Analysis of Weaving, Merging, and Diverging Movements
CIVL 4162/6162
Weaving, Diverging, Merging Segments

- **Weaving** - one movement must cross the path of another along a length of facility without the aid of signals or other traffic control devices
- **Merging** - two separate traffic streams join to form a single one
- **Diverging** - one traffic stream separates to form two separate traffic streams

Why do we consider these separately from BFS/Multilane Segments?
Figure 15.1  Weaving, Merging, and Diverging Movements Illustrated

(a) Weaving movements cross each others path.

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

(c) Diverging movements divide to form separate traffic streams.
## LOS for W/M/D Segments

**Table 15.1: Level-of-Service Criteria for Weaving, Merging, and Diverging Segments**

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Weaving Areas</th>
<th>Merge or Diverge Areas</th>
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### Table 15.1 Level-of-Service Criteria for Weaving, Merging, and Diverging Segments
Flows in a Weaving Segment and the Weaving Diagram
Weaving Configurations

(a) One-Sided Ramp-Weave

(b) One-Sided Major Weave

(c) Two-Sided Weaving Segment w/ Single-Lane Raps

(d) Two-Sided Weaving Segment w/ Three Lane Changes
Weaving Configuration Parameters

(a) A Five-Lane Ramp-Weave Section

(b) A Four-Lane Major Weave Section
(No Lane Balance)

(c) A Four-Lane Major Weave Section
(With Lane Balance)
Figure 15.2 Influence Areas for Merge, Diverge, and Weaving Segments (Source: Used with permission of Transportation Research Board, National Research Council, modified from Highway Capacity Manual, 2000, Exhibit 13-13, p. 13-21.)
Weaving Analysis - Input Requirements

- Existing roadway and traffic conditions are required, including:
  - Length and width of weaving area
  - Number of lanes
  - Type of configuration
  - Terrain/grade conditions
  - FFS
  - Hourly volumes
Step 1: Input Data
Specify geometry, weaving and nonweaving volumes, and the segment’s free-flow speed.

Step 2: Adjust Volume
Adjust demand volumes to reflect the peak hour factor, heavy-vehicle presence, and driver population (Equation 12-1).

Step 3: Determine Configuration Characteristics
Determine the lane-change characteristics that define the effects of configuration.

Step 4: Determine Maximum Weaving Length
Estimate the maximum length for weaving operations under the specified conditions (Equation 12-4).

Length less than the maximum

Length exceeds the maximum

Go to Chapter 13

Step 5: Determine Weaving Segment Capacity
Estimate the weaving segment capacity and the v/c ratio for the existing or projected demand flow rates (Equations 12-5 through 12-9).

\( \frac{v}{c} \leq 1.00 \)

\( \frac{v}{c} > 1.00 \)

Level of Service = LOS F

Step 6: Determine Lane-Changing Rates
Estimate the rate at which weaving and nonweaving vehicles make lane changes (Equations 12-10 through 12-16).

Step 7: Determine Average Speeds of Weaving and Nonweaving Vehicles
Estimate the average speed of weaving and nonweaving vehicles in the weaving segment; compute the space mean speed of all vehicles in the weaving segment (Equations 12-17 through 12-20).

Step 8: Determine LOS
Convert the space mean speed to the weaving segment density. Compare the results to the LOS criteria and assign the appropriate level of service (Equation 12-21 and Exhibit 12-10).
Symbol Definition

- $v_{FF}$: freeway-to-freeway demand flow rate in the weaving section (pc/h)
- $v_{RF}$: ramp-to-freeway demand flow rate in the weaving section (pc/h)
- $v_{FR}$: freeway-to-ramp demand flow rate in the weaving section (pc/h)
- $v_{RR}$: ramp-to-ramp demand flow rate in the weaving section (pc/h)
- $v_{W}$: weaving demand flow rate in the weaving section (pc/h): $v_{W} = v_{RF} + v_{FR}$
- $v_{NW}$: non-weaving demand flow rate in the weaving section (pc/h): $v_{NW} = v_{FF} + v_{RR}$
- $v$: total demand flow rate in the weaving section (pc/h), $v = v_{W} + v_{NW}$
- $VR$: volume ratio: $VR = v_{W}/v$
- $N$: number of lanes within the weaving section
- $N_{W}$: number of lanes from which a weaving maneuver may be made with one or no lane changes.
- $S_{W}$: average speed of weaving vehicles within the weaving section (mi/h)
- $S_{NW}$: average speed of non-weaving vehicles within the weaving section (mi/h)
- $S$: average speed of all vehicles within the weaving section (mi/h)
- FFS: free-flow speed of the weaving section (mi/h)
Figure 15.8 (continued) Weaving Variables Defined for One-Sided Weaving Segments (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-7, p. 12.)

Symbol Definition

D \quad \text{average density of all vehicles within the weaving section (pc/mi/ln)}
W \quad \text{weaving intensity factor}
L_S \quad \text{length of the weaving section (ft), based on short length definition.}
LC_{RF} \quad \text{minimum number of lane changes that must be made by a single weaving vehicle moving from the on-ramp to the facility.}
LC_{FR} \quad \text{minimum number of lane changes that must be made by a single weaving vehicle moving from the facility to the ramp.}
LC_{MIN} \quad \text{minimum rate of lane changing that must exist for all weaving vehicles to successfully complete their weaving maneuvers (lc/h) } \quad LC_{MIN} = (LC_{RF} \times v_{RF}) + (LC_{FR} \times v_{FR})
LC_W \quad \text{total rate of lane changing by weaving vehicles within the weaving section (lc/h)}
LC_{NW} \quad \text{total rate of lane changing by non-weaving vehicles within the weaving section (lc/h)}
LC_{ALL} \quad \text{total lane-changing rate of all vehicles within the weaving section (lc/h) } \quad LC_{ALL} = LC_W + LC_{NW}
Step-1: Input Data

- Ensure to write all the input data in one place before analyzing the weaving section
Step-2: Determining Flow Rate

\[ v_i = \frac{V_i}{PHF \times N \times f_{HV} \times f_p} \]

- \( v_i \): Demand flow rate, pc/h, under equivalent based conditions
- \( V_i \): Demand volume, veh/hr under prevailing conditions
- \( PHF \): Peak Hour Factor
- \( f_{HV} \): Heavy-vehicle adjustment factor
- \( f_p \): Driver-population adjustment factor
Figure 15.3 Flows in a Weaving Segment and the Weaving Diagram

- $v_{o1}$: larger outer flow
- $v_{o2}$: smaller outer flow
- $v_{w1}$: larger weaving flow
- $v_{w2}$: smaller weaving flow
- $v_w$: Total weaving = $v_{w1} + v_{w2}$
- $v_{nw}$: Total non-weaving = $v_{o1} + v_{o2}$
- $V$: Total Demand = $v_w + v_{nw}$
- $VR$: Volume Ratio = $v_w / V$
- $R$: Weaving Ratio = $v_{w2} / v_w$
Step-3: Determine Configuration Characteristics

- **One Sided Weaving**
  - $L_{CRF}$ - minimum # of lane changes that a ramp-to-facility weaving vehicle must make to successfully complete the ramp-to-facility movement.
  
  - $L_{CFR}$ - minimum # of lane changes that a facility-to-ramp weaving vehicle must make to successfully complete the facility-to-ramp movement.
  
  - $N_{WV}$ - number of lanes from which a weaving maneuver may be completed with one lane change, or no lane change.

$$L_{C_{MIN}} = (L_{C_{FR}}) + (L_{C_{RF}})$$
Step-3: Determine Configuration Characteristics

- **Two Sided Weaving**
  - \( L_{RR} \) - minimum number of lane changes required for ‘ramp-to-ramp’ movement.
  - \( N_{WV} = 0 \) (only vehicles moving ramp to ramp are considered to be weaving)

\[
LC_{MIN} = (LC_{RR} \times \frac{1}{RR})
\]

**Symbol Definition**

- \( v_W \) total weaving demand flow rate within the weaving section (pc/h) \( v_W = v_{RR} \)
- \( v_{NW} \) total non-weaving demand flow rate within the weaving section (pc/h) \( v_{NW} = v_{FR} + v_{RF} + v_{FF} \)
- \( LC_{RR} \) minimum number of lane changes that must be made by one ramp-to-ramp vehicle to complete a weaving maneuver.
- \( LC_{MIN} \) minimum rate of lane changing that must exist for all weaving vehicles to successfully complete their weaving maneuvers (lc/h) \( LC_{MIN} = (LC_{RR} \times v_{RR}) \)
Figure 15.8  Weaving Variables Defined for One-Sided Weaving Segments (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-7, p. 12.)
Figure 15.9  Weaving Variables Defined for Two-Sided Weaving Segments (Source: Roess, R., et al., Analysis of Freeway Weaving Sections, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelson and Associates, Brooklyn, NY, September 2007, Exhibit 24-8, p. 13.)
Step-4: Maximum Weaving Length

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

**Figure 15.6** Measuring the Length of a Weaving Segment (Source: Roess, R., et al., *Analysis of Freeway Weaving Sections*, Final Report, Draft Chapter for the HCM, National Cooperative Highway Research Program Project 3-75, Polytechnic University and Kittelsson and Associates, Brooklyn, NY, September 2007, Exhibit 24-2, p. 2.)
Step-5: Capacity of the Weaving Segment

- Based on Breakdown Density

Calculate \( C_{IWL} \) (cap per lane of weaving section under ideal conditions):

\[
c_{IWL} = c_{IFL} \left[ 438.2(1 + VR)^{1.6} \right] + [0.0765L_s] + [119.8N_{WV}]
\]

Convert \( C_{IWL} \) to total capacity for the weaving segment under prevailing conditions:

\[
c_{W1} = c_{IWL} \times N \times f_{HV} \times f_p
\]
## Capacity Values - $C_{IFL}$

### Table 15.2: Basic Facility Capacity Values ($c_{IFL}$) for Use in Equation 15-5

<table>
<thead>
<tr>
<th>Freeways</th>
<th>Multilane Highways and C–D Roadways</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFS (mi/h)</td>
<td>Capacity (pc/h/ln)</td>
</tr>
<tr>
<td>≥ 70</td>
<td>2,400</td>
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<tr>
<td>65</td>
<td>2,350</td>
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<tr>
<td>60</td>
<td>2,300</td>
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<tr>
<td>55</td>
<td>2,250</td>
</tr>
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</table>

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Step-5: Capacity of the Weaving Segment

• Based on Maximum Weaving Flow Rate

Calculate $C_{IW}$ (based on # weaving lanes):

$$c_{IW} = \frac{2,400}{VR} \text{ for } N_{WL} = 2 \text{ lanes}$$

$$c_{IW} = \frac{3,500}{VR} \text{ for } N_{WL} = 3 \text{ lanes}$$

Convert $C_{IW}$ to total capacity for the weaving segment under prevailing conditions:

$$c_{w2} = c_{IW} \times f_{HV} \times f_{p}$$

• Final Capacity and v/C ratio

$$c_{w} = \text{Min} \ (c_{w1}, c_{w2})$$

$$\frac{v}{c} = \frac{vf_{HV}f_{p}}{c_{w}}$$

If $v/c > 1.0$, LOS = F, and STOP
Step-6: Total Lane Changing

- **For Weaving Vehicles**
  
  Total lane changing rate for weaving vehicles

  \[
  LC_W = LC_{MIN} + 0.39[(L_S - 300)^{0.5}N^2(1 + ID)^{0.8}]
  \]

- **For Non-Weaving Vehicles**

  \[
  LC_{NW1} = 0.206v_{NW} + 0.542L_S - (192.6N)
  \]

  \[
  LC_{NW2} = 2135 + 0.223(v_{NW} - 2000)
  \]
Step-6: Total Lane Changing

- **Lane Changing Index**
  Total lane changing rate for weaving vehicles

  \[ I_{NW} = \frac{L_{SID} v_{NW}}{10,000} \]

- **\( I_{NW} \) Ranges**
  - If \( I_{NW} < 1,300 \)
    - \( LC_{NW} = LC_{NW1} \)
  - If \( I_{NW} > 1,950 \)
    - \( LC_{NW} = LC_{NW2} \)
  - If \( 1300 < I_{NW} < 1,950 \)

  \[
  LC_{NW} = LC_{NW1} + (LC_{NW2} - LC_{NW1}) \left( \frac{I_{NW} - 1300}{650} \right)
  \]

- **Total Lane Changing**

  \[
  LC_{ALL} = LC_{W} + LC_{NW}
  \]
Step-7: Average Speed

- **Weaving Vehicles**

\[
S_W = S_{MIN} + \left( \frac{S_{MAX} - S_{MIN}}{1 + W} \right)
\]

\[
W = 0.226 \left( \frac{LC_{ALL}}{L_S} \right)^{0.789}
\]

\[
S_W = 15 + \left( \frac{FFS - 15}{1 + W} \right)
\]

- **Non-Weaving Vehicles**

\[
S_{NW} = FFS - (0.0072LC_{MIN}) + (0.0048v/N)
\]

- **Average Speed**

\[
S = \frac{v_W + v_{NW}}{S_W + S_{NW}}
\]
Step-8: Determine Density

\[ D = \left( \frac{V}{N} \right) \frac{1}{S} \]

where \( D \) is the average density for all vehicles in the weaving segment (pc/mi/ln).
## LOS for W/M/D Segments

### Table 15.1: Level-of-Service Criteria for Weaving, Merging, and Diverging Segments

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**Table 15.1 Level-of-Service Criteria for Weaving, Merging, and Diverging Segments**
Example

What are the level of service and capacity of the weaving segment on the urban freeway shown below? ID = 0.8 int./mi -10 percent trucks; PHF=0.91; level terrain; fp=1, FFS=65 mph

$L_s = 1,500$ ft

$\nu_{FF} = 1,815$ veh/h
$\nu_{RF} = 1,037$ veh/h
$\nu_{FR} = 692$ veh/h
$\nu_{RR} = 1,297$ veh/h
$\nu = 4,841$ veh/h
Example (We solved this in class)

- A typical ramp weave section on a six lane freeway (three lanes in each direction). Determine LOS under prevailing conditions.