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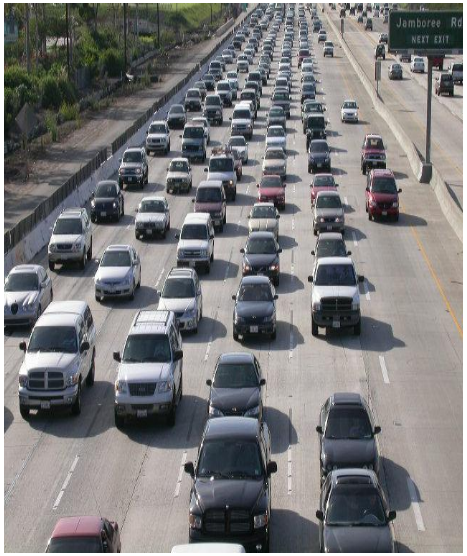
SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Transport Engineering
CENG 3201

Chapter 4
Highway Capacity and Level of Service Concepts

Tamru T.



2012 EC (2019/20 GC)
1st Sem

Lecture Overview

- Highway Capacity
- Factors affecting level of service
- Determining the capacity and LOS of a highway
  - Analysis Methodologies for Basic Freeway Sections and Multilane Highways
    - Operational analysis
    - Service flow rate and service volume analysis
    - Design analysis
  - Analysis method of Two-Lane Rural Highways Capacity

Highway Capacity

- The maximum hourly flow rate at which the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under prevailing roadway, traffic and control conditions with a reasonable expectation of occurrence.
- Highway capacity depends on certain conditions as listed below;
  - Road way characteristics:
  - Traffic conditions:
  - Control conditions:

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Level of Service (LOS)

- A quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Capacity	Vs	LOS
Quantitative measure		Qualitative measure.

- Is related with the *physical characteristics* of the highway and the different *operating characteristics* that can occur when the highway carries different traffic volumes.
- Capacity could be constant. But actual flow will be different for different days and different times in a day itself. LOS is related to the traffic service quality to a given flow rate of traffic.
- Speed-flow-density relationships are the principal factor affecting the level of service of a highway segment under ideal conditions.

Level of Service (LOS) Cont

- Highway capacity manual (HCM) divides the quality of traffic into six levels ranging from level A to level F.
  - ***LOS A:***
    - Free-flow operations. At these low densities, operation of each vehicle is not greatly influenced by the presence of others. Average spacing of 146m (24 car lengths).
    - This represents free-flow conditions
    - Only the geometric design features of the highway may limit the speed of the car.
    - Comfort and convenience levels for road users are very high as vehicles have almost complete freedom to maneuver.

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Level of Service (LOS) Cont…

- ***LOS B:***
  - Drivers begin to respond to the existence of other vehicles in the traffic stream, although operation is still at the free-flow speed. Average spacing of 89m (15 car lengths).
  - Comfort and convenience levels for road users are still relatively high as vehicles have only slightly reduced freedom to maneuver.
  - Minor accidents are accommodated with ease although local deterioration in traffic flow conditions would be more discernible than in service A.

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Level of Service (LOS) Cont…

- ***LOS C:***
  - Operations remain at the FFS, but drivers now need to adjust their course to find gaps they can use to pass or merge. Average spacing of 62m (10 car lengths).
  - There are marked restrictions in the ability to maneuver and care is required when changing lane.
  - While minor incidents can still be absorbed, major incidents will result in the formation of queues.
  - The speed chosen by the driver is substantially affected by that of the other vehicles.
  - Driver comfort and convenience have decreased perceptibly at this level.

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Level of Service (LOS) Cont…

- ***LOS D:***
  - Density deteriorates more quickly with flow. Average spacing of 46m (7 car lengths).
  - The highway is operating at high-density levels but stable flow still prevails.
  - Small increases in flow levels will result in significant operational difficulties on the highway.
  - There are severe restrictions on a driver's ability to maneuver, with poor levels of comfort and convenience.

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Level of Service (LOS) Cont…

- ***LOS E:***
  - Difficult to maneuver. Average spacing of 36m (6 car lengths).
  - Represents the level at which the capacity of the highway has been reached.
  - Traffic flow conditions are best described as unstable with any traffic incident causing extensive queuing and even breakdown.
  - Levels of Basic Elements of comfort and convenience are very poor and all speeds are low if relatively uniform.

Level of Service (LOS) Cont…

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

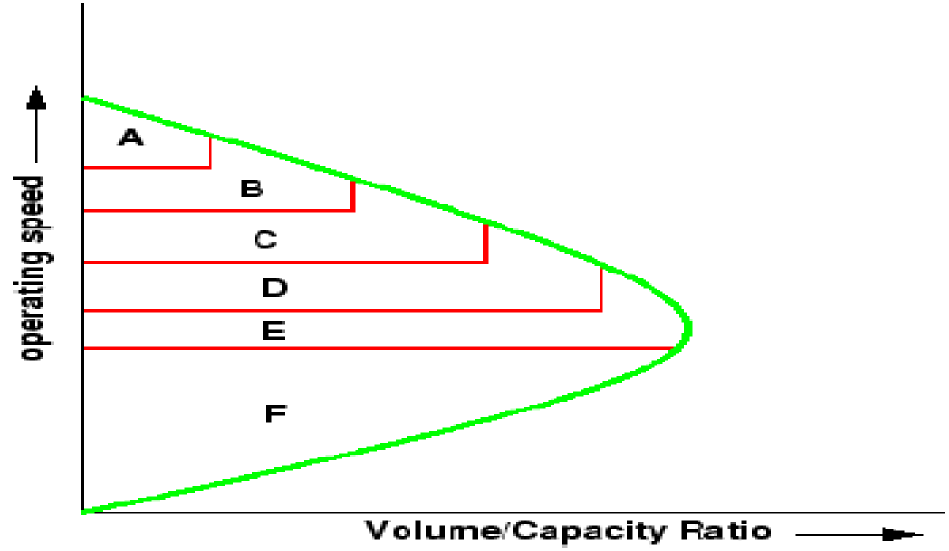
Level of Service (LOS) Cont…

Factors affecting level of service

- Speed and travel time
- Traffic interruptions/restrictions
- Freedom to travel with desired speed
- Driver comfort and convenience
- Operating cost.
- Lane width,
- Lateral obstruction,
- Traffic composition,
- Grade and
- Driver population

Level of Service (LOS) Cont…

- Highway Capacity Manual (HCM) used travel speed and volume by capacity ratio (v/c ratio) to distinguish between various levels of service.
- The value of v/c ratio can vary between 0 and 1.



Relation between level of service (LOS), speed and flow/capacity

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Level of Service (LOS) Cont…

- *Hourly volume (V):-* The highest hourly volume within a 24-hour period
- *Peak-hour factor (PHF):-* The ratio of the hourly volume to the peak 15 minute flow (V_{15}) enlarged to an hourly value

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

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

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

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Level of Service (LOS) Cont…

Two lane rural Highway

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

Freeways:-

- Are the only type of facilities providing pure uninterrupted flow.
- Are generally classified by the total number of lanes provided in both direction.

Multilane Highways

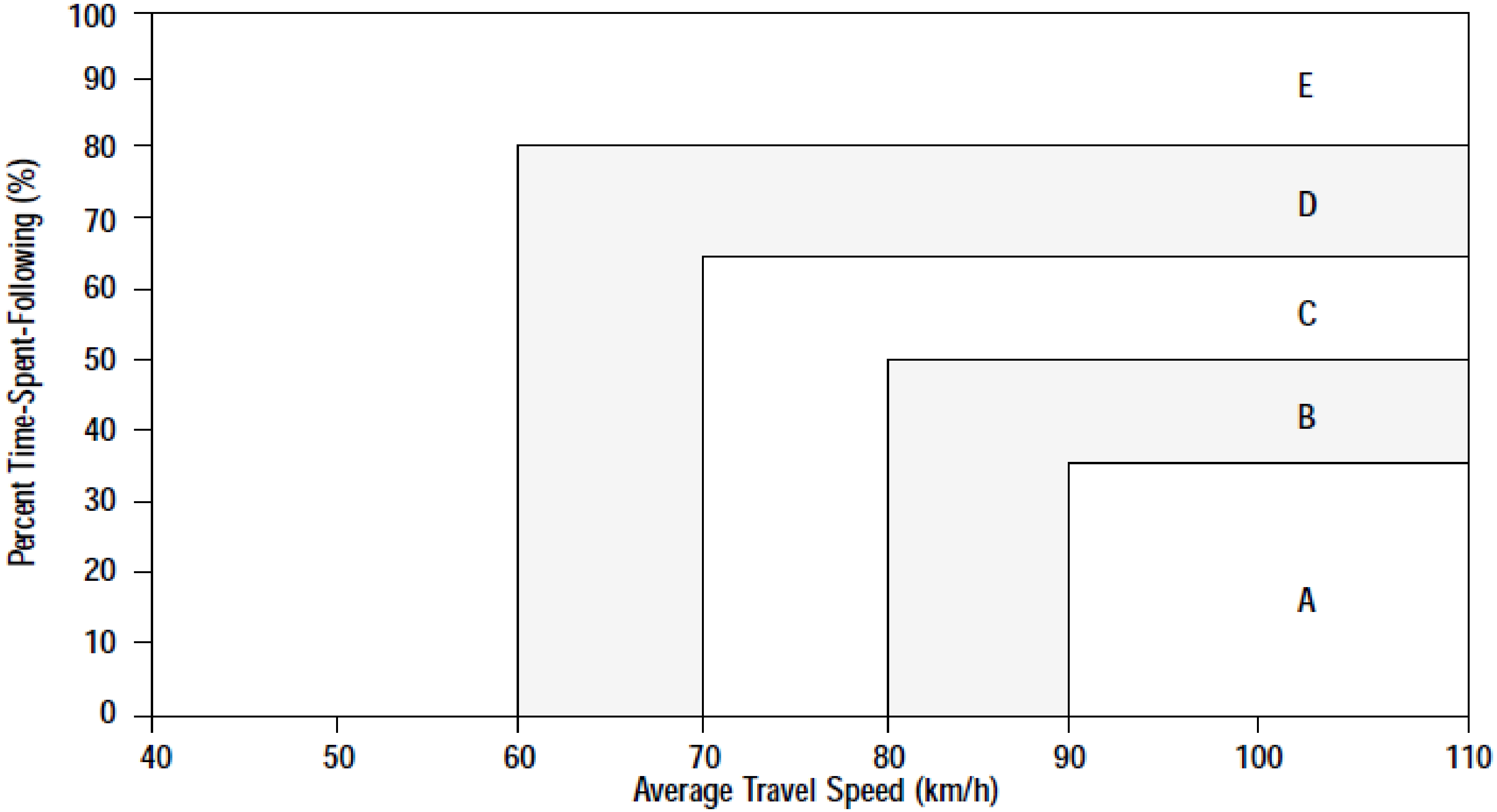
- Are classified by the number of lanes and the type of median treatment provided.
- They generally consists of 4 or 6 lane alignments.
- They can be undivided or divided. In some suburban areas, also two-way left turn lane (as a median)

Two-Lane Rural Highways LOS

Defined in terms of two measures of effectiveness:

- *Average travel speed (ATS):-* is the average speed of all vehicles traversing the defined analysis segment for the specified time period, which is usually the peak 15-minutes of a peak hour.
- *Percent time spent following (PTSF):-* is the aggregate percentage of time that all drivers spend in queues, unable to pass, with the speed restricted by the queue leader.

Two-Lane cont…



Relation between level of service (LOS), speed and %time-spent-following

Types of Analysis

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

Two-Lane Rural Highways LOS

- *Class I:-* Two lane highway on which motorists expect to travel at high speed. Include inter-city routes, primary arterials connecting major traffic generators, daily commuters routes, the primary links in stat e or national highway networks.

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

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

Two-Lane LOS Cont…

- *Class II:-* Two lane highway on which motorists do not necessarily expect to travel at high speed. Scenic or recreational routes, or routes that pass through rugged terrain, are typically assigned to class II, and these routes generally serve shorter trip lengths than class I routes.

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

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

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Free-flow speed

Defined in terms of two measures of effectiveness:

- *Field Measurement:-* must be made at total flow levels higher than 200 pc/h, the free-flow speed may be estimated as:

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

Where:

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

Free-flow speed Cont…

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

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

Where:

- FFS = free-flow speed for the facility, km/hr,
- BFFS =base free-flow speed for the facility, km/hr;
  - Class I highways usually in the 88-105 km/h range and
  - Class II highways usually in the 72-80 km/h range.
  - Sometimes the design speed is a reasonable surrogate for the BFFS.
- f_{LS} = adjustment for lane and shoulder width, km/h and
- f_A = adjustment for access point density, km/h

Free-flow speed Cont…

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

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

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

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

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Demand Flow Rate

- Requires that an hourly volume reflecting prevailing conditions be adjusted to reflect peak flow rates within the hour and base conditions.

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

Where:

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

Demand Flow Rate Cont…

- *Grade Adjustment Factors* f_G:- two grade adjustment factors will be required: one for the ATS determination and one for the PTSF determination.
- **For ATS**

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

Table: Grade Adjustment Factor (f_G) for General Terrain Segments and Specific Downgrades ATS Determinations

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Demand Flow Rate Cont…

- **For PTSF**

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

Table: Grade Adjustment Factor (f_G) for General Terrain Segments and Specific Downgrades PTSF Determinations

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Demand Flow Rate Cont…

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

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

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Average Travel Speed

Once the appropriate demand flow rate(s) are computed, the average travel speed in the section is estimated using :

$$ATS = FFS - 0.0125v_p - f_{np}$$

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np}$$

Where:

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

Percent Time Spent Following

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

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

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

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

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

Where:

PTSF = percent time spent following, two directions, %

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

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

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

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

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

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

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

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Table:- Coefficients "a" and "b"

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

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

Table : Adjustment (fnp) to PTSF for Percent "No Passing" Zones in Single-Direction Segments

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

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

Example 1 (two lanes highway)

One segment of a class I two lane highway is on rolling terrain and has two way hourly volume of 500 veh/hr with $PHF = 0.94$, and the traffic stream contains 5% large trucks, 2% buses, and 6% recreational vehicles. For these conditions determine the **two-way segment** LOS.

- No passing Zone =40%
- Lane Width = 3.4m
- Shoulder Width = 0.8m
- Directional Split= 60/40
- BFFS= 88km/h
- 12 access point per km

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Exercise (two lanes highway)

A class I two lane highway is on rolling terrain and has analysis direction hourly volume of 1200 veh/hr and opposing direction volume of 400veh/hr with *PHF = 0.95*, and the traffic stream contains 14% trucks and buses, and 4% recreational vehicles. Determine the **peak direction** LOS.

Other data

- No passing Zone = 50%
- Lane Width = 3.3m
- Shoulder Width = 1.2m
- BFFS= 100km/h
- 12access points/km

QUESTIONS?

Level of Service for **Multilane Highway**

- Speed-Flow Characteristics

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

For Multilane highways, the measure of effectiveness used to define levels of service is density.

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

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

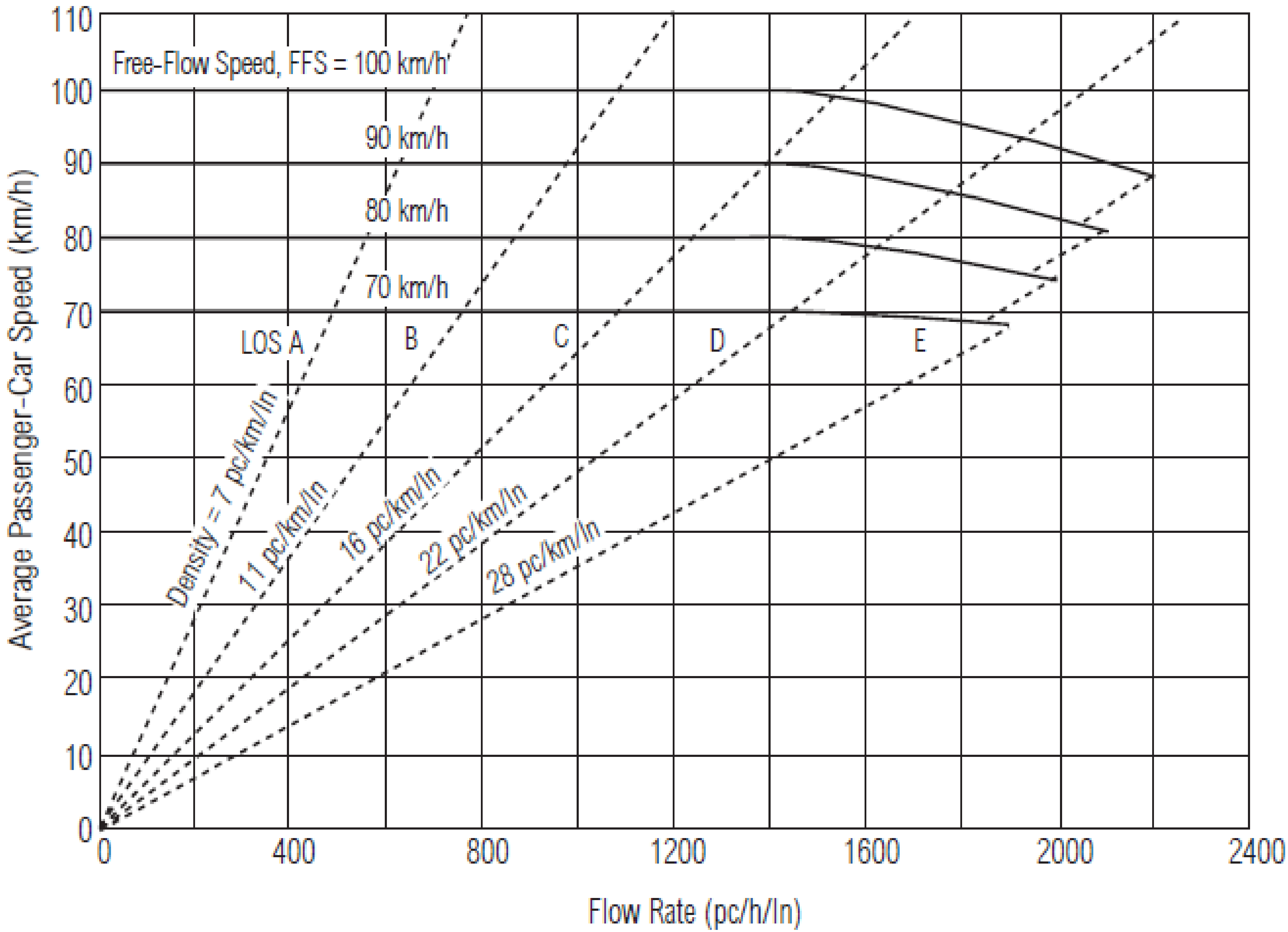

Fig Speed-Flow Curves for Multilane Highway Sections

Types of Analysis

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

All forms of analysis require the determination of the free-flow speed of the facility in question.

Operational Analysis

- All traffic, roadway, and control conditions are defined for an existing or projected highway section, and the expected level of service and operating parameters are determined.
- Convert the existing or forecast demand volumes to an equivalent flow rate under ideal conditions:

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

Where:

V_P = demand flow rate under equivalent ideal conditions, pc/h/ln

PHF = peak-hour factor

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

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

f_P = adjustment factor for driver population presence of occasional or non-familiar of a facility

Heavy Vehicle Adjustment Factor; f_{HV}

- Based upon the concept of passenger-car equivalents.
- A passenger-car equivalent is the number of passenger cars displaced by one truck, bus, or RV in a given traffic stream under prevailing conditions.
- Two passenger car equivalent values are defined:
  - E_T = passenger car equivalent for trucks and buses in the traffic stream under prevailing conditions
  - E_R = passenger car equivalent for RV's in the traffic stream under prevailing conditions

- *Where:* P_T = proportion of trucks and buses in the traffic stream,
  P_R = proportion of RV s in the traffic stream
  E_T = passenger car equivalent for trucks and buses,
  E_R = passenger car equivalent for RV s

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

Heavy Vehicle Adjustment cont……

- By definition, the heavy-vehicle adjustment factor , f_{HV} converts veh/h to pc/h when divided into the flow rate in veh/h. Thus:

$$V_{pce} = \frac{V_{vph}}{f_{HV}}.$$

- Where: V_{pce} = flow rate, pce/h
  V_{vph} = flow rate, veh/h

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

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

Passenger-Car Equivalents for Specific Grades on Freeways and Multilane Highways should be considered.

Driver Population Adjustment Factor; fp

- It is correction for the case when non commuter drivers are prevalent in the traffic stream.
- Not well defined and is dependent upon local conditions.

The values for **fp** range from **0.85 to 1.00**. Typically, the analyst should select **1.00,** which reflects weekday commuter traffic (i.e., users familiar with the highway),

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Free-Flow Speed for Multilane

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

Where:

- **FFS** = free-flow speed of the freeway, km/hr;
- **BFFS** = base free-flow speed of the freeway , km/hr

  (base free-flow use 97km/hr for both rural and suburban if no date is available)
- $\mathbf{f_{LW}}$ = adjustment for lane width, km/h;
- $\mathbf{f_{LC}}$ = adjustment for lateral clearance, km/h;
- $\mathbf{f_{M}}$ = adjustment for type of median, km/h;
- $\mathbf{f_{A}}$ = adjustment for access points, km/h

Free-Flow Speed for Multilane Cont…

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

Adjustment to Free-Flow Speed for Lane Width on a Multilane (f_{LW})

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

Note:

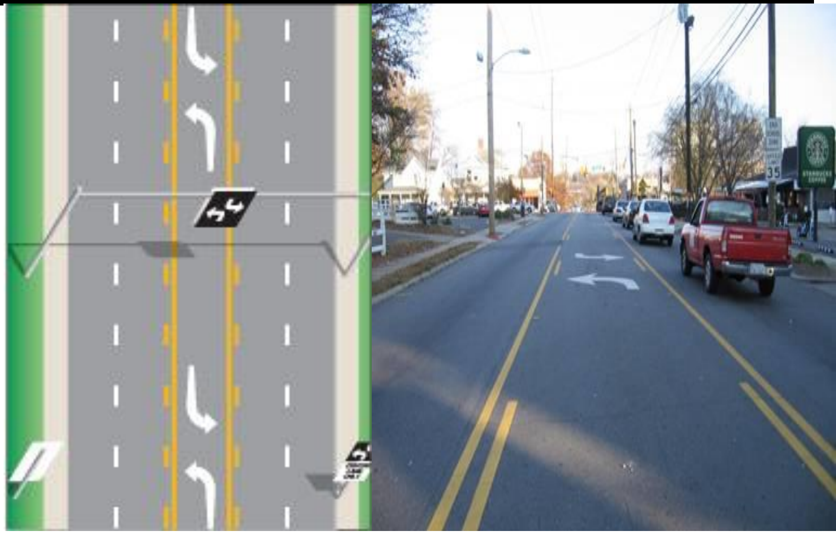
a. Total lateral clearance is the sum of the lateral clearances of the median (if greater than 1.8 m, use 1.8 m) and shoulder (if greater than 1.8 m, use 1.8 m). Therefore, for purposes of analysis, total lateral clearance cannot exceed 3.6 m.

Adjustment to Free-Flow Speed for Lateral Clearance on a Multilane (f_{LC})

Free-Flow Speed for Multilane Cont…

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

Adjustment to Free-Flow Speed for Median Type on Multilane Highways (f_M)



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

Adjustment to Free-Flow Speed for Access-Point Density on a Multilane Highway (f_A)

Example 3 (Multi lanes)

A 4.5km road segments five lanes highway with two travel lane in each direction separated by TWLTL. The grade of the highway is 4% with 1630m. Peak hour volume is 1500veh/h.

- Level terrain
- 75km/h field measure BFFS
- 3.6m lane width
- Greater lateral clearance both direction
- Truck and buses =9%
- Rvs= 3%
- PHF=0.9
- Drivers are commuter
- 6 access points/km

Find the LOS of at peak hour, speed and density for the different road section.

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Free-Flow Speed for Freeways

- For basic freeway segment, the measure of effectiveness used to define levels of service is density.
- The base conditions under which the full capacity of a basic freeway segment is achieved are good weather, good visibility, and no incidents or accidents.

Criteria	LOS				
	A	B	C	D	E
FFS = 120 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	120.0	120.0	114.6	99.6	85.7
Maximum v/c	0.35	0.55	0.77	0.92	1.00
Maximum service flow rate (pc/h/ln)	840	1320	1840	2200	2400
FFS = 110 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	110.0	110.0	108.5	97.2	83.9
Maximum v/c	0.33	0.51	0.74	0.91	1.00
Maximum service flow rate (pc/h/ln)	770	1210	1740	2135	2350
FFS = 100 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	100.0	100.0	100.0	93.8	82.1
Maximum v/c	0.30	0.48	0.70	0.90	1.00
Maximum service flow rate (pc/h/ln)	700	1100	1600	2065	2300
FFS = 90 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	90.0	90.0	90.0	89.1	80.4
Maximum v/c	0.28	0.44	0.64	0.87	1.00
Maximum service flow rate (pc/h/ln)	630	990	1440	1955	2250

Note:
The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. The speed criterion is the speed at maximum density for a given LOS.

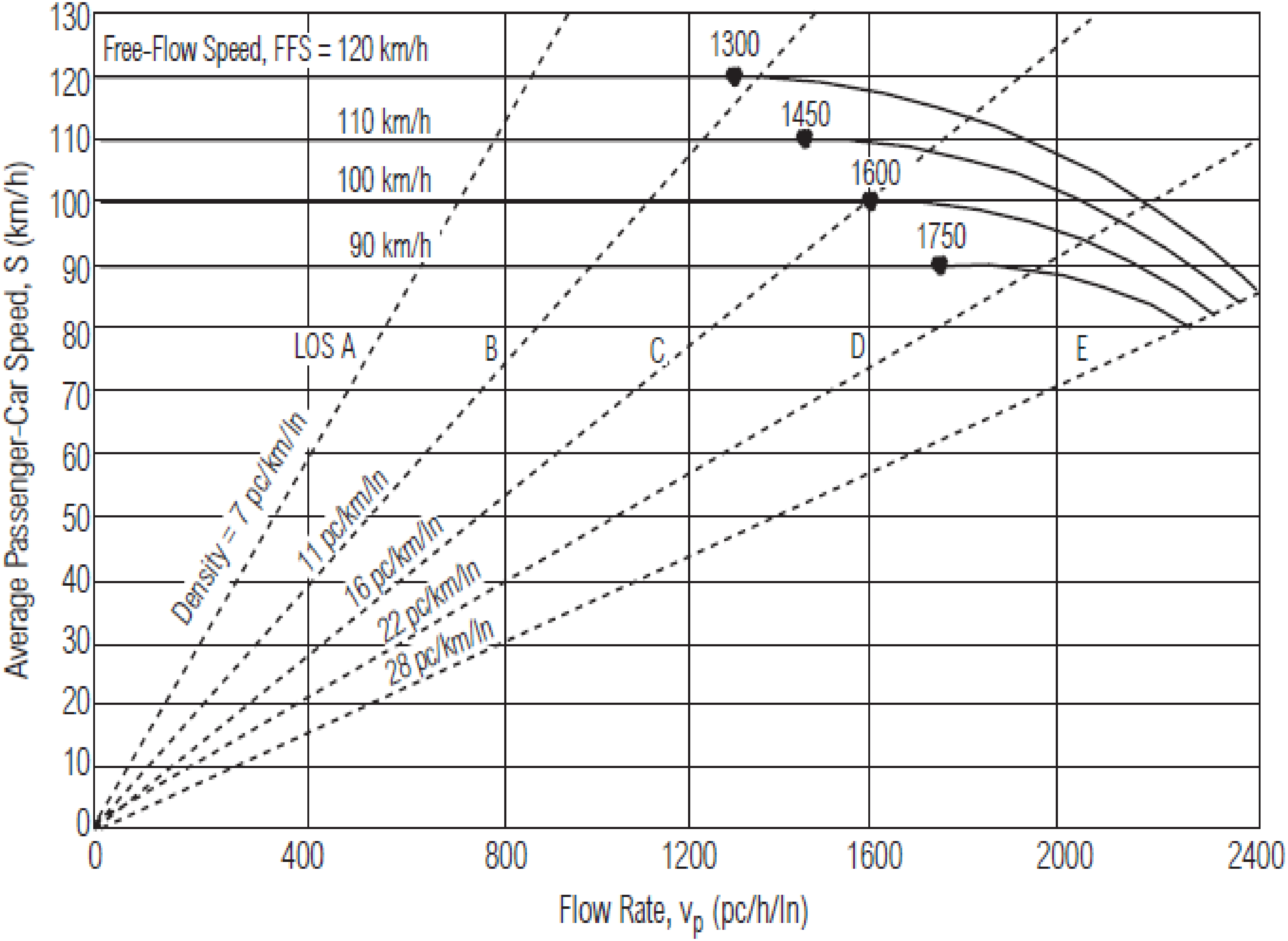

Fig Speed-Flow Curves for Basic Freeway Sections

Free-Flow Speed for Freeways

- An average speed measured when flow is less than or equal to 1,000 veh/h/ln may be taken to represent the free-flow speed.

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

Where:

- FFS = free-flow speed of the freeway, km/h;
- BFFS = base free-flow speed of the freeway km/h

(113km/h for urban and suburban freeways, 121km/h for rural freeways);

- f_{LW} = adjustment for lane width, km/h;
- f_{LC} = adjustment for lateral clearance, km/h;
- f_{N} = adjustment for number of lanes, km/h;
- f_{ID} = adjustment for interchange density, km/h

Free-Flow Speed for Freeways Cont…

Adjustment to Free-Flow Speed for Lane Width on a Freeway (f_{LW})

Lane Width (m)	Reduction in Free-Flow Speed, f_{LW} (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

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

Right-Shoulder Lateral Clearance (m)	Reduction in Free-Flow Speed, f_{LC} (km/h) – Lanes in One Direction: 2	3	4	≥ 5
≥ 1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.7	0.3	0.2
1.2	1.9	1.3	0.7	0.4
0.9	2.9	1.9	1.0	0.6
0.6	3.9	2.6	1.3	0.8
0.3	4.8	3.2	1.6	1.1
0.0	5.8	3.9	1.9	1.3

Free-Flow Speed for Freeways Cont…

Adjustment to Free-Flow Speed for Number of Lanes on a Freeway (f_N)

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (km/h)
≥ 5	0.0
4	2.4
3	4.8
2	7.3

Note: For all rural freeway segments, f_N is 0.0.

Interchanges per Kilometer	Reduction in Free-Flow Speed, f_{ID} (km/h)
≤ 0.3	0.0
0.4	1.1
0.5	2.1
0.6	3.9
0.7	5.0
0.8	6.0
0.9	8.1
1.0	9.2
1.1	10.2
1.2	12.1

Adjustment to Free-Flow Speed for Interchange Density on a Freeway (f_{ID})

Example 4 (basic Free way)

In particular urban , which is expect in growing area it has existing four lane free way and the following data:

- Hourly Volume
  existing v = 5500 VPH (both direction)
  In three years v = 6050 VPH (both direction)
- Traffic Growth factor 5%
- PHF = 0.94
- Traffic Composition
  Buses = 12%
  RV = 10%
- Terrain = Rolling
- Drivers are commuters
- Lane = 4 lane (total)
- FFS from field measurement = 110km/h
- Assume all parameters are constant for the future
- 50/50 directional split

✓ What is current LOS during PH?

✓ What LOS will occur in 3 years?

✓ When should a 3^{rd} lane be added in each direction to avoid over capacity demand?

QUESTIONS?