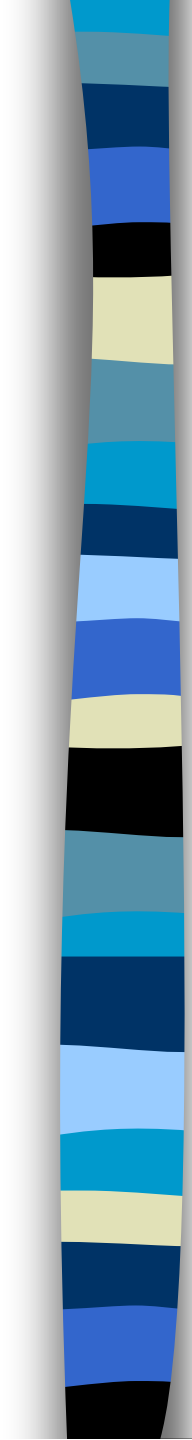


Chapter 12: Capacity and Level-of-Service Analysis for Freeways and Multilane Highways

Chapter objectives: By the end of these chapters the student will be able to:

- Explain why capacity is the heart of transportation issues.
- Define capacity and level-of-service concept and explain why capacity is not a fixed value
- Explain the relationship between the v/c ratio and level of service
- Estimate (determine) the free-flow speed of a freeway or a multilane
- Obtain proper passenger-car equivalents for trucks, buses, and RVs (Grade affects the performance of these vehicles)
- Conduct operational and planning analyses for the basic freeway and multilane highway segments



Issues of traffic capacity analysis

- How much traffic a given facility can accommodate?
- Under what operating conditions can it accommodate that much traffic?

Highway Capacity Manual (HCM)

- ❖ 1950 HCM by the Bureau of Public Roads
- ❖ 1965 HCM by the TRB
- ❖ 1985 HCM by the TRB (Highway Capacity Software published)
- ❖ 1994 updates to 1985 HCM
- ❖ 1997 updates to 1994 HCM
- ❖ 2001 updates to 2000 HCM
- ❖ 2010 HCM is scheduled to be published.

Highway capacity software



Demonstrate in
class

12.1.1 The capacity concept

The capacity of a facility is:

*“the maximum **hourly rate** at which **persons or vehicles** can be **reasonably expected** to traverse **a point or uniform segment** of a lane or roadway **during a given time period** under prevailing conditions.”*

HCM analyses are usually for the peak (worst) 15-min period.

- ❖ Traffic
- ❖ Roadway
- ❖ Control

Some regularity expected (capacity is not a fixed value)

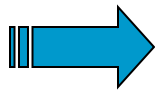
Sometimes using persons makes more sense, like transit

With different prevailing conditions, different capacity results.

12.1.2 Level of service

“Level of service (LOS) is 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.”

LOS A (best)



LOS F (worst or system breakdown)

A	Free flow
B	Reasonably free flow
C	Stable flow
D	Approaching unstable flow
E	Unstable flow
F	Forced flow

← SF_A

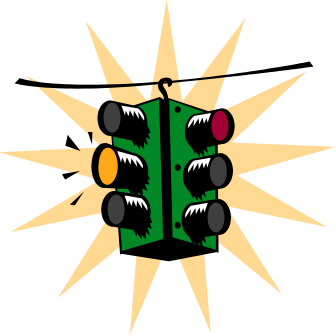
← SF_B

← SF_C

← SF_D

← SF_E

MOE in 2000 HCM

	Uninterrupted	Fwy: Basic sections	Density (pc/mi/ln)
		Fwy: Weaving areas	Density (pc/mi/ln)
		Fwy: Ramp junctions	Density (pc/mi/ln)
		Multilane highways	Density (pc/mi/ln)
		Two-lane highways	Percent-time spent following Average upgrade speed
	Interrupted	Signalized intersections	Approach delay (sec/veh)
		Unsignalized intersections	Average total delay (sec/veh)
		Arterials	Average travel speed
		Transit	Load factor (pers/seat)
		Pedestrians	Space (sq ft/ped)

12.1.3 The v/c ratio and its use in capacity analysis

$$v/c = \frac{\text{Rate of flow}}{\text{Capacity}}$$

The comparison of true demand flows to capacity is a principal objective of capacity and LOS analysis.

The volume capacity ratio indicates the proportion of the facility's capacity being utilized by current or projected traffic. ➔ Used as a measure of the sufficiency of existing or proposed capacity.

v/c is usually less than or equal to 1.0. However, if a projected rate of flow is used, it may become greater than 1.0. The actual v/c cannot be greater than 1.0 if departure volume is used for v.

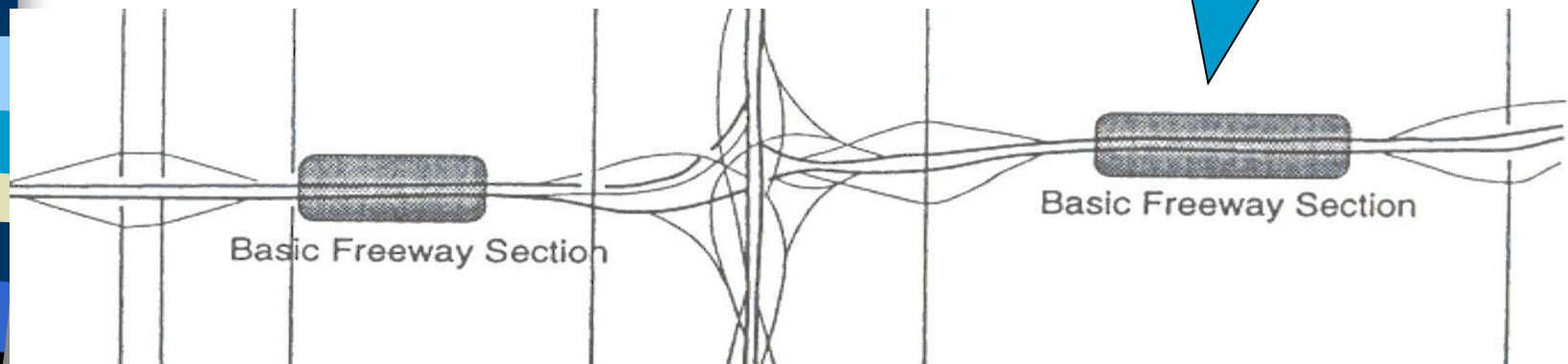


A v/c ratio above 1.0 predicts that the planned design facility will fail! Queue will form.

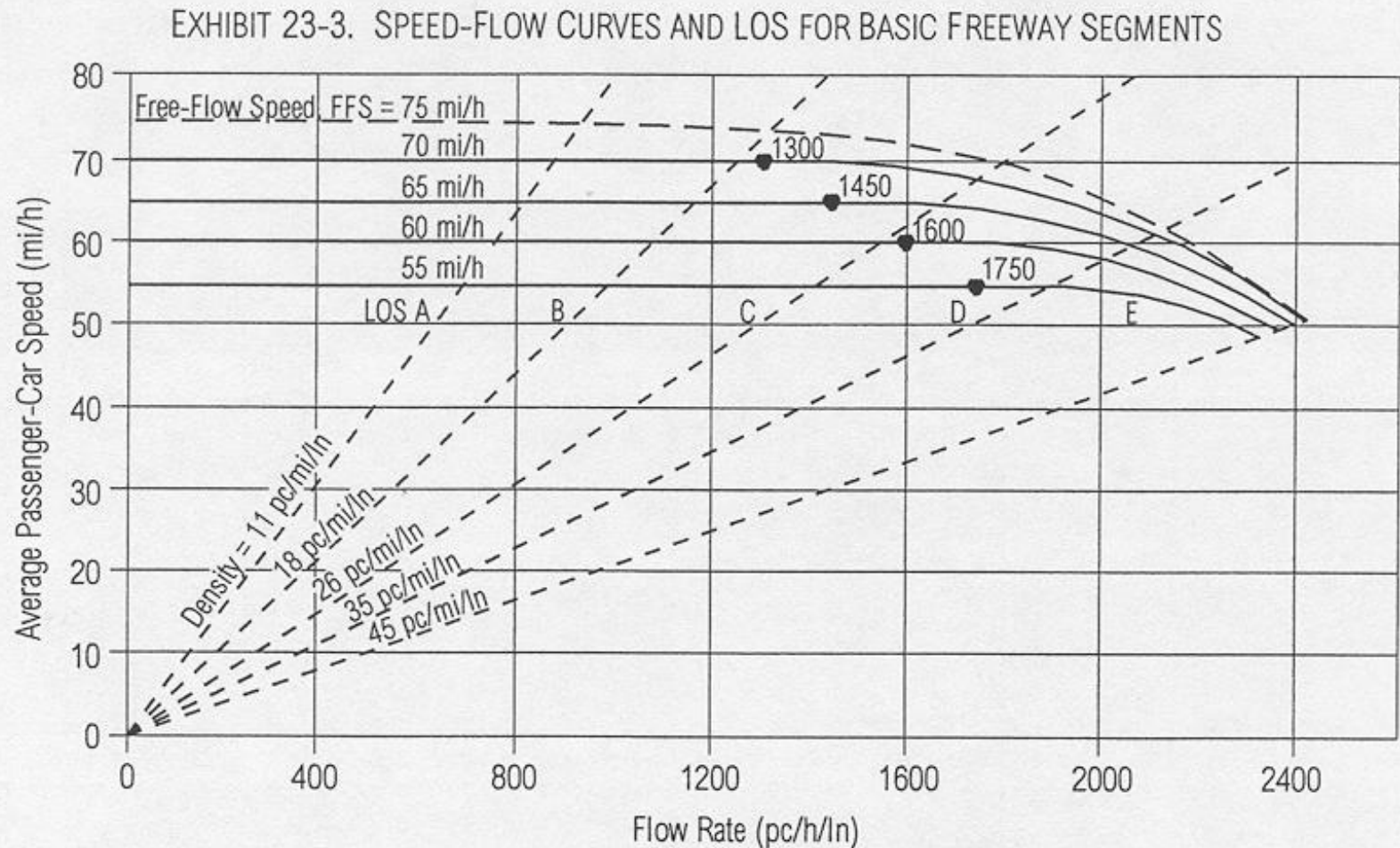
12.2 Freeways and multilane highways



Basic freeway segments:
Segments of the freeway that are outside of the influence area of ramps or weaving areas.



12.2.2 Basic freeway and multilane highway characteristics



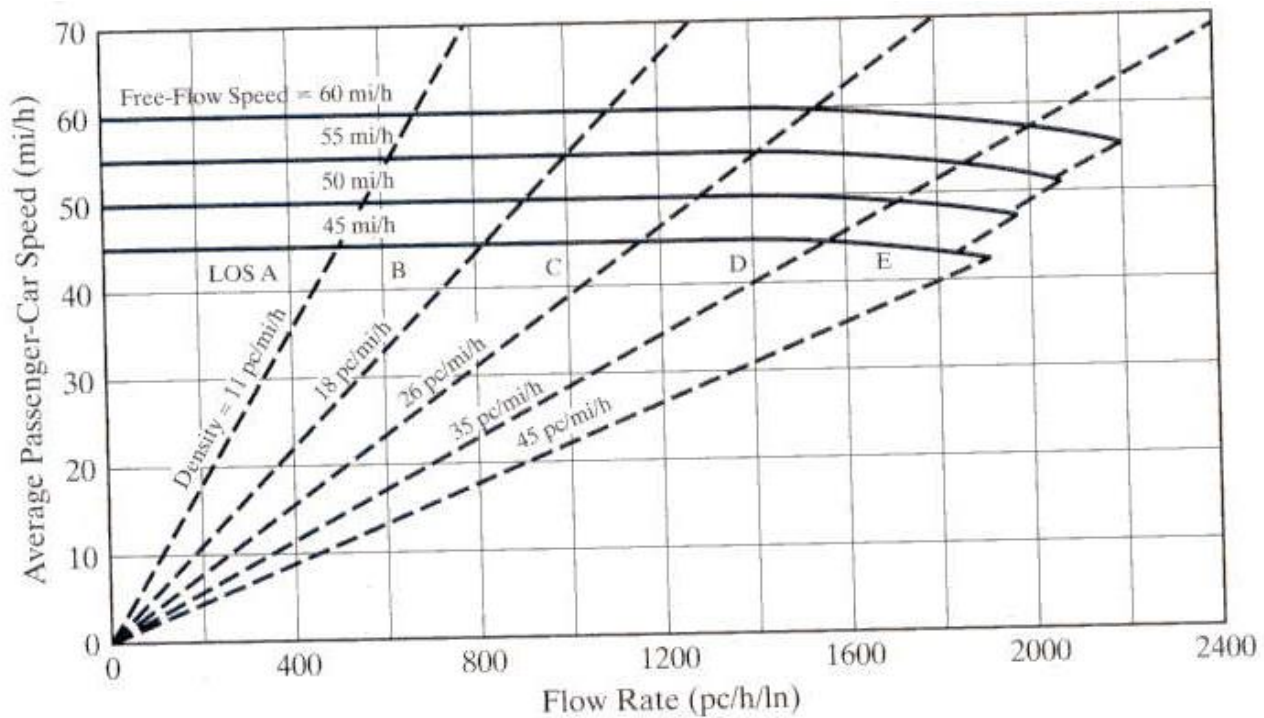


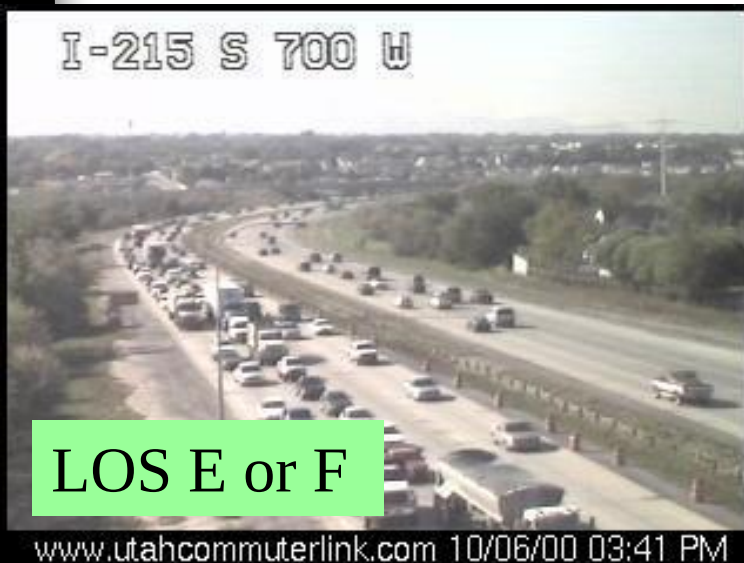
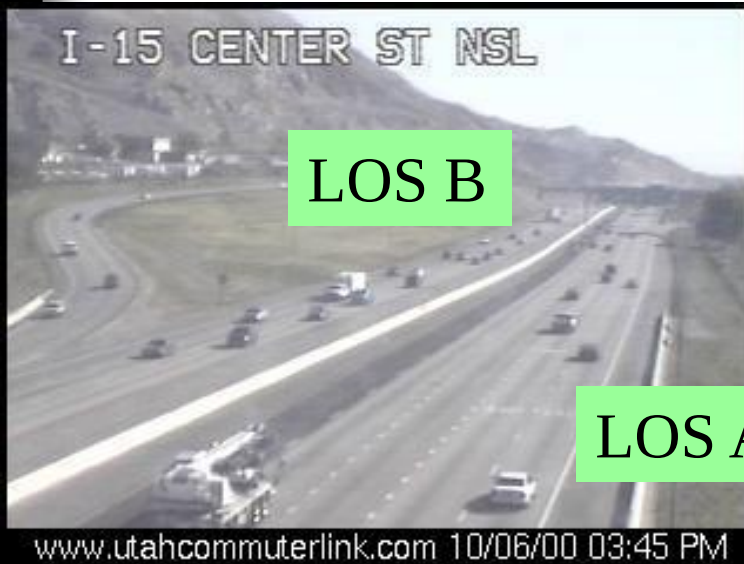
Figure 12.4: Speed-Flow Curves for Multilane Highway Sections (Used with permission of Transportation Research Board of the National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 21-3, pg. 21-4.)

(For multilane highways)

Basic capacities under ideal conditions

Freeway: ffs = 70 mph	2400 pcphpl
ffs = 65 mph	2350 pcphpl
ffs = 60 mph	2300 pcphpl
ffs = 55 mph	2250 pcphpl
Multilane: ffs = 60 mph	2200 pcphpl
ffs = 55 mph	2100 pcphpl
ffs = 50 mph	2000 pcphpl
ffs = 45 mph	1900 pcphpl

LOS Criteria



Level of Service	Density Range for Basic Freeway Sections (pc/mi/ln)	Density Range for Multilane Highways (pc/mi/ln)
A	$\geq 0 \leq 11$	$\geq 0 \leq 11$
B	$> 11 \leq 18$	$> 11 \leq 18$
C	$> 18 \leq 26$	$> 18 \leq 26$
D	$> 26 \leq 35$	$> 26 \leq 35$
E	$> 35 \leq 45$	$> 35 \leq (40-45)$ depending on FFS
F	> 45	$> (40-45)$ depending on FFS

12.3 Analysis methodologies

Most capacity analysis models include the determination of capacity under ideal roadway, traffic, and control conditions, that is, after having taken into account adjustments for prevailing conditions.

Multilane highways

12-ft lane width, 6-ft lateral clearance, all vehicles are passenger cars, familiar drivers, free-flow speeds ≥ 60 mph. Divided. Zero access points. Capacity used is usually *average per lane* (e.g. 2400 pcphpl in one direction)

Basic freeway segments

Min. lane widths of 12 feet

Min. right-shoulder lateral clearance of 6 feet (median $\rightarrow$ 2 ft)

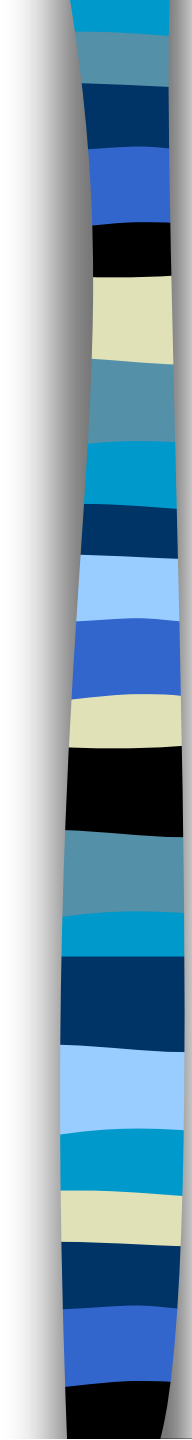
Traffic stream consisting of passenger cars only

Ten or more lanes (in urban areas only)

Interchanges spaced every 2 miles or more

Level terrain, with grades no greater than 2%, length affects

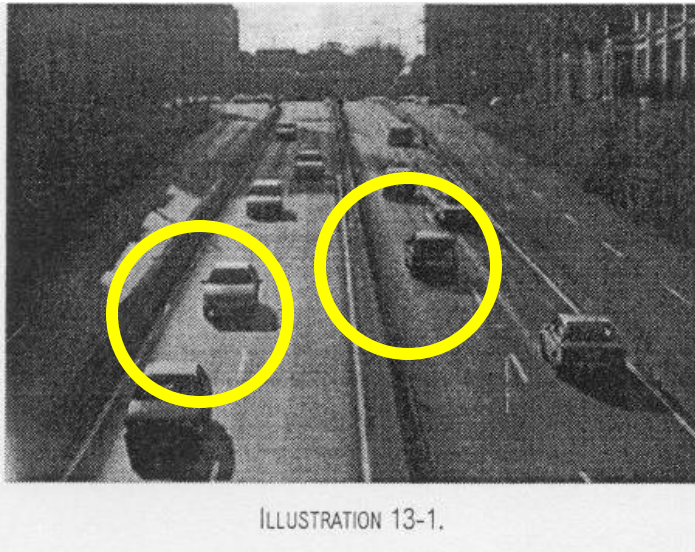
Driver population dominated by regular and familiar users



Prevailing condition types considered:

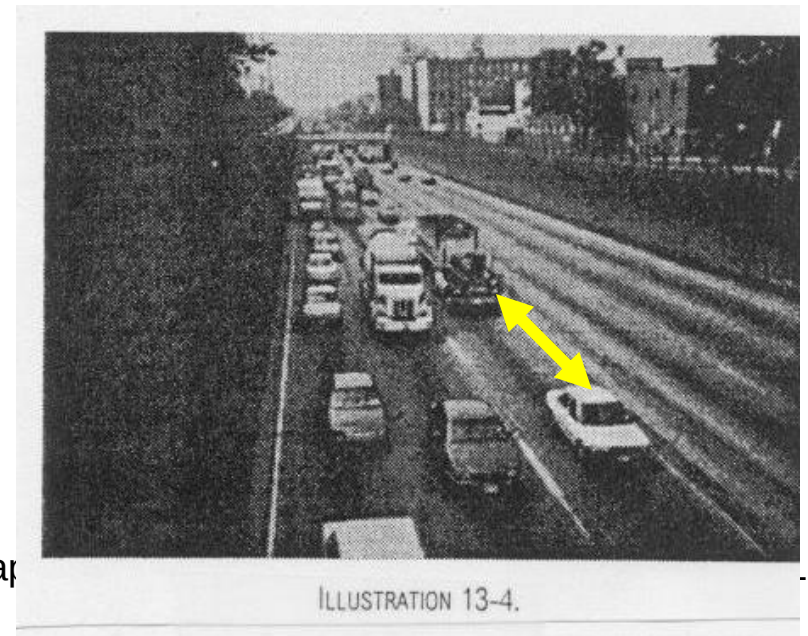
- Lane width
- Lateral clearances
- Number of lanes (freeways)
- Type of median (multilane highways)
- Frequency of interchanges (freeways) or access points (multilane highways)
- Presence of heavy vehicles in the traffic stream
- Driver populations dominated by occasional or unfamiliar users of a facility

Factors affecting: examples



Drivers shy away from concrete barriers

Trucks occupy more space: length and gap



12.3.1 Types of analysis

- Operational analysis
(Determine speed and flow rate, then density and LOS)

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

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

- Service flow rate and service volume analysis (for desired LOS) *MSF = Max service flow rate*

$$SF_i = MSF_i * N * f_{HV} * f_p$$

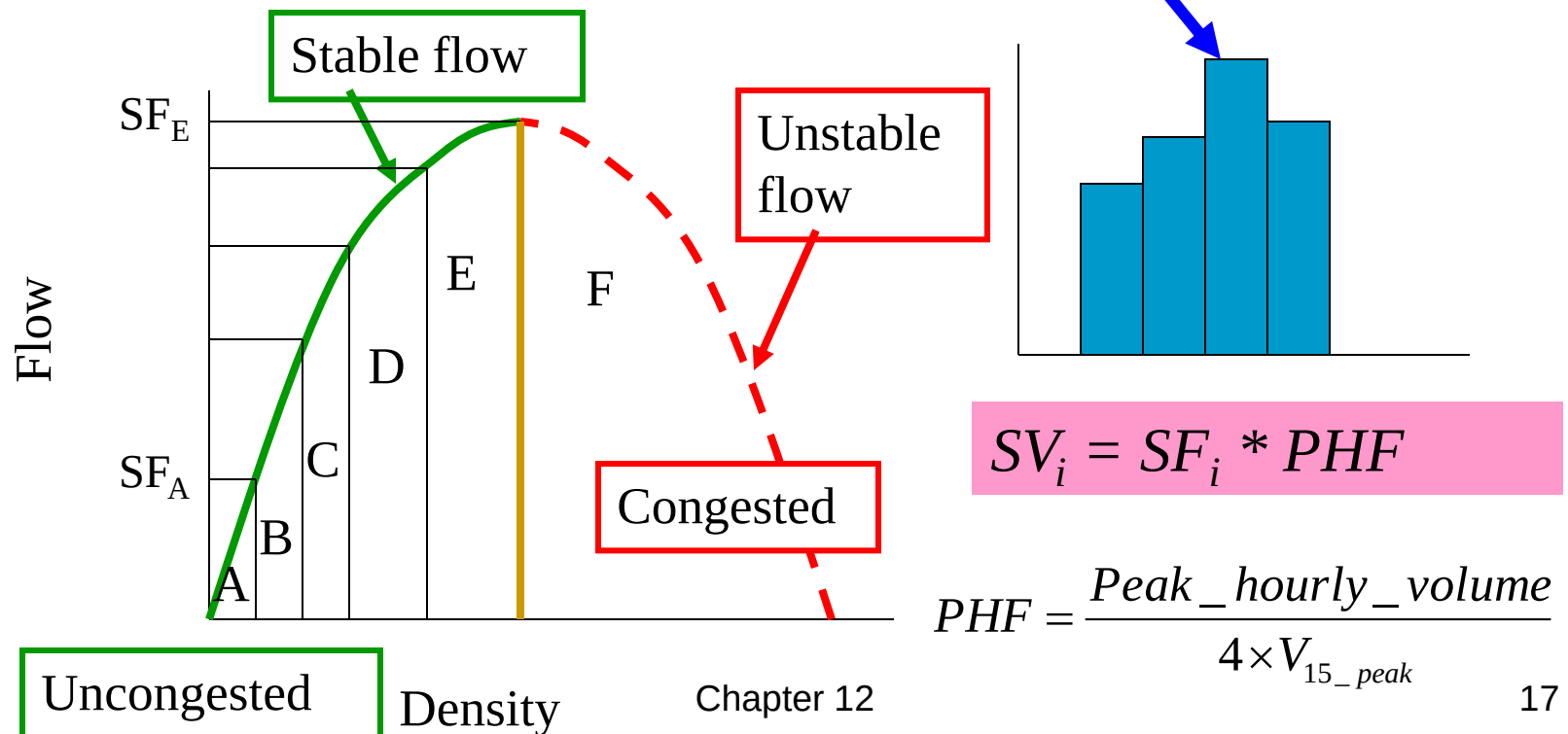
$$SV_i = SF_i * PHF$$

- Design analysis (Find the number of lanes needed to serve desired MSF)

$$N_i = \frac{DDHV}{PHF * MSF_i * f_H * f_p}$$

Service flow rates vs. service volumes

What is used for analysis is *service flow rate*. The actual number of vehicles that can be served during one peak hour is *service volume*. This reflects the peaking characteristic of traffic flow.



12.3.2 Operational analysis steps

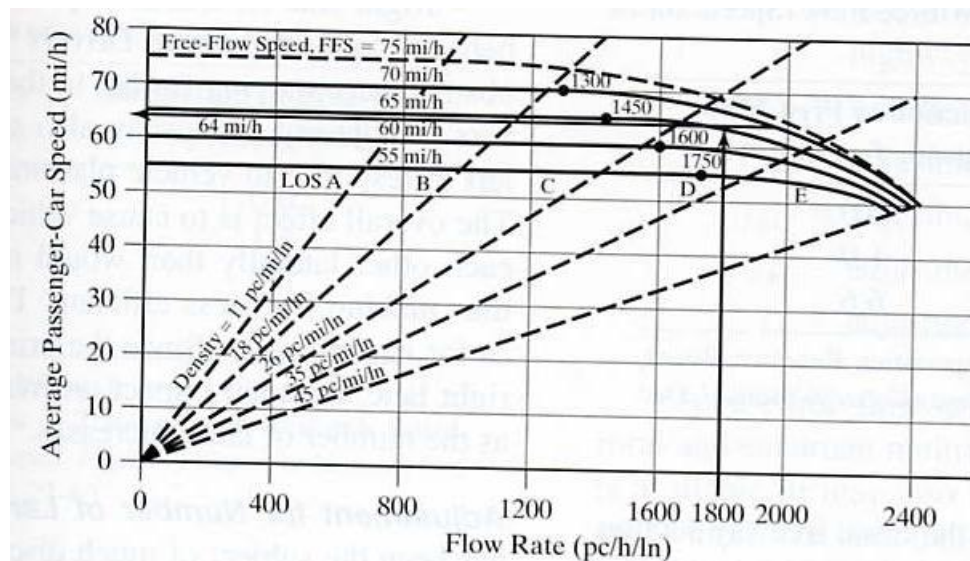
Free-flow speed (read carefully definitions of variables):

$$FFS = BFFS_i - f_{LW} - f_{LC} - f_N - f_{ID} \quad \text{Basic freeway segments, eq. 12-5}$$

$$FFS = BFFS_i - f_{LW} - f_{LC} - f_M - f_A \quad \text{Multilane highway sections, eq. 12-6}$$

Passenger car equivalent flow rate:

$$v_p = V / (PHF \times N \times f_{HV} \times f_p)$$



Use either the graph or compute:

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

Then Table 12.2 for LOS.

See Figure 12.4 for multilane highway sections.

12.3.2 (cont.)

Density criteria are independent of FFS level

Table 12.3 for basic freeway segments

Table 12.4 for multilane highways

Level-of-Service Criteria for Basic Freeway Segments

Criteria	LOS				
	A	B	C	D	E
FFS = 75 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Maximum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
Maximum v/c	0.34	0.56	0.76	0.90	1.00
Maximum service flow rate (pc/h/ln)	820	1350	1830	2170	2400
FFS = 70 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Maximum speed (mi/h)	70.0	70.0	68.2	61.5	53.3
Maximum v/c	0.32	0.53	0.74	0.90	1.00
Maximum service flow rate (pc/h/ln)	770	1260	1770	2150	2400
FFS = 65 mi/h					

12.3.3 Heavy-vehicle adjustment factor

$$\begin{aligned} f_{HV} &= \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \\ &= \frac{1}{P_P \times 1 + P_T E_T + P_R E_R} \\ &= \frac{1}{(1 - P_T - P_R) \times 1 + P_T E_T + P_R E_R} \end{aligned}$$

P_P = percent passenger cars

P_T = percent trucks & buses

P_R = percent recreational vehicles (RVs)

E_T = PCE for trucks and buses

E_R = PCE for RVs

Grade and slope length affects the values of E_T and E_R .

How we deal with long, sustaining grades...

There are 3 ways to deal with long, sustaining grades: extended general freeway segments, specific upgrades, and specific downgrades.

(1) Extended segments: where no one grade of 3% or greater is longer than $\frac{1}{4}$ mi or where no one grade of less than 3% is longer than $\frac{1}{2}$ mi. And for planning analysis.

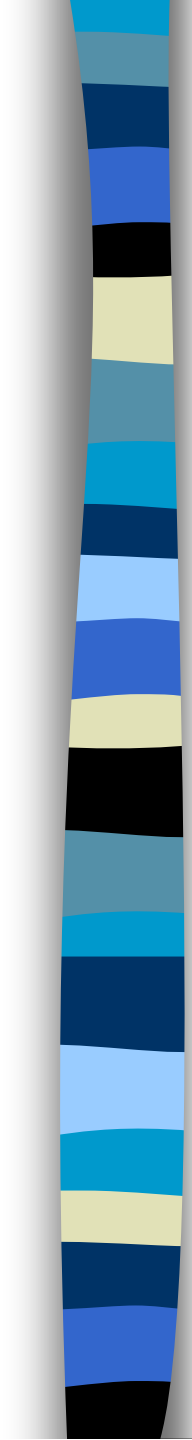
Extended segments	Type of Terrain		
	Level	Rolling	Mountains
E_T (trucks & buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

How we deal with long, sustaining grades...(cont)

(2) Specific upgrades: Any freeway grade of more than $\frac{1}{2}$ mi for grades less than 3% or $\frac{1}{4}$ mi for grades of 3% or more. (For a composite grade, refer to page 313.) Use the tables for E_T and E_R for specific grades.

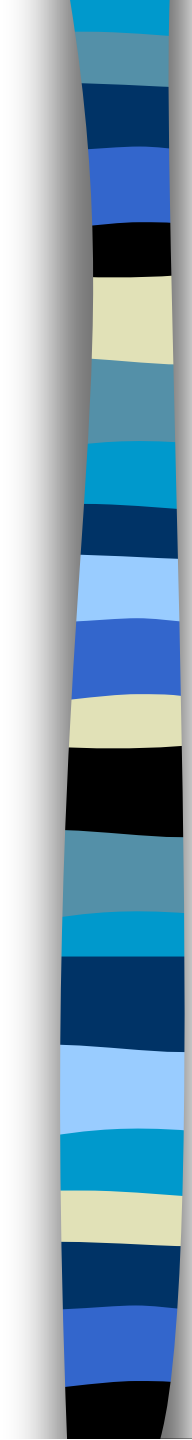
(3) Specific downgrades:

- If the downgrade is not severe enough to cause trucks to shift into low gear, treat it as a level terrain segment.
- Otherwise, use the table for downgrade E_T
- For RVs, downgrades may be treated as level terrain.



Average grade or composite grade?

- In a basic freeway segment analysis, an overall average grade can be substituted for a series of grades **if no single portion of the grade is steeper than 4% or the total length of the grade is less than 4,000 ft.**
- For grades outside these limits, the composite grade procedure is recommended. The composite grade procedure is used to determine an equivalent grade that will result in the same final truck speed as used to determine an equivalent grade that will result in the same final truck speed as would a series of varying grades. (page 313-314: read these pages carefully for strength and weakness of this method)
- For analysis purposes, the impact of a grade is worst at the end of its steepest (uphill) section. **(e.g. if 1000 ft of 4% grade were followed by 1000 ft of 3% grade, passenger-car equivalents would be found for a 1000 ft, 4%)**



12.3.4 Determining the driver population factor

- Not well established
- Between a value of 1.00 for commuters to 0.85 as a lower limit for other driver populations
- Usually 1.00
- If there are many unfamiliar drivers use a value between 1.00 and 0.85
- For a future situation 0.85 is suggested

(We will go through Example 12-4 manually.)

Planning analysis

You want to find out how many lanes are needed for the targeted level of service.

Step 1: Find f_{HV} using for E_T and E_R .

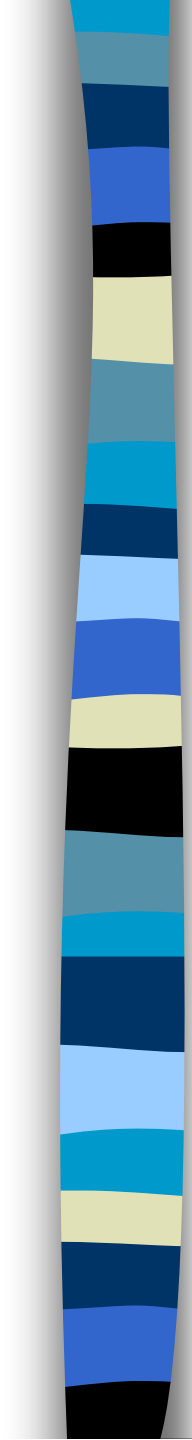
Step 2: Try 2 lanes in each direction, unless it is obvious that more lanes will be needed.

Step 3: Convert volume (vph) to flow rate (pcphpl), v_p , for the current number of lanes in each direction.

Step 4: If v_p exceeds capacity, add one lane in each direction and return to Step 2.

Step 5: Compute FFS.

Step 6: Determine the LOS for the freeway with the current number of lanes being considered. If the LOS is not good enough, add another lane and return to Step 3.



12.4 Sample applications

- We will use HCS+ in Room 234CB

12.5 Calibration issues

It is suggested you read this section. It will be helpful when you want to use local values (Remember HCS values are national average values).