10-mph Pace

The 10-mph pace is the 10-mph range encompassing the greatest percentage of all the measured speeds in a spot speed study. It is described by the speed value at the lower end of the range and the percentage of all vehicles that are within the range; as such, it is an alternative indicator of speed dispersion. Most engineers believe that...
safety is enhanced when the 10-mph pace includes a large percentage (more than 70 percent) of all the free-flowing vehicles at a location. (Note: 10 mph = 16 km/h.)

**85th Percentile Speed**

The 85th percentile speed is the speed at or below which 85 percent of the free-flowing vehicles travel. Traffic engineers have assumed that this high percentage of drivers will select a safe speed on the basis of the conditions at the site. The 85th percentile speed has traditionally been considered in an engineering study to establish a speed limit. The 85th percentile speed for a normal distribution is shown in Figure E-1. In most cases, the difference between the 85th percentile speed and the average speed provides a good approximation of the speed sample’s standard deviation.

**Advisory Speed**

At certain locations on the highway system, such as horizontal curves, intersections, or steep downgrades, the safe speed on the roadway may be less than the posted speed limit. Rather than lowering the regulatory speed limits at each of these locations, traffic engineers often place standard warning signs accompanied by a square black-and-yellow advisory speed plate as shown in Figure E-2. Although this sign provides a warning to approaching drivers, it is not legally enforceable.
Arterial

Arterials provide the high-speed, high-volume network for travel between major points in rural areas. They generally have minimum design speeds of at least 37 mph (60 km/h). Most intersections are at grade (i.e., at the same level), and access to abutting property is permitted but controlled. Utilities are usually permitted within the right-of-way. All rural arterials, including freeways, constitute about 9 percent of the rural highway length in the United States and carry 64 percent of the rural vehicle miles of travel.

The principal purpose of urban arterials is to provide mobility. Design speeds may be as low as 31 to 37 mph (50 to 60 km/h), but higher speeds are common, particularly for principal arterials. In developed areas, principal arterials are often spaced at intervals of 0.6 to 1.2 mi (1 to 2 km). Principal arterials, including freeways, account for 9 percent of the urban street length and carry 58 percent of all urban travel.

Average Speed

The average (or mean) speed is the most common measure of central tendency. Using data from a spot speed study, the average is calculated by summing all the measured speeds and dividing by the sample size, n.

Basic Speed Law

The Uniform Vehicle Code (National Committee on Uniform Traffic Laws and Ordinances 1992) and most state motor vehicle laws include a basic speed law with wording similar to the following: No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard for the weather, visibility, traffic, and the surface and width of the roadway.

Braking Distance

Braking distance, assumed for design purposes to be on a wet pavement surface, is the distance required to stop a vehicle from the
instant brake application begins. The minimum braking distance for a vehicle on a level roadway increases with the square of the speed:

\[ b = \frac{V^2}{254f} \]

where

- \( b \) = braking distance (m),
- \( V \) = initial speed (km/h), and
- \( f \) = coefficient of friction between tires and roadway.

The dashed line in Figure E-3 shows braking distance as a function of a vehicle’s initial speed. The solid line shows the total stopping distance.

![Figure E-3 Design values for braking and stopping distance. (Note: 1 m = 3.28 ft and 1 km/h = 0.62 mph.)](image)

**Business District**

For the purpose of establishing statutory speed limits, the Uniform Vehicle Code (National Committee on Uniform Traffic Laws and Ordinances 1992) defines a business district as the territory contiguous to and including any highway when within any 180 m along such highway there are buildings in use for business or industrial purposes, including but not limited to hotels, banks, or office buildings that occupy at least 90 m of frontage on one side or 90 m collectively on both sides of the highway. (Note: 1 m = 3.28 ft.)
Collector Roads and Streets

Collector roads and streets collect vehicles from local roads and abutting properties and route them to arterials. Traffic volumes are relatively low and design speeds may be as low as 31 mph (50 km/h). Collectors have all intersections at grade and little access control. They may also have pedestrians and parked vehicles. Collectors represent 23 percent of the rural highway length and carry 25 percent of the rural vehicle miles of travel.

Collector streets in urban areas have design speeds of 31 mph (50 km/h) or greater. Their function is divided equally between mobility and access. Collectors are more likely than minor arterials to accommodate parking, pedestrians, bicycles, and local buses. Collectors and minor arterials account for 21 percent of urban street length and carry 28 percent of all urban travel.

Compliance with Speed Regulations

There is no commonly accepted definition of compliance with speed regulations. Motorists traveling less than the posted speed limit might appear to be in compliance, but under certain weather, visibility, or traffic conditions, they may be violating the basic speed law. In the more general case of free-flowing vehicles under favorable environmental conditions, measures of compliance (actually, noncompliance) include the percentage of vehicles exceeding the posted limit by 6 or 9 mph (10 or 15 km/h), or the percentage of vehicles exceeding the roadway’s design speed.

Costs of Motor Vehicle Crashes

In highway safety analyses, it is often necessary to assign costs to traffic crashes. For example, the National Safety Council (NSC) recommends economic costs for crashes on the basis of productivity lost and expenses incurred because of collisions. NSC also estimated comprehensive costs for crashes, which included economic costs and a measure of the value of lost quality of life associated with deaths.
and injuries. The Federal Highway Administration (FHWA) has also suggested collision costs based on two different injury scales: (a) the KABC scale, with four injury levels ranging from Killed to Possible Injury; and (b) the Abbreviated Injury Scale, with six injury levels ranging from Killed to Minor. Table E-1 compares the costs recommended by NSC (1996) and FHWA (Judycki 1994).

### Table E-1 National Safety Council and FHWA Traffic Crash Costs

<table>
<thead>
<tr>
<th>Type of Injury</th>
<th>Economic</th>
<th>Comprehensive</th>
<th>KABC Scale</th>
<th>Abbreviated Injury Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>790,000</td>
<td>2,790,000</td>
<td>2,600,000</td>
<td>2,600,000</td>
</tr>
<tr>
<td>Critical</td>
<td></td>
<td></td>
<td></td>
<td>1,980,000</td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td></td>
<td></td>
<td>490,000</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>41,200</td>
<td>138,000</td>
<td>189,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Serious</td>
<td>13,900</td>
<td>35,700</td>
<td>36,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Evident</td>
<td></td>
<td></td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Moderate</td>
<td>7,900</td>
<td>17,000</td>
<td>19,000</td>
<td></td>
</tr>
<tr>
<td>Possible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>6,000(^a)</td>
<td>1,700(^a)</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>No injury—property damage only</td>
<td>6,000</td>
<td>1,700</td>
<td>2,000</td>
<td>5,000</td>
</tr>
</tbody>
</table>

\(^a\) NSC economic costs include minor injuries whereas comprehensive costs exclude all injuries.

### Crash Probability

In typical use, crash probability refers to the long-term likelihood that a driver will be involved in a crash under a specified set of conditions (e.g., on a given trip, during the coming year). Estimates of national crash experience can be used to calculate average crash probabilities. However, crash probability is known to vary with driver characteristics, vehicle type, roadway features, and environmental factors, so the crash probability for an individual motorist may be substantially more or less than the average.
Crash Severity

A fatal crash is a crash that results in one or more deaths within 30 days of the crash. A nonfatal injury crash is a crash in which at least one person is injured, but no injury results in death. A property-damage-only (PDO) crash is a collision that results in property damage, but in which no person is injured.

Cross Section

The roadway cross section consists of those geometric features perpendicular to the direction of travel. Common cross-section elements include the following:

- Number of lanes—determined by the projected traffic volume for a facility.
- Lane width—must be sufficient to accommodate the design vehicle, allow for imprecise steering maneuvers, and provide clearance for traffic flow in adjacent lanes. It is dependent on the design vehicle, design speed, volume, the presence or absence of shoulders, horizontal alignment, and the presence of oncoming traffic.
- Cross slope—promotes drainage of surface water.
- Shoulders—used for emergency stopping and for lateral support of base and surface courses.
- Medians—used to separate opposing directions of traffic on multilane highways.
- Marginal elements—curbs, gutters, sidewalks, roadside slopes, and barriers.

Design Driver

A roadway's design must be compatible with drivers’ capabilities and limitations. The design driver embodies those specific human characteristics that should be recognized in designing and operating the road. It is inappropriate to design for the median driver because this would potentially put half the drivers at risk. On the other hand, it is
probably not realistic to design for the 99th percentile value of every human characteristic. Although the American Association of State Highway and Transportation Officials (AASHTO) does not provide an explicit description of the design driver, the following elements certainly should be included:

- Familiarity: The designer should assume that motorists are driving on a roadway for the first time and that they have no familiarity with its features.
- Driver age: Certain human performance characteristics deteriorate with age. Persons over the age of 65 constitute an increasing portion of the driving population, and their special needs must be considered in highway design.
- Vision: States specify a level of visual acuity (typically 20/30 corrected) that drivers must satisfy to retain their license. Designers must not only consider this requirement for their state, but also recognize that drivers from other jurisdictions with potentially inferior visual acuity standards will be using their roads. Most states do not test drivers for nighttime vision; nevertheless, the significant amount of travel during the hours of darkness suggests that designers should consider this factor.
- Eye height: The height of a driver’s eye above the pavement affects the length of road ahead that a driver can see; eye height is a function of both the human and the vehicle. AASHTO’s recommended value (AASHTO 1994) of 1070 mm corresponds to the 7th percentile driver in a passenger car.
- Impairment: Motorists may become impaired by fatigue, medication, alcohol, and drugs. These imperfections, at least to the extent that they are legal (e.g., a blood alcohol content below 0.08), should be recognized by the designer. As a consequence, engineers must design for the prudent, rather than the perfect, driver.

Design Speed

AASHTO defines a roadway’s design speed as “the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the high-
way govern” (AASHTO 1994). This is the maximum speed prudent drivers would choose when environmental conditions are very good and traffic volumes are light. Subject to the constraints of environmental quality, economics, aesthetics, and social impacts, AASHTO recommends higher design speeds to promote safety, mobility, and efficiency. Certain highway design features, including curvature, sight distance, and roadside elements, are highly sensitive to the choice of design speed; others, including lane and shoulder widths, do not change appreciably with design speed. In planning a roadway, the engineer initially selects a design speed; that decision, in turn, establishes upper or lower bounds on the facility’s geometric design parameters. This is the principal use of design speed. On a rural, level, straight roadway with no access points and obstacle-free roadsides, the concept of design speed is not meaningful.

Drivers exceeding the design speed by a small amount under favorable conditions will not necessarily have a crash, principally because AASHTO incorporates safety factors into its design recommendations. For example, the stopping sight distance model assumes a very conservative perception-reaction time and a wet roadway surface; an alert driver can react quicker and a vehicle on a dry roadway can decelerate to a stop in a much shorter distance than the design value. Likewise, an attentive motorist can exceed a horizontal curve’s design speed without running off the roadway.

Higher design speeds enhance safety, principally by accommodating minor driver errors and providing greater opportunities for crash avoidance. AASHTO strongly recommends consistency in design speed along a roadway section to avoid misleading motorists. Although it appears reasonable that the posted speed limit should not exceed a highway’s design speed, the existing roadway system includes countless horizontal curves with safe speeds below the design speed or posted speed limit; these situations are routinely handled with curve warning signs and advisory speed plates (see Figure E-2).

Engineering Study

The Uniform Vehicle Code (National Committee on Uniform Traffic Laws and Ordinances 1992) and state motor vehicle laws
authorize state and local highway agencies to determine whether the statutory speed limit on a section of road is greater or less than is reasonable under the conditions that exist at the location. This determination must be based on an engineering study, which requires data collection and analysis in the determination of an appropriate limit. The data considered would typically include the following factors:

- Area—rural, suburban, or urban;
- Results of a spot speed study, principally the 85th percentile and 10-mph (16-km/h) pace speeds;
- Crash experience, with particular attention to speed-related crashes;
- Traffic volume and composition (i.e., types of vehicles);
- Existing traffic controls (regulatory and warning);
- Design features, including horizontal and vertical alignment, sight distance, and lane width;
- Pavement surface condition;
- Parking;
- Presence and usage of driveways;
- Roadside hazards;
- Pedestrians and bicycles;
- Speed limits on adjacent roadway sections; and
- Existing level of speed enforcement.

Typically, the speed data—particularly the 85th percentile speed—provide the first approximation of the speed zone limit. The limit may be adjusted from this value on the basis of the other factors.

**Externalities**

“Externalities” refers to the risks imposed on others not taken into account by an individual’s decision. In the case of speed choice, the term refers to the risks imposed on other road users (e.g., other drivers and vehicle occupants, pedestrians, bicyclists) by an individual driver’s selection of a driving speed. For example, a driver’s decision to accept a higher risk of death or injury in exchange for a shorter trip
time almost certainly increases the risk for other road users. Externalities are one of the primary reasons for regulating speed.

**Fatality Rates**

There are four common methods of calculating fatality rates:

- **Travel-based fatality rate**—fatalities per 100 million vehicle-mi of travel (100 mvm). In 1996, the United States had a travel-based fatality rate of 1.7 fatalities per 100 mvm. This rate is commonly used in the highway engineering community. (Note: 100 million vehicle-mi = 161 million vehicle-km.)

- **Registered vehicle fatality rate**—fatalities per 100,000 registered vehicles. In 1996, the United States had a registered vehicle death rate of 20.8 fatalities per 100,000 registered vehicles.

- **Population fatality rate**—fatalities per 100,000 population. In 1996, the United States had a population death rate of 15.8 fatalities per 100,000 people. This method of normalizing fatalities is commonly used by the health profession for infection and mortality rates.

- **Driver fatality rate**—fatalities per 100,000 licensed drivers. In 1996, the United States had a driver fatality rate of 23.3 fatalities per 100,000 licensed drivers.

**Free Flow**

A free-flowing vehicle is one whose driver has the ability to choose a speed of travel without undue influence from other traffic, conspicuous police presence, or environmental factors. In other words, the driver of a free-flowing vehicle chooses a speed that he or she finds comfortable on the basis of the appearance of the road.

In conducting a spot speed study, the field observer detects and records the speed of free-flowing vehicles. Vehicles operating under the following conditions are not free flowing and must be excluded from the sample:

- Two vehicles in the same lane have a headway (time from the front of one vehicle to the front of the following vehicle) of less than 4 s.
• A vehicle’s brake lights are on.
• A vehicle is accelerating or decelerating; this includes a vehicle entering or leaving the roadway at nearby ramps, intersections, and driveways.
• Enforcement or emergency vehicles with flashing lights are nearby.
• Oversize loads or funeral convoys are present.
• Pedestrians, animals, debris, or disabled vehicles are on or adjacent to the roadway.
• There is interference from maintenance crews.

A field observer can monitor these conditions and select a sample of truly free-flowing vehicles. However, most automatic devices used to detect and record the speeds of passing vehicles are unable to detect these interfering factors. As a result, data from automatic speed monitoring stations underestimate the free-flow speed of traffic.

**Freeway**

A freeway is a type of principal arterial designed to move large traffic volumes at high speeds. It is characterized by limited access, grade separations rather than intersections at cross streets (i.e., intersecting traffic crosses the freeway at a different level), minimum design speed of 50 mph (80 km/h), and medians to separate opposing traffic flows. Because of their superior design features, freeways have low crash rates relative to other rural roads. They constitute only 1 percent of rural highway length but carry 24 percent of all rural travel.

Freeways in urban areas are intended to move large volumes of traffic at higher speed with limited access to adjacent property. Design speeds are similar to those of rural freeways, but urban freeways often have three or four lanes in each direction and interchanges spaced at less than 1.2 mi (2 km). Most traffic traveling through an urban area uses a freeway. Although urban freeways account for less than 3 percent of the street length in urban areas, they carry more than one-third of all urban travel.
Geometric Design Standards

The geometric design standards for streets and highways specify desirable and minimum values for most geometric features, including horizontal alignment, vertical alignment, cross section, and roadside elements.

Highway Capacity

All roads, streets, and freeways have an upper limit on the amount of traffic they can accommodate during an hour. For uninterrupted flow facilities (e.g., ones without traffic signals), this flow rate is related to speed as shown in Figure E-4. At very high flow rates, the speed of the traffic stream decreases slightly; under these conditions, even a small incident can cause the flow to become unstable, and both the volume and the speed will decrease. Traffic density is the number of vehicles in a single lane 0.6 mi (1 km) in length. At low densities, motorists are able to select their speed; as conditions become more congested density increases and speeds tend to decrease. The diagonal line in Figure E-4 shows the reciprocal of density as a function of the flow rate.

Highway Functional Classification

In designing a highway facility, the engineer initially defines the function that the facility will serve. The level of service required for the anticipated volume and composition of traffic determines the subsequent selection of design speed and geometric criteria. AASHTO recommends design characteristics for four classes of rural highway: freeway, arterial, collector, and local (AASHTO 1994).
The terminology used for roadway classification in urban areas is similar to that for rural areas. However, most urban areas have special conditions that can alter the design and operation of their roadways. Factors such as higher population density, one-way streets, parking, pedestrians, and transit influence urban street and roadway design.

**Horizontal Alignment**

Horizontal alignment parameters include the curve radii \( R \) and the roadway superelevation. To provide motorist comfort and permit higher operating speeds, road segments on horizontal curves are superelevated or banked. (See Figure E-5.) The superelevation rate \( e \) may be as high as 0.12, but it is typically limited to 0.08 in areas subject to ice and snow. The engineer selects \( R \) as a function of the highway’s design speed and the superelevation.

**Level of Service**

A roadway’s operational condition as perceived by motorists is referred to as the level of service. In highway capacity analysis, this parameter has six designated levels, from A (the best condition with no congestion and higher operating speeds) to E (capacity) and F (the worst situation with extreme congestion and stop-and-go traffic). On a freeway section, most drivers judge the level of roadway performance by their travel speed. However, studies have documented that high speeds can be maintained on well-designed freeways over a considerable range of traffic volumes (see Figure E-4). As a result, the level of service for freeway sections is based on the density of traffic (vehicles per kilometer per lane); as density increases, the level of service deteriorates.
Local Roads and Streets

Local roads and streets primarily provide access to the farm, residence, business, or other abutting property. Because these facilities are not intended to accommodate much through traffic, they may have lower design speeds. Pedestrians, bicycles, and parked vehicles may use these facilities. Although 68 percent of all rural highway length in the United States is classified as local, these roads account for only 11 percent of all rural vehicle miles of travel.

Local urban streets provide access to property and connections to roadways of higher functional class. Design speeds are typically 37 mph (60 km/h) or less, and through traffic is discouraged. Traffic calming techniques are being used with increasing frequency to control vehicle volumes and speeds on local urban streets. Local streets account for 70 percent of the urban street length and carry 14 percent of all urban travel.

Median Speed

The median speed, another measure of central tendency, is the middle (or 50th percentile) value. It is readily determined by arranging all of the speed observations from low to high and then selecting the middle value. If the speed data are approximately symmetrical, the average and median will have similar values.

Operating Speed

Operating speed is the speed at which drivers of free-flowing vehicles choose to drive on a section of roadway. Figure E-6 compares the design speeds and two operating speeds (average and 95th percentile) at 12 two-lane study sites in Arkansas, Illinois, and Texas when the national 55-mph (89-km/h) speed limit was in effect (Messer et al. 1981). The dashed line represents the situation where the design and operating speeds are equal. On roadways with 50-mph (80-km/h) design speeds, average operating speeds exceeded the design speed by about 6 mph (10 km/h), and the 95th percentile speeds were 17 mph (27 km/h) greater than the design speed. These parameters increased
by relatively small amounts on highways with design speeds of 60 and 70 mph (97 and 113 km/h).

**Perception-Reaction Time**

In the context of geometric design, perception-reaction time is the interval between the instant the motorist recognizes the existence of an object or hazard on the roadway ahead and the moment the driver actually applies the brakes or takes another action. Although most alert drivers have perception-reaction times of less than 1 s, AASHTO recommends a value for stopping sight distance calculations of 2.5 s (AASHTO 1994). Vehicle speed does not affect reaction time, but the distance traveled by a vehicle during a fixed time period obviously increases with speed.

**Residence District**

For the purpose of establishing statutory speed limits, the Uniform Vehicle Code (National Committee on Uniform Traffic Laws and Ordinances 1992) defines a residence district as the territory contiguous to and including a highway not comprising a business district when the property on such highway for a distance of 90 m or more is in the main improved with residences or residences and buildings in use for business. (Note: 1 m = 3.28 ft.)
Roadside Elements

Roadside elements consist of relatively flat slopes (which provide adequate recovery room for errant vehicles), ditches and other drainage features, highway appurtenances (e.g., signs, signals, and street lights), and traffic barriers to shield traffic from steep slopes or other potentially hazardous objects.

Safe Curve Speed

The safe speed through horizontal curves is often less than the design speed on adjacent sections of tangent roadway. However, the “safe speed” on a horizontal curve is much less than the speed at which a motorist would run off the roadway. Rather, it is the speed at which the unbalanced side force experienced by the driver and other vehicle occupants starts to become uncomfortable. To quantify this feeling, traffic engineers adapted the ball bank indicator from airplanes; a modern version of this device is shown in Figure E-7. This device is mounted in a typical passenger vehicle, and readings are taken as the vehicle negotiates a curve at progressively higher speeds. The readings, of course, increase with speed. The maximum recommended values, initially established around 1940, are 14 degrees for test speeds of less than 20 mph (32 km/h), 12 degrees for speeds between 22 and 37 mph (35 and 60 km/h), and 10 degrees for speeds of 40 mph (65 km/h) or greater. An FHWA study (Chowdhury et al. 1998) evaluated the behavior of contemporary drivers in horizontal curves and recommended raising these values.
Sight Distance

Sight distance is the length of roadway ahead visible to the driver. AASHTO design standards discuss four types of sight distance—decision, intersection, passing, and stopping (AASHTO 1994).

Sight Distance, Decision

Decision sight distance is the length of roadway required for a driver to detect an unexpected hazard in the environment, recognize the hazard, select an appropriate speed and path, and initiate and complete the required maneuver safely and efficiently. In contrast to stopping sight distance, this model assumes that the driver will not simply slam on the brakes but rather will assess the situation, make an informed decision, and implement the action without interfering with other traffic. Table E-2 indicates decision sight distances on rural highways where the expected maneuvers are a controlled stop and a speed or path change.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Decision Sight Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>60</td>
<td>95</td>
</tr>
<tr>
<td>70</td>
<td>125</td>
</tr>
<tr>
<td>80</td>
<td>155</td>
</tr>
<tr>
<td>90</td>
<td>185</td>
</tr>
<tr>
<td>100</td>
<td>225</td>
</tr>
<tr>
<td>110</td>
<td>265</td>
</tr>
<tr>
<td>120</td>
<td>305</td>
</tr>
</tbody>
</table>

Note: 1 m = 3.28 ft and 1 km/h = 0.62 mph.

Sight Distance, Intersection

AASHTO identifies several intersection sight distance criteria that must be considered by the designer (AASHTO 1994). At the risk of oversimplification, intersections on high-speed rural highways must provide sufficient sight distance for motorists under the following conditions:
• A driver approaching an intersection controlled by a Yield or Stop sign or a traffic signal must have sufficient distance to see and react to the traffic control.
• Drivers stopped at a Yield or Stop sign and preparing to cross or turn onto a through highway must be able to see a sufficient distance to make their maneuver with safety and without significantly interfering with motorists on the through road.
• Drivers on the major roadway intending to turn left onto a cross street must have adequate sight distance to make their maneuver with safety.

AASHTO prescribes numerical values for these and other situations at intersections; in all cases, the required sight distances increase with the speeds of traffic approaching the intersection on the controlled approaches and on the through highway. Many jurisdictions specify intersection sight distances that are less stringent than those recommended by AASHTO.

Sight Distance, Passing

Passing sight distance is the length of roadway that a motorist must be able to see ahead in order to safely complete a passing maneuver on a two-lane highway. The AASHTO model for passing sight distance design assumes that the passing maneuver, once initiated, will be completed (AASHTO 1994). The passing sight distance model uses a driver eye height of 1070 mm and a height for the opposing vehicle of 1300 mm. The model also makes assumptions about the relative speeds of the passing vehicle, the passed vehicle, and an oncoming vehicle. AASHTO’s assumptions for design purposes are fairly conservative and result in long distances. By contrast, passing sight distances for operational purposes assume that a partially completed passing maneuver may be aborted if an opposing vehicle comes into view while the passing vehicle is in the left lane. This assumption shortens the necessary sight distance considerably. Values from the operational analysis are used by traffic engineers in
establishing the location and length of marked no-passing zones. Table E-3 compares the passing sight distances for design and operational purposes.

### Table E-3 Passing Sight Distances

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Design</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>345</td>
<td>150</td>
</tr>
<tr>
<td>60</td>
<td>407</td>
<td>170</td>
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<td>200</td>
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<td>240</td>
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<td>90</td>
<td>605</td>
<td>280</td>
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<td>100</td>
<td>670</td>
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<td>110</td>
<td>728</td>
<td>360</td>
</tr>
<tr>
<td>120</td>
<td></td>
<td>392</td>
</tr>
</tbody>
</table>

Note: 1 m = 3.28 ft and 1 km/h = 0.62 mph.

### Sight Distance, Stopping

Stopping sight distance is the minimum distance for a vehicle traveling at or near a highway's design speed on wet pavement to come to a complete stop before reaching a stationary object (150 mm high) in its path (AASHTO 1994). Adequate stopping sight distance, which should be provided at every point along all roads, consists of two components—the motorist’s perception-reaction distance and the vehicle’s braking distance. Stopping sight distance may be calculated using the following formula:

\[ d = 0.278tV + \frac{V^2}{254f} \]

where

- \( d \) = minimum stopping sight distance (m);
- \( t \) = perception-reaction time, assumed to be 2.5 s;
- \( V \) = initial speed (km/h); and
- \( f \) = coefficient of friction between tires and roadway.

The solid line in Figure E-3 shows the relationship between stopping sight distance and highway design speed. The difference between the stopping and braking distances is the length of highway traveled during the perception-reaction time.
Speed Change Lanes

Speed change lanes include acceleration and deceleration lanes, which are used in conjunction with interchange ramps to permit entering vehicles to attain the speed of the through traffic and exiting vehicles to decelerate outside of the through-traffic lanes.

Speed Dispersion

The speeds of individual vehicles on a street or highway vary, often in the manner suggested by Figure E-1. Speed dispersion refers to this spread in vehicle speeds. Speed dispersion can be quantified in various ways including the standard deviation, variance, 10-mph pace, or range (high minus low). There is general agreement that the safest conditions occur when all vehicles at a site are traveling at about the same speed.

Speed Limit, Absolute

An absolute speed limit specifies a numerical value, the exceeding of which is always in violation of the law, regardless of the conditions or hazards involved. Many enforcement officers prefer absolute speed limits because they reduce the incidence of challenged citations. However, absolute speed limits lack flexibility, particularly in those situations where traffic conditions vary widely. Approximately two-thirds of the states have absolute speed limits. Prima facie speed limits are the alternative to absolute limits.

Speed Limit, Differential

The motor vehicle codes in some states prescribe different speed limits for different classes of vehicles. For example, the maximum speed limit on a rural section of Interstate might be 75 mph (121 km/h) for cars, pickup trucks, and vans, but 65 mph (105 km/h) for large trucks. The primary rationale for this type of regulation is that large trucks have much longer stopping distance than cars. In the absence of differential speed limits, studies have found that large trucks travel 1 to 2 mph (2 to 3 km/h) slower than cars on level sections of rural
Interstate. This value may double when differential speed limits are introduced, but the actual difference between car and truck speeds rarely approaches the difference cited in the code.

**Speed Limit, Posted**

The posted speed limit is the value conveyed to the motorist on a black-on-white regulatory sign such as the one shown in Figure E-8. Standard engineering practice is to post speed limits for freeways, arterials, and any roadway or street where speed zoning has altered the limit from the statutory value. They are also used at any point where the speed limit changes, including points beyond major rural intersections where traffic may change from one road to another.

**Figure E-8 Speed limit sign.**

**Speed Limit, Prima Facie**

A prima facie speed limit is one above which drivers are presumed to be driving unlawfully. Nevertheless, if charged with a violation, drivers have the opportunity to demonstrate in court that their speed was safe for conditions at the time and not in violation of the basic speed limit, even though they may have exceeded the numerical limit. Approximately one-third of the states have prima facie speed limits or limits of each type (i.e., prima facie and absolute). Absolute speed limits are the alternative to prima facie limits.

**Speed Limit, Statutory**

State motor vehicle laws specify numerical values for speed limits on specific categories of streets and highways. For example, a code might limit speeds to 25 mph (40 km/h) in residential areas, 30 mph (48 km/h) in business districts, and 55 mph (89 km/h) on all other roads. Unless otherwise prohibited by law, these limits may be altered on the basis of an engineering study.
Speed Limit, Variable

The typical speed zoning process establishes a limit that is posted and enforceable 24 h/d. In reality, streets and highways experience conditions of traffic, weather, and incidents when lower limits would be appropriate. In some cases, the conditions will be such that motorists could not possibly travel at the posted speed limit. On the other hand, an urban speed limit established in part because of daytime pedestrian traffic may be unrealistically low for conditions at night. One method of addressing these types of situations is through the use of variable speed limits.

An urban freeway variable speed limit system would operate in the following manner. Detectors would monitor the actual volume, speed, and density of traffic in sections of the freeway. This information would be used to determine where congestion is causing traffic to slow. In advance of these locations, electronic speed limit signs (similar to Figure E-8, but with changeable numbers) would be remotely controlled to alter the posted speed limit. Motorists who comply with these regulations would decrease their speed and not approach the end of a stopped or slow-moving traffic queue at normal freeway speeds.

Speed Parameters

Field data from spot speed studies of free-flowing vehicles (see Figure E-9) are processed to determine typical data parameters of central tendency (average or median) and dispersion (standard deviation, variance, 10-mph pace, and range).

Speed Standard Deviation

The standard deviation, which has the units of speed (km/h), is the positive square root of the speed variance. Speed standard deviations are often 3.7 to 4.3 mph (6 to 7 km/h) on urban streets and 5.6 to 6.8 mph (9 to 11 km/h) on freeways. The standard deviation’s value is strongly influenced by a few vehicles traveling at very high or very low speeds; elimination of these vehicles will reduce the standard deviation. The standard deviation is readily calculated from a sample of speed measurements such as those shown in Figure E-9. It may be roughly
approximated by the speed range (largest observed speed minus the smallest) divided by 6. The standard deviation may also be estimated as the difference between the 85th percentile and average speeds.

Speed Variance

Speed variance for a spot speed study is calculated by summing the squares of the differences between each measured speed and the average speed, and dividing the total by the sample size minus one \( (n - 1) \). The variance, which is the square of the standard deviation, thus has

![SPOT SPEED SURVEY DATA FORM](image)

Figure E-9 Sample speed data collection form.

Speed Variance

Speed variance for a spot speed study is calculated by summing the squares of the differences between each measured speed and the average speed, and dividing the total by the sample size minus one \( (n - 1) \). The variance, which is the square of the standard deviation, thus has
units of speed squared (km²/h²). Speed variance has little practical value and is rarely cited as an output value from a spot speed study. The variance’s principal application is in determining the standard deviation.

The technical literature includes studies in which analysts relied on selected speed parameters, rather than having the original data such as that shown in Figure E-9. Using speed study results that report only the average and the 85th percentile speeds, these analysts have attempted to quantify speed dispersion by calculating the numerical difference between these two values. Although this difference usually provides a good approximation of the speed sample’s standard deviation, these analysts have unfortunately and incorrectly labeled this result as “speed variance.” In reality, it is an estimate of standard deviation.

**Speed Zone**

Speed zoning is the process of establishing a reasonable and safe speed limit for a section of roadway where the statutory speed limits given in the motor vehicle laws [e.g., 30 mph (48 km/h) in business districts] do not fit the road or traffic conditions at a specific location. The limits may be altered on the basis of an engineering study. To be enforceable, the new limits must be posted along the roadway using a standard regulatory sign such as the one shown in Figure E-8. In addition, speed limits that are increased or decreased as a result of the speed zoning process must be recorded in documents maintained by an appropriate agency (e.g., state supreme court library). Speed zones should be periodically restudied.

The basic principles of speed zoning should also be applied to special situations such as school crossings and roadway construction areas. In addition, they may be used to establish minimum speed limits for freeways.

**Spot Speed Study**

Engineers conduct spot speed studies by measuring and recording the speeds of a sample of free-flowing vehicles as they pass a point on a street or highway. The measurements are usually made with a hand-held radar or laser speed meter. The field data are typically recorded on a data form similar to the one shown in Figure E-9. This study is an essential ele-
ment in the more comprehensive engineering study required for speed zoning. Unless there is an interest in other conditions, a spot speed study is normally conducted on a straight, level road during daylight, off-peak hours. Speed data are collected separately by direction. Minimum sample sizes of at least 100 vehicles are necessary to properly represent the speed characteristics of the traffic at the study site.

Traffic Calming

Traffic calming is a term used to identify various engineering techniques to physically control vehicle speeds and/or volumes on local streets. The techniques, which include speed humps, traffic diverters, narrow roadways, and staggered alignment, are deployed in response to complaints by adjacent property owners of speeding traffic or excessive traffic volumes. Although these techniques have been found effective on local streets, they must be planned and implemented carefully to ensure that the original problems are not simply moved to another local street.

Vehicle Alignment

A roadway’s vertical alignment consists of grades, where the elevation changes at a fixed rate per unit distance along the highway, and vertical curves, where the highway grade increases or decreases. These features are portrayed in Figure E-10. As indicated in Table E-4, AASHTO recommends maximum grades for rural highways as a function of highway classification and type of terrain (AASHTO 1994). Maximum grades on urban freeways are identical to those for rural freeways, but grades steeper than those given in Table E-4 are permitted on urban arterial, collector, and local streets. Minimum lengths of crest vertical curves are a function of the approach and departure grades as well as the stopping sight distance for the roadway’s design speed.
Vehicle Miles of Travel

The total amount of travel on a roadway segment or on an entire roadway system is typically expressed in vehicle miles of travel (VMT). The numerical value may be obtained by multiplying the length of a section (in miles) by average traffic volume (vehicles per day), summing these values for all sections of interest, and expanding the results to an annual value. VMT is commonly used to characterize the amount of travel on different classes of roadway and as a normalizing factor in calculating crash or fatality rates.

REFERENCES

ABBREVIATIONS
AASHTO American Association of State Highway and Transportation Officials
NSC National Safety Council


Table E-4 Maximum Vertical Grades for Rural Roads

<table>
<thead>
<tr>
<th>Terrain</th>
<th>Maximum Grade (%)</th>
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</tr>
<tr>
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<td>4–5</td>
</tr>
<tr>
<td>Mountainous</td>
<td>5–6</td>
</tr>
</tbody>
</table>