Chapter 9
Capacity and Level of Service for Highway Segments
Definitions and Concepts

Types of Facilities
Facilities may generally be classified into one of two categories:

- Uninterrupted Flow Facilities
  - They have no fixed elements, such as traffic signals and stop signs, that cause interruption to traffic flow. Examples of Uninterrupted flow facilities are freeway two-lane highway and multilane highway.

- Interrupted Flow Facilities
  - They have fixed elements causing periodic interruption to traffic flow. Examples of interrupted flow facilities are signalised intersections, Unsignalized intersections (stop or yield controlled approach), and arterial.
Definitions and Concepts

Level of Service

Level of service is a qualitative measure that describes operational conditions within a traffic stream and their perception by drivers or/and passengers.

These conditions are in terms of such factors as speed and travel time, traffic interruption, comfort and convenience, and safety.

Six LOS’s are defined for each type of facilities. They are given letter A to F, with LOS A representing the best operating conditions and LOS F the worst.

Level A: Represents free flow at low concentration with no restriction due to traffic conditions.

Level B: the lower limit of which is often used for the design of rural highways, is the zone of stable flow with more marked restriction.
Definitions and Concepts

Level of Service

Level C: denote the zone of stable flow with more marked restriction on the driver’s selection of speed and with reduced ability to pass.

Level D: reflect little freedom for driver maneuverability.

Level E: Low operating speeds and volumes near or at capacity, which the area is of unstable flow.

Level F: provided by the familiar traffic jam with frequent interruptions and breakdown of flow.
In general, the capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point during a given time period under prevailing roadway, traffic and control conditions.

**Prevailing road conditions:**

Physical features that cause reductions in traffic flow

- Narrow traffic lanes
- Inadequate shoulders
- Side obstructions (poles, bridges, retaining wall)
- Parked cars close to edge of the carriageway
- Imperfect horizontal or vertical curvature
- The layout of intersection on roads

**Prevailing traffic conditions:**

They are not fixed but vary from hour to hour throughout the day. Hence the flows at any particular time are a function of:

- The speed of vehicles
- The composition of the traffic streams
- The manner in which they interact with each other
- The physical features of the roadway itself
- Type of driver population
- Directional distribution of traffic
Definitions and Concepts
Capacity (continue)

Prevailing control conditions:
They refer to the types and specific design of control devices and traffic regulations present on a given facility.
- the location, type, and timing of traffic signals;
- stop and yield signs;
- lane use restrictions; and
- turn restrictions.

Basic Principles of traffic flow

Traffic flow measures

The operational state of any given traffic stream is defined by three primarily measures:
- Speed. (Studied in chapter 2).
- Volume and/or rate of flow. (Studied in chapter 2).
- Density.
Density is defined as the number of vehicles occupying a unit length of a traffic lane at a given instant (veh/km).

Density (used in USA) = Concentration (Used in England)

It can be computed from the speed and the rate of flow, which is:

\[ q = V \times K \]

Where:

- \( q \) = Rate of flow, in vehicle/hr;
- \( V \) = Average travel speed in Km/hr; and
- \( K \) = Density in vehicle/km.

<table>
<thead>
<tr>
<th>( V )</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K )</td>
<td>20</td>
<td>40</td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>( q )</td>
<td>1200</td>
<td>1600</td>
<td>1500</td>
<td>1700</td>
</tr>
</tbody>
</table>

A freeway is defined as a divided highway with full control of access and two or more lanes for the exclusive use of traffic in each direction.

- Freeways provide uninterrupted flow.
- There are no signalized or stop-controlled at-grade intersections, and 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.
Capacity Analysis and Design for a Freeway Segment

Definition

Basic freeway segments are outside of the influence area of ramps or weaving areas of the freeway. This Figure illustrates a basic freeway segment.

The following Figures illustrate the ramp influence area and weaving segment:

On- And Off-Ramp Influence Areas

Capacity Analysis and Design for a Freeway Segment

Definition

a. Ramp-Weave

Type A Weaving Segments

b. Major Weave
Capacity Analysis and Design for a Freeway Segment

Freeway Capacity Terms

Freeway capacity: the maximum sustained 15-min flow rate, expressed in passenger cars per hour per lane, that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction of flow.

Traffic characteristics: any characteristic of the traffic stream that may affect capacity, free-flow speed, or operations, including the percentage composition of the traffic stream by vehicle type and the familiarity of drivers with the freeway.

Roadway characteristics: the geometric characteristics of the freeway segment under study, including the number and width of lanes, right-shoulder lateral clearance, interchange spacing, vertical alignment, and lane configurations.

Free-flow speed (FFS): the mean speed of passenger cars that can be accommodated under low to moderate flow rates on a uniform freeway segment under prevailing roadway and traffic conditions.

Base conditions: an assumed set of geometric and traffic conditions used as a starting point for computations of capacity and level of service (LOS).

Capacity analysis is based on freeway segments with uniform traffic and roadway conditions. If any of the prevailing conditions change significantly, the capacity of the segment and its operating conditions change as well. Therefore, each uniform segment should be analyzed separately.
Base Conditions for Basic Freeway Segments

The base conditions under which the full capacity of a basic freeway segment is achieved are good weather, good visibility, and no incidents or accidents. For the analysis procedures in this chapter, these base conditions are assumed to exist. If any of these conditions fails to exist, the speed, LOS, and capacity of the freeway segment all tend to be reduced.

The specific speed-flow-density relationship of a basic freeway segment depends on prevailing traffic and roadway conditions. A set of base conditions for basic freeway segments has been established.

These base conditions represent a high operating level, with a free-flow speed (FFS) of 110 km/h or greater.

- Minimum lane widths of 3.6 m;
- Minimum right-shoulder lateral clearance between the edge of the travel lane and the nearest obstacle or object that influences traffic behavior of 1.8 m;
- Minimum median lateral clearance of 0.6 m;
- Traffic stream composed entirely of passenger cars;
- Five or more lanes for one direction (in urban areas only);
- Interchange spacing at 3 km or greater;
- Level terrain, with grades no greater than 2 percent; and
- A driver population composed principally of regular users of the facility.

These base conditions represent a high operating level, with a free-flow speed (FFS) of 110 km/h or greater.
Base Conditions for Basic Freeway Segments

Capacity Analysis and Design for a Freeway Segment

Examples of interchanges

Interchange Spacing
Capacity Analysis and Design for a Freeway Segment

Methodology

The methodology described in this section is for the analysis of basic freeway segments. The following Figure illustrates input to and the basic computation order of the method for basic freeway segments. The primary output of the method is LOS.
Continue:
Basic Freeway Segment Methodology

- Define speed-flow curve
- Determine speed using speed-flow curve
- Compute density using flow rate and speed
- Determine LOS
Definition

This section treats the capacity analysis of multilane highway that cannot be classified as a freeways because they are undivided, lack control of access, or both.

Between points of fixed interruption, multilane highways operate under uninterrupted conditions.

Definition

Such flow however is not as efficient as flow on freeways because of source of side- and medium-frictions which exist on multilane highways, such as:

- Vehicles enter and leave the roadside to access parking lots, driveways, Unsignalized intersection, and other points.
- The friction due to opposing vehicles on undivided multilane roadways also impacts negatively on flow.
- The visual impact of development fronting directly on the highway influences the driver behaviour, and contributes to its being less efficient than on comparable freeways.
Capacity Analysis and Design for a Multilane Highway

Definition

Multilane highways may exhibit some of the following characteristics:

- Posted speed limits are usually between 60 and 100 km/h
- They may be undivided or include medians
- They are located in suburban areas or in high-volume rural corridors
- They may include a two-way, left-turn median lane (TWLTL)
- Traffic volumes range from 15,000 to 40,000/day
- Volumes are up to 100,000/day with grade separations and no cross-median access
- Traffic signals at major crossing points are possible
- There is partial control of access

Figure 9.14  Typical Multilane Highways
The procedures in this chapter determine the reduction in travel speed that occurs for less-than-base conditions. Under base conditions, the full speed and capacity of a multilane highway are achieved. These conditions include good weather, good visibility, and no incidents or accidents.

Studies of the flow characteristics of multilane highways have defined base conditions for developing flow relationships and adjustments to speed.
BASE CONDITIONS FOR MULTILANE HIGHWAYS

The base conditions for multilane highways are as follows:

- 3.6-m minimum lane widths;
- 3.6-m minimum total lateral clearance in the direction of travel—this represents the total lateral clearances from the edge of the travelled lanes to obstructions along the edge of the road and in the median (in computations, lateral clearances greater than 1.8 m are considered in computations to be equal to 1.8 m);
- Only passenger cars in the traffic stream;
- No direct access points along the roadway;
- A divided highway; and
- Free-flow speed (FFS) higher than 100 km/h.

5.4.3 Methodology

The same methodology used in the freeway section is applied to the multilane highway.
LOS Criteria

Although speed is a major concern of drivers, freedom to maneuver within the traffic stream and the proximity to other vehicles are also important. LOS criteria are listed in Exhibit 21-2.

The criteria are based on the typical speed-flow and density-flow relationships shown in Exhibit and 12-2. Exhibit 21-3 shows LOS boundaries as sloped lines, each corresponding to a constant value of density.

<table>
<thead>
<tr>
<th>Free-Flow Speed</th>
<th>Criteria</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 km/h</td>
<td>Maximum density (pc/km/ln)</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Average speed (km/h)</td>
<td>100.0</td>
<td>100.0</td>
<td>98.4</td>
<td>91.5</td>
<td>88.0</td>
</tr>
<tr>
<td></td>
<td>Maximum volume to capacity ratio (v/c)</td>
<td>0.32</td>
<td>0.50</td>
<td>0.72</td>
<td>0.92</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>700</td>
<td>1100</td>
<td>1575</td>
<td>2015</td>
<td>2200</td>
</tr>
<tr>
<td>90 km/h</td>
<td>Maximum density (pc/km/ln)</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Average speed (km/h)</td>
<td>90.0</td>
<td>90.0</td>
<td>89.8</td>
<td>84.7</td>
<td>80.8</td>
</tr>
<tr>
<td></td>
<td>Maximum v/c</td>
<td>0.30</td>
<td>0.47</td>
<td>0.68</td>
<td>0.89</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>630</td>
<td>990</td>
<td>1435</td>
<td>1860</td>
<td>2100</td>
</tr>
<tr>
<td>80 km/h</td>
<td>Maximum density (pc/km/ln)</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Average speed (km/h)</td>
<td>80.0</td>
<td>80.0</td>
<td>80.0</td>
<td>77.6</td>
<td>74.1</td>
</tr>
<tr>
<td></td>
<td>Maximum v/c</td>
<td>0.28</td>
<td>0.44</td>
<td>0.64</td>
<td>0.85</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>560</td>
<td>880</td>
<td>1280</td>
<td>1705</td>
<td>2000</td>
</tr>
<tr>
<td>70 km/h</td>
<td>Maximum density (pc/km/ln)</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Average speed (km/h)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
<td>69.6</td>
<td>67.9</td>
</tr>
<tr>
<td></td>
<td>Maximum v/c</td>
<td>0.26</td>
<td>0.41</td>
<td>0.59</td>
<td>0.81</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum service flow rate (pc/h/ln)</td>
<td>490</td>
<td>770</td>
<td>1120</td>
<td>1530</td>
<td>1900</td>
</tr>
</tbody>
</table>

Exhibit 21-2. LOS Criteria for multilane Highway
Determining FFS

The FFS can be estimated indirectly when field data are not available.

\[
FFS = BFFS - f_{LW} - f_{LC} - f_{M} - f_{A}
\]

- **BFFS** = base FFS (km/h);
- **FFS** = estimated FFS (km/h);
- **f_{LW}** = adjustment for lane width, from Exhibit 21-4 (km/h);
- **f_{LC}** = adjustment for lateral clearance, from Exhibit 21-5 (km/h);
- **f_{M}** = adjustment for median type, from Exhibit 21-6 (km/h);
- **f_{A}** = adjustment for access points, from Exhibit 21-7 (km/h).
Adjustment for Lane Width

Exhibit 21-4. Adjustments for Lane Width

<table>
<thead>
<tr>
<th>Lane Width (m)</th>
<th>Reduction in FFS (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>0.0</td>
</tr>
<tr>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td>3.4</td>
<td>2.1</td>
</tr>
<tr>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>3.2</td>
<td>5.6</td>
</tr>
<tr>
<td>3.1</td>
<td>8.1</td>
</tr>
<tr>
<td>3.0</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Adjustment for Lateral Clearance

Exhibit 21-5 lists the speed reductions caused by the lateral clearance for fixed obstructions on the roadside or in the median. Fixed obstructions with lateral clearance effects include light standards, signs, trees, abutments, bridge rails, traffic barriers, and retaining walls. Standard raised curbs are not considered obstructions.
**Adjustment for Lateral Clearance**

Exhibit 21-5 shows the appropriate reduction in FFS based on the total lateral clearance, which is defined as:

\[ TLC = LCR + LCL \]

- **TLC** = total lateral clearance (m),
- **LCR** = lateral clearance (m), from the right edge of the travel lanes to roadside obstructions (if greater than 1.8 m, use 1.8 m), and
- **LCL** = lateral clearance (m), from the left edge of the travel lanes to obstructions in the roadway median (if the lateral clearance is greater than 1.8 m, use 1.8 m). For undivided roadways, there is no adjustment for left-side lateral clearance. The undivided design is taken into account by the median adjustment. To use Exhibit 21-5 for undivided highways, the lateral clearance on the left edge is always 1.8 m. Lateral clearance in the median of roadways with two-way left-turn lanes (TWLTs) is considered to be 1.8 m.

### Exhibit 21-5. Adjustments Lateral Clearance

<table>
<thead>
<tr>
<th>Four-Lane Highways</th>
<th>Six-Lane Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Lateral Clearance(^a) (m)</td>
<td>Reduction in FFS (km/h)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>3.6</td>
<td>0.0</td>
</tr>
<tr>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>2.4</td>
<td>1.5</td>
</tr>
<tr>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>1.2</td>
<td>3.0</td>
</tr>
<tr>
<td>0.8</td>
<td>5.8</td>
</tr>
<tr>
<td>0.0</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Note:
- Total lateral clearance is the sum of the lateral clearances of the shoulder (if greater than 1.8 m, use 1.8 m) and roadside obstructions (if greater than 1.8 m, use 1.8 m). Therefore, for purposes of analysis, total lateral clearance cannot exceed 3.0 m.

Thus, a total lateral clearance of 3.6 m is used for a completely unobstructed roadside and median; however, the actual value is used when obstructions are located closer to the roadway. The adjustment for lateral clearance on six-lane highways is slightly less than for four-lane highways because lateral obstructions have a minimal effect on traffic operations in the center lane of a three-lane roadway.
Adjustment for Median Type

The values in Exhibit 21-6 indicate that the average FFS should be decreased by 2.6 km/h for undivided highways to account for the friction caused by opposing traffic in an adjacent lane.

<table>
<thead>
<tr>
<th>Median Type</th>
<th>Reduction in FFS (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undivided highways</td>
<td>2.6</td>
</tr>
<tr>
<td>Divided highways (including TWLTLs)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Exhibit 21-6. Adjustments for Median Type

Adjustment for Access-Point Density

Exhibit 21-7 presents the adjustment to FFS for various levels of access-point density. The data indicate that for each access point per kilometer the estimated FFS decreases by approximately 0.4 km/h, regardless of the type of median. The access-point density on a divided roadway is determined by dividing the total number of access points (i.e., intersections and driveways) on the right side of the roadway in the direction of travel by the segment’s total length in kilometers.
Adjustment for Access-Point Density

An intersection or driveway should only be included if it influences traffic flow. Access points unnoticed by the driver or with little activity should not be included in determining access-point density.

<table>
<thead>
<tr>
<th>Access Points/Kilometer</th>
<th>Reduction in FFS (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
</tr>
<tr>
<td>12</td>
<td>8.0</td>
</tr>
<tr>
<td>18</td>
<td>12.0</td>
</tr>
<tr>
<td>≥ 24</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Exhibit 21-7. ACCESS-POINT DENSITY ADJUSTMENT
Determining Flow Rate

The hourly flow rate must reflect:
• The influence of heavy vehicles;
• The temporal variation of traffic flow over an hour; and
• The characteristics of the driver population.

These effects are reflected by adjusting hourly volumes or estimates, typically reported in vehicles per hour (veh/h), to arrive at an equivalent passenger-car flow rate in passenger cars per hour (pc/h). The equivalent passenger-car flow rate is calculated using the heavy-vehicle and peak-hour adjustment factors and is reported on a per lane basis (pc/h/ln).

Determining Flow Rate

The following equation is used to calculate the equivalent passenger-car flow

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

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.
**Peak-Hour Factor**

PHF represents the variation in traffic flow within an hour. Observations of traffic flow consistently indicate that the flow rates found in the peak 15-min period within an hour are not sustained throughout the entire hour.

**Heavy-Vehicle Adjustments**

The presence of heavy vehicles in the traffic stream decreases the FFS because base conditions allow a traffic stream of passenger cars only. Therefore, traffic volumes must be adjusted to reflect an equivalent flow rate expressed in passenger cars per hour per lane (pc/h/ln). This is accomplished by applying the heavy-vehicle factor \( f_{HV} \). Once values for ET and ER have been determined, the adjustment factor for heavy vehicles may be computed as shown in Equation.

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

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.
Adjustment for heavy vehicles in the traffic stream applies to three types of vehicles: trucks, RVs, and buses. No evidence indicates any distinct differences in the performance characteristics of trucks and buses on multilane highways; therefore, buses are considered trucks in this method. Finding the heavy-vehicle adjustment factor requires two steps. First, find an equivalent truck factor \( E_T \) and RV factor \( E_R \) for prevailing operating conditions. Second, using \( E_T \) and \( E_R \), compute an adjustment factor for all heavy vehicles in the traffic stream.

**Extended General Highway Segments**

Passenger-car equivalents can be selected for two conditions: extended general highway segments and specific grades. Values of passenger-car equivalents are selected from Exhibits 21-8 through 21-11. For long segments of highway in which no single grade has a significant impact on operations, Exhibit 21-8 is used to select passenger-car equivalents for trucks and buses \( (E_T) \) and for RVs \( (E_R) \).

**EXHIBIT 21-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED GENERAL HIGHWAY SEGMENTS**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type of Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level</td>
</tr>
<tr>
<td>( E_T ) (trucks and buses)</td>
<td>1.5</td>
</tr>
<tr>
<td>( E_R ) (RVs)</td>
<td>1.2</td>
</tr>
</tbody>
</table>

A long multilane highway segment can be classified as an extended general highway segment if no grade exceeding 3 percent is longer than 0.8 km, and if grades of 3 percent or less do not exceed 1.6 km.

**Specific Grade**

Any grade of 3 percent or less that is longer than 1.6 km or a grade greater than 3 percent that is longer than 0.8 km should be treated as an isolated, specific grade. In addition, the upgrade and downgrade must be treated separately, because the impact of heavy vehicles differs substantially in each.

**Equivalents for Extended General Highway Segments**

For an extended general segment analysis, the terrain of the highway must be classified as level, rolling, or mountainous. These three classifications are discussed below.
Level Terrain

Level terrain is any combination of horizontal and vertical alignment that permits heavy vehicles to maintain approximately the same speed as passenger cars. This type of terrain generally includes short grades of no more than 1 to 2 percent.

Rolling Terrain

Rolling terrain is any combination of horizontal and vertical alignment that causes heavy vehicles to reduce their speeds substantially below those of passenger cars. However, the terrain does not cause heavy vehicles to operate at crawl speeds for any significant length of time or at frequent intervals.

Mountainous Terrain

Mountainous terrain is any combination of horizontal and vertical alignment that causes heavy vehicles to operate at crawl speeds for significant distances or at frequent intervals. For these general highway segments, values of \( E_T \) and \( E_R \) are selected from Exhibit 21-8.

Equivalents for Specific Grades

Any highway grade of more than 1.6 km for grades less than 3 percent or of 0.8 km for grades of 3 percent or more should be considered a separate segment. Analysis of such segments must consider the upgrade and downgrade conditions and whether the grade is single and isolated, with a constant percentage of change, or part of a series forming a composite grade.

Equivalents for Specific Upgrades

Exhibits 21-9 and 21-10 give passenger-car equivalents for trucks and buses \( (E_T) \) and for RVs \( (E_R) \), respectively, on uniform upgrades on four- and six-lane highways. Exhibit 21-9 is based on an average weight-to-power ratio of 100 kg/kW, which is typical of trucks on multilane highways in the United States.

Equivalents for Specific Downgrades

Downgrade conditions for trucks and buses on four- or six-lane highways are analyzed using equivalents from Exhibit 21-11. For all downgrades less than 4 percent and for steeper downgrades less than or equal to 3.2 km long, use the passenger-car equivalents for trucks and buses in level terrain, given in Exhibit 21-8. For grades of at least 4 percent and longer than 3.2 km, use the specific values shown in Exhibit 21-11. For all cases of RVs on downgrades, use the passenger-car equivalents for level terrain, given in Exhibit 21-8.
Equivalents for Composite Grades

When several consecutive grades of different steepness form a composite grade, an average, uniform grade is computed and used in analysis. The average grade is commonly computed as the total rise from the beginning of the grade divided by the total horizontal distance over which the rise occurs.

The composite grade technique is reasonably accurate for segment lengths of 1200 m or less, or for grades of 4 percent or less. For steeper grades and longer segment lengths, a more exact technique is described in Appendix A of Chapter 23. If a large change in grade occurs for a significant length, the analyst should consider segmenting the roadway to apply the composite grade technique.

Sometimes a single, steep grade creates a critical effect that might not be identified in a length of highway to be analyzed; in this case, the composite grade technique can be supplemented by a specific grade analysis.

<table>
<thead>
<tr>
<th>Upgrade (%)</th>
<th>Length (%)</th>
<th>Percentage of Interior and Exterior Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - 3</td>
<td>0.0 - 0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4 - 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.8 - 1.2</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
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<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6 - 2.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>1.5</td>
</tr>
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<td>&gt; 3 - 4</td>
<td>0.0 - 0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4 - 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.8 - 1.2</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.2 - 1.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6 - 2.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>1.5</td>
</tr>
<tr>
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<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4 - 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.8 - 1.2</td>
<td>1.5</td>
</tr>
<tr>
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<td>1.2 - 1.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 5 - 6</td>
<td>0.0 - 0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4 - 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.8 - 1.2</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.2 - 1.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>0.0 - 0.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4 - 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.8 - 1.2</td>
<td>1.5</td>
</tr>
<tr>
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<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

EXHIBIT 23-6: PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UNIFORM UPGRADES.
### Exhibit 21-10. Passenger-Car Equivalents for RVs on Uniform Upgrades

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Length (miles)</th>
<th>$E_R$</th>
<th>Percentage of RVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤2</td>
<td>All</td>
<td>1.2</td>
<td>1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2</td>
</tr>
<tr>
<td>&gt;2–3</td>
<td>0.0–0.8</td>
<td>1.2</td>
<td>1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2</td>
</tr>
<tr>
<td></td>
<td>&gt;0.8</td>
<td>1.2</td>
<td>1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2</td>
</tr>
<tr>
<td>&gt;3–4</td>
<td>0.0–0.4</td>
<td>1.2</td>
<td>1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2</td>
</tr>
<tr>
<td></td>
<td>&gt;0.4–0.8</td>
<td>2.5</td>
<td>2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0</td>
</tr>
<tr>
<td></td>
<td>&gt;0.8</td>
<td>3.0</td>
<td>2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5</td>
</tr>
<tr>
<td>&gt;4–5</td>
<td>0.0–0.4</td>
<td>2.5</td>
<td>2.0 2.0 2.0 1.5 1.5 1.5 1.5 1.5 1.5 1.5</td>
</tr>
<tr>
<td></td>
<td>&gt;0.4–0.8</td>
<td>4.0</td>
<td>3.0 3.0 3.0 2.5 2.5 2.5 2.5 2.5 2.5 2.5</td>
</tr>
<tr>
<td></td>
<td>&gt;0.8</td>
<td>4.5</td>
<td>3.5 3.5 3.5 3.0 3.0 3.0 3.0 3.0 3.0 3.0</td>
</tr>
<tr>
<td>&gt;5</td>
<td>0.0–0.4</td>
<td>4.0</td>
<td>3.0 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5</td>
</tr>
<tr>
<td></td>
<td>&gt;0.4–0.8</td>
<td>6.0</td>
<td>4.0 4.0 4.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0</td>
</tr>
<tr>
<td></td>
<td>&gt;0.8</td>
<td>6.0</td>
<td>4.5 4.5 4.5 3.5 3.5 3.5 3.5 3.5 3.5 3.5</td>
</tr>
</tbody>
</table>

### Exhibit 21-11. Passenger-Car Equivalents for Trucks on Downgrades

<table>
<thead>
<tr>
<th>Downgrade (%)</th>
<th>Length (miles)</th>
<th>$E_T$</th>
<th>Percentage of Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4</td>
<td>All</td>
<td>1.5</td>
<td>1.5 1.5 1.5 1.5</td>
</tr>
<tr>
<td>4–5</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5 1.5 1.5 1.5</td>
</tr>
<tr>
<td>4–5</td>
<td>&gt; 6.4</td>
<td>2.0</td>
<td>2.0 2.0 2.0 2.0</td>
</tr>
<tr>
<td>&gt; 5–6</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5 1.5 1.5 1.5</td>
</tr>
<tr>
<td>&gt; 5–6</td>
<td>&gt; 6.4</td>
<td>5.5</td>
<td>4.0 4.0 4.0 4.0</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>≤ 6.4</td>
<td>1.5</td>
<td>1.5 1.5 1.5 1.5</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>&gt; 6.4</td>
<td>7.5</td>
<td>6.0 5.5 4.5 4.5</td>
</tr>
</tbody>
</table>
Driver Population Factor

The adjustment factor $f_p$ reflects the effect weekend recreational and perhaps even midday drivers have on the facility. The values for $f_p$ range from 0.85 to 1.00. Typically, the analyst should select 1.00, which reflects weekday commuter traffic (i.e., users familiar with the highway), unless there is sufficient evidence that a lesser value, reflecting more recreational or weekend traffic characteristics, should be applied. When greater accuracy is needed, comparative field studies of weekday and weekend traffic flow and speeds are recommended.

DETERMINING LOS

The LOS on a multilane highway can be determined directly from Exhibit 21-3 on the basis of the FFS and the service flow rate ($v_p^s$) in pc/h/ln. The procedure is as follows:

- Step 1. Define and segment the highway as appropriate.
- Step 2. On the basis of the measured or estimated FFS, construct an appropriate speed-flow curve of the same shape as the typical curves shown in Exhibit 21-3. The curve should intercept the y-axis at the FFS.
- Step 3. Based on the flow rate $v_p^s$, read up to the FFS curve identified in Step 2 and determine the average passenger-car speed and LOS corresponding to that point.

- Step 4. Determine the density of flow according to Equation 21-5.

\[
D = \frac{v_p^s}{S}
\]

(21-5)

where

- $D$ = density (pc/km/ln),
- $v_p^s$ = flow rate (pc/h/ln), and
- $S$ = average passenger-car travel speed (km/h).

The LOS also can be determined by comparing the computed density with the density ranges provided in Exhibit 21-2.
Example Problem 1 (Part I)

The Highway  A 5.23-km undivided four-lane highway on level terrain. A 975-m segment with 2.5 percent grade also is included in the study.

The Question  What are the peak-hour LOS, speed, and density for the level terrain portion of the highway?

The Facts  
- Level terrain,
- 74.0-km/h field-measured FFS,
- 3.4-m lane width,
- 1,900-veh/h peak-hour volume,
- 13 percent trucks and buses,
- 2 percent RVs, and
- 0.90 PHF.

Outline of Solution  All input parameters are known. Demand will be computed in terms of pc/h/ln, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

1. Find $f_{HV}$ (use Exhibit 21-8 and Equation 21-4)

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

   \[
   f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(1.2 - 1)}
   \]

   $f_{HV} = 0.935$

2. Find $v_p$ (use Equation 21-3)

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

   \[
   v_p = \frac{1,900}{0.90 \cdot 2 \cdot 0.935 \cdot 1.00}
   \]

   $v_p = 1,129$ pc/h/ln

3. Determine LOS (use Exhibit 21-3)

   LOS C

The Results

- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.3 pc/km/ln.
**Example Problem 1 (Part II)**

**The Highway**
A 5.23-km undivided four-lane highway on level terrain. A 975-m segment with 2.5 percent grade also is included in the study.

**The Question**
What are peak-hour LOS, speed, and density of traffic on the 2.5 percent grade? Does this operation still meet the minimum required LOS D?

**The Facts**

- 2.5 percent grade (upgrade and downgrade),
- 74.0 km/h field-measured FFS,
- 3.4-m lane width,
- 1,900 veh/h peak-hour volume,
- 13 percent trucks and buses,
- 2 percent RVs, and
- 0.90 PHF.
Comments

For the 2.5 percent downgrade, trucks, buses, and RVs all operate as though on level terrain. Therefore, results obtained in Part I are applicable for downgrade results of the 2.5 percent grade segment.

Assume FFS of 74.0 km/h applies to both upgrade and downgrade segments.

Outline of Solution All input parameters are known. Demand will be computed in terms of pc/h/ln, and the LOS determined from the speed-flow diagram. An estimate of passenger-car speed is determined from the graph, and a value of density is calculated using speed and flow rate.

Steps

1. Find $f_{HV}$ (use Exhibits 21-9 and 21-10).

\[
\begin{align*}
1 & = f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \\
1 & = f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(3.0 - 1)} \\
f_{HV} & = 0.905
\end{align*}
\]

2. Find $v_p$.

\[
\begin{align*}
V & = PHF \times N \times f_{HV} \times f_p \\
V & = 1.900 \\
v_p & = \frac{v}{0.90 \times 2 \times 0.905 \times 1.00} \\
v_p & = 1.166 \text{ pc/h/ln}
\end{align*}
\]

3. Determine LOS (use Exhibit 21-3).

- LOS C (upgrade)
- LOS C (downgrade)

The Results

Downgrade:
- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.3 pc/km/ln.

Upgrade:
- LOS C,
- Speed = 74.0 km/h, and
- Density = 15.8 pc/km/ln.