Cairo University
Faculty of Engineering
Public Works Department

Traffic Engineering

Highway Capacity and Level of Service

Dr. Dalia Said,
Assistant Professor, Highway and Traffic Engineering
Civil Engineering Department,
Cairo University,
dalia_said@yahoo.com

Highway Capacity and LOS: Objectives

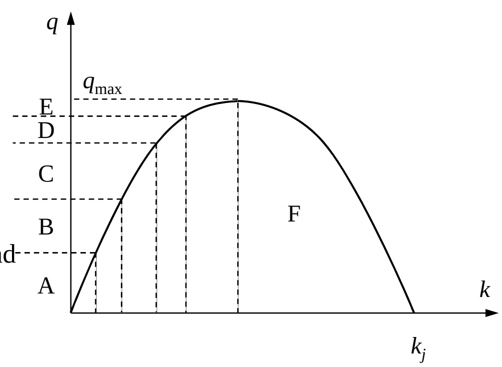
- Capacity:
  - The maximum hourly flow rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway under prevailing *roadway*, *traffic* and *control conditions*
  1. Roadway conditions:
     - Associated with the geometric design of the road
     - Examples: number of lanes, lane width, shoulder width, horizontal and vertical alignment, …
  2. Traffic conditions:
     - Associated with characteristics of traffic stream
     - Examples: traffic composition, directional distribution on two-lane highways, …
  3. Control conditions:
     - Include traffic control devices, signal phasing, cycle length, …
- Capacity analysis involves the quantitative evaluation of the capability of a road section to carry traffic
- Level of service (LOS): a qualitative measure of:
  - The operating conditions within a traffic system, and
  - How these conditions are perceived by drivers and passengers

Highway Capacity and LOS: Objectives

- Capacity analysis: How much traffic can a given facility accommodate?
- LOS: Under what type of operations can this facility carry this much traffic?

Concept of LOS

- Six levels of service
  - A → highest
  - B
  - C
  - D
  - E
  - F → lowest
- We will study three types of road segments:
  - Two-lane highways
  - Multi-lane highways
  - Basic freeway sections



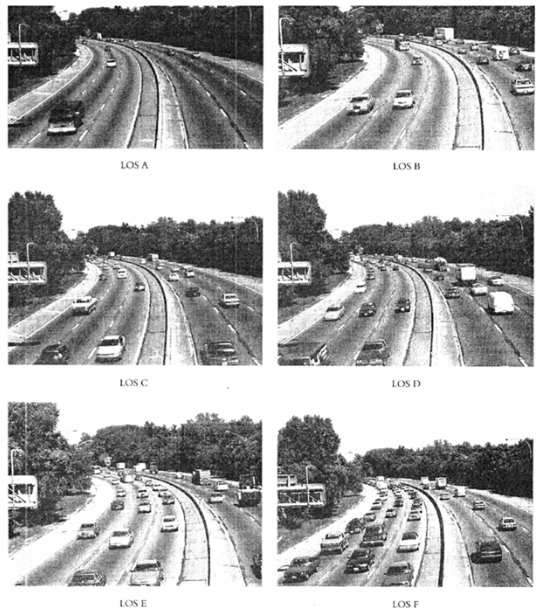


Figure 9.12 Levels of Service for Freeways

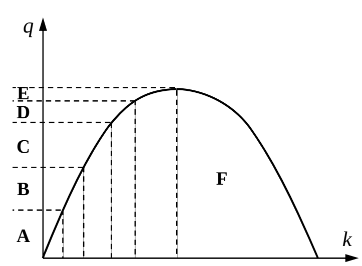
Two-Lane Highways

- Factors describing service quality:
  - Percent time spent following another vehicle (PTSF):
    - **The average percentage of time that vehicles are traveling behind slower vehicles (time headway between consecutive vehicles is less than 3 s)**
  - Average travel speed (ATS):
    - **The space mean speed of vehicles in the traffic stream**
- Ideal capacity of a two-lane highway is:
  - 1700 pc/h for each direction of travel
  - 3200 pc/h for the two directions of the extended segment
  - 3200-3400 pc/h for short sections of two-lane highway, such as a tunnel or bridge
- Base conditions for two-lane highways:
  - Level terrain
  - Passing permitted
  - Lane width ≥ 12ft and clear shoulders ≥ 6 ft (See Fig. 9.10a)
  - Same traffic volume in both directions (50/50 directional split)
  - All passenger cars in traffic stream
  - No restriction on through traffic due to control

- The performance of a highway at traffic volumes less than capacity is expressed by the LOS
- For LOS analysis, two-lane highways are classified into two classes:
  - Class I:
    - Two-lane highways that function as primary arterials, daily commuter routes, and links to other arterial highways
    - Motorists' expectations are that travel will be at relatively high speeds
  - Class II:
    - Two-lane highways where the expectation of motorists is that travel speeds will be slower than that for Class I roads (e.g. scenic roads, rugged terrain, ..)
    - Average trip lengths on Class II highways are shorter than on Class I highways
- LOS is based on:
  - Two measures for Class I highways: PTSF and ATS (Table 9.1)
  - A single measure for Class II highways: PTSF (Table 9.2)

LOS Designations:

- **LOS A**
  - For Class I: ATS is ≥ 50 mph, and PTSF is ≤ 35%
  - For Class II: PTSF is ≤ 40 %
  - Flow rate < 490 pc/h (both directions)
- **LOS B**
  - For Class I: ATS is 50-55 mph, and PTSF is 35-50%
  - For Class II: PTSF is 40-55 %
  - Flow rate < 780 pc/h (both directions)
- **LOS C**
  - For Class I: ATS is 45-50 mph, and PTSF is 50-65%
  - For Class II: PTSF is 55-70 %
  - Flow rate < 1190 pc/h (both directions)
- **LOS D**
  - Flow is unstable
  - Passing capacity approaches zero
  - For Class I: ATS is 40-45 mph, and PTSF is 65-80%
  - For Class II: PTSF is 70-85 %
  - Flow rate < 1830 pc/h (both directions)
- **LOS E**
  - Traffic operations are unstable and difficult to predict
  - Passing has become virtually impossible
  - For Class I: ATS is ≤ 40 mph, and PTSF is ≥ 80%
  - For Class II: PTSF is ≥ 85 %
  - Flow rate < 3200 pc/h (both directions)
- **LOS F**
  - Congested flow (demand is greater than capacity)



– Types of analysis:
  - Operational level of analysis:
    – LOS is required for specific traffic and roadway characteristics
  - Planning level of analysis:
    – AADT or DHV is required for specific LOS and roadway characteristics

– Analysis can be carried out for:
  - Two-way traffic
  - A specific direction
  - A directional segment with a passing lane

Evaluating LOS of Two-Way Segments

– Analysis is usually performed on extended lengths (at least 2 mi) in level or rolling terrain
  - Level terrain: segments contain flat grades of 2% or less
  - Rolling terrain: segments contain short or medium length grades of 4% or less

– For operational analysis of Class I:
  - Calculate ATS and PTSF
  - Find LOS from Table 9.1

– For operational analysis of Class II:
  - Calculate PTSF
  - Find LOS from Table 9.2

(a) Calculating PTSF:

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

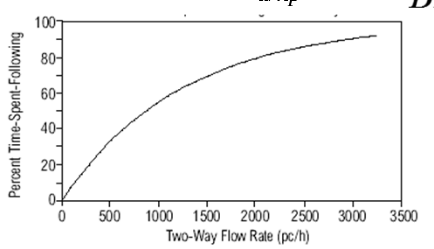
- *BPTSF* = base percent time spent following for both directions
- $f_{d/np}$ (Table 9.3) = adjustment in PTSF to account for the combined effect of:
  - **– Percent of directional distribution of traffic**
  - **– Percent of passing zones**

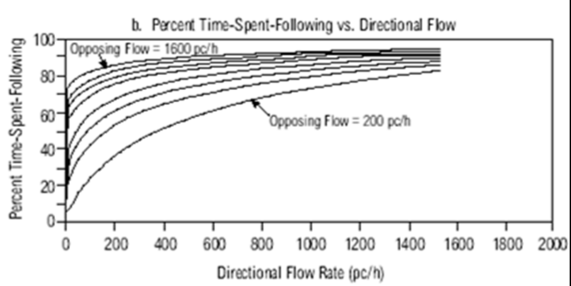
$$BPTSF = 100\left|1 - e^{-0.000879\, v_p}\right|$$

• v_p = passenger-car equivalent flow rate for the ***peak 15-min period***

(a) Calculating PTSF:

$$PTSF = BPTSF + f_{d/np} \qquad BPTSF = 100\left|1 - e^{-0.000879\, v_p}\right|$$





(a) Calculating PTSF:

- v_p = passenger-car equivalent flow rate for the peak 15-min period

$$v_p = \frac{V}{\text{PHF} \times f_G \times f_{HV}}$$

- – ***V*** **= hourly volume (veh/h)**
- – **PHF = peak-hour factor**
- – f_G **= grade adjustment factor for level or rolling terrain (Table 9.4)**
- – f_{HV} **= adjustment factor for the effect of heavy vehicles**

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

(a) Calculating PTSF:

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

- – *P_T & P_R = proportion of trucks (and buses) and RVs in traffic*
- – *E_T & E_R = passenger car equivalent for trucks (and buses) and RVs in traffic (Table 9.5)*

- – Note that f_G, E_T & E_R are functions of v_p and therefore iterative process is required:

1. First, estimate v_p using PHF only
2. Use the calculated v_p to estimate f_G, E_T & E_R and recalculate v_p
3. If the second value of v_p is within the range used to estimate f_G, E_T & E_R
   - – **The computed value is correct**
4. Otherwise, estimate f_G, E_T & E_R
   - – **Recalculate v_p and check the last two values of v_p**

(b) Calculating ATS:

$ATS = FFS - 0.00776v_p - f_{np}$

- ATS = average travel speed for both directions of travel combined (mi/h)
- FFS = free flow speed, the mean speed at low flow when volumes are < 200 pc/h
- f_{np} = adjustment for the percentage of no-passing zones (Table 9.6)
- v_p is calculated similar to previously but
  - **f_G is obtained from Table 9.7**
  - **E_T & E_R are obtained from Table 9.8**

(b) Calculating ATS:

– FFS can be determined in three different ways:

1. Field measurements at volumes < 200 pc/h
2. Field measurements at volumes > 200 pc/h using the following correction:

$$FFS = S_{FM} + 0.00776\frac{V_f}{f_{HV}}$$

   - **S_{FM} = mean speed of traffic measured in the field (mi/h)**
   - **V_f = observed flow rate (veh/h)**
   - **f_{HV} = heavy vehicle adjustment factor**

3. Indirect estimation, when field data are unavailable

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

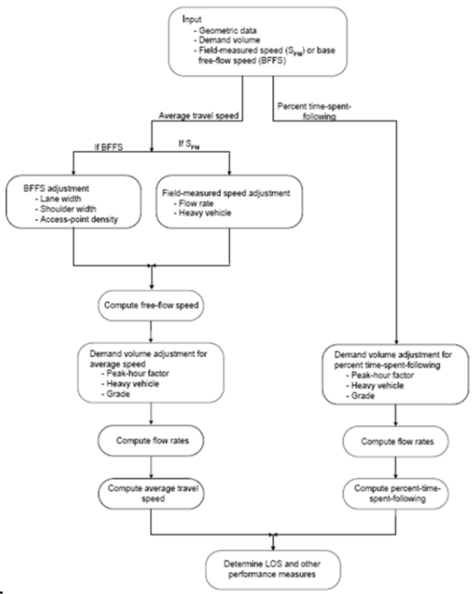
   - **FFS = estimated free-flow speed (mi/h)**
   - **$BFFS$ = base free-flow speed (mi/h)**
   - **f_{LS} = adjustment factor for lane and shoulder width (Table 9.9)**
   - **f_A = adjustment factor for number of access points per mile (Table 9.10)**

– Note that $BFFS$ depends on local conditions and the transportation engineer should estimate it based on their knowledge of the area and the speeds on similar facilities

   - **The range of $BFFS$ is 45–65 mi/h**
   - **Posted speed limits may serve as surrogates for $BFFS$**

Two-Lane Highway Methodology

EXHIBIT 20-1. TWO-LANE HIGHWAY METHODOLOGY



(*HCM* 2000)

•Example:

Determine the LOS for a 5-mile two-lane highway in rolling terrain. The existing data for this road are as follows:

- Volume = 1215 veh/h (two-way)
- Percent trucks = 8
- Percent RV's = 4
- Peak hour factor = 0.95
- Percent directional split = 60 – 40
- Percent no-passing zone = 40
- *BFFS* = 60 mi/h
- Lane width = 10 ft
- Shoulder width = 5 ft
- Number of access points = 15 point/mi
- LOS should be determined for both Class I and Class II highways.

(a) Calculating PTSF:

(b) Calculating ATS:

- Determining LOS:

Multilane Highways

- Multilane highways differ from both two-lane highways and freeways
- They may exhibit some of the following characteristics:
  - Posted speed limits are usually between 40 and 55 mi/h
  - They may be undivided or include medians
  - They are located in suburban areas or in high-volume rural corridors
  - They may include a two-way left-turn median lane (TWLTL)
  - Traffic volumes range from 15,000 to 40,000/day
  - Volumes are up to 100,000/day with grade separations and no cross-median access
  - Traffic signals at major crossing points are possible
  - There is partial control of access
- LOS can be described by any two of three performance characteristics:
  - Flow rate, v_p (pc/h/ln)
  - Average car speed, S (mi/h)
  - Density, D (pc/mi/ln)

• Base free-flow conditions include:

– Lane width = 12 ft

– Total lateral clearance (edge of the road + median) ≥ 12 ft (See Fig. 9.10a)

– No trucks, buses, or RV's

– A divided highway

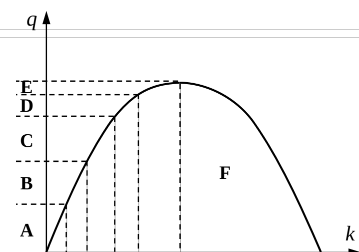
– No direct access points along the highway

– Level grade

– Drivers are familiar with the freeway

– FFS higher than 60 mi/h

LOS Designations:



- **LOS A**
  - Travel conditions are completely free flow
  - Density (*D*) ≤ 11 pc/mi/ln
- **LOS B**
  - Travel conditions are at free flow
  - Localized reduction in LOS
  - *D* ≤ 18 pc/mi/ln
- **LOS C**
  - Traffic density begins to influence operations
  - Travel speed shows some reduction when free flow speeds exceed 50 mi/h
  - *D* ≤ 26 pc/mi/ln
- **LOS D**
  - The ability to manoeuvre is severely restricted due to congestion
  - Queues may begin to form
  - *D* ≤ 35 pc/mi/ln
- **LOS E**
  - Operations are unstable and at near capacity
  - Vehicles operate at the minimum spacing for which uniform flow can be maintained
  - *D* ≤ 45 pc/mi/ln
- **LOS F**
  - Breakdown in vehicular flow (forced-flow)
  - Number of cars arriving at a point > the number discharged

LOS analysis can be used for operational or design purposes

LOS Determination:

- **The procedure for LOS determination involves the following steps:**
  - Step 1: compute the value of flow rate (v_p)

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

- V = hourly peak volume in one direction (veh/h)
- N = number of lanes/direction
- PHF = peak-hour factor
- f_p = adjustment factor for the effect of driver population = 0.85–1.00
- f_{HV} = adjustment factor for the effect of heavy vehicles

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

LOS Determination:

Step 1 (cont'd)

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

- Two cases for E_T and E_R
  - **Case 1: Extended general segment**
    - » *Not too long or too steep grades*
    - » *Area is level, rolling, or mountainous*
    - » *Use Table 9.25*
  - **Case 2: Specific grade**
    - » *L > 1.0 mi & G < 3% or L > 0.5 mi & G > 3%*
    - » *For upgrades: use Table 9.26 for* E_T *&* *Table 9.27 for* E_R
    - » *For downgrades: use Table 9.28 for* E_T *&* $E_R = E_R$ *for level grade*

– Step 2: compute the value of free-flow speed (*FFS*)

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

- BFFS = base free-flow speed (assume 60 mi/h if field data are unavailable)
- f_{LW} = adjustment factor for lane width (Table 9.29)
- f_{LC} = adjustment factor for lateral clearance (Table 9.30)
- f_M = adjustment factor for median type (Table 9.31)
- f_A = adjustment factor for access point density (Table 9.32)

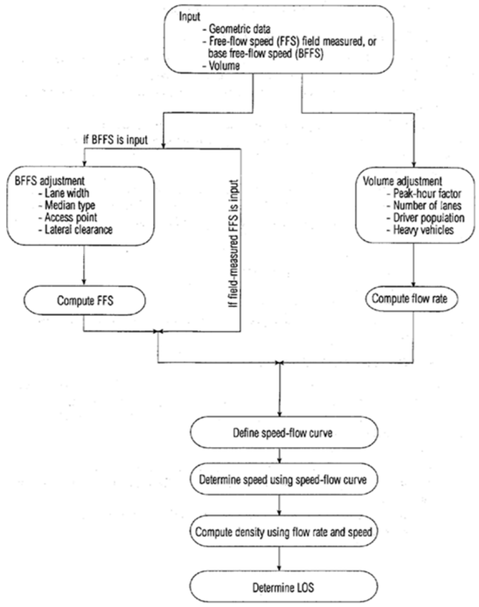
– Step 3: determine the value of average passenger car speed (*S*)

- If $v_p \leq 1400$ pc/h/ln, $S = FFS$
- Otherwise, use *FFS* and v_p to determine *S* from Figure 9.7

– Step 4: compute the density ($D = v_p/S$)

– Step 5: use *D* to get LOS from Table 9.24

EXHIBIT 21-1. MULTILANE HIGHWAY METHODOLOGY



(*HCM* 2000)

Example:

A 3200 ft segment of 3.25 mi four-lane undivided multilane highway in a suburban area is at a 2.5% grade. The highway is in level terrain, and lane widths are 11 ft. The measured free-flow speed is 46.0 mi/h. The directional peak hour volume is 1900 veh/h, PHF is 0.9, and there are 13% trucks and 2% RV's. Determine the LOS, speed, and density for the upgrade and downgrade.

For the downgrade:

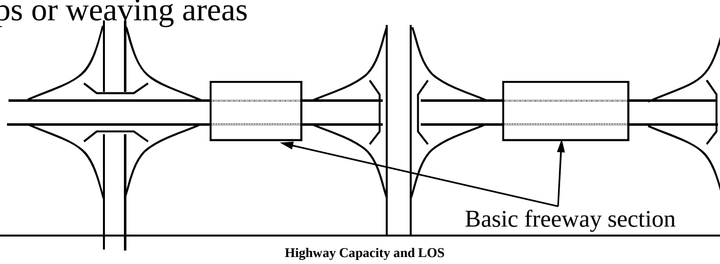
For the downgrade:

For the upgrade:

For the upgrade:

Basic Freeway Sections

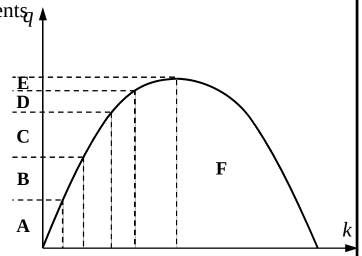
- A freeway is a divided highway with full access control and two or more lanes in each direction
- Opposing traffic is separated by a raised barrier, an at-grade median, or a raised traffic island
- A freeway is composed of three elements:
  - Basic freeway sections
  - Weaving areas
  - Ramp junctions
- Basic freeway sections are segments outside the influence area of ramps or weaving areas



- Base free-flow conditions include:
  - Lane width = 12 ft
  - Lateral clearance ≥ 6 ft (See Fig. 9.10a)
  - No trucks, buses, or RV's
  - Number of lanes ≥ 5/direction (urban freeways)
  - Spacing between interchanges ≥ 2 miles
  - Level grade ($G \leq 2\%$)
  - Drivers are familiar with the freeway

LOS Designations:

- **LOS A**
  - Vehicles are completely unimpeded in their ability to manoeuvre
  - Density (D) ≤ 11 pc/mi/ln
- **LOS B**
  - Free-flow conditions, and ability to manoeuvre is slightly restricted
  - Minor incidents and break downs are easily absorbed
  - D ≤ 18 pc/mi/ln
- **LOS C**
  - Near free-flow speed, but freedom to manoeuvre is noticeably restricted
  - Substantial local deterioration in service due to minor incidents
  - D ≤ 26 pc/mi/ln
- **LOS D**
  - Freedom to manoeuvre is more noticeably limited
  - Minor incidents can create queuing
  - D ≤ 35 pc/mi/ln
- **LOS E**
  - No useable gaps, and little room to manoeuvre
  - Minor incidents cause immediate and extensive queuing
  - D ≤ 45 pc/mi/ln
- **LOS F**
  - Breakdown in vehicular flow (forced-flow)
  - Number of cars arriving at a point > the number discharged



LOS Designations:

- As per multilane highways,
  - LOS of basic freeway sections can be described by any two of
    - v_p (pc/h/ln)
    - S (mi/h)
    - D (pc/mi/ln)

LOS Determination:

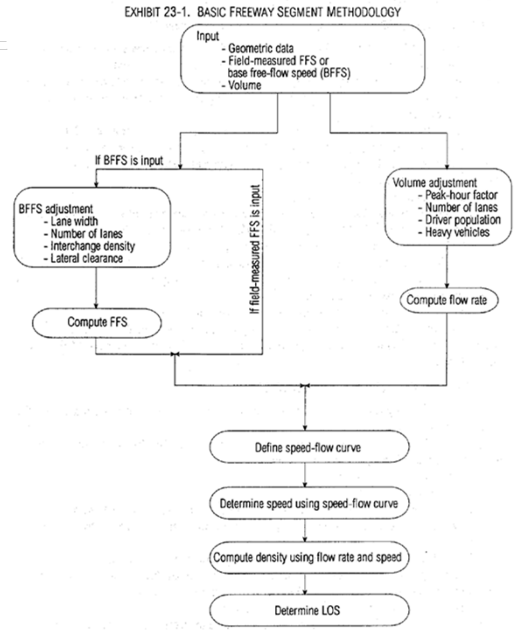
- The procedure for LOS determination is very similar to that of multilane highways:
  - Step 1: compute the value of flow rate (v_p)
    - Same as multilane highways except that G & L for the definition of specific grades are:
      - $L > 0.25$ mi & $G > 3\%$ or $L > 0.5$ mi & $G < 3\%$
  - Step 2: compute the value of free-flow speed (FFS)

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

    - $BFFS$ = base free-flow speed (assume 65 mi/h for urban and 70 mi/h for rural freeways)
    - f_{LW} = adjustment factor for lane width (Table 9.34)
    - f_{LC} = adjustment factor for lateral clearance (Table 9.35)
    - f_N = adjustment factor for number of lanes (Table 9.36)
    - f_{ID} = adjustment factor for interchange density (Table 9.37)

LOS Determination:

- Step 3: compute average passenger car speed (S)
  - From Figure 9.9 and using FFS and v_p
- Step 4: compute the density ($D = v_p / S$)
- Step 5: use D to get LOS from Table 9.33



(*HCM* 2000)

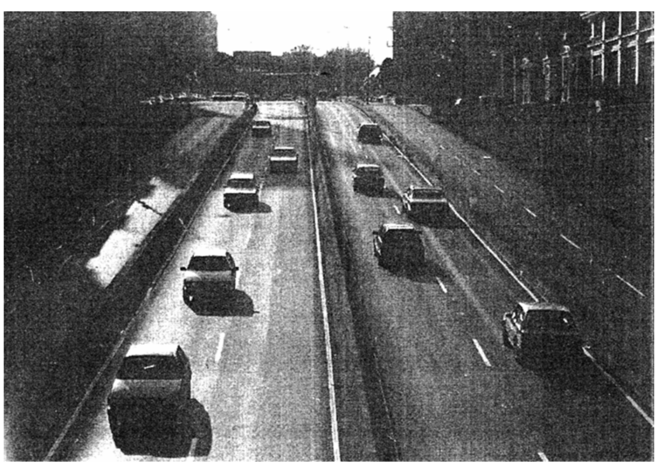
- Example:
  - Determine the LOS on a regular weekday on a 0.40-mi section of a six-lane urban freeway with a grade of 2 percent, using the following data:
    - Hourly volume, V = 3000 veh/h, PHF = 0.85
    - Percentage trucks = 12%, percentage RV's = 2%
    - Lane width = 11 ft, shoulder width = 6 ft
    - Terrain = level
    - Base free-flow speed = 70 mi/h
    - Interchange spacing = 1 mile
    - Driver population adjustment factor f_p = 1.0

- Compute v_p:
  - V = 3000 veh/h, PHF = 0.85, N = 3, f_p = 1.00 (given)
  - P_T = 0.12 & P_R = 0.02 (given)
  - From Table 9.25: E_T = 1.5 & E_R = 1.2

$$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} = \frac{1}{1+0.12(1.5-1)+0.02(1.2-1)} = 0.94$$

$$v_p = \frac{V}{\text{PHF}\times N\times f_{HV}\times f_p} = \frac{3000}{0.85\times 3\times 1\times 0.94} = 1251\,\text{pc/h/ln}$$

Fig 9.10 (a)



Vehicles shying away from both roadside and median barriers.