533372 Highway Engineering

Traffic and Road Characteristics

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Types of Facilities

- Uninterrupted flow facilities:
  have no external interruptions to the traffic stream

- Interrupted flow facilities:
  facilities that incorporate fixed external interruptions into their design and operation

Capacity of Facility

จำนวนสูงสุดของคน หรือยานพาหนะที่คาดว่าสามารถเคลื่อนผ่านจุด หรือช่วงระยะใดระยะหนึ่งซึ่งมีลักษณะคงที่ (Uniform) ของช่องจราจรหนึ่ง หรือของถนนสายหนึ่งในช่วงระยะเวลาที่กำหนดภายใต้สภาพทั่วไปของถนนและการควบคุมต่างๆ

Time period:

ช่วงเวลาที่ใช้ในการวิเคราะห์โดยทั่วไปที่ใช้ในการศึกษาเรื่องความจุเท่ากับ 15 นาที ซึ่งจัดเป็นระยะเวลาที่สั้นที่สุดที่การไหลของกระแสจราจรจะเป็นไปอย่างคงที่ (Stable flow)

Level of service (LOS):

คุณภาพในการสัญจรของยานพาหนะบนถนนที่รับรู้โดยผู้ใช้ถนนในรูปของความสะดวก ความปลอดภัย ความรวดเร็ว ตลอดจนความมีอิสระในการขับขี่ ณ ความเร็วที่ต้องการ แบ่งออกได้เป็น 6 ระดับ A - F

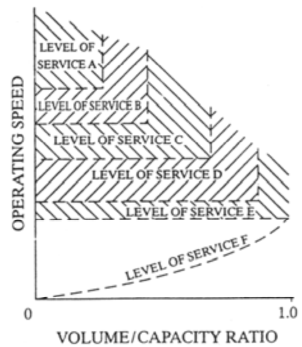


Figure 4.5.1 Levels of service. (From Highway Research Board [4.8].)

Service flow rate:

อัตราการไหลรายชั่วโมงของผู้คน หรือยานพาหนะที่คาดว่าสามารถเคลื่อนที่ผ่านจุดที่กำหนด หรือช่วงระยะใดระยะหนึ่งซึ่งมีลักษณะคงที่ (Uniform) ของช่องจราจรหนึ่ง หรือของถนนสายหนึ่ง ภายในช่วงระยะเวลาที่กำหนด ภายใต้สภาพทั่วไปของถนน กระแสจราจร และการควบคุมต่างๆ ณ ระดับการให้บริการหนึ่ง

Traffic Stream Parameters

Volume and rate of flow

1. Daily volumes
   - Average annual daily traffic (AADT)
   - Average annual weekday traffic (AAWT)
   - Average daily traffic (ADT)
   - Average weekday traffic (AWT)

2. Hourly volumes

$$DDHV = AADT * K * D$$

DDHV = directional design hour volume

K = proportion of daily traffic occurring during the peak hour

D = proportion of peak hour traffic traveling the peak direction of flow

General ranges for K and D factors

Facility type	Normal range of value	
	K-factor	D-factor
Rural	0.15-0.25	0.65-0.80
Suburban	0.12-0.15	0.55-0.65
Urban:		
Radial route	0.07-0.12	0.55-0.60
Circumferential route	0.07-0.12	0.50-0.55

Example: for rural highway

AADT = 20 years forecast traffic volume, 30,000 veh/day

K = range from 0.15 to 0.25

D = range from 0.65 to 0.80

$$DDHV_{LOW} = 30{,}000 * 0.15 * 0.65 = 2{,}925\ veh/h$$

$$DDHV_{HIGH} = 30{,}000 * 0.25 * 0.80 = 6{,}000\ veh/h$$

3. Subhourly volumes and rates of flow

- Illustration of volumes and rates of flow

Time interval	Volume for time interval (vehs)	Rate of flow for time interval (vehs/h)
5:00-5:15 PM	1,000	1,000/0.25
5:15-5:30 PM	1,100	1,100/0.25
5:30-5.45 PM	1,200	1,200/0.25
5.45-6.00 PM	900	900/0.25
5.00-6.00 PM	$\sum$ = 4,200	

- Queuing analysis

Time interval	Arriving vehicles (vehs)	Departing vehicles (vehs)	Queue size at end of period (vehs)
5:00-5:15 PM	1,000	1,050	0
5:15-5:30 PM	1,100	1,050	0+1,100-1,050 = 50
5:30-5.45 PM	1,200	1,050	50+1,200-1,050 = 200
5.45-6.00 PM	900	1,050	200+900-1,050 = 50

- Peak hour factor (PHF)

$$PHF = \frac{hourly\ volume}{\max.\ rate\ of\ flow}$$

For standard 15-minute analysis period

$$PHF = \frac{V}{4 * V_{m15}}$$

V = hourly volume, vehs

V_{m15} = maximum 15-minute volume within the hour, vehs

Example: by using data from the table

$$PHF = \frac{4{,}200}{4 * 1{,}200} = 0.875$$

- In practical, the PHF generally varies between 0.70 (rural and sparsely developed areas) to 0.98 (dense urban areas)

$$v = \frac{V}{PHF}$$

ν = maximum rate of flow within the hour, veh/h

V = hourly volume, veh/h

Speed and Travel Time

$$S = \frac{d}{t}$$

S = speed, mi/h or ft/s

d = distance traversed, mi or ft

t = time to traverse distance d, h or s

Two ways for computing average speed

- Time mean speed (TMS):

$$TMS = \frac{\sum_i \left(\frac{d}{t_i}\right)}{n}$$

- Space mean speed (SMS):

$$SMS = \frac{d}{\left(\frac{\sum_i t_i}{n}\right)} = \frac{nd}{\sum_i t_i}$$

S = speed, mi/h or ft/s

d = distance traversed, mi or ft

t = time to traverse distance d, h or s

Illustrative computation of TMS and SMS

Vehicle No.	Distance d (ft)	Travel time t (s)	Speed (ft/s)
1	1,000	18.0	1,000/18 = 55.6
2	1,000	20.0	1,000/20 = 50.0
3	1,000	22.0	1,000/22 = 45.5
4	1,000	19.0	1,000/19 = 52.6
5	1,000	20.0	1,000/20 = 50.0
6	1,000	20.0	1,000/20 = 50.0
Total	6,000	119	303.7
Average	6,000/6 = 1,000	119/6 = 19.8	303.7/6 = 50.6

TMS = 50.6 ft/s
SMS = 1,000/19.8 = 50.4 ft/s

Density and Occupancy

Density:
The number of vehicles occupying a given length of highway or lane (veh/mi or veh/mi/ln)

Occupancy:
The proportion of time that a detector is “occupied” or covered by a vehicle in a defined time period

$$D = \frac{5{,}280 * O}{L_v + L_d}$$

D = Traffic density, veh/mi or veh/mi/ln

L_v = Average length of a vehicle, ft

L_d = Length of the detector (which is normally a loop detector), ft

O = “Occupancy” over a given detector

Spacing and Headway

Spacing:
The distance between successive vehicles in a traffic lane, measured from some common reference point on the vehicles, such as the front bumper or front wheels

$$D = \frac{5{,}280}{d_a}$$

D = Density, veh/mi/ln

d_a = average spacing between vehicle in the lane, ft

Headway:
The time interval between successive vehicles as they pass a point along the lane, also measured between common reference points on the vehicles

$$v = \frac{3{,}600}{h_a}$$

ν = Rate of flow, veh/h/ln

h_a = average headway in the lane, s

Average speed can also be computed from headway and spacing measurements as:

$$S = \frac{(d_a / h_a)}{1.47} = 0.68(d_a / h_a)$$

S = Average speed, mi/h

D_a = Average spacing, ft

h_a = average headway, s

A Sample Problem:

Traffic in a congested multilane highway lane is observed to have an average spacing of 200 ft, and an average headway of 3.8 s. Estimate the rate of flow, density, and speed of traffic in this lane.

Solution:

$$v = \frac{3{,}600}{3.8} = 947 \ veh / h / \ln$$

$$D = \frac{5{,}280}{200} = 26.4 \, veh / mi / \ln$$

$$S = 0.68(200/3.8) = 35.8 \, mi / h$$

Relationships among Flow Rate, Speed, and Density

$$v = S * D$$

ν = Rate of flow, veh/h or veh/h/ln

S = Space mean speed, mi/h

D = Density, veh/mi or veh/mi/ln

Ideal conditions

- 12-ft minimum lane width
- 2-ft minimum lateral clearance from the left-side median
- 6-ft minimum right side lateral clearance between the edge of the travel lane and the nearest object that influences driving behavior
- All passenger-car traffic composition
- Five or more lanes per direction (urban freeways only)
- Driver population consisting mostly of regular users of the facility (commuters)
- Level terrain (grades no greater than 2%)
- Access spacing of 2 mi or greater

Factors Influencing to Capacity, Service Flow Rate, and Level of Service

สภาพหรือองค์ประกอบทั่วไปที่มีผลต่อการดำเนินการด้านการจราจร และกระแสจราจร อันมีผลกระทบต่อความจุ อัตราการไหลบริการ และระดับการให้บริการของสิ่งอำนวยความสะดวก

1. Road way conditions:

ลักษณะของถนนซึ่งครอบคลุมถึงตัวแปรทางด้านเรขาคณิตที่มีผลต่อการเปลี่ยนแปลงของกระแสจราจร

- o ชนิดของสิ่งอำนวยความสะดวก
- o ความกว้างของช่องจราจร
- o ความกว้างของไหล่ทาง และสิ่งกีดขวางด้านข้าง
- o ความเร็วออกแบบ
- o ทางโค้งแนวราบและแนวดิ่ง

2. Geographical conditions:

มีอิทธิพลต่อการกำหนดโค้งราบและโค้งดิ่ง ในการวิเคราะห์ความจุของถนนนิยมแบ่งลักษณะภูมิประเทศออกเป็น 3 ลักษณะ

- o Level terrain
- o Rolling terrain
- o Mountainous terrain

3. Traffic conditions:

ลักษณะหรือองค์ประกอบของกระแสจราจรที่มีอิทธิพลต่อการสัญจรบนท้องถนน โดยองค์ประกอบดังกล่าวที่สำคัญ คือ ประเภทของยานพาหนะซึ่งยานพาหนะประเภทหลักที่พิจารณา ได้แก่ รถยนต์นั่งส่วนบุคคล (Passenger cars) และรถบรรทุกหนัก (Heavy vehicles) โดยรถบรรทุกหนักที่ใช้ศึกษาเรื่องความจุ แบ่งออกเป็น 3 ประเภท

- o Trucks (T)
- o Recreational vehicles (RV)
- o Buses (Bus)

4. Control conditions:

การควบคุมสิ่งอำนวยความสะดวกเพื่อความเรียบร้อย ซึ่งก็คือ สัญญาณไฟจราจร หรือป้ายสัญญาณต่าง ๆ การควบคุมเหล่านี้จะมีผลกระทบโดยตรงต่อความจุของถนน อัตราการไหล และระดับการให้บริการ ในการวิเคราะห์สิ่งอำนวยความสะดวกชนิดที่มีการไหลอย่างไม่ต่อเนื่อง เช่น บริเวณทางแยก (Signalized intersections)

Capacity and Level-of-Service Analysis for Freeways and Multilane Highways

Freeway:

ถนนหรือทางที่มีการแบ่งช่องทางและทิศทางการจราจรอย่างชัดเจน ในแต่ละทิศทางจะมีช่องจราจร 2 ช่องหรือมากกว่า มีการควบคุมการเข้าและออกทางด่วนอย่างสมบูรณ์ (Full control access) จึงจัดเป็น Uninterrupted flow facility เนื่องจากไม่มีการรบกวนกระแสจราจรจากสิ่งภายนอก เช่น ป้ายหยุดและสัญญาณไฟจราจร

The components of freeway:

o Basic freeway segments or uninfluenced area

ช่วงของทางด่วนที่ไม่ถูกรบกวนเนื่องจากการเข้า-ออกของกระแสจราจร ณ บริเวณทางร่วมทางเชื่อมเลย และไม่มีการวิ่งไขว้กัน หรือการเปลี่ยนช่องจราจรสลับไปมาของยวดยาน (Weaving) ในบริเวณนี้ด้วย

o Ramp junction

บริเวณหรือจุดที่เส้นทาง On-ramp หรือ Off-ramp ตัดกับทางด่วน ในบริเวณนี้ กระแสจราจรของทางด่วนจะถูกการจราจรเข้า-ออกรบกวนมาก

o Weaving area

ส่วนของทางด่วนที่มีการเคลื่อนที่ไขว้กัน (Cross) ของการไหลของกระแสจราจร 2 กระแสหรือมากกว่า บริเวณดังกล่าวมักเกิดขึ้นเมื่อ Merge area และ Diverge area อยู่ติดกัน หรือเส้นทาง On-ramp และเส้นทาง Off-ramp มีการเชื่อมด้วยช่องจราจรเสริมชนิดต่อเนื่องเพื่อช่วยระบายการจราจร

Influenced Area

o On-ramp

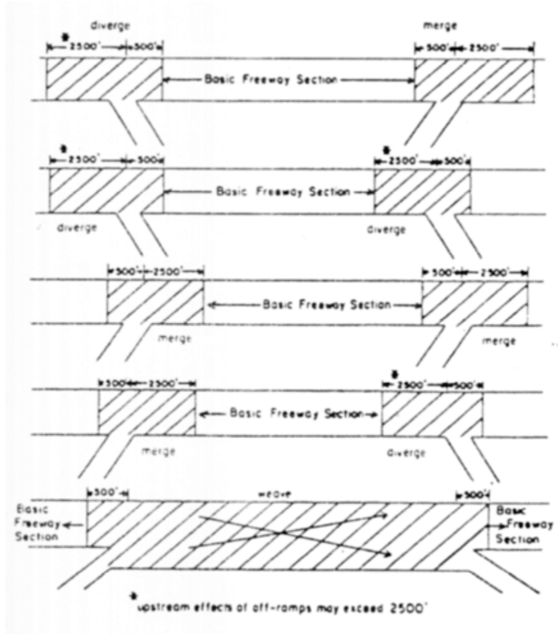
ครอบคลุมพื้นที่ที่อยู่เหนือกระแสจราจร (Upstream) 500 ฟุต และพื้นที่ใต้กระแสจราจร (Downstream) 2,500 ฟุต จากบริเวณทางเชื่อม (Ramp junction)

o Off-ramp

ครอบคลุมพื้นที่ที่อยู่เหนือกระแสจราจร 2,500 ฟุต และพื้นที่ใต้กระแสจราจร 500 ฟุต จากบริเวณทางเชื่อม

o Weaving area

ครอบคลุมพื้นที่ที่อยู่เหนือกระแสจราจร 500 ฟุต จากจุดเข้า (Merge point) ถึงจุดใต้กระแสจราจร 500 ฟุต จากจุดออก (Diverge point)



Freeway capacity:

อัตราการไหลสูงสุดในช่วงเวลา 15 นาที ที่ทางด่วนจะรองรับได้ ซึ่งวัดได้จากกระแสจราจรที่เคลื่อนที่ผ่านจุดๆ หนึ่งบนทางด่วน หรือช่วงระยะทางที่สม่ำเสมอ (Uniform) ของทางด่วน ภายใต้สภาพทั่วไปของถนนและกระแสจราจร ความจุนี้จะนับเพียงทิศทางเดียว หน่วยเป็น veh/h

Basic considerations:

o Design speed

o Ideal condition

Analysis Methodologies for Basic Freeway Sections and Multilane Highways

o The impact of a variety of prevailing conditions, including:

- 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

o The relation among LOS, density, design speed, average travel speed, volume-capacity ratio (v/c), and maximum service flow rate (MSF) are considered

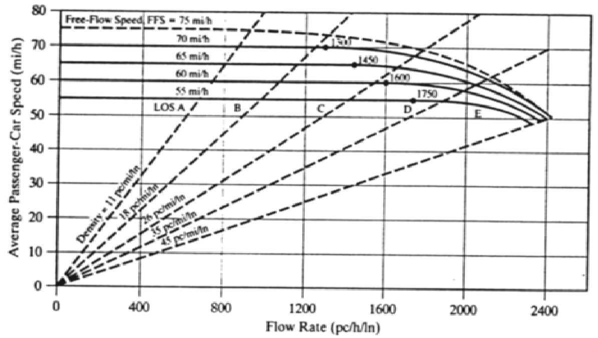


Figure 12.3: Speed-Flow Curves for Basic Freeway Sections (Used with permission of Transportation Research Board, National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 23-3, pg. 23-5.)

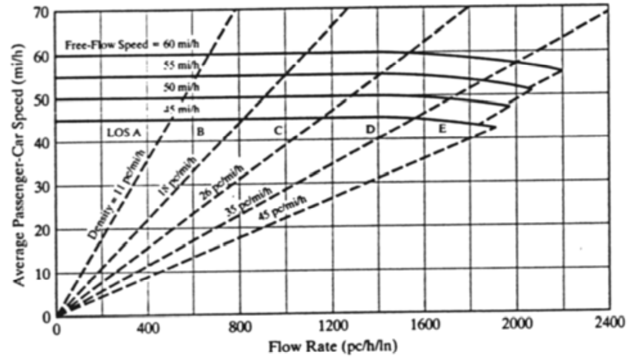


Figure 12.4: Speed-Flow Curves for Multilane Highway Sections (Used with permission of Transportation Researc National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 21-3, pg. 21-4.)

Table 12.2: Level-of-Service Criteria for Freeways and Multilane Highways

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

Table 12.3: Level-of-Service Criteria for Basic Freeway Sections

Criteria	A	B	C	D	E
Free-Flow Speed = 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	1,350	1,830	2,170	2,400
Free-Flow Speed = 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	1,260	1,770	2,150	2,400
Free-Flow Speed = 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	1,170	1,680	2,090	2,350
Free-Flow Speed = 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	1,080	1,560	2,020	2,300
Free-Flow Speed = 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	1,430	1,910	2,250

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.
(Used with permission of Transportation Research Board, National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 23-2, pg. 23-3.)

Table 12.4: Level of Service Criteria for Multilane Highways

Criteria	Level of Service				
	A	B	C	D	E
Free-Flow Speed = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	40
Minimum speed (mi/h)	60.0	60.0	59.4	56.7	55.0
Maximum *v/c*	0.30	0.49	0.70	0.90	1.00
Maximum service flow rate (pc/h/ln)	660	1,080	1,550	1,980	2,200
Free-Flow Speed = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	41
Minimum 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	1,430	1,850	2,100
Free-Flow Speed = 50 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	43
Minimum speed (mi/h)	50.0	50.0	50.0	48.9	47.5
Maximum *v/c*	0.28	0.65	0.65	0.86	1.00
Maximum service flow rate (pc/h/ln)	550	900	1,300	1,710	2,000
Free-Flow Speed = 45 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum 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	1,170	1,550	1,900

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.

(Used with permission of Transportation Research Board, National Research Council, from *Highway Capacity Manual*, Dec 2000, Exhibit 21-2, pg. 21-3.)

- Basic relationship
  - Maximum service flow rate per lane, MSF

$$MSF_i = c_j * (v/c)_i$$

MSF_i = อัตราการไหลบริการสูงสุดต่อช่องจราจรสำหรับระดับบริการ i ภายใต้ Ideal conditions, pcphpl

c_j = ความจุภายใต้ Ideal conditions สำหรับส่วนประกอบของทางด่วนที่มีความเร็วออกแบบเท่ากับ j ค่า c_j จะเท่ากับ MSF ที่ระดับการให้บริการ E

Design speed (mph)	c_j (pcphpl)
60, 70	2,000
50	1,900

- Service flow rate per lane, SF

$$SF_i = MSF \times N \times f_w \times f_{HV} \times f_p \qquad or$$

$$SF_i = c_j \times (v/c)_i \times N \times f_w \times f_{HV} \times f_p$$

SF_i = อัตราการไหลบริการสำหรับระดับบริการ i ภายใต้ Ideal conditions สำหรับ N ช่องจราจรในทิศทางเดียว, veh/h

N = จำนวนช่องจราจรทั้งหมดในทิศทางเดียวของทางด่วน

f_w = ตัวประกอบเพื่อปรับผลกระทบของความกว้างช่องทางจราจรและสิ่งกีดขวางด้านข้างที่ไม่เป็นไปตามทฤษฎี

f_{HV} = ตัวประกอบเพื่อปรับผลกระทบของการมีรถบรรทุกหนักในกระแสจราจร

f_p = ตัวประกอบเพื่อปรับผลกระทบจากการเดินทาง การขับขี่ ที่นอกเหนือจากวันธรรมดา

Types of Analysis

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

Operational analysis

- In this form of analysis, all traffic, roadway, and control conditions are defined for an existing or projected highway sections, and the expected level of service and operating parameters are determined
- The basic approach is to convert the existing or forecast demand volumes to an equivalent flow rate under ideal conditions

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

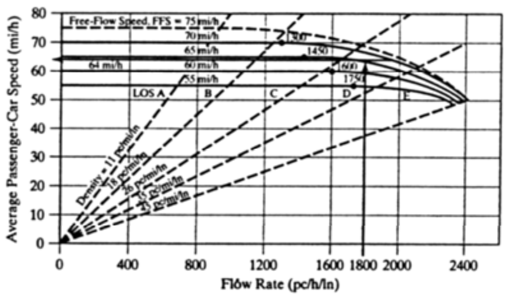
v_p = demand flow rate under equivalent ideal conditions, pc/h/ln

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 presence of occasional or non-familiar users of a facility



Example:

v_p = adjusted demand flow = 1,800 pc/h/ln

Free flow speed = 65 mi/h

From chart,

The expected speed = 64 mi/h

Level of service = D

Density = flow rate/speed = 1,800/64 = 28.13 veh/mi/ln

Service flow rate and service volume analysis

- Service flow rate for a given level of service

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

SF_i = service flow rate for level of service "i", veh/h

MSF_i = maximum service flow rate for level of service "i", pc/h/ln (see Table 12.3 for freeways and Table 12.4 for multilane highway)

- Service flow rate can be converted to service volumes over the full peak hour

$$SV_i = SF_i * PHF$$

SV_i = service volume over a full peak hour for level of service "i"

- Design analysis
  - An existing or forecast demand volume is used to determine the number of lanes needed to provide for a specified level of service

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

N_i = number of lanes (in one direction) required to provide level of service "i"

DDHV = directional design hour volume, veh/h

Determining the Free-Flow Speed

- Freeways
  - The free-flow speed of a freeway can be estimated as:

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

FFS = free-flow speed of the freeway, mi/h

BFFS = base free-flow speed of the freeway (70 mi/h for urban and suburban freeways, 75 mi/h for rural freeways)

f_{LW} = adjustment for lane width, mi/h

f_{LC} = adjustment for lateral clearance, mi/h

f_N = adjustment for number of lanes, mi/h

f_{ID} = adjustment for interchange density, mi/h

- *Lane width adjustment (f_{LW}):*

the base condition for lane width is an average width of 12 ft or greater. For narrower lanes, the base free-flow speed is reduced by the factors shown in Table 12.5

Table 12.5: Adjustment to Free-Flow Speed for Lane Width on a Freeway

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

(Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, Dec 2000, Exhibit 23-4, pg. 23-6.)

- *Adjustment for number of lanes (f_N)*
- *Interchange density adjustment (f_{ID})*

- *Lateral clearance adjustment (f_{LC}):*

base lateral clearance is 6 ft or greater on the right side and 2 ft or greater on the median, or left, side of the basic freeway section. Adjustments for right-side lateral clearances less than 6 ft are given in Table 12.6

Table 12.6: Adjustment to Free-Flow Speed for Lateral Clearance on a Freeway

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	2.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

(Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, Dec 2000, Exhibit 23-5, pg. 23-6.)

Multilane highways

- The free-flow speed of a multilane highway can be estimated as:

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

FFS = free-flow speed of the multilane highway, mi/h

BFFS = base free-flow speed of the multilane highway
- 60 mi/h for rural and suburban multilane highways
- for speed limits of 40 and 45 mi/h, BFFS is approximately 7 mi/h higher than the posted speed limit
- for speed limits of 50 and 55 mi/h, BFFS is approximately 5 mi/h higher than the posted speed limit

f_{LW} = adjustment for lane width, mi/h

f_{LC} = adjustment for lateral clearance, mi/h

f_M = adjustment for type of median, mi/h

f_A = adjustment for access points, mi/h

- *Lane width adjustment (f_{LW}):* Table 12.9
- *Lateral clearance adjustment (f_{LC}):* Table 12.10
- *Median-type adjustment (f_M):* Table 12.11
- *Access-point density adjustment (f_A):* Table 12.12

Determining the Heavy-Vehicle Factor

- Two categories of heavy vehicles:
  - Trucks and buses
  - Recreational vehicles (RVs)
- The concept of passenger car equivalents and their relationship to the heavy-vehicle adjustment factor

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

- The heavy-vehicle factor can be estimated as:

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

P_T = proportion of trucks and buses in the traffic stream

P_R = proportion of RVs in the traffic stream

E_T = passenger car equivalent for trucks and buses

E_R = passenger car equivalent for RVs

o Example

Traffic stream of 1,000 veh/h , containing 10% trucks and 2% RVs. Field studies indicate that for this particular traffic stream, each truck displaces 2.5 passenger cars (E_T) from the traffic stream, and each RV displaces 2.0 passenger cars (E_R) from the traffic stream. What is the total number of equivalent passenger cars/h in the traffic stream?

$$f_{HV} = \frac{1}{1+0.10(2.5-1)+0.02(2.0-1)}$$
$$= \frac{1}{1.170}$$
$$= 0.8547$$

o Passenger-car equivalents for extended freeway and multilane highway sections

- A long section of roadway may be considered as a single extended section if no one grade of 3% or greater is longer than 0.25 miles, and if no grade of less than 3% is longer than 0.5 miles
- The passenger-car equivalent for freeways and multilane highways on extended sections can be varied on types of terrain (see Table 12.13)

o Passenger-car equivalents for specific grades on freeways and multilane highways

HCM 2000 specifies passenger car equivalents for:

- Trucks and buses on specific upgrades (Table 12.14)
- RVs on specific upgrades (Table 12.15)
- Trucks and buses on specific downgrades (Table 12.16)
- The passenger car equivalent for RVs on downgrade sections is taken to be the same as that for level terrain sections (equal to 1.2)

o Composite grades

- Average grade technique
- Composite grade technique

Determining the Driver Population Factor

- In general, the factor ranges between a value of 1.00 (for commuter traffic streams) to 0.85 as a lower limit for other driver populations.
- Unless specific evidence for a lower value is available, a value of 1.00 is generally used in analysis
- Where a future situation is being analyzed, and recreational users dominate the driver population, a value of 0.85 is suggested as it represents a "worst-case" scenario

Example 1: An Urban Freeway

An old 6-lane urban freeway has the following characteristics: 11-ft lanes; frequent roadside obstructions located 2 ft from the right pavement edge; and an interchange density of 2.00 interchanges/mile (i.e., average interchange spacing of 0.50 mile). What is the free-flow speed of this freeway?

Solution: The free-flow speed of a freeway may be estimated using equation

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

The following values are used in this computation:

BFFS = 70 mi/h for urban and suburban freeways

f_{LW} = 1.9 mi/h (Table 12.5, 11-ft lanes)

f_{LC} = 1.6 mi/h (Table 12.6, 2-ft lateral clearance, 3 lanes)

f_N = 3 mi/h (Table 12.7, 3 lanes in one direction)

f_{ID} = 7.5 mi/h (Table 12.8, 2.00 interchanges/mi)

Then:

$$FFS = 70.0 - 1.9 - 1.6 - 3.0 - 7.5 = 56.0\, mi/h$$

Example 2: A Four-Lane Suburban Multilane Highway

A 4-lane undivided multilane highway in a suburban area has the following characteristics: posted speed limit = 50 mi/h; 11-ft lanes; frequent obstructions located 4 ft from the right pavement edge; 30 access points/mi on the right side of the facility. What is the free-flow speed for the direction described?

Solution: The free-flow speed for a multilane highway is computed using equation

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

The following values are used in this computation:

BFFS = 55.0 mi/h (5 mi/h more than the posted speed limit)

f_{LW} = 1.9 mi/h (Table 12.9, 11-ft lanes)

f_{LC} = 0.4 mi/h (Table 12.10, total lateral clearance = 10 ft, 4-lane highway)

f_M = 1.6 mi/h (Table 12.11, undivided highway)

f_A = 7.5 mi/h (Table 12.12, 30 access points/mi)

Then: $FFS = 55.0 - 1.9 - 0.4 - 1.6 - 7.5 = 43.6\, mi/h$

Note: In selecting the adjustment for lateral clearance, the total lateral clearance is 4 ft (for the right side) plus an assumed value of 6.0 ft (for the left of median side) of an undivided highway

Example 3: Determination and Use of the Heavy-Vehicle Adjustment Factor

Consider the following situation: A volume of 2,500 veh/h traverses a section of freeway and contains 15% trucks and 5% RVs. The section in question is on a 5% upgrade, 0.75 miles in length. What is the equivalent volume in passenger-car equivalents?

Solution: The solution is started by finding the passenger car equivalent of trucks and RVs on the freeway section described (5% upgrade, 0.75 miles). These are found in Tables 12.14 and 12.15 respectively:

E_T = 2.5 (Table 12.14, 15% trucks, >4-5%, >0.50-0.75 mi)

E_R = 3.0 (Table 12.15, 5% RVs, >4-5%, >0.50 mi)

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

$$f_{HV} = \frac{1}{1 + 0.15(2.5 - 1) + 0.05(3.0 - 1)}$$

$$= \frac{1}{1.325} = 0.7547$$

and the passenger-car equivalent volume may be estimated as:

$$V_{pce} = \frac{V_{vph}}{f_{HV}} = \frac{2{,}500}{0.7547} = 3{,}313\ pc/h$$

The solution can also be found by applying the passenger car equivalent directly:

Truck pces:	2,500x0.15x2.5 = 938
RV pces:	2,500x0.05x3.0 = 375
Pass Cars:	2,500x0.80x1.0 = 2,000
TOTAL pces:	3,313

Example 4: Analysis of an Older Urban Freeway

A section of an old freeway in New York City is a four-lane freeway with the following characteristics:

- o Ten-foot travel lanes
- o Lateral obstructions at 0 ft at the roadside
- o Interchange density = 2.0 interchanges per mile
- o Rolling terrain

The roadway has a current peak demand volume of 3,500 veh/h. The peak-hour factor is 0.95, and there are no trucks, buses, or RVs in the traffic stream, as the roadway is classified as a parkway and such vehicles are prohibited. At what level of service will the freeway operating during its peak period of demand?

Solution:

Step 1: Determine the Free-Flow Speed of the Freeway

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

Where: BFFS = 70 mi/h (urban freeway default)

f_{LW} = 6.6 mi/h (Table 12.5, 10-ft lanes)

f_{LC} = 3.6 mi/h (Table 12.6, 2 lanes, 0-ft obstructions)

f_N = 4.5 mi/h (Table 12.7, 2 lanes)

f_{ID} = 7.5 mi/h (Table 12.8, 2 interchanges/mi)

Thus:

$$FFS = 70.0 - 6.6 - 3.6 - 4.5 - 7.5 = 47.8\ mi/h$$

$$say\ 48\ mi/h$$

Step 2: Determine the Demand Flow Rate in Equivalent pce Under Base Conditions

The demand volume may be converted to an equivalent flow rate under conditions using Equation:

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

Where: V = 3,500 veh/h (given)

PHF = 0.95 (given)

N = 2 lanes (given)

f_{HV} = 1.0 (no trucks, buses, or RVs in the traffic stream)

f_p = 1.00 (assumed commuter driver population)

Then:

$$v_p = \frac{3{,}500}{0.95*2*1.00*1.00} = 1{,}842\ \ pc/h/\ln$$

Step 3: Find the Level of Service and the Speed and Density of the Traffic Stream

$$D = \frac{v_p}{S} = \frac{1{,}842}{48} = 38.4\ \ pc/mi/\ln$$

From Table 12.2: the density 38.4 pc/mi/ln fall within the defined boundaries of 35-45 pc/mi/ln for LOS E

Example 5: Analysis of a Multilane Highway Section

A four-lane multilane highway section with a full median carries a peak-hour volume of 2,600 veh/h in the heaviest direction. There are 12% trucks and 2% RVs in the traffic stream. Motorists are primarily regular users of the facility. The section under study is on a 3% sustained grade, 1 mile in length. The PHF is 0.88.

Field studies have been conducted to determine that free-flow speed of the facility is 55.0 mi/h.

At what level of service will this facility operate during the peak hour?

Solution: As the peak volume would be expected to travel upgrade during one peak and downgrade during the other. It will be necessary to examine the downgrade as well as the upgrade under peak demand conditions.

Step 1: Determine the Upgrade Demand Flow Rate in Equivalent pces Under Base Conditions

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

is used to convert the peak hour demand volume to an equivalent flow rate in pces under base condition:

Where: V = 2,600 veh/h (given)

PHF = 0.88 (given)

N = 2 lanes (given)

f_p = 1.00 (regular users)

The heavy-vehicle factor, f_{hv}, is computed using Equation:

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

Where: P_T = 0.12 (given)

P_R = 0.02 (given)

ET = 1.5 (Table 12.14, ≥2-3%, >0.75-1.00 mi, 12% trucks)

ER = 3.0 (Table 12.15, >2-3%, >0.50 mi, 2% RVs)

Then:

$$f_{HV} = \frac{1}{1 + 0.12(1.5 - 1) + 0.02(3.0 - 1)}$$
$$= \frac{1}{1.10} = 0.909$$

and:

$$v_p = \frac{2,600}{0.88 * 2 * 0.909 * 1.00} = 1,625\ pc/h/\ln$$

Step 2: Determine the Downgrade Demand Flow Rate in Equivalent pces Under Base Conditions

The downgrade computation follows the same procedure as the upgrade computation, except that the passenger car equivalents for trucks and RVs are selected for the downgrade condition. Note that passenger car equivalents for downgrade RVs are found assuming level terrain.

ET = 1.5 (Table 12.16, <4%, all lengths, 12% trucks)

ER = 1.2 (Table 12.13, level terrain)

Then:

$$f_{HV} = \frac{1}{1 + 0.12(1.5 - 1) + 0.02(1.2 - 1)}$$
$$= \frac{1}{1.064} = 0.940$$

$$v_p = \frac{2,600}{0.88 * 2 * 0.940 * 1.00} = 1,572\ pc/h/\ln$$

Step 3: Find the Level of Service and the Speed and Density of the Traffic Stream

Level of service and speed determinations are made using Figure 12.4 for multilane highways. Remember that the free-flow speed was field-measured as 55 mi/h. From the Figure, we found that the expected speeds for both upgrade and downgrade sections are approximately 54 mi/h.

The density for upgrade and downgrade section is estimated as the flow rate divided by the expected speed:

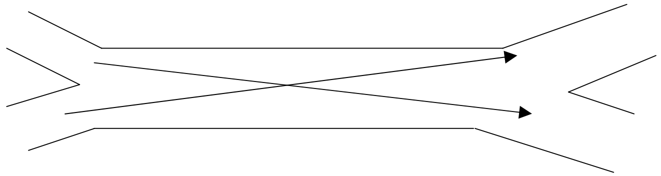
$$D_{up} = \frac{1{,}625}{54} = 30.1 \ pc/mi/\ln$$

$$D_{down} = \frac{1{,}572}{54} = 29.1 \ pc/mi/\ln$$

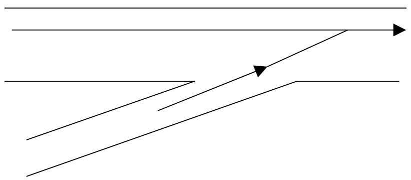
both of which are between the limits defined for LOS D: 26-35 pc/mi/ln

Weaving, Merging, and Diverging Movements on Freeways and Multilane Highways

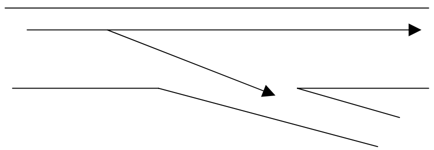
Weaving:
Weaving occurs when one movement must cross the path of another along a length of facility without the aid of signals or other control devices, with the exception of guide and/or warning signs. Such situations are created when a merge area is closely followed by a diverge area.



Merging:
Merging occurs when two separate traffic streams join to form a single stream. Merging can occur at an on-ramp to a freeway or multilane highway, or when two significant facilities join to form one.



Diverging:
Diverging occurs when one traffic stream separates form two separate traffic streams. This occurs at off-ramps from freeways and multilane highways, but can also occur when a major facility splits to form two separate facilities.



A Common Point: Converting Demand Volumes

$$v_i = \frac{V_i}{PHF * f_{HV} * f_p}$$

Where:

v_i = demand flow rate, pc/h, under equivalent base conditions

V_i = demand volume, veh/h, under prevailing conditions

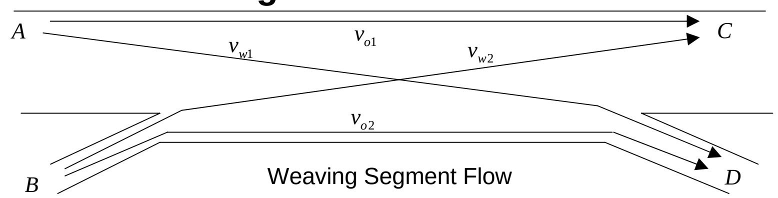
PHF = peak-hour factor

f_{hv} = heavy-vehicle adjustment factor

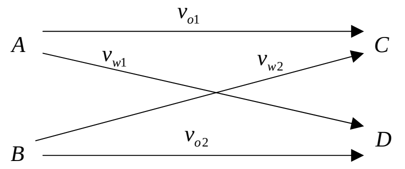
f_p = driver-population adjustment factor

Analysis of Weaving Areas

o Flow in weaving area



Weaving Segment Flow



Weaving Diagram

$v_{w1}, v_{w2} = weaving\ flow$

$v_{o1}, v_{o2} = non-weaving\ flow$

$v_w = total\ weaving\ flow,\ pc/h = v_{w1} + v_{w2}$

$v_{nw} = total\ non-weaving\ or\ outer\ flow,\ pc/h = v_{o1} + v_{o2}$

$v = total\ demand\ flow,\ pc/h = v_w + v_{nw}$

$VR = volume\ ratio = v_w / v$

$R = weaving\ ratio = v_{w2} / v_w$

o Lane configuration

Type A configurations:
The most common Type A weaving configuration is often referred to as a *ramp-weave.* It is form by a one-lane on-ramp followed by a one-lane off-ramp connected by a continuous auxiliary lane. The unique feature of a type A weaving configuration is that *each and every weaving vehicle must make at least one lane-change.* Further, all of these required lane-changes are cross a single lane line, which is referred to as a *crown line.*

Type B configurations:
In Type B weaving configurations, one of the two weaving movements can be completed without making a lane-change.

Type C configurations:
In a Type C configurations, there is also a “through” lane for one of the weaving movements. Again, this weaving maneuver may be completed without a lane-change.

Configuration	No. of Required Lane-Changes for:	
	Primary Weaving Movement	Secondary Weaving Movement
Type A	1	1
Type B	0	1
Type C	0	≥ 2

o Width of a weaving area and type of operation

Type A configurations:
weaving vehicles rarely occupy more than 1.4 lanes in a Type A configuration.

Type B configurations:
weaving vehicles can occupy up to 3.5 lanes in a Type B configuration.

Type C configurations:
weaving vehicles can occupy no more than 3.0 lanes of a Type C configuration.

o Computational procedures for weaving area analysis

1. Specify all traffic and geometric conditions for the site.
2. Convert all component demand volumes to peak flow rates in pc/h under equivalent base conditions.
3. Assume that operations are *unconstrained*, and estimate the resulting speed of weaving and non-weaving vehicles in the weaving area.
4. Using the results of Step 3, determine whether actual operations are *unconstrained* or *constrained*. If they are constrained, re-estimate the speed of weaving and non-weaving vehicles assuming the constrained result.
5. Compute the weighted average speed and density for all vehicles in the weaving area.
6. Determine level of service from the estimated density in the weaving area.
7. Check input variables against limitations of the methodology.
8. Determine the capacity of the weaving section.

o Estimate the average speed of weaving and non-weaving vehicles

$$S_i = S_{\min} + \frac{S_{\max} - S_{\min}}{1 + W_i}$$

Where: S_i = average speed of weaving (w) or non-weaving (nw) vehicles, mi/h

S_{min} = minimum expected average speed in a weaving area, mi/h

S_{max} = maximum expected average speed in a weaving area, mi/h

W_i = weaving intensity factor for weaving (w) or non-weaving (nw) vehicles

$$S_i = 15 + \frac{FFS - 10}{1 + W_i}$$

The weaving intensity factors is computed as:

$$W = \frac{a(1+VR)^b \left(v/N\right)^c}{L^d}$$

Where: VR = volume ratio (v_w/v)

v = total demand flow rate in the weaving area, equivalent pc/h under base conditions

L = length of the weaving area, ft

a, b, c, d = constant of calibration

Constant of calibration vary with three conditions:

1. Whether the speed of weaving or non-weaving vehicles is being estimated
2. Configuration of the weaving area (Type A, B, or C)
3. Whether the operation of the section is *constrained* or *unconstrained*

o Determining the type of operation

Unconstrained operation are expected when:

$$N_w \le N_w(\max)$$

Constrained operation are expected when:

$$N_w > N_w(\max)$$

Where: N_w = number of lanes weaving vehicles must occupy to achieve balanced equilibrium operation with non-weaving vehicles, lanes

$N_{w\,(max)}$ = maximum number of lanes that can be occupied by weaving vehicles in a given configuration, lanes

Criteria for Unconstrained vs. Constrained Operation

Configuration	Equation for N_w (lanes)	N_w (max) (lanes)
Type A	$\frac{0.74 * N * VR^{0.571} * L^{0.234}}{S_w^{0.438}}$	1.4
Type B	$N * \left[0.085 + 0.703VR + \left(\frac{234.8}{L}\right) - 0.018(S_{nw} - S_w)\right]$	3.5
Type C	$N * [0.761 + 0.047VR - 0.00011L - 0.005(S_{nw} - S_w)]$	3.0*

o Determining level of service in the weaving area

- To apply level-of-service criteria, an average density for the weaving area must be determined.
- To determine average density, a weighted average space mean speed for all vehicles in the weaving area must be compute:

$$S = \frac{v_{nw} + v_w}{\left(\frac{v_{nw}}{S_{nw}}\right) + \left(\frac{v_w}{S_w}\right)}$$

Where: S = space mean speed of all vehicles in weaving area, mi/h

- The average density in the section is computed as:

$$D = \frac{\left(v/N\right)}{S}$$

Where: D = density, pc/mi/ln

- For weaving areas operating under unconstrained conditions:

$$N_{wA} = N_w$$
$$N_{nwA} = N - N_w$$

- For weaving areas operating under constrained conditions:

$$N_{wA} = N_w(\max)$$
$$N_{nwA} = N - N_w(\max)$$

Where: N_w = number of lanes actually occupied by weaving vehicles

N_{nwA} = number of lanes actually occupied by non-weaving vehicles

- Separate densities for weaving and non-weaving vehicles may be computed as:

$$D_w = \frac{\left(v_w/N_{wA}\right)}{S_w}$$

$$D_{nw} = \frac{\left(v_{nw}/N_{nwA}\right)}{S_{nw}}$$

Where: D_w = average density of weaving vehicles, pc/mi/ln

D_{nw} = average density of non-weaving vehicles, pc/mi/ln

o **Additional limitations on weaving-area operations**

Configuration	Weaving Capacity v_w (max) (pc/h)	Maximum *v/N* (pc/h/ln)	Maximum *VR*		Maximum *R*	Maximum Weaving Length, *L* (ft)
A	2,800	c	N	VR	0.50	2,500
			2	1.00		
			3	0.45		
			4	0.35		
			5	0.20		
B	4,000	c	0.80		0.50	2,500
C	3,500	c	0.50		0.40	2,500

o **Capacity of Weaving Area**

$$c = c_b * f_{HV} * f_p$$
$$c_h = c * PHF$$

Where: c = capacity of the weaving area, veh/h

c_b = capacity of the weaving area in equivalent pc/h under base condition

c_h = capacity of the weaving area expressed as a full-hour volume under prevailing conditions

Analysis of Merge and Diverge Areas

o **Structure of the methodology for analysis of merge and diverge areas**

Where: v_F = freeway demand flow rate immediately upstream of merge or diverge junction, in pc/h under equivalent base conditions

v_{12} = freeway demand flow rate in lanes 1 and 2 of the freeway immediately upstream of the merge or diverge junctions, in pc/h under equivalent base conditions

v_R = ramp demand flow rate, in pc/h under equivalent base conditions

v_{R12} = total demand flow rate entering a merge influence area, v_R+v_{12}, in pc/h under equivalent base conditions

v_{FO} = total outbound demand flow continuing downstream on the freeway, pc/h under equivalent base conditions

D_R = average density in the ramp influence area, pc/mi/ln

S_R = space mean speed of all vehicles in the ramp influence area, mi/h

$L_{a\ or\ d}$ = length of the acceleration or deceleration lane, ft

RFFS = free-flow speed of the ramp, mi/h

- The analysis methodology for merge or diverge junctions is illustrated the following analysis steps:

1. Specify all traffic and roadway data for the junction to be analyzed: peak-hour demands, PHF, traffic composition, driver population, and geometric details of the site, including the free-flow speed for the facility and for the ramp.
2. Convert all demand volumes to flow rates in pc/h under equivalent base conditions.
3. Determine the demand flow in lanes 1 and 2 of the facility immediately upstream of the merge or diverge junction using the appropriate algorithm as specified.
4. Determine whether the demand flow exceeds the capacity of any critical element of the junction. Where demand exceeds capacity, level of service F is assigned and the analysis is complete.
5. If operation is determined to be stable, determine the density and speed of all vehicles within the ramp influence area. Table 13.1 is used to determine level of service based on the density in the ramp influence area.

o Estimating demand flow rates in lanes 1 and 2

- Merge areas:

$$v_{12} = v_F * P_{FM}$$

Where: P_{FM} = proportion of approaching vehicles remaining in lanes 1 and 2 immediately upstream of the merge junction, in decimal form

$$L_{EQ} = 0.214(v_F + v_R) + 0.444L_a + 52.32RFFS - 2{,}403$$

Where: L_{EQ} = equivalent distance, ft

$$L_{EQ} = \frac{v_d}{0.1096 + 0.000107L_a}$$

Where: L_{EQ} = equivalent distance, ft

v_d = demand flow rate on the adjacent downstream off-ramp, pc/h under equivalent base conditions

- Diverge areas:

$$v_{12} = v_R + (v_F - v_R)P_{FD}$$

Where: P_{FD} = proportion of approaching vehicles remaining in lanes 1 and 2 immediately upstream of the diverge junction, in decimal form

$$L_{EQ} = \frac{v_u}{0.071 + 0.000023v_F - 0.000076v_R}$$

Where: L_{EQ} = equivalent distance, ft

v_u = demand flow rate on the adjacent upstream on-ramp pc/h under equivalent base conditions

$$L_{EQ} = \frac{v_d}{1.15 - 0.000032v_F - 0.000369v_R}$$

o Capacity considerations

- The specific checkpoints that should be compared to the capacity criteria of Table 13.8 may be summarized as follows:

1. For merge areas, the maximum facility flow occurs downstream of the merge. Thus, the facility capacity is compared with the downstream facility flow ($v_{FO} = v_F + V_R$)
2. For diverge areas, the maximum facility flow occurs upstream of the diverge. Thus, the facility capacity is compared to the approaching upstream facility flow, v_F
3. Where lanes are added or dropped at a merge or diverge, both the upstream (v_F) and downstream (v_{FO}) facility flows must be compared to capacity criteria.
4. For merge areas, the flow entering the ramp influence area is $v_{R12} = v_{12} + v_R$. This sum is compared to the maximum desirable flow indicated in Table 13.8
5. For diverge areas, the flow entering the ramp influence area is v_{12}, as the off-ramp flow is already included. It is compared directly with the maximum desirable flow indicated in Table 13.8.
6. All ramp flows, v_R, must be checked against the ramp capacities given in Table 13.8

o Determining density and level of service in the ramp influence area

- For merge areas:

$$D_R = 5.475 + 0.00734v_R + 0.0078v_{12} - 0.00627L_a$$

- For diverge areas:

$$D_R = 4.252 + 0.0086v_{12} - 0.009L_d$$

o **Determining expected speed measures**

- The definition of variables in Table 13.9 and 13.10:

S_R = space mean speed of vehicles within the ramp influence area; v_{R12} for merge area; v_{12} for diverge areas; mi/h

S_O = space mean speed of vehicles traveling in outer lanes (lanes 3 and 4 where they exist) within the 1,500 ft length range of the ramp influence area, mi/h

S = space mean speed of vehicles in all lanes within the 1,500-ft range of the ramp influence area, mi/h

M_s = speed proportioning factor for merge areas

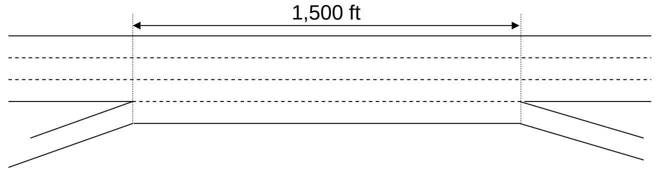
D_s = speed proportioning factor for diverge areas

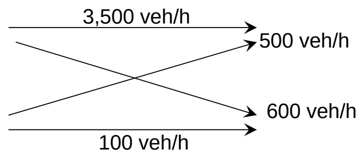
v_{oa} = average demand flow rate in outer lanes, computed as $(v_F - v_{12})/N_o$, pc/h/ln

N_o = number of outer lanes (one for three-lane segments, two for four-lane segment)

Example 6: Analysis of a Ramp-Weave Area

The Figure as shown below illustrates a typical ramp-weave section on a six-lane freeway (three lanes in each direction). The analysis is to determine the expected level of service and capacity for the prevailing conditions shown.





10% trucks, all mvts

Level terrain

$PHF = 0.90$

$FFS = 65\ mi/h$

Solution:

Step 1: Convert All Demand Volumes to Flow Rates in pc/h Under Equivalent Base Conditions

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

Where: PHF = 0.9 (given)

f_p = 1.00 (assume drivers are familiar with the site)

From Table 12.13: E_T= 1.5 for trucks on level terrain

Then: $$f_{HV} = \frac{1}{1+P_T(E_T-1)} = \frac{1}{1+0.10(1.5-1)} = 0.952$$

Thus:

$$v_{o1} = \frac{3{,}500}{0.90*0.952*1.00} = 4{,}085\ pc/h$$

$$v_{o2} = \frac{100}{0.90*0.952*1.00} = 117\ pc/h$$

$$v_{w1} = \frac{600}{0.90*0.952*1.00} = 700\ pc/h$$

$$v_{w2} = \frac{500}{0.90*0.952*1.00} = 584\ pc/h$$

and:

$$v_w = 700+584 = 1{,}284\ pc/h$$
$$v_{nw} = 4{,}085+117 = 4{,}202\ pc/h$$
$$v = 1{,}284+4{,}202 = 5{,}486\ pc/h$$
$$v/N = 5{,}486/4 = 1{,}372\ pc/h$$
$$VR = 1{,}284/5{,}485 = 0.23$$
$$L = 1{,}500\ ft$$

Step 2: Estimate the Average (Space Mean) Speed of Weaving and Non-weaving Vehicles in the Section

$$S_i = 15 + \left[\frac{FFS-10}{1+W_i}\right]$$

and:

$$W_i = \frac{a(1+VR)^b \left(v/N\right)^c}{L^d}$$

The constant of calibration are drawn from Table 13.3 for Type A configurations operating under unconstrained conditions.

$a\ (weaving) = 0.15$
$a\ (non-weaving) = 0.0035$
$b\ (weaving) = 2.2$
$b\ (non-weaving) = 4.0$
$c\ (weaving) = 0.97$
$c\ (non-weaving) = 1.3$
$d\ (weaving) = 0.80$
$d\ (non-weaving) = 0.75$

Thus:

$$W_w = \frac{0.15(1+0.23)^{2.2}(1{,}372)^{0.97}}{1{,}500^{0.80}} = 0.752$$

$$S_w = 15 + \left[\frac{65-10}{1+0.752}\right] = 46.4\ mi/h$$

$$W_{nw} = \frac{0.0035(1+0.23)^{4.0}(1{,}372)^{1.3}}{1{,}500^{0.75}} = 1.372$$

$$S_{nw} = 15 + \left[\frac{65-10}{1+0.398}\right] = 54.3\ mi/h$$

Step 3: Determine the Type of Operations

The number of lanes weaving vehicles must occupy to achieve unconstrained operation is given by:

$$N_w = \frac{0.74 * N * VR^{0.571} * L^{0.234}}{S_w^{0.438}}$$

$$= \frac{0.74 * 4 * 0.23^{0.571} * 1{,}500^{0.234}}{46.4^{0.438}} = 1.32 \ lanes < 1.4$$

We can conclude from the result that the section is operating under unconstrained conditions and the speeds estimated in Step 2 are correct.

Step 4: Determine the Weighted Average Speed for the Weaving Area

$$S = \frac{v_{nw} + v_w}{\left(\frac{v_{nw}}{S_{nw}}\right) + \left(\frac{v_w}{S_w}\right)} = \frac{1{,}284 + 4{,}202}{\left(\frac{4{,}202}{54.3}\right) + \left(\frac{1{,}284}{46.4}\right)}$$

$$= 52.2 \ mi/h$$

Step 5: Determine Average Density and Level of Service for the Weaving Area

- The average density for the weaving area is given by Equation:

$$D = \frac{\left(v/N\right)}{S} = \frac{1{,}372}{52.2} = 26.3 \ pc/mi/\ln$$

- Comparing this with the criteria of Table 13.1 indicates that *the prevailing level of service is C.*

- Separate density may be computed for weaving and non-weaving vehicles as shown below:

$$N_{wA} = 1.32 \ lanes$$

$$N_{nwA} = 4 - 1.32 \ lanes$$

$$D_w = \frac{(v_w / N_{wA})}{S_w} = \frac{(1{,}284/1.32)}{46.4} = 20.9 \ pc/mi/\ln$$

$$D_{nw} = \frac{(v_{nw} / N_{nwA})}{S_{nw}} = \frac{(4{,}202/2.68)}{54.3} = 28.9 \ pc/mi/\ln$$

- Weaving vehicles are experiencing *level of service C*, and non-weaving vehicles are experiencing *level of service D*

Step 6: Check Other Limitations on Weaving-Area Operations

- The limitations of Table 13.5 (on page 89) should be checked to ensure that none of the input parameters exceed maximum values for Type A configuration.

Parameter	Maximum Value (Table 13.5)	Actual Value
Weaving capacity	2,800 pc/h	1,283 pc/h
Maximum v/N	2,350 pc/h/ln	1,372 pc/h/ln
Maximum VR	0.35	0.23
Maximum L	2,500 ft	1,500 ft

- From the Table, they indicate that none of the maximums are violated

Step 7: Determine the Capacity of the Weaving Area

- The capacity of this weaving area (Type A, four lanes, 1,500 ft, VR = 0.23, FFS= 65 mi/h) is found equal to:

VR	Capacity
0.20	8,170 pc/h
0.23	c_b
0.30	7,470 pc/h

- Using straight-line interpolation:

$$c_b = 7{,}470 + \left(\frac{0.30 - 0.23}{0.30 - 0.20}\right) * (8{,}170 - 7{,}470) = 7{,}960 \ pc/h$$

- This can be converted to a capacity (maximum flow rate) in veh/h:

$$c = c_b * f_{HV} * f_p = 7{,}960 * 0.952 * 1.00 = 7{,}578 \ veh/h$$

and can be converted to a full-hour maximum volume in veh/h as follows:

$$c_h = c * PHF = 7{,}578 * 0.90 = 6{,}820 \ veh/h$$