CHAPTER 24

FREEWAY WEAVING

CONTENTS

EXHIBITS

I. INTRODUCTION

SCOPE OF THE METHODOLOGY

Background and concepts for this chapter are given in Chapter 13, "Freeway Concepts"

Detailed procedures for the analysis of operations in freeway weaving segments are contained in this chapter. Guidelines are also given for the application of these procedures to weaving segments on multilane highways.

A discussion of basic concepts and definitions is given in Chapter 13, "Freeway Concepts." This section contains a complete discussion and definition of unconstrained and constrained operations in weaving segments and of the three types of weaving configuration: Type A, Type B, and Type C. An understanding of these concepts and definitions is critical to the correct application of the methodology of this chapter and to adequately interpret the results of analysis.

The procedures of this chapter have been assembled from a variety of sources and studies. The form of the speed prediction algorithm was developed as a result of a research project in the 1980s (*1*). Concepts of configuration type and type of operation were developed in an earlier study (*2*) in the 1970s and updated in another study of freeway capacity procedures published in 1979 (*3*). The final weaving procedures for the 1997 HCM are also documented (*4*). Several other documents describe the development of weaving segment analysis procedures (*5–7*).

LIMITATIONS OF THE METHODOLOGY

The methodology in this chapter does not specifically address the following subjects (without modifications by the analyst):

- Special lanes, such as high-occupancy vehicle lanes, in the weaving segment;
- Ramp metering on entrance ramps forming part of the weaving segment;
- Specific operating conditions when oversaturated conditions occur;
- Effects of speed limits or enforcement practices on weaving segment operations;
- Effects of intelligent transportation system technologies on weaving segment operations;
- Weaving segments on collector-distributor roadways;
- Weaving segments on urban streets; and
- Multiple weaving segments.

The last subject, which has been treated in previous editions of this manual, has been deleted. Multiple weaving segments must now be divided into appropriate merge, diverge, and simple weaving segments for analysis.

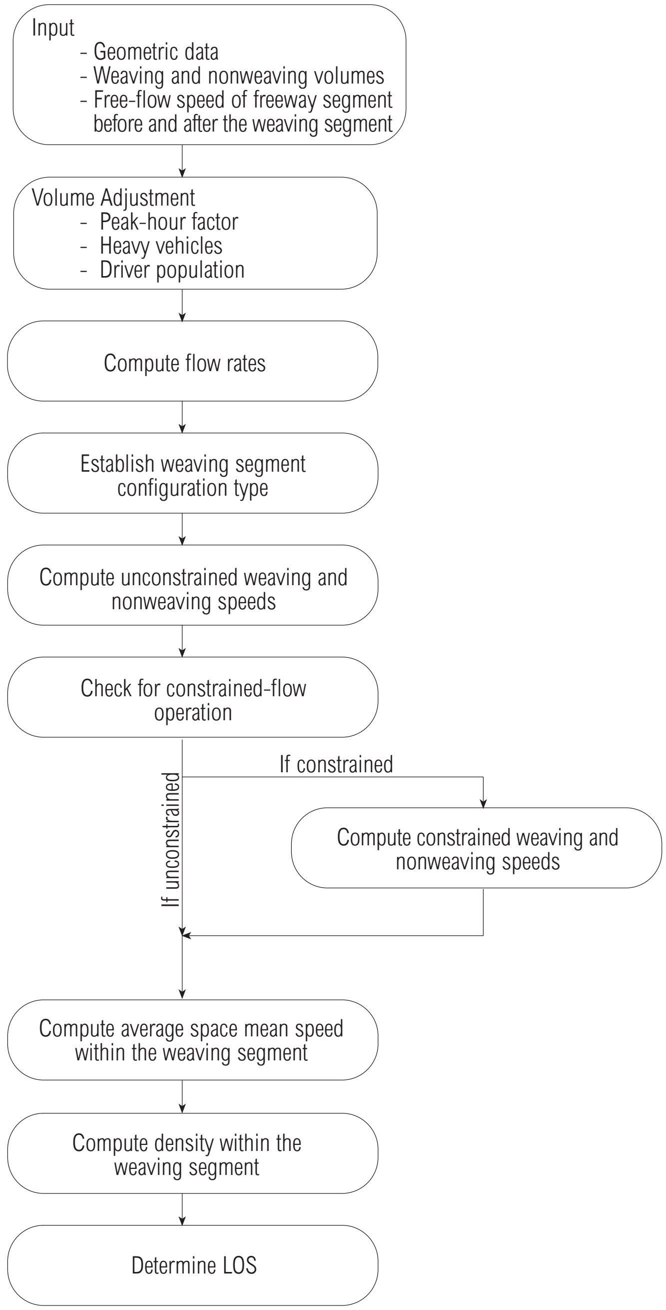
II. METHODOLOGY

The methodology presented in this chapter has five distinct components:

- Models predicting the space mean speed (average running speed) of weaving and nonweaving vehicles in the weaving segment (models are specified for each configuration type and for unconstrained and constrained operations);
- Models describing the proportional use of lanes by weaving and nonweaving vehicles, used to determine whether operations are unconstrained or constrained;
- An algorithm that converts predicted speeds to an average density within the weaving segment;
- Definition of level-of-service (LOS) criteria based on density within the weaving segment; and
- A model for the determination of the capacity of a weaving segment.

Exhibit 24-1 summarizes the methodology for freeway weaving segments.

EXHIBIT 24-1. FREEWAY WEAVING METHODOLOGY



LOS

The LOS of the weaving segment is determined by comparing the computed density with the criteria of Exhibit 24-2. A single LOS is used to characterize total flow in the weaving segment, although it is recognized that in some situations (particularly in cases of constrained operations) nonweaving vehicles may achieve higher-quality operations than weaving vehicles.

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

In general, these criteria allow for slightly higher densities at any given level-of-service threshold than on a comparable basic freeway segment or multilane highway segment. This follows the philosophy that drivers expect and will accept higher densities on weaving segments than on basic freeway or multilane highway segments. The LOS E/F boundary does not follow this approach. Rather, it reflects densities that are somewhat less than those identified for basic freeway or multilane highway segments. Because of the additional turbulence on weaving segments, it is believed that breakdown occurs at somewhat lower densities than on basic freeway and multilane highway segments.

WEAVING SEGMENT PARAMETERS

Exhibit 24-3 illustrates and defines the variables that are used in the analysis of weaving segments. These variables are used in the algorithms that make up the methodology.

All existing or projected roadway and traffic conditions must be specified when applying the methodology. Roadway conditions include length of the segment, number of lanes, type of configuration under study, and type of terrain or grade conditions. If freeway free-flow speed (FFS) is not known, the characteristics of the basic freeway segment or multilane highway must be specified to allow its determination using the algorithms of Chapter 21 or 23.

DETERMINING FLOW RATES

All of the models and equations in this chapter are based on peak 15-min flow rates in equivalent passenger cars per hour. Thus, hourly volumes must be converted to this basis using Equation 24-1.

If 15-min flow rates are specified initially, set the PHF to 1.00 before applying this conversion

$$v = \frac{V}{PHF * f_{HV} * f_p} \tag{24-1}$$

where

v = peak 15-min flow rate in an hour (pc/h),

V = hourly volume (veh/h),

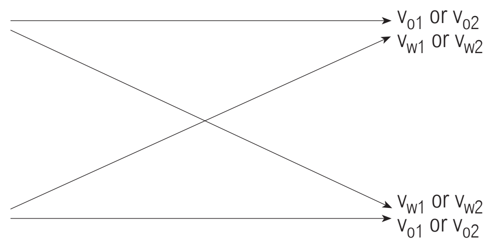
f_{HV} = heavy-vehicle adjustment factor (from basic freeway segment or multilane highway methodology), and

f_p = driver population factor (from basic freeway segment or multilane highway methodology).

WEAVING SEGMENT DIAGRAM

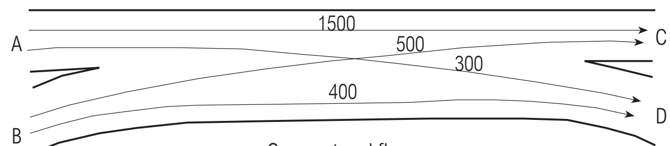
After volumes have been converted to flow rates, it is useful to construct a weaving diagram of the type shown in Exhibit 24-4. All flows are shown as flow rates in equivalent passenger cars per hour, and critical analysis variables are identified and placed on the diagram. The diagram may now be used as a reference for all input information required in applying the methodology.

EXHIBIT 24-3. PARAMETERS AFFECTING WEAVING SEGMENT OPERATION

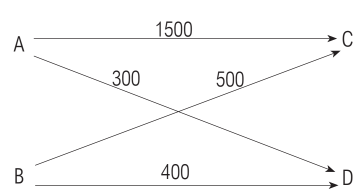


Symbol	Definition
L	Length of weaving segment (m)
N	Total number of lanes in the weaving segment
N_w	Number of lanes to be used by weaving vehicles if unconstrained operation is to be achieved
N_w(max)	Maximum number of lanes that can be used by weaving vehicles for a given configuration
N_{nw}	Number of lanes used by nonweaving vehicles
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) ($v_{nw} = v_{o1} + v_{o2}$)
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

EXHIBIT 24-4. CONSTRUCTION AND USE OF WEAVING DIAGRAMS



Segment and flows



Weaving diagram

WEAVING SEGMENT CONFIGURATION

Weaving segment configuration is based on the number of lane changes required of each weaving movement. A complete discussion of this concept is found in Chapter 13. Exhibit 24-5 may be used to establish configuration type.

See Chapter 13 for diagrams and concepts of the three weaving segment configurations

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

Note:
N/A = not applicable; configuration is not feasible.

The three types of geometric configurations are defined as follows:

- Type A—Weaving vehicles in both directions must make one lane change to successfully complete a weaving maneuver.
- Type B—Weaving vehicles in one direction may complete a weaving maneuver without making a lane change, whereas other vehicles in the weaving segment must make one lane change to successfully complete a weaving maneuver.
- Type C—Weaving vehicles in one direction may complete a weaving maneuver without making a lane change, whereas other vehicles in the weaving segment must make two or more lane changes to successfully complete a weaving maneuver.

DETERMINING WEAVING AND NONWEAVING SPEEDS

The heart of the weaving segment analysis procedure is the prediction of space mean speeds of weaving and nonweaving flows within the weaving segment. They are predicted separately because under some conditions they can be quite dissimilar, and the analyst must be aware of this.

The algorithm for prediction of average weaving and nonweaving speeds may be generally stated by Equation 24-2.

$$S_i = S_{min} + \frac{S_{max} - S_{min}}{1 + W_i} \tag{24-2}$$

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 underpredict high speeds. Setting the minimum and maximum speeds in this way constrains the algorithm to a reasonable prediction range. With these assumptions incorporated, the speed prediction is given by Equation 24-3.

$$S_i = 24 + \frac{S_{FF} - 16}{1 + W_i} \tag{24-3}$$

Attributes of weaving segments captured by the model

where S_{FF} is the average free-flow speed of the freeway segments entering and leaving the weaving segment (km/h).

Initial estimates of speed are always based on the assumption of unconstrained operation. This assumption is later tested, and speeds are recomputed if operations turn out to be constrained.

The combination of Equations 24-2 and 24-3 yields sensitivities that are consistent with observed operations of weaving segments.

- As the length of the weaving segment increases, speeds also increase, and the intensity of lane changing declines.
- As the proportion of weaving vehicles in total flow (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 (v/N) increases, speeds decrease, reflecting more intense demand.
- Constrained operations yield lower weaving speeds and higher nonweaving speeds than unconstrained operations. This reflects the fact that weaving vehicles are constrained to less space than equilibrium would require, whereas nonweaving vehicles have correspondingly more than their equilibrium share of space. In Exhibit 24-6, this is reflected by differences in the constant a.

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

- 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.
- The sensitivity of nonweaving speeds to the volume ratio (VR) is greatest for Type B and C configurations. Because these configurations can accommodate higher proportions of weaving vehicles and because each has a through lane for one weaving movement, nonweaving vehicles are more likely to share lanes with weaving vehicles than in Type A configurations, where the opportunity to segregate is greater.

The last point is important and serves to highlight the essential difference between Type A configurations (particularly ramp-weaves) and others (Types B and C). Because 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 nonweaving vehicles gravitate to outer lanes. Thus there is substantially more segregation of weaving and nonweaving flows in Type A configurations.

This difference makes Type A segments behave somewhat differently from other configurations. Speeds tend to be higher in Type A segments than in Types B or C given the same length, width, and demand flows. However, this does not suggest that Type A segments always operate better than Types B or C for similar lengths, widths, and flows. Type A segments have more severe restrictions on the amount of weaving traffic that can be accommodated than do other configurations.

Determining Weaving Intensity

The weaving intensity factors (W_w and W_{nw}) are a measure of the influence of weaving activity on the average speeds of both weaving and nonweaving vehicles. These factors are computed by Equation 24-4.

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

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.

Constants for Computing Weaving Intensity Factors

Constants for computation of weaving intensity factors (a, b, c, d) are given in Exhibit 24-6. Values for these constants vary on the basis of three factors:

- Whether the average speed prediction is for weaving or nonweaving vehicles,
- Configuration type (A, B, or C), and
- Whether the operation is unconstrained or constrained.

DETERMINING TYPE OF OPERATION

The determination of whether a particular weaving segment is operating in an unconstrained or constrained state is based on the comparison of two variables that are defined in Chapter 13:

N_w	=	number of lanes that must be used by weaving vehicles to achieve equilibrium or unconstrained operation, and
$N_w(max)$	=	maximum number of lanes that can be used by weaving vehicles for a given configuration.

Definition of constrained weaving segment

Fractional values for lane use requirements of weaving vehicles may occur because weaving and nonweaving vehicles share some lanes. Cases for which $N_w < N_w(\text{max})$ are unconstrained because there are no impediments to weaving vehicles using the number of lanes required for equilibrium. If $N_w \geq N_w(\text{max})$, weaving vehicles are constrained to using $N_w(\text{max})$ lanes and therefore cannot occupy as much of the roadway as would be needed to establish equilibrium operations. Exhibit 24-7 provides algorithms for the computation of N_w and shows the values of $N_w(\text{max})$, which are discussed more fully in Chapter 13.

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]

Note:
a. For two-sided weaving segments, all freeway lanes may be used by weaving vehicles.

The equations of Exhibit 24-7 rely on the prediction of unconstrained weaving and nonweaving speeds. The equations take these results and predict the number of lanes weaving vehicles would have to occupy to achieve unconstrained speeds. If the result indicates that constrained operations exist, speeds must be recomputed using constrained equations.

The limit on maximum number of weaving lanes, N_w(max), is most restrictive for Type A segments and reflects the need for weaving vehicles to cluster in the two lanes adjacent to the crown line. The through weaving lane in Type B and C configurations provides for greater occupancy of lanes by weaving vehicles.

Type A segments have another unusual, but understandable, characteristic. As the length of a Type A segment increases, constrained operation is more likely to result. As the length increases, the speed of weaving vehicles is also able to increase. Thus, weaving vehicles use more space as length increases, and the likelihood of requiring more than the maximum of 1.4 lanes to achieve equilibrium also increases.

Types B and C show the opposite trend. Increasing length has less effect on weaving speed than in Type A configurations. First, acceleration and deceleration from low-speed ramps are less of an issue for Types B and C, which are, by definition, major weaving segments. Second, the substantial mixing of weaving and nonweaving vehicles in the same lanes makes the resulting speeds less sensitive to length. In Type B and C segments, the proportion of lanes needed by weaving vehicles to achieve unconstrained operation decreases as length increases.

The analyst should note that under extreme conditions (high VR, short length), the equation for Type B segments can predict values of $N_w > N$. While this is not practical and reflects portions of the research database with sparse field data, it may always be taken to indicate constrained operations.

DETERMINING WEAVING SEGMENT SPEED

Once speeds have been estimated and the type of operation determined (which may cause a recomputation of estimated speeds), the average space mean speed of all vehicles in the segment is computed according to Equation 24-5.

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

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).

DETERMINING DENSITY

The average speed for all vehicles may be used to compute density for all vehicles in the weaving segment as shown in Equation 24-6.

$$D = \frac{\left(\frac{v}{N}\right)}{S} \tag{24-6}$$

where *D* is the average density for all vehicles in the weaving segment (pc/km/ln).

DETERMINING WEAVING SEGMENT CAPACITY

Capacity of a weaving segment defined

The capacity of a weaving segment is any combination of flows that causes the density to reach the LOS E/F boundary condition of 27.0 pc/km/ln for freeways or 25.0 pc/km/ln for multilane highways. Thus, capacity varies with a number of variables: configuration, number of lanes, free-flow speed of the freeway or multilane highway, length, and volume ratio. Because of the form of predictive algorithms, generation of a simple closed-form solution for capacity given the specification of the other variables is not possible. Rather, a trial-and-error process must be used.

Capacity attributes of weaving segments

Exhibit 24-8 shows tabulated values of weaving segment capacity for a number of situations. As a rough estimate, straight-line interpolation may be used for intermediate values. The tabulated capacities reflect some other limitations on weaving segment operations that reflect field observations:

- The capacity of a weaving segment may never exceed the capacity of a similar basic freeway or multilane highway segment.
- Field studies suggest that weaving flow rates should not exceed the following values: 2,800 pc/h for Type A, 4,000 pc/h for Type B, and 3,500 pc/h for Type C configurations. Even though higher weaving flows have been observed, they are likely to cause failure regardless of the results of analysis using the procedures in this manual.
- Field studies indicate that there are also limitations on the proportion of weaving flow (VR) that can be accommodated by various configurations: 1.00, 0.45, 0.35, or 0.20 for Type A with two, three, four, or five lanes, respectively; 0.80 for Type B; and 0.50 for Type C. At higher volume ratios, stable operations may still occur, but operations will be worse than those anticipated by the methodology, and failure could occur.
- For Type C segments, the weaving ratio, R, should not exceed 0.40, with the larger weaving flow being in the direction of the through weaving lane. At higher weaving ratios or where the dominant weaving flow is not in the direction of the through weaving lane, stable operations may still occur, but operations will be worse than those estimated by the methodology. Breakdown may occur in some cases.
- The maximum length for which weaving analysis is conducted is 750 m for all configuration types. Beyond these lengths, merge and diverge areas are considered separately using the methodology of Chapter 25, “Ramps and Ramp Junctions.”

As noted previously, the capacity of a weaving segment is represented by any set of conditions that results in an average density of 27 pc/km/ln (for freeways) or 25 pc/km/ln (for multilane highways). Thus, capacity varies with the configuration, the length and width of the weaving segment, the proportion of total flow that weaves (VR), and the free-flow speed of the freeway. For any given set of conditions, the algorithms described herein must be solved iteratively to find capacity.

EXHIBIT 24-8. CAPACITY FOR VARIOUS WEAVING SEGMENTS

(A) Type A Weaving Segments—120-km/h Free-Flow Speed					
Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	6050	6820	7200[b]	7200[b]	7200[b]
0.20	5490	6260	6720	7050	7200[b]
0.30	5040	5780	6240	6570	6830
0.40	4660	5380	5530	5800[c]	6050[c]
0.45[d]	4430	5000[c]	5270[c]	5550[c]	5800[c]
Four-Lane Segments					
0.10	8060	9010	9600[b]	9600[b]	9600[b]
0.20	7320	8340	8960	9400	9600[b]
0.30	6710	7520[c]	8090[c]	8510[c]	8840
0.35[e]	6370[c]	7160[c]	7700[c]	8000[f]	8000[f]
Five-Lane Segments					
0.10	10,080	11,380	12,000[b]	12,000[b]	12,000[b]
0.20[g]	9150	10,540[c]	11,270[c]	11,790[c]	12,000[b]

(B) Type A Weaving Segments—110-km/h Free-Flow Speed					
Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	5770	6470	6880	7050[b]	7050[b]
0.20	5250	5960	6280	6680	6900
0.30	4830	5520	5940	6240	6480
0.40	4480	5150	5250[c]	5530[c]	5760[c]
0.45[d]	4190	4790[c]	5020[c]	5310[c]	5530[c]
Four-Lane Segments					
0.10	7690	8630	9180	9400[b]	9400[b]
0.20	7000	7940	8500	8900	9200
0.30	6440	7180[c]	7710[c]	8090[c]	8390[c]
0.35[e]	6080[c]	6830[c]	7360[c]	7730[c]	8030[c]
Five-Lane Segments					
0.10	9610	10,790	11,470	11,750[b]	11,750[b]
0.20[g]	8750	10,030[c]	10,690[c]	11,160[c]	11,520[c]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(C) Type A Weaving Segments—100-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	5470	6110	6480	6730	6910
0.20	5000	5640	6020	6290	6490
0.30	4610	5240	5620	5900	6110
0.40	4290	4900	4990[c]	5250[c]	5460[c]
0.45[d]	4000	4520[c]	4790[c]	5040[c]	5200[c]
Four-Lane Segments					
0.10	7300	8150	8630	8970	9220
0.20	6660	7520	8030	8380	8650
0.30	6080[c]	6830[c]	7310[c]	7650[c]	7920[c]
0.35[e]	5780[c]	6520[c]	6990[c]	7330[c]	7600[c]
Five-Lane Segments					
0.10	9120	10,180	10,790	11,210	11,500[b]
0.20[g]	8330	9500[c]	10,080[c]	10,510[c]	10,830[c]

(D) Type A Weaving Segments—90-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	5160	5730	6050	6270	6430
0.20	4730	5310	5650	5880	6060
0.30	4380	4850	5290	5540	5720
0.40	4090	4420[c]	4730[c]	4960[c]	5140[c]
0.45[d]	3850	4240[c]	4470[c]	4780[c]	4950[c]
Four-Lane Segments					
0.10	6880	7460	8070	8350	8570
0.20	6310	7080	7530	7840	8080
0.30	5790[c]	6360[c]	6890[c]	7190[c]	7430[c]
0.35[e]	5520[c]	6180[c]	6590[c]	6910[c]	7140[c]
Five-Lane Segments					
0.10	8600	9550	10,080	10,440	10,710
0.20[g]	8060[c]	8930[c]	9460[c]	9820[c]	10,100[c]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(E) Type B Weaving Segments—120-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	7200[b]	7200[b]	7200[b]	7200[b]	7200[b]
0.20	6830	7200[b]	7200[b]	7200[b]	7200[b]
0.30	6120	6690	7010	7200[b]	7200[b]
0.40	5550	6100	6430	6670	6850
0.50	5100	5630	5950	6180	6370
0.60	4750	5260	5570	5800	5980
0.70	4180	4990	5290	5520	5690
0.80[h]	3900	4820	5000[f]	5000[f]	5000[f]
Four-Lane Segments					
0.10	9600[b]	9600[b]	9600[b]	9600[b]	9600[b]
0.20	9110	9600[b]	9600[b]	9600[b]	9600[b]
0.30	8170	8910	9350	9600[b]	9600[b]
0.40	7400	8140	8570	8890	9130
0.50	6670[c]	7500	7930	8000[f]	8000[f]
0.60	6070[c]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5580[c]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]
Five-Lane Segments					
0.10	12,000[b]	12,000[b]	12,000[b]	12,000[b]	12,000[b]
0.20	11,390	12,000[b]	12,000[b]	12,000[b]	12,000[b]
0.30	10,210	11,140	11,690	12,000[b]	12,000[b]
0.40	9270[c]	10,000[f]	10,000[f]	10,000[f]	10,000[f]
0.50	8000[f]	8000[f]	8000[f]	8000[f]	8000[f]
0.60	6670[f]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5760[f]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(F) Type B Weaving Segments—110-km/h Free-Flow Speed					
Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	7050[b]	7050[b]	7050[b]	7050[b]	7050[b]
0.20	6460	6950	7050[b]	7050[b]	7050[b]
0.30	5810	6320	6620	6830	6980
0.40	5280	5790	6090	6300	6470
0.50	4860	5350	5650	5860	6030
0.60	4550	5010	5300	5510	5680
0.70	4320	4770	5050	5250	5410
0.80[h]	3650	4600	4880	5000[f]	5000[f]
Four-Lane Segments					
0.10	9400[b]	9400[b]	9400[b]	9400[b]	9400[b]
0.20	8610	9270	9400[b]	9400[b]	9400[b]
0.30	7750	8430	8820	9100	9310
0.40	7040	7720	8120	8400	8620
0.50	6370[c]	7140	7530	7820	8000[f]
0.60	5810[c]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5350[c]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]
Five-Lane Segments					
0.10	11,750[b]	11,750[b]	11,750[b]	11,750[b]	11,750[b]
0.20	10,760	11,590	11,750[b]	11,750[b]	11,750[b]
0.30	9690	10,540	11,030	11,370	11,640
0.40	8830[c]	9650	10,000[f]	10,000[f]	10,000[f]
0.50	7960[c]	8000[f]	8000[f]	8000[f]	8000[f]
0.60	6670[f]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5760[f]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(G) Type B Weaving Segments—100-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	6750	6900[b]	6900[b]	6900[b]	6900[b]
0.20	6070	6510	6750	6900[b]	6900[b]
0.30	5490	5950	6210	6400	6540
0.40	5010	5470	5740	5930	6070
0.50	4620	5070	5340	5530	5680
0.60	4330	4760	5020	5220	5360
0.70	4120	4530	4790	4970	5120
0.80[h]	3600	4380	4630	4820	4960
Four-Lane Segments					
0.10	9000	9200[b]	9200[b]	9200[b]	9200[b]
0.20	8100	8680	9010	9200[b]	9200[b]
0.30	7320	7930	8280	8530	8710
0.40	6680	7290	7650	7900	8100
0.50	6060[c]	6760	7120	7370	7580
0.60	5540[c]	6340	6670[f]	6670[f]	6670[f]
0.70	5130[c]	5640[b]	5760[f]	5760[f]	5760[f]
0.80[h]	4800[c]	5000[f]	5000[f]	5000[f]	5000[f]
Five-Lane Segments					
0.10	11,250	11,500[b]	11,500[b]	11,500[b]	11,500[b]
0.20	10,120	10,850	11,260	11,500[b]	11,500[b]
0.30	9150	9910	10,350	10,660	10,890
0.40	8370[c]	9110	9560	9880	10,000[f]
0.50	7570[c]	8000[f]	8000[f]	8000[f]	8000[f]
0.60	6670[f]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5760[f]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(H) Type B Weaving Segments—90-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	6270	6600	6750[b]	6750[b]	6750[b]
0.20	5670	6050	6270	6410	6520
0.30	5150	5560	5790	5950	6070
0.40	4720	5130	5370	5540	5670
0.50	4370	4770	5010	5190	5320
0.60	4110	4500	4730	4900	5030
0.70	3910	4290	4520	4690	4820
0.80[h]	3440	4150	4380	4540	4670
Four-Lane Segments					
0.10	8350	8800	9000[b]	9000[b]	9000[b]
0.20	7560	8070	8360	8550	8690
0.30	6870	7410	7720	7940	8100
0.40	6290	6840	7160	7390	7560
0.50	5740[c]	6360	6680	6920	7090
0.60	5270[c]	5990	6310	6530	6670[f]
0.70	4890[c]	5350[c]	5760[f]	5760[f]	5760[f]
0.80[h]	4590[c]	5000[f]	5000[f]	5000[f]	5000[f]
Five-Lane Segments					
0.10	10,440	10,990	11,250[b]	11,250[b]	11,250[b]
0.20	9450	10,090	10,440	10,680	10,860
0.30	8580	9260	9650	9920	10,120
0.40	7890[c]	8550	8950	9230	9450
0.50	7170[c]	7960	8000[f]	8000[f]	8000[f]
0.60	6580[c]	6670[f]	6670[f]	6670[f]	6670[f]
0.70	5760[f]	5760[f]	5760[f]	5760[f]	5760[f]
0.80[h]	5000[f]	5000[f]	5000[f]	5000[f]	5000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(I) Type C Weaving Segments—120-km/h Free-Flow Speed

Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	7200[b]	7200[b]	7200[b]	7200[b]	7200[b]
0.20	6590	7200[b]	7200[b]	7200[b]	7200[b]
0.30	5890	6540	6930	7200	7200[b]
0.40	5530	5960	6350	6620	6840
0.50[i]	4890	5500	5870	6140	6360
Four-Lane Segments					
0.10	9600[b]	9600[b]	9600[b]	9600[b]	9600[b]
0.20	8780	9600[b]	9600[b]	9600[b]	9600[b]
0.30	7850	8720	9230	9590	9600[b]
0.40	7110	7950	8470	8750[f]	8750[f]
0.50[i]	6520	7000[f]	7000[f]	7000[f]	7000[f]
Five-Lane Segments					
0.10	12,000[b]	12,000[b]	12,000[b]	12,000[b]	12,000[b]
0.20	11,520[c]	12,000[b]	12,000[b]	12,000[b]	12,000[b]
0.30	10,140[c]	11,170[c]	11,670[f]	11,670[f]	11,670[f]
0.40	8750[f]	8750[f]	8750[f]	8750[f]	8750[f]
0.50[i]	7000[f]	7000[f]	7000[f]	7000[f]	7000[f]

(J) Type C Weaving Segments—110-km/h Free-Flow Speed

Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	7010	7050[b]	7050[b]	7050[b]	7050[b]
0.20	6240	6830	7050[b]	7050[b]	7050[b]
0.30	5610	6200	6550	6790	6980
0.40	5090	5670	6020	6270	6470
0.50[i]	4680	5240	5590	5840	6030
Four-Lane Segments					
0.10	9350	9400[b]	9400[b]	9400[b]	9400[b]
0.20	8320	9100	9400[b]	9400[b]	9400[b]
0.30	7470	8270	8730	9060	9300
0.40	6240	7560	8030	8360	8620
0.50[i]	5830	6990	7000[f]	7000[f]	7000[f]
Five-Lane Segments					
0.10	11,750[b]	11,750[b]	11,750[b]	11,750[b]	11,750[b]
0.20	10,900[c]	11,750[b]	11,750[b]	11,750[b]	11,750[b]
0.30	9630[c]	10,570[c]	10,910	11,320	11,630
0.40	8590[c]	8750[f]	8750[f]	8750[f]	8750[f]
0.50[i]	7000[f]	7000[f]	7000[f]	7000[f]	7000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(K) Type C Weaving Segments—100-km/h Free-Flow Speed					
	Length of Weaving Segment (m)				
Volume Ratio, VR	150	300	450	600	750[a]
Three-Lane Segments					
0.10	6570	6900[b]	6900[b]	6900[b]	6900[b]
0.20	5890	6410	6700	6900	6900[b]
0.30	5310	5850	6160	6370	6540
0.40	4840	5370	5680	5910	6080
0.50[i]	4460	4970	5290	5510	5690
Four-Lane Segments					
0.10	8760	9200[b]	9200[b]	9200[b]	9200[b]
0.20	7850	8540	8930	9200	9200[b]
0.30	7080	7790	8210	8500	8720
0.40	6450	7150	7580	7880	8110
0.50[i]	5950	6630	7000[f]	7000[f]	7000[f]
Five-Lane Segments					
0.10	11,500[b]	11,500[b]	11,500[b]	11,500[b]	11,500[b]
0.20	10,250[c]	11,050[c]	11,170	11,500	11,500[b]
0.30	9110[c]	9960[c]	10,260	10,620	10,900
0.40	8170[c]	8750[f]	8750[f]	8750[f]	8750[f]
0.50[i]	7000[f]	7000[f]	7000[f]	7000[f]	7000[f]

Notes:
Refer to the last page of Exhibit 24-8.

EXHIBIT 24-8 (CONTINUED). CAPACITY FOR VARIOUS WEAVING SEGMENTS

(L) Type C Weaving Segments—90-km/h Free-Flow Speed					
Volume Ratio, VR	Length of Weaving Segment (m)				
	150	300	450	600	750[a]
Three-Lane Segments					
0.10	6120	6520	6730	6750[b]	6750[b]
0.20	5510	5970	6230	6400	6520
0.30	5000	5480	5750	5940	6090
0.40	4570	5050	5330	5530	5680
0.50[i]	4230	4700	4980	5180	5330
Four-Lane Segments					
0.10	8150	8700	8980	9000[b]	9000[b]
0.20	7350	7960	8300	8530	8700
0.30	6660	7300	7670	7920	8110
0.40	5640	6730	7110	7370	7580
0.50[i]	5300	6260	6640	6900	7000[f]
Five-Lane Segments					
0.10	10,770[c]	11,250[b]	11,230	11,250[b]	11,250[b]
0.20	9580[c]	10,270[c]	10,380	10,660	10,870
0.30	8570[c]	9310[c]	9580	9900	10,140
0.40	7720[c]	8470[c]	8750[f]	8750[f]	8750[f]
0.50[i]	7000[f]	7000[f]	7000[f]	7000[f]	7000[f]

Notes:
a. Weaving segments longer than 750 m are treated as isolated merge and diverge areas using the procedures of Chapter 25, "Ramps and Ramp Junctions."
b. Capacity constrained by basic freeway capacity.
c. Capacity occurs under constrained operating conditions.
d. Three-lane Type A segments do not operate well at volume ratios greater than 0.45. Poor operations and some local queuing are expected in such cases.
e. Four-lane Type A segments do not operate well at volume ratios greater than 0.35. Poor operations and some local queuing are expected in such cases.
f. Capacity constrained by maximum allowable weaving flow rate: 2,800 pc/h (Type A), 4,000 (Type B), 3,500 (Type C).
g. Five-lane Type A segments do not operate well at volume ratios greater than 0.20. Poor operations and some local queuing are expected in such cases.
h. Type B weaving segments do not operate well at volume ratios greater than 0.80. Poor operations and some local queuing are expected in such cases.
i. Type C weaving segments do not operate well at volume ratios greater than 0.50. Poor operations and some local queuing are expected in such cases.

It is possible to do so using a spreadsheet properly programmed for such iteration. Capacities have been determined for freeway facilities and are shown in Exhibit 24-8. These capacities represent maximum 15-min flow rates under equivalent base conditions and are rounded to the nearest 10 pc/h. To find the capacity under a given set of prevailing conditions Equation 24-7 is used.

$$c = c_b * f_{HV} * f_p \tag{24-7}$$

where

c = capacity under prevailing conditions stated as a flow rate for the peak 15 min of the hour (veh/h),

c_b = capacity under base conditions stated as a flow rate for the peak 15 min of the hour in Exhibit 24-8 (pc/h),

f_{HV} = heavy-vehicle adjustment factor (basic freeway segments or multilane highways), and

f_p = driver population factor (basic freeway segments or multilane highways).

If a capacity in terms of an hourly volume is desired, it may be computed using Equation 24-8.

$$c_h = c * PHF \tag{24-8}$$

where

c_h = capacity under prevailing conditions expressed as an hourly volume (veh/h), and

PHF = peak-hour factor.

MULTIPLE WEAVING SEGMENTS

When a series of closely spaced merge and diverge areas creates several sets of weaving movements (between different merge-diverge pairs) that share the same segment of the roadway, a multiple weaving segment is created. In previous editions of this manual, a specific procedure for analysis of two-segment multiple weaving segments, involving two sets of overlapping weaving movements, was presented. Although it constituted a logical approach, it did not address cases where three or more sets of weaving movements overlapped, and it was not extensively supported by field data.

It is recommended that such cases be segregated into merge areas, diverge areas, and simple weaving segments, as appropriate, and that each segment be analyzed accordingly. Chapter 22 contains information on this procedure.

COLLECTOR-DISTRIBUTOR ROADWAYS

A common design practice often results in weaving segments that occur on collector-distributor roadways that are part of a freeway or multilane highway interchange. Although the procedures of this chapter could be applied to such cases (using appropriate free-flow speeds), whether the LOS criteria specified herein should apply is unclear. Because many such segments operate at low speeds and correspondingly high densities, stable operations may exist beyond the maximum densities specified herein, which are intended for freeway or multilane highway weaving.

III. APPLICATIONS

Guidelines for required inputs and estimated values are given in Chapter 13

The methodology of this chapter can be used to analyze the capacity and LOS of freeway weaving segments. First, the analyst identifies the primary output. Primary outputs typically solved for in a variety of applications include LOS, number of lanes required (N), weaving segment length required (L), and weaving segment configuration type (Type). Performance measures related to density and speed are also achievable but are considered secondary outputs.

Second, the analyst must identify the default values or estimated values for use in the analysis. Basically, the analyst has three sources of input data:

1. Default values found in this manual,
2. Estimates and locally derived default values developed by the analyst, and
3. Values derived from field measurements and observation.

For each of the input variables, a value must be supplied to calculate the outputs, both primary and secondary.

A common application of the method is to compute the LOS of an existing or a changed segment in the near term or distant future. This type of application is termed operational, and its primary output is LOS, with secondary outputs for density and speed. Another application is to check the adequacy of or to recommend the required number of lanes, weaving segment length, or weaving configuration given the volume or flow rate and LOS goal. This application is termed design since its primary outputs are geometric attributes of the weaving segment. Other outputs from this application include speed and density.

Another general type of analysis is termed planning. These analyses use estimates, HCM default values, and local default values as inputs in the calculation. LOS or weaving segment attributes can be determined as outputs, along with the secondary outputs of density and speed. The difference between planning analysis and operational or design analysis is that most or all of the input values in planning come from estimates or default values, whereas the operational and design analyses use field measurements or known values for inputs. Note that for each of the analyses, FFS of the weaving segment, either measured or estimated, is required as an input for the computation.

COMPUTATIONAL STEPS

The worksheet for freeway weaving computations is shown in Exhibit 24-9. The worksheet is also included in Appendix A. For all applications, the analyst provides general information and site information.

Operational (LOS)

For operational (LOS) analysis, all required input data are entered as input. After converting volumes to flow rates, the unconstrained weaving intensity factor is used to estimate weaving and nonweaving speeds. The number of lanes weaving vehicles must occupy to achieve unconstrained operation is determined. If this value is less than the maximum number of lanes, then unconstrained flow exists, and previously computed speeds will apply to the analysis. If the number of lanes required for unconstrained operation is greater than or equal to the maximum number of lanes, then weaving and nonweaving speeds must be computed for constrained operation. Then the space mean speed for all vehicles in the weaving segment is computed followed by density. Finally, level of service is determined using the density value for the weaving segment.

Design (N, L, Type)

The objective of design (N, L, Type) analysis is to estimate the length of a weaving segment, the number of lanes, or weaving segment configuration type given volumes and free-flow speed. A desired level of service is stated and entered in the worksheet. Then a weaving segment length, number of lanes, and configuration type are assumed, and the procedure for operational (LOS) analysis is performed. The level-of-service result with the assumed parameters is then compared with the desired level of service. If the desired level of service is not met, a new combination of parameter values is assumed. These iterations are continued until the desired level of service is achieved.

PLANNING APPLICATIONS

Planning (LOS)
Planning (N, L, Type)

The two planning applications, planning (LOS) and planning (N, L, Type), directly correspond to procedures described for operational and design analysis.

The first criterion that categorizes these as planning applications is the use of estimates, HCM default values, or local default values on the input side of the calculation. Another factor that defines a given application as planning is the use of annual average daily traffic (AADT) to estimate directional design-hour volume (DDHV). Guidelines for calculating DDHV are given in Chapter 8. The analyst typically has few, if any, of the input values required to perform planning applications. More information on the use of default values is contained in Chapter 13.

ANALYSIS TOOLS

The worksheet shown in Exhibit 24-9 and provided in Appendix A can be used to perform operational (LOS), design (N, L, Type), planning (LOS), and planning (N, L, Type) analyses.

EXHIBIT 24-9. FREEWAY WEAVING WORKSHEET

FREEWAY WEAVING WORKSHEET

General Information		Site Information	
Analyst	________	Freeway/Direction of Travel	________
Agency or Company	________	Weaving Segment Location	________
Date Performed	________	Jurisdiction	________
Analysis Time Period	________	Analysis Year	________

❑ Operational (LOS) ❑ Design (N, L, Type) ❑ Planning (LOS) ❑ Planning (N, L, Type)

Inputs

Freeway free-flow speed, S_{FF} = ________ km/h
Weaving number of lanes, N = ________
Weaving segment length, L ________ m
Terrain ❑ Level ❑ Rolling
Weaving type ❑ Type A ❑ Type B ❑ Type C
Volume ratio, $VR = \frac{v_w}{v}$ ________
Weaving ratio, $R = \frac{v_{w2}}{v_w}$ ________

Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}									
v_{o2}									
v_{w1}									
v_{w2}									
v_w									
v_{nw}									
v									

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)				
b (Exhibit 24-6)				
c (Exhibit 24-6)				
d (Exhibit 24-6)				
Weaving intensity factor, W_i $W_i = \frac{a(1 + VR)^b (v/N)^c}{(3.28L)^d}$				
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$				

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) ________
Maximum number of lanes, $N_w(max)$ (Exhibit 24-7) ________
❑ If $N_w < N_w(max)$ unconstrained operation ❑ If $N_w \geq N_w(max)$ constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	
Level of service, LOS (Exhibit 24-2)	
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Determine level of service of a major weaving segment	Operational (LOS)
2	Determine level of service of a ramp-weaving segment	Operational (LOS)
3	Determine level of service of a ramp-weaving segment with constrained operation	Operational (LOS)
4	Design a major weaving segment for a desired level of service	Design (N, L, Type)
5	Design a weaving segment using sensitivity analysis	Planning (N, L, Type)

EXAMPLE PROBLEM 1

The Weaving Segment A major weaving segment on an urban freeway as shown on the worksheet.

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

The Facts

- √ 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.

Comments

- √ Use Chapter 23, "Basic Freeway Segments," to identify f_{HV} and f_p.

Outline of Solution All input parameters are known, so no default values are required. Demand volumes are converted to flow rates, and weaving configuration type is determined. Weaving and nonweaving speeds are computed and used to determine weaving segment speed. The density in the weaving segment is calculated, and level of service is determined. Finally, capacity is determined.

Steps

1. Convert volume (veh/h) to flow rate (pc/h) (use Equation 24-1).	$v = \frac{V}{(PHF)(f_{HV})(f_p)}$ $v(A\text{-}C) = \frac{1{,}815}{(0.91)(0.952)(1.000)} = 2{,}095$ pc/h v(A-D) = 799 pc/h v(B-C) = 1,197 pc/h v(B-D) = 1,497 pc/h
1a. Determine f_p (use Chapter 23).	$f_p = 1.000$
1b. Determine f_{HV} (use Chapter 23).	$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)}$ $f_{HV} = \frac{1}{1+0.10(1.5-1)+0} = 0.952$
2. Determine weaving segment configuration type (use Exhibit 24-5).	Type B (Movement A-D requires one lane change; Movement B-C requires none)
3. Compute critical variables.	v_w = 1,197 + 799 = 1,996 pc/h v_{nw} = 2,095 + 1,497 = 3,592 pc/h v = 1,996 + 3,592 = 5,588 pc/h $VR = \frac{1{,}996}{5{,}588} = 0.357$ $R = \frac{799}{1{,}996} = 0.400$

4. Compute weaving and nonweaving speeds assuming unconstrained operation (use Exhibit 24-6 and Equations 24-3 and 24-4).	$W_i = \dfrac{a(1+VR)^b\left(\dfrac{v}{N}\right)^c}{(3.28L)^d}$ $\quad S_i = 24 + \dfrac{S_{FF}-16}{1+W_i}$ $W_w = \dfrac{0.08(1+0.357)^{2.2}\left(\dfrac{5,588}{4}\right)^{0.70}}{(3.28*450)^{0.50}} = 0.648$ $W_{nw} = \dfrac{0.0020(1+0.357)^{6.0}\left(\dfrac{5,588}{4}\right)^{1.0}}{(3.28*450)^{0.50}} = 0.454$ $S_w = 24 + \dfrac{110-16}{1+0.648} = 81.0$ km/h $S_{nw} = 24 + \dfrac{110-16}{1+0.454} = 88.6$ km/h
5. Check type of operation (use Exhibit 24-7).	N_w = 4[0.085 + 0.703(0.357) + (71.57/450) – 0.0112(88.6 – 81.0)] = 1.64 N_w(max) = 3.5, therefore unconstrained operation
6. Compute weaving segment speed (use Equation 24-5).	$S = \dfrac{v}{\left(\dfrac{v_w}{S_w}\right)+\left(\dfrac{v_{nw}}{S_{nw}}\right)} = \dfrac{5,588}{\left(\dfrac{1,996}{81.0}\right)+\left(\dfrac{3,592}{88.6}\right)} = 85.7$ km/h
7. Compute weaving segment density (use Equation 24-6).	$D = \dfrac{\left(\dfrac{v}{N}\right)}{S} = \dfrac{\left(\dfrac{5,588}{4}\right)}{85.7} = 16.3$ pc/km/ln
8. Determine level of service (use Exhibit 24-2).	LOS C
9. Determine weaving segment capacity (use Exhibit 24-8 and Equations 24-7 and 24-8).	c_b = 8,421 pc/h [Exhibit 24-8(F)] $c = c_b * f_{HV} * f_p$ = 8,421 * 0.952 * 1.000 = 8,017 veh/h c_h = c * PHF = 8,017 * 0.91 = 7,295 veh/h

The Results This weaving segment will operate at LOS C during the peak hour. Weaving segment density is 16.3 pc/km/ln. The capacity of the weaving segment is estimated as 8,020 veh/h (for the 15-min volume), or 7,290 veh/h (for the full-hour volume).

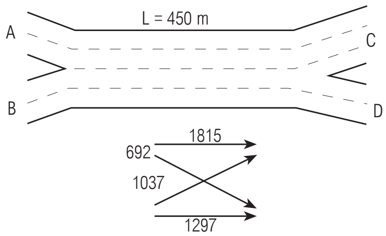
Example Problem 1

FREEWAY WEAVING WORKSHEET

General Information		**Site Information**	
Analyst	M.E.	Freeway/Direction of Travel	-
Agency or Company	CEI	Weaving Segment Location	-
Date Performed	8/3/99	Jurisdiction	-
Analysis Time Period	AM-Peak	Analysis Year	1999

☒ Operational (LOS) ☐ Design (N, L, Type) ☐ Planning (LOS) ☐ Planning (N, L, Type)

Inputs



Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Freeway free-flow speed, S_{FF} = 110 km/h

Weaving number of lanes, N = 4

Weaving segment length, L 450 m

Terrain ☒ Level ☐ Rolling

Weaving type ☐ Type A ☒ Type B ☐ Type C

Volume ratio, $VR = \frac{v_w}{v}$ 0.357

Weaving ratio, $R = \frac{v_{w2}}{v_w}$ 0.400

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}				1,815	0.91	10	0.952	1.000	2,095
v_{o2}				1,297	0.91	10	0.952	1.000	1,497
v_{w1}				1,037	0.91	10	0.952	1.000	1,197
v_{w2}				692	0.91	10	0.952	1.000	799
v_w				1,729	0.91	10	0.952	1.000	1,996
v_{nw}				3,112	0.91	10	0.952	1.000	3,592
v				4,841	0.91	10	0.952	1.000	5,588

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)	0.08	0.0020		
b (Exhibit 24-6)	2.2	6.0		
c (Exhibit 24-6)	0.70	1.0		
d (Exhibit 24-6)	0.50	0.50		
Weaving intensity factor, W_i $W_i = \frac{a(1 + VR)^b (v/N)^c}{(3.28L)^d}$	0.648	0.454		
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	81.0	88.6		

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) 1.64

Maximum number of lanes, N_w(max) (Exhibit 24-7) 3.5

☒ If $N_w < N_w$(max) unconstrained operation ☐ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	85.7
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	16.3
Level of service, LOS (Exhibit 24-2)	C
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	8,421
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	8,017
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	7,295

EXAMPLE PROBLEM 2

The Weaving Segment A ramp-weaving segment on a rural freeway as shown on the worksheet.

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

The Facts

- √ Flow rate (A-C) = 4,000 pc/h,
- √ Flow rate (B-C) = 600 pc/h,
- √ FFS = 120 km/h for freeway,
- √ Flow rate (A-D) = 300 pc/h,
- √ Flow rate (B-D) = 100 pc/h, and
- √ Weaving segment length = 300 m.

Outline of Solution All input parameters are known, so no default values are required. Demand flows are given as equivalent passenger cars per hour under base conditions. Thus, no conversion of flows is required. Weaving configuration type is determined. Weaving and nonweaving speeds are computed, followed by weaving segment speed. The density in the weaving segment is calculated, and level of service is determined. Capacity is then determined.

Steps

1. Determine weaving segment configuration type (use Exhibit 24-5).	Type A (Movements A-D and B-C require one lane change)
2. Compute critical variables.	$v_w = 600 + 300 = 900$ pc/h $v_{nw} = 4{,}000 + 100 = 4{,}100$ pc/h $v = 900 + 4{,}100 = 5{,}000$ pc/h $VR = \frac{900}{5{,}000} = 0.180$ $R = \frac{300}{900} = 0.333$
3. Compute weaving and nonweaving speeds assuming unconstrained operation (use Exhibit 24-6 and Equations 24-3 and 24-4).	$W_i = \frac{a(1+VR)^b\left(\frac{v}{N}\right)^c}{(3.28L)^d}$ $\quad S_i = 24 + \frac{S_{FF} - 16}{1+W_i}$ $W_w = \frac{0.15(1+0.180)^{2.2}\left(\frac{5{,}000}{4}\right)^{0.97}}{(3.28 * 300)^{0.80}} = 0.879$ $W_{nw} = \frac{0.0035(1+0.180)^{4.0}\left(\frac{5{,}000}{4}\right)^{1.3}}{(3.28 * 300)^{0.75}} = 0.410$ $S_w = 24 + \frac{120-16}{1+0.879} = 79.3$ km/h $S_{nw} = 24 + \frac{120-16}{1+0.410} = 97.8$ km/h
4. Check type of operation (use Exhibit 24-7).	$N_w = 1.21(N)VR^{0.571}L^{0.234}/S_w{}^{0.438}$ $N_w = \frac{1.21(4)\,(0.180^{0.571})\,(300^{0.234})}{79.3^{0.438}} = 1.02$ N_w(max) = 1.4, therefore unconstrained operation
5. Compute weaving segment speed (use Equation 24-5).	$S = \frac{v}{\left(\frac{v_w}{S_w}\right)+\left(\frac{v_{nw}}{S_{nw}}\right)} = \frac{5{,}000}{\left(\frac{900}{79.3}\right)+\left(\frac{4{,}100}{97.8}\right)} = 93.9$ km/h

6. Compute weaving segment density (use Equation 24-6).	$D = \frac{\left(\frac{v}{N}\right)}{S} = \frac{\left(\frac{5,000}{4}\right)}{93.9} = 13.3$ pc/km/ln
7. Determine level of service (use Exhibit 24-2).	LOS C
8. Determine weaving segment capacity (use Exhibit 24-8).	c_b = 8,474 pc/h [Exhibit 24-8(A)]

The Results This weaving segment will operate at LOS C during the peak hour. The weaving segment density is 13.3 pc/km/ln, and the capacity is estimated to be 8,470 pc/h. Because neither the traffic composition nor the PHF is specified, capacities per full hour and for prevailing conditions cannot be determined.

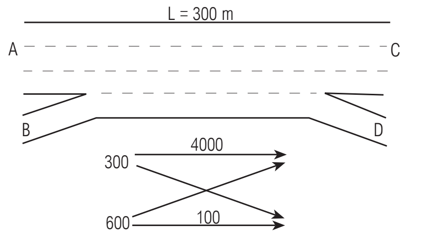
Example Problem 2

FREEWAY WEAVING WORKSHEET

General Information		**Site Information**	
Analyst	M.E.	Freeway/Direction of Travel	-
Agency or Company	CEI	Weaving Segment Location	-
Date Performed	8/3/99	Jurisdiction	-
Analysis Time Period	AM-Peak	Analysis Year	1999

☒ Operational (LOS) ☐ Design (N, L, Type) ☐ Planning (LOS) ☐ Planning (N, L, Type)

Inputs



Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Freeway free-flow speed, S_{FF} = 120 km/h
Weaving number of lanes, N = 4
Weaving segment length, L 300 m
Terrain ☐ Level ☐ Rolling
Weaving type ☒ Type A ☐ Type B ☐ Type C
Volume ratio, $VR = \frac{v_w}{v}$ 0.180
Weaving ratio, $R = \frac{v_{w2}}{v_w}$ 0.333

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}									4,000
v_{o2}									100
v_{w1}									600
v_{w2}									300
v_w									900
v_{nw}									4,100
v									5,000

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)	0.15	0.0035		
b (Exhibit 24-6)	2.2	4.0		
c (Exhibit 24-6)	0.97	1.3		
d (Exhibit 24-6)	0.80	0.75		
Weaving intensity factor, W_i $W_i = \frac{a(1 + VR)^b (v/N)^c}{(3.28L)^d}$	0.879	0.410		
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	79.3	97.8		

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) 1.02
Maximum number of lanes, N_w(max) (Exhibit 24-7) 1.4
☒ If $N_w < N_w$(max) unconstrained operation ☐ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	93.9
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	13.3
Level of service, LOS (Exhibit 24-2)	C
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	8,474
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	-
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	-

EXAMPLE PROBLEM 3

The Weaving Segment A ramp-weaving segment on an urban freeway as shown on the worksheet.

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

The Facts

- √ Volume (A-C) = 975 veh/h,
- √ Volume (A-D) = 650 veh/h,
- √ Volume (B-C) = 520 veh/h,
- √ Volume (B-D) = 0 veh/h,
- √ 15 percent trucks,
- √ PHF = 0.85,
- √ Rolling terrain,
- √ Drivers are regular commuters,
- √ FFS = 110 km/h for freeway, and
- √ Weaving segment length = 300 m.

Comments

- √ Use Chapter 23, "Basic Freeway Segments," to identify f_{HV} and f_p.

Outline of Solution All input parameters are known, so no default values are required. Demand volumes are converted to flow rates, and weaving configuration type is determined. Weaving and nonweaving speeds are computed and used to determine weaving segment speed. The density in the weaving segment is calculated, and level of service is determined. Capacity is then determined.

Steps

1. Convert volume (veh/h) to flow rate (pc/h) (use Equation 24-1).	$v = \dfrac{V}{(PHF)(f_{HV})(f_p)}$ $v(A\text{-}C) = \dfrac{975}{(0.85)(0.816)(1.000)} = 1{,}406$ pc/h v(A-D) = 937 pc/h v(B-C) = 750 pc/h
1a. Determine f_p (use Chapter 23).	$f_p = 1.000$
1b. Determine f_{HV} (use Chapter 23).	$f_{HV} = \dfrac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$ $f_{HV} = \dfrac{1}{1 + 0.15(2.5 - 1) + 0} = 0.816$
2. Determine weaving segment configuration type (use Exhibit 24-5).	Type A (all weaving vehicles must make one lane change)
3. Compute critical variables.	$v_w = 937 + 750 = 1{,}687$ pc/h $v_{nw} = 1{,}406$ pc/h v = 1,406 + 1,687 = 3,093 pc/h $VR = \dfrac{1{,}687}{3{,}093} = 0.545$ $R = \dfrac{750}{1{,}687} = 0.445$

4. Compute weaving and nonweaving speeds assuming unconstrained operation (use Exhibit 24-6 and Equations 24-3 and 24-4).	$W_i = \frac{a(1+VR)^b \left(\frac{v}{N}\right)^c}{(3.28L)^d}$ $\quad S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$ $W_w = \frac{0.15(1+0.545)^{2.2}\left(\frac{3,093}{3}\right)^{0.97}}{(3.28 * 300)^{0.80}} = 1.319$ $W_{nw} = \frac{0.0035(1+0.545)^{4.0}\left(\frac{3,093}{3}\right)^{1.3}}{(3.28 * 300)^{0.75}} = 0.938$ $S_w = 24 + \frac{110-16}{1+1.319} =$ 64.5 km/h $S_{nw} = 24 + \frac{110-16}{1+0.938} =$ 72.5 km/h
5. Check type of operation (use Exhibit 24-7).	$N_w = 1.21(N)VR^{0.571}L^{0.234}/S_w^{0.438}$ $N_w = 1.21(3)(0.545^{0.571})(300^{0.234})/64.5^{0.438} = 1.57$ $N_w(max) = 1.4$, therefore constrained operation
6. Repeat Step 4 for constrained operation.	$W_w = \frac{0.35(1+0.545)^{2.2}\left(\frac{3,093}{3}\right)^{0.97}}{(3.28 * 300)^{0.80}} = 3.077$ $W_{nw} = \frac{0.0020(1+0.545)^{4.0}\left(\frac{3,093}{3}\right)^{0.97}}{(3.28 * 300)^{0.75}} = 0.536$ $S_w = 24 + \frac{110-16}{1+3.077} =$ 47.1 km/h $S_{nw} = 24 + \frac{110-16}{1+0.536} =$ 85.2 km/h
7. Compute weaving segment speed (use Equation 24-5).	$S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)} = \frac{3,093}{\left(\frac{1,687}{47.1}\right) + \left(\frac{1,406}{85.2}\right)} =$ 59.1 km/h
8. Compute weaving segment density (use Equation 24-6).	$D = \frac{\left(\frac{v}{N}\right)}{S} = \frac{\left(\frac{3,093}{3}\right)}{59.1} =$ 17.4 pc/km/ln
9. Determine level of service (use Exhibit 24-2).	LOS D
10. Determine weaving segment capacity (use Exhibit 24-8 and Equations 24-7 and 24-8).	c_b = 4,790 pc/h [Exhibit 24-8(B)] $c = c_b * f_{HV} * f_p$ = 4,790 * 0.816 * 1.000 = 3,909 veh/h c_h = c * PHF = 3,909 * 0.85 = 3,323 veh/h

The Results The weaving segment will operate at LOS D during the peak hour. The weaving segment density is 17.4 pc/km/ln, and the capacity is estimated as 3,910 veh/h (for the 15-min flow rate), or 3,320 veh/h (for the full-hour volume). Note that the three-lane ramp-weave has a volume ratio of 0.545, which exceeds the maximum recommended for such segments (0.45). Thus, operations may actually be worse than predicted.

The capacity estimates must also be carefully considered. They reflect the maximum VR that is tabulated for Type A, three-lane weaving segments (0.45). The actual value for a VR of 0.545 would be expected to be lower than the values shown.

One approach to improving operations would be to change the configuration (Type A segments do not handle volume ratios of 0.545 efficiently) to Type B by adding a lane to the off-ramp on Leg D. This lane, not needed for general purposes, would have to be dropped or designed into the ramp's other terminus. This calculation, in effect, emphasizes the importance of configuration. The Type A configuration is not appropriate for the balance of flows presented.

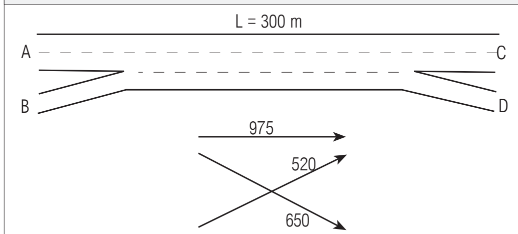
Example Problem 3

FREEWAY WEAVING WORKSHEET

General Information		Site Information	
Analyst	M.E.	Freeway/Direction of Travel	-
Agency or Company	CEI	Weaving Segment Location	-
Date Performed	8/9/99	Jurisdiction	-
Analysis Time Period	AM-Peak	Analysis Year	1999

☒ Operational (LOS) ☐ Design (N, L, Type) ☐ Planning (LOS) ☐ Planning (N, L, Type)

Inputs



Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Freeway free-flow speed, S_{FF} = 110 km/h
Weaving number of lanes, N = 3
Weaving segment length, L 300 m
Terrain ☐ Level ☒ Rolling
Weaving type ☒ Type A ☐ Type B ☐ Type C
Volume ratio, $VR = \frac{v_w}{v}$ 0.545
Weaving ratio, $R = \frac{v_{w2}}{v_w}$ 0.444

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}				975	0.85	15	0.816	1.000	1,406
v_{o2}				0	0.85	15	0.816	1.000	0
v_{w1}				650	0.85	15	0.816	1.000	937
v_{w2}				520	0.85	15	0.816	1.000	750
v_w									1,687
v_{nw}									1,406
v									3,093

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)	0.15	0.0035	0.35	0.0020
b (Exhibit 24-6)	2.2	4.0	2.2	4.0
c (Exhibit 24-6)	0.97	1.3	0.97	1.3
d (Exhibit 24-6)	0.80	0.75	0.80	0.75
Weaving intensity factor, W_i $W_i = \frac{a(1 + VR)^b (v/N)^c}{(3.28L)^d}$	1.319	0.938	3.077	0.536
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	64.5	72.5	47.1	85.2

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) 1.57
Maximum number of lanes, N_w(max) (Exhibit 24-7) 1.4
☐ If $N_w < N_w$(max) unconstrained operation ☒ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	59.1
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	17.4
Level of service, LOS (Exhibit 24-2)	D
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	4,790
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	3,909
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	3,323

EXAMPLE PROBLEM 4

The Weaving Segment Alternative major weaving segments are being considered at a major junction between two urban freeways as shown on the worksheets. Several design constraints exist. Entry Leg A (left side) has two lanes; Entry Leg B (right side) has three lanes. Exit Leg C (left side) has three lanes; Exit Leg D (right side) has two lanes. The maximum length of the weaving segment is 300 m. The FFS of all entry and exit legs is 120 km/h.

The Question What are the required number of lanes and weaving segment configuration to achieve LOS C?

The Facts

- √ Flow rate (A-C) = 2,000 pc/h,
- √ Flow rate (A-D) = 1,450 pc/h,
- √ Flow rate (B-C) = 1,500 pc/h,
- √ Flow rate (B-D) = 2,000 pc/h,
- √ FFS = 120 km/h for both freeways, and
- √ Weaving segment length = 300 m.

Outline of Solution Demand flows are given in passenger cars per hour for equivalent base conditions. Therefore, no conversion of flows is required. Weaving number of lanes and configuration are assumed, and LOS is determined. If the LOS is below C, a better configuration is assumed until LOS C or better is achieved.

Steps

1. Assume lane configuration shown on the worksheet.	
2. Determine weaving segment configuration type (use Exhibit 24-5).	Type C (Movement B-C requires no lane change; Movement A-D requires two lane changes).
3. Compute critical variables.	$v_w = 1{,}500 + 1{,}450 = 2{,}950$ pc/h $v_{nw} = 2{,}000 + 2{,}000 = 4{,}000$ pc/h $v = 4{,}000 + 2{,}950 = 6{,}950$ pc/h $VR = \frac{2{,}950}{6{,}950} = 0.424$ $R = \frac{1{,}450}{2{,}950} = 0.492$
4. Compute weaving and nonweaving speeds assuming unconstrained operation (use Exhibit 24-6 and Equations 24-3 and 24-4).	$W_i = \frac{a(1+VR)^b\left(\frac{v}{N}\right)^c}{(3.28L)^d}$ $\quad S_i = 24 + \frac{S_{FF} - 16}{1+W_i}$ $W_w = \frac{0.08(1+0.424)^{2.3}\left(\frac{6{,}950}{5}\right)^{0.80}}{(3.28 * 300)^{0.60}} = 0.944$ $W_{nw} = \frac{0.0020(1+0.424)^{6.0}\left(\frac{6{,}950}{5}\right)^{1.1}}{(3.28 * 300)^{0.60}} = 0.765$ $S_w = 24 + \frac{120-16}{1+0.944} =$ 77.5 km/h $S_{nw} = 24 + \frac{120-16}{1+0.765} =$ 82.9 km/h

5. Check type of operation (use Exhibit 24-7).	$N_w = N[0.761 + 0.047VR - 0.00036L - 0.0031(S_{nw} - S_w)]$ $N_w = 5[0.761 + (0.047 * 0.424) - (0.00036 * 300) - 0.0031(82.9 - 77.5)] = 3.28$ $N_w(max) = 3.0$, constrained operation
6. Repeat Step 4 for constrained operation.	$W_w = \dfrac{0.14(1+0.424)^{2.3}\left(\dfrac{6,950}{5}\right)^{0.80}}{(3.28 * 300)^{0.60}} = 1.651$ $W_{nw} = \dfrac{0.0010(1+0.424)^{6.0}\left(\dfrac{6,950}{5}\right)^{1.1}}{(3.28 * 300)^{0.60}} = 0.382$ $S_w = 24 + \dfrac{120-16}{1+1.651} = 63.2$ km/h $S_{nw} = 24 + \dfrac{120-16}{1+0.382} = 99.3$ km/h
7. Compute weaving segment speed (use Equation 24-5).	$S = \dfrac{v}{\left(\dfrac{v_w}{S_w}\right)+\left(\dfrac{v_{nw}}{S_{nw}}\right)} = \dfrac{6,950}{\left(\dfrac{2,950}{63.2}\right)+\left(\dfrac{4,000}{99.3}\right)} = 79.9$ km/h
8. Compute weaving segment density (use Equation 24-6).	$D = \dfrac{\left(\dfrac{v}{N}\right)}{S} = \dfrac{\left(\dfrac{6,950}{5}\right)}{79.9} = 17.4$ pc/km/ln
9. Determine level of service (use Exhibit 24-2).	LOS D

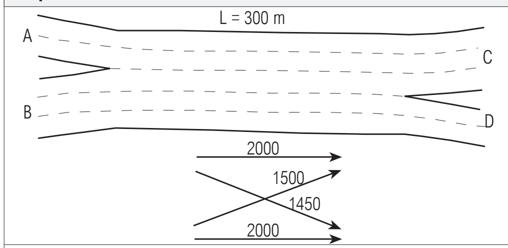
Example Problem 4

FREEWAY WEAVING WORKSHEET

General Information		Site Information	
Analyst	M.E.	Freeway/Direction of Travel	-
Agency or Company	CEI	Weaving Segment Location	-
Date Performed	8/9/99	Jurisdiction	-
Analysis Time Period	AM-Peak	Analysis Year	1999

☐ Operational (LOS) ☒ Design (N, L, Type) ☐ Planning (LOS) ☐ Planning (N, L, Type)

Inputs



Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Freeway free-flow speed, S_{FF} = 120 km/h
Weaving number of lanes, N = 5
Weaving segment length, L 300 m
Terrain ☐ Level ☐ Rolling
Weaving type ☐ Type A ☐ Type B ☒ Type C
Volume ratio, $VR = \frac{v_w}{v}$ 0.424
Weaving ratio, $R = \frac{v_{w2}}{v_w}$ 0.492

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}									2,000
v_{o2}									2,000
v_{w1}									1,500
v_{w2}									1,450
v_w									2,950
v_{nw}									4,000
v									6,950

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)	0.08	0.0020	0.14	0.0010
b (Exhibit 24-6)	2.3	6.0	2.3	6.0
c (Exhibit 24-6)	0.80	1.1	0.80	1.1
d (Exhibit 24-6)	0.60	0.60	0.60	0.60
Weaving intensity factor, W_i $W_i = \frac{a(1+VR)^b (v/N)^c}{(3.28L)^d}$	0.944	0.765	1.651	0.382
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	77.5	82.9	63.2	99.3

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) 3.28
Maximum number of lanes, N_w(max) (Exhibit 24-7) 3.0
☐ If $N_w < N_w$(max) unconstrained operation ☒ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	79.9
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	17.4
Level of service, LOS (Exhibit 24-2)	D
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	

The trial design just misses the design objective of LOS C. There are other troubling aspects of the results as well. The R value (0.492) exceeds the maximum recommended for Type C segments (0.40), and the segment might, therefore, operate worse than expected. The constrained operating condition produces a large difference in speed between weaving and nonweaving traffic streams. That is also undesirable. There is no additional length available, since the maximum of 300 m has already been used. The width cannot be made six lanes without adding lanes to entry and exit roadways as well, where they are apparently not needed. The only other potential change would be to alter the configuration to a Type B design. This is best accomplished by adding a lane to Leg D. The lane will make weaving more efficient and can be dropped further downstream on Leg D.	
10. Assume lane configuration shown on the worksheet.	
11. Determine weaving segment configuration type (use Exhibit 24-5).	Type B (Movement B-C requires no lane change; Movement A-D requires one lane change).
12. Compute weaving and nonweaving speeds assuming unconstrained operation (use Exhibit 24-6 and Equations 24-3 and 24-4).	$W_i = \frac{a(1+VR)^b\left(\frac{v}{N}\right)^c}{(3.28L)^d}$ $\quad S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$ $W_w = \frac{0.08(1+0.424)^{2.2}\left(\frac{6,950}{5}\right)^{0.70}}{(3.28 * 300)^{0.50}} = 0.880$ $W_{nw} = \frac{0.0020(1+0.424)^{6.0}\left(\frac{6,950}{5}\right)^{1.0}}{(3.28 * 300)^{0.50}} = 0.739$ $S_w = 24 + \frac{120-16}{1+0.880} = 79.3$ km/h $S_{nw} = 24 + \frac{120-16}{1+0.739} = 83.8$ km/h
13. Check type of operation (use Exhibit 24-7).	$N_w = N[0.085 + 0.703VR + (71.57/L) - 0.0112(S_{nw} - S_w)]$ $N_w = 5[0.085 + (0.703 * 0.424) + (71.57/300)$ $- 0.0112(83.8 - 79.3)] = 2.86$ $N_w(max) = 3.5$, unconstrained operation
14. Compute weaving segment speed (use Equation 24-5).	$S = \frac{v}{\left(\frac{v_w}{S_w}\right)+\left(\frac{v_{nw}}{S_{nw}}\right)} = \frac{6,950}{\left(\frac{2,950}{79.3}\right)+\left(\frac{4,000}{83.8}\right)} = 81.8$ km/h
15. Compute weaving segment density (use Equation 24-6).	$D = \frac{\left(\frac{v}{N}\right)}{S} = \frac{\left(\frac{6,950}{5}\right)}{81.8} = 17.0$ pc/km/ln
16. Determine level of service (use Exhibit 24-2).	LOS C

The Results Whereas the level of service does improve to barely provide the desired LOS C, there are many other beneficial effects of providing the Type B configuration. Unconstrained operation prevails, and the difference in speed between the weaving and nonweaving streams is reduced substantially. This calculation illustrates the advantage of a Type B configuration in handling high proportions of weaving traffic.

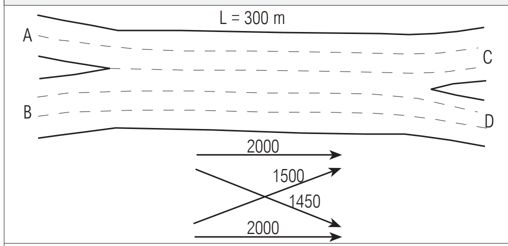
Example Problem 4

FREEWAY WEAVING WORKSHEET

General Information		Site Information	
Analyst	M.E.	Freeway/Direction of Travel	-
Agency or Company	CEI	Weaving Segment Location	-
Date Performed	8/9/99	Jurisdiction	-
Analysis Time Period	AM-Peak	Analysis Year	1999

☐ Operational (LOS) ☒ Design (N, L, Type) ☐ Planning (LOS) ☐ Planning (N, L, Type)

Inputs



Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Freeway free-flow speed, S_{FF} = 120 km/h

Weaving number of lanes, N = 5

Weaving segment length, L 300 m

Terrain ☐ Level ☐ Rolling

Weaving type ☐ Type A ☒ Type B ☐ Type C

Volume ratio, $VR = \frac{v_w}{v}$ 0.424

Weaving ratio, $R = \frac{v_{w2}}{v_w}$ 0.492

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}									2,000
v_{o2}									2,000
v_{w1}									1,500
v_{w2}									1,450
v_w									2,950
v_{nw}									4,000
v									6,950

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)	0.08	0.0020		
b (Exhibit 24-6)	2.2	6.0		
c (Exhibit 24-6)	0.70	1.0		
d (Exhibit 24-6)	0.50	0.50		
Weaving intensity factor, W_i $W_i = \frac{a(1 + VR)^b (v/N)^c}{(3.28L)^d}$	0.880	0.739		
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	79.3	83.8		

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) 2.86

Maximum number of lanes, N_w(max) (Exhibit 24-7) 3.5

☒ If $N_w < N_w$(max) unconstrained operation ☐ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

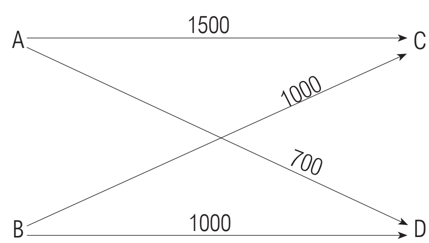
Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	81.8
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	17.0
Level of service, LOS (Exhibit 24-2)	C
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	

EXAMPLE PROBLEM 5

The Weaving Segment A major interchange is to be built to join two major freeways in a suburban area.

The Question What are the required number of lanes, length, and configuration of the weaving segment to achieve LOS C operation?

The Facts The flows analyzed are shown in the weaving diagram below. The flow rates are given in passenger cars per hour under base conditions. Since the interchange will join two future facilities, there is considerable flexibility in both the length and the width of the segment. The free-flow speed is 120 km/h.



The Results Since the length, width, and configuration to be used are open to question, so is the issue of whether to have a weaving segment at all. Speed, density, and level of service will be determined from trial computations for a range of conditions covering three, four, and five lanes, with the length ranging from 150 m to 750 m. All three types of weaving configuration will also be evaluated. This is a time-consuming process, and the use of a programmable calculator or spreadsheet is recommended. The analysis results are shown in the table on the next page.

A number of points should be made concerning the results and the effect on the final design decision.

1. Before all the potential solutions are examined, the configuration of entry and exit legs should be considered. To provide for minimum LOS C, two lanes are needed on each entry and exit leg. The five-lane option is eliminated because the four-lane option is able to meet the criteria.
2. If the legs are simply connected, a four-lane Type A configuration will result, and LOS C is produced. The main drawback of this configuration is that the operation is constrained. This indicates serious imbalance between weaving and nonweaving flows. Also, the VR of 0.405 is higher than the maximum recommended for Type A, 0.35. Traffic operation may be worse than predicted here.
3. There is no easy way to produce a Type C configuration given the criteria for entry and exit legs.
4. A Type B configuration can be achieved by adding one lane to Leg C. The resulting four-lane Type B segment will operate within all recommended parameters and meet minimum required LOS C for all lengths evaluated. A three-lane Type B configuration will result if a lane is merged at the entrance to and diverged at the exit from the segment. LOS C can also be met with three lanes if the length is 300 m or longer.

The results do not yield a clear answer, but they provide the analyst with the information to make a judgment. Obviously, the best operation will result from a long Type B segment with four lanes. However, economic and environmental considerations will also affect the final decision.

No. of Lanes	L (m)	S (km/h)	D (pc/km/ln)	LOS	Cons Y/N
Type A Configurations					
3	150	59.3	23.6	E	N
	300	72.5	19.3	D	N
	450	80.6	17.4	D	N
	600	79.3	17.7	D	Y
	750	83.5	16.8	C	Y
4	150	61.9	17.0	C	Y
	300	73.7	14.2	C	Y
	450	81.2	12.9	C	Y
	600	86.5	12.1	C	Y
	750	90.5	11.6	B	Y
5	150	66.9	12.6	C	Y
	300	79.2	10.6	B	Y
	450	86.6	9.7	B	Y
	600	91.7	9.2	B	Y
	750	95.5	8.8	B	Y
Type B Configurations					
3	150	74.3	18.8	D	N
	300	83.3	16.8	C	N
	450	88.3	15.8	C	N
	600	91.8	15.3	C	N
	750	94.4	14.8	C	N
4	150	80.7	13.0	C	N
	300	89.4	11.7	B	N
	450	94.2	11.1	B	N
	600	97.4	10.8	B	N
	750	99.7	10.5	B	N
5	150	83.3	10.1	B	Y
	300	94.0	8.9	B	N
	450	98.4	8.5	B	N
	600	101.4	8.3	B	N
	750	103.5	8.1	B	N
Type C Configurations					
3	150	71.2	19.7	D	N
	300	82.0	17.1	D	N
	450	88.1	15.9	C	N
	600	92.2	15.2	C	N
	750	95.3	14.7	C	N
4	150	78.4	13.4	C	N
	300	88.9	11.8	B	N
	450	94.6	11.1	B	N
	600	98.4	10.7	B	N
	750	101.1	10.4	B	N
5	150	82.6	10.2	B	Y
	300	92.2	9.1	B	Y
	450	99.2	8.5	B	N
	600	102.7	8.2	B	N
	750	105.2	8.0	B	N

Note:
Cons—constrained flow; Y/N—yes/no.

V. REFERENCES

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3. Roess, R. P., et al. *Freeway Capacity Analysis Procedures.* Final Report, Project DOT-FH-11-9336. Polytechnic Institute of New York, Brooklyn, 1979.
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APPENDIX A. WORKSHEET

FREEWAY WEAVING WORKSHEET

FREEWAY WEAVING WORKSHEET

General Information		Site Information	
Analyst	____________	Freeway/Direction of Travel	____________
Agency or Company	____________	Weaving Segment Location	____________
Date Performed	____________	Jurisdiction	____________
Analysis Time Period	____________	Analysis Year	____________

❑ Operational (LOS) ❑ Design (N, L, Type) ❑ Planning (LOS) ❑ Planning (N, L, Type)

Inputs

Freeway free-flow speed, S_{FF} = ________ km/h

Weaving number of lanes, N = ________

Weaving segment length, L ________ m

Terrain ❑ Level ❑ Rolling

Weaving type ❑ Type A ❑ Type B ❑ Type C

Volume ratio, $VR = \frac{v_w}{v}$ ________

Weaving ratio, $R = \frac{v_{w2}}{v_w}$ ________

Sketch (show lanes, L, v_{o1}, v_{o2}, v_{w1}, v_{w2})

Conversion to pc/h Under Base Conditions

(pc/h)	AADT (veh/day)	K	D	V (veh/h)	PHF	% HV	f_{HV}	f_p	$v = \frac{V}{PHF * f_{HV} * f_p}$
v_{o1}									
v_{o2}									
v_{w1}									
v_{w2}									
v_w									
v_{nw}									
v									

Weaving and Nonweaving Speeds

	Unconstrained		Constrained	
	Weaving (i = w)	Nonweaving (i = nw)	Weaving (i = w)	Nonweaving (i = nw)
a (Exhibit 24-6)				
b (Exhibit 24-6)				
c (Exhibit 24-6)				
d (Exhibit 24-6)				
Weaving intensity factor, W_i $W_i = \frac{a(1+VR)^b (v/N)^c}{(3.28L)^d}$				
Weaving and nonweaving speeds, S_i (km/h) $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$				

Number of lanes required for unconstrained operation, N_w (Exhibit 24-7) ________

Maximum number of lanes, N_w(max) (Exhibit 24-7) ________

❑ If $N_w < N_w$(max) unconstrained operation ❑ If $N_w \geq N_w$(max) constrained operation

Weaving Segment Speed, Density, Level of Service, and Capacity

Weaving segment speed, S (km/h) $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)}$	
Weaving segment density, D (pc/km/ln) $D = \frac{v/N}{S}$	
Level of service, LOS (Exhibit 24-2)	
Capacity for base condition, c_b (pc/h) (Exhibit 24-8)	
Capacity as a 15-min flow rate, c (veh/h) $c = c_b * f_{HV} * f_p$	
Capacity as a full-hour volume, c_h (veh/h) $c_h = c(PHF)$	