LC<sub>RR</sub> = minimum number of lane changes that must be made by one ramp-to-ramp vehicle to execute the desired maneuver successfully.

LC<sub>MIN</sub> for two-sided weaving segments is given by Equation 12-3:

\[ LC_{MIN} = LC_{RR} \times v_{RR} \]

For two-sided weaving segments, the value of \( N_{WL} \) is always 0 by definition.

**Step 4: Determine Maximum Weaving Length**

The concept of maximum length of a weaving segment is critical to the methodology. Strictly defined, maximum length is the length at which weaving turbulence no longer has an impact on operations within the segment, or alternatively, on the capacity of the weaving segment.

Unfortunately, depending on the selected definition, these measures can be quite different. Weaving turbulence will have an impact on operations (i.e., weaving and nonweaving vehicle speeds) for distances far in excess of those defined by when the capacity of the segment is no longer affected by weaving.

This methodology uses the second definition (based on the equivalence of capacity). If the operational definition were used, the methodology would produce capacity estimates in excess of those for a similar basic freeway segment, which is illogical. The maximum length of a weaving segment (in feet) is computed from Equation 12-4:

\[ L_{MAX} = \left[5,728(1 + VR)^{1.6}\right] - \left[1,566 N_{WL}\right] \]

where \( L_{MAX} \) is the maximum weaving segment length (using the short length definition) and other variables are as previously defined.

As \( VR \) increases, it is expected that the influence of weaving turbulence would extend for longer distances. All values of \( N_{WL} \) are either 0 (two-sided weaving segments) or 2 or 3 (one-sided weaving segments). Having more lanes from which easy weaving lane changes can be made reduces turbulence, which in turn reduces the distance over which such turbulence affects segment capacity.

Exhibit 12-9 illustrates the sensitivity of maximum length to both \( VR \) and \( N_{WL} \). As expected, \( VR \) has a significant impact on maximum length, as does the configuration, as indicated by \( N_{WL} \). While the maximum lengths shown can compute to very high numbers, the highest results are well outside the calibration range of the equation (limited to about 2,800 ft), and many of the situations are improbable. Values of \( VR \) on segments with \( N_{WL} = 2.0 \) lanes rarely rise above the range of 0.40 to 0.50. While values of \( VR \) above 0.70 are technically feasible on segments with \( N_{WL} = 3.0 \) lanes, they are rare.

While the extreme values in Exhibit 12-9 are not practical, it is clear that the maximum length of weaving segments can rise to 6,000 ft or more. Furthermore, the maximum length can vary over time, as \( VR \) is not a constant throughout every demand period of the day.
**Exhibit 12-9**
Variation of Weaving Length Versus Volume Ratio and Number of Weaving Lanes (ft)

<table>
<thead>
<tr>
<th>VR</th>
<th>N&lt;sub&gt;WL&lt;/sub&gt; = 2</th>
<th>N&lt;sub&gt;WL&lt;/sub&gt; = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>3,540</td>
<td>1,974</td>
</tr>
<tr>
<td>0.2</td>
<td>4,536</td>
<td>2,970</td>
</tr>
<tr>
<td>0.3</td>
<td>5,584</td>
<td>4,018</td>
</tr>
<tr>
<td>0.4</td>
<td>6,681</td>
<td>5,115</td>
</tr>
<tr>
<td>0.5</td>
<td>7,826</td>
<td>6,260</td>
</tr>
<tr>
<td>0.6</td>
<td>9,019</td>
<td>7,453</td>
</tr>
<tr>
<td>0.7</td>
<td>10,256</td>
<td>8,690</td>
</tr>
<tr>
<td>0.8</td>
<td>11,538</td>
<td>9,972</td>
</tr>
</tbody>
</table>

The value of $L_{MAX}$ is used to determine whether continued analysis of the configuration as a weaving segment is justified:

- If $L_S < L_{MAX}$, continue to Step 5; or
- If $L_S \geq L_{MAX}$, analyze the merge and diverge junctions as separate segments by using the methodology in Chapter 13.

If the segment is too long to be considered a weaving segment, then the merge and diverge areas are treated separately. Any distance between the two falling outside the influence areas of the merge and diverge segments would be considered to be a basic freeway segment and would be analyzed accordingly.

### Step 5: Determine Weaving Segment Capacity

The capacity of a weaving segment is controlled by one of two conditions:

- Breakdown of a weaving segment is expected to occur when the average vehicle density of all vehicles in the segment reaches 43 pc/mi/ln; or
- Breakdown of a weaving segment is expected to occur when the total weaving demand flow rate exceeds
  - 2,400 pc/h for cases in which $N_{WL} = 2$ lanes, or
  - 3,500 pc/h for cases in which $N_{WL} = 3$ lanes.

The first criterion is based on the criteria listed in Chapter 11, Basic Freeway Segments, which state that freeway breakdowns occur at a density of 45 pc/mi/ln. Given the additional turbulence in a weaving segment, breakdown is expected to occur at slightly lower densities.

The second criterion recognizes that there is a practical limit to how many vehicles can actually cross each other’s path without causing serious operational failures. The existence of a third lane from which weaving maneuvers can be made with two or fewer lane changes in effect spreads the impacts of turbulence across segment lanes and allows for higher weaving flows.

For two-sided weaving segments ($N_{WL} = 0$ lanes), no limiting value on weaving flow rate is proposed. The analysis of two-sided weaving segments is approximate with this methodology, and a density sufficient to cause a breakdown is generally reached at relatively low weaving flow rates.

### Weaving Segment Capacity Determined by Density

The capacity of a weaving segment, based on reaching a density of 43 pc/mi/ln, is estimated by using Equation 12-5:
Step 8: Determine LOS

The LOS in a weaving segment, as in all freeway analysis, is related to the density in the segment. Exhibit 12-10 provides LOS criteria for weaving segments on freeways, collector–distributor (C-D) roadways, and multilane highways. This methodology was developed for freeway weaving segments, although an isolated C-D roadway was included in its development. The methodology may be applied to weaving segments on uninterrupted segments of multilane surface facilities, although its use in such cases is approximate.

<table>
<thead>
<tr>
<th>LOS</th>
<th>Freeway Weaving Segments</th>
<th>Weaving Segments on Multilane Highways or C-D Roadways</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0–10</td>
<td>0–12</td>
</tr>
<tr>
<td>B</td>
<td>&gt;10–20</td>
<td>&gt;12–24</td>
</tr>
<tr>
<td>C</td>
<td>&gt;20–28</td>
<td>&gt;24–32</td>
</tr>
<tr>
<td>D</td>
<td>&gt;28–35</td>
<td>&gt;32–36</td>
</tr>
<tr>
<td>E</td>
<td>&gt;35–43</td>
<td>&gt;36–40</td>
</tr>
<tr>
<td>F</td>
<td>&gt;43, or demand exceeds capacity</td>
<td>&gt;40, or demand exceeds capacity</td>
</tr>
</tbody>
</table>

The boundary between stable and unstable flow—the boundary between levels of service E and F—occurs when the demand flow rate exceeds the capacity of the segment, as described in Step 5. The threshold densities for other levels of service were set relative to the criteria for basic freeway segments (or multilane highways). In general, density thresholds in weaving segments are somewhat higher than those for similar basic freeway segments (or multilane highways). It is believed that drivers will tolerate higher densities in an area where lane-changing turbulence is expected than on basic segments.

To apply density criteria, the average speed of all vehicles, computed in Step 7, must be converted to density by using Equation 12-22.

\[
D = \frac{\frac{v}{N}}{S}
\]

where \(D\) is density in passenger cars per mile per lane and all other variables are as previously defined.

SPECIAL CASES

Multiple Weaving Segments

When a series of closely spaced merge and diverge areas creates overlapping weaving movements (between different merge–diverge pairs) that share the same segment of a roadway, a multiple weaving segment is created. In earlier editions of the HCM, a specific application of the weaving methodology for two-segment multiple weaving segments was included. While it was a logical extension of the methodology, it did not address cases in which three or more sets of weaving movements overlapped, nor was it well-supported by field data.
Multiple weaving segments should be segregated into separate merge, diverge, and simple weaving segments, with each segment appropriately analyzed by using this chapter’s methodology or that of Chapter 13, Freeway Merge and Diverge Segments. Chapter 11, Basic Freeway Segments, contains information relative to the process of identifying appropriate segments for analysis.

**C-D Roadways**

A common design practice often results in weaving movements that occur on C-D roadways that are part of a freeway interchange. The methodology of this chapter may be approximately applied to such segments. The FFS used must be appropriate to the C-D roadway. It would have to be measured on an existing or similar C-D roadway, as the predictive methodology of FFS given in Chapter 11 does not apply to such roadways. It is less clear that the LOS criteria of Exhibit 12-10 are appropriate. Many C-D roadways operate at lower speeds and higher densities than on basic segments, and the criteria of Exhibit 12-10 may produce an inappropriately negative view of operations on a C-D roadway.

If the measured FFS of a C-D roadway is high (greater than or equal to 50 mi/h), the results of analysis can be expected to be reasonably accurate. At lower FFS values, results would be more approximate.

**Multilane Highways**

Weaving segments may occur on surface multilane highways. As long as such segments are a sufficient distance away from signalized intersections—so that platoon movements are not an issue—the methodology of this chapter may be approximately applied.

**Arterial Weaving**

The methodology of this chapter does not apply to weaving segments on arterials. Arterial weaving is strongly affected by the proximity and timing of signals along the arterial. At the present time, there are no generally accepted analytic methodologies for analyzing weaving movements on arterials.
**Step 5: Determine Weaving Segment Capacity**

The capacity of a two-sided weaving segment can only be estimated when a density of 43 pc/h/ln is reached. This estimation is made by using Equation 12-5 and Equation 12-6:

\[ c_{RLW} = c_{RL} - [438.2(1 + VR)^{1.6}] + [0.0765L_s] + [119.8N_{WL}] \]
\[ c_{RLW} = 2,300 - [438.2(1 + 0.072)^{1.6}] + [0.0765 \times 750] + [119.8 \times 0] \]
\[ c_{RLW} = 1,867 \text{ pc/h/ln} \]
\[ c_{W} = c_{RLW} \times N \times f_{IV} \times f_p = 1,867 \times 3 \times 0.816 \times 1 = 4,573 \text{ veh/h} > 4,415 \text{ veh/h} \]

Because the capacity of the segment exceeds the demand volume (in vehicles per hour), LOS F is not expected, and the analysis may be continued.

**Step 6: Determine Lane-Changing Rates**

Equation 12-10 through Equation 12-15 are used to estimate the lane-changing rates of weaving and nonweaving vehicles in the weaving segment. In turn, these will be used to estimate weaving and nonweaving vehicle speeds.

**Weaving Vehicle Lane-Changing Rate**

\[ LC_W = LC_{MN} + 0.39\left[ (L_s - 300)(N^2)(1 + ID)^{0.8} \right] \]
\[ LC_W = 782 + 0.39\left[ 750 \times 2 \times 5,017 \right] = 961 \text{ lc/h} \]

**Nonweaving Vehicle Lane-Changing Rate**

\[ I_{NW} = \frac{L_s \times ID \times v_{NW}}{10,000} = \frac{750 \times 2 \times 5,017}{10,000} = 753 < 1,300 \]
\[ LC_{NW} = (0.206\sigma_{NW}) + (0.542L_s) - (192.6N) \]
\[ LC_{NW} = (0.206 \times 5,017) + (0.542 \times 750) - (192.6 \times 3) = 862 \text{ lc/h} \]

**Total Lane-Changing Rate**

\[ LC_{ALL} = LC_W + LC_{NW} = 961 + 862 = 1,823 \text{ lc/h} \]

**Step 7: Determine Average Speeds of Weaving and Nonweaving Vehicles**

The average speeds of weaving and nonweaving vehicles are computed from Equation 12-18 through Equation 12-20:

\[ W = 0.226\left( \frac{LC_{ALL}}{L_s} \right)^{0.789} = 0.226\left( \frac{1,823}{750} \right)^{0.789} = 0.456 \]

Then

\[ S_W = 15 + \left( \frac{FFS - 15}{1 + W} \right) = 15 + \left( \frac{60 - 15}{1 + 0.456} \right) = 45.9 \text{ mi/h} \]
and
\[ S_{NW} = FFS - (0.0072LC_{MN}) - \left( 0.0048 \frac{v}{N} \right) \]
\[ S_{NW} = 75 - (0.0072 \times 782) - \left( 0.0048 \times \frac{5408}{3} \right) = 45.7 \text{ mi/h} \]

Equation 12-21 is now used to compute the average speed of all vehicles in the segment:
\[ S = \frac{v_{NW} + v_{W}}{S_{NW}} + \frac{v_{W}}{S_{W}} = \frac{5017 + 391}{45.7} + \frac{391}{45.7} = 45.7 \text{ mi/h} \]

**Step 8: Determine LOS**

The average density in this two-sided weaving segment is estimated by using Equation 12-22:
\[ D = \frac{v}{N} = \left( \frac{5408}{3} \right) = 39.4 \text{ pc/mi/ln} \]

From Exhibit 12-10, this density is clearly in LOS E. It is not far from the 43 pc/h/ln that would likely cause a breakdown.

**Discussion**

This two-sided weaving segment operates at LOS E, not far from the LOS E/F boundary. The \( v/c \) ratio is 4,150/4,573 = 0.91. The major problem is that 300 veh/h crossing the freeway from ramp to ramp creates a great deal of turbulence in the traffic stream and limits capacity. Two-sided weaving segments do not operate well with such large numbers of ramp-to-ramp vehicles. If this were a basic freeway segment, the per lane flow rate of 5,408/3 = 1,803 pc/h/ln would not be considered excessive and would be well within a basic freeway segment's capacity of 2,300 pc/h/ln.

**EXAMPLE PROBLEM 4: DESIGN OF A MAJOR WEAVING SEGMENT FOR A DESIRED LOS**

**The Weaving Segment**

A weaving segment is to be designed between two major junctions in which two urban freeways join and then separate as shown in Exhibit 12-18. Entry and exit legs have the numbers of lanes shown. The maximum length of the weaving segment is 1,000 ft, based on the location of the junctions. The FFS of all entry and exit legs is 75 mi/h. All demands are shown as flow rates under equivalent ideal conditions.
passing lanes or multilane highways), calculate the directional demand flow rate of motorized traffic in the outside lane with Equation 15-24:

$$v_{OL} = \frac{V}{PHF \times N}$$

where

- $v_{OL}$ = directional demand flow rate in the outside lane (veh/h),
- $V$ = hourly directional volume (veh/h),
- $PHF$ = peak hour factor, and
- $N$ = number of directional lanes (=1 for two-lane highways).

**Step 3: Calculate the Effective Width**

The effective width of the outside through lane depends on both the actual width of the outside through lane and the shoulder width, since cyclists will be able to travel in the shoulder where one is provided. Moreover, striped shoulders of 4 ft or greater provide more security to cyclists by giving cyclists a dedicated place to ride outside of the motorized vehicle travelway. Thus, an 11-ft lane and adjacent 5-ft paved shoulder results in a larger effective width for cyclists than a 16-ft lane with no adjacent shoulder.

Parking occasionally exists along two-lane highways, particularly in developed areas (Class III highways) and near entrances to recreational areas (Class II and Class III highways) where a fee is charged for off-highway parking or where the off-highway parking is inadequate for the parking demand. On-highway parking reduces the effective width, because parked vehicles take up shoulder space and bicyclists leave some shy distance between themselves and the parked cars.

Equation 15-25 through Equation 15-29 are used to calculate the effective width, $W_e$, on the basis of the paved shoulder width, $W_s$, and the hourly directional volume per lane, $V$:

If $W_s$ is greater than or equal to 8 ft:

$$W_e = W_v + W_s - (\%OHP \times 10 \text{ ft})$$

If $W_s$ is greater than or equal to 4 ft and less than 8 ft:

$$W_e = W_v + W_s - 2 \times (\%OHP(2 \text{ ft} + W_s))$$

If $W_s$ is less than 4 ft:

$$W_e = W_v + (\%OHP(2 \text{ ft} + W_s))$$

with, if $V$ is greater than 160 veh/h/ln:

$$W_v = W_{OL} + W_s$$

Otherwise,

$$W_v = (W_{OL} + W_s)(2 - 0.005V)$$

where

$W_e$ = effective width as a function of traffic volume (ft).
Step 4: Calculate the Effective Speed Factor

The effect of motor vehicle speed on bicycle quality of service is primarily related to the differential between motor vehicle and bicycle travel speeds. For instance, a typical cyclist may travel in the range of 15 mi/h. An increase in motor vehicle speeds from 20 to 25 mi/h is more readily perceived than a speed increase from 60 to 65 mi/h, since the speed differential increases by 100% in the first instance compared with only 11% in the latter. Equation 15-30 shows the calculation of the effective speed factor that accounts for this diminishing effect.

\[
S_t = 1.1199 \ln(S_p - 20) + 0.8103
\]

where

\(S_t\) = effective speed factor, and

\(S_p\) = posted speed limit (mi/h).

Step 5: Determine the LOS

With the results of Steps 1–4, the bicycle LOS score can be calculated from Equation 15-31:

\[
BLOS = 0.507 \ln(v_{OL}) + 0.1999S_t(1 + 10.38HV)^2 + 7.066(1/P)^2 - 0.005(W_e)^2 + 0.057
\]

where

\(BLOS\) = bicycle level of service score;

\(v_{OL}\) = directional demand flow rate in the outside lane (veh/h);

\(HV\) = percentage of heavy vehicles (decimal); if \(V < 200\) veh/h, then \(HV\) should be limited to a maximum of 50%;

\(P\) = FHWA’s 5-point pavement surface condition rating; and

\(W_e\) = average effective width of the outside through lane (ft).

Finally, the BLOS score value is used in Exhibit 15-4 to determine the bicycle LOS for the segment.