JCE 4600
Basic Freeway Segments
HCM Applications

- What is a Freeway?
  - divided highway with full control of access
  - two or more lanes for the exclusive use of traffic in each direction
  - no signalized or stop-controlled at-grade intersections
  - direct access to and from adjacent property is not permitted
  - access to and from the freeway is limited to ramp locations
  - opposing directions of flow are continuously separated by a raised barrier, an at-grade median, or a continuous raised median

- Areas of Freeway Analysis
  - Freeway Facilities – Chapter 10
  - Basic Freeway Segments - Chapter 11
  - Freeway Weaving - Chapter 12
  - Ramps and Ramp Junctions - Chapter 13
  - Multi-lane Highways – Chapter 14
  - Two-lane Highways – Chapter 15
Basic Freeway Segments
FLOW CHARACTERISTICS

- **Under saturated flow**
  - unaffected by upstream or downstream conditions

- **Queue discharge flow**
  - traffic flow that has just passed through a bottleneck and is accelerating back to the FFS
  - relatively stable as long as the effects of another bottleneck downstream are not present
  - depending on horizontal and vertical alignments, queue discharge flow usually accelerates back to the FFS of the facility within 0.5 to 1 mi downstream from the bottleneck

- **Oversaturated flow**
  - traffic flow that is influenced by the effects of a downstream bottleneck
  - traffic flow can vary over a broad range of flows and speeds depending on the severity of the bottleneck
  - queues may extend several thousand feet upstream from the bottleneck
Sample Speed-Flow Curve: Basic Freeway Segments

- Undersaturated Flow
- Queue Discharge Flow
- Oversaturated Flow

Note: I-405, Los Angeles, Calif.
Source: California Department of Transportation, 2008.
HCM Speed-Flow Curve

Break Points
FFS = 75 mph; 1000 pc/h/ln
FFS = 70 mph; 1200 pc/h/ln
FFS = 65 mph; 1400 pc/h/ln
FFS = 60 mph; 1600 pc/h/ln
FFS = 55 mph; 1800 pc/h/ln
Calculation Procedures

1. **Step 1: Input Data**
   - Geometric data
   - Demand volume
   - Measured FFS (if available)

2. **Step 2: Compute FFS**
   - Lane width adjustment
   - Lateral clearance adjustment
   - Use Equation 11-1

3. **Step 3: Select FFS Curve**

4. **Step 4: Adjust Demand Volume**
   - Peak hour factor
   - Number of lanes (one direction)
   - Heavy vehicle adjustment
   - Driver population adjustment
   - Use Equation 11-2
   - Compare adjusted demand flow rate to base capacity

5. **LOS = F**
   - Go to Chapter 10, Freeway Facilities

6. **Step 5: Estimate Speed and Density**
   - Exhibit 11-3 or Exhibit 11-2
   - Equation 11-4

7. **Step 6: Determine LOS (A-E)**
   - Exhibit 11-5
Base (Optimal) Conditions

- 12 ft lane widths
- 6 ft right-shoulder lateral clearance
- 2 ft median lateral clearance
- passenger cars only
- 2 mi or greater interchange spacing
- Level terrain (2 percent maximum grades)
- regular user driver population
Calculation of Free Flow Speed

\[ FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84} \]

where

- \( FFS \) = FFS of basic freeway segment (mi/h),
- \( f_{LW} \) = adjustment for lane width (mi/h),
- \( f_{LC} \) = adjustment for right-side lateral clearance (mi/h), and
- \( TRD \) = total ramp density (ramps/mi).
Lane Width and Lateral Clearance

- Standard Freeway Lane Width = 12 feet
- Standard Freeway Shoulder Width = 10 feet
Calculation of Free Flow Speed

\[ FFS = 75.4 - f_{LW} - f_{LC} - 3.22 TRD^{0.84} \]

where

- \( FFS \) = FFS of basic freeway segment (mi/h),
- \( f_{LW} \) = adjustment for lane width (mi/h),
- \( f_{LC} \) = adjustment for right-side lateral clearance (mi/h), and
- \( TRD \) = total ramp density (ramps/mi).

<table>
<thead>
<tr>
<th>Lane Width (ft)</th>
<th>Reduction in Free-Flow Speed, ( f_{LW} ) (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>6.6</td>
</tr>
</tbody>
</table>
Calculation of Free Flow Speed

\[ FFS = 75.4 - f_{LW} - f_{LC} - 3.22 \cdot TRD^{0.84} \]

where

- \( FFS \) = FFS of basic freeway segment (mi/h),
- \( f_{LW} \) = adjustment for lane width (mi/h),
- \( f_{LC} \) = adjustment for right-side lateral clearance (mi/h), and
- \( TRD \) = total ramp density (ramps/mi).

### EXHIBIT 11-9 ADJUSTMENTS FOR RIGHT-SHOULDER LATERAL CLEARANCE

<table>
<thead>
<tr>
<th>Right-Shoulder Lateral Clearance (ft)</th>
<th>Reducing in Free-Flow Speed, ( f_{LC} ) (mi/h)</th>
<th>Lanes in One Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>( \geq 6 )</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td>1</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>0</td>
<td>3.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Interchange Density

- Freeway segments with closely spaced interchanges, such as those in heavily developed urban areas, operate at lower FFS than suburban or rural freeways where interchanges are less frequent.
- The merging and weaving associated with interchanges affect the speed of traffic. Speeds generally decrease with increasing frequency of interchanges.
- The ideal average interchange spacing over a reasonably long section of freeway is 2 mi or greater.
- The minimum average interchange spacing considered possible over a substantial length of freeway is 0.5 mi.
- FHWA usually requires a minimum 1 mi spacing between interchanges in urban areas.
- Examples
Interchange Density

\[ FFS = 75.4 - f_{LW} - f_{LC} - 3.22 TRD^{0.84} \]

where

- \( FFS \) = FFS of basic freeway segment (mi/h),
- \( f_{LW} \) = adjustment for lane width (mi/h),
- \( f_{LC} \) = adjustment for right-side lateral clearance (mi/h), and
- \( TRD \) = total ramp density (ramps/mi).

- Calculation: Number of ramps (on and off) 3 miles upstream and 3 miles downstream of the midpoint of the freeway segment/divided by 6 miles
Pick Free-flow Speed Curve

- Round to nearest 5 mph
Free Flow Speed Example

- 4 Lanes
- 11’ Lanes
- 2’ Right Shoulders
- 8 Ramps in 6 Miles
Calculation of Flow Rate

\[ v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \]

where

- \( v_p \) = 15-min passenger-car equivalent flow rate (pc/h/ln),
- \( V \) = hourly volume (veh/h),
- \( PHF \) = peak-hour factor,
- \( N \) = number of lanes,
- \( f_{HV} \) = heavy-vehicle adjustment factor, and
- \( f_p \) = driver population factor.
EXHIBIT 8-10. RELATIONSHIP BETWEEN SHORT-TERM AND HOURLY FLOWS

Source: Minnesota Department of Transportation.
Peak Hour Factor (PHF)

- Typically, facilities are designed for peak 15 minute flow interval
- 15 minute flows are accounted for through the Peak Hour Factor (PHF)
- Definition:

\[
\text{Hourly Volume} = \frac{\text{Peak 15 Minute Volume} \times 4}{\text{Peak 15 Minute Volume}}
\]

- Typically range from 0.75-0.98
- Example Problem
Heavy Vehicles

- Heavy Vehicles induce frequent gaps of excessive length both in front of and behind themselves.
- The speed of vehicles in adjacent lanes and their spacing may be affected by these generally slower-moving large vehicles.
- Physical space taken up by a large vehicle is typically two to three times greater in terms of length than that taken up by a typical passenger car.
Calculation of Flow Rate

\[
V_p = \frac{V}{PHF \times N \times f_{HV} \times f_p}
\]

where

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

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

where

- \( E_T, E_R \) = passenger-car equivalents for trucks/buses and recreational vehicles (RVs) in the traffic stream, respectively;
- \( P_T, P_R \) = proportion of trucks/buses and RVs in the traffic stream, respectively; and
- \( f_{HV} \) = heavy-vehicle adjustment factor.
Calculation of Heavy Vehicle Factor

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

where
- \( E_T, E_R \) = passenger-car equivalents for trucks/buses and recreational vehicles (RVs) in the traffic stream, respectively;
- \( P_T, P_R \) = proportion of trucks/buses and RVs in the traffic stream, respectively;
- \( f_{HV} \) = heavy-vehicle adjustment factor.
Upgrades

- **Extended Segments**
  - Less than or equal to 2%
  - Less than 0.25 miles
  - Between 2% and 3% and less than 0.5 miles

- **Specific Grades**
  - Greater than 3%
  - Longer than 0.25% miles
  - Between 2% and 3% and longer than 0.5 miles
Downgrades

- RV – always level terrain \((Er = 1.2)\)
- Trucks/Busses – Only apply where trucks must use low gears (engine brakes)
  - Grades greater than 4%
Calculation of Heavy Vehicle Factor

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

where:
- \( E_T, E_R \) = passenger-car equivalents for trucks/buses and recreational vehicles (RVs) in the traffic stream, respectively;
- \( P_T, P_R \) = proportion of trucks/buses and RVs in the traffic stream, respectively; and
- \( f_{HV} \) = heavy-vehicle adjustment factor.

<table>
<thead>
<tr>
<th>EXHIBIT 11-10 PASSENGER-CAR EQUIVALENTS ON EXTENDED FREeway SEgments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>( E_T ) (trucks and buses)</td>
</tr>
<tr>
<td>( E_R ) (RVs)</td>
</tr>
</tbody>
</table>

Level Terrain - heavy vehicles maintain the same speed as passenger cars
Rolling Terrain - heavy vehicles reduce speeds below passenger cars
Mountainous Terrain - heavy vehicles operate at crawl speeds
### Calculation of Flow Rate

#### Exhibit 11-11: Passenger-Car Equivalents for Trucks and Buses on Upgrades

<table>
<thead>
<tr>
<th>Upgrade (%)</th>
<th>Length (mi)</th>
<th>$E_t$</th>
<th>Percentage of Trucks and Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>&lt; 2</td>
<td>All</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>≥ 2–3</td>
<td>0.00–0.25</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.25–0.50</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.50–0.75</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.75–1.00</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.00–1.50</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.50</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>&gt; 3–4</td>
<td>0.00–0.25</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.25–0.50</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.50–0.75</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.75–1.00</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.00–1.50</td>
<td>3.5</td>
<td>3.5</td>
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<tr>
<td></td>
<td>&gt; 1.50</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>&gt; 4–5</td>
<td>0.00–0.25</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.25–0.50</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.50–0.75</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.75–1.00</td>
<td>4.0</td>
<td>3.5</td>
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<tr>
<td></td>
<td>&gt; 1.00</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>&gt; 5–6</td>
<td>0.00–0.25</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.25–0.30</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.30–0.50</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.50–0.75</td>
<td>5.0</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.75–1.00</td>
<td>5.5</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.00</td>
<td>6.0</td>
<td>5.0</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>0.00–0.25</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.25–0.30</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.30–0.50</td>
<td>5.0</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.50–0.75</td>
<td>5.5</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.75–1.00</td>
<td>6.0</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.00</td>
<td>7.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Driver Population

Three Primary Driver Tasks
- Control involves the driver’s interaction with the vehicle in terms of speed and direction (accelerating, braking, and steering)
- Guidance refers to maintaining a safe path and keeping the vehicle in the proper lane.
- Navigation means planning and executing a trip

Studies have noted that non-commuter driver populations do not display the same characteristics as regular commuters. For recreational traffic, capacities have been observed to be as much as 10 to 15 percent lower than for commuter traffic traveling on the same segment, but FFS does not appear to be similarly affected.
Calculation of Flow Rate

\[ v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p} \]

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

- \( f_p \) values range from 0.85 to 1.00
- 1.00 reflects commuter traffic
- comparative field studies of commuter and recreational traffic flow and speeds are recommended to determine lower values
Flow Rate Example

- **Calculation Inputs**
  - 4 Lanes; 11’ Lanes; 2’ Right Shoulders; 8 Ramps in 6 Miles
  - 5200 vph
  - PHF = 0.95
  - 12% Trucks
  - 0.2% RVs
  - Level Terrain
  - Urban / Local Users

- What if we were on a 6% uphill grade for 0.55 miles?
Look up LOS / Calculate Density

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density Range (pc/mi/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0–11</td>
</tr>
<tr>
<td>B</td>
<td>&gt; 11–18</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 18–26</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 26–35</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 35–45</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 45</td>
</tr>
</tbody>
</table>
Freeway LOS A-D

- **LOS A**
  - Free-flow operations with free-flow speeds
  - Vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream
  - The effects of incidents or point breakdowns are easily absorbed

- **LOS B**
  - Reasonably free flow and free-flow speeds are maintained
  - The ability to maneuver within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high
  - The effects of minor incidents and point breakdowns are still easily absorbed

- **LOS C**
  - Flow with speeds at or near the free-flow speeds of the freeway
  - Freedom to maneuver within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver.
  - Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage

- **LOS D**
  - Speeds begin to decline slightly and density begins to increase somewhat more quickly
  - Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels.
  - Even minor incidents can be expected to create queuing, because the traffic stream has little space to absorb disruptions.
Freeway LOS E

- Operation at capacity are volatile
- Virtually no usable gaps in the traffic stream
- Vehicles are closely spaced, leaving little room to maneuver within the traffic stream at speeds that still exceed 49 mi/h.
- Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can establish a disruption wave that propagates throughout the upstream traffic flow
- At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing
- Maneuverability within the traffic stream is extremely limited, and the level of physical and psychological comfort afforded the driver is poor
Conditions generally exist within queues forming behind breakdown points (Breakdown occurs when the v/c ratio exceeds 1.0)
- Traffic incidents and other “non recurring” congestion (What are typical traffic incidents?)
- Points of “recurring” congestion, such as merge or weaving segments and lane drops

Operations immediately downstream of the breakdown point are generally at or near capacity

Operations improve (assuming that there are no additional downstream bottlenecks) as discharging vehicles move away from the bottleneck

LOS F is used to describe conditions at the point of the breakdown or bottleneck and the queue discharge flow that occurs at speeds lower than the lowest speed for LOS E, as well as the operations within the queue that forms upstream

Whenever LOS F conditions exist, they have the potential to extend upstream for significant distances
Basic Freeway Segment Methodology Limitations

- HOV, truck, and climbing lanes
- Extended bridge and tunnel segments
- Toll plaza segments
- FFS below 55 mph or above 75 mph
- v/c greater than 1
- Downstream blockages (Over Saturation)
- Posted speed limits / Police enforcement
- ITS
  - Advanced traveler information systems (ATIS)
  - Ramp metering
Relation of Basic Freeway Flow Theory to HCM Procedures

- What is similar?
- What is different?
- Why are these different?
- Do they seem to fit together?
Problem 1.

Given an existing six-lane freeway in a growing urban area. What is the current LOS during the peak hour? What LOS will occur in 3 years? When should a fourth lane be added in each direction to avoid an excess of demand over capacity?

√ 4,800 veh/h (one direction, existing)
√ 0.80 PHF
√ Lane widths = 12 feet
√ Right Shoulder Clearance = 4 feet
√ 6 lanes; (3 in each direction)
√ Commuter traffic
√ 2.5% grade for 1 mile
√ 12 percent trucks; .5 percent RVs
√ 5,200 veh/h (one direction, in 3 years)
√ 2 ramps downstream of the midpoint and 4 ramps upstream of the midpoint
√ Beyond 3 years, traffic grows at 2 percent
√ Percent trucks, RV, and PHF remains constant over time
√ State assumptions clearly for information not provided