Highway Capacity and Level of Service

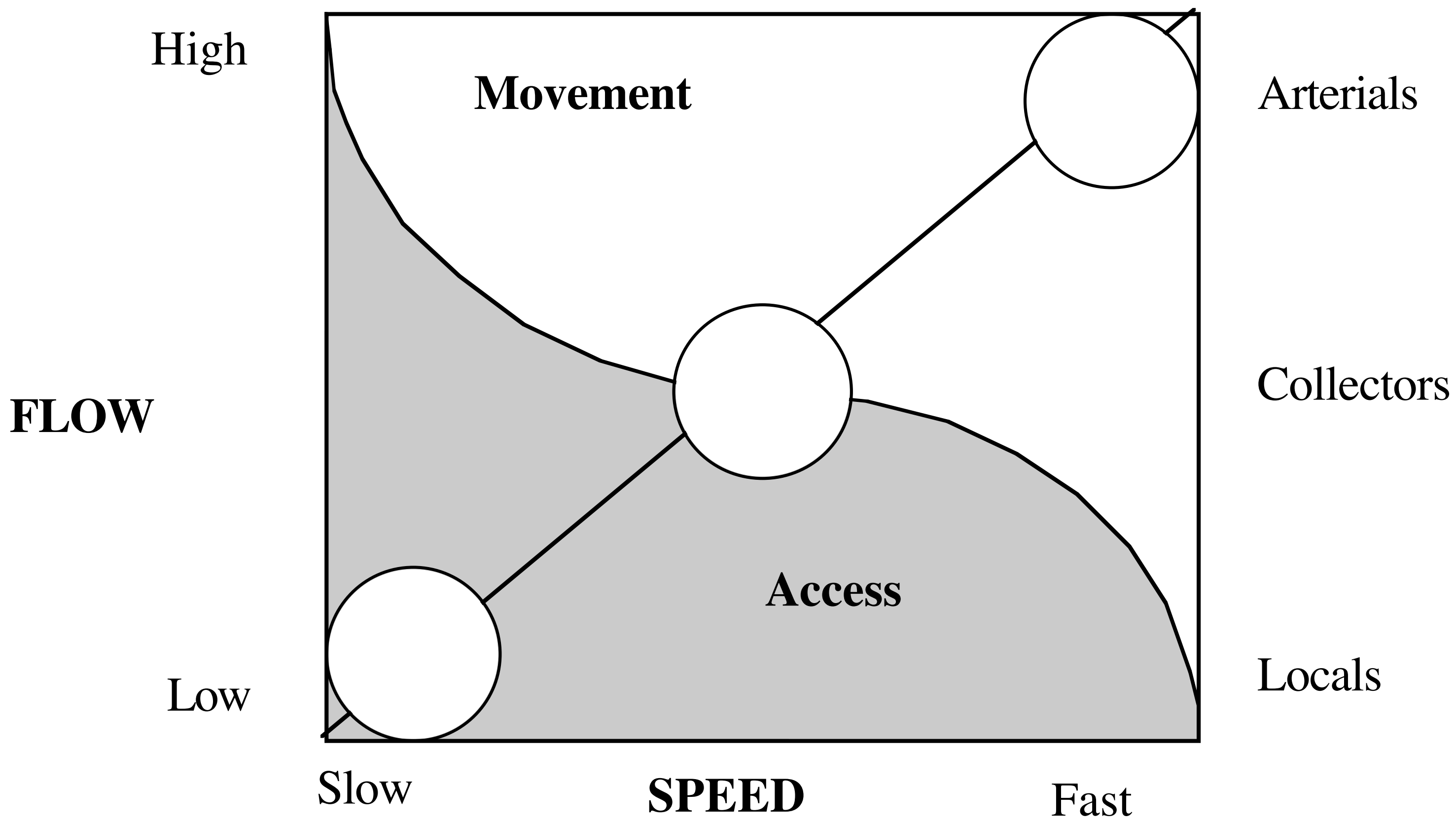
CE454

Urban Transportation Systems

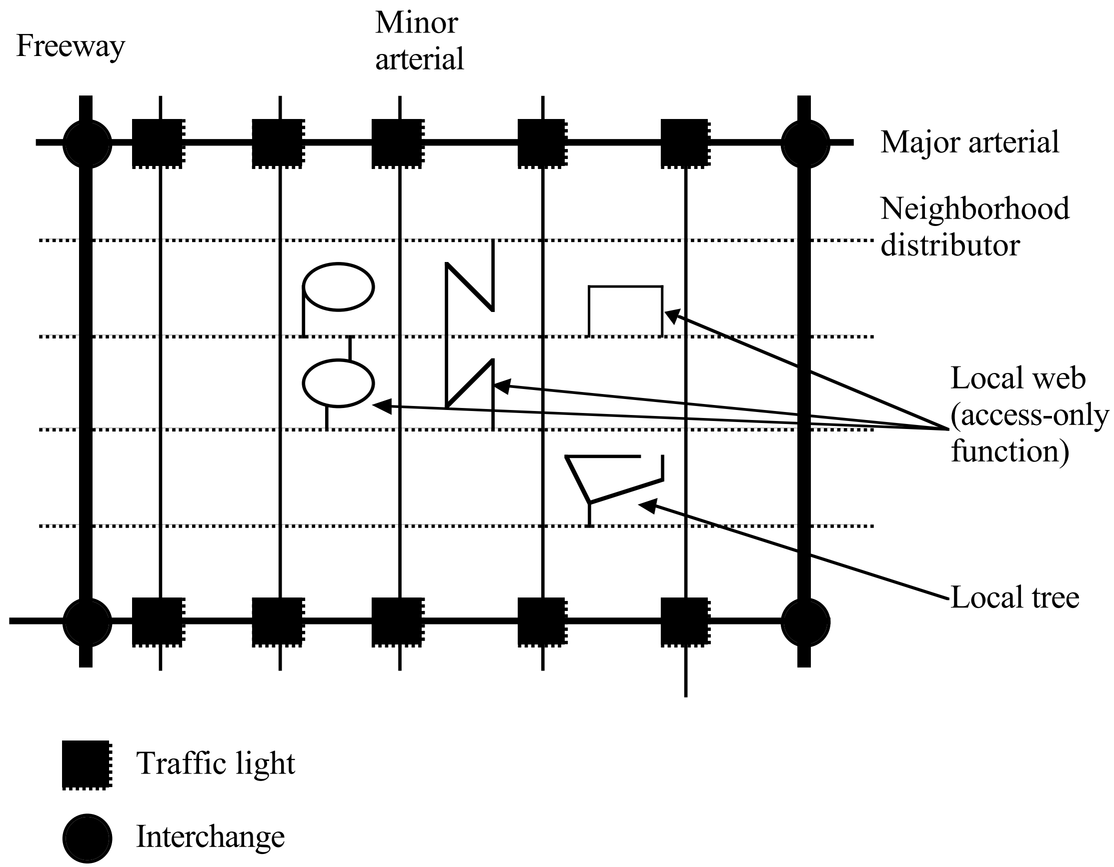
Freeway Sections

- "A Freeway is a divided highway with full access control and 2 or more lanes in each direction for the exclusive purpose of moving traffic"
- It serves no access function, and is at the top of the hierarchy of roads.
- A basic freeway section is an area separated from on and off ramps, so that we are dealing only with a "pipeline" and no complications.

Hierarchy of Roads

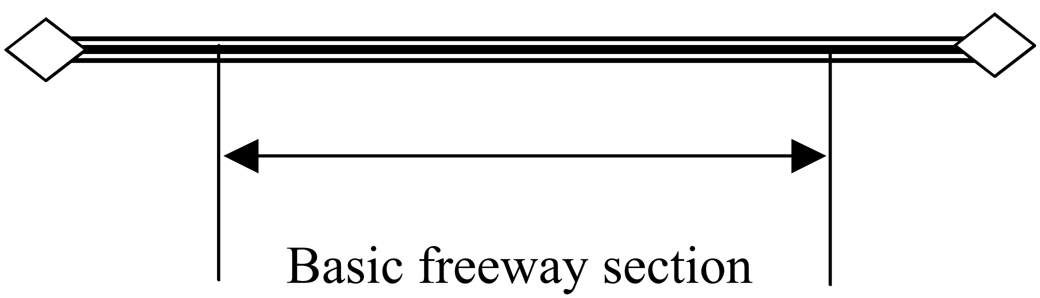


Typical Urban Network Elements



Basic Freeway Section

- A freeway consists of basic freeway sections, weaving areas, and ramp junctions (merges and diverges)



Objective

- The objective is to be able to assess the level of service on freeway segments and to design freeway segment to attain a specific level of service. By design, it means determining acceptable grade and width (number of lanes).

- In ideal conditions
  - Lane Width: Lanes are 3.65 m wide
  - Lateral Clearance: There is lateral clearance between the edge of the right (outside) lane and an obstacle 2 meters or greater.
  - Vehicle Equivalents: There are no trucks, buses, RVs or other heavy vehicles in the traffic stream.
  - Spacing: Interchanges are at least 3 km apart
  - Grades: Grades do not exceed 2 %
  - Driver Population: Drivers are familiar with the road (i.e. commuters)
  - Urban Freeways are 5 lanes in each direction

Capacity and Level Of Service

- Capacity is the maximum sustained 15 min rate of flow in pcphpl (passenger cars per hour per lane) that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in 1 direction.
- LOS Level of Service qualititatively measures operating conditions within a traffic systems as a function of variance from ideal conditions. A is best, F is worst.

LOS	Conditions Density pcpmpl	Density pc/km/lane
A	< 10 pcpmpl	<6
B	< 16	<10
C	< 24	<15
D	< 32	<19.2
E	< 45	<27
F	≥45	≥27

Flow Rate Per Lane

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

where v_p = highest 15 minute volume per lane in passenger car equivalents

V =hourly volume (vehicles per hour)

PHF = Peak Hour Factor (hourly volume divided by 4 times the peak 15 minute volume)

N = number of lanes in one direction

f_{HV} = factor that adjusts for number of heavy vehicles in the traffic stream

f_p = driver population factor

Example 1

- Given 15 minute volumes of 1000, 900, 800, 850, 2 lanes, 100% commuter traffic, and a heavy vehicle factor of 1. (and otherwise ideal conditions) What is the highest 15 minute volume per lane in passenger car equivalents?
- PHF = (1000 + 900 + 800 + 850) / (4* 1000)= 0.89
- Peak hour factors generally range from 0.85 to 1.0 (perfectly even traffic). (and in principle range from 0.25 (perfectly concentrated traffic) to 1.0.

$$v_p = \frac{V}{PHF\, N\, f_{HV}\, f_p} = \frac{3550}{0.89 * 2 * 1 * 1} = 2000\, pcphpl$$

Heavy Vehicle Factor

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

- where:
- P_T, P_R, = proportion of heavy trucks, recreational vehicles
- E_T, E_R, = Passenger Car Equivalent (PCE) of heavy trucks, recreational vehicles

- Passenger Car Equivalents -- Converting Trucks, Buses and RV's to cars.
- Trucks weigh more than cars and have greater difficulty maintaining speed uphill, as a result, they drive slower than cars, and gaps open in front. Moreover, they are longer and thus take more space. Trucks and buses have near identical characteristics, so they are lumped together. RV's are somewhat different (not as heavy as trucks)

Passenger Car Equivalents

- Tables 7.3-7.6 have PCE's of trucks and RV's for extended general freeway segments (level terrain, rolling terrain, and mountainous terrain), specific upgrades, and specific downgrades.
- Level Terrain - Grades are short and < 2%
- Rolling Terrain - Grades are longer and may be > 2%
- Mountainous Terrain - Grades are longer still and may be >> 2%
- Specific Upgrades. Any grade > 3% and longer than 0.5 km or less than 3% but longer than 1 km should be considered a specific upgrade and analyzed separately from and extended general freeway segment
- Specific Downgrades: Any grade that requires trucks to shift into low gear should be considered a specific downgrade
- Composite Grades - With multiple upgrades of different slopes, it is common practice to determine the average grade and use Tables 9.3 or 9.4

Example 2

- Determine the heavy vehicle factor of the following conditions: 4% upgrade 10% trucks, 4% recreational vehicles 1 km segment
- From Table 7.4, 4% grade, 1/2 - 3/4 mile, 10% truck --> $E_T = 7.0$
- From Table 7.5 4% grade > 1/2 mile, 4% RV --> $E_R = 2.5$ passenger car equivalents

Example 2 Continued

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

$$f_{HV} = \frac{1}{1 + .10\left(7.0 - 1\right) + .04\left(2.5 - 1\right)}$$

$$= 0.6$$

Example 1 Revisited

$$v_p = \frac{V}{PHF\ N\ f_{HV}\ f_p} = \frac{3550}{0.89 * 2 * 0.6 * 1} = 3333 pcphpl$$

- Redoing Example 1 with $f_{HV} = 0.6$
- 3333 pcphpl is greatly in excess of capacity. Thus it is unlikely that with these grades and % trucks, that that kind of volume could be sustained.

Driver Adjustment Factor

- Driver adjustment factor - generally assume to be 1.0 unless otherwise specified, as peak hours tend to be commuter times.

Determination of Freeflow Speeds (Multi-Lane Highways)

- Determination of freeflow speeds (FFS). How fast will traffic go when unimpeded. Actual Freeflow speed will differ from ideal (FFS_i), as it will be affected by lane width f_{LW}, right shoulder lateral clearance f_{LC}, and interchange density (access points) f_A. (There are other adjustments for number lanes (f_N) and median (f_M)). These adjustment factors are in Tables 7.9 - 7.12. Normally assume 70 - 75 mph (120 kph)
- **FFS** = $FFS_i - f_{LW} - f_{LC} - f_A - f_N - f_M$

F_A - Adjustment for access points (Multi-Lane Highways)

- Rule: Number of Access Points per Mile (NAPM)
- If NAPM ≤ 40, $f_A = 0.25 * NAPM$
- If NAPM >40, f_A=10

Example 3

- Calculate adjusted freeflow speed for a multi-lane highway
  - Ideal FFS = 120 km/hr. Given 4 lanes, 3 m lanes, lateral clearance = 1 meter, interchange density = 1 per 4 km. (0.41 interchanges per mile)
  - Table 7.11 give lane width adjustment, at 10ft: 6.5 mph = 10.5 km/hr
  - Table 7.12 gives a right shoulder lateral clearance adjustment at 3 ft, 4 lanes 2.4 mph = 4.0 km/hr
  - Equation 7.10 gives adjustment for interchange density. less than 0.5 interchanges per mile, f_A=0.25 * 0.41= 0.10 mph =0.16 km/hr reduction

- Net **FFS** = **FFS**$_i$ - f_{LW} - f_{LC} - f_A = 120 - 10.5 - 4.0 -0.16=105.3

Example 4

- Determine the number of lanes required to maintain level of service D (or better) on a freeway section, given the following info:
  - 15 minute volumes = 2000, 1800, 1750, 1700
  - Trucks and buses = 5%
  - RVs = 0%
  - Free flow speed = 120 km/hr
  - Lane width = 3.65 m
  - lateral obstruction none
  - interchange spacing 1 interchange per km.
  - fp = 0.95
  - Rolling terrain
  - FFS = 113.5 at N=4, 115 at N=5,6
- Required maximum density at LOS D = 32 pcpmpl = 20 pc/km/lane
  - Q=KV

Example 4 Continued

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + 0.05(3.0 - 1)} = 0.91$$

$$v_p = \frac{V}{PHF\ N\ f_{HV}\ f_p} = \frac{2000+1800+1750+1700}{0.91*4*0.91*0.95} = 2305\,pcphpl$$

$$v_p = \frac{V}{PHF\ N\ f_{HV}\ f_p} = \frac{2000+1800+1750+1700}{0.91*5*0.91*0.95} = 1843\,pcphpl$$

$$v_p = \frac{V}{PHF\ N\ f_{HV}\ f_p} = \frac{2000+1800+1750+1700}{0.91*6*0.91*0.95} = 1536\,pcphpl$$

PHF = (2000 + 1800 + 1750 + 1700) / (4* 2000)= 0.91

Try N = 4,5,6 $Q=v_p$ V = net FFS

Q = KV Solve for K

Try N = 4

2305=K*113.5 → K=20.3 > 19.2 unacceptable

N = 5

1843=K*115 -> K= 16 < 19.2 acceptable

N = 6

1536 = K 115 → K= 13.35 << 19.2 over designed.(LOS C)

<u>Choose N=5</u>

Two Lane, Two-Way Rural Highways

- Two levels of analysis: Operational and System Planning.

- Operational: Describe quality of service with
- Average travel speed
- Percent Time delay
- Capacity Utilization (V/C)
- Average percentage of marked no passing zones

Highway Systems Planning

- Planning level analysis for 2 lane roads requires less data than operational analysis. For instance, it may be conducted before a design is finalized, to enable comparisons between alternatives.
- $SF_i = K * AADT / PHF$
  - *AADT* = maximum average annual daily traffic for a level of service (in vehicles/day)
  - *PHF* = Peak Hour Factor
  - SF_i = Maximum service flow rate at a level of service (in vehicles/hour)
  - *K* = Design hour factor (proportion of AADT expected to occur in design hour). **K=DHV/AADT**

- The following assumptions underlie the analysis
- Traffic mix 14% trucks, 4% RVs, 0% buses
- Directional split = 60/40
- Percentage of no passing zones = 20% for level terrain, 40% for rolling terrain, 60% for mountainous terrain
- Lane width = 3.65 m,
- Shoulder width = 1.82 m
- Design Speed = 96 km/hour

Example: Computing LOS with Planning Level Analysis

- Present volume on road is 10000 AADT, which is growing at 1% per year. Terrain is level. Determine Hourly Service Flow in 10 years.

- AADT in 10 years = $10000\,(1 + 0.01)^{10}$= 11046 AADT
- K_{30} factor = 0.12 (from figure 7.9)
- PHF (LOS D) given (or from table) = 0.95
- $SF_D = K * AADT / PHF$ =0.12*11046/0.95= 1395

Level of Service (Two lane Rural Highways)

LOS	Speed (mph)	Speed (km/hour)	Percent Time Delay	Maximum Flow (SFR) (pc/hr) in both directions
A	>60	96	<30%	420
B	>55	88	30-45%	750
C	>52	83	45-60%	1200
D	>50	80	60-75%	1800
E	>45	72	75-100%	2800
F	<45	72	>100%	2800

Capacity (Maximum Service Flow Rate)

$$SF_i = 2800 \left(\frac{v}{c} \right)_i f_d f_w f_g f_{HV}$$

- SF_i = Service flow rate for LOS i or speed i in vehicles/hour for BOTH directions for prevailing roadway and traffic conditions.
- v/c_i = volume to capacity ratio for a given LOS I or speed I (table 7.15)
- f_d = adjustment factor for directional distribution (table 7.14)
- f_w = adjustment factor for lane width and shoulder width (table 7.16)
- f_g = adjustment factor for operation of passenger cars on grades (assume 1.0 unless told otherwise - specific upgrade)
- f_{HV} = adjustment factor for traffic mix. (table 7.17)

Example 1

- Determine the level of service at which a two lane road will operate, given:
  - No Grade: Level Terrain
  - Lane width 3.65 m, 2 m shoulders,
  - 30% No passing Zone
  - 50/50 Directional Split
  - Proportion of trucks 0.15
  - Proportion of RVs 0.05
  - Proportion of buses 0.01
  - 15 minute Volumes: 400, 300, 350, 350

- Solution:
- f_d (from table 7.14) = 1.0
- f_g = 1.0
- f_w for LOS A - D (from table 7.16) = 1.0
- f_w for LOS E (from table 7.16) = 1.0
- f_{HV} (table 7.17)

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

$$= \frac{1}{1 + 0.15\left(E_T - 1\right) + 0.05\left(E_R - 1\right) + 0.01\left(E_B - 1\right)}$$

Example 1 (Heavy Vehicle Factor)

- LOS A
  - $E_T = 2$, $E_R = 2.2$, $E_B = 1.8$

$$f_{HV} = \frac{1}{1 + 0.15(2.0 - 1) + 0.05(2.2 - 1) + 0.01(1.8 - 1)} = 0.82$$

- LOS B and C
  - $E_T = 2.2$, $E_R = 2.5$, $E_B = 2.0$

$$f_{HV} = \frac{1}{1 + 0.15(2.2 - 1) + 0.05(2.5 - 1) + 0.01(2.0 - 1)} = 0.79$$

- LOS D and E
  - $E_T = 1.8$, $E_R = 2.0$, $E_B = 1.6$

$$f_{HV} = \frac{1}{1 + 0.15(1.8 - 1) + 0.05(2.0 - 1) + 0.01(1.6 - 1)} = 0.85$$

Example 1 (Service Flow Equations)

$$SF_A = 2800\left(\frac{v}{c}\right)_A f_d f_w f_g f_{HV} = 2800(0.105)(1)(1)(1)(0.82) = 241$$

$$SF_B = 2800\left(\frac{v}{c}\right)_B f_d f_w f_g f_{HV} = 2800(0.225)(1)(1)(1)(0.79) = 498$$

$$SF_C = 2800\left(\frac{v}{c}\right)_C f_d f_w f_g f_{HV} = 2800(0.375)(1)(1)(1)(0.79) = 830$$

$$SF_D = 2800\left(\frac{v}{c}\right)_d f_d f_w f_g f_{HV} = 2800(0.61)(1)(1)(1)(0.85) = 1451$$

$$SF_E = 2800\left(\frac{v}{c}\right)_E f_d f_w f_g f_{HV} = 2800(1.00)(1)(1)(1)(0.85) = 2380$$

Example 1 (Compute LOS)

- Convert hourly volume to equivalent 15 minute peak using PHF.
- Calculate PHF
- PHF = Peak Hour Factor (hourly volume divided by 4 times the peak 15 minute volume)
- 15 minute Volumes: 400, 300, 350, 350, Hourly = 1400
- 4* Peak = 1600
- PHF = 1400/1600 = 0.875. v = 1400 / 0.875 = 1600 vehicles/hour
- 2380 = LOS E >1451 > LOS D = 1600, then LOS is E.