CIVE 440

Traffic Engineering and Simulation – Highways part 1

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Faculty of Engineering

Department of Civil Engineering and Applied Mechanics

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HIGHWAYS

Limited access highways (freeways) are high-speed road systems characterised by:

- Continuous, uninterrupted traffic flow
- No direct traffic control (traffic lights)
- High capacity
- High speed
- Limited access
  - Entrance and exit ramps
  - No private entrances
  - Grade-separated interchanges

OTHER HIGHWAYS

Other types of highways:

- Multi-lane highways
- Two-lane highways

These may or may not be limited access, and may or may not have access ramps.

- No median

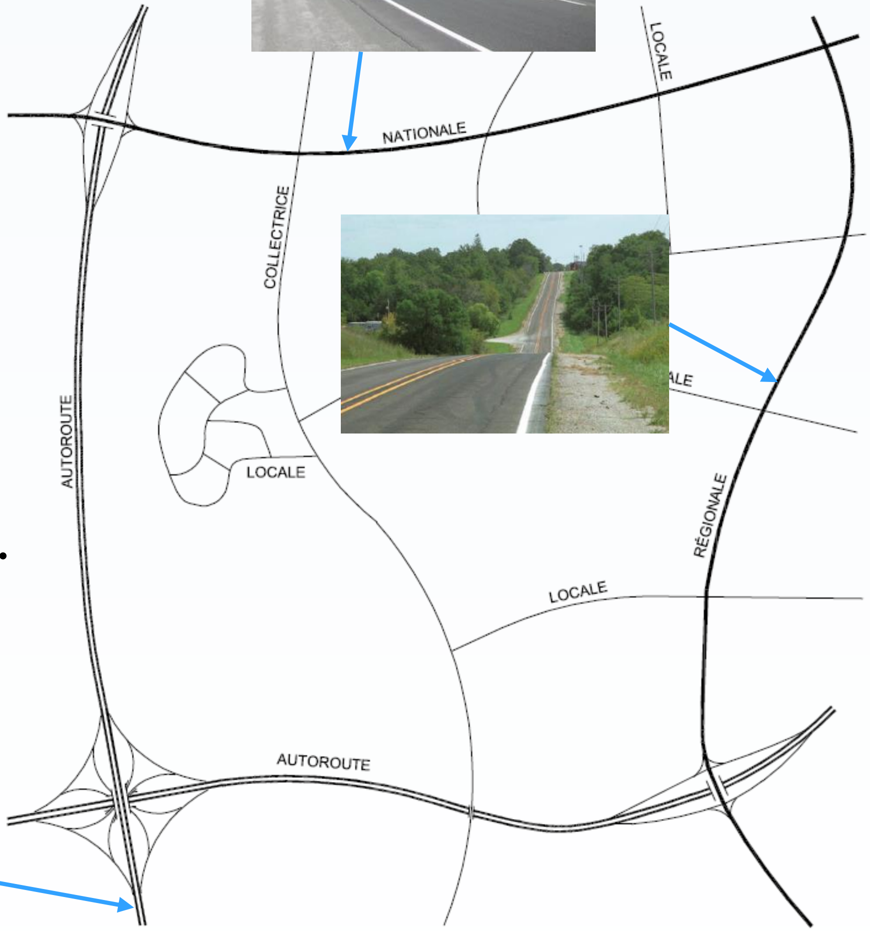
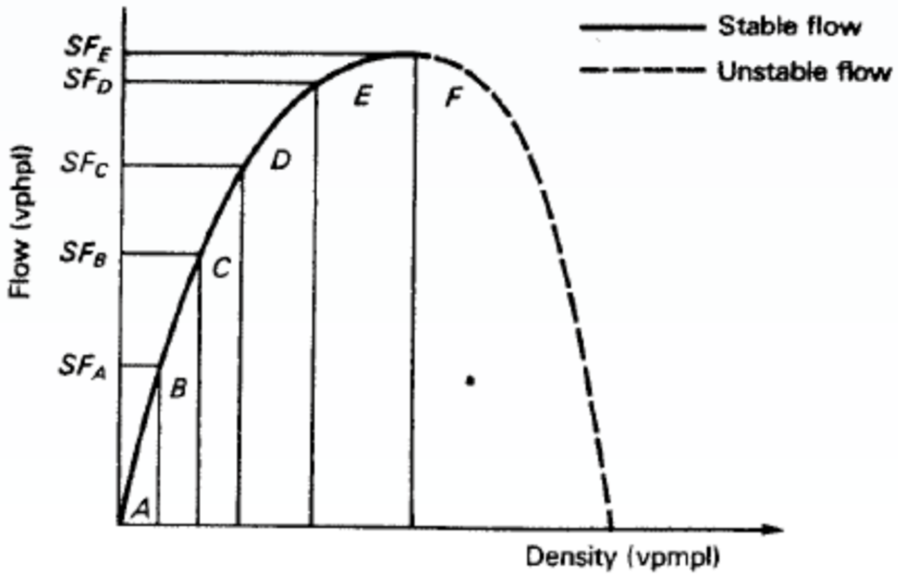


Figure 1.4–1
Raccordements théoriques entre les classes de routes

HIGHWAY CAPACITY

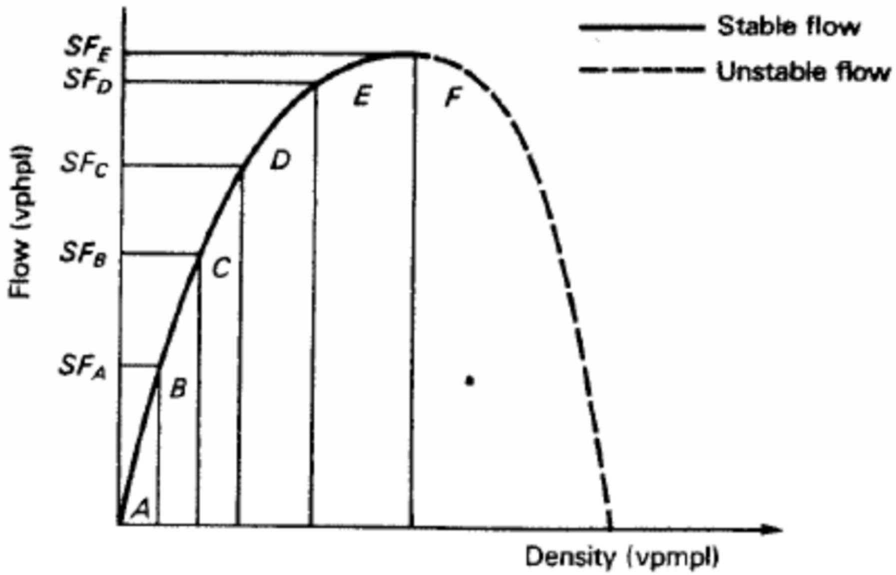
With the exception of effects due to microscopic turbulence, macroscopic flow models (e.g. Greenshields) are integral to highway capacity.

- 2000~2400 pc/h/ln
- Reductions from oversaturation or road design
- HCM 2010 Ch.10-15



For limited-access and multilane highways, density is used to determine the LOS. The LOS characterizes conditions of congestion.

- Maximum capacity occurs near LOS E, and breaks down in LOS F.
- The variations in speed between A-D are very minimal but flow values change rapidly: density is influenced.
- Flows in LOS A-D are governed by demand.



LEVEL OF SERVICE

Except for the boundary between E and F, level of service is an arbitrary scale of road congestion based on density.

Table 11-5, HCM 2010

LOS	Density (pc/km/ln)
A	<7
B	7-11
C	11-16
D	16-22
E	22-28
F	>28

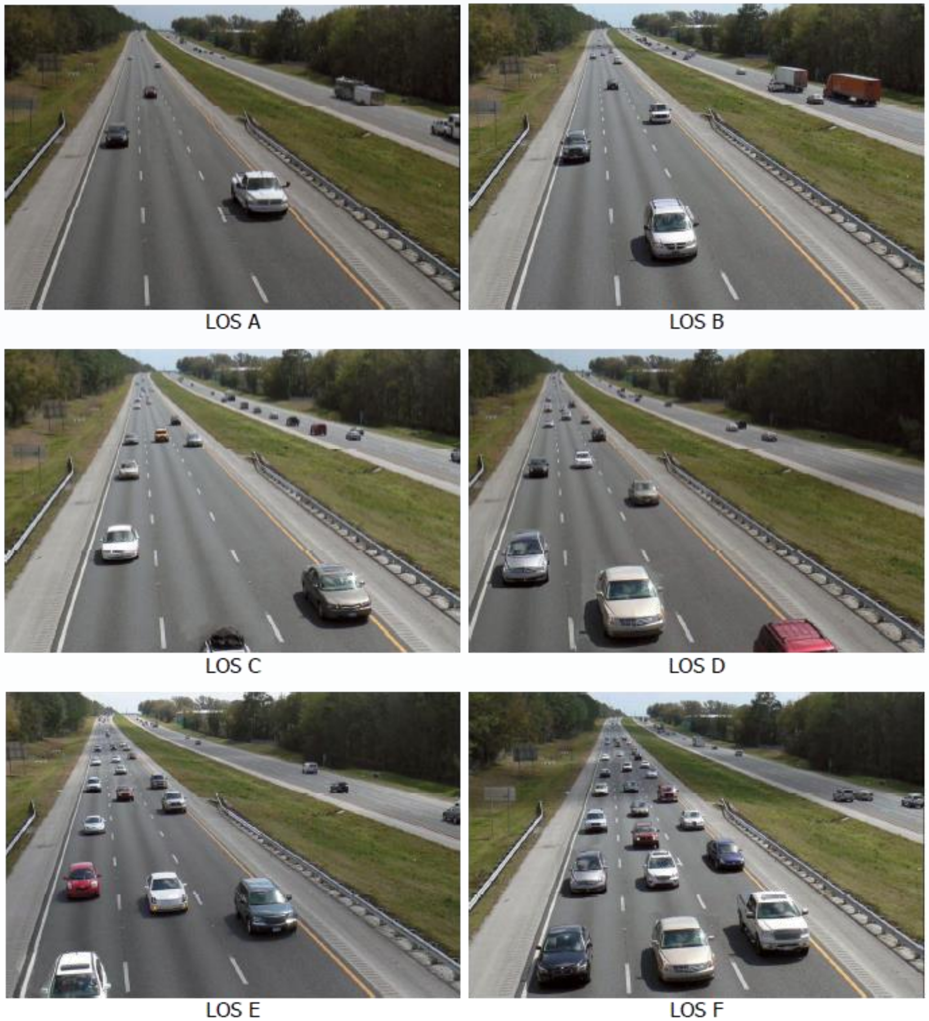


Table 12.1: Measures of Effectiveness Defining Levels of Service in HCM 2000

Type of Flow	Type of Facility	Measure of Effectiveness
Uninterrupted Flow	Freeways	
	Basic sections	Density (pc/mi/ln)
	Weaving areas	Density (pc/mi/ln)
	Ramp junctions	Density (pc/mi/ln)
	Multilane Highways	Density (pc/mi/ln)
	Two-Lane Highways	Average Travel Speed (mi/h)
		Percent Time Spent Following (%)
Interrupted Flow	Signalized Intersections	Control Delay (s/veh)
	Unsignalized Intersections	Control Delay (s/veh)
	Urban Streets	Average Travel Speed (mi/h)
	Transit	Service Frequency (veh/day)
		Service Headway (min)
		Passengers/Seat
	Pedestrians	Space (ft^2/ped)
	Bicycles	Frequency of (Conflicting) Events (events *k*)

Limited-access highways (freeways):

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

Multi-lane highways:

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

FREE-FLOW SPEED (LIMITED-ACCESS)

Strictly speaking free-flow speed is the intercept with the flow model (e.g. Greenshields) when density or flow is 0.

- Steady-state flow
- Idealised driving speed on an empty road
  - In practice, it can be measured in flows of less than 1000 pc/h/ln
- It is not the speed limit, though the speed limit will typically reflect the free-flow speed and vice versa
- Updated definition in the HCM 2010 ($v_f = FFS$) for limited-access highways:

$$v_f = v_{fb} - f_{LW} - f_{LC} - 4.8(TRD)^{0.84}$$

Base free-flow speed v_{fb}:

- Maximum speed of 85th centile of drivers under ideal driving conditions and roads designs
- 120 km/h for rural highways
- 110 km/h for urban highways
- Posted speed limits account for some (but not all) non-ideal conditions and road design. v_{fb} is not the speed limit
- Speed limits (as well as the free-flow speed) do not account for unusual driving conditions, including:
  - Poor visibility
  - Slippery pavement conditions
  - Heavy congestion/turbulent flow/stationary overflow on highway ramps

Adjustment factor for lane width f_{LW}:

- Account for difficulty maneuvering in lanes

Tab. 11-8, HCM 2010

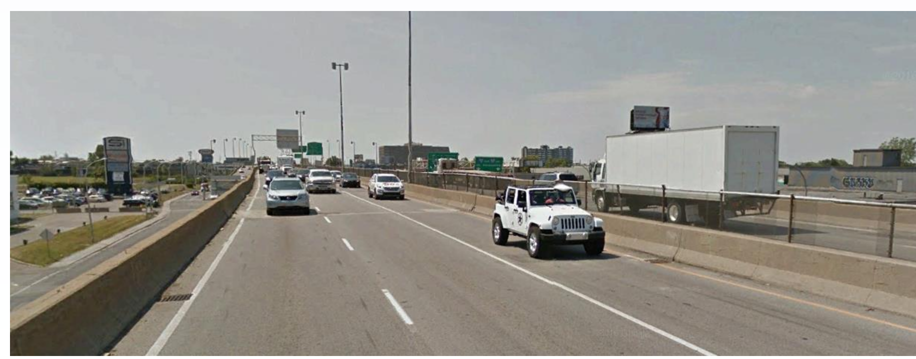
Average lane width (m)	Adjustment factor f_{LW} (km/h)
≥3.6	0.0
3.3-3.6	3.0
3.0-3.3	10.5

Adjustment factor for right-shoulder lateral clearance f_{LC}:

- Account for presence of obstacles or barriers in right shoulder

Tab. 11-9, HCM 2010

Right-shoulder lateral clearance (m)	Adjustment factor f_{LC} (km/h)			
	2 lanes	3 lanes	4 lanes	≥5 lanes
≥1.83	0.00	0.00	0.00	0.00
1.52	0.97	0.64	0.32	0.16
1.22	1.93	1.29	0.64	0.32
0.91	2.90	1.93	0.97	0.48
0.61	3.86	2.57	1.29	0.64
0.30	4.83	3.22	1.61	0.80
0.00	5.79	3.86	1.93	0.97



Total ramp density $\boldsymbol{TRD}$:

- The total amount of highway ramps (entrance and exit) present 4.8 km upstream and downstream of the point of calculation divided by 9.6 km.
- Exit ramps may experience overflows onto the highway
- Exit ramps also experience last minute lane changes which causes turbulence within the traffic stream
- Entrance ramps cause turbulence in the highway when cars attempts to merge into the traffic stream

Limited-access highways (freeways):

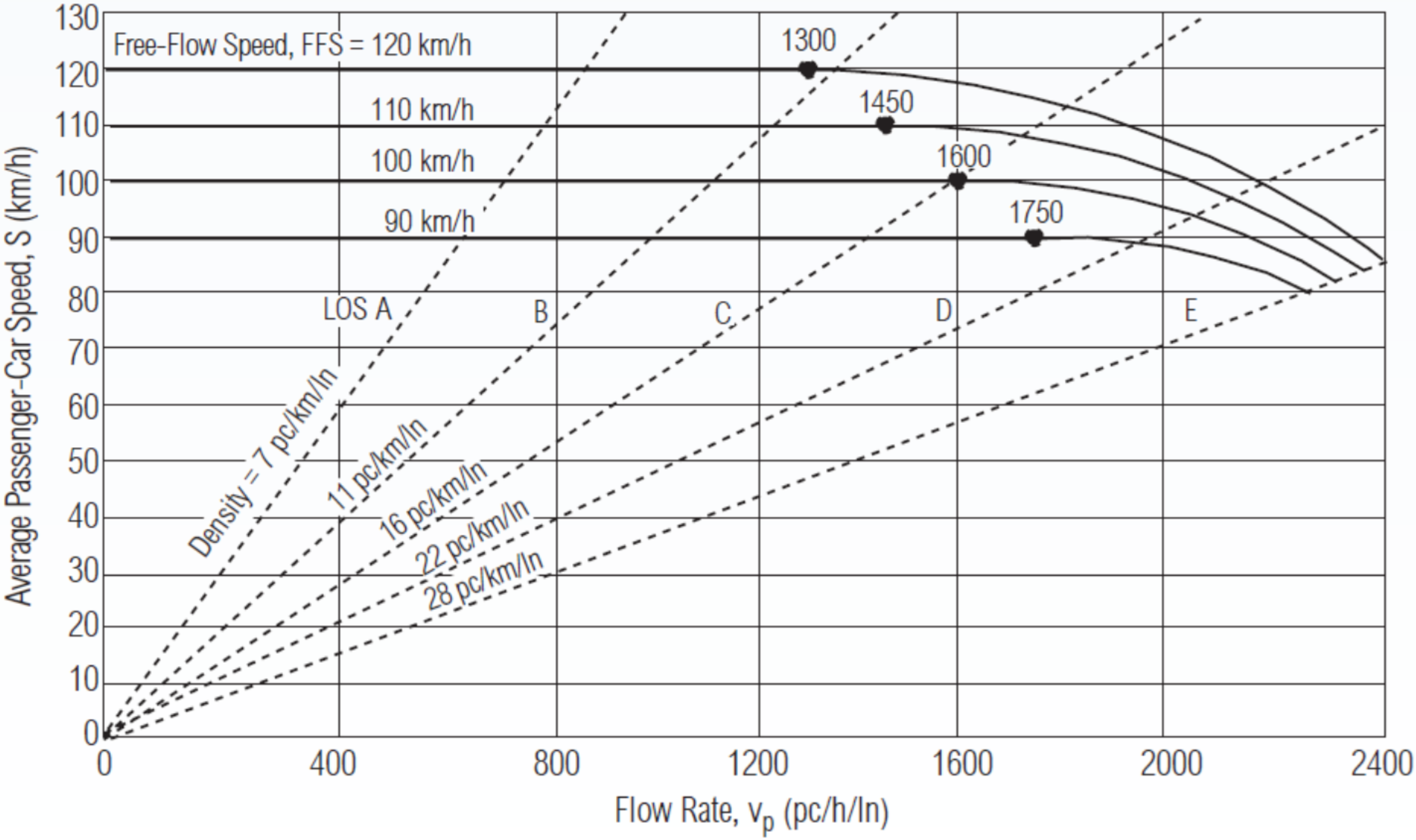
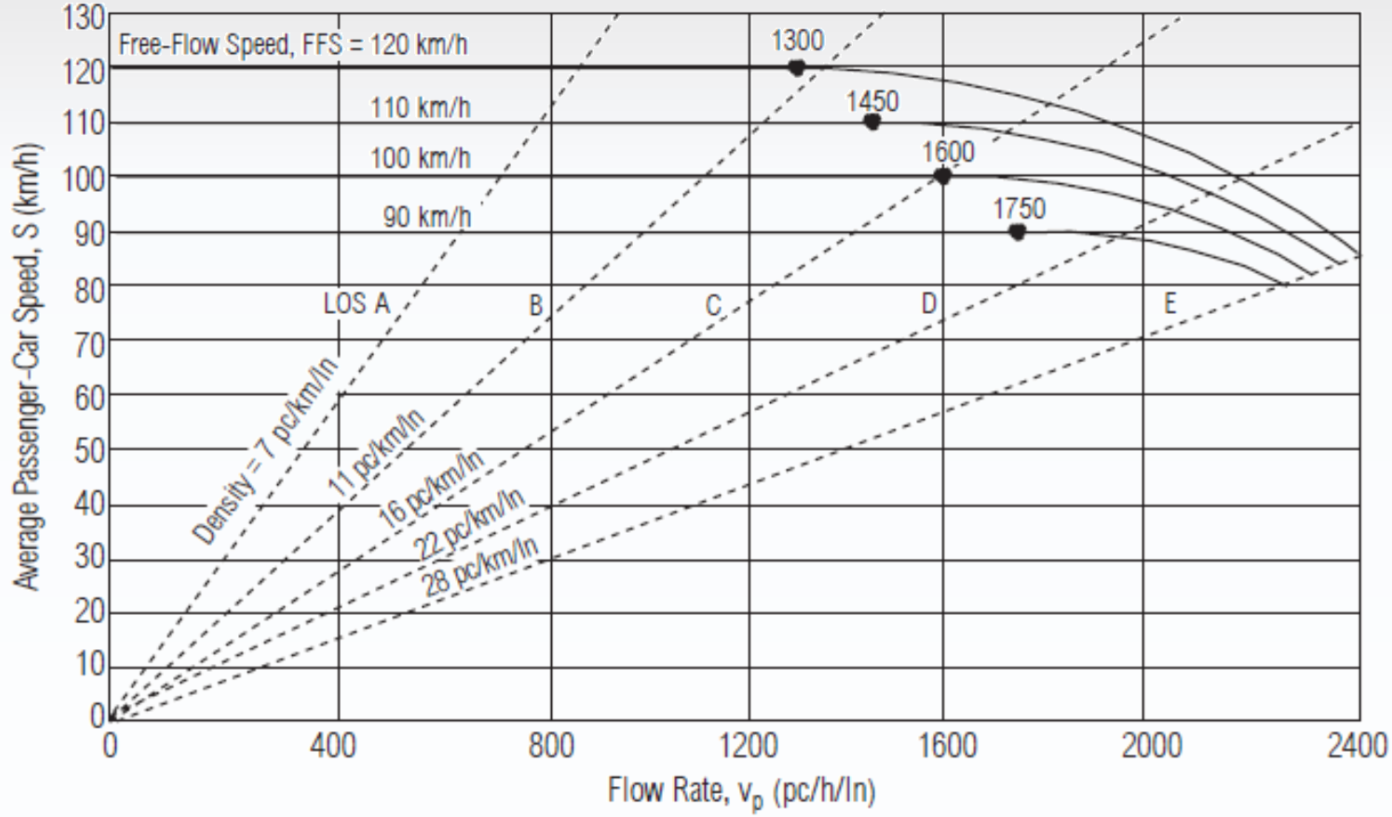


EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS



Note:

Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 120, 110, 100, and 90 km/h, respectively.

For $90 \le FFS \le 120$ and for flow rate (v_p)

$(3100 - 15FFS) < v_p \le (1800 + 5FFS)$,

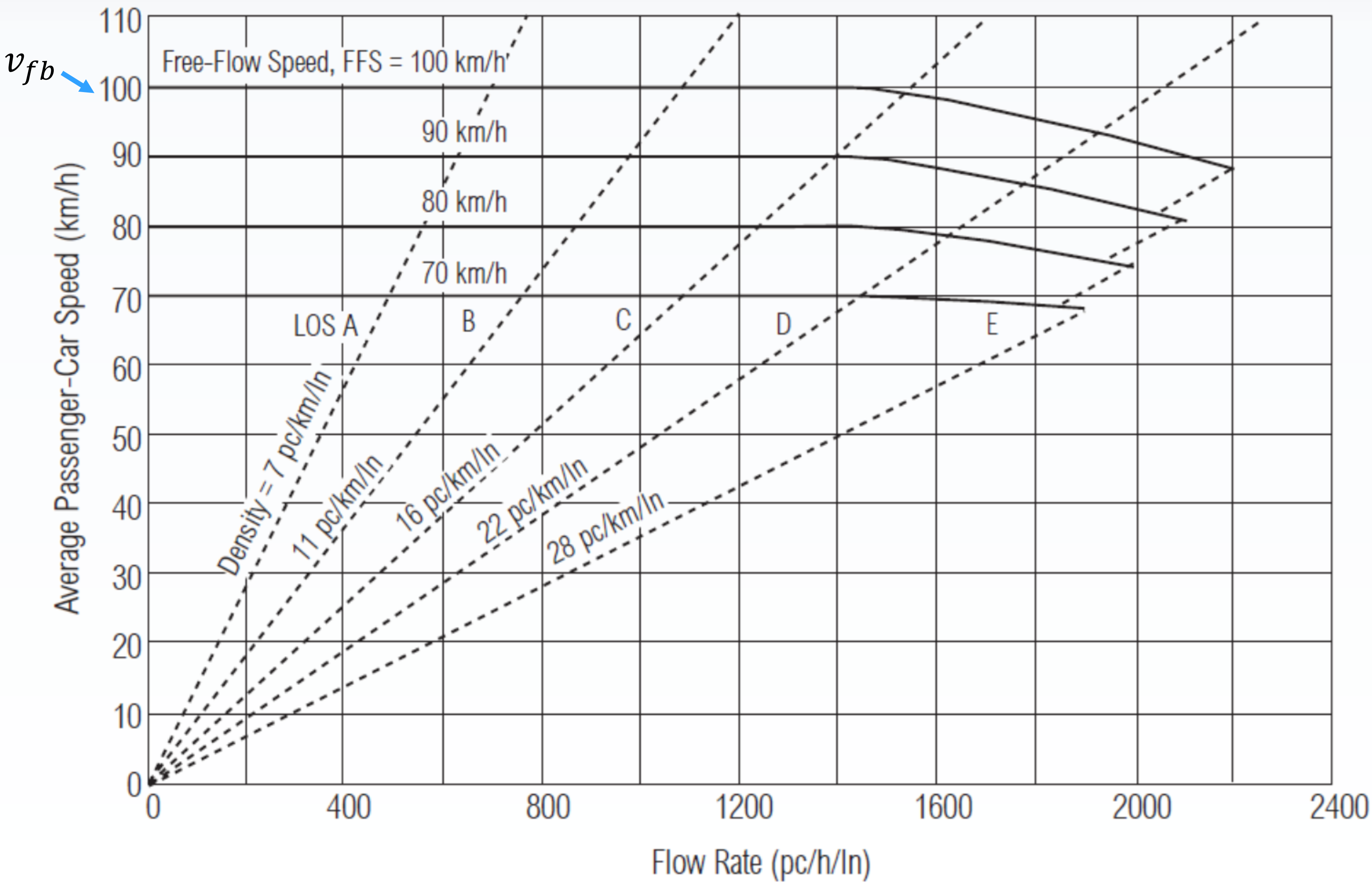
$$S = FFS - \left[\frac{1}{28}(23FFS - 1800)\left(\frac{v_p + 15FFS - 3100}{20FFS - 1300}\right)^{2.6} \right]$$

For $90 \le FFS \le 120$ and

$v_p \le (3100 - 15FFS)$,

$S = FFS$

Multi-lane highways:



DESIGN FLOW RATE

The design flow rate determines the effective demand that needs to be met by the design capacity.

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p} \qquad (23\text{-}2)$$

where

v_p = 15-min passenger-car equivalent flow rate (pc/h/ln),
V = hourly volume (veh/h),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = heavy-vehicle adjustment factor, and
f_p = driver population factor.

Heavy vehicle adjustment factor f_{HV}:

- Account for increased size of heavy vehicles and slower acceleration and deceleration times, especially in hilly environments.

$$f_{hv} = \frac{100}{100 + P_T(E_T - 1) + P_R(E_R - 1)}$$

- P_T, P_R = proportion of trucks and buses, and recreational vehicles, respectively
- E_T, E_R = passenger-car equivalents of trucks and buses, and recreational vehicles, respectively

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

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

Upgrade (%)	Length (km)	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	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.8–1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 1.2–1.6	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.6–2.4	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 2.4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3–4	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8–1.2	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 1.2–1.6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.6–2.4	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 2.4	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4–5	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.8–1.2	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 1.2–1.6	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.6	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5–6	0.0–0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.5	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.5–0.8	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.8–1.2	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.2–1.6	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.6	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.4–0.5	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.5–0.8	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.8–1.2	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 1.2–1.6	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.6	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

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

Upgrade (%)	Length (km)	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	0.0–0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3–4	0.0–0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.4–0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
> 4–5	0.0–0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
> 5	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	> 0.4–0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.5	3.5	3.0	3.0	2.5	2.0

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

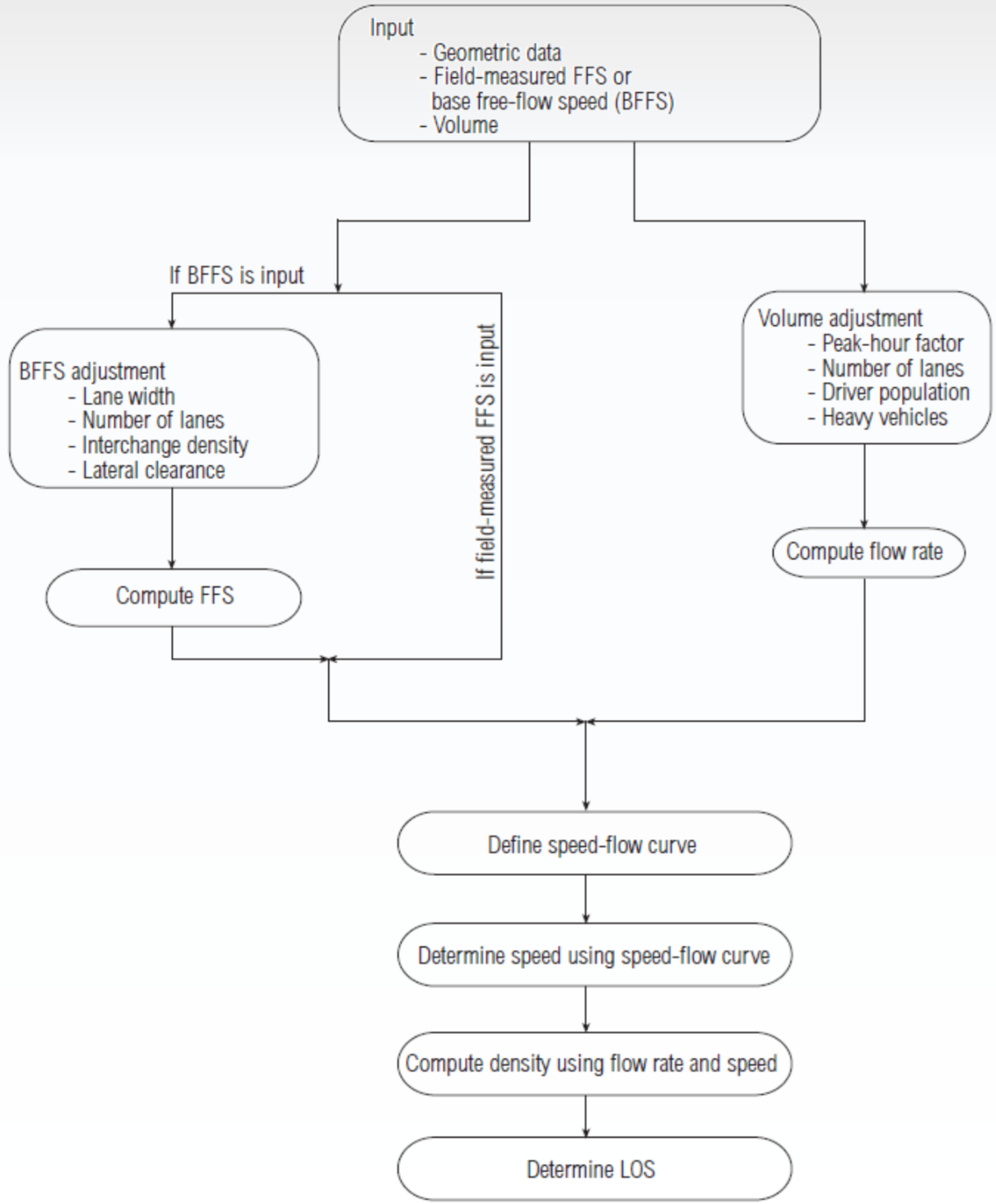
Downgrade (%)	Length (km)	E_T			
		Percentage of Trucks			
		5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4–5	≤ 6.4	1.5	1.5	1.5	1.5
4–5	> 6.4	2.0	2.0	2.0	1.5
> 5–6	≤ 6.4	1.5	1.5	1.5	1.5
> 5–6	> 6.4	5.5	4.0	4.0	3.0
> 6	≤ 6.4	1.5	1.5	1.5	1.5
> 6	> 6.4	7.5	6.0	5.5	4.5

(RV's use level terrain value for downgrades)

Driver population adjustment factor f_P:

- Unfamiliar drivers can increase effective demand
- Typically we use 1.0 (commuter traffic)
- When evidence exists that unfamiliar drivers such as tourists exist, we need to use <1
- Range is 0.85 to 1

EXHIBIT 23-1. BASIC FREEWAY SEGMENT METHODOLOGY



BASE CONDITIONS

- 3.6 m lane width
- 1.8 m shoulder clearance
- 0.6m median clearance
- Passenger cars only
- 5 or more lanes in each direction
- 3.2 km or greater interchange spacing
- Level terrain (grade <2%)
- Driver population familiar with road
- Free flow speed of 110 km/h or higher

EXAMPLE

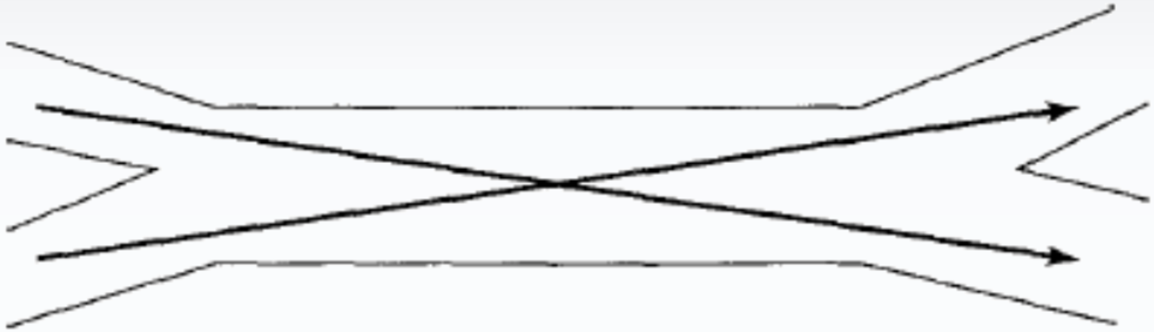
Determine the minimum number of lanes required for a maximum LOS D during peak hour for the following conditions:

- Demand of 4000 veh/h
- Mountains
- 15% trucks, 3% RVs
- 3.65 m wide lanes
- Lateral clearance of ≥ 1.7 m
- 85% commuters
- PHF = 0.85
- ~2 ramps/km

WEAVING SEGMENTS

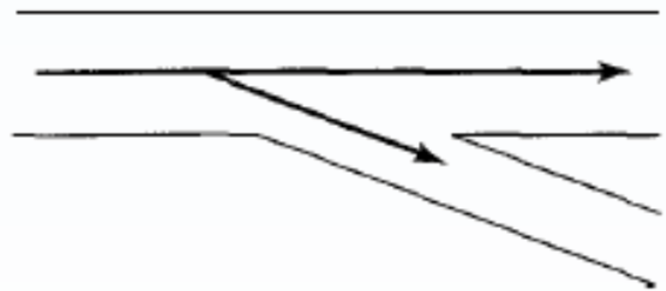
Weaving occurs when one movement must cross the path of another (Mandatory Lane Change) without the aid of a signal or other control devices, with the exception of markings and/or warning signs.

- Such situations are created when a merge area is closely followed by a diverge area
- The maneuvers always require lane changes in at least one stream (otherwise it’s a simple junction)
- Furthermore, vehicles that do not have to alter their direction of travel also might undertake Discretionary Lane Changes anyway to avoid turbulence



(a) Weaving movements cross each other'spath.

(b) Merging movements join to form a single traffic stream.

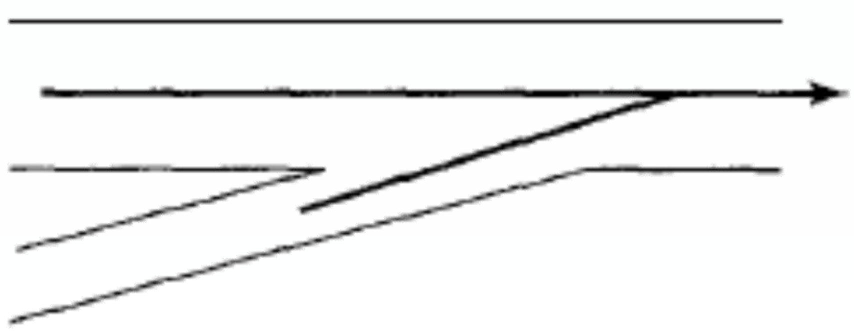


(c) Diverging movements divide to form separate traffic streams.

MERGING

Merging occurs when two streams of traffic merge onto a single stream:

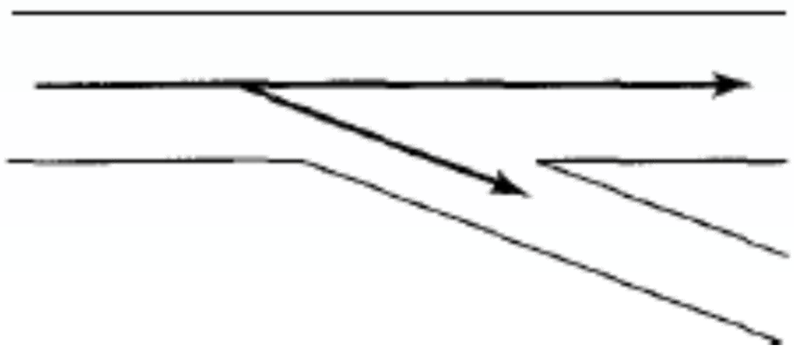
- Occurs at on-ramps or at highway junctions
- Merging always generates conflicts
- Vehicles might undertake Discretionary Lane Changes to avoid turbulence



DIVERGING

Diverging occurs when one stream of traffic splits into two separate streams:

- If the primary segment has multiple lanes, diverging vehicles may have to properly align themselves which might require Mandatory Lane Changes
- Vehicles might undertake Discretionary Lane Changes to avoid turbulence and may generate conflicts
- Occurs primarily at off-ramps and also at major junctions

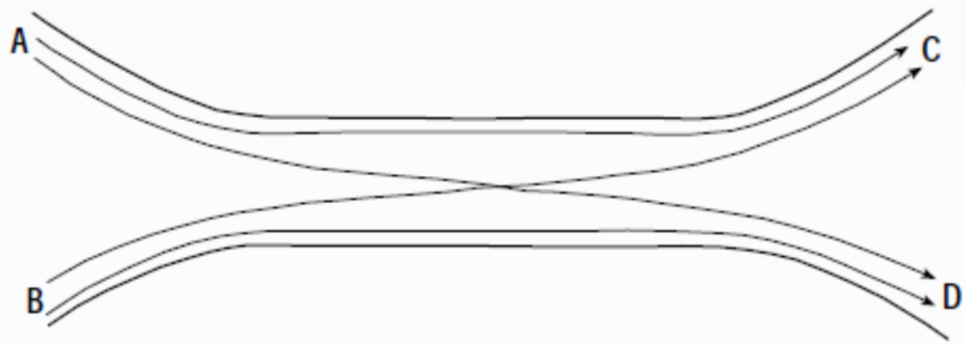


WEAVING ZONES

How do distinguish between weaving zones and overlapping merge + diverge zones?

- Weaving occurs when a merge is "closely followed" by diverge segment
  - Any addition of temporary lanes spanning the merge and diverge points are termed **auxiliary lanes**
- "Closely followed" is not well-defined
  - May be problem-specific
- Measuring LOS for all these three different movements is based on traffic density (k)

WEAVING MOVEMENTS



- **A→D**, **B→C** are weaving flows – mandatory lane changes
- **A→C**, **B→D** are non-weaving flows – discretionary lane changes possible

Weaving segment operations are influenced by:

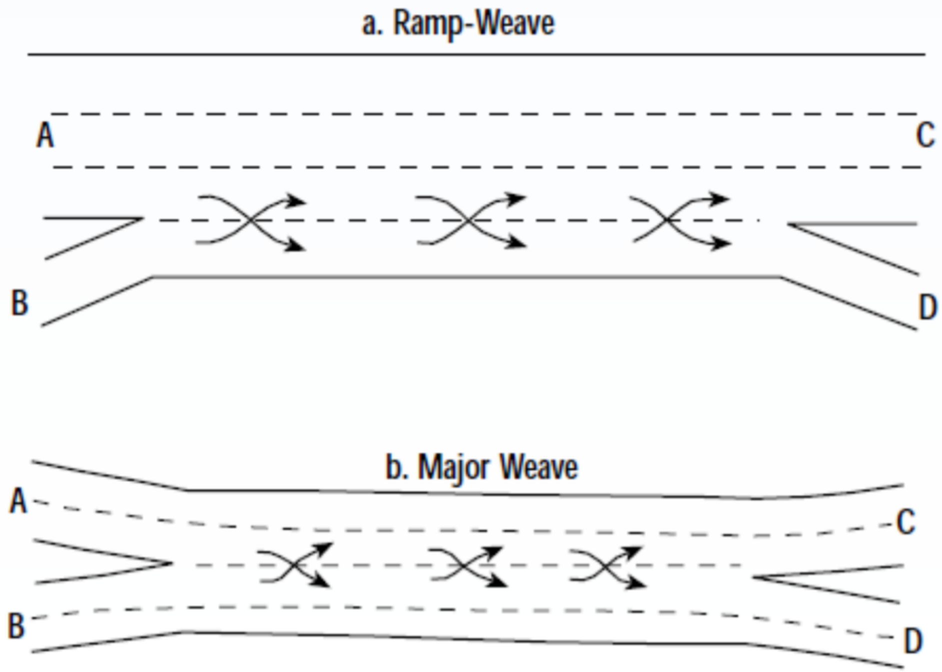
- Configuration
- Length
- Width

WEAVING CONFIGURATIONS

Type A:

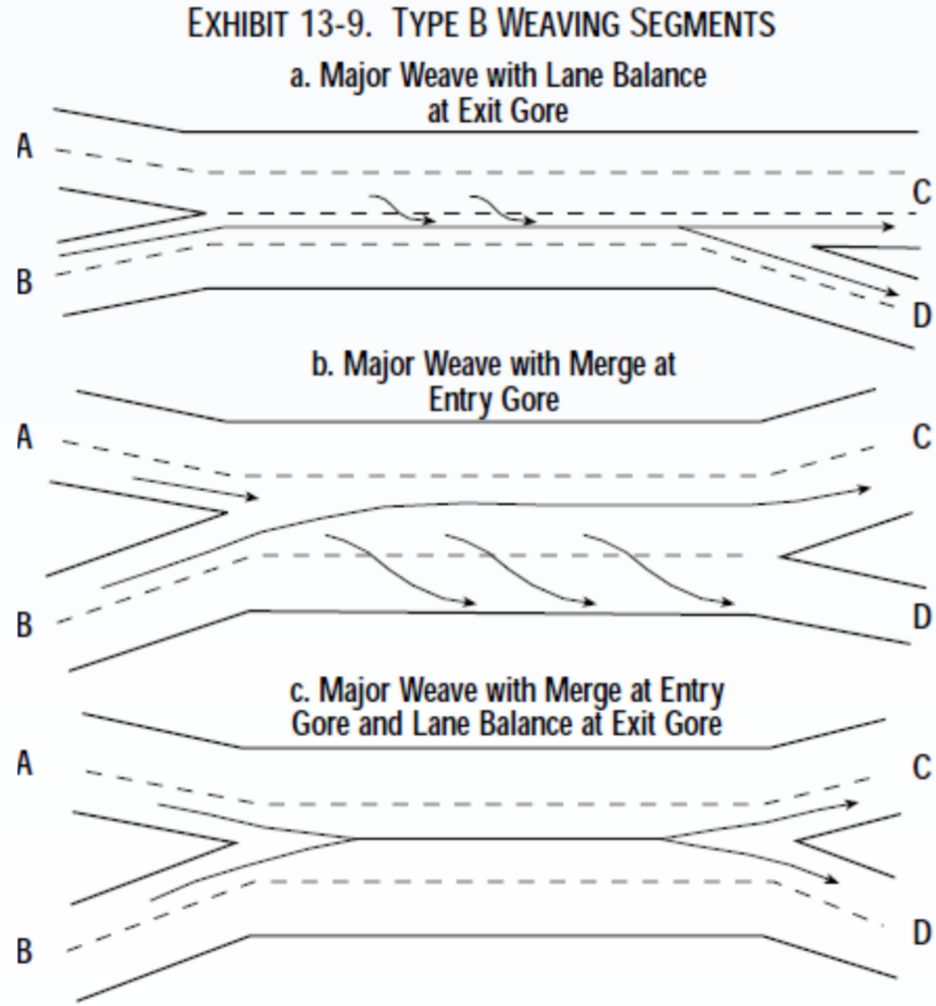
- All weaving flows (A→D, B→C vehicles) must make one lane change

EXHIBIT 13-8. TYPE A WEAVING SEGMENTS



Type B:

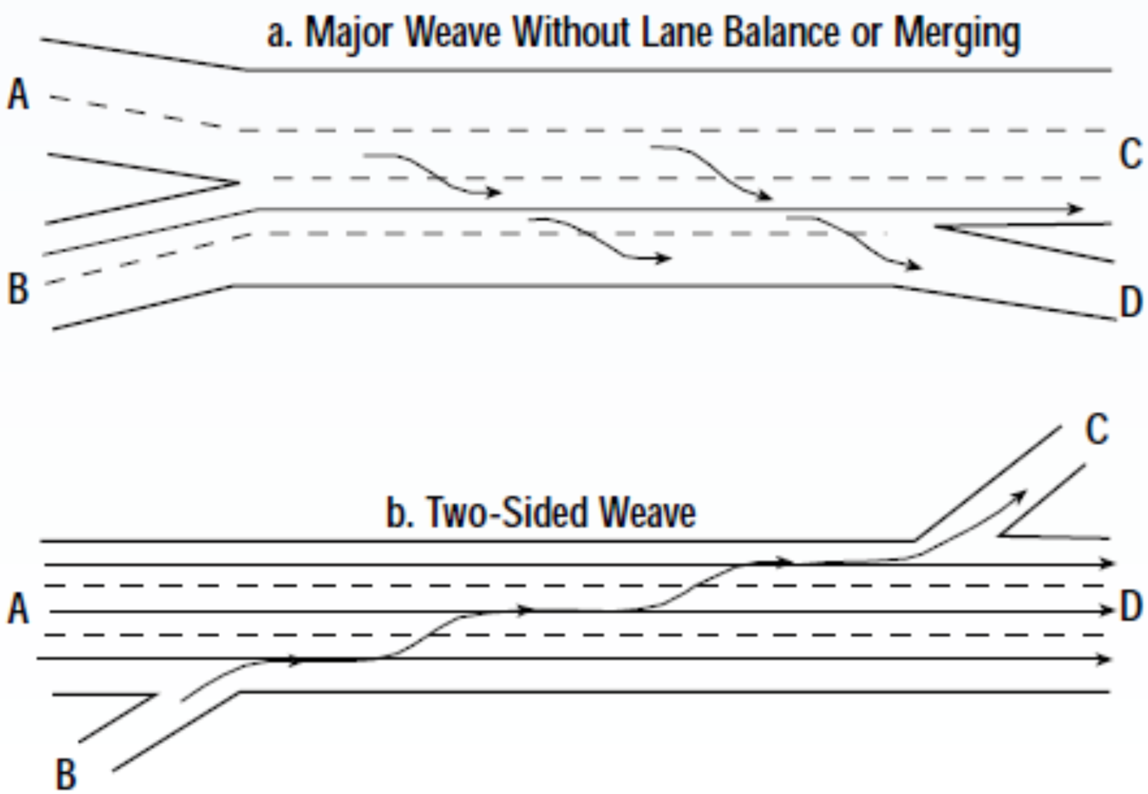
- One weaving flow (**A→D -or- B→C** vehicles) can do so without a lane change
- The other movement requires at most one lane change



Type C:

- One weaving flow (**A→D -or- B→C** vehicles) can do so without a lane change
- The second movement requires at least two lane changes

EXHIBIT 13-10. TYPE C WEAVING SEGMENTS



Summary of weaving zone types:

EXHIBIT 24-5. DETERMINING CONFIGURATION TYPE

Number of Lane Changes Required by Movement v_{w1}	Number of Lane Changes Required by Movement v_{w2}		
	0	1	≥ 2
0	Type B	Type B	Type C
1	Type B	Type A	N/A
≥ 2	Type C	N/A	N/A

OTHER WEAVING ZONE DETAILS

A gore (gore point or gore zone, “*musoir*”) is a triangular piece of land found where roads merge or split.

- Diverge areas often include shock absorbing equipment

All of the lane changes occur across a line that connects from the entrance gore area directly to the exit gore area.

- Such a line is referred to as a crown line.
- Lane changing into the first lane may be protected with a solid line (special engineering case).

Weaving configuration determines no. of lane changes involved.

- Given a flow rate of 1000 veh/hr/ln:
  - Type A requires 2000 lane changes
  - Type B requires 1000 lane changes
  - Type C requires 2000 lane changes or more

Configuration also influences proportional use of lanes by weaving and non-weaving traffic. If weaving vehicles are not in the specific lanes, they cannot complete maneuvers efficiently

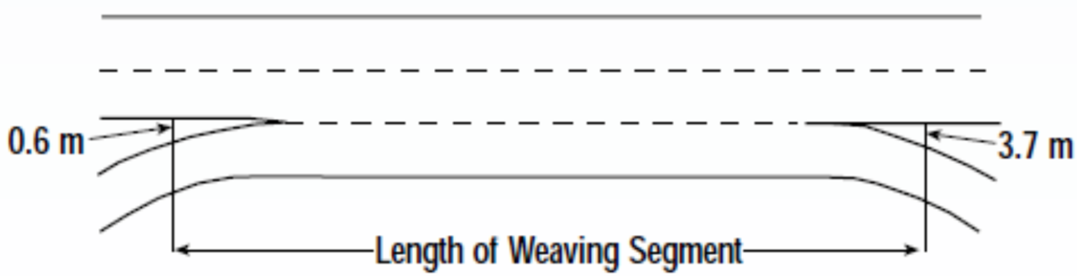
- Type A is worst because all weaving vehicles have to be next to crown line
- Type B is the most flexible

WEAVING LENGTH

Drivers have a fixed weaving length L of the segment before which to complete the weaving movement (constrains time and space)

- The shorter the length, the higher the lane change intensity and turbulence (configuration and flow being constant)

EXHIBIT 13-11. MEASURING THE LENGTH OF A WEAVING SEGMENT



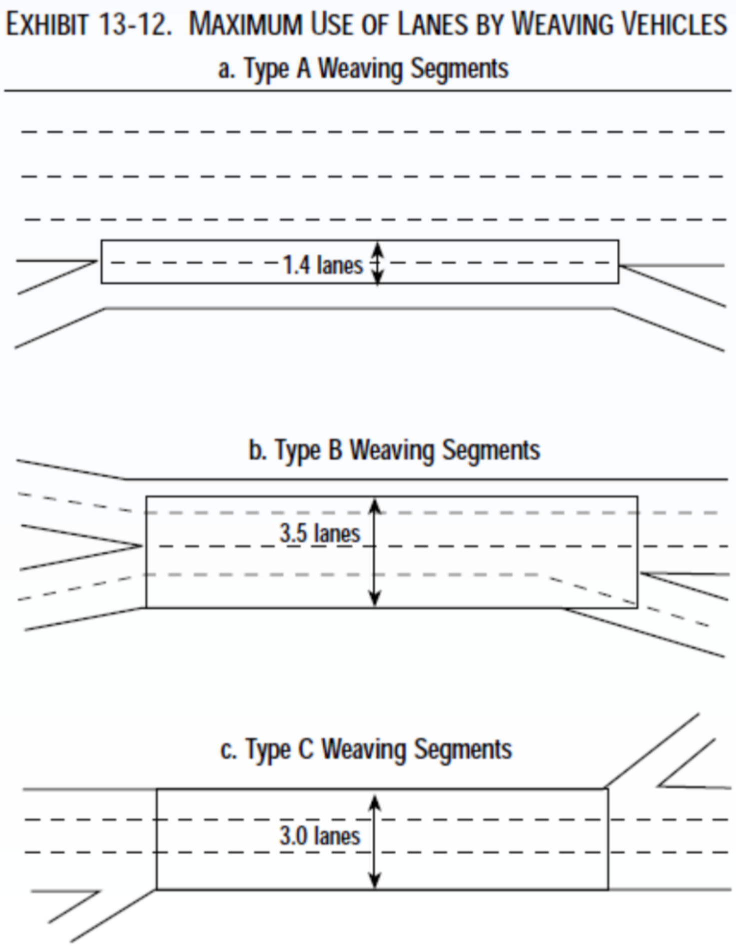
If $L > 750\ m$, we deal with merge and diverge separately!

WEAVING WIDTH

Weaving width N defined as the total no. of lanes between the entry and exit regions.

- As the no. of lanes increases the total volume throughput increases.

However, the number of discretionary lane changes within the weaving segment also increases!



We will see the importance of the weaving width in the weaving segment capacity analysis.

Some definitions:

- N_w = no. of lanes weaving vehicles must occupy to achieve equilibrium (steady-state flow, i.e. $Q_D = Q_C$)
- $N_w(\max)$ = maximum number of lanes that can be obtained by weaving vehicles based on geometry
- Unconstrained: If $N_w < N_w(\max)$, then weaving vehicles will reach equilibrium with non-weaving vehicles
- Otherwise, flow is constrained (equilibrium is not reached)
- Under unconstrained conditions both weaving and non-weaving vehicles operate similarly. In constrained conditions, however, operating conditions for weaving vehicles are markedly worse

LEVEL OF SERVICE

Similar in concept as with highways.

EXHIBIT 24-2. LOS CRITERIA FOR WEAVING SEGMENTS

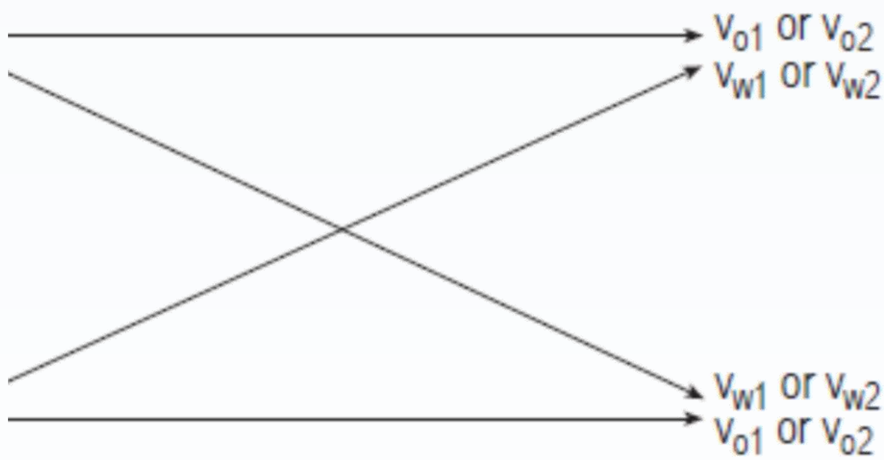
LOS	Density (pc/km/ln)	
	Freeway Weaving Segment	Multilane and Collector-Distributor Weaving Segments
A	≤ 6.0	≤ 8.0
B	> 6.0–12.0	> 8.0–15.0
C	> 12.0–17.0	> 15.0–20.0
D	> 17.0–22.0	> 20.0–23.0
E	> 22.0–27.0	> 23.0–25.0
F	> 27.0	> 25.0

Design flow rate as with ordinary highways.

WEAVING PARAMETERS

Symbol	Definition
L	Length of weaving segment (m)
N	Total number of lanes in the weaving segment
N_w	Number of lanes to be used by weaving vehicles if unconstrained operation is to be achieved
$N_w(max)$	Maximum number of lanes that can be used by weaving vehicles for a given configuration
N_{nw}	Number of lanes used by nonweaving vehicles
VR	Volume ratio; the ratio of weaving flow rate to total flow rate in the weaving segment ($VR = v_w/v$)
R	Weaving ratio; the ratio of the smaller weaving flow rate to total weaving flow rate ($R = v_{w2}/v_w$)
S_w	Speed of weaving vehicles in the weaving segment (km/h)
S_{nw}	Speed of nonweaving vehicles in the weaving segment (km/h)
S	Speed of all vehicles in the weaving segment (km/h)
D	Density of all vehicles in the weaving segment (pc/km/ln)
W_w	Weaving intensity factor for prediction of weaving speed
W_{nw}	Weaving intensity factor for prediction of nonweaving speed

WEAVING PARAMETERS



v	Total flow rate in the weaving segment (pc/h)
v_{o1}	Larger of the two outer, or nonweaving, flow rates in the weaving segment (pc/h)
v_{o2}	Smaller of the two outer, or nonweaving, flow rates in the weaving segment (pc/h)
v_{w1}	Larger of the two weaving flow rates in the weaving segment (pc/h)
v_{w2}	Smaller of the two weaving flow rates in the weaving segment (pc/h)
v_w	Total weaving flow rate in the weaving segment (pc/h) ($v_w = v_{w1} + v_{w2}$)
v_{nw}	Total nonweaving flow rate in the weaving segment (pc/h) ($v_{nw} = v_{o1} + v_{o2}$)

WEAVING ZONE SPEED COMPONENTS

Determining speed is a critical component

- It is not straight-forward to determine the speed
- The flow is turbulent and is mixture of weaving and non-weaving flows

$$S_i = S_{min} + \frac{S_{max} - S_{min}}{1 + W_i} \quad (24\text{-}2)$$

where

S_i = average speed of weaving (i = w) or nonweaving (i = nw) vehicles (km/h),
S_{min} = minimum speed expected in a weaving segment (km/h),
S_{max} = maximum speed expected in a weaving segment (km/h), and
W_i = weaving intensity factor for weaving (i = w) and nonweaving (i = nw) flows.

For the purposes of these procedures, the minimum speed, S_{min}, is set at 24 km/h. The maximum speed, S_{max}, is taken to be the average free-flow speed of the freeway segments entering and leaving the weaving segment plus 8 km/h.

- The addition of 8 km/h to the free-flow speed adjusts for the tendency of the algorithm to under predict high speeds.
- Setting the minimum and maximum speeds in this way constrains the algorithm to a reasonable prediction range.

$$S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$$

- Please note, initial speed estimates are for unconstrained situation only

WEAVING INTENSITY

$$W_i = \frac{a(1+VR)^b \left(\frac{v}{N}\right)^c}{(3.28L)^d} \qquad (24\text{-}4)$$

where

W_i	=	weaving intensity factors for weaving (i = w) and nonweaving (i = nw) flows;
VR	=	volume ratio;
v	=	total flow rate in the weaving segment (pc/h);
N	=	total number of lanes in the weaving segment;
L	=	length of the weaving segment (m); and
a, b, c, d	=	constants of calibration.

VR is the proportion of weaving vehicles in the total flow.

EXHIBIT 24-6. CONSTANTS FOR COMPUTATION OF WEAVING INTENSITY FACTORS

General Form

$$W = \frac{a(1+VR)^b \left(\frac{v}{N}\right)^c}{(3.28L)^d}$$

	Constants for Weaving Speed, S_w				Constants for Nonweaving Speed, S_{nw}			
	a	b	c	d	a	b	c	d
Type A Configuration								
Unconstrained	0.15	2.2	0.97	0.80	0.0035	4.0	1.3	0.75
Constrained	0.35	2.2	0.97	0.80	0.0020	4.0	1.3	0.75
Type B Configuration								
Unconstrained	0.08	2.2	0.70	0.50	0.0020	6.0	1.0	0.50
Constrained	0.15	2.2	0.70	0.50	0.0010	6.0	1.0	0.50
Type C Configuration								
Unconstrained	0.08	2.3	0.80	0.60	0.0020	6.0	1.1	0.60
Constrained	0.14	2.3	0.80	0.60	0.0010	6.0	1.1	0.60

Notes:

- As the length of the weaving segment increases, speeds also increase, and the intensity of lane changing declines.
- As traffic becomes imbalanced (VR increases), speeds decrease, reflecting the increased turbulence caused by higher proportions of weaving vehicles in the traffic stream.
- As average total flow per lane increases, speeds decrease, reflecting more intense demand.
- Constrained operations yield lower weaving speeds and higher non-weaving speeds than unconstrained operations.
- Type B configurations are the most efficient for handling large weaving flows. Weaving speeds of such flows are higher than for Type A and C configurations of equal length and width.

- The sensitivity of speeds to length is greatest for Type A configurations, because weaving vehicles are often accelerating or decelerating as they traverse the weaving segment (see constant d value).
- The sensitivity of non-weaving speeds to the volume ratio (VR) is greatest for Type B and C configurations (see constant b value – non-weaving)
    - These configurations can accommodate higher proportions of weaving vehicles and because each has a through lane for one weaving movement, non-weaving vehicles are more likely to share lanes with weaving vehicles than in Type A configurations, where the opportunity to segregate is greater
- All weaving vehicles must cross a crown line in Type A segments, weaving vehicles tend to concentrate in the two lanes adjacent to the crown line, whereas non-weaving vehicles gravitate to outer lanes. Thus there is substantially more segregation of weaving and non-weaving flows in Type A configurations.

WEAVING ZONE SPEED

$$S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)} \qquad (24\text{-}5)$$

where

S = space mean speed of all vehicles in the weaving segment (km/h),
S_w = space mean speed of weaving vehicles in the weaving segment (km/h),
S_{nw} = space mean speed of nonweaving vehicles in the weaving segment (km/h),
v = total flow rate in the weaving segment (pc/h),
v_w = weaving flow rate in the weaving segment (pc/h), and
v_{nw} = nonweaving flow rate in the weaving segment (pc/h).

RAMP LANE DESIGN

EXHIBIT 24-7. CRITERIA FOR UNCONSTRAINED VERSUS CONSTRAINED OPERATION OF WEAVING SEGMENTS

Configuration	Number of Lanes Required for Unconstrained Operation, N_w	N_w(max)
Type A	$1.21(N)\, VR^{0.571} L^{0.234} / S_w^{0.438}$	1.4
Type B	$N[0.085 + 0.703VR + (71.57/L) - 0.0112(S_{nw} - S_w)]$	3.5
Type C	$N[0.761 + 0.047VR - 0.00036L - 0.0031(S_{nw} - S_w)]$	3.0[a]

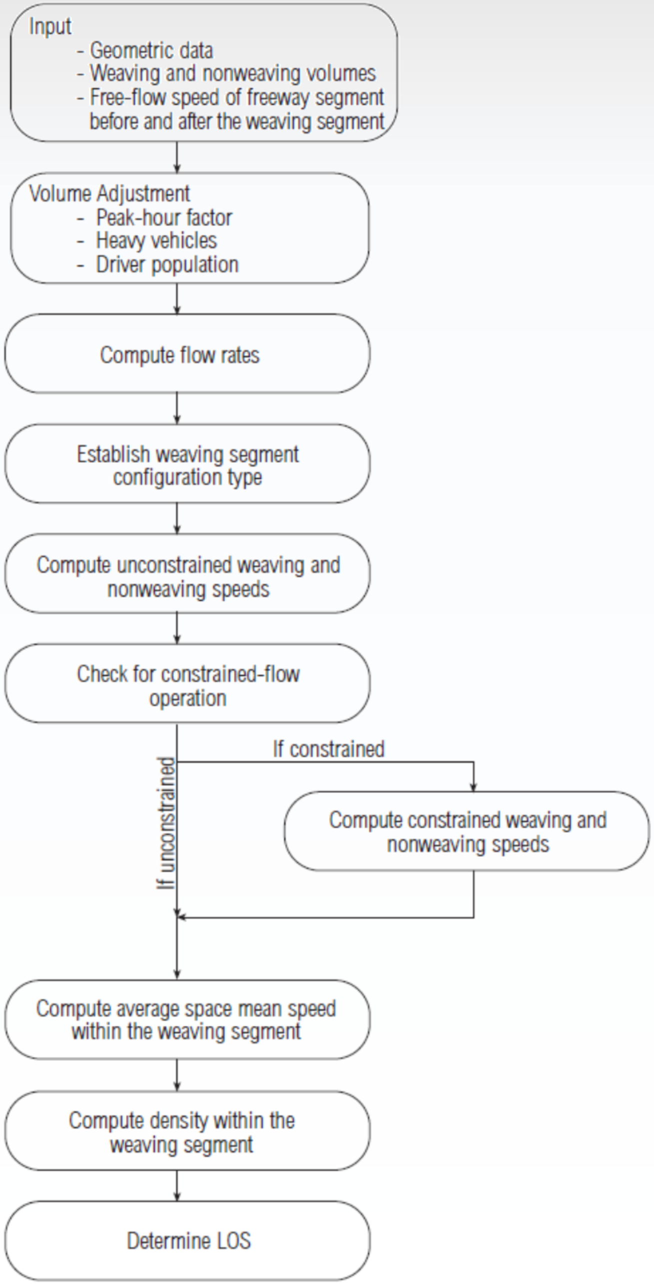
CAPACITY ANALYSIS

Average density of weaving segment:

$$k_w = \frac{V}{NS}$$

- Capacity is the flow that pushes density to E/F boundary flow, i.e. 27 for freeways and 25 for multilane highways
- Capacity varies as a function of:
  - Configuration
  - No. of lanes
  - Free-flow speed
  - Length
  - Volume ratio

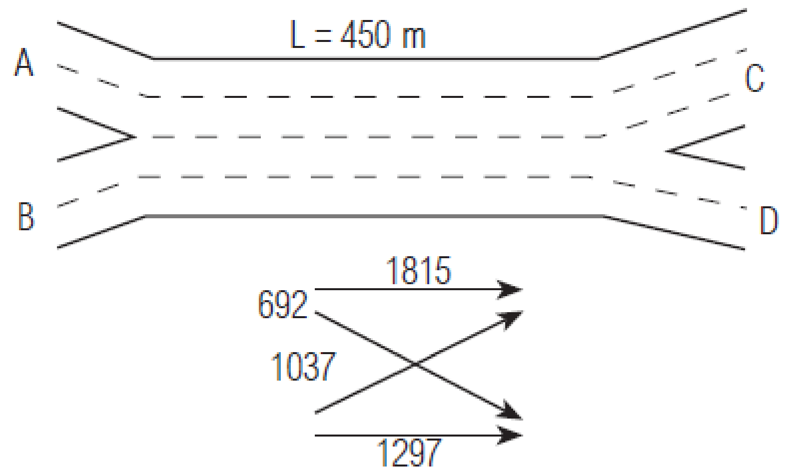
EXHIBIT 24-1. FREEWAY WEAVING METHODOLOGY



EXAMPLE

What are the level of service and capacity of the weaving segment?

- √ Volume (A-C) = 1,815 veh/h,
- √ Volume (A-D) = 692 veh/h,
- √ Volume (B-C) = 1,037 veh/h,
- √ Volume (B-D) = 1,297 veh/h,
- √ 10 percent trucks,
- √ PHF = 0.91,
- √ Level terrain,
- √ Drivers are regular commuters,
- √ FFS = 110 km/h for freeway, and
- √ Weaving segment length = 450 m.



That's all for today!