

Freeway & Highway Level of Service

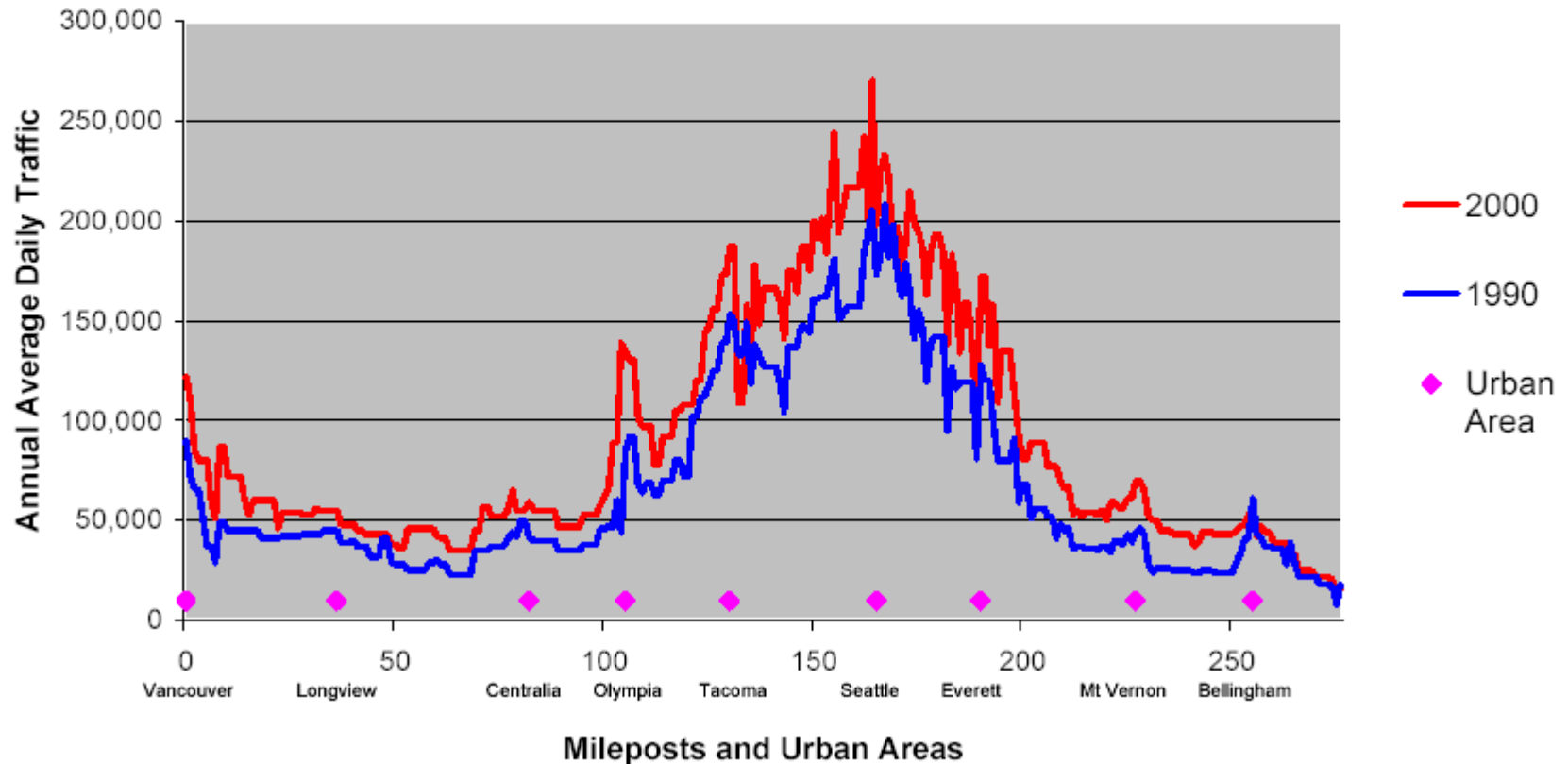


Outline

- 1. Definitions**
- 2. Level of Service (LOS)**
- 3. Freeway Segment LOS Determination**
 - a. Free-flow speed**
 - b. Flow Rate**
- 4. Multilane Highway LOS**
- 5. Design Traffic Volume**

I-5 Average Daily Traffic

Interstate 5 - Oregon to Canada
Traffic Volume Comparison - 1990 and 2000

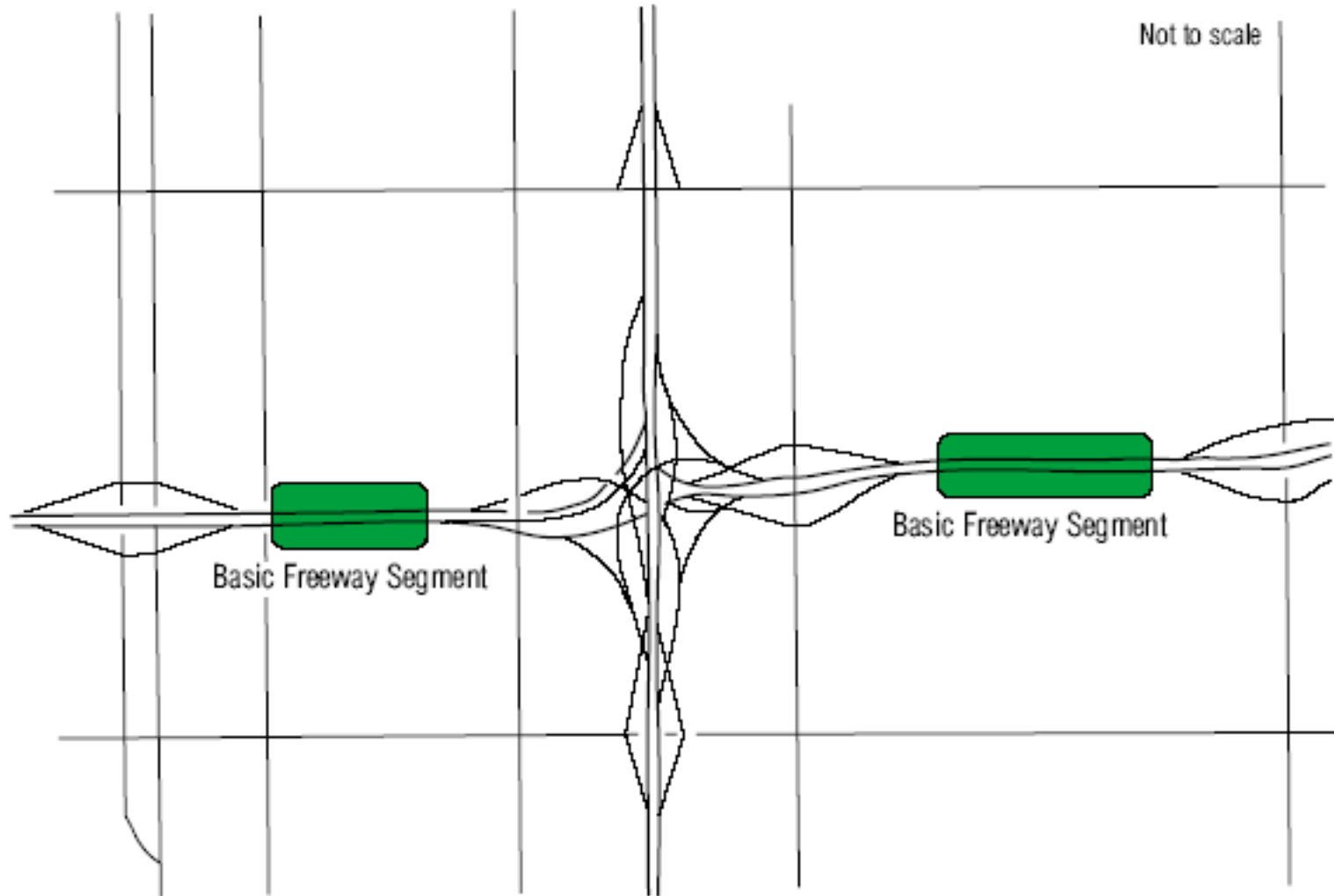


from the WSDOT 2001 *Annual Traffic Report*

Freeway Defined

- **A divided highway with full control of access and two or more lanes for the exclusive use of traffic in each direction.**
- **Assumptions**
 - No interaction with adjacent facilities (streets, other freeways)
 - Free-flow conditions exist on either side of the facility being analyzed
 - Outside the influence of ramps and weaving areas

Basic Freeway Segment



From *Highway Capacity Manual*, 2000

Definitions

- **Freeway Capacity**

- The maximum sustained 15-min flow rate, expressed in passenger cars per hour per lane, that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction of flow.

Definitions – Flow Characteristics

- **Undersaturated**

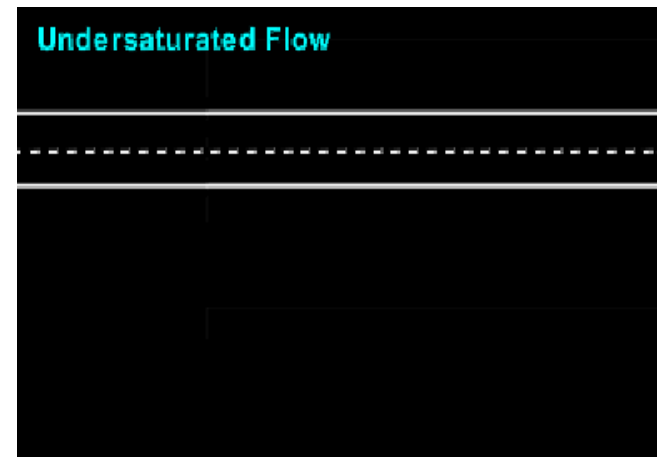
- Traffic flow that is unaffected by upstream or downstream conditions.

- **Queue discharge**

- Traffic flow that has just passed through a bottleneck and is accelerating back to the FFS of the freeway.

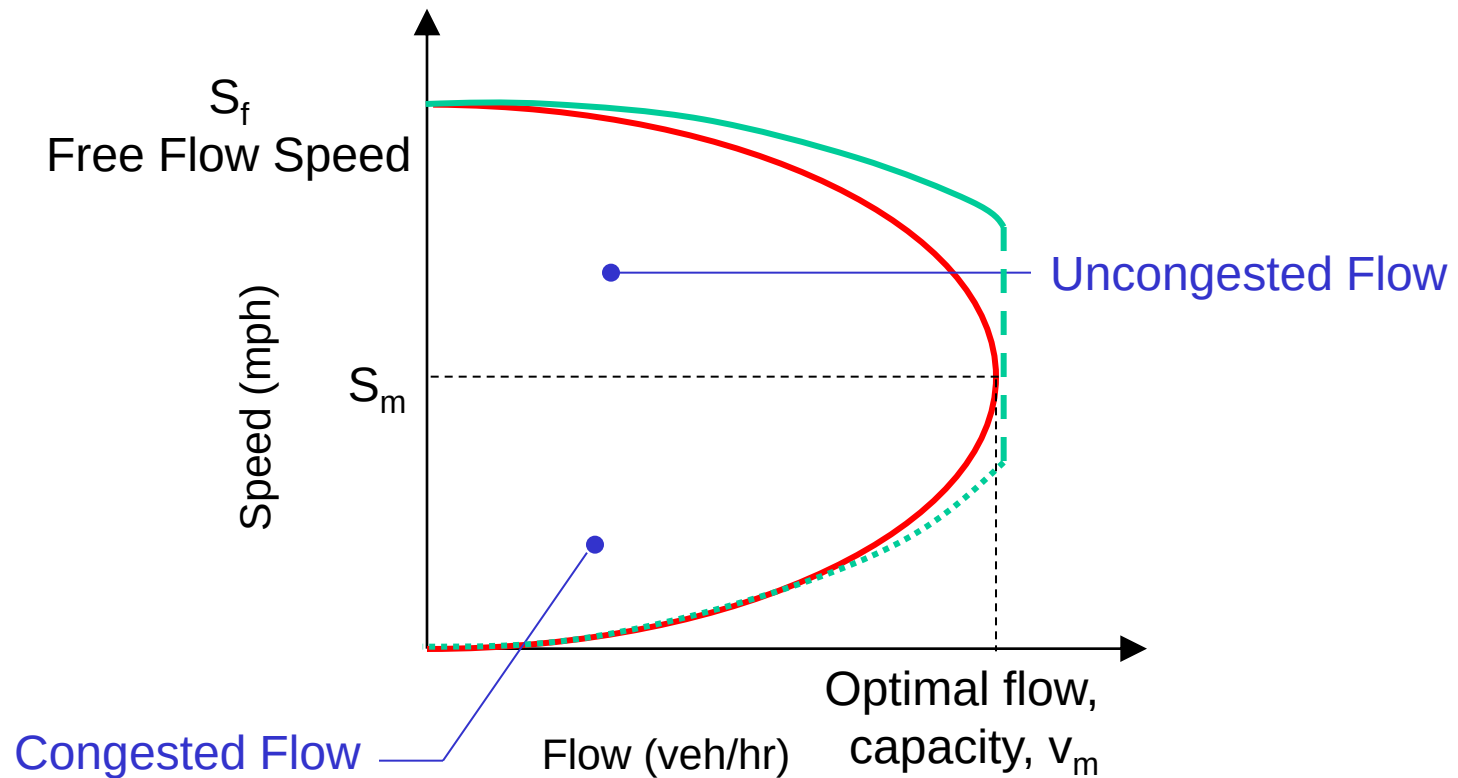
- **Oversaturated**

- Traffic flow that is influenced by the effects of a downstream bottleneck.

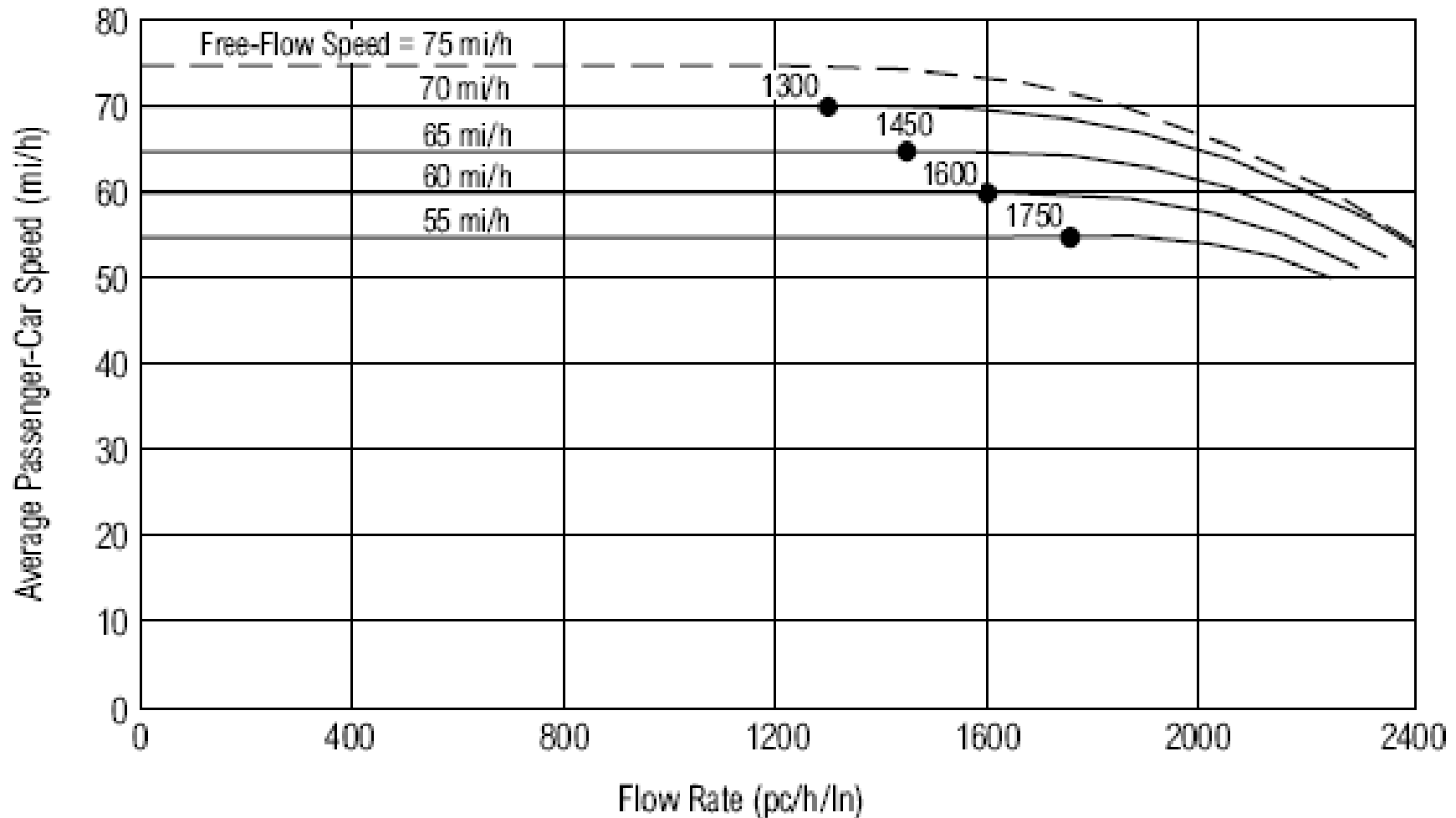


From *Highway Capacity Manual*, 2000

Speed vs. Flow



Uncongested Flow



From *Highway Capacity Manual*, 2000

Definitions – Free-Flow Speed

- **Free-Flow Speed (FFS)**
 - The mean speed of passenger cars that can be accommodated under low to moderate flow rates on a uniform freeway segment under prevailing roadway and traffic conditions.
- **Factors affecting free-flow speed**
 - Lane width
 - Lateral clearance
 - Number of lanes
 - Interchange density
 - Geometric design

Definitions

- **Passenger car equivalents**
 - Trucks and RVs behave differently
 - Baseline is a freeway with all passenger cars
 - Traffic is expressed in passenger cars per lane per hour (pc/lane/hr or pcplph)
- **Driver population**
 - Non-commuters suck more at driving
 - They may affect capacity
- **Capacity**
 - Corresponds to LOS E and $v/c = 1.0$

Definitions – Level of Service (LOS)

- **Chief measure of “quality of service”**
 - Describes operational conditions within a traffic stream.
 - Does not include safety
 - Different measures for different facilities
- **Six measures (A through F)**
- **Freeway LOS**
 - Based on traffic density

Levels of Service

- **LOS A**
 - Free-flow operation
- **LOS B**
 - Reasonably free flow
 - Ability to maneuver is only slightly restricted
 - Effects of minor incidents still easily absorbed



Levels of Service

- **LOS C**

- Speeds at or near FFS
- Freedom to maneuver is noticeably restricted
- Queues may form behind any significant blockage.



- **LOS D**

- Speeds decline slightly with increasing flows
- Density increases more quickly
- Freedom to maneuver is more noticeably limited
- Minor incidents create queuing



Levels of Service

- **LOS E**
 - Operation near or at capacity
 - No usable gaps in the traffic stream
 - Operations extremely volatile
 - Any disruption causes queuing
- **LOS F**
 - Breakdown in flow
 - Queues form behind breakdown points
 - Demand > capacity

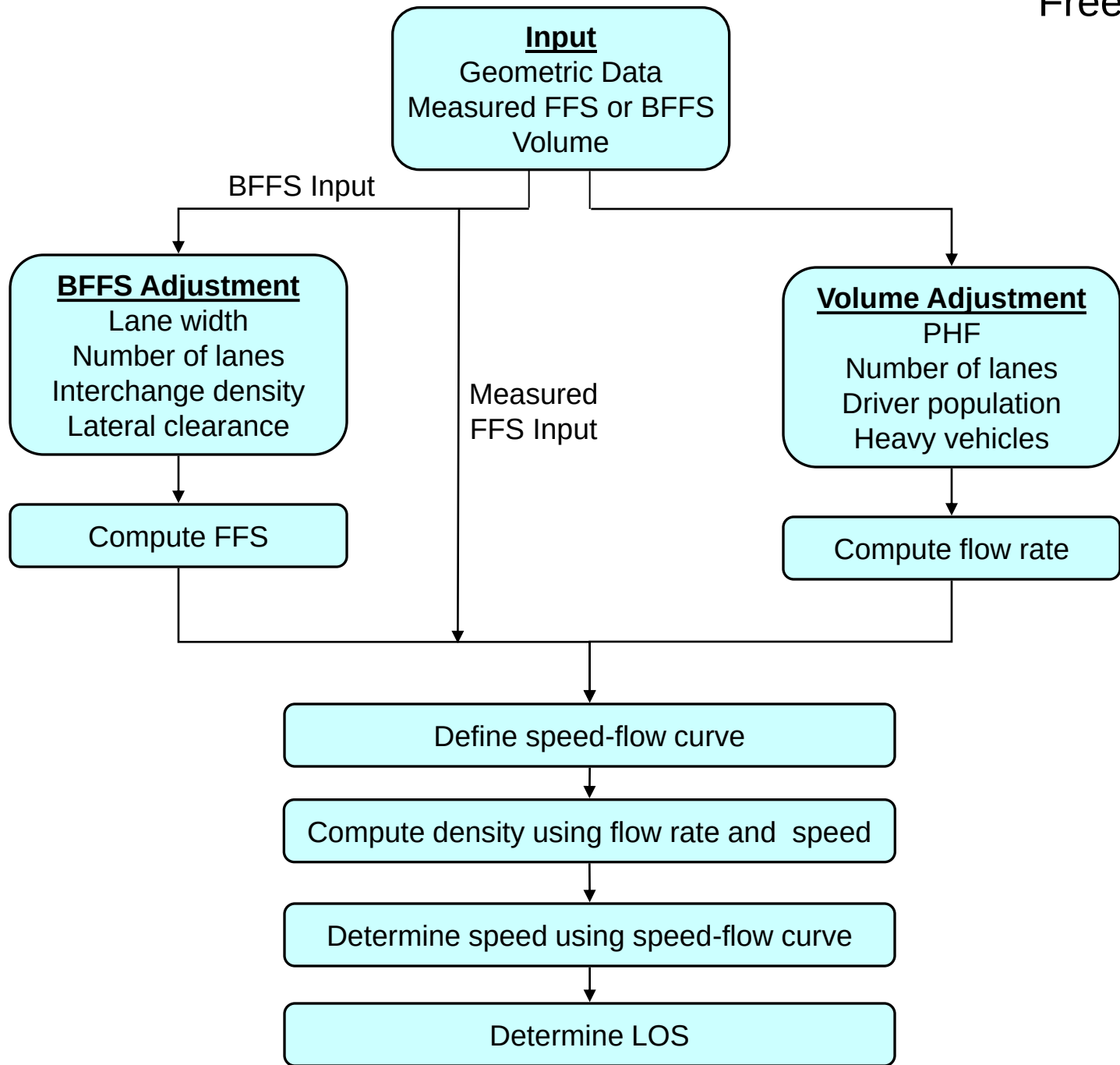


Freeway LOS



LOS Calculation

- **Does not consider**
 - Special lanes reserved for a particular type of vehicle (HOV, truck, climbing, etc.)
 - Extended bridge and tunnel segments
 - Segments near a toll plaza
 - Facilities with FFS < 55 mi/h or > 75 mi/h
 - Demand conditions in excess of capacity
 - Influence of downstream blockages or queuing
 - Posted speed limit
 - Extent of police enforcement
 - Intelligent transportation system features
 - Capacity-enhancing effects of ramp metering



LOS 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
Minimum 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
Minimum 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					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum 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 service flow rate (pc/h/ln)	600	990	1430	1910	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.

Determining FFS

- **Measure FFS in the field**
 - Low to moderate traffic conditions
- **Use a baseline and adjust it (BFFS)**

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

FFS = free-flow speed (mph)

BFFS = base free-flow speed, 70 mph (urban), 75 mph (rural)

f_{LW} = adjustment for lane width (mph)

f_{LC} = adjustment for right-shoulder lateral clearance (mph)

f_N = adjustment for number of lanes (mph)

f_{ID} = adjustment for interchange density (mph)

Lane Width Adjustment (f_{LW})

- **Base condition ($f_{LW} = 0$)**
 - Average width of 12 ft. or wider across all lanes

EXHIBIT 23-4. ADJUSTMENTS FOR LANE WIDTH

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
12	0.0
11	1.9
10	6.6

Lateral Clearance Adjustment (f_{LC})

- **Base condition ($f_{LC} = 0$)**
 - 6 ft. or greater on right side
 - 2 ft. or greater on the median or left side

EXHIBIT 23-5. ADJUSTMENTS 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

From *Highway Capacity Manual*, 2000

Number of Lanes Adjustment (f_N)

- **Base condition ($f_N = 0$)**
 - 5 or more lanes in one direction
 - Do not include HOV lanes
 - $f_N = 0$ for all rural freeway segments

EXHIBIT 23-6. ADJUSTMENTS FOR NUMBER OF LANES

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (mi/h)
≥ 5	0.0
4	1.5
3	3.0
2	4.5

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

Interchange Density Adjustment (f_{IC})

- **Base condition ($f_{IC} = 0$)**
 - 0.5 interchanges per mile (2-mile spacing)
 - Interchange defined as having at least one on-ramp
 - Determined over 6-mile segment

EXHIBIT 23-7. ADJUSTMENTS FOR INTERCHANGE DENSITY

Interchanges per Mile	Reduction in Free-Flow Speed, f_{ID} (mi/h)
0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

From *Highway Capacity Manual*, 2000

Determining Flow Rate

- Adjust hourly volumes to get pc/lh/hr

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

v_p = 15-minute passenger-car equivalent flow rate (pcphpl)

V = hourly volume (veh/hr)

PHF = peak hour factor

N = number of lanes in one direction

f_{HV} = heavy-vehicle adjustment factor

f_p = driver population adjustment factor

Peak Hour Factor (PHF)

- **Typical values**
 - 0.80 to 0.95
 - Lower PHF characteristic of rural or off-peak
 - Higher PHF typical of urban peak-hour

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

V = hourly volume (veh/hr) for hour of analysis

V_{15} = maximum 15-min. flow rate within hour of analysis

4 = Number of 15-min. periods per hour

Heavy Vehicle Adjustment (f_{HV})

- **Base condition ($f_{HV} = 1.0$)**
 - No heavy vehicles
 - Heavy vehicle = trucks, buses, RVs
- **Two-step process**
 - Determine passenger-car equivalents (E_T)
 - Determine f_{HV}

Passenger-Car Equivalents (E_T)

- **Extended segments method**
 - Determine the type of terrain and select E_T
 - No one grade of 3% or more is longer than 0.25 miles
OR
 - No one grade of less than 3% is longer than 0.5 miles

EXHIBIT 23-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED FREEWAY SEGMENTS

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 (E_T)

- **Specific grades method**
 - Any grade of 3% or more that is longer than 0.25 miles
OR
 - Any grade of less than 3% that is longer than 0.5 miles

EXHIBIT 23-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON DOWNGRADES

Downgrade (%)	Length (mi)	E_T			
		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

From *Highway Capacity Manual*, 2000

EXHIBIT 23-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UPGRADES

Freeway LOS

Upgrade (%)	Length (mi)	E _T								
		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	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	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	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	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
	> 0.25-0.30	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

Passenger-Car Equivalents (E_T)

EXHIBIT 23-10. PASSENGER-CAR EQUIVALENTS FOR RVs ON UPGRADES

Upgrade (%)	Length (mi)	E_R								
		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	4.0	3.5	3.0	3.0	2.5	2.0

Passenger-Car Equivalents (E_T)

- **Composite grades method**
 - Determines the effect of a series of steep grades in succession
 - **Method OK if...**
 - All subsection grades are less than 4%
 - OR
 - Total length of composite grade is less than 4000 ft.
 - Otherwise, use a detailed technique in the *Highway Capacity Manual (HCM)*

Determine f_{HV}

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

f_{HV} = Heavy vehicle adjustment factor

E_T, E_R = Passenger-car equivalents for trucks/buses and RVs

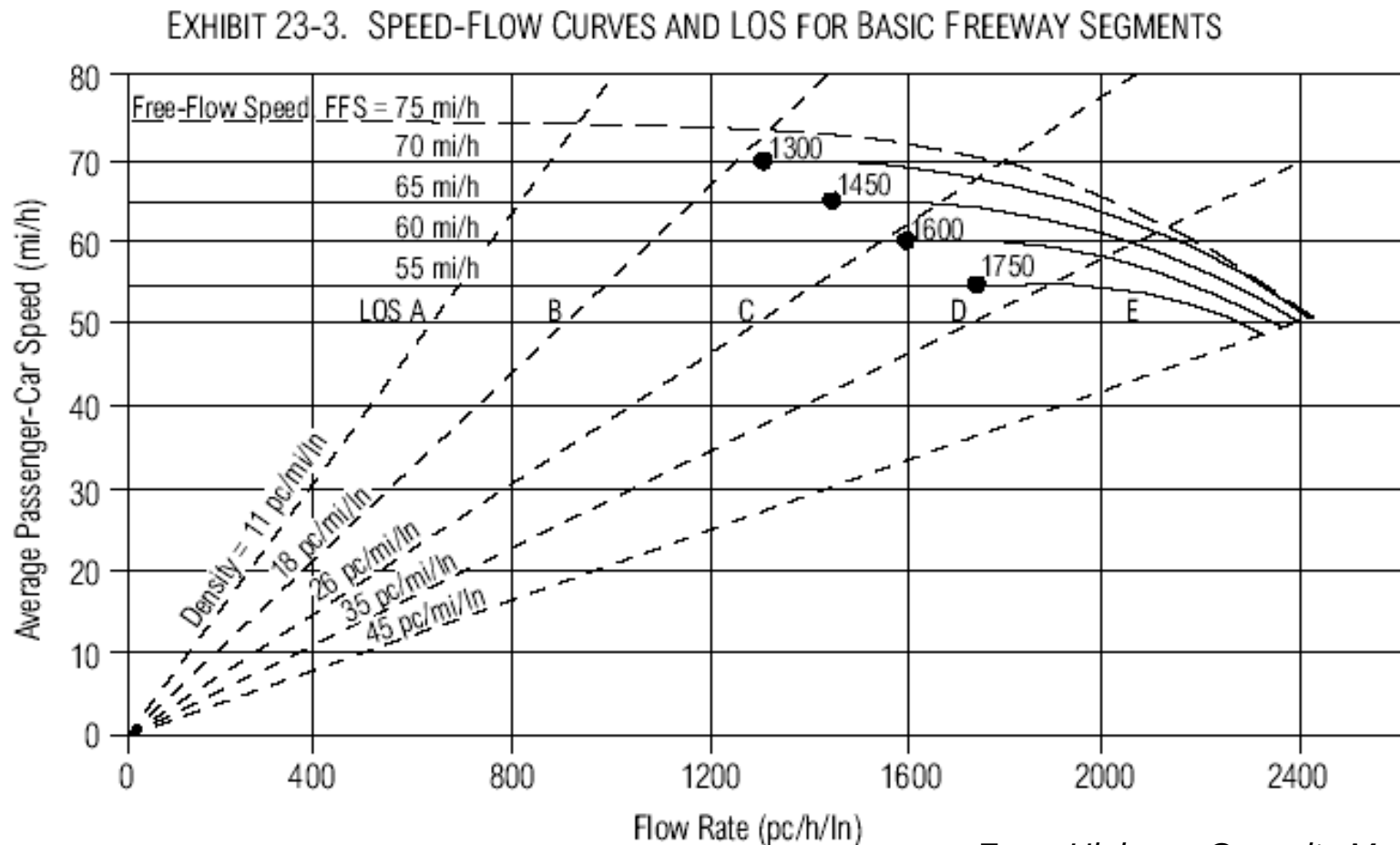
P_T, P_R = Proportion of trucks/buses and RVs in traffic stream

Driver Population Adjustment (f_p)

- **Base condition ($f_p = 1.0$)**
 - Most drivers are familiar with the route
 - Commuter drivers
 - Typical values between 0.85 and 1.00
- **Two-step process**
 - Determine passenger-car equivalents (E_T)
 - Determine f_{HV}

Define Speed-Flow Curve

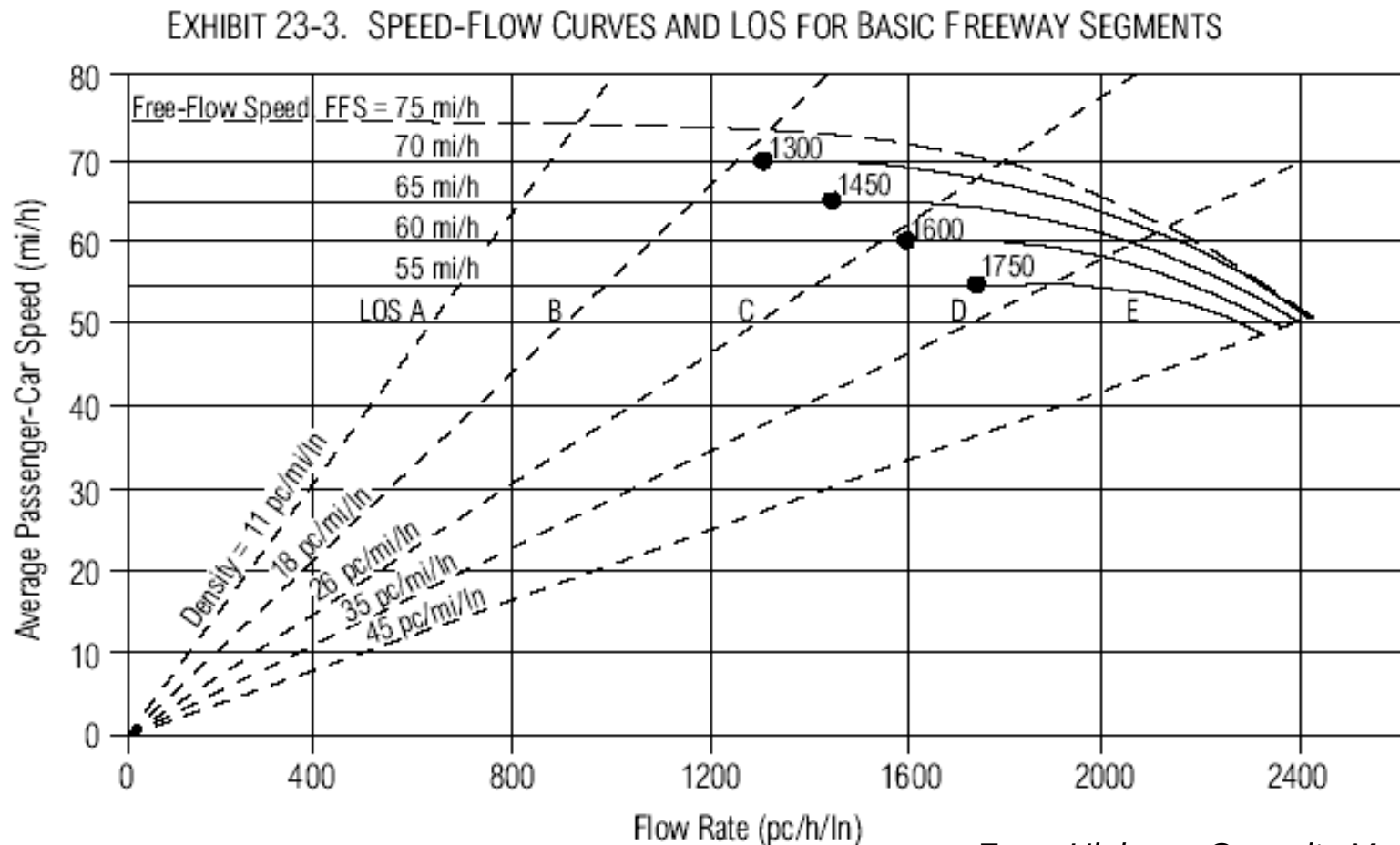
Select a Speed-Flow curve based on FFS



From *Highway Capacity Manual*, 2000

Determine Average PC Speed (S)

Use v_p and FFS curve to find average passenger car speed (S)



From *Highway Capacity Manual*, 2000

Determine Average PC Speed (S)

For $70 < FFS \leq 75$ mph AND $(3400 - 30FFS) < v_p \leq 2400$

$$S = FFS - \left[\left(FFS - \frac{160}{3} \right) \left(\frac{v_p + 30FFS - 3400}{30FFS - 1000} \right)^{2.6} \right]$$

For $55 < FFS \leq 70$ mph AND $(3400 - 30FFS) < v_p \leq (1700 + 10FFS)$

$$S = FFS - \left[\frac{1}{9} (7FFS - 340) \left(\frac{v_p + 30FFS - 3400}{40FFS - 1700} \right)^{2.6} \right]$$

For $55 < FFS \leq 75$ mph AND $v_p < (3400 - 30FFS)$

$$S = FFS$$

Determine Density

- Calculate density using:

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

D = density (pc/mi/ln)

v_p = flow rate (pc/hr/ln)

S = average passenger-car speed (mph)

Determine LOS

LOS 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
Minimum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
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FFS = 65 mi/h					
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Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
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Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
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Maximum service flow rate (pc/h/ln)	600	990	1430	1910	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.

Example

Determine the typical LOS for SR 520 eastbound near Microsoft (MP 10.25 – shown in the picture below) at 7 a.m. and 10 p.m.

Geometry

- 11 ft. lane width
- Left lateral clearance = 5 ft.
- Right lateral clearance = 4 ft.

Other

- 7 am PHF = 0.95
- 10 pm PHF = 0.99
- 2% trucks
- 3% buses



from WSDOT's SRWeb
<http://srvview.wsdot.wa.gov/>

Determine FFS

EXHIBIT 23-4. ADJUSTMENTS FOR LANE WIDTH

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
12	0.0
11	1.9
10	6.6

Determine FFS

EXHIBIT 23-5. ADJUSTMENTS 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

EXHIBIT 23-6. ADJUSTMENTS FOR NUMBER OF LANES

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (mi/h)
≥ 5	0.0
4	1.5
3	3.0
2	4.5

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

Determine FFS

from Microsoft MapPoint

In a 6-mile stretch from I-405 to Redmond there are 5 interchanges

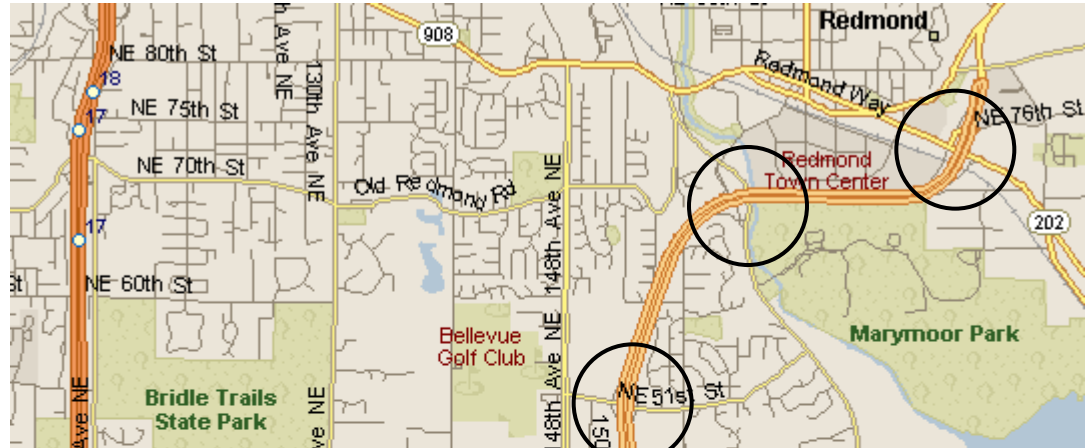


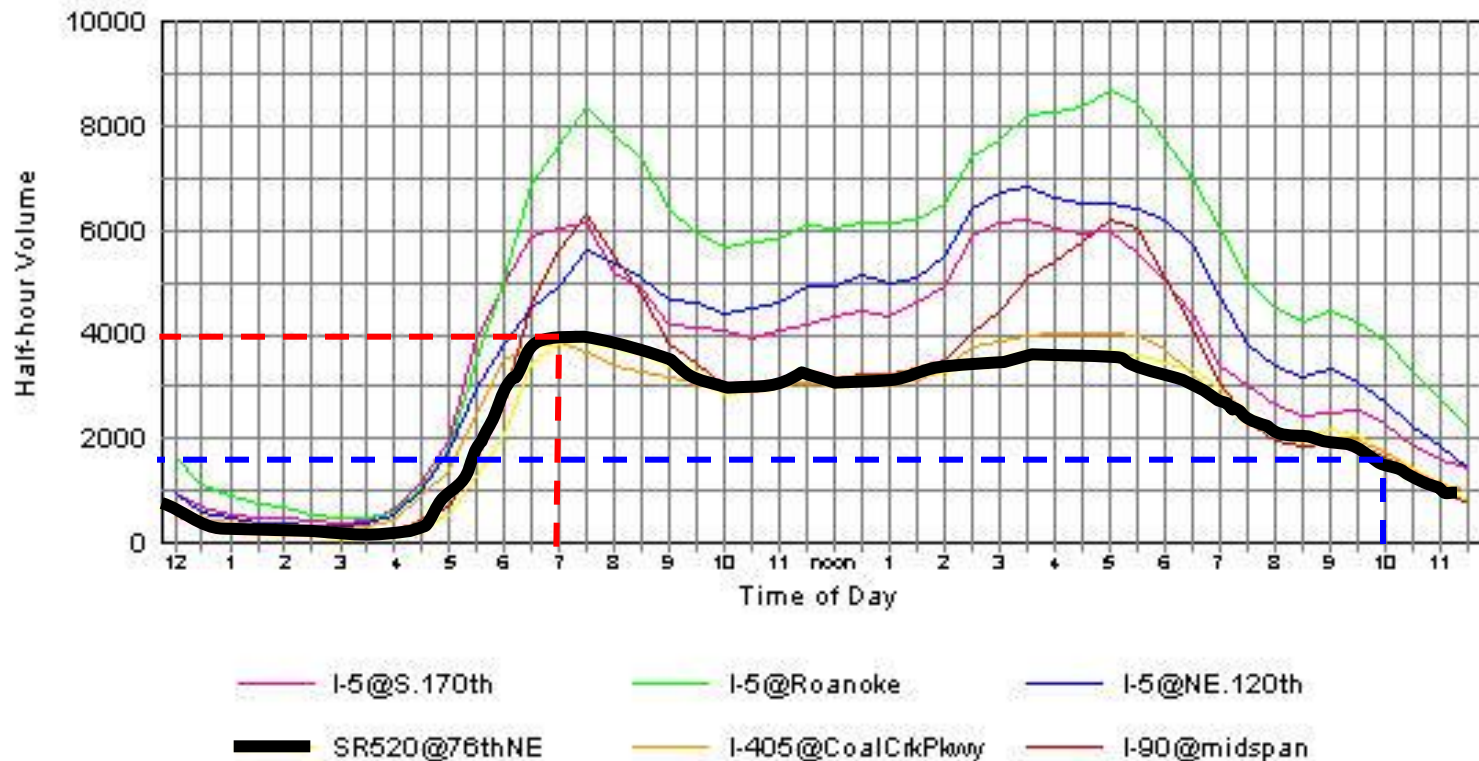
EXHIBIT 23-7. ADJUSTMENTS FOR INTERCHANGE DENSITY

Interchanges per Mile	Reduction in Free-Flow Speed, f_{ID} (mi/h)
0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

Determine FFS

Determine Flow Rate (v_p)

Freeway Volumes by Time of Day



At 7am the $\frac{1}{2}$ hour volume is about 4000 veh/hr

At 10 pm the $\frac{1}{2}$ hour volume is about 1700 veh/hr

Graph from the Puget Sound Regional Council's *Puget Sound Trends*, No. T6, July 1997

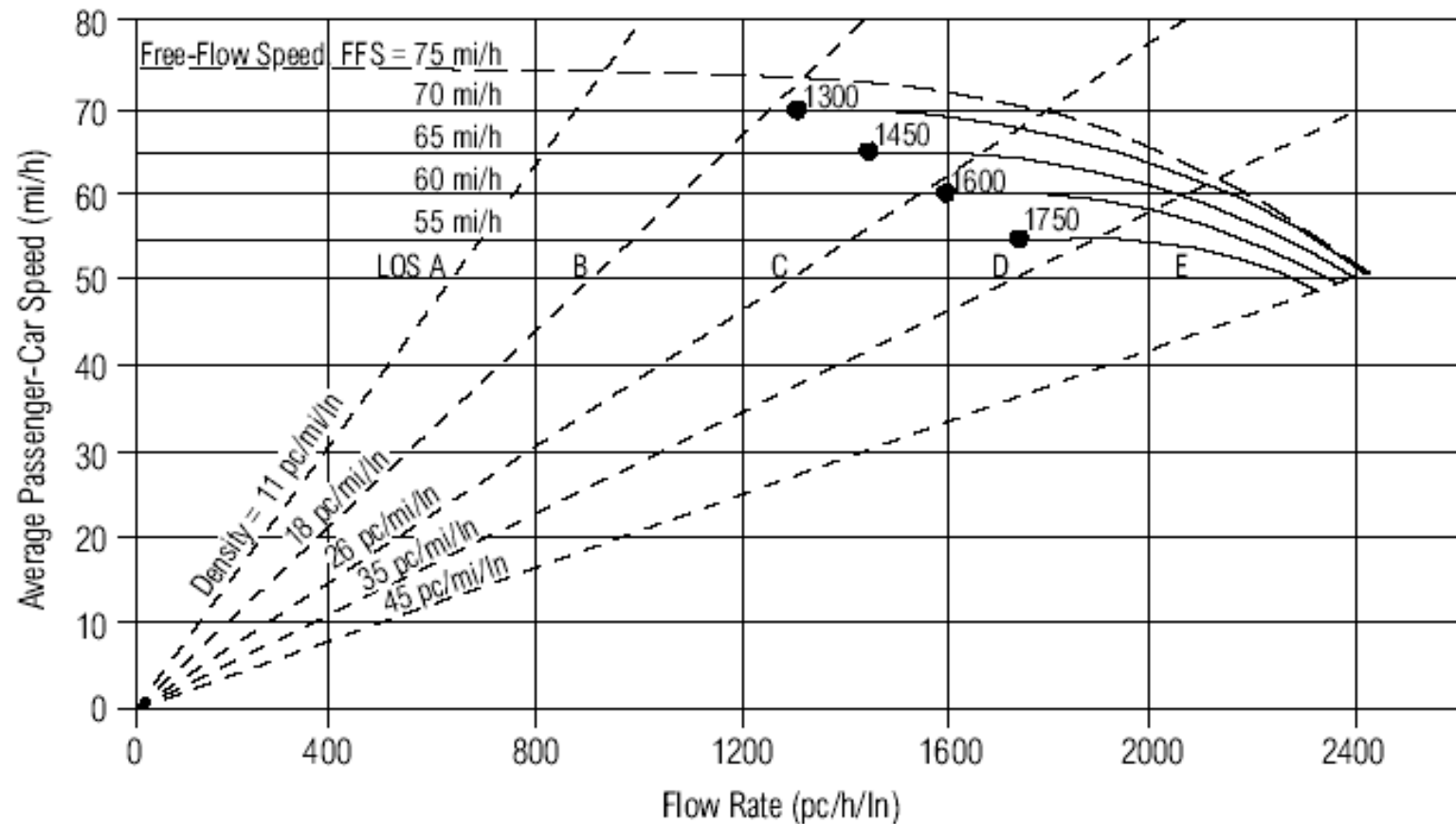
Determine Flow Rate (v_p)

EXHIBIT 23-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED FREEWAY SEGMENTS

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

Determine LOS

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS



LOS 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
Minimum 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
Minimum 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					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum 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 service flow rate (pc/h/ln)	600	990	1430	1910	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.

Multilane Highway LOS



Multilane Highway LOS

- **Similar to Freeway LOS**
- **A few minor differences**

Base Conditions for Multilane Highway

- **Level terrain, with grades no greater than 2 percent**
- **Minimum lane width = 12 ft**
- **Objects no closer than 6 ft from the edge of the traveled pavement (at the roadside or median)**
- **No direct access points along the roadway**
- **Divided highway**
- **Traffic stream composed entirely of passenger cars**
- **Free flow speed of 60 mph or more**
- **Driver population composed principally of regular users**

Free Flow Speed (FFS)

- **Measure FFS in the field**
 - Low to moderate traffic conditions
- **Use a baseline and adjust it (BFFS)**

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

FFS = free-flow speed (mph)

BFFS = base free-flow speed, 60 mph is typically used

f_{LW} = adjustment for lane width (mph)

f_{LC} = adjustment for right-shoulder lateral clearance (mph)

f_M = adjustment for median type (mph)

f_A = adjustment for access points (mph)

Lane Width Adjustment (f_{LW})

- **Base condition ($f_{LW} = 0$)**
 - Average width of 12 ft. or wider across all lanes

EXHIBIT 21-4. ADJUSTMENT FOR LANE WIDTH

Lane Width (ft)	Reduction in FFS (mi/h)
12	0.0
11	1.9
10	6.6

Same as Freeway LOS

Lateral Clearance Adjustment (f_{LC})

$$TLC = LC_R + LC_L$$

- **Base condition ($f_{LC} = 0$)**
 - 12 ft or greater TLC
- **$LC_L = 6$ ft for undivided highways**
 - (accounted for in median type adjustment)
- **$LC_L = 6$ ft for two-way left-turn lanes**

EXHIBIT 21-5. ADJUSTMENT FOR LATERAL CLEARANCE

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance ^a (ft)	Reduction in FFS (mi/h)	Total Lateral Clearance ^a (ft)	Reduction in FFS (mi/h)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Note:

a. 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.

Median Adjustment (f_M)

- **Base condition ($f_M = 0$)**
 - Divided highway

EXHIBIT 21-6. ADJUSTMENT FOR MEDIAN TYPE

Median Type	Reduction in FFS (mi/h)
Undivided highways	1.6
Divided highways (including TWLTLs)	0.0

Access-Point Density Adjustment (f_A)

- For each access point/mi FFS decreases by 0.25 mph
- Base condition ($f_A = 0$)
 - 0 access points per mile
- For $\text{NAPM} \leq 40$: $f_A = 0.25 \times \text{NAPM}$
- For $\text{NAPM} > 40$: $f_A = 10$

EXHIBIT 21-7. ACCESS-POINT DENSITY ADJUSTMENT

Access Points/Mile	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

Determining Flow Rate

- Adjust hourly volumes to get pc/lh/hr

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

v_p = 15-minute passenger-car equivalent flow rate (pcphpl)

V = hourly volume (veh/hr)

PHF = peak hour factor

N = number of lanes in one direction

f_{HV} = heavy-vehicle adjustment factor

f_p = driver population adjustment factor

Same as Freeway LOS

Heavy Vehicle Adjustment (f_{HV})

- **Base condition ($f_{HV} = 1.0$)**
 - No heavy vehicles
 - Heavy vehicle = trucks, buses, RVs
- **Two-step process**
 - Determine passenger-car equivalents (E_T)
 - Determine f_{HV}

Same as Freeway LOS

Passenger-Car Equivalents (E_T)

- **Extended segments method**
 - Determine the type of terrain and select E_T
 - No one grade of 3% or more is longer than **0.5 miles**
 - OR
 - No one grade of less than 3% is longer than **1 mile**

EXHIBIT 21-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED GENERAL HIGHWAY SEGMENTS

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 (E_T)

- **Specific grades method**
 - Any grade of 3% or more that is longer than **0.5 miles**
 - OR
 - Any grade of less than 3% that is longer than **1 mile**

EXHIBIT 21-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS ON DOWNGRADES

Downgrade (%)	Length (mi)	E_T			
		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

From *Highway Capacity Manual*, 2000

EXHIBIT 21-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UNIFORM UPGRADES

Multilane Highway LOS

Same as
Freeway LOS

Upgrade (%)	Length (mi)	E_T								
		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	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	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	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25–0.50	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
	> 0.25–0.30	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

Passenger-Car Equivalents (E_T)

EXHIBIT 21-10. PASSENGER-CAR EQUIVALENTS FOR RVS ON UNIFORM UPGRADES

Grade (%)	Length (mi)	E_R								
		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	4.0	3.5	3.0	3.0	2.5	2.0

Same as Freeway LOS

Passenger-Car Equivalents (E_T)

- **Composite grades method**
 - Determines the effect of a series of steep grades in succession
 - **Method OK if...**
 - All subsection grades are less than 4%
 - OR
 - Total length of composite grade is less than 4000 ft.
 - Otherwise, use a detailed technique in the *Highway Capacity Manual (HCM)*

Same as Freeway LOS

From *Highway Capacity Manual*, 2000

Determine f_{HV}

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

f_{HV} = Heavy vehicle adjustment factor

E_T, E_R = Passenger-car equivalents for trucks/buses and RVs

P_T, P_R = Proportion of trucks/buses and RVs in traffic stream

Same as Freeway LOS

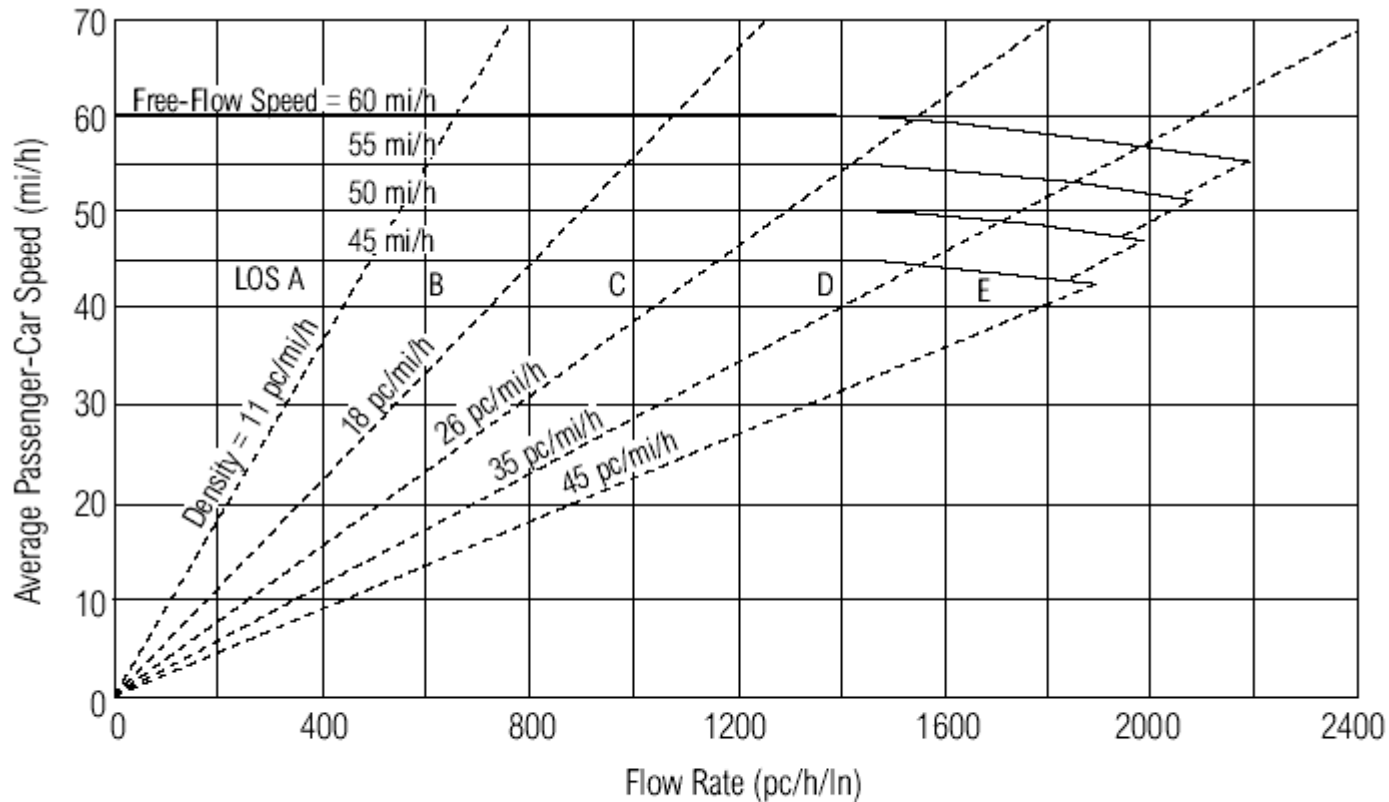
Driver Population Adjustment (f_p)

- **Base condition ($f_p = 1.0$)**
 - Most drivers are familiar with the route
 - Commuter drivers
 - Typical values between 0.85 and 1.00

Same as Freeway LOS

Determine Average PC Speed (S)

Use v_p and FFS curve to find average passenger car speed (S)



Note:

Maximum densities for LOS E occur at a v/c ratio of 1.0. They are 40, 41, 43, and 45 pc/mi/ln at FFS of 60, 55, 50, and 45 mi/h, respectively. Capacity varies by FFS. Capacity is 2,200, 2,100, 2,000, and 1,900 pc/h/ln at FFS of 60, 55, 50, and 45 mi/h, respectively.

From *Highway Capacity Manual*, 2000

Determine Average PC Speed (S)

For $55 < FFS \leq 60$ mph AND $v_p > 1400$

$$S = FFS - \left[\left(\frac{3}{10} FFS - 13 \right) \left(\frac{v_p - 1400}{28FFS - 880} \right)^{1.31} \right]$$

For $50 < FFS \leq 55$ mph AND $v_p > 1400$

$$S = FFS - \left[\left(\frac{34}{205} FFS - \frac{219}{41} \right) \left(\frac{v_p - 1400}{\frac{171}{5} FFS - 1181} \right)^{1.31} \right]$$

For $55 < FFS \leq 75$ mph AND $v_p < (3400 - 30FFS)$

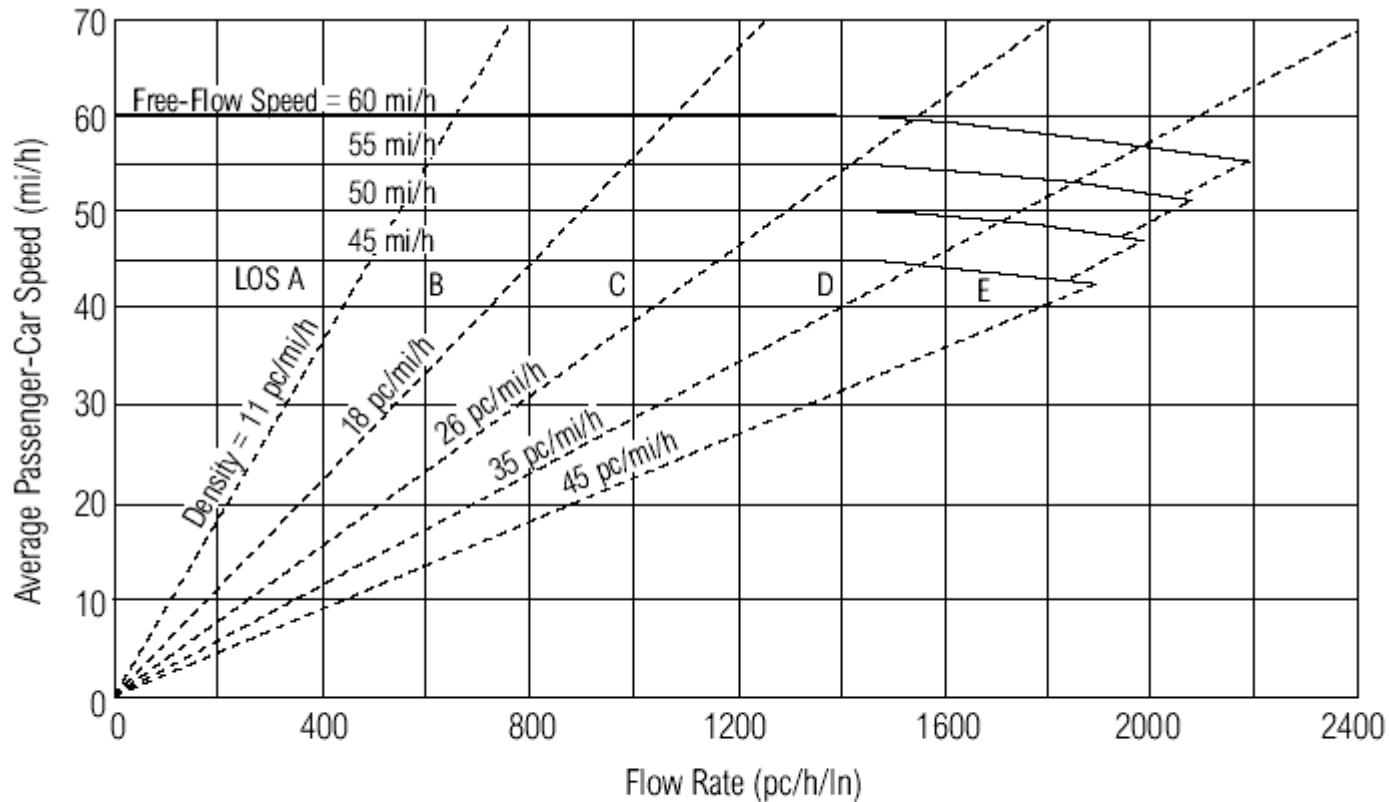
$$S = FFS - \left[\left(\frac{1}{5} FFS - \frac{56}{9} \right) \left(\frac{v_p - 1400}{36FFS - 1120} \right)^{1.31} \right]$$

For $v_p < 1400$

$$S = FFS$$

Determine LOS

Use v_p and passenger car speed (S)



Note:

Maximum densities for LOS E occur at a v/c ratio of 1.0. They are 40, 41, 43, and 45 pc/mi/ln at FFS of 60, 55, 50, and 45 mi/h, respectively. Capacity varies by FFS. Capacity is 2,200, 2,100, 2,000, and 1,900 pc/h/ln at FFS of 60, 55, 50, and 45 mi/h, respectively.

From *Highway Capacity Manual*, 2000

Determine Density

- Calculate density using:

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

D = density (pc/mi/ln)

v_p = flow rate (pc/hr/ln)

S = average passenger-car speed (mph)

LOS Criteria for Multilane Highways

		LOS				
Free-Flow Speed	Criteria	A	B	C	D	E
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 volume to capacity ratio (v/c)	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate (pc/h/ln)	660	1080	1550	1980	2200
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 service flow rate (pc/h/ln)	600	990	1430	1850	2100
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 service flow rate (pc/h/ln)	550	900	1300	1710	2000
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 service flow rate (pc/h/ln)	490	810	1170	1550	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.

Design Traffic Volumes



Design Traffic Volumes

- **Need to select the appropriate hourly traffic volume to get the design LOS**

Definitions

- **Annual average daily traffic (AADT)**
 - Annual traffic averaged on a daily basis
- **Design hourly volume (DHV)**
 - Traffic volume used for design calculations
 - Typically between the 10th and 50th highest volume hour of the year (30th highest is most common)
- **K-factor**
 - Relationship between AADT and DHV

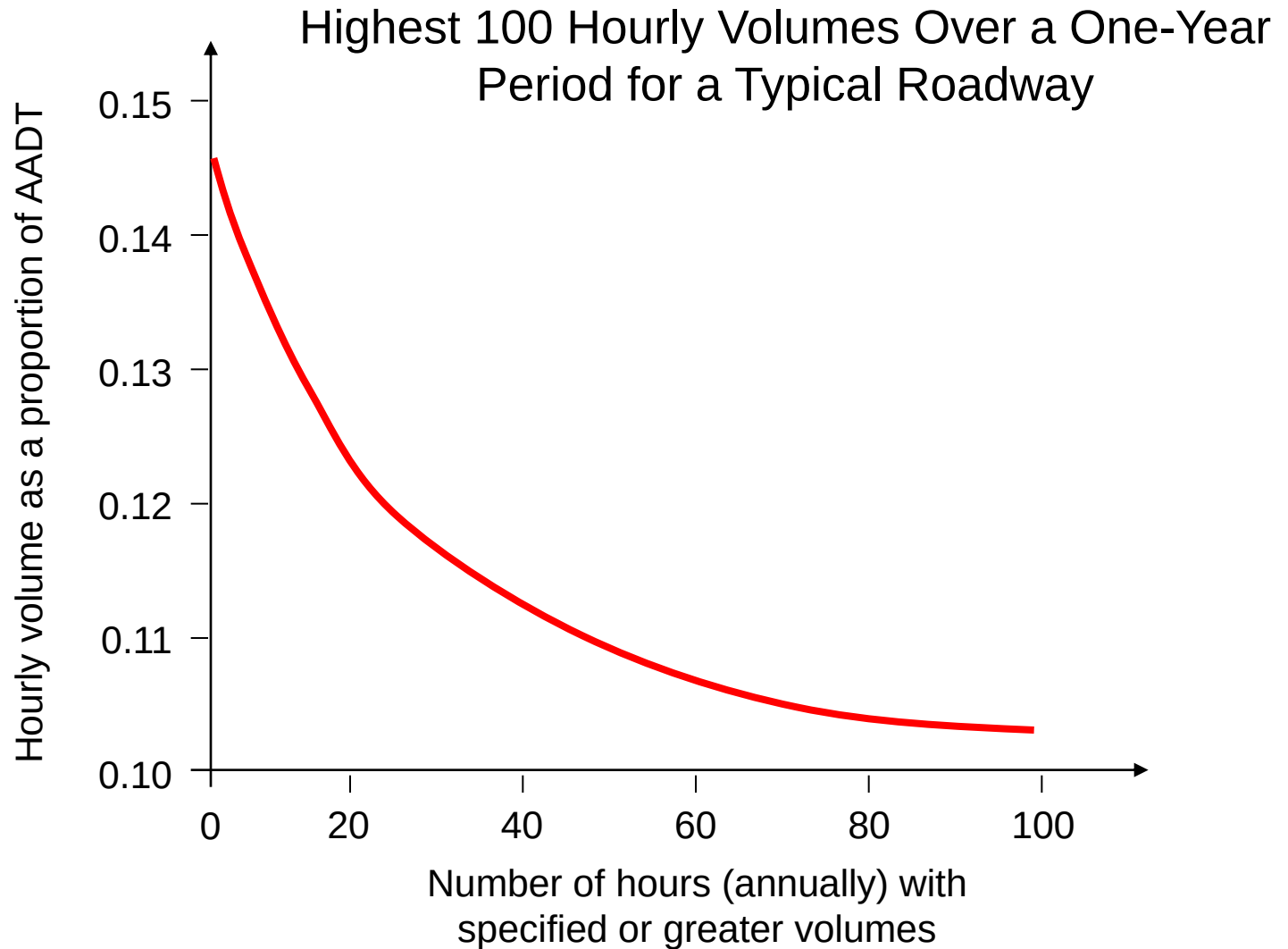
$$K = \frac{DHV}{AADT}$$

Definitions

- **Directional distribution factor (D)**
 - Factor reflecting the proportion of peak-hour traffic traveling in the peak direction
 - Often there is much more traffic in one direction than the other
- **Directional design-hour volume (DDHV)**

$$DDHV = K \times D \times AADT$$

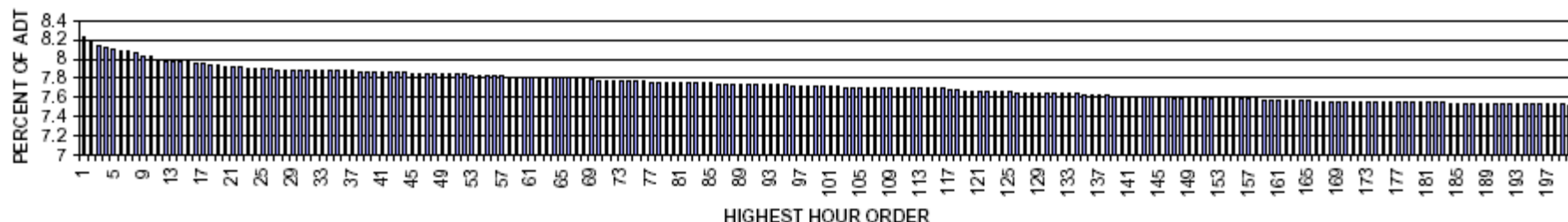
Typical Graph



PEAK HOUR REPORT FOR PEAK 200 HOURS OF 2002--DATA SUMMARY

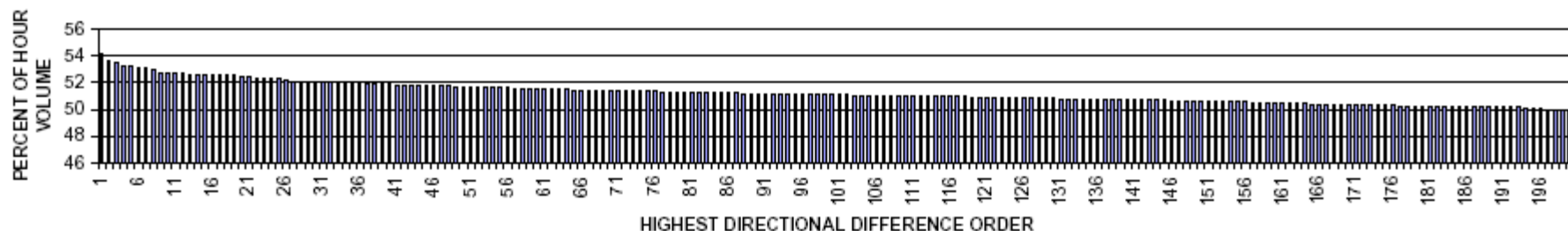
SITE	ADT	K-30 FACTOR	% OF ADT	K-50 FACTOR	% OF ADT	K-100 FACTOR	% OF ADT	K-200 FACTOR	% OF ADT	D-FACTOR	% OF ADT
B02-Data ADT=	21,030	ON SR 12 W/O MONTE BRADY LOOP RD WYE CONN MP 12.30 K 30 FACTOR=	11.52	K-50 FACTOR=	11.01	K 100 FACTOR=	10.39	K-200 FACTOR	9.58	D FACTOR=	57.26
B03-Data ADT=	13,054	ON SR 395 S/O VINEYARD DR - PASCO MP 27.20 K 30 FACTOR=	10.35	K-50 FACTOR=	9.97	K 100 FACTOR=	9.47	K-200 FACTOR	8.89	D FACTOR=	52.65
B04-Data ADT=	27,230	ON SR 90 W/O CLE ELUM OFF RAMP MP 82.70 K 30 FACTOR=	15.67	K-50 FACTOR=	14.98	K 100 FACTOR=	14.18	K-200 FACTOR	12.97	D FACTOR=	61.93
D1-Data ADT=	136,632	ON SR 405 AT 112TH AVE SE UXING MP 9.26 K 30 FACTOR=	7.54	K-50 FACTOR=	7.49	K 100 FACTOR=	7.41	K-200 FACTOR	7.3	D FACTOR=	52.72
D10-Data ADT=	100,280	ON SR 520 W/O 76TH AVE NE UXING MP 4.00 K 30 FACTOR=	7.89	K-50 FACTOR=	7.84	K 100 FACTOR=	7.72	K-200 FACTOR	7.52	D FACTOR=	51.1

SR 520 MP 4.0 TOLL PLAZA ADC SITE D10
K FOR PEAK 200 HOURS OF 2002



ADT= 100280 K 30 FACTOR= 7.89 K 100 FACTOR= 7.72 K 200 FACTOR= 7.52 D FACTOR= 51.1

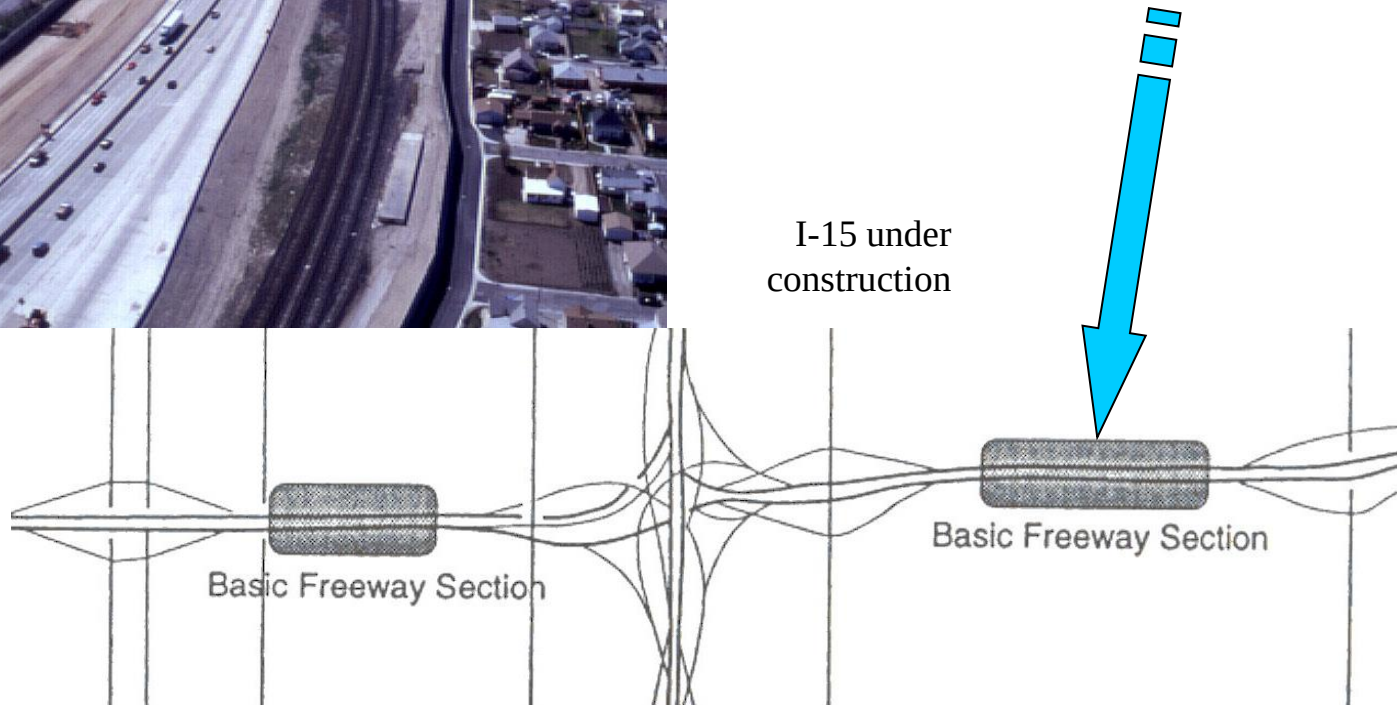
SR 520 MP 4.0 TOLL PLAZA ADC SITE D10
D % IN THE PEAK 200 HOURS OF 2002



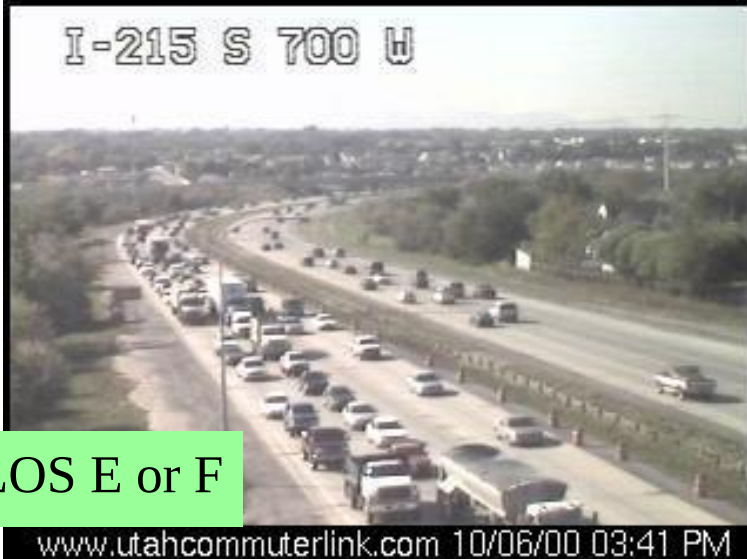
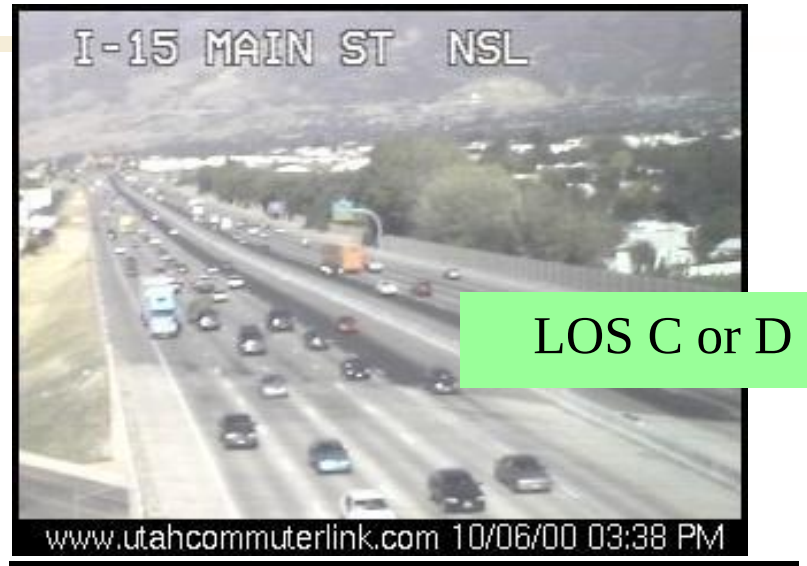
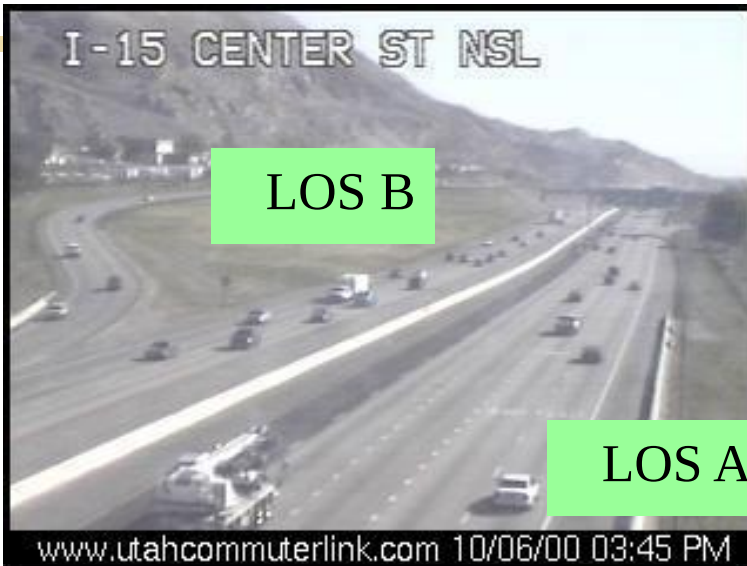
Basic freeway segments



Basic freeway segments: Segments of the freeway that are outside of the influence area of ramps or weaving areas and have uniform traffic and roadway conditions.



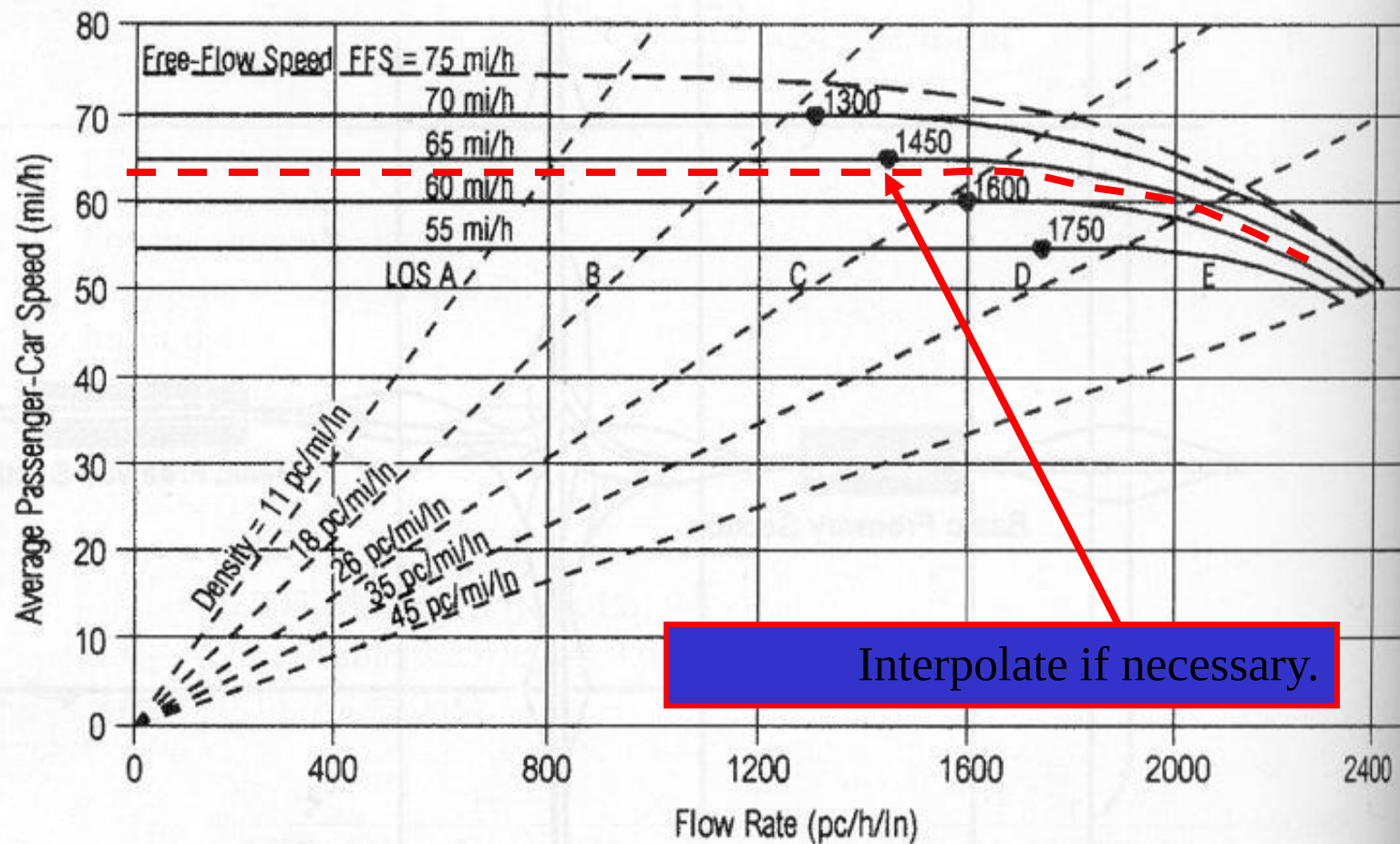
Level of service example



Level of service	Density range (pc/mi/ln)
A	0 - 11.0
B	11.1 - 18.0
C	18.1 - 26.0
D	26.1 - 35.0
E	35.1 - 45.0
F	> 45.0

Performance measures for basic freeway segments

Performance measures can be: Density, speed, and volume-to-capacity



Performance measures (cont)

Density criteria are independent of FFS level

Table 9.33 Level-of-Service Criteria for Basic Freeway Segments

Criteria	LOS				
	A	B	C	D	E
<i>FFS = 75 mi/h</i>					
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
<i>FFS = 70 mi/h</i>					
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
<i>FFS = 65 mi/h</i>					

Base conditions and ideal condition for freeway flow & affecting factors

Base conditions for freeway capacity: Good weather, good visibility, no incidents

Ideal conditions for freeway flow (& factors affecting its level of service):

Min. lane widths of 12 feet

Min. right-shoulder lateral clearance of 6 feet (median → 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

What's needed for a basic freeway segment analysis are these two values

Determination of free-flow speed (FFS), mph:

$$FFS = BFFS_i - f_{LW} - f_{LC} - f_N - f_{ID} \quad (9.22)$$

For freeways, $BFFS_i$ (i.e., deal FFS) is 70 (for urban) or 75 mph (for rural). If field study results exist, use FFS from those studies. Field FFS is estimated by travel time studies. FFS is approximately average speeds taken when flow rate is not more than 1300 pcphpl.

f_N adjustment is for urban freeways only. For rural freeways, $f_N = 0$. f_{ID} is done using a plus/minus 3-mile stretch (i.e. 6 miles). Must have one or more on-ramps. (# of on-ramps/6)

Determination of 15-min. passenger-car equivalent flow rate (v_p) pcphpl:

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \quad (9.21)$$

Once you have *FFS* and v_p ...

You can determine density which is the primary measure of effectiveness of basic freeway segments.

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

For the LOS range from A to D, S (speed) is basically *FFS*. Toward the upper end of LOS D to E, S does decrease from *FFS* as shown in the speed-flow rate diagram(Fig. 9.9).

Heavy-vehicle adjustment factor

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

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

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

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 0.5 km or where no one grade of less than 3% is longer than 1 km. 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

(See p.367 for the descriptions of Level, Rolling and Mountains terrain types.)

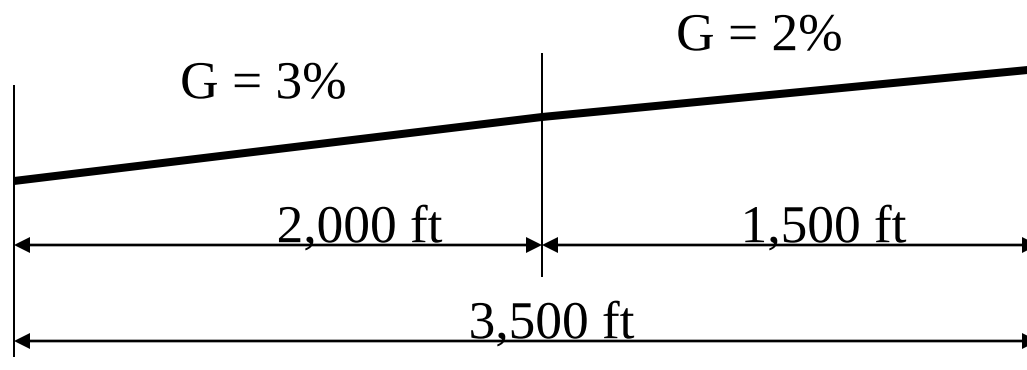
How we deal with long, sustaining grades...(cont)

(2) **Specific upgrades:** Any freeway grade of more than 1.0 km for grades less than 3 percent or 0.5 km for grades of 3 percent or more should be considered as a separate segment. 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.

What if you have a composite grade in your analysis segment?



Using the average grade method:

$$\text{Total rise} = (0.03 \times 2000) + (0.02 \times 1500) = 90 \text{ ft}$$

$$\text{Average grade} = 90 / (2000 + 1500) = 0.026 \text{ or } 2.6\%$$

$$\text{Total length} = 3500 / 5280 = 0.66 \text{ mi}$$

Note: you do not need to know the precise procedure in this class, which is discussed in detail in CE561. After all, the “precise” method assumes the entry speed of 55 mph—a remnant of the federal 55-mph speed limit law.

Four types of analysis

Type		Input	Output
Operational	I	v_p, FFS	LOS
	II	v_p, LOS, FFS	S (Speed)
	III	FFS, LOS	V_p (service volume = $V_p * PHF$)
Planning	IV	v_p, LOS	N (No. of lanes)

For planning analysis, you need to estimate the directional design hourly volume (DDHV):

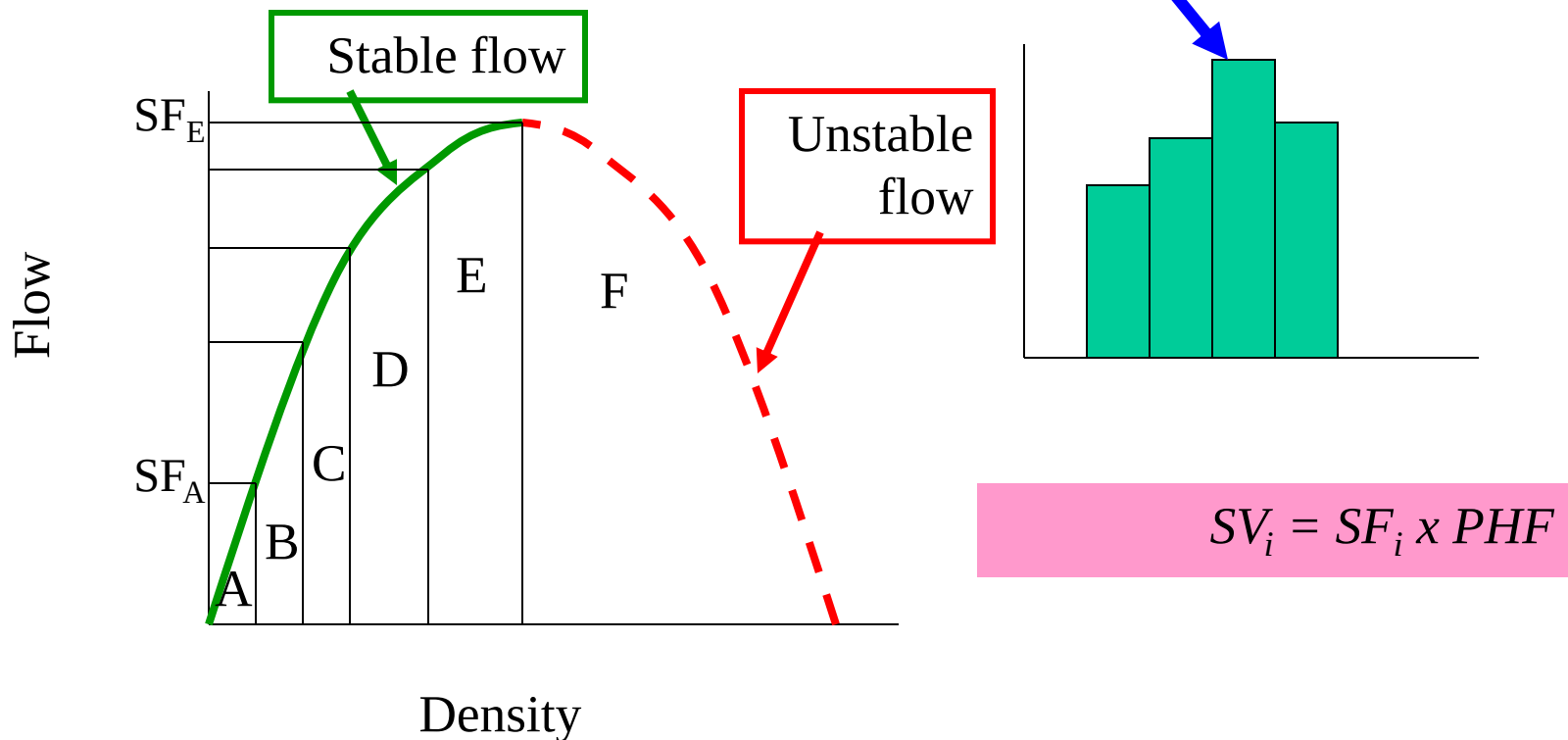
$$DDHV = AADT \times K \times D$$

besides all other potential prevailing conditions. Then,

$$V = DDHV / (\text{no. of lanes})$$

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.



Problem 9-12: This is a case of planning analysis – given v_p and LOS, find number of lanes needed

- Step 1: Compute heavy vehicle adjustment factor

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

- Step 2: Assume number of lanes (freeway ≥ 4 lanes – 2 lane each way minimum) and compute 15-min peak passenger-car equivalent flow rate.
Hint 1: Design volume of a freeway is given for each direction. Hint 2: Highest freeway lane capacity is about 2300 pcphpl.

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

- Step 3: Compute free flow speed given BFFS (70 mph in this case) and number of lanes used in Step 2 and other data.

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

- Step 4: Compute density using v_p and FFS and determine LOS to see if computed LOS meets the desired LOS. (Tab 9-33)

Repeat steps 2 to 4 till design LOS is met.

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

Primary References

- Mannering, F.L.; Kilareski, W.P. and Washburn, S.S. (2005). *Principles of Highway Engineering and Traffic Analysis*, Third Edition. Chapter 6
- Transportation Research Board. (2000). *Highway Capacity Manual 2000*. National Research Council, Washington, D.C.