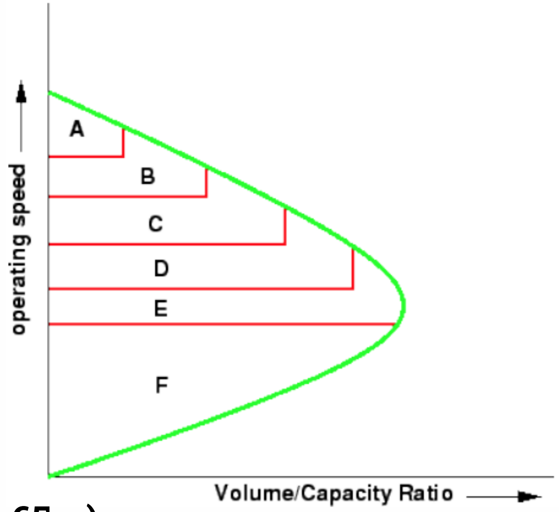
$$DDHV = K \times D \times AADT$$

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

FACTORS AFFECTING LEVEL OF SERVICE

One can drive from a road under different operating characteristics and traffic volumes.

- Speed and travel time
- Traffic interruptions/restrictions
- Freedom to travel with desired speed
- Driver comfort and convenience
- Operating cost



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

- **Lane Width**: traffic flow tends to be restricted when lane widths are narrower than **12 ft (3.65m).**
- **Lateral Obstruction:** 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:** vehicles other than passenger cars-such as trucks, buses, and recreational vehicles-in a traffic stream
- **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).
- **Driver Population:** a driver population consisting primarily of weekday commuters is assumed. However, it is known that other driver populations do not exhibit the same behavior.

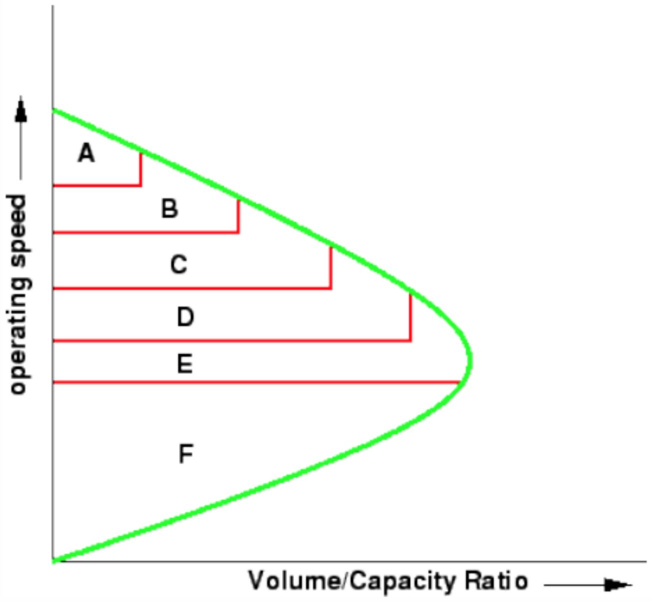
FACTORS AFFECTING LEVEL OF SERVICE

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.

LOS	Quality	Speed (kmph)	V/C	Description
A	Free-flow	80	0.6	High level of physical and psychological comfort
B	Reasonable free-flow	70	0.7	Reasonable level of physical and psychological comfort
C	Near free-flow	60	0.8	Local deterioration possible with blockages
D	Medium flow	50	0.85	Non-recoverable local disruptions
E	At capacity flow	40	0.9	Minor disturbances resulting breakdown
F	Congested flow	15	1.0	Break down of flow capacity drops



SPEED-FLOW CHARACTERISTICS

- Ideal characteristics and criteria describing freeways and multilane highways 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.
- 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.**
- Figure shows the standard curves calibrated for use in the capacity analysis of basic freeway sections
  - freeways, the free-flow speed is maintained until flows reach 1,300 to 1,750 pc/hr/ln.
- The maximum service flow rate at level of service i (MFR) is the maximum flow that a section of the freeway can maintain at level of service i under ideal conditions. Ideal conditions are defined as follows:

- 12-ft minimum lane widths
- 6-ft minimum right-shoulder clearance between the edge of the travel lane and objects (utility poles, retaining walls, etc.) that influence driver behavior
- 2-ft minimum median lateral clearance
- Only passenger cars in the traffic stream
- Five or more lanes in each travel direction (urban areas only)
- 2-mi or greater interchange spacing
- Level terrain (no grades greater than 2%)
- A driver population of mostly familiar roadway users

- **Service flow rates** are stated in terms of peak flows within the peak hour, usually for a 15-minute analysis period.

The maximum Service flow rate is determined as the product of the capacity under ideal conditions multiplied by the maximum volume-to-capacity ratio for the level of service i.

SERVICE FLOW RATE AND SERVICE MEASURE

- The service measure for basic freeway segments is **density**.
- Density is typically measured in terms of passenger cars per mile per lane (pc/mi/ln).
- Traffic density is the primary determinant of freeway level of service;
- The density can be calculated then referenced in Table 6.1 or Fig. 6.2 to arrive at a level of service for the freeway segment.

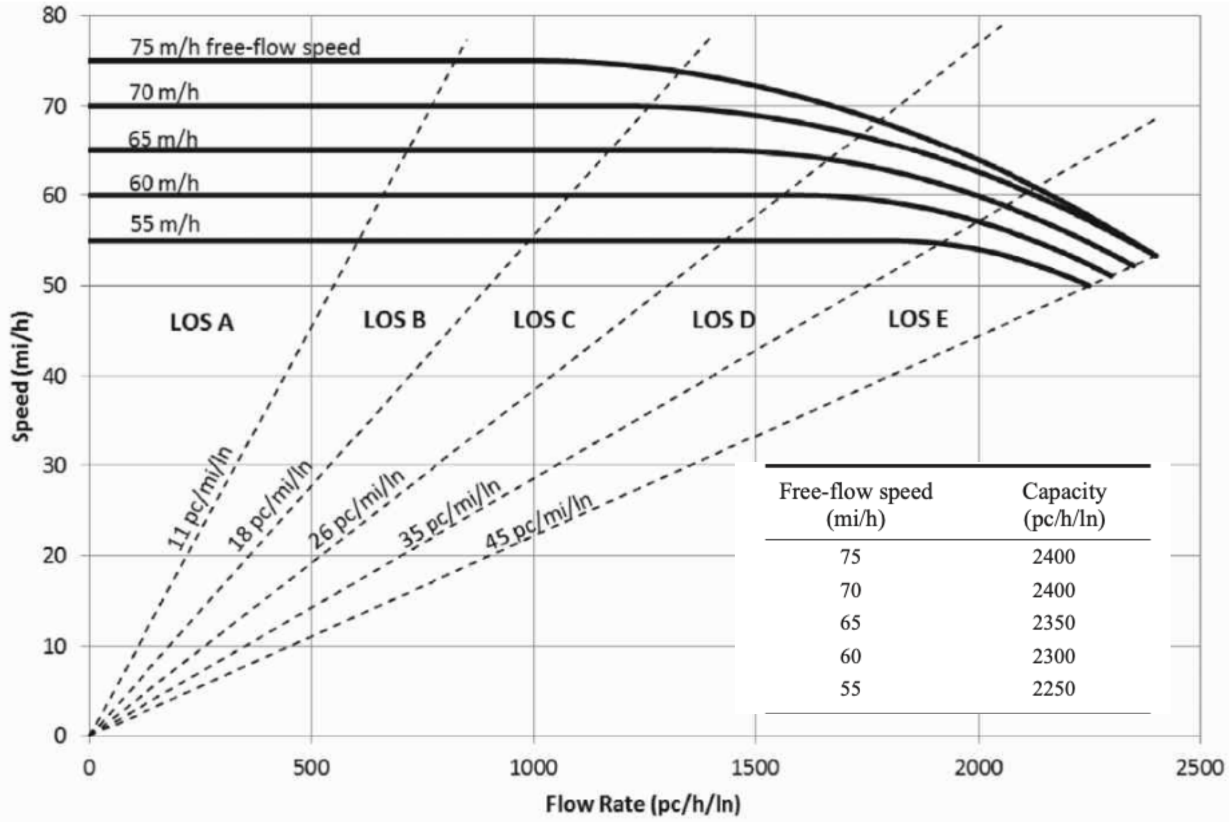


Table 6.1 LOS Criteria for Basic Freeway Segments

Criterion	LOS				
	A	B	C	D	E
			FFS = 75 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	75.0	73.8	68.3	60.9	53.3
Maximum *v/c*	0.34	0.55	0.74	0.89	1.00
Maximum flow rate (pc/h/ln)	825	1330	1775	2130	2400
			FFS = 70 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	70.0	70.0	66.7	60.3	53.3
Maximum *v/c*	0.32	0.52	0.72	0.88	1.00
Maximum flow rate (pc/h/ln)	770	1260	1735	2110	2400
			FFS = 65 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	65.0	65.0	64.0	58.8	52.2
Maximum *v/c*	0.30	0.50	0.71	0.88	1.00
Maximum flow rate (pc/h/ln)	710	1170	1665	2060	2350
			FFS = 60 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	60.0	60.0	60.0	57.1	51.1
Maximum *v/c*	0.29	0.47	0.68	0.87	1.00
Maximum flow rate (pc/h/ln)	660	1080	1560	2000	2300
			FFS = 55 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum *v/c*	0.27	0.44	0.64	0.85	1.00
Maximum flow rate (pc/h/ln)	605	990	1430	1915	2250

Note: Density is the primary determinant of LOS. Maximum flow rate values are rounded to the nearest 5 passenger cars.

SPEED-FLOW ANALYSIS

Types of Analysis

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

- Operational analysis
- Design analysis

All forms of analysis require the determination of the **free-flow speed of the facility**

Operational Analysis

- 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)**
- Using the appropriate expected average speed, with he demand flow rate V_P, with the speed-flow curves chart to determine the level of service and

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

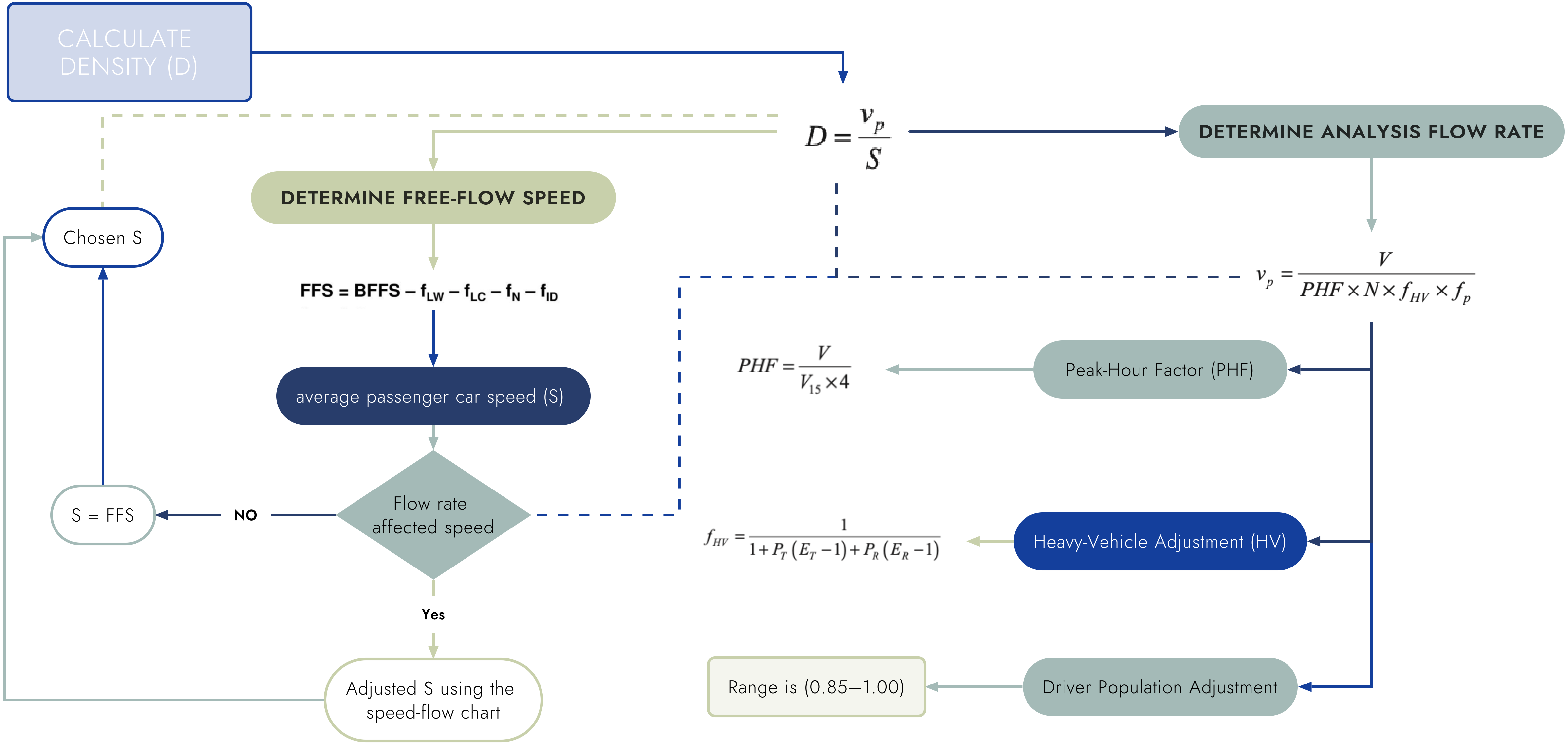
D = density in pc/mi/ln,
v_p = flow rate in pc/h/ln, and
S = average passenger car speed in mi/h.

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

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
f_{Hv} = adjustment factor for presence of heavy vehicles
f_P = adjustment factor for presence of occasional or non-familiar users of a facility

DETERMINE LOS FOR A FREEWAY

The final step before level of service can be determined is to calculate the **density** of the traffic stream



PEAK-HOUR FACTOR (PHF)

- As previously mentioned, vehicle arrivals during the period of analysis [typically the highest hourly volume within a 24-h period (peak hour)] will likely be nonuniform. To account for this varying arrival rate, the peak 15-min vehicle arrival rate within the analysis hour is usually used for practical traffic analysis purposes.
- The further the PHF is from unity (1), the more peaked or nonuniform the traffic flow is during the hour, vice versa

Uniform demand

Assume that 50 vehicle were counted durning each of all possible 5-min interval durning the peak hour. Compute PHF:

$$PHF = \frac{V}{N_t \times (60/t)} = \frac{50 \times (12)}{50 \times (60/5)} = \frac{600}{600} = 1$$

Extremely peak demand

consider extreme case where 250 vehicle were counted during 15-min interval and no vehicles were observed during the rest of the day.

$$PHF = \frac{V}{N_t \times (60/t)} = \frac{250}{250 \times (60/15)} = \frac{250}{1000} = 0.25$$

$$PHF = \frac{V}{N_t \times (60/t)} = \frac{V}{V_{15} \times (4)}$$

PHF = peak-hour factor,
V = hourly volume for hour of analysis,
V_{15} = maximum 15-min volume within hour of analysis, and
4 = number of 15-min periods per hour.

HEAVY-VEHICLE ADJUSTMENT

- Large trucks, buses, and recreational vehicles have performance characteristics (slow acceleration and inferior braking) and dimensions (length, height, and width) that have an adverse effect on roadway capacity.
- Recall that base conditions stipulate that no heavy vehicles are present in the traffic stream, and when prevailing conditions indicate the presence of such vehicles, the adjustment factor f_{HV} is used to translate the traffic stream from base to prevailing conditions

Example

consider a freeway with a 1.0 mi 4% upgrade with a traffic stream having 8% trucks, 2% buses, and 2% recreational vehicles.

- Tables 6.6 and 6.7 must be used because the grade is too steep and long for Table 6.5 to apply.
- The corresponding equivalency factors for this roadway are E_T = 2.5 (for a combined truck and bus percentage of 10) and E_R = 3.0, as obtained from Tables 6.6 and 6.7, respectively.
- from the given percentages of heavy vehicles in the traffic stream, P_T = 0.1 and PR = 0.02

$$f_{HV} = \frac{1}{1 + 0.1(2.5 - 1) + 0.02(3 - 1)} = 0.84$$

or a 16% reduction in effective roadway capacity relative to the base condition of no heavy vehicles in the traffic stream.

Table 6.5 Passenger Car Equivalents (PCEs) for Extended Freeway Segments

	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

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

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, from Table 6.5,
E_R = passenger car equivalent for recreational vehicles, from Table

DRIVER POPULATION ADJUSTMENT

- Under base conditions, the traffic stream is assumed to consist of regular weekday drivers and commuters who have high familiarity with the roadway .
- There are times when the traffic stream has a driver population that is less familiar with the roadway in question (such as weekend drivers or recreational drivers). Such drivers can cause a significant reduction in roadway capacity relative to the base condition of having only familiar drivers.
- To account for the composition of the driver population, the adjustment factor f_p is used, and its recommended range is **0.85–1.00:**
  - Normally, the analyst should select a value of 1.00 for primarily commuter (or familiar-driver) traffic streams.
  - for other driver populations (for example, a large percentage of tourists), the loss in roadway capacity can vary from 1% to 15%. so should be f_p 0.9 or 0.85

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

FREE-FLOW SPEED

- For basic freeway segments, FFS is the mean speed of passenger cars operating in flow rates up to 1300 passenger cars per hour per lane (pc/h/ln). If FFS is to be estimated rather than measured, the following equation can be used.
- It accounts for the roadway characteristics of **lane width, right-shoulder lateral clearance, and ramp density.**
- **The base free-flow speed (BFFS)**
- applies to freeways in urban and rural areas as constant value. BFFS is assumed to be 70 mi/h for freeway in urban setting or 75 for a freeway in rural area

Lane Width Adjustment

- When lane widths are narrower than the base 12 ft, the adjustment factor f_{LW} is used to reflect the impact on free-flow speed.

Lane width (ft)	Reduction in free-flow speed, f_{LW} (mi/h)
12	0.0
11	1.9
10	6.6

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

FFS = estimated free-flow speed in mi/h

BFFS = estimated free-flow speed in mi/h, for base conditions

f_{LW} = adjustment for lane width in mi/h

f_{LC} = adjustment for lateral clearance in mi/h

f_N = adjustment for number of lanes in mi/h

f_{ID} = adjustment for interchange density in mi/h

$$FFS = BFFS - [(3.1)(12 - W)^{1.77}] - [2.4 - (0.4)(LC)] - [7.5 - 1.5N] + 4.4 - (8.45ACCESS)$$

FREE-FLOW SPEED

Lateral Clearance Adjustment

- When obstructions are closer than 6 ft (at the roadside) from the traveled pavement, the adjustment factor f_{LC} is used to reflect the impact on FFS.

Right-shoulder lateral clearance (ft)	Reduction in free-flow speed, f_{LC} (mi/h), lanes in one direction			
	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

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

Number of lanes Adjustment

- a freeway with five or more lanes in a single direction is the base condition
- Rural freeways typically have only two lanes in each direction, thus no FFS agusitemnt is made for number of lanes, (f_N)=0

Number of Lanes (One Direction)	Reduction in Free-Flow Speed f_N (mph)
>=5	0.0
4	1.5
3	3.0
2	4.5

FFS = estimated free-flow speed in mi/h

BFFS = estimated free-flow speed in mi/h, for base conditions

f_{LW} = adjustment for lane width in mi/h

f_{LC} = adjustment for lateral clearance in mi/h

f_N = adjustment for number of lanes in mi/h

f_{ID} = adjustment for interchange density in mi/h

$$FFS = BFFS - [(3.1)(12 - W)^{1.77}] - [2.4 - (0.4)(LC)] - [7.5 - 1.5N] + 4.4 - (8.45ACCESS)$$

FREE-FLOW SPEED

Interchange Density Adjustment

- **The base interchange density is 0.5 interchanges per mile, or 2 mile interchange spacing. Base free-flow speed is reduced when interchange density becomes greater.**
- Interchange density is determined over a 6 miles segment of freeway (3 mi upstream and 3 mi downstream)
- An interchange is defined as having at least one on-ramp. Therefore, interchanges that have only off-ramps would not be considered in determining interchange density

Interchanges per Mile	Reduction in Free-Flow Speed f_{ID} (mph)
<=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

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

FFS = estimated free-flow speed in mi/h

BFFS = estimated free-flow speed in mi/h, for base conditions

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FREE-FLOW SPEED

Example

An extended freeway segment has observed free-flow speed of 70 mi/h with three lanes per direction, 11-ft lane width, 3-ft lateral clearance, and about one interchange per mile

By calculation

$$FFS = 70 - [(3.1)(12-11)^{1.77}] - [2.4-(0.4)(3)] - [7.5-1.5(3)] + 4.4 - [8.4(1)]$$

$$FFS = 58.7mi/h$$

Using tables

$$FFS = 70 - 1.9 - 1.2 - 3 - 2.5 = 61.4mi/h$$

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

FFS = estimated free-flow speed in mi/h

BFFS = estimated free-flow speed in mi/h, for base conditions

f_{LW} = adjustment for lane width in mi/h

f_{LC} = adjustment for lateral clearance in mi/h

f_N = adjustment for number of lanes in mi/h

f_{ID} = adjustment for interchange density in mi/h

$$FFS = BFFS - [(3.1)(12-W)^{1.77}] - [2.4-(0.4)(LC)] - [7.5-1.5N] + 4.4 - [8.45ACCESS]$$

EXAMPLE6.1

A **six-lane urban freeway** (three lanes in each direction) is on **rolling terrain** with **11-ft lanes**, **obstructions 2 ft** from the right edge of the traveled pavement, and **nine ramps** within three miles upstream and three miles downstream of the midpoint of the analysis segment. The traffic stream consists primarily of **commuters**. A directional weekday **peak-hour volume of 2300** vehicles is observed, with **700 vehicles arriving in the most congested 15- min period.** If the traffic stream has **15% large trucks and buses** and **no recreational vehicles,** determine the level of service.

- **Determine the flow rate**

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

with

$$PHF = \frac{2300}{700 \times 4} = 0.821 \qquad f_{HV} = \frac{1}{1+0.15(2.5-1)} = 0.816$$

$N = 3$ (given),
$f_p = 1.0$ (commuters), and
$E_T = 2.5$ (rolling terrain, Table 6.5).

$$v_p = \frac{2300}{0.821 \times 3 \times 0.816 \times 1.0} = 1144.4 \rightarrow 1145 \text{ pc/h/ln}$$

- **Determine the free-flow speed**

$f_{LW} = 1.9$ mi/h (Table 6.3),
$f_{LC} = 1.6$ mi/h (Table 6.4), and
$TRD = \frac{9}{6} = 1.5$ ramps/mi

$$FFS = 70 - [(3.1)(12-11)^{1.77}] - [2.4 - (0.4)(2)] - [7.5 - 1.5(3)] + 4.4 - [8.45(1.5)]$$

$$FFS = 70 - [3.1] - [1.6] - [3] + [4.4 - 12.67] = 54 mi/h$$

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

$$FFS = 70 - 1.9 - 1.6 - 3 - 5 = 58.5 mi/h$$

EXAMPLE6.1

A **six-lane urban freeway** (three lanes in each direction) is on **rolling terrain** with **11-ft lanes**, **obstructions 2 ft** from the right edge of the traveled pavement, and **nine ramps** within three miles upstream and three miles downstream of the midpoint of the analysis segment. The traffic stream consists primarily of **commuters**. A directional weekday **peak-hour volume of 2300** vehicles is observed, with **700 vehicles arriving in the most congested 15- min period.** If the traffic stream has **15% large trucks and buses** and **no recreational vehicles,** determine the level of service.

- **Determine the Average free-flow speed**

Obtaining average passenger car speed from Fig. 6.2 for a flow rate of 1145 and a FFS of 58.5 mi/h yields an S of 58.5 mi/h

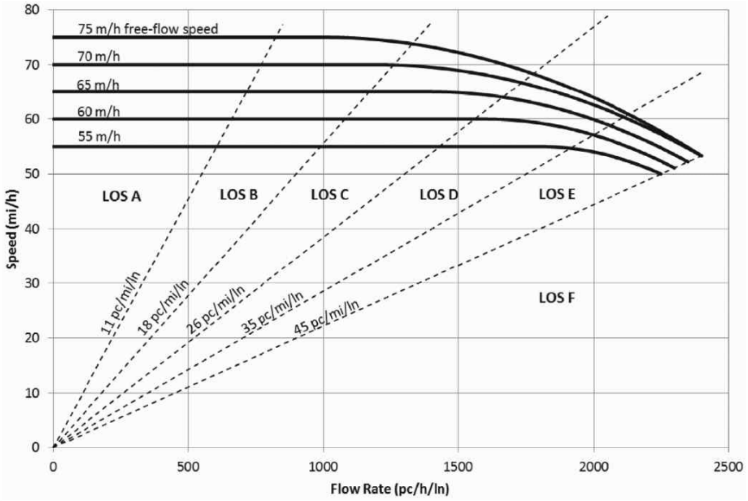

Figure 6.2 Basic freeway segment speed-flow curves and level-of-service criteria. (U.S. Customary)
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- **Determine the density**

$$D = \frac{v_p}{s} = \frac{1145}{58.5} = 19.6pc/mi/ln$$

From Table 6.1, it can be seen that this corresponds to LOS C (18 is max density for LOS B] < 19.56 < 26.0 is max density for LOS C) Thus, this freeway segment operates at level of service C.

EXAMPLE6.2

Consider the freeway and traffic conditions in Example 6.1. At some point further along the roadway there is a **6% upgrade that is 1.5 mi long.** All other characteristics are the same as in Example 6.1. What is the level of service of this portion of the roadway, and how many vehicles can be added before the roadway reaches capacity (assuming that the proportion of vehicle types and the peak-hour factor remain constant)?

- **Determine the flow rate**

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

with

$$PHF = \frac{2300}{700 \times 4} = 0.821 \quad f_{HV} = \frac{1}{1 + 0.15(3.5 - 1)} = 0.727$$

$N = 3$ (given),
$f_p = 1.0$ (commuters), and

From Table 6.6, $E_T = 3.5$,

$$v_p = \frac{2300}{0.821 \times 3 \times 0.727 \times 1.0} = 1284.5 \rightarrow 1285 \text{ pc/h/ln}$$

- **Determine the free-flow speed**

$f_{LW} = 1.9$ mi/h (Table 6.3),
$f_{LC} = 1.6$ mi/h (Table 6.4), and
$TRD = \frac{9}{6} = 1.5$ ramps/mi

$$FFS = 70 - [(3.1)(12 - 11)^{1.77}] - [2.4 - (0.4)(2)] - [7.5 - 1.5(3)] + 4.4 - [8.45(1.5)]$$

$$FFS = 70 - [3.1] - [1.6] - [3] + [4.4 - 12.67] = 54 mi/h$$

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

$$FFS = 70 - 1.9 - 1.6 - 3 - 5 = 58.5 mi/h$$

EXAMPLE6.2

Consider the freeway and traffic conditions in Example 6.1. At some point further along the roadway there is a **6% upgrade that is 1.5 mi long.** All other characteristics are the same as in Example 6.1. What is the level of service of this portion of the roadway, and how many vehicles can be added before the roadway reaches capacity (assuming that the proportion of vehicle types and the peak-hour factor remain constant)?

- **Determine the Average free-flow speed**

the average passenger car speed (S) is still 58.5 mi/h

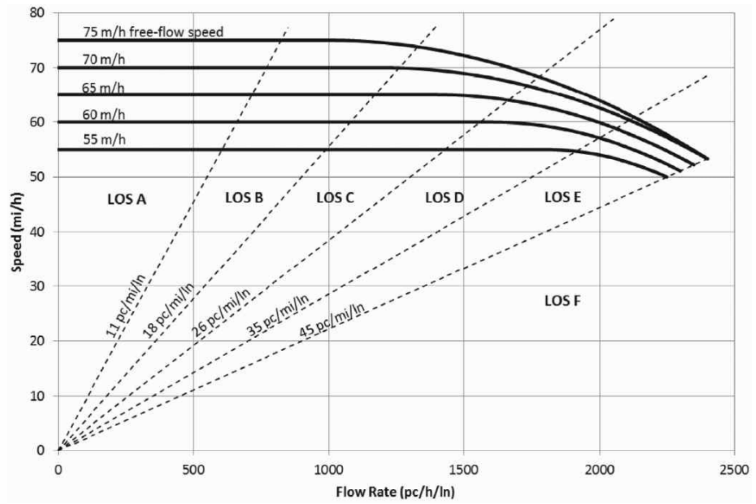


Figure 6.2 Basic freeway segment speed-flow curves and level-of-service criteria. (U.S. Customary)
Reproduced with permission of the Transportation Research Board, *Highway Capacity Manual* 2010, Copyright, National Academy of Sciences, Washington, D.C. Exhibit 11-6, p. 11-8.

- **Determine the density**

$$D = \frac{v_p}{s} = \frac{1284}{58.5} = 22pc/mi/ln$$

From Table 6.1, it can be seen that this corresponds to LOS C (18 is max density for LOS B] < 22 < 26.0 is max density for LOS C) Thus, this freeway segment operates at level of service C.

EXAMPLE6.2

Consider the freeway and traffic conditions in Example 6.1. At some point further along the roadway there is a **6% upgrade that is 1.5 mi long.** All other characteristics are the same as in Example 6.1. What is the level of service of this portion of the roadway, and how many vehicles can be added before the roadway reaches capacity (assuming that the proportion of vehicle types and the peak-hour factor remain constant)?

- **determine how many vehicles can be added before capacity**

Recall that capacity corresponds to a volume-to-capacity ratio of 1.0 (the threshold between LOS E and LOS F):

at FFS 60 mi/h, MSF = 2300

at FFS 55 mi/h, MSF = 2250

Use Linear Interpolation Equation to find MSF at FFS 58.5 mi/h

$$\text{Linear Interpolation}(y) = y_1 + (x - x_1)\frac{(y_2 - y_1)}{(x_2 - x_1)}$$

$$MSF_{58.5} = 2300 + (58.5 - 60)\frac{(2250 - 2300)}{(55 - 60)} = 2285pc/h/ln$$

- **Determine the volume for MSF**

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \longrightarrow 2285 = \frac{V}{0.821 \times 3 \times 0.727 \times 1}$$

$$V = 4092veh/h$$

This means that about 1792 vehicles (4092 – 2300) can be added during the peak hour before capacity is reached.

EXERCISE

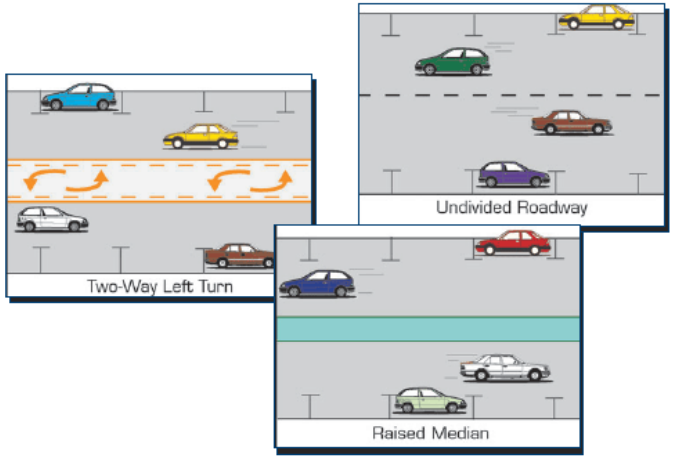
A four-lane freeway (two lanes in each direction) is located in mountainous terrain with 11-ft lane, a 5-ft right-side shoulder, interchange spacing of one every 10 miles, and a 60 mi/h base free-flow speed During the peak hour there are 12% large trucks and 6% recreational vehicles. PHF is 0.88 and the driver population adjustment is determined to be 0.9. The freeway is currently operating at capacity during the peak-hour. If an additional 11-ft lane is added (in each direction), and all factors are the same, what will be the current LOS and LOS after adding the lane.

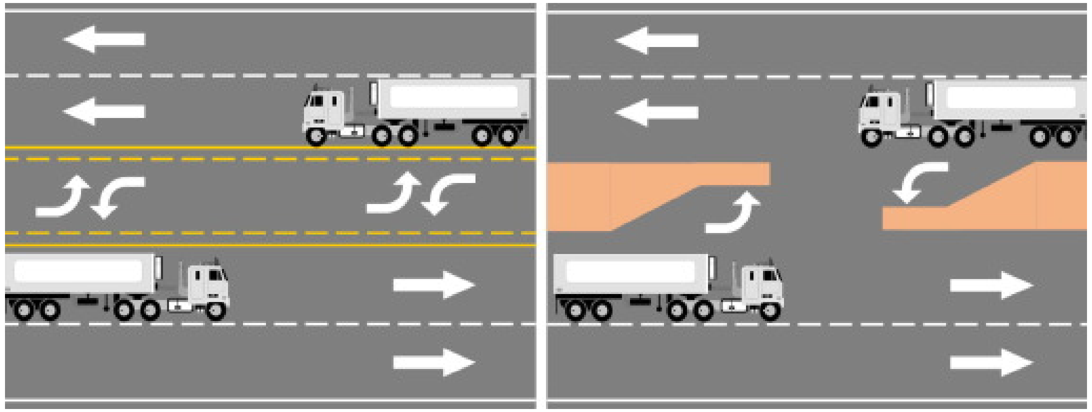
MULTILANE HIGHWAYS

MULTILANE HIGHWAYS

Multilane highways are similar to freeways in most respects, <u>except for a few key differences:</u>

- **Vehicles may enter or leave the roadway** at at-grade intersections and driveways (multilane highways do not have full access control).
- **Multilane highways may or may not be divided** (by a barrier or median separating opposing directions of flow), whereas freeways are always divided.
- **Traffic signals may be present**. Design standards (such as design speeds) are sometimes lower than those for freeways.
- **The visual setting** and development along multilane highways are usually **more distracting** to drivers than in the freeway case.
- Multilane highways usually have four or six lanes (both directions), have posted speed limits between 40 and 60 mi/h, and can have physical medians, medians that are two-way left-turn lanes (TWLTLs), or opposing directional volumes that may not be divided by a median at all.





BASE CONDITIONS AND CAPACITY

- 12-ft minimum lane widths
- 12-ft minimum total lateral clearance from roadside objects (right shoulder and median) in the travel direction
- Only passenger cars in the traffic stream
- No direct access points along the roadway
- Divided highway
- Level terrain (no grades greater than 2%)
- Driver population of mostly familiar roadway users
- Free-flow speed of 40-60 mi/h

The capacity (c)

For multilane highway segments, in pc/h/ln, is given in Table 6.10. From Table 6.9, note again that these capacity values correspond to the maximum service flow rate at LOS E and a v/c of 1.0.

Free-flow speed (mi/h)	Capacity (pc/h/ln)
60	2200
55	2100
50	2000
45	1900

MULTILANE HIGHWAYS

The determination of level of service on multilane highways closely mirrors the procedure for freeways. The main differences lie in some of the adjustment factors and their values.

Table 6.9 LOS Criteria for Multilane Highways

Criterion	LOS				
	A	B	C	D	E
			FFS = 60 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	40
Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
Maximum *v/c*	0.30	0.49	0.70	0.90	1.00
Maximum flow rate (pc/h/ln)	660	1080	1550	1980	2200
			FFS = 55 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	41
Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
Maximum *v/c*	0.29	0.47	0.68	0.88	1.00
Maximum flow rate (pc/h/ln)	600	990	1430	1850	2100
			FFS = 50 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	43
Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
Maximum *v/c*	0.28	0.45	0.65	0.86	1.00
Maximum flow rate (pc/h/ln)	550	900	1300	1710	2000
			FFS = 45 mi/h		
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	45.0	45.0	45.0	44.4	42.2
Maximum *v/c*	0.26	0.43	0.62	0.82	1.00
Maximum flow rate (pc/h/ln)	490	810	1170	1550	1900

Note: Density is the primary determinant of LOS. Maximum flow rate values are rounded to the nearest 5 passenger cars.

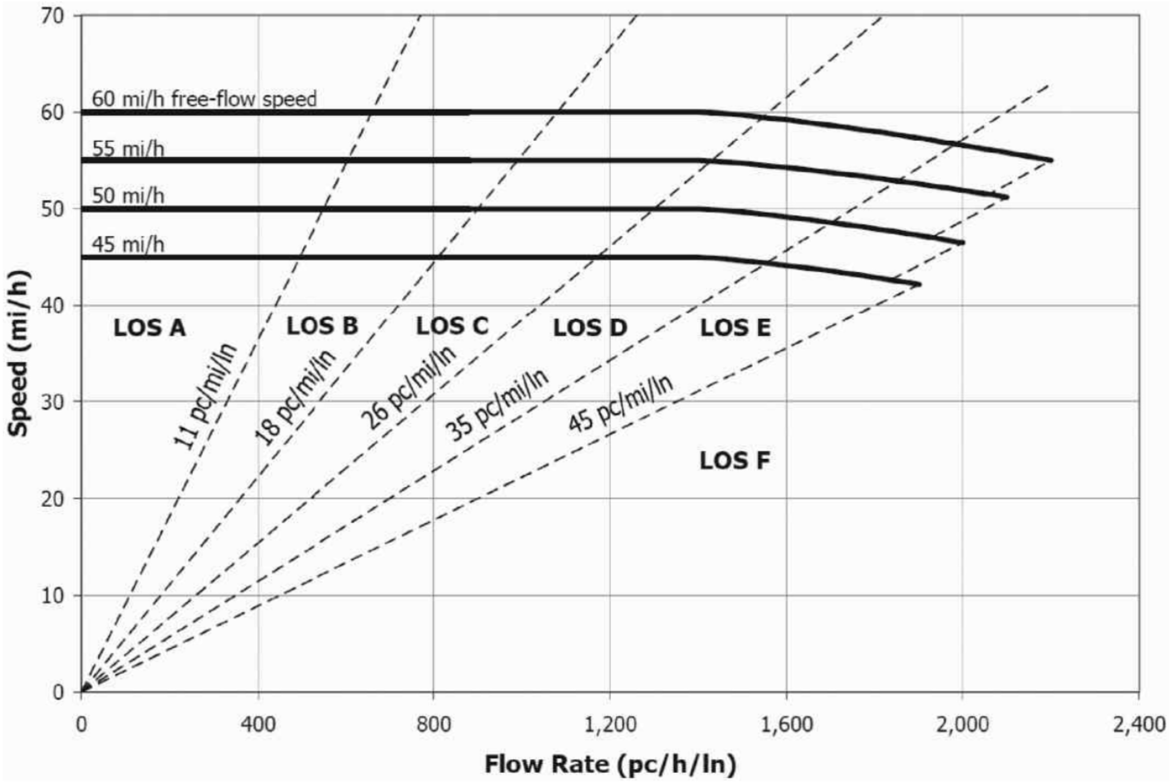


Figure 6.4 Multilane highway speed-flow curves and level-of-service criteria. (U.S. Customary)
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FREE-FLOW SPEED

- FFS for multilane highways is the mean speed of passenger cars operating in flow rates up to 1400 passenger cars per hour per lane (pc/h/ln). If FFS is to be estimated rather than measured, the following equation can be used, which takes into account the roadway characteristics of lane width, lateral clearance, presence (or lack) of a median, and access frequency
- The main difference is highway FFS includes an adjustment for median type. The presence of a physical barrier or wide separation between opposing flows (such as a TWLTL) will lead to higher free- flow speeds than if there is no separation or physical barrier between opposing flows.
- For multilane highways, research has found that free-flow speeds, under base conditions, are about 7 mi/h higher than the speed limit for 40- and 45-mi/h posted-speed-limit roadways, and about 5 mi/h higher for 50-mi/h and higher posted-speed-limit roadways.

Lane Width Adjustment

- The same lane width adjustment factor values are used for multilane highways

Lane width (ft)	Reduction in free-flow speed, f_{LW} (mi/h)
12	0.0
11	1.9
10	6.6

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

FFS = estimated free-flow speed in mi/h

BFFS = estimated free-flow speed in mi/h, for base conditions

f_{LW} = adjustment for lane width in mi/h

f_{LC} = adjustment for lateral clearance in mi/h

f_M = adjustment for median type in mi/h, and fA

f_A= adjustment for the number of access points along the roadway in mi/h.

FREE-FLOW SPEED

Lateral Clearance Adjustment

- The adjustment factor for potentially restrictive lateral clearances (f_{LC}) is determined first by computing the total lateral clearance
- For undivided highways, there is no adjustment for left-side lateral clearance because this is already taken into account in the f_M term (thus LC_L = 6 ft)
- If an individual lateral clearance (either left or right side) exceeds 6 ft, 6 ft is used
- Highways with TWLTLs are considered to have LC_L equal to 6 ft.

Total lateral clearance* (ft)	Reduction in free-flow speed (mi/h)	
	Four-lane highways	Six-lane highways
12	0.0	0.0
10	0.4	0.4
8	0.9	0.9
6	1.3	1.3
4	1.8	1.7
2	3.6	2.8
0	5.4	3.9

$$TLC = LC_R + LC_L$$

TLC = total lateral clearance in ft,

LC_R = lateral clearance on the right side of the travel lanes to obstructions (retaining walls, utility poles, signs, trees, etc.), and

LC_L = lateral clearance on the left side of the travel lanes to obstructions.

FREE-FLOW SPEED

Median Adjustment

- Values for the adjustment factor for median type, f_M, are provided in Table 6.12. This table shows that undivided highways have a free-flow speed that is 1.6 mi/h lower than divided highways (which include those with two-way left-turn lanes).

Median type	Reduction in free-flow speed (mi/h)
Undivided highways	1.6
Divided highways (including TWLTLs)	0.0

Access Frequency Adjustment

- The number of access points per mile, f_A.
- Access points are defined to include intersections and driveways (on the right side of the highway in the direction being considered) that significantly influence traffic flow, and thus do not generally include driveways to individual residences or service driveways at commercial sites. Adjustment values for access point frequency are provided in Table 6.13.

Access points/ mile	Reduction in free-flow speed (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

FREE-FLOW SPEED

Analysis Flow Rate

- The analysis flow rate for multilane highways is determined in the same manner as for freeways
- There is one minor difference for multilane highways—the guidelines for an extended segment analysis. An extended segment (general terrain type) analysis can be used for multilane highway segments if grades of 3% or less do not extend for more than 1 mi or any grades greater than 3% do not extend for more than 0.5 mi.

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

Calculate Density and Determine LOS

- The procedure for calculating density and determining LOS for multilane highways is essentially the same as for freeways (see Section 6.4.5).
- Equation 6.6 is applied to arrive at a density. However, slightly different speed-flow curves and level-of-service criteria are used for multilane highways.

EXAMPLE6.3

A four-lane undivided highway (two lanes in each direction) has 11-ft lanes, with 4-ft shoulders on the right side. There are seven access points per mile, and the posted speed limit is 50 mi/h. **What is the estimated free-flow speed?**

- **Determine the flow rate**

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

$BFFS$ = 55 mi/h (assume FFS = posted speed + 5 mi/h),

f_{LW} = 1.9 mi/h (Table 6.3),

f_{LC} = 0.4 mi/h (Table 6.11, with TLC = 4 + 6 = 10 from Eq. 6.8, with LCL = 6 ft because the highway is undivided),

f_M = 1.6 mi/h (Table 6.12), and

f_A = 1.75 mi/h (Table 6.13, by interpolation).

$$FFS = 55 - 1.9 - 0.4 - 1.6 - 1.75 = \underline{\underline{49.35 \text{ mi/h}}}$$

which means that the more restrictive roadway characteristics relative to the base conditions result in a reduction in free-flow speed of **5.65 mi/h.** Note that for further analysis, this FFS value should be rounded to **50 mi/h.**

EXAMPLE6.4

A six-lane divided highway (three lanes in each direction) is on rolling terrain with two access points per mile and has 10-ft lanes, with a 5-ft shoulder on the right side and a 3-ft shoulder on the left side. The peak-hour factor is 0.80, and the directional peak-hour volume is 3000 vehicles per hour. There are 6% large trucks, 2% buses, and 2% recreational vehicles. A significant percentage of non-familiar roadway users are in the traffic stream (the driver population adjustment factor is estimated as 0.95). No speed studies are available, but the posted speed limit is 55 mi/h. **Determine the level of service**

- **Determine the flow rate**

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

$$\begin{aligned}
BFFS &= 60 \text{ mi/h (assume FFS = posted speed + 5 mi/h)},\\
f_{LW} &= 6.6 \text{ mi/h (Table 6.3)},\\
f_{LC} &= 0.9 \text{ mi/h (Table 6.11, with TLC = 5 + 3 = 8 from Eq. 6.8)},\\
f_M &= 0.0 \text{ mi/h (Table 6.12), and}\\
f_A &= 0.5 \text{ mi/h (Table 6.13, by interpolation)}.
\end{aligned}$$

$$FFS = 60.0 - 6.6 - 0.9 - 0.0 - 0.5 = 52.0 \text{ mi/h}$$

- **Determine the free-flow speed**

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

$$\begin{aligned}
V &= 3000 \text{ veh/h (given)},\\
PHF &= 0.80 \text{ (given)},\\
N &= 3 \text{ (given)},\\
f_p &= 0.95 \text{ (given)},\\
E_T &= 2.5 \text{ (Table 6.5), and}\\
E_R &= 2.0 \text{ (Table 6.5)}.
\end{aligned}$$

$$f_{HV} = \frac{1}{1+0.08(2.5-1)+0.02(2-1)} = 0.877$$

EXAMPLE6.4

A six-lane divided highway (three lanes in each direction) is on rolling terrain with two access points per mile and has 10-ft lanes, with a 5-ft shoulder on the right side and a 3-ft shoulder on the left side. The peak-hour factor is 0.80, and the directional peak-hour volume is 3000 vehicles per hour. There are 6% large trucks, 2% buses, and 2% recreational vehicles. A significant percentage of non-familiar roadway users are in the traffic stream (the driver population adjustment factor is estimated as 0.95). No speed studies are available, but the posted speed limit is 55 mi/h. **Determine the level of service**

Determine the free-flow speed

$$v_p = \frac{3000}{0.8 \times 3 \times 0.877 \times 0.95} = 1500.3 \ \ \text{pc/h/ln}$$

Using Fig. 6.4, for FFS = 50 mi/h, note that the 1500.3-pc/h/ln flow rate intersects this curve in the LOS D density region. Therefore, this highway is operating at LOS D.

EXAMPLE6.5

A local manufacturer wishes to open a factory near the segment of highway described in Example 6.4. **How many large trucks can be added to the peak-hour directional volume before capacity is reached?** (Add only trucks and assume that the PHF remains constant.)

- **Determine the Max truck volume**

- Note that FFS will remain unchanged at 50 mi/h.
- Table 6.9 shows that capacity for FFS = 50 mi/h is 2000 pc/h/ln.
- The current number of large trucks and buses in the peak-hour traffic stream is 240 (0.08 × 3000) and the current number of recreational vehicles is 60 (0.02 × 3000).
- Let us denote the number of new trucks added as V_{nt}, so the combination of Eqs. 6.3 and 6.5 gives

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

$$\begin{aligned} v_p &= 2000 \text{ pc/h/ln}, \\ V &= 3000 \text{ veh/h (Example 6.4)}, \\ PHF &= 0.80 \text{ (Example 6.4)}, \\ N &= 3 \text{ (Example 6.4)}, \\ f_p &= 0.95 \text{ (Example 6.4)}, \\ E_T &= 2.5 \text{ (Example 6.4), and} \\ E_R &= 2.0 \text{ (Example 6.4).} \end{aligned}$$

$$v_p = \frac{V + V_{nt}}{(PHF)(N)\left[\dfrac{1}{1+\left(\dfrac{240+V_{nt}}{V+V_{nt}}\right)(E_T-1)+\left(\dfrac{60}{V+V_{nt}}\right)(E_R-1)}\right](f_p)}$$

EXAMPLE6.5

A local manufacturer wishes to open a factory near the segment of highway described in Example 6.4. **How many large trucks can be added to the peak-hour directional volume before capacity is reached?** (Add only trucks and assume that the PHF remains constant.)

- **Determine the Max truck volume**

- Note that FFS will remain unchanged at 50 mi/h.
- Table 6.9 shows that capacity for FFS = 50 mi/h is 2000 pc/h/ln.
- The current number of large trucks and buses in the peak-hour traffic stream is 240 (0.08 × 3000) and the current number of recreational vehicles is 60 (0.02 × 3000).
- Let us denote the number of new trucks added as V_{nt}, so the combination of Eqs. 6.3 and 6.5 gives

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

$$\begin{aligned} v_p &= 2000 \text{ pc/h/ln}, \\ V &= 3000 \text{ veh/h (Example 6.4)}, \\ PHF &= 0.80 \text{ (Example 6.4)}, \\ N &= 3 \text{ (Example 6.4)}, \\ f_p &= 0.95 \text{ (Example 6.4)}, \\ E_T &= 2.5 \text{ (Example 6.4), and} \\ E_R &= 2.0 \text{ (Example 6.4).} \end{aligned}$$

$$v_p = \frac{V + V_{nt}}{(PHF)(N)\left[\dfrac{1}{1+\left(\dfrac{240+V_{nt}}{V+V_{nt}}\right)(E_T-1)+\left(\dfrac{60}{V+V_{nt}}\right)(E_R-1)}\right](f_p)}$$

EXAMPLE6.5

A local manufacturer wishes to open a factory near the segment of highway described in Example 6.4. **How many large trucks can be added to the peak-hour directional volume before capacity is reached?** (Add only trucks and assume that the PHF remains constant.)

- **Determine the Max truck volume**

$$2000 = \frac{3000 + V_{nt}}{(0.80)(3)\left[\dfrac{1}{1 + \left(\dfrac{240 + V_{nt}}{3000 + V_{nt}}\right)(2.5 - 1) + \left(\dfrac{60}{3000 + V_{nt}}\right)(2 - 1)}\right](0.95)}$$

V_{nt} = 456 truck/h/ln , which is the number of trucks that can be added to the peak-hour volume before capacity is reached.

EXAMPLE 6.8

A **freeway** is to be designed as a **passenger-car–only** facility for an **AADT of 35,000** vehicles per day. It is estimated that the freeway will have a free-flow speed of **70 mi/h**. The design will be for **commuters**, and the peak-hour factor is estimated to be **0.85 with 65%** of the peak-hour traffic traveling in the peak direction. Assuming that Fig. 6.8 applies, <u>determine the number of lanes required to provide at least LOS C using the highest annual hourly volume and the 30th highest annual hourly volume.</u>

<u>Using the highest annual hourly volume</u>

$$\text{DDHV} = K_1 \times D \times \text{AADT}$$
$$= 0.148 \times 0.65 \times 35{,}000 = 3367 \text{ veh/h}$$

$$v_p = \frac{3367}{0.85 \times 2 \times 1.0 \times 1.0} = 1980.6 \text{ pc/h/ln}$$

$$v_p = \frac{3367}{0.85 \times 3 \times 1.0 \times 1.0} = 1320.4 \text{ pc/h/ln}$$

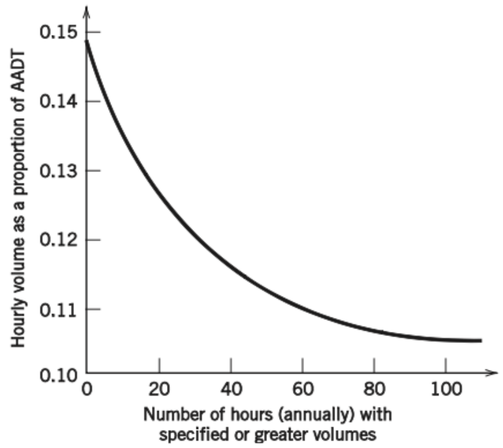
a six-lane freeway is necessary to provide LOS C.

<u>Using the 30th highest annual hourly volume</u>

$$\text{DDHV} = K \times D \times \text{AADT}$$
$$= 0.12 \times 0.65 \times 35{,}000 = 2730 \text{ veh/h}$$

$$v_p = \frac{2730}{0.85 \times 2 \times 1.0 \times 1.0} = 1605.9 \text{ pc/h/ln}$$

a four-lane freeway (two lanes each direction) is adequate for this design traffic flow rate.



	$FFS = 70$ mi/h				
Maximum density (pc/mi/ln)	11	18	26	35	45
Average speed (mi/h)	70.0	70.0	66.7	60.3	53.3
Maximum v/c	0.32	0.52	0.72	0.88	1.00
Maximum flow rate (pc/h/ln)	770	1260	1735	2110	2400