Traffic engineering
Highway Capacity Manual
2010

Uninterrupted traffic flow

Dr. Drago Sever

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  - Dimensioning process
- HCM 2010 - general
- Uninterrupted traffic flow
  - Freeway (basic segment, ramps, weaving area)
  - Highway, rural roads
- Examples (HCS 2010)
About me

Dr. Drago Sever, univ.dipl.ing. of civil eng.

Associated professor from the fields
Trans. engineering. and Trans. technology

Director of Institute of transp. sciences
Head of the Chair of trans. technology and organization

Subjects:
- Dynamics of traffic flow
- Theory of traffic flow
- Traffic technique I and II
- Transportation technology
- Transportation organization and other.

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Introduction

Transportation - Traffic engineering

Transportation (engineering) is the application of technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transportation in order to provide for the safe, efficient, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods.

Transportation engineering is a major component of the logistics, civil engineering and mechanical engineering disciplines.
Transportation - Traffic engineering

- Transportation engineering, as practiced by civil engineers, primarily involves planning, design, construction, maintenance, and operation of transportation facilities.

- The design aspects of TE include the sizing of transportation facilities (how many lanes or how much capacity the facility has), determining the materials and thickness used in pavement designing the geometry (vertical and horizontal alignment) of the roadway (or track).

- Operations and management involve traffic engineering, so that vehicles move smoothly on the road or track.

Criteria to be meet:

- Land space criteria
- Environmental protected
- Economic criteria
- Urbanistical and architecture requirements
- Legal requirements
- Traffic safety
- Traffic volumes
- and many other

Define relevant operational stage of traffic facility based on existing (planned) traffic volumes and existing (planned) geometry (in many variants).
Maximal hourly traffic volume in average day
- based on 16 hours traffic counts in average day (normally in cities where no automatic counters exist);
- based on AADT (K is defined on 300.st peak hour volume)

\[ v_{eval} = K \cdot \text{AADT} \]

Morning peak hour volume, afternoon peak hour volume etc.

Existing traffic volumes, planned traffic volumes, planned traffic volume on the end of planning cycle (norm. 20 years for infrastructure facilities)

\[ v_{eval,PC} = q_{eval,\text{today}} \cdot (1 + r)^{PC} \]

\( r \) – growth rate

Evaluation of traffic volume (veh/h)

Introduction

Unique signing system of the state roads
- each road -> road segment -> counting place
- traffic volumes (public data)

[Map and Chart]

www.dc.gov.si/promet
(AADT, r, traffic structure)
**Dimensioning process**

\[ X_i = \frac{v_{eval,i}}{C} \]

<table>
<thead>
<tr>
<th>Var. Time</th>
<th>Existing</th>
<th>Var. 1</th>
<th>Var. 2</th>
<th>…</th>
<th>Var. n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>( x_0 \geq 1 ) ( x_0 &lt; 1 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selected time frame</td>
<td>When ( X = 0 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>( x_{PC} \geq 1 )</td>
<td>( x_{PC} \geq 1 )</td>
<td>( x_{PC} &lt; 1 )</td>
<td>Possible solution</td>
<td>( x_{PC} &lt; 1 )</td>
</tr>
</tbody>
</table>

No additional measurements are needed

---

**Procedures to compute Capacity**

Many procedures exist:
- Depends on legislation in different countries
- Depends on different authors (Brillon, Akcelic, …)
- Depend on different software (Sidra, Vissum, HCS, …)
- General accepted procedure (HCM)
**LOS**

- Level of Service (LOS) is a way of characterizing the performance of portions of the transportation system
- Traditionally, LOS has only been evaluated for automobiles
- Different ways of calculating LOS exist, but the Highway Capacity Manual (HCM) is most commonly accepted

**LOS in HCM**

- An indication of quality of service
- LOS “A” through “F”
- F sometimes over capacity, sometimes just miserable conditions
- Based on service measures of effectiveness (MOEs). MOE’s vary by chapter
- LOS Score for unmotorised traffic (bikes and pedestrians)
- MMLOS is a combination of LOF for all modes
MOEs in HCM

<table>
<thead>
<tr>
<th>System Element</th>
<th>Auto</th>
<th>Service Measures</th>
<th>Pedestrian</th>
<th>Bike</th>
<th>Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway Facility</td>
<td>Density</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Basic Freeway Segment</td>
<td>Density</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Freeway Weaving Segment</td>
<td>Density</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ramp Junction</td>
<td>Density</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Density</td>
<td>--</td>
<td>Index(^a)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>% time following, Speed</td>
<td>--</td>
<td>Index(^b)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Urban Street Facility</td>
<td>Speed</td>
<td>Index(^c)</td>
<td>Index(^d)</td>
<td>Index(^e)</td>
<td>--</td>
</tr>
<tr>
<td>Urban Street Segment</td>
<td>Speed</td>
<td>Index(^b)</td>
<td>Index(^c)</td>
<td>Index(^e)</td>
<td>--</td>
</tr>
<tr>
<td>Signalized Intersection</td>
<td>Delay</td>
<td>Index</td>
<td>Index (^b)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Two-Way Stop</td>
<td>Delay</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>All-Way Stop</td>
<td>Delay</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Roundabout</td>
<td>Delay</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Interchange Ramp Terminal</td>
<td>Delay</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Off-Street Ped/Bike Facility</td>
<td>--</td>
<td>Space, Events(^c)</td>
<td>Index(^c)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes:
(a) See Exhibit 8-1 for the index components.
(b) Not directly calculated; indirectly accounted for by the street crossing delay component of the pedestrian LOS measures for urban street segments.
(c) Events are situations where pedestrians meet bicyclists.

Types of analysis in HCM

- **Operational:** Analyst applies methods directly and supplies all, or nearly all, of the required model inputs from actual or forecasted values. The analyses provide the highest level of accuracy but, also require the most-detailed data collection.

- **Design:** Analyst applies methods to establish the detailed physical features that will allow a new or modified roadway to operate at a desired LOS. Design projects are usually targeted for mid- to long-term implementation. Not all the physical features are reflected in the HCM models.

- **Planning:** In preliminary studies analyst applies methods using default values for some to nearly all of the model inputs. The results are less accurate than in an operations analysis, but the use of default values reduces the amount of data collection and the time required to perform an analysis.
Overview on HCM 2010

- Multimodal approach
- Automotive mode (LOS)
- Pedestrian, bikes (LOS Score)
- Transit mode (LOS)
- Some new methods for different facilities
- All methods are detailed defined in many way (with examples, working sheets)
- Implemented in HCS 2010 (McTrans)
- Only in US Customary unit (metric version is on preparation)
Organization of HCM

Volume 1 – Concepts

Volume 2 – Uninterrupted Flow Facilities
Freeways, rural highways, rural roads

Volume 3 – Interrupted Flow Facilities
Urban arterials, intersections, roundabouts
Signals at freeway interchanges,
Bicycle and Pedestrian paths

Volume 4 – Supplemental Materials (Website)
http://www.hcm.trb.org

Volume 2: Uninterrupted flow

Freeways:
- Chapter 10: Freeway facilities
- Chapter 11: Basic freeway segments
- Chapter 12: Freeway weaving segments
- Chapter 13: Freeway merge and diverge segments

Multilane highways
- Chapter 14: Multilane highways

Two-lane highways
- Chapter 15: Two-lane highways
Basic definitions

- **Freeway** is a separated highway with full control of access and two or more lanes in each direction dedicated to the exclusive use of traffic.

- **Ramp (freeway merge and diverge segment)** in which two or more traffic streams combine to form a single stream (merge) or single stream divides to form two or more streams (diverge).

- **Weaving segment** in which two or more traffic streams travelled in the same direction (merge in diverge) without traffic signs. Two ramps are connected with by a continuous auxiliary lane.

Segments and influence areas

- **Merge Influence Area**
- **Diverge Influence Area**
- **Weaving Influence Area**

1 ft = 0.3048 m; 500 ft = 152.4 m
Major limitations:

- Operation of oversaturated freeway segment (but not necessary oversaturated facility)
- Multiple overlapping breakdowns or bottlenecks
- Conditions where off-ramp queues extend back onto freeway or affect the behavior of exiting vehicle
- Operation of separated high occupancy vehicle (HOV) facilities
- Toll plazas operation
- Operation the segment where free flow speed (FFS) is below 90 km/h or above 120 km/h
- Ramp metering effect
Basic segment is defined as a segment outside influence of merging, diverging or weaving. Basic segment have a same road and traffic characteristics.

**Base conditions:**

- Include good weather, good visibility, no incident or accident, no work zone activities and no pavement deterioration serious enough to affect operations
- No heavy vehicle in the traffic stream
- Minimum 12 ft (3,658 m) lane width and 6 ft (1,829 m) right-side clearance
- A driver population composed primarily of regular users who are familiar with the facility

**Flow characteristics under base conditions**

*Note: I-405, Los Angeles, Calif.*
16.4.2015

HCM 2010 Freeways – Basic segment

**Speed – flow curves under base conditions**

- NEW
- $1 \text{ mi/h} = 1,609334 \text{ km/h}$

![Graph showing speed-flow curves under base conditions.]

**Capacity under base conditions**

- Mainly depends on Free flow speed and varies between 2400 (120 km/h) and 2250 pc/h/line (90 km/h)
- More lines in one direction $\Rightarrow$ $x$ number of lanes
- Reached by density $D = 28$ pc/km/line (45 pc/mi/line)

![Graph showing capacity under base conditions.]

Quality of traffic operations is described by level of service (LOS), where MOE is density of traffic flow.
HCM 2010 Freeways – Basic segment - Methodology

1. Input data
- geometric data, demand volume, measured FFS

2. Compute FFS
- Lane width adjustment
- Lateral clearance adjustment

3. Select FFS curve

4. Adjust demand flow
- Peak hour factor
- Heavy vehicle adjustment
- Driver population adj.

5. Estimate speed and density

6. Determine LOS (A – E)

Measured FFS is not available

Demand flow > capacity

LOS = F

Measured FFS is available

HCM 2010 Freeways – Basic segment

2. Compute FFS

\[
FFS = 75.4 - f_{LW} - f_{LC} - 3.22 \times TRD^{0.84} \quad (\text{mi/h})
\]

<table>
<thead>
<tr>
<th>Average Lane Width (ft)</th>
<th>Reduction in FFS, ( f_w ) (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.12</td>
<td>0.0</td>
</tr>
<tr>
<td>2.11–12</td>
<td>1.0</td>
</tr>
<tr>
<td>2.00–11</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Total ramp density 3 mi left and right from analyzing cross section

Right-Side Lateral Clearance (ft) | Lanes in One Direction |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.6 0.4 0.2 0.1</td>
</tr>
<tr>
<td>3</td>
<td>1.2 0.8 0.4 0.2</td>
</tr>
<tr>
<td>2</td>
<td>1.8 1.2 0.6 0.3</td>
</tr>
<tr>
<td>1</td>
<td>2.4 1.6 0.6 0.4</td>
</tr>
<tr>
<td>0</td>
<td>3.0 2.0 1.0 0.5</td>
</tr>
</tbody>
</table>

| 3.5                               | 3.6 3.4 1.2 0.6        |
5. Estimate speed and density
6. Determine LOS  only valid when v/C <= 1

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density (pc/mi/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤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>Demand exceeds capacity &gt;45</td>
</tr>
</tbody>
</table>

\[ D = \frac{v}{S} \text{ (pc/mi/lane)} \]
weaving / nonweaving movements

Geometry characteristics:
- Length
- Width
- Configuration

Require special attention when driving through

Length and width

1 ft = 0.3048 m

Ls (ft) - short length, distance between the end points of any barrier marking that prohibit lane changing
Lb (ft) - base length, distance between points in the respective gore area where the left edge of the ramp and right edge of freeway meet.

On average Ls=0.77 Lb, exceptionally Ls=Lb
Influence are: 500 ft left and right on the freeway

Width depend on the number of lanes in weaving area cross section and configuration.
Configuration of weaving segments

It is refers to way that entry and exit lanes are linked. The configuration determine how many lanes changes a weaving driver must make to complete the weaving maneuver successfully.

Types of configuration: one-sided and two-sided.

Configuration parameters:
- \( L_{Crf} \) – min. number of lane changes that ramp to freeway weaving vehicle must make to complete maneuver successfully,
- \( L_{Cfr} \) – min. number of lane changes that freeway to ramp weaving vehicle must make to complete maneuver successfully,
- \( N_{wl} \) – number of lanes which a weaving maneuver may be completed with one lane change or no lane change

One-sided and two-sided segments

No weaving maneuver require more than two lane changes to be completed successfully

At least one weaving maneuver requires three or more lane changes to be complete successfully
### Configuration parameters

- **LCrf = 1**  
- **LCfr = 1**  
- **Nwl = 2**

- **LCrf = 1**  
- **LCfr = 0**  
- **Nwl = 2**

- **LCrf = 0**  
- **LCfr = 1**  
- **Nwl = 3**

### Methodology

1. **Input data**  
   Geometry, volume, speed

2. **Adjust volume**  
   PHF, fHV, fDP

3. **Determine configuration characteristics**

4. **Determine maximum weaving length**
   - Length exceeds the maximum
   - **v/C > 1**

5. **Determine capacity**  
   Ch. 13

6. **Determine lane changing rate**  
   NU F

7. **Determine average speed of weaving and nonweaving vehicles**

8. **Determine LOS (A – E)**
3. Determine configuration char.

Determine minimum rate at which weaving vehicles must change lane to complete all weaving maneuvers successfully - LCmin:

- One-sided weaving segments:
  \[ LC_{MIN} = (LC_{RF} \times v_{RF}) + (LC_{FR} \times v_{FR}) \] (lc/h)  
  \[ Nwl = 2 \text{ ali } 3 \]

- Two-sided weaving segments:
  \[ LC_{MIN} = LC_{RR} \times v_{RR} \] (lc/h)  
  \[ Nwl = 0 \]

4. Determine max. weaving length

\[ L_{MAX} = \left[ 5,728 (1 + VR)^{1.5} \right] - \left[ 1,566 N_{wl} \right] \] (ft)

Volume ratio by one-sided segments:

\[ VR = \frac{v_{w}}{v} = \frac{v_{w}}{v_{w} + v_{wr}} = \frac{v_{RF}}{v_{RF} + v_{FR}} + \left( v_{RR} + v_{FR} \right) \]

If \( L_s \geq L_{max} \) – analyze merge and diverge junctions as separate segments by using methodology in Ch. 13.
5. Determine capacity

- By density: based on reaching a density of 43 pc/mi/ln

\[ c_{wL} = c_{HF} - \left[ 438.2(1 + VR)^{1.7} \right] + \left[ 0.0765L_3 \right] + \left[ 119.8N_{mL} \right] \]

- By demand flows: capacity is defined:

\[ c_w = c_{wL}N_{fHV} f_p \] (pc/h)

\[
\begin{align*}
  c_{HW} &= \frac{2.400}{VR} \quad \text{for } N_{wL} = 2 \text{ lanes} \\
  c_{HW} &= \frac{3.500}{VR} \quad \text{for } N_{wL} = 3 \text{ lanes}
\end{align*}
\]

**Smaller value of capacity is used.**

v/C ratio:

\[ v/C = \frac{vf_{HV} f_p}{c_w} \]

v/C > 1 => NU F

v/C < 1 => NU A · E

7. Determine average speed

8. Determine LOS

\[
S = \frac{v_w + v_{NW}}{\left( \frac{v_w}{S_w} + \frac{v_{NW}}{S_{NW}} \right)} \quad \text{(mi/h)}
\]

\[
D = \frac{v}{S} \quad \text{(pc/mi/ln)}
\]

<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</td>
<td>&gt;36</td>
</tr>
<tr>
<td>F</td>
<td>Demand exceeds capacity</td>
<td></td>
</tr>
</tbody>
</table>

Density (pc/mi/ln)
Freeway merge and diverge segments (Ch. 13)

Classification of ramps

- **Freeway junctions:**
  - Ramp-freeway junction – merge: on-ramp, diverge: off-ramp,
  - Merging two major facilities: main merge junction,
  - Diverge two major facilities: main diverge junction;
- Majority of ramps are right-hand ramp – join from the right, some are left-hand ramp;
- They may have one or two lanes. Before merging with freeway two lanes join into one acceleration on-ramp;
- Merge and diverge operations are affected by the size of freeway segment into one direction.
Ramp influence area

Also impact onto neighbors junctions.

Acceleration – deceleration lane
Criteria for define LOS

The criteria for defining LOS is average density of traffic flow at the ramp:

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density (pcv/mln)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤10</td>
<td>Unrestricted operations</td>
</tr>
<tr>
<td>B</td>
<td>&gt;10–20</td>
<td>Merging and diverging maneuvers noticeable to drivers</td>
</tr>
<tr>
<td>C</td>
<td>&gt;20–28</td>
<td>Influence area speeds begin to decline</td>
</tr>
<tr>
<td>D</td>
<td>&gt;28–35</td>
<td>Influence area turbulence becomes intrusive</td>
</tr>
<tr>
<td>E</td>
<td>&gt;35</td>
<td>Turbulence felt by virtually all drivers</td>
</tr>
<tr>
<td>F</td>
<td>Demand exceeds capacity</td>
<td>Ramp and freeway queues form</td>
</tr>
</tbody>
</table>

HCM 2010 Freeways – Ramps - Methodology

1. Input data
Geometry, FFS, demand flows, demand flow adjustments -> adjusted flow rates

2. Compute demand flow rate in Lane 1 and 2 immediately upstream of ramp

3. Compute capacity and compare with demand flow

Demand greater than capacity

NU F

4. Compute density and determine LOS

5. Estimate speed
2. Estimate v$_{12}$

On-ramps:

\[ v_{12} = v_F \times P_{FM} \text{ (pc/h)} \]

<table>
<thead>
<tr>
<th>No. of Freeway Lanes *</th>
<th>Model(s) for Determining $P_{FM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>$P_{FM} = 1.000$</td>
</tr>
<tr>
<td></td>
<td>$P_{FM} = 0.5775 + 0.000028 L_a$</td>
</tr>
<tr>
<td>6</td>
<td>$P_{FM} = 0.7289 - 0.0000135 (v_F + v_2) - 0.003296S_{12} + 0.000003L_{VP}$</td>
</tr>
<tr>
<td></td>
<td>$P_{FM} = 0.5847 + 0.2628 (v_F / L_{CON})$</td>
</tr>
<tr>
<td>8</td>
<td>For $v_F / S_8 \leq 72$: $P_{AM} = 0.2178 - 0.000125v_F + 0.0115 (L_a / S_{12})$</td>
</tr>
<tr>
<td></td>
<td>For $v_F / S_8 &gt; 72$: $P_{AM} = 0.2178 - 0.000125v_F$</td>
</tr>
</tbody>
</table>

Off-ramps:

\[ v_{12} = v_R + (v_F - v_R)P_{TD} \text{ (pc/h)} \]

<table>
<thead>
<tr>
<th>No. of Freeway Lanes *</th>
<th>Model(s) for Determining $P_{TD}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>$P_{TD} = 1.000$</td>
</tr>
<tr>
<td></td>
<td>$P_{TD} = 0.760 - 0.000025v_F - 0.030046v_2$</td>
</tr>
<tr>
<td>6</td>
<td>$P_{TD} = 0.717 - 0.000039v_F + 0.604(v_2 / L_{13})$</td>
</tr>
<tr>
<td></td>
<td>$P_{TD} = 0.616 - 0.000021v_F + 0.124(v_F / L_{CON})$</td>
</tr>
<tr>
<td>8</td>
<td>$P_{TD} = 0.436$</td>
</tr>
</tbody>
</table>
3. Estimate the capacity

<table>
<thead>
<tr>
<th>FFS (mi/h)</th>
<th>Capacity of Upstream/Downstream Freeway Segment (v)</th>
<th>Max. Desirable Flow Rate (v_{d,1})</th>
<th>Max. Desirable Flow Rate (v_{d,2})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Lanes in One Direction</td>
<td>Entering Merge Influence Area</td>
<td>Entering Diverge Influence Area</td>
</tr>
<tr>
<td>≥70</td>
<td>2</td>
<td>4,800 7,200</td>
<td>9,600 2,400</td>
</tr>
<tr>
<td>65</td>
<td>3</td>
<td>4,700 7,100</td>
<td>9,400 2,350</td>
</tr>
<tr>
<td>60</td>
<td>4</td>
<td>4,800 6,900</td>
<td>9,200 2,300</td>
</tr>
<tr>
<td>55</td>
<td>≥4</td>
<td>4,500 6,750</td>
<td>9,000 2,250</td>
</tr>
</tbody>
</table>

Notes: a. Demand in excess of these capacities results in LOS F.

4. Estimate density and LOS

On ramps:

\[ D_R = 5.475 + 0.00734v_R + 0.0078v_{12} - 0.00627L_A \]  (pc/mi/ln)

Off ramps:

\[ D_R = 4.252 + 0.0086v_{12} - 0.009L_D \]  (pc/mi/ln)

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density (pc/mi/ln)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤10</td>
<td>Unrestricted operations</td>
</tr>
<tr>
<td>B</td>
<td>&gt;10 - 20</td>
<td>Merging and diverging maneuvers noticeable to drivers</td>
</tr>
<tr>
<td>C</td>
<td>&gt;20 - 28</td>
<td>Influence area speeds begin to decline</td>
</tr>
<tr>
<td>D</td>
<td>&gt;28 - 35</td>
<td>Influence area turbulence becomes intrusive</td>
</tr>
<tr>
<td>E</td>
<td>&gt;35</td>
<td>Turbulence felt by virtually all drivers</td>
</tr>
<tr>
<td>F</td>
<td>Demand exceeds capacity</td>
<td>Ramp and freeway queues form</td>
</tr>
</tbody>
</table>
Two-lane highways (Ch. 15)

Introduction

- The most common type of roads; one lane in each direction, passing maneuver,

- **Functions**: efficient mobility – connection major trip destinations, accessibility to remote populated area, *serve* recreation areas, small towns, rural areas and community,
HCM 2010 Two-lane highways

Classification

- **Class I**: where motorists expect to travel at relatively high speed. Are major intercity routes and primary connector of major traffic generators. Long distance trips.

- **Class II**: where motorists not necessary expect to travel at high speed. Access route to Class I, recreational routes, pass through rugged terrain. Serve relative short trips.

- **Class III**: serving moderately developed areas. Local traffic mixed with through traffic, density of access points, Reduced speed limits reflect the higher activity level.

---

HCM 2010 Two-lane highways

Capacity

Capacity of two lane highway under **base condition** is 1700 pc/h in one direction with max. 3200 pc/h in both direction.

Base condition:
- Lane width >= 12 ft (3,658 m)
- Clear shoulders >= 6 ft (1,829 m)
- No no-passing zones,
- All passenger cars in the traffic stream,
- Level terrain
- No impediments to through traffic (traffic signals, turning veh.)
LOS (automobile mode)

- **Average travel speed (ATS)** reflects mobility.
- **Percent time-spending-following (PTSF)** reflects the freedom of maneuver and the comfort and convenience of travel.
- **Percent of free-flow speed (PFFS)** represents the ability of vehicles to travel at or near the posted speed limit.

<table>
<thead>
<tr>
<th>LOS</th>
<th>Class I Highways</th>
<th>Class II Highways</th>
<th>Class III Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATS (mi/h)</td>
<td>PTSF (%)</td>
<td>PTSF (%)</td>
</tr>
<tr>
<td>A</td>
<td>&gt;55</td>
<td>&lt;35</td>
<td>&lt;40</td>
</tr>
<tr>
<td>B</td>
<td>&gt;50-55</td>
<td>&gt;35-50</td>
<td>&gt;40-55</td>
</tr>
<tr>
<td>C</td>
<td>&gt;45-50</td>
<td>&gt;50-65</td>
<td>&gt;55-70</td>
</tr>
<tr>
<td>D</td>
<td>&gt;40-45</td>
<td>&gt;65-80</td>
<td>&gt;70-85</td>
</tr>
<tr>
<td>E</td>
<td>≤40</td>
<td>&gt;80</td>
<td>&gt;85</td>
</tr>
</tbody>
</table>

1 mi/h = 1,609 km/h

LOS (bicycle mode)

- Average effective width of the outside through lane
- Motorized vehicle volumes
- Motorized vehicle speed
- Heavy vehicle (trucks) volumes
- Pavement condition

<table>
<thead>
<tr>
<th>LOS</th>
<th>BLOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤1.5</td>
</tr>
<tr>
<td>B</td>
<td>&gt;1.5-2.5</td>
</tr>
<tr>
<td>C</td>
<td>&gt;2.5-3.5</td>
</tr>
<tr>
<td>D</td>
<td>&gt;3.5-4.5</td>
</tr>
<tr>
<td>E</td>
<td>&gt;4.5-5.5</td>
</tr>
<tr>
<td>F</td>
<td>&gt;5.5</td>
</tr>
</tbody>
</table>
HCM 2010 Two-lane highways – Methodology – Automobile

1. Input data
   Geometry, volumes, class, FFS

2. Estimate FFS - Field measures or estimate on BFFS

3. Demand adj. for ATS
   PHF, heavy veh. adj., grade adj.

4. Estimate ATS
   No-pass. zone adj.

5. Demand adj. for PTSF
   PHF, heavy veh. adj., grade adj.

6. Estimate PTSF
   No-pass. zone adj.

7. Estimate PFFS

8. Determine LOS and capacity

---

HCM 2010 Two-lane highways

2. Estimate FFS

Measurement:
Low traffic – 100 veh. in each dir.

Estimate:
Max. speed allowed (mi/h)

\[ \text{FFS} = S_{IM} + 0.00776 \left( \frac{v}{f_{HV,ATS}} \right) \text{ (mi/h)} \]

\[ \text{FFS} = BFFS - f_L - f_A \text{ (mi/h)} \]

### Lane Width (ft)

<table>
<thead>
<tr>
<th></th>
<th>20 &lt; w</th>
<th>22 &lt; w</th>
<th>24 &lt; w</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 – 30</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
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<tr>
<td>&gt;30 – 40</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt;40 – 50</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt;50 – 60</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

### Shoulder Width (ft)

<table>
<thead>
<tr>
<th></th>
<th>10 &lt; s</th>
<th>12 &lt; s</th>
<th>14 &lt; s</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 &lt; s</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt;20 &lt; s</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt;40 &lt; s</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt;60 &lt; s</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

### Access Points per Mile (Two Directions)

<table>
<thead>
<tr>
<th></th>
<th>Reduction in FFS (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Note: Reductions greater than 5.0 are recommended.
3. Demand adj. for ATS

\[ v_{i,ATS} = \frac{V_i}{PHF \times f_{r,ATS} \times f_{HV,ATS}} \] (pc/h)

Heavy veh. adj. factor

\[ f_{HV,ATS} = \frac{1}{1 + P_1(E_r - 1) + P_0(E_r - 1)} \]

Grade adj. factor:
- Extended segments (>= 2 mi) of level terrain
- Extended segments (>= 2 mi) of rolling terrain
- Specific upgrades (depends on length, grade and directional volume)
- Specific downgrades (any grade of 3% or steeper and 0.6 mi (800 m) or longer)

4. Estimate the ATS

\[ ATS_d = FFS - 0.00776(v_{d,ATS} + v_{v,ATS}) - f_{MP,ATS} \] (mi/h)

<table>
<thead>
<tr>
<th>Operating Demand Flow Rate, (D_{ATS,mi})</th>
<th>FFS x 60 mi/h</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.1</td>
<td>1.5</td>
<td>1.9</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>200</td>
<td>1.2</td>
<td>1.6</td>
<td>2.1</td>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>300</td>
<td>1.3</td>
<td>1.8</td>
<td>2.3</td>
<td>2.7</td>
<td>3.2</td>
</tr>
<tr>
<td>400</td>
<td>1.4</td>
<td>2.0</td>
<td>2.5</td>
<td>2.9</td>
<td>3.4</td>
</tr>
<tr>
<td>500</td>
<td>1.6</td>
<td>2.4</td>
<td>2.9</td>
<td>3.4</td>
<td>3.9</td>
</tr>
<tr>
<td>600</td>
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<td>2.8</td>
<td>3.4</td>
<td>3.9</td>
<td>4.4</td>
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<tr>
<td>700</td>
<td>2.0</td>
<td>3.2</td>
<td>3.8</td>
<td>4.3</td>
<td>4.8</td>
</tr>
<tr>
<td>800</td>
<td>2.2</td>
<td>3.6</td>
<td>4.2</td>
<td>4.8</td>
<td>5.3</td>
</tr>
<tr>
<td>900</td>
<td>2.4</td>
<td>4.0</td>
<td>4.6</td>
<td>5.2</td>
<td>5.8</td>
</tr>
<tr>
<td>1,000</td>
<td>2.6</td>
<td>4.4</td>
<td>5.0</td>
<td>5.6</td>
<td>6.2</td>
</tr>
<tr>
<td>1,100</td>
<td>2.8</td>
<td>4.8</td>
<td>5.4</td>
<td>6.0</td>
<td>6.6</td>
</tr>
<tr>
<td>1,200</td>
<td>3.0</td>
<td>5.2</td>
<td>5.8</td>
<td>6.4</td>
<td>7.0</td>
</tr>
<tr>
<td>1,300</td>
<td>3.2</td>
<td>5.6</td>
<td>6.2</td>
<td>6.8</td>
<td>7.4</td>
</tr>
<tr>
<td>1,400</td>
<td>3.4</td>
<td>6.0</td>
<td>6.6</td>
<td>7.2</td>
<td>7.8</td>
</tr>
</tbody>
</table>

1 mi/h = 1,609 km/h for C. I and III only
6. Estimate PTSF

\[ PTSE_d = BPTSE_d + f_{op,PTSF} \frac{v_d,PTSF}{v_d,PTSF + v_e,PTSF} \]

\[ BPTSE_d = 100 \left[ 1 - \exp \left( -\frac{v_e,PTSF}{v_d,PTSF} \right) \right] \]

<table>
<thead>
<tr>
<th>Opposing Demand Flow Rate, (v_d (pcu/h))</th>
<th>Coefficient (a)</th>
<th>Coefficient (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>-0.0031</td>
<td>0.2937</td>
</tr>
<tr>
<td>1.00</td>
<td>0.0010</td>
<td>0.6716</td>
</tr>
<tr>
<td>1.50</td>
<td>0.0013</td>
<td>0.8551</td>
</tr>
<tr>
<td>2.00</td>
<td>0.0016</td>
<td>0.9256</td>
</tr>
<tr>
<td>2.50</td>
<td>0.0019</td>
<td>0.9850</td>
</tr>
<tr>
<td>3.00</td>
<td>0.0021</td>
<td>1.0211</td>
</tr>
</tbody>
</table>

Note: Straight-line interpolation of the nearest values is recommended.

HCM 2010 Two-lane highways

6. Estimate PFFS

\[ PFFS = \frac{ATS_d}{FFS} \]

for C. I and II only

7. Estimate LOS and capacity

**LOS:**
- **Class I:** ATS in PTSF (worst of)
- **Class II:** PTSF
- **Class III:** PFFS

**Capacity:**

\[ c_{ATS} = 1,700 f_{r,ATS} f_{HV,ATS} \]

\[ c_{PTSF} = 1,700 f_{r,PTSF} f_{HV,PTSF} \]

Class I: lower of both
Class II: on PTSF
Class III: on ATS
### HCM 2010 Two-lane highways – Methodology – Bicycle

1. **Input data**
   Geometry, volumes, speed limit, on highway parking, pavement

2. **Calculate the directional flow rate in the outside lane**

3. **Calculate the effective width**

4. **Calculate the effective speed factor**
   Speed limit

5. **Determine LOS**
   BLOS score

### 3. Determine the effective width

1 ft = 0.304 m

![Diagram showing effective width calculation](Configuration no 5e - New Sidewalk & No Parking on South Side, Widened Lawn Extension on North Side. TOTAL PAVED WIDTH: 32)
3. Determine the effective width

If \( W_i \) is greater than or equal to 8 ft:
\[
W_e = W_i + W_s - (\%OHP \times 10 \text{ ft})
\]
If \( W_i \) is greater than or equal to 4 ft and less than 8 ft:
\[
W_e = W_o + W_s - 2 \times (\%OHP(2 \text{ ft} + W_i))
\]
If \( W_i \) is less than 4 ft:
\[
W_e = W_o + (\%OHP(2 \text{ ft} + W_i))
\]
with, if \( V \) is greater than 160 veh/h:
\[
W_o = W_{OL} + W_s
\]
Otherwise,
\[
W_o = (W_{OL} + W_s) \times (2 - 0.005V)
\]

5. Determine the LOS

Effective speed factor
\[
S_f = 1.1199 \ln(S_p - 20) + 0.8103
\]
\[
BLOS = 0.507 \ln(v_{OL}) + 0.1999S_f (1 + 10.38HV)^2
+ 7.066(1/P)^2 - 0.005(W_s)^2 + 0.057
\]

FHWA 5-point pavement surface condition rating

<table>
<thead>
<tr>
<th>LOS</th>
<th>BLOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt;5.5</td>
</tr>
<tr>
<td>B</td>
<td>&gt;1.5-2.5</td>
</tr>
<tr>
<td>C</td>
<td>&gt;2.5-3.5</td>
</tr>
<tr>
<td>D</td>
<td>&gt;3.5-4.5</td>
</tr>
<tr>
<td>E</td>
<td>&gt;4.5-5.5</td>
</tr>
<tr>
<td>F</td>
<td>&gt;5.5</td>
</tr>
</tbody>
</table>
Questions?

THANKS FOR YOUR ATTENTION!

Drago.Sever@UM.SI