Capacity and Level-of-Service Analysis

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Introduction

- The underlying objective is to quantify a roadway's performance with regard to specified traffic volumes.
- The comparative performance of various roadway segments is important because it can be used as a basis to allocate limited roadway construction and improvement funds.
- The purpose of this lecture is to apply the elements of uninterrupted traffic flow theory to the practical field analysis of traffic flow and capacity.
- The main challenge of such a process is to adapt the theoretical formulations to the wide range of conditions that occur in the field.
- For example, q_{cap} is defined as the highest traffic flow rate that the roadway is capable of supporting.
  - It can be shown that the capacity of a roadway segment is a function of factors such as roadway type (freeway, multilane highway, or two-lane highway), free-flow speed, number of lanes, and widths of lanes and shoulders.
  - The method of capacity determination clearly must account for a wide variety of physical and operational roadway characteristics.

Introduction

- Also, recall that we previously defined traffic flow on the basis of units of vehicles per hour.
- Two practical issues arise :
  1. In many cases vehicular traffic consists of a variety of vehicle types with substantially different performance characteristics.
     - These performance differentials may be magnified by changing roadway geometrics (upgrades or downgrades), which have a differential effect on the acceleration and deceleration capabilities of the various types of vehicles.
     - Therefore, traffic must be defined not only in terms of veh per unit time but also in terms of vehicle composition
  2. The temporal distribution of traffic.
     - The analysis of roadway traffic usually focuses on the most critical condition, which is the most congested hour within a 24-hour daily period
     - Even within this most congested peak hour, traffic flow is likely to be nonuniform. It is therefore necessary to arrive at some method of defining and measuring the nonuniformity of flow within the peak hour.

Our objective 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.

Level-of-Service Concept

- The Highway Capacity Manual (HCM) is produced by the Transportation Research Board [2010]
- It is a synthesis of the state of the art in methodologies for quantifying traffic operational performance and capacity utilization (congestion level) for a variety of transportation facilities.
- One of the main concepts defined in the HCM is the concept of level of service (LOS).
- It represents a qualitative ranking of the traffic operational conditions experienced by users of a facility under specified roadway, traffic, and traffic control conditions.
- Current practice designates six levels of service ranging from A to F, with level of service A representing the best operating conditions and level of service F the worst.
- Motorists tend to evaluate their received quality of service in terms of factors such as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.
- It is important to select a measure that encompasses some or all of these factors.
- The performance measure that is selected for level-of-service (LOS) analysis for a particular transportation facility is referred to as the service measure.

Level-of-Service Concept

Level of service A

- Represents free-flow conditions.
- Individual users are virtually unaffected by the presence of others in the traffic stream.
- Freedom to select speeds and to maneuver within the traffic stream is extremely high.
- The general level of comfort and convenience provided to drivers is excellent.

LOS A

Level-of-Service Concept

Level of service B

- LOS B also allows speeds at or near free-flow speeds, but the presence of other users in the traffic stream begins to be noticeable.
- Freedom to select speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream relative to LOS A.

LOS B

Level-of-Service Concept

Level of service C

- LOS C has speeds at or near free-flow speeds, but the freedom to maneuver is noticeably restricted
- Lane changes require careful attention on the part of drivers.
- The general level of comfort and convenience declines significantly at this level.
- Disruptions in the traffic stream, such as an incident, can result in significant queue formation and vehicular delay.
- In contrast, the effects of incidents at LOS A or LOS B are minimal, with only minor delay in the immediate vicinity of the event.

LOS C

Level-of-Service Concept

Level of service D

- LOS D represents the conditions where speeds begin to decline slightly with increasing flow.
- The freedom to maneuver becomes more restricted, and drivers experience reductions in physical and psychological comfort.
- Incidents can generate lengthy queues because the higher density associated with this LOS provides little space to absorb disruptions in the traffic flow.

LOS D

Level-of-Service Concept

Level of service E

- LOS E represents operating conditions at or near the roadway's capacity.
- Even minor disruptions to the traffic stream, such as vehicles entering from a ramp or vehicles changing lanes, can cause delays as other vehicles give way to allow such maneuvers.
- In general, maneuverability is extremely limited, and drivers experience considerable physical and psychological discomfort.
- In roadway design, the possibility of degradation of level of service to LOS E should be avoided, although this is not always possible due to financial and environmental constraints.

LOS E

Level-of-Service Concept

Level of service F

- LOS F describes a breakdown in vehicular flow.
- Queues form quickly behind points in the roadway where the arrival flow rate temporarily exceeds the departure rate.
- Such points occur at incidents and on- and off-ramps, where incoming traffic results in capacity being exceeded.
- Vehicles typically operate at low speeds under these conditions and are often required to come to a complete stop, usually in a cyclic fashion.
- The cyclic formation and dissipation of queues is a key characterization of LOS F.

LOS F

Level-of-Service Determination

- There are several steps in a basic level-of-service determination for an uninterrupted flow facility.
- This section describes the general details of each step.
- Facility-specific details of these steps are described in the sections that follow.

Level-of-Service Determination

Base Conditions and Capacity

- The determination of a roadway's level of service begins with the specification of base roadway conditions.
- The effects of vehicle performance and roadway design characteristics on traffic flow are measured quantitatively, relative to the base traffic and roadway design conditions.
- For uninterrupted-flow roadways:
  - Relating to roadway conditions
    - Lane widths, lateral clearances, access frequency, and terrain
  - Traffic stream conditions
    - Heavy vehicles and driver population characteristics.
- Base conditions are defined as those conditions that represent unrestrictive geometric and traffic conditions.
- The capacity of a particular roadway segment will be greatest when all roadway and traffic conditions meet or exceed their base values.

Level-of-Service Determination

Base Conditions and Capacity

- Empirical studies have identified the values of these base conditions for which the capacity of a roadway segment is maximized.
- Values in excess of the base conditions will not increase the capacity of the roadway, but values more restrictive than the base conditions will result in a lower capacity.
  - For example, studies have identified a base lane width of 12 ft. That is, lane widths in excess of 12 ft will not result in increased capacity; however, lane widths less than 12 ft will result in a reduction in capacity.
- Capacity values for base conditions have been determined for all uninterrupted-flow facility types from field studies.
- It should be noted that for purposes of level-of-service analysis, capacity is defined not as the absolute maximum flow rate ever observed for a particular facility type, but rather as the maximum flow rate that can be reasonably expected on a recurring basis

Level-of-Service Determination

Free-Flow Speed

- Free-flow speed (FFS) is the speed of traffic as the traffic density approaches zero.
- In practice, FFS is governed by roadway design characteristics (horizontal and vertical curves, lane and shoulder widths, and median design), the frequency of access points, the complexity of the driving environment (possible distractions from roadway signs and the like), and posted speed limits.
- The free-flow speed must be determined given the characteristics of the roadway segment.
- FFS is the mean speed of traffic as measured when flow rates are low to moderate
- Ideally, FFS should be measured directly in the field at the site of interest.
- However, if this is not possible or feasible, an alternative method can be employed to arrive at an estimate of FFS under the prevailing conditions.
- This method makes adjustments to a base FFS (BFFS) depending on the physical characteristics of the roadway segment, such as lane width, shoulder width, and access frequency.
- This method has the same basic structure for the various roadway types, but contains adjustment factors and values appropriate for each roadway type.

Level-of-Service Determination

Analysis Flow Rate

- One of the fundamental inputs to a traffic analysis is the actual traffic volume on the roadway, in vehicles per hour, which is given the symbol V.
- Generally, the highest volume in a 24-hour period (the peak-hour volume) is used for V in traffic analysis computations.
- However, this hourly volume needs to be adjusted to reflect the temporal variation of traffic demand within the analysis hour, the impacts due to heavy vehicles, and, in the case of freeway and multilane roadways, the characteristics of the driving population.
- To account for these effects, the hourly volume is divided by adjustment factors to obtain an equivalent flow rate in terms of passenger cars per hour (pc/h).
- Additionally, the flow rate is expressed on a per-lane basis $(pc/h/\mathrm{ln})$ by dividing by the number of lanes in the analysis segment.

Level-of-Service Determination

Service Measure(s) and Determining LOS

- Once the previous steps have been completed, all that remains is to calculate the value of the service measure and then determine the LOS from the service measure value.
- For freeways and multilane highways, this is a relatively straightforward task.
- However, for two-lane highways, there are actually two service measures, and the calculation of these and the subsequent LOS determination are more involved.

Basic Freeway Segments

- A basic freeway segment is defined as a section of a divided roadway having two or more lanes in each direction, full access control, and traffic that is unaffected by merging or diverging movements near ramps.
- It is important to note that capacity analysis for divided roadways focuses on the traffic flow in one direction only.
- This is reasonable because the objective is to measure the highest level of congestion.
- Due to directional imbalance of traffic flows — for example, morning rush hours having higher volumes going toward the central city and evening rush hours having higher volumes going away from the central city — consideration of traffic volumes in both directions is likely to seriously understate the true level of traffic congestion.

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.

Table 1: Level-of-service criteria

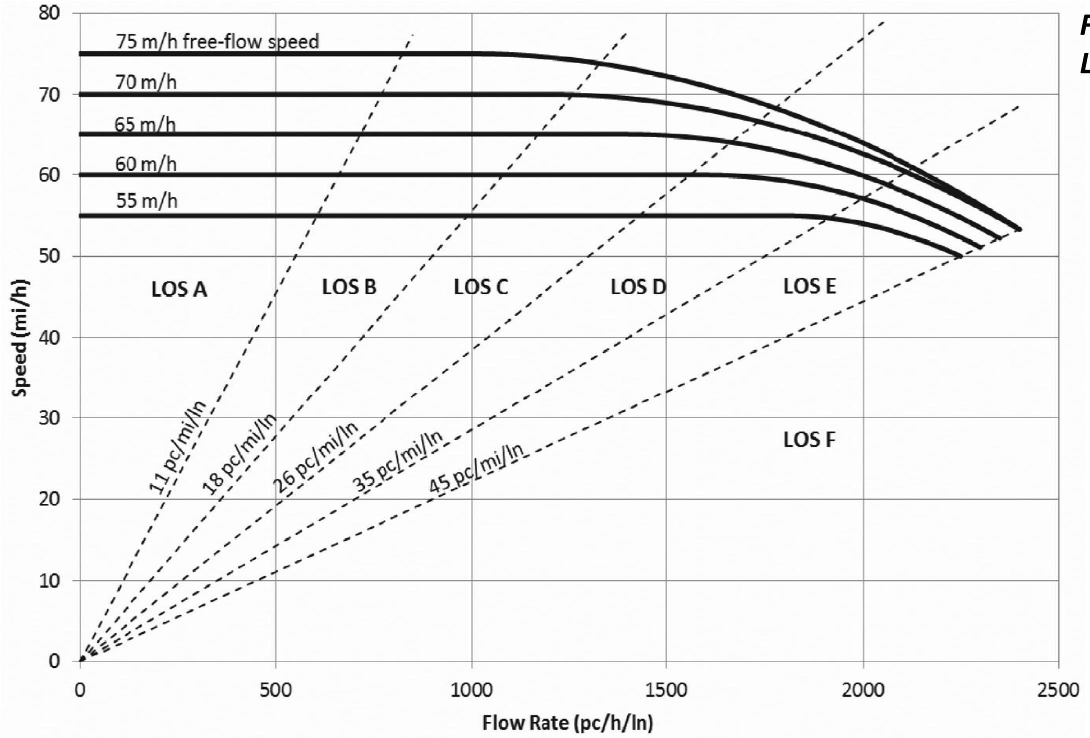


Fig 1: A graphical representation Level-of-service criteria

- The maximum service flow rate is the maximum flow rate, under base conditions, that can be sustained for a given level of service.
- This value is related to speed and density.
- This speed-flow-density relationship is central to the analysis of basic freeway segments, as will be outlined in the remainder of this section.

Basic Freeway Segments

Base Conditions and Capacity

- The base conditions for a basic freeway segment are defined as
  - 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
- These conditions represent a high operating level, with a FFS of 70 mi/h or higher.
- The capacity, c, for basic freeway segments, in passenger cars per hour per lane (pc/h/ln), is given in Table in front.
- Note that (In the previous Table), the upper boundary of LOS E corresponds to the value of capacity and a v/c of 1.0. Other values of v/c for a specific level of service are obtained by simply dividing the maximum flow rate for that level of service by capacity (the maximum flow rate at LOS E).

Table 2: capacity of basic freeway segments

Free-flow speed (mi/h)	Capacity (pc/h/ln)
75	2400
70	2400
65	2350
60	2300
55	2250

Basic Freeway Segments

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) and therefore provides a good measure of the relative mobility of individual vehicles in the traffic stream.
- Une faible densité de trafic donne aux véhicules individuels la possibilité de changer de voie et de vitesse avec une relative facilité, tandis qu'une densité élevée rend très difficile pour les véhicules individuels de manœuvrer dans le flux de trafic.
- Ainsi, la densité du trafic est le principal déterminant du niveau de service des autoroutes.
- La densité est calculée comme le débit divisé par la vitesse.
- Les sections suivantes décrivent comment arriver aux valeurs de débit et de vitesse pour les conditions de chaussée et de circulation données.
- Une fois que les valeurs de débit et de vitesse ont été déterminées en fonction des conditions données, une densité peut être calculée puis référencée dans le tableau 1 ou la figure 1 pour trouver le niveau de service pour du segment étudié.

$$q = uk$$

q = flow in veh/h,

u = speed in mi/h, and

k = density in veh/mi.

Segments d'autoroute de base

Determine 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.

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

FFS = estimated free-flow speed in mi/h,
f_{LW} = adjustment for lane width in mi/h,
f_{LC} = adjustment for lateral clearance in mi/h,
TRD = adjustment for total ramp density in mi/h.

- The constant value of 75.4 is considered to be the base free-flow speed (BFFS) and applies to freeways in urban and rural areas.
- The HCM recommends that the calculated free-flow speed be rounded to the nearest 5 mi/h.

Basic Freeway Segments

<u>Determine Free-Flow Speed</u>

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.
- Such an adjustment is needed because narrow lanes cause traffic to slow as a result of reduced psychological comfort and limits on driver maneuvering and accident avoidance options.

Determine Free-Flow Speed
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.
Such an adjustment is needed because narrow lanes cause traffic to slow as a result of reduced psychological comfort and limits on driver maneuvering and accident avoidance options.

Table 3: Adjustment for Lane Width

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

FFS = estimated free-flow speed in mi/h,
f_{LW} = adjustment for lane width in mi/h,
f_{LC} = adjustment for lateral clearance in mi/h,
TRD = adjustment for total ramp density in mi/h.

Basic Freeway Segments

Determine 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.
- Again, these conditions lead to reduced psychological comfort for the driver and consequently reduced speeds.
- An obstruction is a right-side object that can either be continuous (such as a retaining wall or barrier) or periodic (such as light posts or utility poles).
- Table 4 provides corrections for obstructions on the right side of the roadway.

Table 4: Adjustment for Right-Shoulder Lateral Clearance

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

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

FFS = estimated free-flow speed in mi/h,
f_{LW} = adjustment for lane width in mi/h,
f_{LC} = adjustment for lateral clearance in mi/h,
TRD = adjustment for total ramp density in mi/h.

Basic Freeway Segments

<u>Determine Free-Flow Speed</u>

Total Ramp Density Adjustment

- Ramp density provides a measure of the impact of merging and diverging traffic on free-flow speed.
- Total ramp density is the number of on- and off-ramps (in one direction) within a distance of three miles upstream and three miles downstream of the midpoint of the analysis segment, divided by six miles.

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22 TRD^{0.84}$$

FFS = estimated free-flow speed in mi/h,
f_{LW} = adjustment for lane width in mi/h,
f_{LC} = adjustment for lateral clearance in mi/h,
TRD = adjustment for total ramp density in mi/h.

Basic Freeway Segments

Determine Analysis Flow Rate

- The analysis flow rate is calculated using the following equation

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

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

- The adjustment factors PHF, f_{HV}, and f_p are described next

Basic Freeway Segments

Determine Analysis Flow Rate

Peak-Hour Factor

- Vehicle arrivals during the period of analysis (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 peak-hour factor has been developed for this purpose, and is defined as the ratio of the hourly volume to the maximum 15-min flow rate expanded to an hourly volume, as follows:

$$PHF = \frac{V}{V_{15} \times 4}$$

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.

- The further the PHF is from unity, the more peaked or nonuniform the traffic flow is during the hour.

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

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

Basic Freeway Segments

Determine Analysis Flow Rate

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.
- In the presence of heavy vehicles the adjustment factor f_{HV} is used to translate the traffic stream from base to prevailing conditions.
- Determine the passenger car equivalent (PCE) for each large truck, bus, and recreational vehicle in the traffic stream.
    - These values represent the number of passenger cars that would consume the same amount of roadway capacity as a single large truck, bus, or recreational vehicle.
    - These are denoted E_T for large trucks and buses and E_R for recreational vehicles, and are a function of roadway grades because steep grades will tend to magnify the poor performance of heavy vehicles as well as the sight distance problems caused by their larger dimensions

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

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

Basic Freeway Segments

Determine Analysis Flow Rate

Heavy-Vehicle Adjustment

- For segments of freeway that contain a mix of grades, an extended segment analysis can be used as long as no single grade is steep enough or long enough to significantly impact the overall operations of the segment.
- As a guideline, an extended segment analysis can be used for freeway segments where
  - No single grade that is less than 3% is more than 0.5 mi long,
  - Or no single grade that is 3% or greater is longer than 0.25 mi.
- If an extended segment analysis is used, the terrain must be generally classified according to the following definitions

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

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

Basic Freeway Segments

Determine Analysis Flow Rate

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

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

Heavy-Vehicle Adjustment

- Level terrain
  - Any combination of horizontal and vertical alignment permitting heavy vehicles to maintain approximately the same speed as passenger cars. This generally includes short grades of no more than 2%.
- Rolling terrain
  - Any combination of horizontal and vertical alignment that causes heavy vehicles to reduce their speed substantially below those of passenger cars but does not cause heavy vehicles to operate at their limiting speed for the given terrain for any significant length of time or at frequent intervals due to high grade resistance.
- Mountainous terrain
  - Any combination of horizontal and vertical alignment that causes heavy vehicles to operate at their limiting speed for significant distances or at frequent intervals.

Table 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

Basic Freeway Segments

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

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

Determine Analysis Flow Rate

Heavy-Vehicle Adjustment

- Any grade that does not meet the conditions for an extended segment analysis must be analyzed as a separate segment because of its significant impact on traffic operations.
- Tables 6 and 7 provide these values for positive grades
- Note that the equivalency factors presented in these tables increase with increasing grade and length of grade, but decrease with increasing heavy vehicle percentage.
- This decrease with increasing percentage is due to the fact that heavy vehicles tend to group together as their percentages increase on steep, extended grades, thus decreasing their adverse impact on the traffic stream.
- Sometimes it is necessary to determine the cumulative effect on traffic operations of several significant grades in succession.
- For this situation, a distance-weighted average may be used if all grades are less than 4% or the total combined length of the grades is less than 4000 ft.
- For example, a 2% upgrade for 1000 ft followed immediately by a 3% upgrade for 2000 ft would use the equivalency factor for a 2.67% upgrade [(2 × 1000 + 3 × 2000)/3000] for 3000 ft or 0.568 mi.
- For information on additional analysis situations involving composite grades, refer to the Highway Capacity Manual [Transportation Research Board 2010].

Basic Freeway Segments

Upgrade (%)	Length (mi)	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	0.0–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50–0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75–1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.00–1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3–4	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50–0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 0.75–1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.00–1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4–5	0.0–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.50–0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.75–1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5–6	0.00–0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.35–0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.30–0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.50–0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 0.75–1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.25–0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.30–0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.50–0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 0.75–1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Table 6: Passenger Car Equivalents (E_T) for Trucks and Buses on Specific Upgrades

Upgrade (%)	Length (mi)	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	0.00–0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3–4	0.00–0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.25–0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
> 4–5	0.00–0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
> 5	0.00–0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	> 0.25–0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.50	6.0	4.5	4.0	4.5	3.5	3.0	3.0	2.5	2.0

Table 7: Passenger Car Equivalents (E_R) for RVs on Specific Upgrades

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

Table 8: Passenger Car Equivalents (E_T) for Trucks and Buses on Specific Downgrades

- It is assumed that recreational vehicles are not significantly impacted by downgrades, and therefore downgrade values for ER are drawn from the level-terrain column in Table 6.5.

Basic Freeway Segments

Heavy-Vehicle Adjustment (continued)

- Once the appropriate equivalency factors have been obtained, the following equation is applied to arrive at the heavy-vehicle adjustment factor f_{HV}:

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

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

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

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, 6.6, or 6.8, and
E_R = passenger car equivalent for recreational vehicles, from Table 6.5 or 6.7.

Basic Freeway Segments

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

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

Determine Analysis Flow Rate

Driver Population Adjustment

- Under base conditions, the traffic stream is assumed to consist of regular weekday drivers and commuters.
- Such drivers have a high familiarity with the roadway and generally maneuver and respond to the maneuvers of other drivers in a safe and predictable fashion.
- There are times, however, 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.
- 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%.
- The exact value of the driver population adjustment factor is dependent on local conditions such as roadway characteristics and the surrounding environment (possible driver distractions such as scenic views and the like).
- When the driver population consists of a significant percentage of unfamiliar users, judgment is necessary to determine the exact value of this factor. This usually involves collection of data on local conditions

Basic Freeway Segments

Calculate Density and Determine LOS

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

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

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

- The average passenger car speed is found by reading it from the y-axis of Fig. 1 for the corresponding flow rate (v_p) and free-flow speed.
- Once the density value is calculated, the level of service can be read from Table 1 or Fig. 1.

Basic Freeway Segments - Example

Problem

- 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.

Basic Freeway Segments - Example

Solution

Determine the free-flow speed

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

$\rightarrow$

$f_{LW} = 1.9$ mi/h *Table 3*

$f_{LC} = 1.6$ mi/h *Table 4*

$$TRD = \frac{9}{6} = 1.5 \text{ ramps/mi}$$

$\rightarrow$

$$FFS = 75.4 - 1.9 - 1.6 - 3.22(1.5)^{0.84} = 67.4 \text{ mi/h}$$

Rounding this FFS value to the nearest 5 mi/h gives a FFS of 65 mi/h

Determine the flow rate

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

$\rightarrow$

$$PHF = \frac{2300}{700 \times 4} = 0.821$$

$N = 3$

$f_p = 1.0$ *Commuters*

$E_T = 2.5$ *Rolling terrain*

$$f_{HV} = \frac{1}{1 + 0.15(2.5 - 1)} = 0.816$$

$\rightarrow$

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

Obtaining average passenger car speed from Fig. 1 for a flow rate of 1145 and a FFS of 65 mi/h yields an S of 65 mi/h.

$\rightarrow$

In this case, the average speed is still the same as the FFS because the flow rate is low enough such that it is still on the flat part of the speed-flow curve.

Density

$$D = \frac{1145}{65} = 17.6 \text{ pc/mi/ln}$$

From Table 1 or Fig 1, it can be seen that this corresponds to LOS B.

Basic Freeway Segments - Example

Problem

- Consider the freeway and traffic conditions in the previous example. 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 the previous example.

  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)?

Basic Freeway Segments - Example

Solution

All adjustment factors remain the same except f_{HV} → *From Table 6, $E_T = 3.5$* → $f_{HV} = \frac{1}{1+0.15(3.5-1)} = 0.727$ → $v_p = \frac{2300}{0.821 \times 3 \times 0.727 \times 1.0} = 1284.5 \rightarrow 1285 \text{ pc/h/ln}$

From Fig. 6.2, the average passenger car speed (S) is still 65 mi/h → $D = \frac{1285}{65} = 19.8 \text{ pc/mi/ln}$ *LOS C from Table 1 or Fig 1*

To determine how many vehicles can be added before capacity is reached, the hourly volume at capacity must be computed. → *For a free-flow speed of 65 mi/h, the capacity is 2350 pc/h/ln (Table 1)*

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \Rightarrow 2350 = \frac{V}{0.821 \times 3 \times 0.727 \times 1.0}$$

→ $V = 4208 \text{ veh/h}$

↓

About 1908 vehicles can be added during the peak hour before capacity is reached.

Multilane Highways

- Multilane highways are similar to freeways in most respects, except for a few key differences:
  - Vehicles may enter or leave the roadway at at-grade intersections and driveways (do not have full access control).
  - Multilane highways may or may not be divided (by a barrier or median), whereas freeways are always divided.
  - Traffic signals may be present.
  - Design standards (ex. speed) are sometimes lower than those for freeways.
  - The visual setting and development are usually more distracting to drivers.
- Multilane highways usually have four or six lanes (both directions),
- They have posted speed limits between 40 and 60 mi/h,
- Can have medians that are two-way left-turn lanes, or opposing directional volumes that may not be divided by a median at all.

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.
- The procedure presented is valid only for sections of highway that are not significantly influenced by large queue formations and dissipations resulting from traffic signals (spaced 2.0 mi apart or more), do not have significant on-street parking, do not have bus stops with high usage, and do not have significant pedestrian activity.
- The capacity, c, for multilane highway segments, in pc/h/ln, is given in Table 9.

Table 9: Relationship Between Free-Flow Speed and Capacity on Multilane Highway Segments

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

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

Table 10: Level-of-service criteria

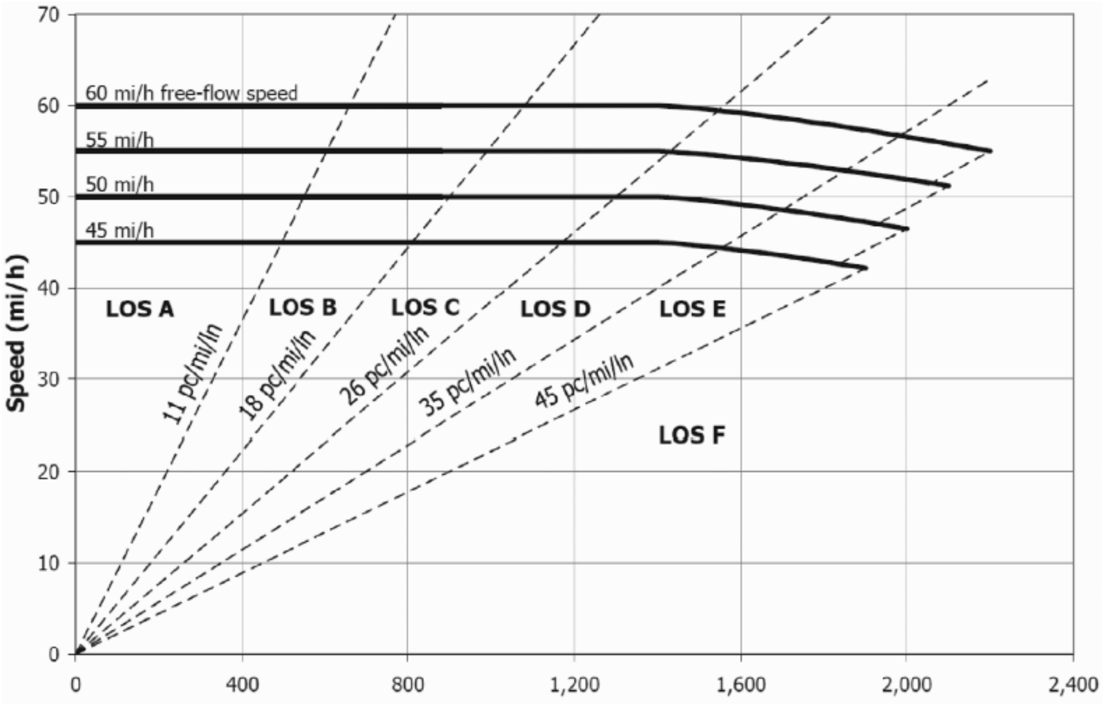


Fig 2: A graphical representation Level-of-service criteria

Multilane Highways

Base Conditions and Capacity

- The base conditions for multilane highways are defined as
  - 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 60 mi/h or more
- Adjustments will have to be made when non-base conditions are encountered.

Service Measure

- Density is the service measure for multilane highways.

Multilane Highways

Determine 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:

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

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

- The main difference with Freeways is that it also includes an adjustment for median type.
- The presence of a physical barrier or wide separation between opposing flows will lead to higher free-flow speeds.
- The HCM recommends that the calculated free-flow speed be rounded to the nearest 5 mi/h.

Multilane Highways

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

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

Determine Free-Flow Speed

Lane Width Adjustment

- The same lane width adjustment factor values are used for multilane highways as are used for freeways (Table 3)

Table 3: Adjustment for Lane Width

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

Multilane Highways

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

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

Determine Free-Flow Speed

Lateral Clearance Adjustment

- We should first compute the total lateral clearance, which is defined as :

$$TLC = LC_R + LC_L$$

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.

- 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 $LC_L = 6\ ft$ in Eq.).
- If an individual lateral clearance (either left or right side) exceeds 6 ft, 6 ft is used in Eq.
- Finally, highways with two-way left-turn lanes (TWLTLs) are considered to have LC_L equal to 6 ft.
- Once the TLC is calculated, the value for f_{LC} can be determined directly from this Table 6:

Table 11: Adjustment for Lateral

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

** Total lateral clearance is the sum of the lateral clearances of the median (if greater than 6 ft, use 6 ft) and shoulder (if greater than 6 ft, use 6 ft). Therefore, for purposes of analysis, total lateral clearance cannot exceed 12 ft.*

Multilane Highways

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

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

Determine Free-Flow Speed

Median Adjustment

- Undivided highways have a free-flow speed that is 1.6 mi/h lower than divided highways

Table 12: Adjustment for Median Type

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

Multilane Highways

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

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

Determine Free-Flow Speed

Access Frequency Adjustment

- 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.

Table 13: Adjustment for Access-Point Frequency

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

Multilane Highways

Determine 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 $0.5\ mi$.

Calculate Density and Determine LOS

- The procedure for calculating density and determining LOS for multilane highways is essentially the same as for freeways.
- A slightly different speed-flow curves and level-of-service criteria are used for multilane highways.
- Table 10 shows the LOS criteria for multilane highways, and Fig. 2 shows the corresponding speed-flow curves for multilane highways.
- The average passenger car speed is found by reading it from the y-axis of Fig. 2 for the corresponding analysis flow rate (vp) and free-flow speed.
- Once the density value is calculated, the level of service can be read from Table 10 or Fig. 2.

Multilane Highways - Example

Problem

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?

Multilane Highways - Example

Solution

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

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

$f_{LW} = 1.9$ mi/h

$f_{LC} = 0.4$ mi/h

TLC = 4 + 6 = 10 from Eq. 6.8, with LCL = 6 ft because the highway is undivided

$f_M = 1.6$ mi/h

$f_A = 1.75$ mi/h

By interpolation

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

➜

- *This 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.*

Multilane Highways - Example

Problem

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 nonfamiliar 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.

Multilane Highways - Example

Solution

We begin by determining FFS

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

$\rightarrow$

$BFFS = 60$ mi/h *(assume FFS = posted speed + 5 mi/h)*

$f_{LW} = 6.6$ mi/h

$f_{LC} = 0.9$ mi/h *TLC = 5 + 3 = 8*

$f_M = 0.0$ mi/h

$f_A = 0.5$ mi/h *By interpolation*

$\rightarrow$

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

Rounding this FFS value to the nearest 5 mi/h gives a FFS of 50 mi/h.

Determine the analysis flow rate

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

$\rightarrow$

$V = 3000$ veh/h

$PHF = 0.80$

$N = 3$

$f_p = 0.95$

$E_T = 2.5$

$E_R = 2.0$

$\rightarrow$

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

$\downarrow$

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

- *Using Fig. 2, 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*

Multilane Highways - Example

Problem

A local manufacturer wishes to open a factory near the segment of highway described in the previous Example. 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.)

We begin by determining FFS

Multilane Highways - Example

Solution

- FFS remains unchanged at 50 mi/h.
- Table 10 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 the two above equations gives:

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

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

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

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

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

$$\rightarrow \quad V_{nt} = 456$$

Two-lane Highways

- Roadways with one lane available in each direction
- A key distinction with the freeways and multilane highways is that traffic in both directions must now be considered
- This is because traffic in an opposing direction has a strong influence on level of service.
  - A high opposing traffic volume limits the opportunity to pass slow-moving vehicles and thus forces a lower traffic speed.
- The type of terrain plays a more critical role in level-of-service calculations because of the limited ability to pass slower-moving vehicles on grades in areas where passing is prohibited due to sight distance restrictions or where opposing traffic does not permit safe passing.

Two-lane Highways

Base Conditions and Capacity

- The base conditions for two-lane highways are defined as:
  - $12 - ft$ minimum lane widths
  - $6 - ft$ minimum shoulder widths
  - 0% no-passing zones on the highway segment
  - Only passenger cars in the traffic stream
  - No direct access points along the roadway
  - No impediments to through traffic due to traffic control or turning vehicles
  - Level terrain (no grades greater than 2%)
- The capacity of extended lengths of two-lane highway under base conditions is 1700 passenger cars per hour (pc/h) in one direction, or 3200 pc/h when both directions are considered.
- Because of interactions between the two directions of traffic flow, the maximum flow rate in the opposing direction is limited to 1500 pc/h when the other direction is at a flow rate of 1700 pc/h.

Two-lane Highways

Service Measures

- Three service measures have been identified for two-lane highways:
    1. Percent time spent following (PTSF)
        - The average percentage of travel time that vehicles must travel behind slower vehicles due to the lack of passing opportunities
        - PTSF is difficult to measure in the field
        - It is recommended that the percentage of vehicles traveling with headways less than 3 seconds at a representative location be used as a surrogate measure.
        - PTSF is generally representative of a driver's freedom to maneuver in the traffic stream.
    2. Average travel speed (ATS)
        - The length of the analysis segment divided by the average travel time of all vehicles traversing the segment during the analysis period.
        - ATS is an indicator of the mobility on a two-lane highway.
    3. Percent of free-flow speed (PFFS)
        1. Average travel speed of the analysis segment divided by the free-flow speed of the analysis segment.
        2. PFFS is an indicator of how closely vehicles are able to travel to their desired speed.

Two-lane Highways

Service Measures

- The service measure, and corresponding thresholds, that govern the determination of level of service depends on the functional classification of the two-lane highway.

  1. Class I
     - Motorists expect to travel at high speeds, as well as avoid extended following of other vehicles.
     - They include intercity routes, primary arterials connecting major traffic generators, daily commuter routes, and primary links in state or national highway networks.
  2. Class II
     - Motorists do not necessarily expect to travel at high speeds.
     - Include shorter routes and routes that pass through rugged terrain, for which travel speeds will generally be lower than for Class I highways.
     - In these situations, motorists primarily want to avoid extended following of other vehicles.
  3. Class III
     - Motorists do not expect frequent passing opportunities, or to travel at high speeds.
     - Scenic routes, recreational routes, or routes that pass through moderately developed areas (small towns).
     - They generally have lower posted speed limits, and motorists usually do not mind following other vehicles or traveling at slower speeds, as long as they are able to travel at a speed close to the posted speed limit.

Two-lane Highways

Determine Free-Flow Speed

- FFS for two-lane highways is the mean speed of all vehicles operating in flow rates up to 200 pc/h total for both directions.
- Free-flow speeds on two-lane highways typically range from 45 to 65 mi/h.
- If field measurement of FFS cannot be made under conditions with a flow rate of 200 pc/h or less, an adjustment can be made with the following equation:

$$FFS = S_{FM} + 0.00776\left(V_f / f_{HV}\right)$$

FFS = estimated free-flow speed in mi/h,
S_{FM} = mean speed of traffic measured in the field in mi/h,
V_f = observed flow rate, in veh/h, for the period when field data were obtained, and
f_{HV} = heavy-vehicle adjustment factor

- If FFS is to be estimated rather than measured in the field, the following equation can be used :

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

FFS = estimated free-flow speed in mi/h,
$BFFS$ = estimated free-flow speed, in mi/h, for base conditions,
f_{LS} = adjustment for lane width and shoulder width in mi/h, and
f_A = adjustment for the number of access points along the roadway in mi/h.

- Speed data and local knowledge of operating conditions on similar facilities can be used in developing an estimate of BFFS.

Two-lane Highways

Determine Free-Flow Speed

Lane Width and Shoulder Width Adjustment

Table 14: Adjustment for Lane Width and Shoulder Width

	Reduction in free-flow speed (mi/h) Shoulder width (ft)			
Lane width (ft)	≥ 0 < 2	≥ 2 < 4	≥ 4 < 6	≥ 6
9 < 10	6.4	4.8	3.5	2.2
≥ 10 < 11	5.3	3.7	2.4	1.1
≥ 11 < 12	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

Lane Width and Shoulder Width Adjustment

- Same as that for multilane highways

Table 15: Adjustment for Access-Point Frequency

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

Two-lane Highways

Determine Analysis Flow Rate

- The hourly volume must be adjusted to account for the peak 15-minute flow rate, the terrain, and the presence of heavy vehicles in the traffic stream.

$$v_i = \frac{V_i}{PHF \times f_G \times f_{HV}}$$

v_i = 15-min passenger car equivalent flow rate for direction i (pc/h),
V_i = hourly volume for direction i (veh/h),
i = "d" for analysis direction, "o" for opposing direction
PHF = peak-hour factor,
f_G = grade adjustment factor, and
f_{HV} = heavy-vehicle adjustment factor.

- It does not contain an adjustment factor for driver population.
- Although it is reasonable to assume that drivers familiar with the highway will use it more efficiently than recreational or other nonfamiliar users of the facility, studies have yet to identify a significant difference between the two driver populations.

Two-lane Highways

Determine Analysis Flow Rate

Peak-Hour Factor

- PHF for two-lane highways is calculated in a manner consistent with that for freeways and multilane highways.
- The only distinction is that, because the two-lane highway analysis methodology considers both directions of traffic flow for the analysis of each travel direction, PHF should be calculated for both directions of traffic flow combined.

Two-lane Highways

Determine Analysis Flow Rate

Grade Adjustment Factor

- The grade adjustment factor accounts for the effect of terrain on the traffic flow.

Table 16: Grade Adjustment Factor for Average Travel Speed (ATS) and Percent Time Spent Following (PTSF)

Directional demand flow rate (veh/h)	Average travel speed (mi/h)		Percent time spent following	
	Level terrain	Rolling terrain	Level terrain	Rolling terrain
≤ 100	1.00	0.67	1.00	0.73
200	1.00	0.75	1.00	0.80
300	1.00	0.83	1.00	0.85
400	1.00	0.90	1.00	0.90
500	1.00	0.95	1.00	0.96
600	1.00	0.97	1.00	0.97
700	1.00	0.98	1.00	0.99
800	1.00	0.99	1.00	1.00
≥ 900	1.00	1.00	1.00	1.00

* Linear interpolation to the nearest 0.01 is recommended.

Two-lane Highways

<u>Determine Analysis Flow Rate</u>

Heavy-Vehicle Adjustment Factor

- The heavy-vehicle adjustment factor accounts for the effect on traffic flow due to the presence of trucks, buses, and recreational vehicles in the traffic stream.
- The heavy-vehicle PCE values for level and rolling terrain for both ATS and PTSF are shown in Table
- Two-lane highways in mountainous terrain must be analyzed as specific upgrades and/or downgrades (the reader is referred to the Highway Capacity Manual).

Table 17: Passenger Car Equivalents for Heavy Vehicles for Average Travel Speed (ATS) and Percent Time Spent Following (PTSF)

Vehicle type	Directional demand flow rate (veh/h)	Average travel speed (mi/h)		Percent time spent following	
		Level terrain	Rolling terrain	Level terrain	Rolling terrain
Trucks and buses, E_T	≤ 100	1.9	2.7	1.1	1.9
	200	1.5	2.3	1.1	1.8
	300	1.4	2.1	1.1	1.7
	400	1.3	2.0	1.1	1.6
	500	1.2	1.8	1.0	1.4
	600	1.1	1.7	1.0	1.2
	700	1.1	1.6	1.0	1.0
	800	1.1	1.4	1.0	1.0
	≥ 900	1.0	1.3	1.0	1.0
RVs, E_R	All flows	1.0	1.1	1.0	1.0

* Linear interpolation to the nearest 0.1 is recommended.

Two-lane Highways

<u>Calculating Service Measures</u>

- If the highway is $Class\ I$, both ATS and $PTSF$ must be calculated.
- If the highway is $Class\ II$, only $PTSF$ needs to be calculated.
- If the highway is $Class\ III$, only ATS needs to be calculated.

Average Travel Speed

- The average travel speed depends on the free-flow speed

$$ATS_d = FFS - 0.00776(v_d + v_o) - f_{np}$$

ATS_d = average travel speed in the analysis direction in mi/h,
FFS = free-flow speed in mi/h,

v_d = analysis flow rate for analysis direction in pc/h,
v_o = analysis flow rate for opposing direction in pc/h,
f_{np} = adjustment factor for the percentage of no-passing zones, *(Table 18)*

Two-lane Highways

Table 18: Adjustment for No-Passing Zones on Average Travel Speed

Opposing flow rate, v_o (pc/h)	No-passing zones (%)				
	≤ 20	40	60	80	100
FFS ≥ 65 mi/h					
≤ 100	1.1	2.2	2.8	3.0	3.1
200	2.2	3.3	3.9	4.0	4.2
400	1.6	2.3	2.7	2.8	2.9
600	1.4	1.5	1.7	1.9	2.0
800	0.7	1.0	1.2	1.4	1.5
1000	0.6	0.8	1.1	1.1	1.2
1200	0.6	0.8	0.9	1.0	1.1
1400	0.6	0.7	0.9	0.9	0.9
≥ 1600	0.6	0.7	0.7	0.7	0.8
FFS = 60 mi/h					
≤ 100	0.7	1.7	2.5	2.8	2.9
200	1.9	2.9	3.7	4.0	4.2
400	1.4	2.0	2.5	2.7	3.9
600	1.1	1.3	1.6	1.9	2.0
800	0.6	0.9	1.1	1.3	1.4
1000	0.6	0.7	0.9	1.1	1.2
1200	0.5	0.7	0.9	0.9	1.1
1400	0.5	0.6	0.8	0.8	0.9
≥ 1600	0.5	0.6	0.7	0.7	0.7
FFS = 55 mi/h					
≤ 100	0.5	1.2	2.2	2.6	2.7
200	1.5	2.4	3.5	3.9	4.1
400	1.3	1.9	2.4	2.7	2.8
600	0.9	1.1	1.6	1.8	1.9
800	0.5	0.7	1.1	1.2	1.4
1000	0.5	0.6	0.8	0.9	1.1
1200	0.5	0.6	0.7	0.9	1.0
1400	0.5	0.6	0.7	0.7	0.9
≥ 1600	0.5	0.6	0.6	0.6	0.7
FFS = 50 mi/h					
≤ 100	0.2	0.7	1.9	2.4	2.5
200	1.2	2.0	3.3	3.9	4.0
400	1.1	1.6	2.2	2.6	2.7
600	0.6	0.9	1.4	1.7	1.9
800	0.4	0.6	0.9	1.2	1.3
1000	0.4	0.4	0.7	0.9	1.1
1200	0.4	0.4	0.7	0.8	1.0
1400	0.4	0.4	0.6	0.7	0.8
≥ 1600	0.4	0.4	0.5	0.5	0.5
FFS ≤ 45 mi/h					
≤ 100	0.1	0.4	1.7	2.2	2.4
200	0.9	1.6	3.1	3.8	4.0
400	0.9	0.5	2.0	2.5	2.7
600	0.4	0.3	1.3	1.7	1.8
800	0.3	0.3	0.8	1.1	1.2
1000	0.3	0.3	0.6	0.8	1.1
1200	0.3	0.3	0.6	0.7	1.0
1400	0.3	0.3	0.6	0.6	0.7
≥ 1600	0.3	0.3	0.4	0.4	0.6

* Linear interpolation to the nearest 0.1 is recommended.

Two-lane Highways

Calculating Service Measures

Percent Time Spent Following

$$PTSF_d = BPTSF_d + f_{np}\left(\frac{v_d}{v_d + v_o}\right)$$

$PTSF_d$ = percent time spent following in the analysis direction,
$BPTSF_d$ = base percent time spent following in the analysis direction,
f_{np} = adjustment factor for the percentage of no-passing zones, *(Table 19)*

$$BPTSF_d = 100\left[1 - \exp\left(a v_d^b\right)\right]$$

Where a and b are constants determined from Table 20

Two-lane Highways

Calculating Service Measures

Percent Time Spent Following

Table 19: Adjustment for No-Passing Zones on Percent Time Spent Following

Two-way flow rate, $v_d + v_o$ (pc/h)	No-passing zones (%) 0	20	40	60	80	100
Directional split = 50/50						
≤ 200	9.0	29.2	43.4	49.4	51.0	52.6
400	16.2	41.0	54.2	61.6	63.8	65.8
600	15.8	38.2	47.8	53.2	55.2	56.8
800	15.8	33.8	40.4	44.0	44.8	46.6
1400	12.8	20.0	23.8	26.2	27.4	28.6
2000	10.0	13.6	15.8	17.4	18.2	18.8
2600	5.5	7.7	8.7	9.5	10.1	10.3
3200	3.3	4.7	5.1	5.5	5.7	6.1
Directional split = 60/40						
≤ 200	11.0	30.6	41.0	51.2	52.3	53.5
400	14.6	36.1	44.8	53.4	55.0	56.3
600	14.8	36.9	44.0	51.1	52.8	54.6
800	13.6	28.2	33.4	38.6	39.9	41.3
1400	11.8	18.9	22.1	25.4	26.4	27.3
2000	9.1	13.5	15.6	16.0	16.8	17.3
2600	5.9	7.7	8.6	9.6	10.0	10.2
Directional split = 70/30						
≤ 200	9.9	28.1	38.0	47.8	48.5	49.0
400	10.6	30.3	38.6	46.7	47.7	48.8
600	10.9	30.9	37.5	43.9	45.4	47.0
800	10.3	23.6	28.4	33.3	34.5	35.5
1400	8.0	14.6	17.7	20.8	21.6	22.3
2000	7.3	9.7	15.7	13.3	14.0	14.5
Directional split = 80/20						
≤ 200	8.9	27.1	37.1	47.0	47.4	47.9
400	6.6	26.1	34.5	42.7	43.5	44.1
600	4.0	24.5	31.3	38.1	39.1	40.0
800	4.8	18.5	23.5	28.4	29.1	29.9
1400	3.5	10.3	13.3	16.3	16.9	32.2
2000	3.5	7.0	8.5	10.1	10.4	10.7
Directional split = 90/10						
≤ 200	4.6	24.1	33.6	43.1	43.4	43.6
400	0.0	20.2	28.3	36.3	36.7	37.0
600	-3.1	16.8	23.5	30.1	30.6	31.1
800	-2.8	10.5	15.2	19.9	20.3	20.8
1400	-1.2	5.5	8.3	11.0	11.5	11.9

* Linear interpolation to the nearest 0.1 is recommended.

Table 20: PTSF Coefficients for Use in Equation

Opposing Flow Rate, v_o (pc/h)	Coefficient a	Coefficient b
≤ 200	–0.0014	0.973
400	–0.0022	0.923
600	–0.0033	0.870
800	–0.0045	0.833
1000	–0.0049	0.829
1200	–0.0054	0.825
1400	–0.0058	0.821
≥ 1600	–0.0062	0.817

* Linear interpolation of a to the nearest 0.0001 and b to the nearest 0.001 is recommended.

Two-lane Highways

Calculating Service Measures

Percent Free-Flow Speed

$$PFFS_d = \frac{ATS_d}{FFS}$$

$PFFS_d$ = percent free-flow speed in the analysis direction

ATS_d = average travel speed in the analysis direction in mi/h,

FFS = free-flow speed in mi/h, as measured in the field and

Two-lane Highways

Determining LOS

- The first step in the LOS determination is to compare the analysis flow rate, v_d, to the directional capacity of $1700\ pc/h$.
- If v_d exceeds 1700, the LOS is F, and the analysis ends.
- In this case, $PTSF$ is virtually 100%, and speeds are highly variable and difficult to estimate.
- If the capacity in the analysis direction is not exceeded, then the combined demand flow rates ($v_d + v_o$) for both directions must be checked against the two-way capacity of $3200\ pc/h$.
  - If the two-capacity is exceeded, refer to the Highway Capacity Manual
- If capacity is not exceeded, the calculated $PTSF$, ATS, and/or $PFFS$ values are used with Table 21 to determine the LOS.
- For a particular LOS category to apply for Class I highways, the thresholds for both $PTSF$ and ATS must be met.
- For example, for $LOS\ B$ to apply, $PTSF$ must be less than or equal to 50% and ATS must be greater than $50\ mi/h$. If, for a particular two-lane highway, $PTSF$ is 45% and ATS is $48\ mi/h$, the LOS would be C.

Table 21: LOS Criteria for Two-Lane Highways

	Class I		Class II	Class III
LOS	Percent time spent following (*PTSF*)	Average travel speed (*ATS*) mi/h	Percent time spent following (*PTSF*)	Percent free-flow speed (*PFFS*)
A	≤ 35	> 55	≤ 40	> 91.7
B	≤ 50	> 50	≤ 55	> 83.3–91.7
C	≤ 65	> 45	≤ 70	> 75.0–83.3
D	≤ 80	> 40	≤ 85	> 66.7–75.0
E	> 80	≤ 40	> 85	≤ 66.7

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

Two-lane Highways - Example

Problem

One segment of a $Class\ I$ two-lane highway is on rolling terrain and has an hourly volume of 1000 veh/h (total for both directions), a directional traffic split of $60/40$, and $PHF\ =\ 0.92$, and the traffic stream contains 5% large trucks, 2% buses, and 6% recreational vehicles. For these conditions, determine the analysis direction [1] and opposing direction [2] flow rates for ATS and $PTSF$.

Two-lane Highways - Example

Solution

Calculate the hourly volume for each direction ➜

$$V_d = 1000 \times 0.60 = 600 \text{ veh/h}$$
$$V_o = 1000 \times 0.40 = 400 \text{ veh/h}$$

Calculate the flow rate, in veh/h, that will be used to determine the grade adjustment and PCE values. ➜

$$\frac{V_d}{PHF} = \frac{600}{0.92} \cong 652$$
$$\frac{V_o}{PHF} = \frac{400}{0.92} \cong 435$$

The values for ATS will result:

f_G = 0.98 [1]; 0.92 [2] — *Table 16 by interpolation*

E_T = 1.6 [1]; 1.9 [2] — *Table 17 by interpolation*

E_R = 1.1 [1]; 1.1 [2] — *Table 17 by interpolation*

➜

$$f_{HV[1]} = \frac{1}{1+0.07(1.6-1)+0.06(1.1-1)} = 0.954$$
$$f_{HV[2]} = \frac{1}{1+0.07(1.9-1)+0.06(1.1-1)} = 0.935$$

Substituting the f_{HV} and f_G values ➜

$$v_d = \frac{600}{0.92 \times 0.98 \times 0.954} = 697.6 \rightarrow \underline{\underline{698 \text{ pc/h}}}$$
$$v_o = \frac{400}{0.92 \times 0.92 \times 0.935} = 505.4 \rightarrow \underline{\underline{506 \text{ pc/h}}}$$

The values for PTSF will result:

f_G = 0.98 [1]; 0.92 [2] — *Table 16 by interpolation*

E_T = 1.1 [1]; 1.5 [2] — *Table 17 by interpolation*

E_R = 1.0 [1]; 1.0 [2] — *Table 17 by interpolation*

➜ f_{HV} = 0.993 [1]; 0.966 [2]

Substituting the f_{HV} and f_G values ➜

$$v_d = \underline{\underline{671 \text{ pc/h}}}$$
$$v_o = \underline{\underline{490 \text{ pc/h}}}$$

Two-lane Highways - Example

Problem

The two-lane highway segment in the previous Example has the following additional characteristics:

11-ft lanes, 2-ft shoulders, access frequency of 10 per mile, 50% no-passing zones, and a base FFS of 55 mi/h. Using the analysis flow rates for ATS and PTSF from the previous Example, determine the level of service for this two-lane highway segment.

Two-lane Highways - Example

Solution

We begin by checking whether the highway segment is over capacity. The flow rates for the analysis direction of 698 and 671 for ATS and $PTSF$, respectively, are both well below the directional capacity of 1700 pc/h. Furthermore, the combined flow rates $(vd + v_o)$ of 1204 and 1161 for ATS and $PTSF$, respectively, are below the two-way capacity of 3200 pc/h.

➔ *We first estimate the free-flow speed*

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

$BFFS = 55$ mi/h

$f_{LS} = 3.0$ mi/h

$f_A = 2.5$ mi/h

➔ $$FFS = 55 - 3.0 - 2.5 = 49.5 \text{ mi/h}$$

The values for ATS will result:

$$ATS = FFS - 0.00776(v_d + v_o) - f_{np}$$

➔

$FFS = 49.5$ mi/h

$v_d = 698$ pc/h

$v_o = 506$ pc/h

$f_{np} = 1.45$ mi/h

$$ATS_d = 49.5 - 0.00776(698 + 506) - 1.45 = 38.7 \text{ mi/h}$$

The values for PTSF will result:

$$PTSF_d = BPTSF_d + f_{np}\left(\frac{v_d}{v_d + v_o}\right)$$

➔ $$BPTSF_d = 100\left[1 - \exp\left(av_d^b\right)\right]$$

$v_d = 698$ pc/h

$a = -0.0028$

$b = 0.8949$

$$BPTSF_d = 100\left[1 - \exp\left(-0.0028(698)^{0.8949}\right)\right] = 62.5\%$$

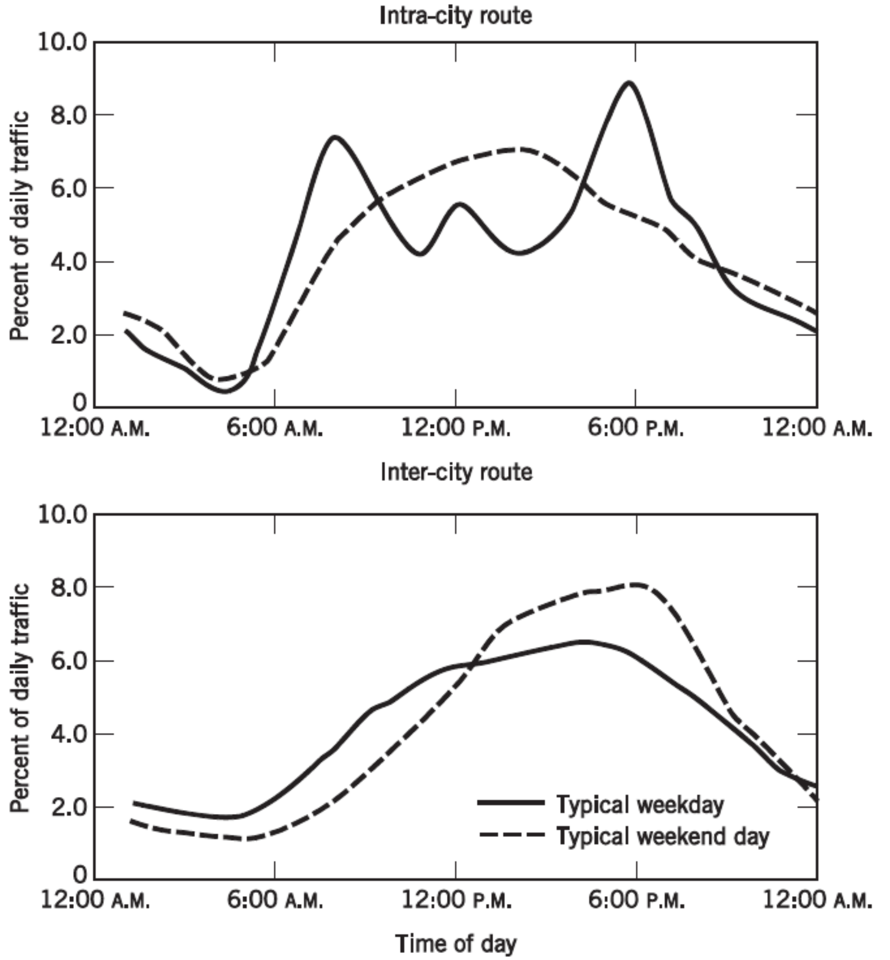
- *f_{np} is found to be 27.75% from Table 19, by linear interpolation for two-way flow rate and percent no-passing zones.*
- *Note that a three-way linear interpolation is also possible with this table if the directional split does not fall into one of the five predefined categories.*

➔ $$PTSF_d = 62.5 + 27.75\left(\frac{698}{698 + 506}\right) = 78.6\%$$

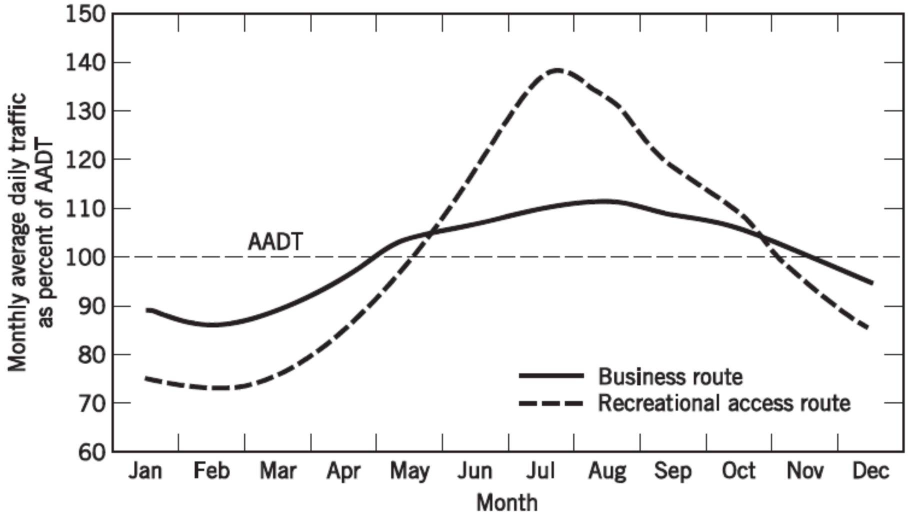
- *LOS is calculated from Table 21 based on the ATS and PTSF values.*
- *For a Class I highway, the LOS is E.*
- *Although PTSF falls within the LOS D category, ATS falls within the LOS E category; thus, ATS governs the LOS.*

Design Traffic Volumes

- In the preceding sections of this chapter, consideration was given to the determination of level of service, given some hourly volume.
- However, a procedure for selecting an appropriate hourly volume is needed to compute the level of service and to determine the number of lanes that need to be provided in a new roadway design to achieve some specified level of service.
- The selection of an appropriate hourly volume is complicated by two issues
- There is considerable variability in traffic volume by time of day, day of week, time of year, and type of roadway. (Right image)



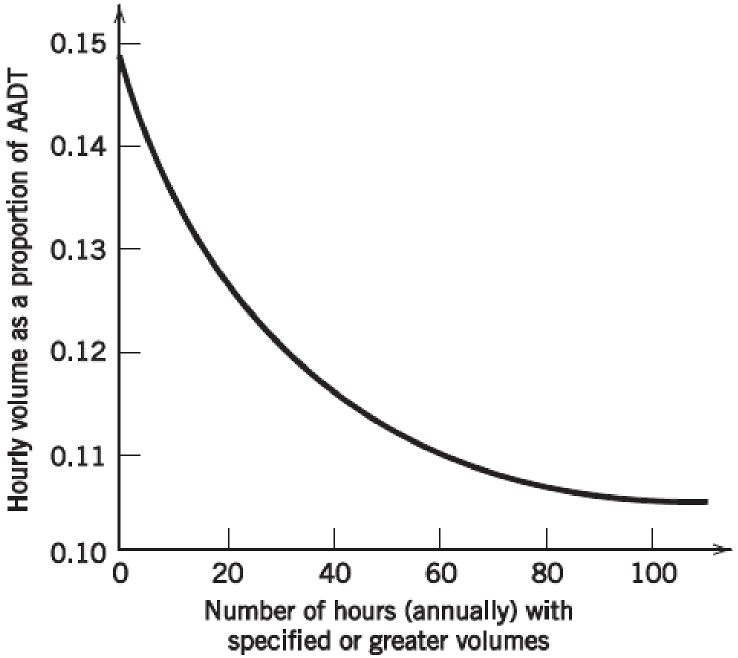
- Left image variations by time of year by comparing the monthly average daily traffic to the annual average daily traffic (AADT)



AADT: The total yearly traffic volume divided by the number of days in the year (vehicles per day)

Design Traffic Volumes

- Given the temporal variability in traffic flow, what hourly volume should be used for design and/or analysis?
- Consider the example diagram
- This figure plots hourly volume (as a percentage of AADT) against the cumulative number of hours that exceed this volume, per year.
  - The highest traffic flow in the year, on this sample roadway, would have an hourly volume of 0.148 × AADT (a volume that is exceeded by zero other hours).
  - Sixty hours in the year would have a volume that exceeds 0.11 × AADT.
- In determining the number of lanes, it is obvious that using the worst single hour in a year would be a wasteful use of resources because additional lanes would be provided for a relatively rare occurrence.
- In contrast, if the 100th highest volume is used, the design level of service will be exceeded 100 times a year, which will result in considerable driver delay.
- Some compromise between the expense of providing additional capacity and the expense of incurring additional driver delay must be made.



Design Traffic Volumes

- A common practice in the United States is to use a design hour-volume (DHV) that is between the 10th and 50th highest-volume hours of the year.
- Perhaps the most common hourly volume used for roadway design is the 30th highest of the year.
- In practice, the K factor is used to convert annual average daily traffic (AADT) to the 30th highest hourly volume.
- K is defined as:

$$K = \frac{\mathrm{DHV}}{\mathrm{AADT}}$$

K = factor used to convert annual average daily traffic to a specified annual hourly volume,
DHV = design hour-volume (typically, the 30th highest annual hourly volume), and
AADT = roadway's annual average daily traffic in veh/day.

- More generally, K_i can be defined as the K-factor corresponding to the i^{th} highest annual hourly volume.
- Finally, in the design and analysis of some highway types (such as freeways and multilane highways), the concern lies with directional traffic flows.

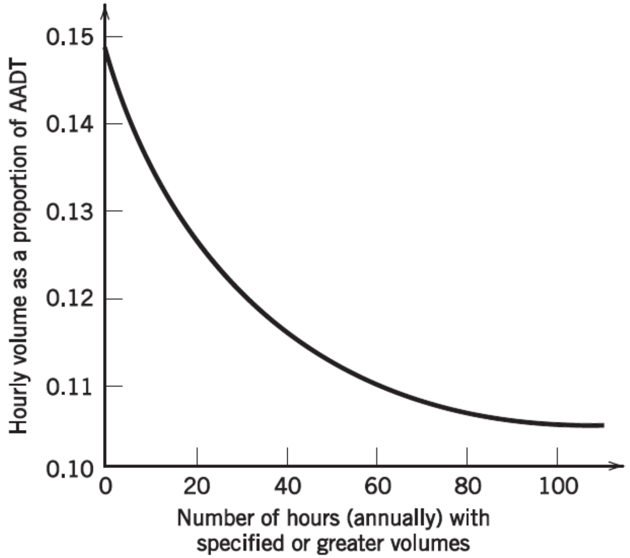
$$\mathrm{DDHV} = K \times D \times \mathrm{AADT}$$

DDHV = directional design-hour volume,
D = directional distribution factor to reflect the proportion of peak-hour traffic volume traveling in the peak direction, and

Design Traffic Volumes - Example

Problem

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 the following Figure applies, 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.



Design Traffic Volumes - Example

Solution

From the Figure:

The highest annual hourly volume: $K_1 = 0.148$

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

From Table 1:

Maximum service flow rate LOS C, $FFS = 70$ mi/h $\rightarrow$ $1735\ pc/h/\text{ln}$ *Per-lane traffic flow should be less than or equal to this value*

For the highest hourly annual volume

We should use the following equation to find v_p, based on an assumed number of lanes.

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \rightarrow v_p = \frac{3367}{0.85 \times 2 \times 1.0 \times 1.0} = 1980.6 \text{ pc/h/ln}$$

V = 3367 (DDHV from above),

f_{HV} = 1.0 (no heavy vehicles), and

f_p = 1.0 (commuters).

This value is higher than 1735, so we need to provide more lanes

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

Since this value is less than 1735, a six-lane freeway is necessary to provide LOS C operation for the design traffic flow rate.

For the 30th highest hourly annual volume

From the Figure:

$K_{30} = K = 0.12$

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

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

So a four-lane freeway is adequate

!

This example demonstrates the impact of the chosen design traffic flow rate on roadway design. Only a 4 lane freeway is necessary to provide LOS C for the 30th highest annual hourly volume, as opposed to a 6 lane freeway needed to satisfy the LOS requirement for the highest annual hourly volume.

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Thank
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