Professional Traffic Operations Engineer Certification Program Refresher Course

Student Supplement

Module 2
Operational Effects of Geometric Designs

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Introduction to Refresher Course

This Refresher Course provides an overview of topics, key references and independent study materials by topic for practicing engineers who intend to take the PTOE certification examination. The suite of modules includes six (6) webinar recordings on traffic operations analysis, operational effects of geometric designs, traffic safety, traffic control devices, traffic engineering studies, and social, environmental, and institutional issues, each accompanied by a student supplement.

This 2022 version of the course and student supplement is an update and expansion to a July 2016 course managed by Robert K. Seyfried, P.E., PTOE. Contributors to that course were:

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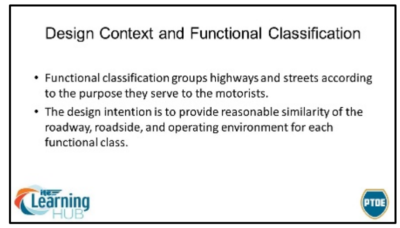
Much appreciation is given to Stephen J. Manhart, P.E., PTOE, PTP, RSP_1, Project Manager for Traffic Engineering, Michael Baker International, Minneapolis, MN, for his review of the student supplements on behalf of the Transportation Professional Certification Board.

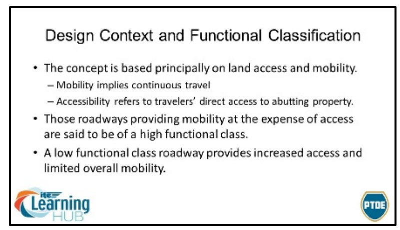
Contents

Module 2- Operational Effects Of Geometric Designs

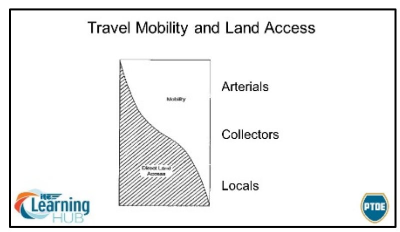
Design Context And Functional Classification



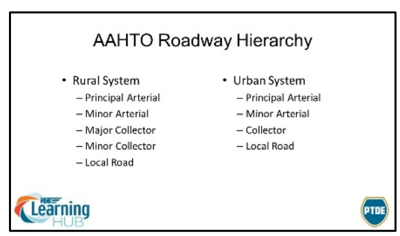
Functional classification groups highways and streets according to the purpose they serve to the motorists. The design intention is to provide reasonable similarity of the roadway, roadside, and operating environment for each functional class. Although classification schemes vary in rural and urban areas, three general categories exist - arterials, collectors, and local streets.



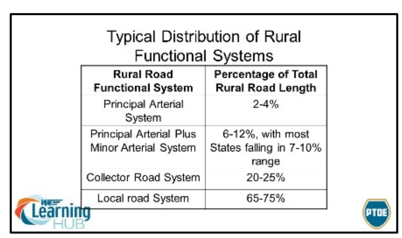
The concept of classifying the highways and street network is based principally on land access and mobility. The idea of mobility implies continuous travel while accessibility refers to travelers' direct access to abutting property. Those roadways providing mobility at the expense of access are said to be of a high functional class. A low functional class roadway provides increased access and limited overall mobility.



Roadway Hierarchy



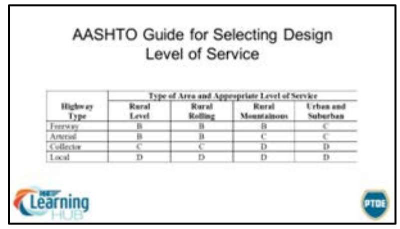
The American Association of State Highway and Transportation Officials (AASHTO) has developed a roadway classification scheme:


Typical Distribution of Rural Functional Systems

Rural Road Functional System	Percentage of Total Rural Road Length
Principal Arterial System	2-4%
Principal Arterial Plus Minor Arterial System	6-12%, with most States falling in 7-10% range
Collector Road System	20-25%
Local road System	65-75%

Rural System:

- Principal Arterial
    - Substantial statewide or interstate travel
    - Movements between population centers >50,000 individuals
    - Includes most existing rural freeways
    - Freeways are defined as having full control of access
- Minor Arterial
    - Link between cities, large towns and traffic generators
    - Continuity between interstate and inter-county service
    - Spacing follows population density
    - Trip lengths greater than those served by lower functional classes
    - Provide generally high travel speeds and minimal interference to through movements
- Major Collector
    - Serve towns not on arterial routes
    - Serve traffic generators not on arterial routes
    - Link to routes of higher classification

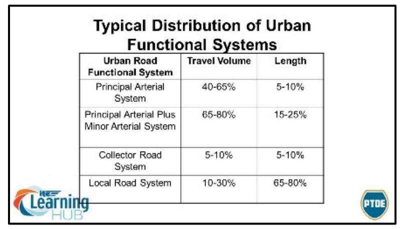


AASHTO Guide for Selecting Design Level of Service

Highway Type	Type of Area and Appropriate Level of Service			
	Rural Level	Rural Rolling	Rural Mountainous	Urban and Suburban
Freeway	B	B	B	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

- Important intra-county routes
- Minor Collector
  - Spacing follows population density
  - Provide service to smaller communities
  - Link locally important traffic generators with outlying remote areas
- Local Road
  - Primarily provides access
  - Serves travel over short distances
  - Contains all rural mileage not in a higher classification

Urban System



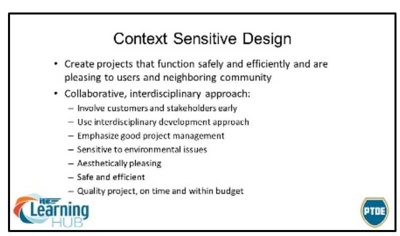
Typical Distribution of Urban Functional Systems

Urban Road Functional System	Travel Volume	Length
Principal Arterial System	40-65%	5-10%
Principal Arterial Plus Minor Arterial System	65-80%	15-25%
Collector Road System	5-10%	5-10%
Local Road System	10-30%	65-80%

- Principal Arterial
  - Serves major centers of activity
  - Serves highest traffic corridors
  - Provides continuity between urban centers and major rural connections
  - Subdivided into interstates, other freeways and expressways, and other principal arterials
- Minor Arterial
  - Includes all arterials not classified as principal
  - Provides intra-community connectivity
  - Ideally does not penetrate neighborhoods
- Collector
  - Provides for land access and traffic circulation within residential neighborhoods and commercial/industrial areas
  - Collects traffic from local road for channelization to the arterial system
  - May carry bus routes and include the entire street grid system
- Local Road
  - All facilities not classified as a higher functional class
  - Direct access to land
  - Service to through traffic is discouraged

Land Use Type

The surrounding land uses have a significant impact on the design of the roadway facility; key is the required level of accessibility along the roadway. As noted in the roadway hierarchy discussion above, roads carrying high speed and high-volume traffic should generally not be used for access to adjacent properties.



Many agencies utilize land use in defining a context classification for roadway design. For example, the Florida Department of Transportation has adopted the following classifications based on land use types:

- C1 Natural Lands - Preserved in a natural or wilderness condition, including lands unsuitable for settlement due to natural conditions.
- C2 Rural - Sparsely settled lands, may include agricultural land, grassland, woodland, and wetlands.

- C2T Rural Town - Small concentrations of developed areas immediately surrounded by rural and natural areas; includes many historic towns.
- C3R Suburban Residential - Mostly residential uses within large blocks and a disconnected / sparse roadway network.
- C3C Suburban Commercial - Mostly non-residential uses with large building footprints and large parking lots. Buildings are within large blocks and a disconnected/sparse roadway network.
- C4 Urban General - Mix of uses set within small blocks with a well-connected roadway network. May extend long distances. The roadway network usually connects to residential neighborhoods immediately along the corridor and/or behind the uses fronting the roadway.
- C5 Urban Center - Mix of uses set within small blocks with a well-connected roadway network. Typically concentrated around a few blocks and identified as part of the civic or economic center of a community, town, or city.
- C6 Urban Core - Areas with the highest densities and building heights and within FDOT classified Large Urbanized Areas (population> 1,000,000). Many are regional centers and destinations. Buildings have mixed uses, are built up to the roadways, and are within a well-connected roadway network.

Freeway Versus Non-Freeway Facilities

Design considerations vary significantly between freeway and non-freeway facilities. Freeways are generally fully access-controlled facilities with no at-grade intersections or driveways. Minimum access locations are usually provided along arterials. Because of their very nature, collector and local roadways are intended to provide for high levels of access.

Access Management

Access control is the legal limitation or restriction of access to and from properties neighboring highway facilities. The principal operational difference between the street or highway with or without access control is the degree of interference with through traffic by other vehicles or pedestrians entering, exiting, and crossing the highway. Both operational safety and efficiency are improved when access points along a highway are controlled. Freeways are generally fully access-controlled facilities with no at-grade intersections or driveways. Minimum access locations are usually provided along arterials. Because of their very nature, collector and local roadways are intended to provide for high levels of access. Efforts should, however, be made to restrict access locations near intersections to avoid vehicle conflicts.

Modal Split

Included in the design context is the anticipated modal split; will there be significant pedestrian or bicycle traffic; are there transit facilities; will this facility accommodate significant freight movement; and similar considerations. Each of these has an impact on the optimal geometric design. These are typically quantified into percentages of heavy vehicles, transit vehicles, bicycles, motorcycles, and pedestrians, and used for design considerations, determining traffic impacts, and quantifying travel demand management for land uses.

Road User Characteristics And Accommodations

There are three components of the highway safety system that must be considered in the traffic operations and roadway design - the road user, the vehicle, and the roadway. System failures - crashes, congestion, etc. - occur when one or more of these elements fail, either individually or through interaction within the environment (weather, light conditions, etc.).

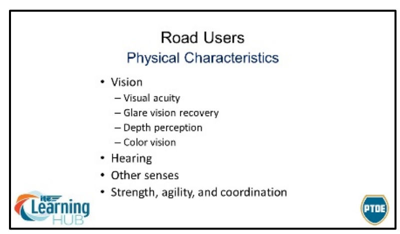
The analysis of road user characteristics includes:

- Consideration of what people can do (the physical characteristics)
- Variability and limitations of these physical characteristics
- Psychological, attitudinal, and other modifying factors that influence people's responses and behavior (what they actually do).

Road users include:

- Drivers. The driving task is very complex. Drivers must possess necessary skills to safely operate a motor vehicle in an uncertain environment, interacting with the roadway and the behavior of other road users.
- Pedestrians. Providing a safe environment for pedestrians requires special considerations. Pedestrians may use the same roadway space as motor vehicles. However, the behaviors and physical limitations of pedestrians are significantly different than those of motor vehicles and their operators. Pedestrians represent a wide range of abilities and limitations, including children, adults, elderly, and those with disabilities.
- Bicyclists. Bicyclists present another set of challenges to the traffic engineer. Their perceptions of the dangers of the cycling task may be limited. In addition, many cyclists are children, with limited skills and lacking experience.

An understanding of the physical characteristics of road users is essential in the design and operation of transportation systems. One must know the capabilities of drivers and pedestrians to provide proper guidance and control. Important physical characteristics include:



- Vision
- Hearing
- Other senses
- Strength and coordination

Of all the physical characteristics of road users, vision is the most important. Vision components that must be considered include:

- Visual Acuity. The ability to discern objects. While minimums are established to obtain a driver's license, there is a great deal of variability among road users. Visual acuity may change during a person's lifetime. It will also vary with the amount of illumination provided. Static visual acuity may be better than dynamic visual acuity. Thus, the placement of a sign to guide or warn drivers may be adequate for most drivers during the day but may be inadequate for the elderly at night. Traffic signs and markings should be placed within a cone of clear vision of approximately 10 degrees.
- Glare Vision and Recovery. Glare greatly impairs the ability to see. Traffic operations decisions must consider glare effects in the placement of roadway illumination and in locating signs and traffic signals. Glare recovery time increases with age.

- Depth Perception. Road user decisions such as determining if a safe passing maneuver can be performed or if there is an adequate gap in traffic for a pedestrian to cross a street are based on the ability to perceive speeds and distances.
- Color Vision. Color vision is important, because color is one of the factors considered in the design of traffic control devices. To accommodate individuals with restricted color vision other factors, such as placement and shape, are used to communicate with the road user.

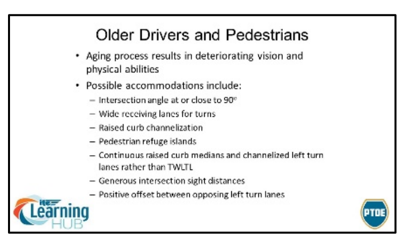
Physical characteristics define what road users can do under a given set of circumstances. However, traffic engineers must consider actual road user behavior, which can be very different based on several modifying factors. Some of these key factors include:

- Psychological factors such as motivation, intelligence level, and attentiveness
- Attitudinal factors including attitudes toward risk and regulation, impatience, and anger
- Maturity and experience
- Fatigue, drugs, and alcohol
- Age and physical disability
- Weather and light conditions

Perception-reaction time (PRT) is defined as a person's ability to recognize and respond to a situation that may require a decision and action. PRT is an important element to be considered in the placement of traffic control devices and in designing roadways. It has been found that most drivers (95 percent) have a PRT of two seconds or less for most common roadway situations. The American Association of State Highway and Transportation Officials (AASHTO) recommends using a value of 2.5 sec. for calculating Stopping Sight Distance (SSD) to include drivers with slower response times and to accommodate drivers affected by the modifying factors listed above. AASHTO recommends that a longer PRT time be used in complex or unexpected situations such as freeway lane drops or exit ramps.

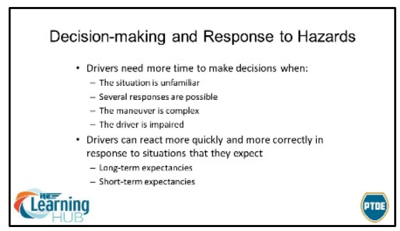
The roadway must be designed so that it can be traversed safely and efficiently by the users. The driving task is performed by the drivers according to their ability to receive and process information, and ultimately perform actions. In addition to the driving task, drivers have limitations on the amount of information they are able to process. If a highway is designed to reinforce driver expectations, drivers will accurately and readily make decisions. When highways are designed with unusual or unexpected situations, driver expectancies are violated, reaction times are increased, and driver error is not uncommon.

The population of road users consists of individuals with substantial variability in capabilities and limitations. Traffic engineers must consider this variability in roadway design and placement of traffic control devices. One must not design for the "average" driver or pedestrian, because this would mean that 50 percent of drivers and pedestrians would not be able to perform the task within the specified time. Designing for the worst condition would be a costly proposition and may result in driver confusion and inefficient operation. In most cases, traffic engineers select design values which can accommodate 85 percent or more of road users.



The elderly and the handicapped pose a special concern to the traffic engineer. The population is aging, yet older people have mobility needs and are road users as drivers and pedestrians. The aging process is accompanied by deterioration in visual and physical skills. Older drivers do not see as well at night. The average walking speed of older pedestrians is slower than the speed of younger people. The following are among the design accommodations that can be made to recognize the limitations of the elderly and the handicapped:

- Intersection angle at or close to 90°
- Wide receiving lanes for turns
- Raised curb channelization
- Acceleration lanes for right turns
- Sloping rather than vertical curbs
- Pedestrian refuge islands
- Continuous raised curb medians and channelized left turn lanes rather than TWLTL
- Generous intersection sight distances
- Positive offset between opposing left turn lanes
- Corner curb radii less than 25 to 30 feet
- Roundabouts limited to single lane
- Extended pedestrian intervals at signalized crosswalks
- Use of RRFBs or similar enhancement devices at unsignalized crosswalks.



Driver error is a significant contributing factor in most crashes. For example, drivers can make errors in judgment concerning closing speed, gap acceptance, curve negotiation, and appropriate speeds to approach intersections. In-vehicle and roadway distractions, driver inattentiveness, and driver weariness can lead to errors. A driver may also be overloaded with information processing required to carry out multiple tasks simultaneously, which may lead to errors. Drivers are more likely to make mistakes when their expectations are not met.

One way to accommodate human limitations is to design roadways to meet driver expectations. When drivers can rely on past experience to assist in the driving task, errors are less likely. Drivers develop both long- and short-term expectancies. Long-term expectancies are global in nature, and drivers anticipate that they will be true everywhere. Examples of long- term expectancies include:

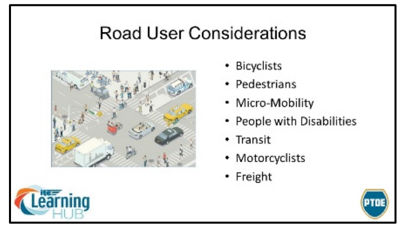
- Freeway exits will be on the right-hand side of the road
- When approaching an intersection, drivers must be in the left lane to make a left turn
- A continuous through lane will not end at an interchange or intersection

Short-term expectancies are developed over the most recent few miles or minutes of travel on a roadway. These may include:

- On a gently winding road, upcoming curves will continue to be gentle
- After traveling at high speed for some considerable distance, the road ahead will be designed to accommodate the same speed
- A road that has the characteristics of a freeway will not have any at-grade intersections or driveways.

Drivers can respond more quickly and correctly to conditions that they expect and are more likely to react more slowly and are more likely to make mistakes when conditions do not meet their expectations. The best (safest) roadway design is one that provides consistency and meets driver’s expectations.

Bicycle



Bicycles are an important element of the transportation system for both utilitarian as well as recreational trips. In many cases, bicycles can safely and comfortably share roads with motor vehicle traffic. Improvements that can considerably enhance the safety of a street or highway for bicycle usage include:

- Paved shoulders
- Wider outside traffic lanes (14-foot [4.2 m]) minimum width) if no shoulder exists
- Bicycle lanes
- Bicycle-safe drainage grates
- Maintaining a smooth, clean riding surface

Providing a secure parking facility at the bicyclist's destination is also an important factor in determining the viability of bicycle use for a particular trip.

Pedestrian

Walking is the most basic mode of transportation and is a fundamental part of the transportation system. Safety is a key consideration in the design of pedestrian facilities. Accessibility and usability are also key considerations for pedestrian facilities which should accommodate pedestrians of all abilities including children, adults, the elderly, and those with disabilities.

Federal regulations provide that when new pedestrian facilities (or projects that alter existing facilities) are planned, those facilities must be designed and constructed to be accessible to and usable by people with disabilities.

Micro-Mobility

Micro-mobility vehicles have proliferated in both large cities and small towns, utilizing existing right-of-way and transportation infrastructure that was not explicitly designed with these vehicles in mind. Designing new facilities that accommodate micro-mobility is an evolving field. The launch of micro-mobility has exposed significant new challenges that must be addressed through policy, planning, design, and maintenance. Several organizations have addressed policy and planning considerations for micro-mobility vehicles, but facility design and maintenance guidance for micro-mobility vehicles remains limited.

Considerations For People With Disabilities

The United States Access Board is developing new guidelines under the Americans with Disabilities Act (ADA) and the Architectural Barriers Act (ABA) that will address access to sidewalks and streets, crosswalks, curb ramps, pedestrian signals, on-street parking, and other components of public rights-of-way. These guidelines also review shared use paths, which are designed primarily for use by bicyclists and pedestrians for transportation and recreation purposes. Known as Public Rights-of-Way Accessibility Guidelines (PROWAG), the latest information on the application and status of these requirements can be found at https://www.access-board.gov/prowag/.

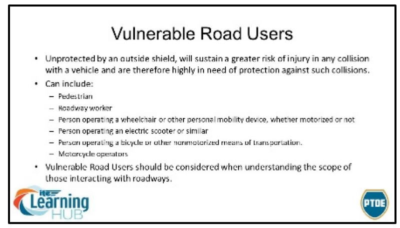
Transit

Design considerations for public transit on city streets and freeways would include both bus and light-rail systems. Each has very specific design requirements and must be considered early in the design process.

Vehicle Characteristics (E.G., Size, Operational Capabilities)

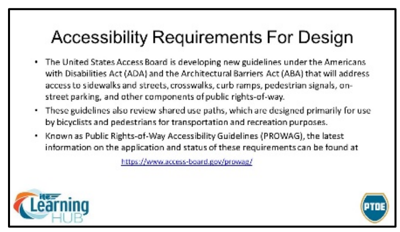
There is not a standard vehicle used on our roadways, but rather a large variety of automobiles, pick-ups, and SUVs, single unit and tractor-trailer trucks, buses, motorcycles, and more. Each has its own operating characteristics; variations in acceleration and deceleration, lengths of vehicle, speeds, turning radii, stopping distances, height of driver eye, and more. These are addressed by selecting an appropriate design vehicle as discussed later in this document.

Vulnerable Road Users



The National Safety Council describes the term *vulnerable road user* (VRU) as those unprotected by an outside shield, as they sustain a greater risk of injury in any collision with a vehicle and are therefore highly in need of protection against such collisions. This broad definition can include (but is not limited to): a pedestrian; a roadway worker; a person operating a wheelchair or other personal mobility device, whether motorized or not; a person operating an electric scooter or similar; and a person operating a bicycle or other nonmotorized means of transportation. Motorcycle operators can also be considered as VRUs due to their lack of vehicle enclosure and higher risk of injury in a collision. This expansive definition should be considered when understanding the scope of those interacting with roadways.

Accessibility Requirements For Design



PROWAG's accessibility guidelines apply to pedestrian facilities in the public right-of-way. The proposed guidelines define the public right-of-way to mean "public land or property, usually in interconnected corridors, that is acquired for or dedicated to transportation purposes". The proposed guidelines ensure that the following facilities for pedestrian circulation and use located in the public right-of-way are readily accessible to and usable by pedestrians with disabilities:

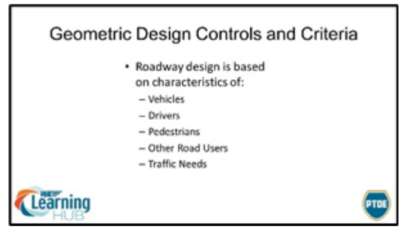
- Sidewalks, pedestrian overpasses and underpasses, and other pedestrian circulation paths, including requirements for pedestrian access routes, alternate pedestrian access routes when pedestrian circulation paths are temporarily closed, and protruding objects along or overhanging pedestrian circulation paths
- Pedestrian street crossings, medians, and pedestrian refuge islands, including requirements for curb ramps or blended transitions, and detectable warning surfaces
- Pedestrian street crossings at roundabouts, including requirements for detectable edge treatments where pedestrian crossing is not intended, and pedestrian activated signals at multi-lane pedestrian street crossings
- Pedestrian street crossings at multi-lane channelized turn lanes at roundabouts and at other signalized intersections, including requirements for pedestrian activated signals
- Pedestrian signals, including requirements for accessible pedestrian signals and pedestrian pushbuttons
- Transit stops and transit shelters for buses and light rail vehicles, including requirements for boarding and alighting areas at sidewalk or street level, boarding platforms, and route signs
- Pedestrian at-grade rail crossings, including requirements for flangeway gaps
- On-street parking that is marked or metered, and passenger loading zones

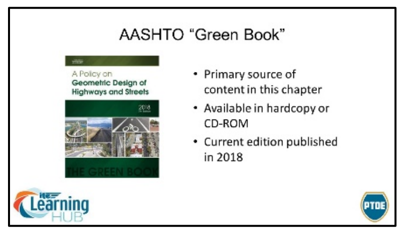
- Pedestrian signs, including requirements for visible characters on signs and alternative requirements for audible sign systems and other technologies
- Street furniture for pedestrian use, including drinking fountains, public toilet facilities, tables, counters, and benches
- Ramps, stairways, escalators, handrails, doors, doorways, and gates.

Any design effort should take into consideration PROWAG guidance.

Geometric Design Controls And Criteria

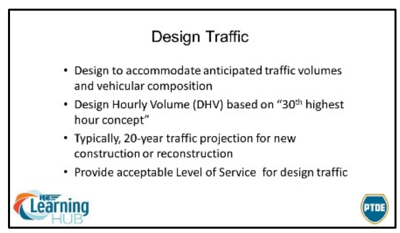
Roadway design is based on the characteristics of vehicles, drivers, pedestrians, and traffic. Design controls are the physical dimensions or limitations of vehicles, drivers, pedestrians, and traffic that guide the geometric design of roads.

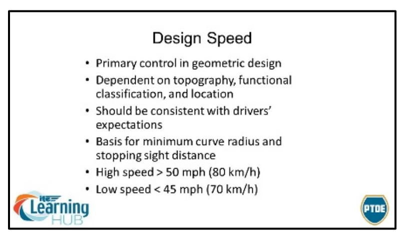




Design Speed

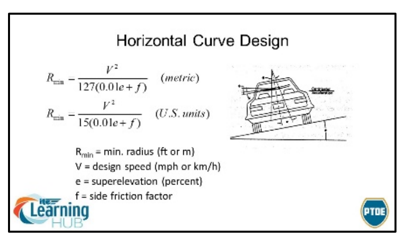
The design speed is the selected speed used to determine the various geometric design features of the roadway. The design speed selected depends on the location of the roadway, the functional classification, and the topography of the land. Highway design features such as horizontal curvature, vertical grades, superelevation, and sight distance are determined once a design speed has been established. High-speed design is 50 mph (80 km/h) or greater while low-speed design is 45 mph (70 km/h) or less.





Horizontal Curve Radius

The horizontal alignment is made up of tangents and curves. Horizontal curve design must meet two criteria: sight distance and lateral acceleration. A minimum stopping sight distance must be provided at all points along a horizontal curve to ensure that objects in the road ahead can be adequately seen as drivers traverse the curve. Lateral acceleration stems from the laws of physics and is the apparent force (centrifugal force) pushing a driver away from the center of the curve. This force is counteracted by side friction between the vehicle tires and pavement surface and superelevation of the pavement. The following expression illustrates the relationship among horizontal curve characteristics and vehicle speed:



$$R_{\min} = \frac{V^2}{127(0.01e + f)} \quad (metric)$$

$$R_{\min} = \frac{V^2}{15(0.01e + f)} \quad (U.S.\ units)$$

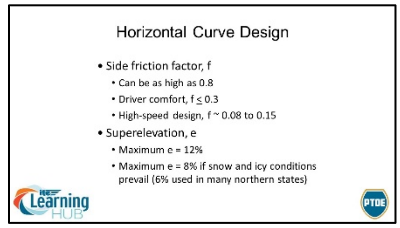
Where:

R_{min} = minimum radius (ft or m)

V = design speed (mph or km/h)

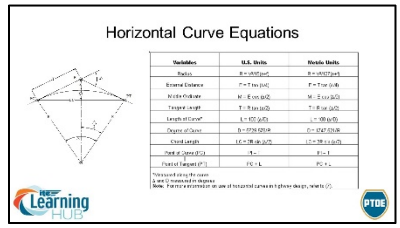
e = rate of superelevation (percent)

f = coefficient of side friction



Although side friction factors can be as high as 0.8 with a dry pavement surface, drivers usually feel comfortable at values of only up to 0.3 in a low-speed operating environment. In a high- speed environment, drivers usually accept less lateral acceleration and consequently the accepted maximum side friction factor is in the range of 0.15 to 0.08.

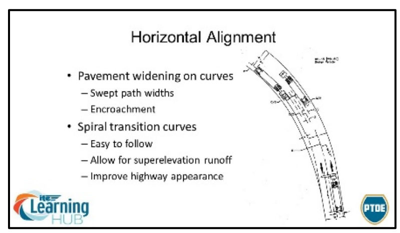
Superelevation



The term superelevation applies to sloping the cross section of a roadway to accommodate a vehicle traveling around a horizontal curve. There is a practical limit to the rate of superelevation—excessive rates may cause slow-moving vehicles to slide toward the center of the roadway when snow and icy conditions prevail. General design practice has been to design high-speed roadways with a maximum rate of superelevation of 12 percent (0.12 ft/ft or m/m). Where snow and icy conditions are common, the maximum rate of superelevation should be limited to 8 percent (although some agencies use a maximum of 6 percent).

Pavement Widening on Curves

When negotiating a horizontal curve, a motorist will perceive the width of the roadway as being reduced because the angle of the view of the roadway ahead changes. Because this may cause difficulty in steering the vehicle and because the vehicle generally occupies a greater width due to the rear wheels tracking inside the front wheels, pavement widths are sometimes widened around curves. As expected, the need for pavement widening around curves increases as the vehicle size increases, and as the pavement width and curve radius decrease.



Transition Design

Transition design covers both the transition in roadway cross-slope as well as transition in curvature in the design of the horizontal alignment. Transitioning the pavement cross-slope on tangent roadway sections to a superelevated cross-slope in curved roadway sections is referred to as superelevation transition. It is done at both ends of a curve (PC and PT) to provide motorist comfort and safety as they negotiate a curve. In this case, the tangent section of roadway is connected directly to the circular curve. Superelevation transition involves rotating the pavement surface about the roadway centerline or along the inside or outside edge of the traveled way. Tangent-to-curve transitions provide for superelevation runoff and tangent runout.

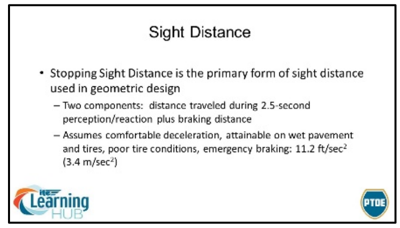
Alignment transition is sometimes accomplished using spiral curves. Spiral transitions introduce motorists to a circular curve gradually, by using one or more curves to connect the tangent roadway segment to the circular curve. The advantages of using spiral curve transitions are that they:

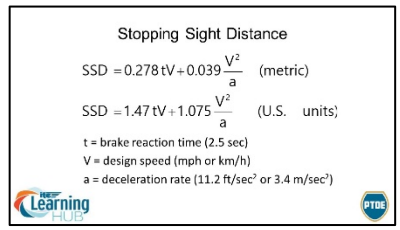
- Simulate the natural driving path of vehicles
- Provide a suitable location for superelevation runoff
- Facilitate pavement widening on a circular curve
- Enhance the appearance or the roadway

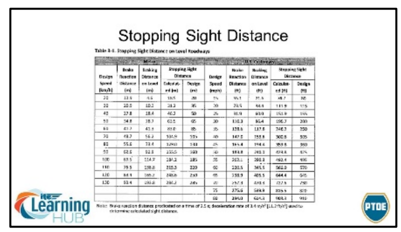
Horizontal curve lengths and radii should be in balance with the corridor terrain and with the lengths of tangents in the horizontal alignment. “Broken back” curves (two horizontal curves in the same direction separated by a short tangent section) should be avoided.

Sight Distances

Highway designers evaluate five different types of sight distance:







- Stopping Sight Distance - Stopping sight distance is the primary form of sight distance used in geometric design. In concept, stopping sight distance should be designed to provide enough distance for a driver traveling at the design speed to safely stop the vehicle before colliding with an obstacle in the roadway. Stopping sight distance (SSD) is made up of two components: distance traveled during perception of and reaction to an obstacle, and distance traveled during braking. SSD on level grades can be calculated using the following equation:

$$SSD = 0.278\,tV + 0.039\,\frac{V^2}{a} \quad \text{(metric)}$$

$$SSD = 1.47\,tV + 1.075\,\frac{V^2}{a} \quad \text{(U.S. units)}$$

where:

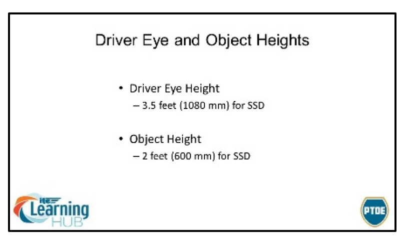
t = brake reaction time (2.5 sec.)

V = design speed (mph [km/h])

a = deceleration rate (11.2 ft/sec2 or 3.4 m/sec2)

Perception/reaction time (PRT) is the amount of time a driver requires to see and identify a stimulus on the roadway and react to it. Based on research, AASHTO recommends a PRT of 2.5 sec. to be used for stopping sight distance. When driving conditions are not clear or situations are unexpected, drivers require longer response times. Desirably, sight distances greater than minimum SSD should be provided where vehicle conflicts or complex conditions exist.

The SSD model assumes deceleration rates that are comfortable and attainable on wet pavements and are within the braking capabilities of typical vehicles.



The *AASHTO Green Book* recommends that SSD be measured from an assumed passenger car driver eye height of 3.5 feet (1080 mm) to a target height of 2.0 feet (600 mm). The assumed target height is based on passenger car taillight height.

When on grades, braking distance may be different than on level terrain. As such, the following equation can be used to modify the braking distance component in the previous equation:

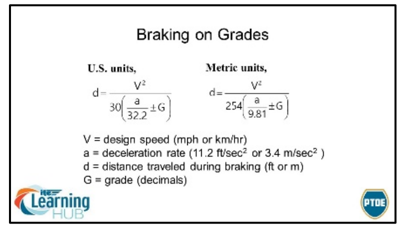
U.S. units,

$$d = \frac{V^2}{30\left(\frac{a}{32.2} \pm G\right)}$$

Metric units,

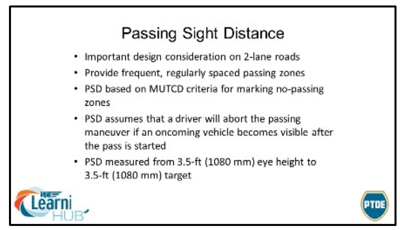
$$d = \frac{V^2}{254\left(\frac{a}{9.81} \pm G\right)}$$

V = design speed (mph or km/hr)
a = deceleration rate (11.2 ft/sec^2 or 3.4 m/sec^2)
d = distance traveled during braking (ft or m)
G = grade (decimals)

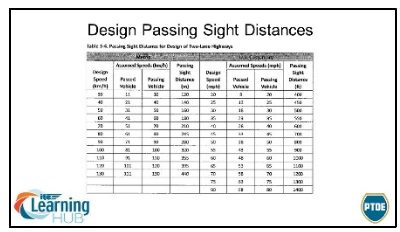


On upgrades, SSD braking distances will be shorter than on level terrain. On downgrades, braking distances will be longer than on level terrain.

- Passing Sight Distance is important on two- lane, two-way roadways where passing maneuvers are performed by faster vehicles passing slower vehicles and where the passing must be accomplished in a lane usually used by opposing traffic. The provision of frequent opportunities to pass is important for both capacity and safety considerations. Passing sight distances are longer than stopping sight distances and are consistent with the Manual on Uniform Traffic Control Devices (MUTCD) criteria for marking no-passing zones.

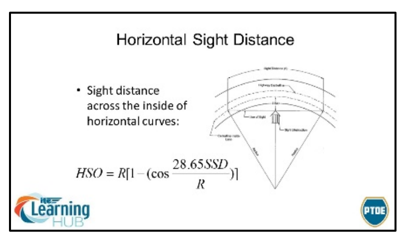


The current AASHTO design passing sight distances are considerably shorter that criteria found in earlier editions of this manual. The passing sight distances assume that a driver who has begun a passing maneuver will abort the maneuver and drop back into the driver's original lane if an oncoming vehicle becomes visible after the pass has begun. Recent research has found that this criteria provides adequate safety for passing vehicles.



Passing sight distance is measured from an assumed passenger car driver eye height of 3.5 feet (1080 mm) to a target height of 3.5 feet (1080 mm) representing the upper portion of the opposing passenger car.

- Horizontal Sight Distance - Roadside objects may restrict available sight distance around a horizontal curve and should be checked to ensure that vehicles traveling the inside lane of the curve have adequate SSD as a minimum. The following expression can be used to calculate the required clearance (horizontal sightline offset) to roadside sight obstructions (measured from the centerline of the inside lane) to provide stopping sight distance:



$$HSO = R[1 - (\cos\frac{28.65SSD}{R})]$$

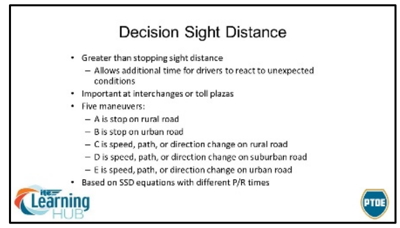
where:

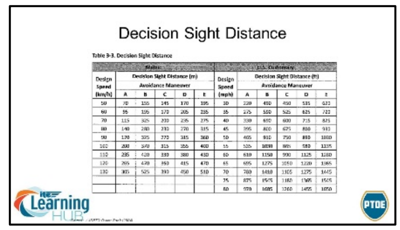
R = curve radius (ft or m)

SSD = stopping sight distance (ft or m)

HSO = horizontal sightline offset (ft or m)

- Decision sight distance - When unexpected conditions or sources of information are present in the roadway environment, stopping sight distance may not be adequate for drivers to recognize the condition and to take appropriate action. As such, decision sight distance can be used in design to allow for additional time by the driver to react to unexpected conditions. Locations where decision sight distance is important include interchanges and complex intersections, lane drops, or at toll plazas that contain a significant amount of visual demand for the driver.





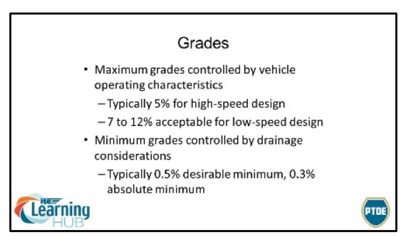
  Various maneuvers are denoted A, B, C, D, and E. Maneuver A is a stop on a rural road; maneuver B is a stop on an urban road; maneuver C is a speed, path, or direction change on a rural road; maneuver D is a speed, path, or direction change on a suburban road; and maneuver E is a speed, path, or direction change on an urban road.

  Decision sight distance can be computed using the stopping sight distance equations; however, rather than using 2.5 seconds for perception-reaction time, other times are used. Maneuver A assumes a 3.1 second perception-reaction time. Maneuver B assumes a 9.1 second perception-reaction time. Maneuver C assumes a perception-reaction time between 10.2 and 11.2 seconds. A perception-reaction time between 12.1 and 12.9 seconds is assumed for Maneuver D. A perception-reaction time between 14.0 and 14.5 seconds is assumed for Maneuver E.

- Intersection Sight Distance - Because intersections are locations where vehicle conflicts occur, a driver needs a clear line of sight both approaching and departing at-grade intersections to make a safe crossing or turning maneuver. The “Intersection Design” section contains more information about intersection sight distance.

Maximum Grade

Maximum grades are set to ensure consistent vehicle speeds on highways. Steep grades force heavy vehicles (such as trucks) to slow, thus disrupting traffic flow. In general, it is appropriate to limit grades to five percent for a 70 mph (120 km/h) design speed. Grades in the range of 7 to 12 percent are acceptable for low-speed designs. A minimum grade of 0.5 percent is desirable in level terrain to ensure proper roadway surface drainage. The absolute minimum grade for drainage is 0.3 percent.



Cross Slope

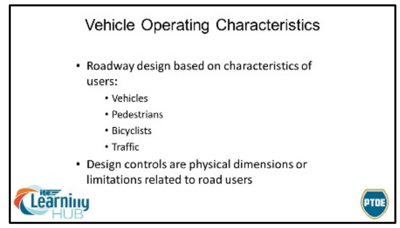
The cross slope is also a consideration in roadway design, and on tangent sections of roadway, serves primarily in a drainage role, allowing rainfall to drain from the roadway surface to a roadside collection facility. Cross slope in a curve is known as superelevation and provides motorist comfort and safety as they negotiate the curve.

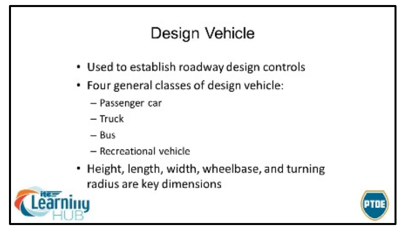
Vertical Clearance

Vertical clearance is an important factor in accommodating taller vehicles along a roadway facility. All intended vehicles should be able to pass under overhead structures without conflict.

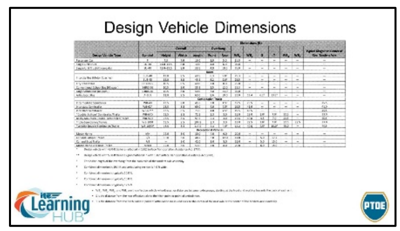
Design Vehicles

Roadways, intersections, ramps, parking lots, and other traffic-related facilities are designed to accommodate certain types of vehicles. Design vehicles are defined by AASHTO as “selected motor vehicles with representative weight, dimensions, and operating characteristics used to establish highway design controls for accommodating vehicles of designated classes.” There are four general classes of vehicles identified in the AASHTO Policy of Geometric Design of Highway and Streets: passenger cars, trucks, buses, and recreational vehicles. There are 19 design vehicles that fall into the four general classes. Key design vehicle dimensions include height, length, width, wheelbase, and turning radius.



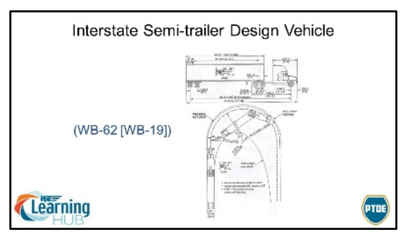


Large vehicles, such as trucks and buses, require more liberal design dimensions than passenger cars. The design dimensions for all 19 design vehicles are presented in the AASHTO Green Book.

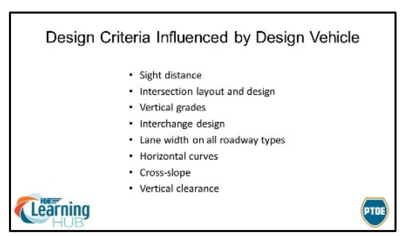


The AASHTO Green Book suggests that the following guidelines should be considered when determining a design vehicle:

- Passenger Car: parking lots
- Single-unit truck: intersections on residential streets and park roads
- City bus: intersections of city streets and state highways that are designated bus routes with limited large truck traffic
- School bus: intersections of low-volume local roads (less than 400 vehicles per day) and highways, and some subdivision streets
- Interstate semi-trailer (WB-65 or 67): intersections of freeway ramp terminals with arterial crossroads, and intersections of state highways with roads carrying a large number of large trucks.



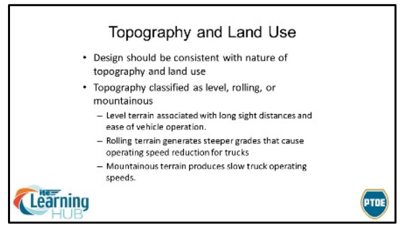
The design vehicle influences various geometric design elements. These include:



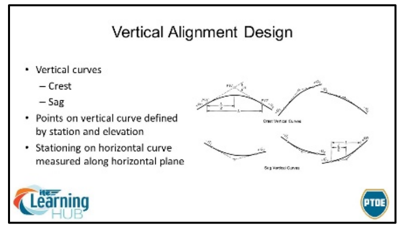
- Sight distance (including stopping, intersection, passing, and decision)
- Intersection layout and design (channelization)
- Grades (critical length and downgrades)
- Interchange design (ramp design, acceleration and deceleration lanes)
- Lane width on all roadway types
- Horizontal curves (radius, superelevation, and pavement widening on curves)
- Cross-slope

- Vertical clearance

Vertical Curvature



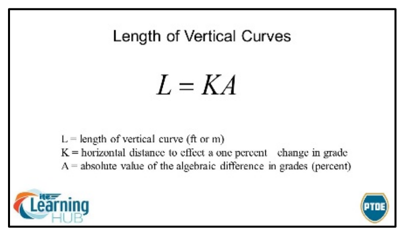
The vertical alignment (profile) consists of tangent grades and vertical curves. The vertical alignment should be carefully coordinated with the horizontal alignment to assure that adequate sight distance is provided, and that distorted appearances are avoided.



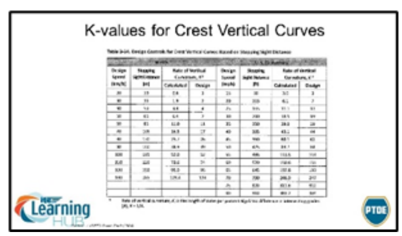
Vertical curves may be either crest or sag curves. In the figure, G_1 is the initial roadway grade while G_2 is the final roadway grade. One-half of the vertical curve length is between the beginning of the curve (PVC) and the point of intersection of the initial and final grades (PVI). The other half of the curve length is between the PVI and the end of the vertical curve (PVT). Such curves are referred to as equal-tangent. Points on a vertical curve are defined by stations and elevations. Stationing along a vertical curve is measured along a horizontal plane. The symbol A is the algebraic difference between the initial and final roadway grades. It is expressed as an absolute value, usually in percent, as follows:

$$A = \left| G_1 - G_2 \right|$$

Because vertical curves used in highway design are based on the parabolic equation and have equal tangent lengths, a constant rate of slope change is a resulting property of these curves. As such, K-values, defined as the horizontal distance to effect a one percent change in grade, can be used to calculate the length of a vertical curve. The relationship between K and the length of a vertical curve is as follows:



$$L = KA$$

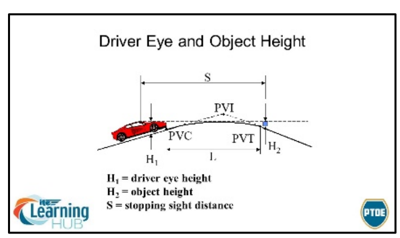


where:

L = length of vertical curve (ft or m)

K = horizontal distance to effect a one percent change in grade

A = absolute value of the algebraic difference in grades (percent)



The K-value is based on stopping sight distance (SSD) criterion and is critical for design. On crest vertical curves, sight distance is limited by both the driver eye and object heights. For SSD, it is generally assumed that the driver eye height used for design is 3.5 feet (1,080 mm); the assumed object height is 2 feet (600 mm). Assumed driver eye height for trucks is 8 feet (2,400 mm). When the SSD is less than the length of vertical curve, the minimum length of curve to provide SSD is as follows:

$$L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

When the stopping sight distance is greater than the length of vertical curve, the expression used to calculate the required length of curve is as follows:

$$L = 2S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{A}$$

where:

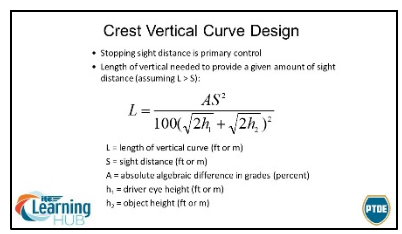
L = minimum length of vertical curve (ft or m)

h_1 = driver eye height (ft or m)

h_2 = object height (ft or m)

A = algebraic difference in vertical grades (percent)

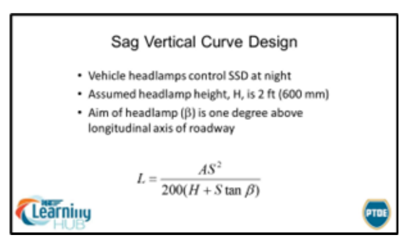
S = stopping sight distance (ft or m)



Determining minimum crest vertical curve lengths for passing sight distance can be done using the same equations as for stopping sight distance. However, the driver eye and object heights assumed in passing sight distance are both 3.5 feet (1080 mm). The length of crest vertical curve necessary to provide adequate passing sight distance is longer than that for providing adequate stopping sight distance.

For sag vertical curves there are at least four different criteria that are used to establish their length:

- Headlight sight distance
- Passenger comfort
- Drainage control
- General appearance



While SSD must be provided in all cases, the other criteria are used to ensure safety and consistency of design. During nighttime driving conditions, a vehicle's headlamp illumination distance controls SSD. It is usually assumed that headlamp height (H) is 2.0 feet (600 mm) and the aim of the headlamp (β) is one degree above the longitudinal axis of the vehicle. When SSD is less than the length of curve, the minimum length of sag curve to provide SSD is:

$$L = \frac{AS^2}{200(H + S \times \tan\beta)}$$

where:

L = minimum length of vertical curve (ft or m)

A = algebraic difference in vertical grades (percent)

S = stopping sight distance (ft or m)

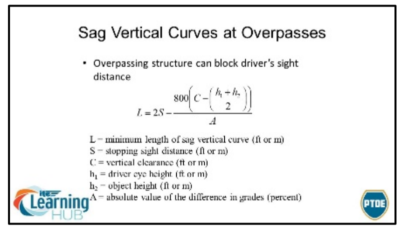
H = headlight height (2.0 ft or 0.6 m)

β = headlight aim angle (1o)

When SSD is greater than the length of vertical curve, the minimum length of sag curve to provide SSD is:

$$L = 2S - \frac{200(H + S \times \tan\beta)}{A}$$

On sag vertical curves, the presence of an overpassing structure can block a driver's sight line. As such, the minimum length of sag curve is based on the required sight distance and the height of the structure is as follows, assuming that sight distance is greater than the length of vertical curve:



$$L = 2S - \frac{800\left(C - \left(\frac{h_1 + h_2}{2}\right)\right)}{A}$$

where:

L = minimum length of sag vertical curve (ft or m)

S = stopping sight distance (ft or m)

C = vertical clearance (ft or m)

h_1 = driver eye height (ft or m)

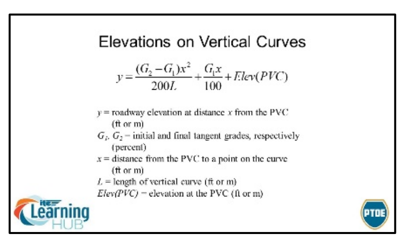
h_2 = object height (ft or m)

A = absolute value of the difference in grades (percent)

When underpass sight distance is a concern, an assumed driver eye height of 8.0 feet (2.4 m) based on eye height of truck drivers. The assumed object height is 2.0 feet (600 mm) based on the taillights of an automobile.

To determine stations and elevations on vertical curves, a parabolic function is used. The general form of the equation is as follows:

$$y = \frac{(G_2 - G_1)x^2}{200L} + \frac{G_1 x}{100} + Elev(PVC)$$



where:

y = roadway elevation at distance x from the PVC (ft or m)

G_1, G_2 = initial and final tangent grades, respectively (percent)

x = distance from the PVC to a point on the curve (ft or m)

L = length of vertical curve (ft or m)

Elev(PVC) = elevation at the PVC (ft or m)

To determine the distance from the PVC to the high or low point on a vertical curve, the following equation can be used:

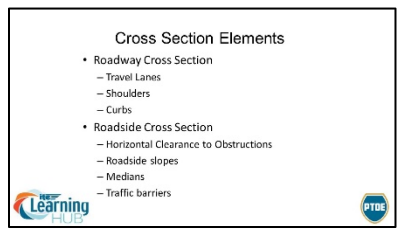
$$x_m = \frac{|G_1|L}{A}$$

where:

x_m = distance from PVC to high or low point on curve (ft or m)

A = absolute difference in grades (percent)

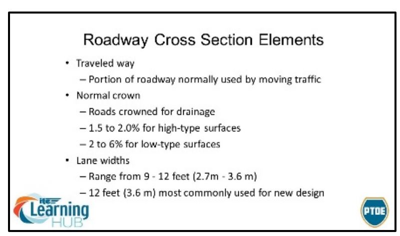
Roadways And Roadsides



The cross section of the highway can be divided into roadway and roadside elements. The roadway cross section is defined as the physical features between the outer edges of pavement, and includes the travel lanes, curbs, and shoulders. The roadside cross section includes the sideslopes, ditches, medians, clearances to obstructions, and barriers.

Roadway

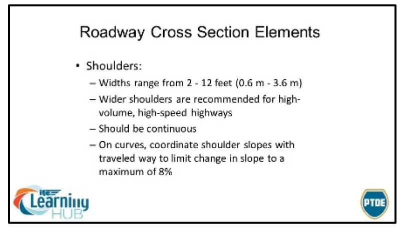
The roadway cross section is that portion which is designated for use by vehicles. The traveled way pavement and cross slope, traffic lane and shoulder widths, shoulder width and cross slopes, and curbs make up the roadway cross section.



Traveled Way - The traveled way is that portion of the roadway normally used by moving traffic. Key pavement characteristics that relate to geometric design include the effect on driver behavior and the pavement's ability to retain its shape and dimensions, to drain, and to retain adequate skid resistance. High-type pavements are usually of the best riding quality and are justified by high traffic volumes. Low-type pavements are not built to the same high standards as the high-type pavements and may not readily drain. High-type pavements cause less interruption to traffic operations, while low-type pavements are generally used where design speed and traffic volume is considered to be very low.

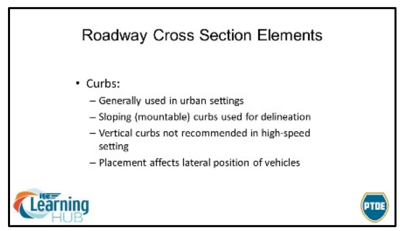
Normal Crown - Pavements on two-lane roadways generally have a high point at the centerline of the pavement, and a uniform cross-slope downward toward both edges. On multilane, divided facilities, the pavement cross-slope can be similar to that of a two-lane facility or it can slope downward from the median edge to the right-hand shoulder edge. High surface type pavements usually have a 1.5 to 2.0 percent crown cross-slope and low-type pavements have a 2 to 6 percent crown cross slope.

Lane Widths - Roadway lane widths generally range from 9 to 12 feet (2.7 to 3.6 m) in width, with 12 feet (3.6 m) being the most widely used. Lower values are permissible on lower functional class roadways, while wider lanes are more desirable on higher functional class roadways. Lane width and restricted lateral clearance affect highway capacity and operations. Narrow lanes force vehicles closer together and tend to lessen vehicle operating speeds. Similarly, restricted clearances to obstructions can reduce the capacity of traffic lanes.



Shoulders - The purpose of the shoulder as a part of the roadway cross section is to accommodate stalled or parked vehicles, provide space for emergency use, and provide lateral support of sub-base, base, and surface courses. The width of shoulders varies from 2 feet (0.6m) on lower functional class roadways to about 12 feet (3.6 m) on major roads, where the entire shoulder may be stabilized or paved. Shoulders that are 12 feet (3.6 m) wide are generally recommended for high-volume, high-speed highways and for highways carrying large truck volumes.

Shoulder cross-slopes should be designed to drain away from the traveled way. On tangent sections of the roadway, shoulders are generally sloped at the same rate as the traveled way, or one to two percent greater. On the outside of horizontal curves, the algebraic difference in the slopes of the traveled way and shoulder should be limited to a maximum of 8 percent, thus limiting the chances of vehicle loss of control.

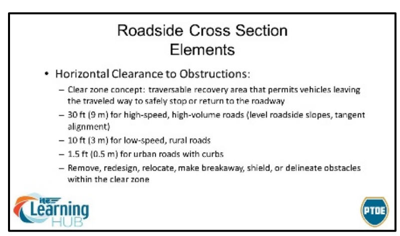


Curbs - Curbs are generally used in urban settings where the objective is to deter vehicles from conflicting with pedestrian movements and to provide proper roadway surface drainage. Curbs may be either sloped or vertical curbs. Sloped curbs are designed for vehicles to cross when necessary. They are generally used in median or intersection areas to delineate vehicle paths. Vertical curbs typically range from 6 to 8 inches (150 to 200 mm) in height with a generally vertical face. They are generally used to discourage vehicles from leaving the roadway.

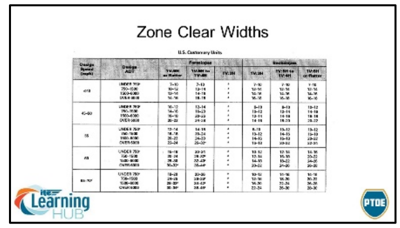
The placement of curbs on roadways affects the lateral placement of moving vehicles. As such, curbs should be offset from the edge of the traveled way by 1 to 2 feet (0.3 to 0.6 m). Curbs are not recommended on roadways with a high design speed such as arterials or freeways. When curbs are impacted at high speeds, drivers may lose control of their vehicles.

Roadside

Roadside cross-sectional elements also have an operational effect on traffic flow, as well as safety of vehicles that leave the roadway. Roadside cross section elements meriting consideration are: horizontal clearance to obstructions, medians, roadside slopes, and traffic barriers.

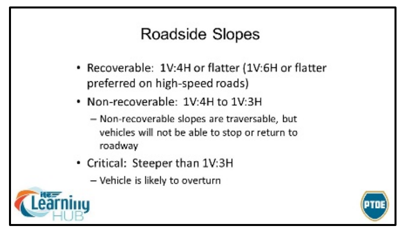


Horizontal clearance to obstructions - The need for a clear roadside exists because crashes on rural highways often involve drivers running off the road and colliding with fixed objects such as bridge piers, sign supports, culverts, ditches, and other design features of the highway. The clear zone is a traversable recovery area that permits vehicles leaving the traveled way to safely stop or return to the roadway. The clear zone is measured from the edge of the traveled way and includes the shoulder. For high-speed, high functional class roadways with level roadside slopes and tangent alignment, the desired clear zone is 30 feet (9 m). Desirably, obstacles in the clear zone area are either removed, redesigned so as to be traversable, relocated, made breakaway, or shielded by traffic barriers or crash cushions.

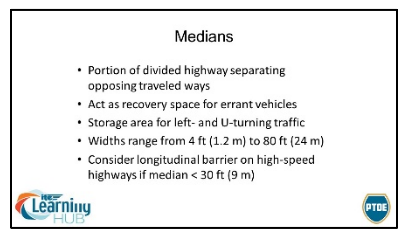


A clear zone of 30 feet (9 m) may not be cost-effective in situations where traffic volumes are low and where a 30-foot (9-m) clear zone is unjustified for environmental or economic reasons. A minimum clear zone width of 10 feet (3 m) may be appropriate for low-speed rural collectors and rural local roads. On urban roadways with curbs, horizontal clearance of at least 1.5 feet (0.5 m) should be provided from the face of curb to any roadside obstacles. However, this horizontal clearance does not represent a clear zone--the same clear zone widths as provided for rural roads are desirable where feasible.

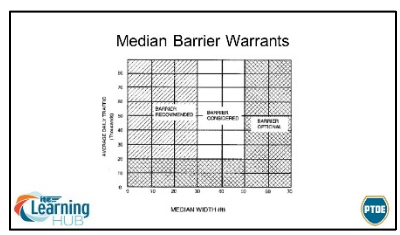
Although the previous discussion provides guidance on clear zone distances, traffic volumes, speeds, and roadside geometry are also important considerations when designing the roadside area. The figure is appropriate for clear zone distance guidance, but the designer must also consider environmental impacts, urban versus rural locations, and economic constraints.



Roadside slopes - Within the clear zone, roadside fill slopes should be as flat as practical. Slopes of 1V:4H are considered "recoverable," with slopes of 1V:6H or flatter preferred on high-speed roads. Slopes between 1V:4H and 1V:3H are "non- recoverable," meaning that vehicles encountering such slopes would be expected to travel to the bottom of the slope. Slopes steeper than 1V:3H are "critical," and may result in vehicles overturning on the slope.



Medians - The median is the portion of a divided highway separating opposing traveled ways. Medians serve to separate opposing traffic, act as recovery space for errant vehicles, and are storage areas for left-turning and U-turning vehicles. Medians generally range from 4 feet (1.2 m) to 80 feet (24 m) or more in width. The optimum median width for two-way left-turn lanes is 10 to 16 feet (3.0 to 4.8 m). Providing two- way left-turn lanes on undivided roads with closely spaced driveways can reduce travel times, improve capacity, and reduce crash frequency. However, non-traversable medians are often desirable to control left turn access in and out of driveways. On high- speed highways, if the median is less than 30 feet (10 m) wide, a median barrier may be warranted depending upon the average daily traffic.



Traffic barriers - Removing, redesigning, relocating, or reducing the severity of impact with an obstacle (by making it breakaway) in the clear zone are preferred methods for improving roadside safety. When such treatments for roadside obstacles cannot be accomplished, installation of a longitudinal barrier or crash cushion must be considered. Installation of a longitudinal barrier should only be considered when the barrier would result in a lower crash severity than potential impacts with the roadside obstacle or condition.

Intersections

An intersection, as defined by the AASHTO Green Book, is "…the general area where two or more highways join or cross, including the roadway and roadside facilities for traffic movements within the area."

Intersection Types (E.G., Stop-Control, Continuous Flow)

The most common forms of at-grade intersections are shown in the figure in the slide. Generally, they are three-legged (a "T" or "Y" intersection), four-legged ("+" intersection), and multi-legged. Rotary intersections are also used; the primary type currently being designed in the modern roundabout described below.

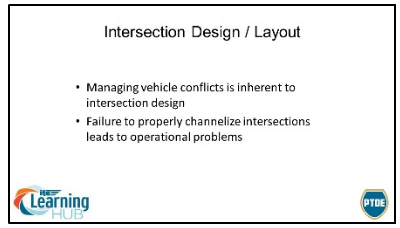
There are some new and innovative intersections that have been designed to improve the safety and efficiency of left turning vehicles while remaining an at-grade intersection. These include the Continuous Flow Intersection (CFI) (also known as the Displaced Left Turn intersection or DLT), the Median U-Turn intersection, the Restricted Crossing U-Turn intersection (RCUT), and more. In the CFI, left turning vehicles make their turn across opposing traffic in advance of the intersection. In the Median U-turn intersection, left turning vehicles proceed through the intersection and then make a U-turn and return to the intersection to make a right turn. In the RCUT, side street traffic desiring to go straight or turn left first turn right, and then make a U-turn to return to the intersection.

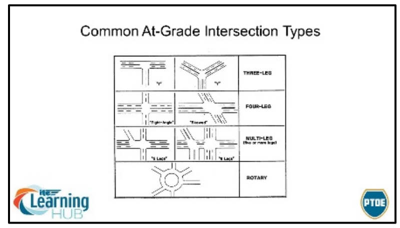
An intersection is defined by both its functional and physical areas. The functional area of an intersection extends both upstream and downstream from the physical intersection area and includes any left- or right-turn lanes and their associated channelization. The functional area on the approach to an intersection consists of three basic elements:

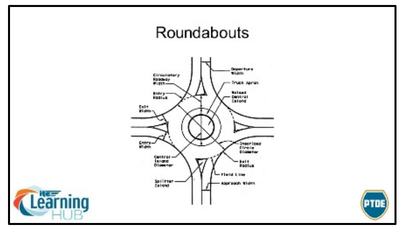
- Perception-reaction distance
- Deceleration/maneuver distance
- Queue storage distance

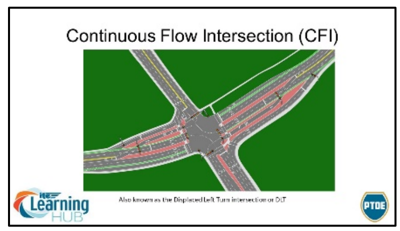
One criterion used to define the downstream functional area is the distance needed for turning vehicles to accelerate to the speed of traffic. Desirably, driveways should not be located within the functional area of an intersection.

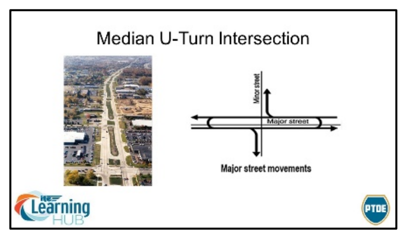
Intersecting roadways should generally meet at as close to right angles and at as nearly level grades as practicable. When the intersecting roadways meet at angles significantly different from 90°, the result can be extensive intersection areas and limited sight distances. Intersections require storage space or storage platforms for stopped vehicles; therefore, the use of flat grades within the intersection proper is desirable. Generally, grades steeper than 3% on intersection approaches should be avoided because many drivers cannot judge the increased or decreased stopping or acceleration distances required.

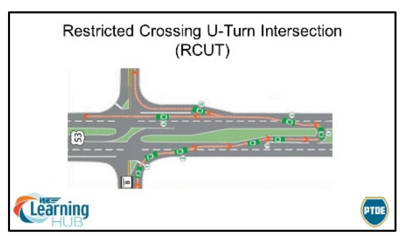


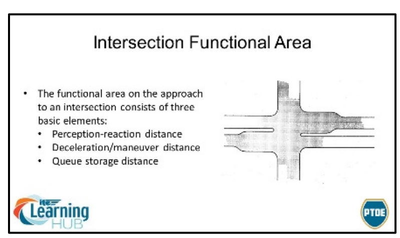






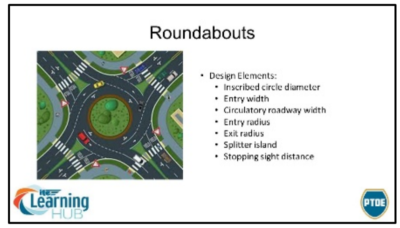






Roundabouts

One specialized type of intersection is the modern roundabout. Roundabout designs can be used at 3-leg, 4-leg, and multi-leg intersections. Roundabouts are a specialized form of intersection design in which all traffic entering the circulating roadway operates under YIELD control. Designing the size of the central island and the deflection of entering vehicle paths is critical to controlling the speeds of vehicles as they enter and pass through the intersection. Roundabouts have proven extremely effective in reducing right-angle and left-turn intersection crashes.

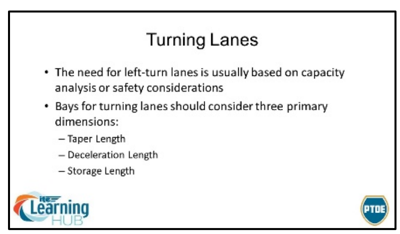


Roundabouts operate most safely when their geometry forces traffic to enter and circulate at slow speeds. Horizontal curvature and narrow pavement widths are used to produce this reduced-speed environment; approaching vehicles must deflect from their normal path to use the roundabout. Key geometric design elements include:

- Inscribed circle diameter - the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway
- Entry width - measured from the point where the yield line intersects the left edge of the traveled-way to the right edge of the traveled way, along a line perpendicular to the right curb line
- Circulatory roadway width – the width of the circular roadway
- Entry radius – the radius of the curve where the entry roadway enters the circular roadway
- Exit radius – the radius of the curve where the exit roadway diverges from the circular roadway
- Splitter island – used to separate the entry lane(s) and the exit lane(s) on one leg of the roundabout.
- Stopping sight distance - required for a driver to perceive and react to an object in the roadway and to brake to a complete stop before reaching that object and should be provided at every point within a roundabout and on each entering and exiting approach.

Turning Lanes

The need for left-turn lanes is usually based on capacity analysis or safety considerations. In general, left-turn lanes should be considered for intersections where the volume of left-turning vehicles during the design hour exceeds 100 vph. If the volume is greater than 300 left-turns per hour, a double left-turn lane should be considered. The length of left-turn storage must be adequate for the expected number of left-turning vehicles. As a rule of thumb, at a signalized intersection, provide enough length to store twice the average number of left-turning vehicles per cycle. Left-turn lanes should desirably be the same width as through lanes, but on low-speed approaches, narrower turn lanes may be acceptable.

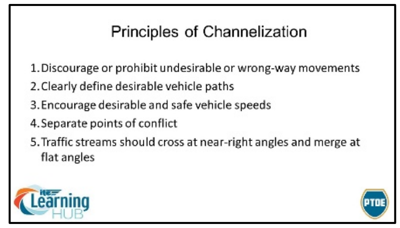


For right-turning roadways, 12-foot (3.6-m) lanes are also desirable. Right-turn lanes adjacent to curbs should be designed to full widths. Right-turn lanes should be considered if the volume of right-turning vehicles exceeds 300 vph during the design hour.

Turn Bay Design

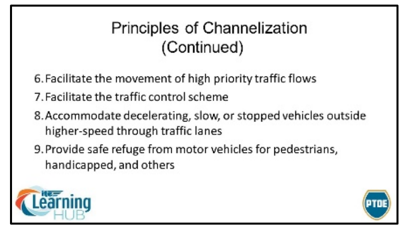
Bays for turning lanes should consider three primary dimensions:

- Taper Length provides the shift from the through lane to the turn lane and is typically based on the approach speed of the roadway; longer tapers are needed for higher speeds.
- Deceleration Length is the space needed for a turning vehicle to enter the turn lane and slow to a stop before the intersection. Most agencies assume the deceleration starts at the beginning of the taper.
- Storage Length is the space needed for cars to queue while waiting to complete their turn. If an analysis of the intersection has been completed, the 95th percentile queue length, the distance at which 95% of the queues will be at or below, can be used for the necessary storage length.

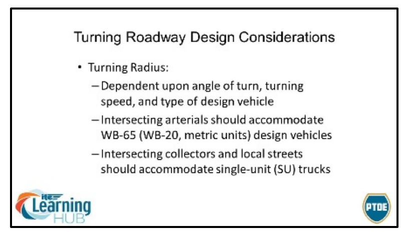


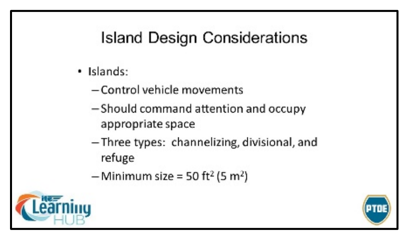
Medians And Channelizing Islands

Conflicts are inherent to intersection design. Many potential conflicts can be minimized using appropriate channelization techniques. The nine principles of channelization are as follows:



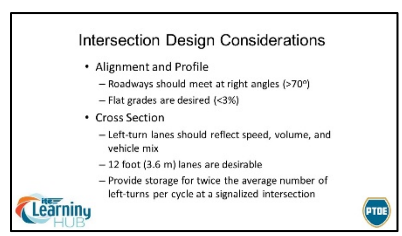
- Undesirable or wrong-way movements should be discouraged or prohibited through channelization
- Desirable paths for vehicles should be clearly defined by all elements of the intersection
- Desirable and safe vehicle speeds should be encouraged by the design of the intersection
- The design of the intersection should wherever possible separate points of conflict
- Traffic streams should cross at near-right angles and merge at flat angles
- The design of the intersection should facilitate the movement of high priority traffic flows
- The design of the intersection should facilitate its scheme of traffic control
- The intersection should accommodate decelerating, slow, or stopped vehicles outside higher-speed through traffic lanes
- Safe refuge from motor vehicles for pedestrians, handicapped, and others should be provided where appropriate



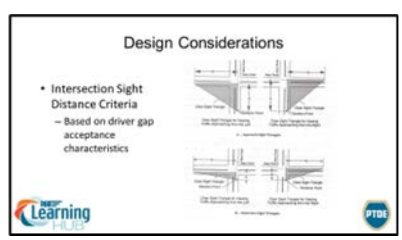


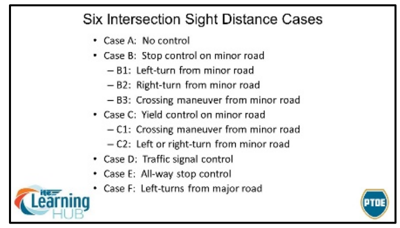
Sight Distance

Intersection design must provide sufficient sight distances for the driver to perceive potential conflicts and to carry out the actions necessary to negotiate the intersection safely. At intersection approaches, speeds and the required driver action govern sight distances. At intersection departures, the designer must provide for all maneuvers permitted upon departure from the stopped position. Intersection sight distance is divided into six forms:



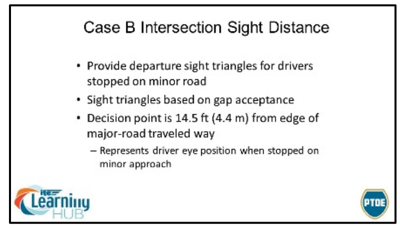
- Case A: Intersections with no control
- Case B: Intersections with stop sign control on the minor road
    - Case B1:Left turn from the minor road
    - Case B2: Right turn from the minor road



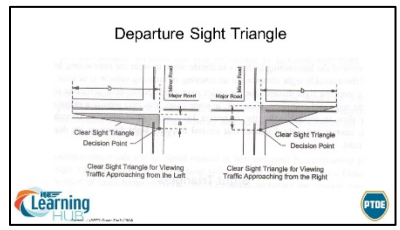


    - Case B3: Crossing maneuver from the minor road
- Case C: Intersections with Yield control on the minor road
    - Case C1: Crossing maneuver from the minor road
    - Case C2: Left or right turn from the minor road
- Case D: Intersections with traffic signal control
- Case E: Intersections with all-way stop control
- Case F: Left turns from the major road

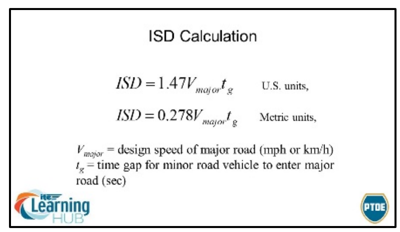
A detailed discussion of all cases is contained in the AASHTO Green Book.



For Case A, the length of the approach sight triangles should be sufficient so that a vehicle approaching the intersection can slow or stop before reaching the intersection if a vehicle is present on a conflicting approach. It should be noted that dimension "a" is measured along the minor road. This is the location when the minor road driver should begin to brake if a vehicle is approaching on the major road. Similarly, dimension "b" is measured along the major road.



For Case B, departure sight triangles should be provided for drivers stopped on the minor road. These sight triangles are for situations where traffic is approaching the stopped vehicle from either the left or the right. The recommended sight triangle dimensions are based on the concept of gap acceptance. The decision point is 14.5 feet (4.4 m) from the edge of the major-road traveled way. This location represents the position of the driver's eye when stopped on the minor road. The AASHTO Green Book indicates that the decision point can be increased to 18.0 feet (5.4 m) when practical to increase the size of the sight triangle.



Case B intersection sight distance (ISD) along the major road is based on the concept of gap acceptance. As such, ISD is calculated as follows:

$$ISD = 1.47V_{major}t_g \text{ (U.S. units)}$$

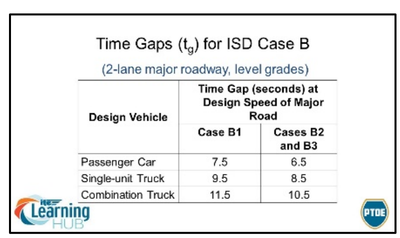
$$ISD = 0.278V_{major}t_g \text{ (metric units)}$$

where:

V_{major} = design speed of major road (mph or km/h)

t_g = time gap for minor road vehicle to enter major road (sec)

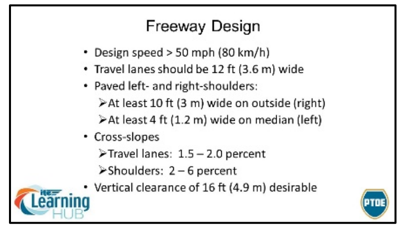
The time gaps for the Case B1, B2, and B3 conditions depend on type of design vehicles, type of maneuver by the entering vehicle, width of the major road, and grade on the minor road approach. Normally, the left turn from the minor road (Case B1) is the most critical maneuver in terms of sight distance. Because the time gaps are based on a two-lane highway with no median and with grades less than three percent, adjustments can be made if these conditions do not hold. On multi-lane highways for Case B1, add 0.5 sec. for passenger cars and 0.7 sec. for trucks for each


Time Gaps (t_g) for ISD Case B
(2-lane major roadway, level grades)

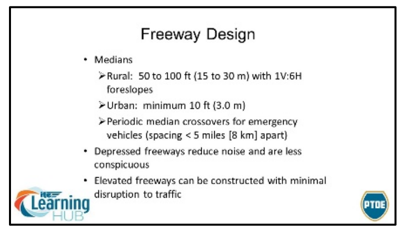
Design Vehicle	Time Gap (seconds) at Design Speed of Major Road	
	Case B1	Cases B2 and B3
Passenger Car	7.5	6.5
Single-unit Truck	9.5	8.5
Combination Truck	11.5	10.5

additional lane greater than one, from the left, that must be crossed by a turning vehicle. On multi-lane highways for Cases B2 and B3, do the same for each lane that must be crossed and for narrow medians that cannot store the design vehicle. For Case B1, add 0.2 sec. to the time gap for each upgrade percent above 3 percent. For Cases B2 and B3, add 0.1 sec. for each percent upgrade above 3 percent.

Freeways, Ramps, And Interchanges



Freeways fall into the arterial functional class and are high-speed, high-volume roadways with full-control of access. Preference is given to through traffic by prohibiting crossing at-grade. The greatest amount of traffic operational efficiency and capacity at intersections occurs when intersecting roadways are grade-separated. Grade-separations are commonly referred to as interchanges and act as a physical separation between intersecting roadways.



In general, freeway design speeds should not be less than 50 mph (80 km/h). In rural areas, the design speed should be 70 mph (110 km/h), except in mountainous terrain where a design speed of 50 to 60 mph (80 to 100 km/h) may be used. Travel lanes should be 12 feet (3.6 m) wide with a high-type pavement.

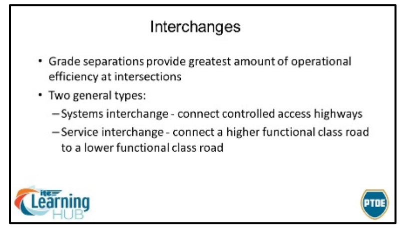
Paved shoulders should be provided on both the left and right sides of the through travel lanes. Right shoulders should be at least 10 feet (3.0 m) wide and may be 12 feet (3.6 m) when the design directional hourly truck traffic exceeds 250 vph. On four-lane freeways, the median (or left-side) shoulder should be 4 to 8 feet (1.2 to 2.4 m) wide. On six-lane freeways, the paved median shoulder width should be 10 to 12 feet (3.0 to 3.6 m) wide.

Travel lanes typically have a 1.5 to 2.0 percent normal crown cross-slope while shoulders are typically sloped 2 to 6 percent. Vertical grades should not generally exceed 7 percent in mountainous terrain with flatter grades more common in rolling or level terrain. A 16-foot (4.9 m) vertical clearance is desirable. A vertical clearance of 14 feet (4.3 m) may be used in urban areas if an alternate freeway facility with a 16-foot (4.9-m) vertical clearance is nearby.

In urban areas, depressed or elevated freeways are more common than in rural areas. Depressed freeways are typically constructed parallel to the at-grade street network and must provide adequate vertical clearance. Frontage roads are also common adjacent to depressed freeways in urban areas. Because of right-of-way restrictions, depressed freeways often have retaining walls. These walls should be located 0.6 m (2 ft) beyond the edge of the outside (right) shoulder. Depressed freeways reduce noise and are less conspicuous than elevated freeways but require a significant drainage network. Elevated freeways can be constructed with minimal disruption to surface highway and street traffic. The disadvantage of elevated freeways is that the structure must be maintained and it requires a closed drainage system. Appropriate vertical clearance must be provided below the structure and a 4.5 to 6.0 m (15 to 20 ft) lateral clearance to adjacent buildings must be provided to provide clear sight distance and to permit access to the exterior of the building by maintenance, construction, or emergency response equipment.

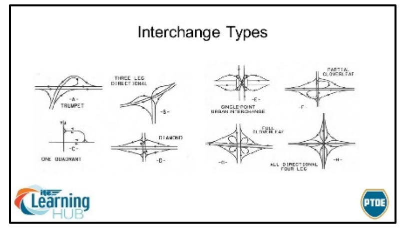
System Interchange Versus Service Interchange

Interchanges can be divided into two broad categories: system interchanges and service interchanges. System interchanges connect two controlled access highways or freeways and have no at-grade intersections at ramp terminals. Service interchanges connect a higher functional class roadway to a lower functional class roadway and may have at-grade intersections at ramp terminals. Both the directional and full cloverleaf interchanges are examples of systems interchanges. They provide for continuous traffic flows at relatively high speeds. The diamond, partial cloverleaf, and single-point urban (SPUI) interchanges are examples of service interchanges because some movements at these interchanges must pass through an at-grade intersection.



Interchange Types

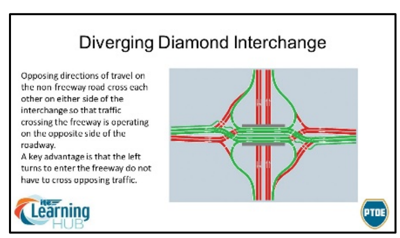
The most common types of interchanges include trumpet, diamond, partial cloverleaf (parclo), cloverleaf, and directional. Interchange forms (A) and (B) are three-leg designs. Three-leg designs are common when future expansion in the unused quadrant of the interchange is unlikely. All remaining configurations, (C) through (H), are considered four-leg design.



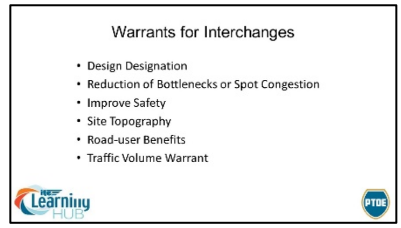
Although uncommon, the ramp in one quadrant configuration (C) may be used at locations where two intersecting roadways have low traffic volumes and are subject to topographic or other controls.

- Diamond interchanges (D) are very common in both rural and urban areas. They require little right-of-way and allow traffic to enter and leave the major road at high-speeds. The ramp terminals form at-grade intersections at the crossing road – these locations may be signalized or STOP-controlled, or may be roundabouts, depending on traffic volumes. The ramp, cross-street, and traffic control should be designed to provide efficient operations and to discourage wrong-way movements at each intersection.
- Single-point urban interchanges (SPUI) (E) are primarily used in urban areas with limited right-of-way. Turning movements are usually controlled by a single traffic signal and left-turning movements do not conflict with one another. These interchanges have greater capacity than diamond interchanges but are more costly to construct.
- Cloverleaf interchanges (G) are more common in rural areas than urban areas because they require significant space. When loop ramps are in two quadrants, these are referred to as partial cloverleafs (F). When loop ramps are in all four quadrants, these are referred to as full cloverleafs. Loop ramps accommodate left-turning vehicles–such ramps generate weaving maneuvers and require longer travel distances for left-turning traffic.
- Directional interchanges (H) utilize one-way roadways that do not deviate much from the intended travel direction. Such connections improve operational efficiency by increasing speed and capacity and eliminating weaving maneuvers. The Alternative Four-Way Directional (Turbine) Interchange is a prime example.

A relatively new interchange design is the Diverging Diamond Interchange (DDI), also known as the Double Crossover Diamond (DCD) interchange and is a variation of the traditional diamond interchange. Opposing directions of travel on the non-freeway road cross each other on either side of the interchange so that traffic crossing the freeway on the overpass or underpass is operating on the opposite side of the roadway. A key advantage is that the left turns to enter the freeway do not have to cross opposing traffic.



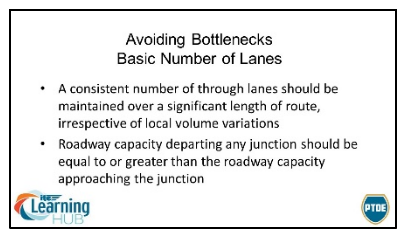
The following six criteria give helpful insight when deciding between an interchange or an at-grade intersection configuration at crossing roadways:



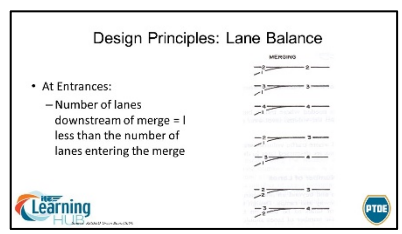
- Design designation. The decision to develop a roadway with full control of access becomes the warrant to provide all intersecting highways with grade separations. The main concern in this situation is the continuous flow of traffic on the major roadway.
- Reduction of bottlenecks or spot congestion. Insufficient capacity on heavily traveled routes may result in intolerable congestion on one or more intersection approaches.
- Improve safety. Some at-grade intersections may have extremely high crash rates or severity. A grade separation may be warranted if less expensive methods of alleviating or eliminating hazardous conditions are not possible.
- Site topography. At some locations, grade separations are the only economically feasible alternative. The site topography may be such that an at-grade intersection would be extremely expensive.
- Road-user benefits. Grade separations can reduce the user costs due to delay at congested intersections.
- Traffic volume warrant. A specific volume warrant cannot be established for an interchange; however, volumes greater than capacity may justify an interchange.

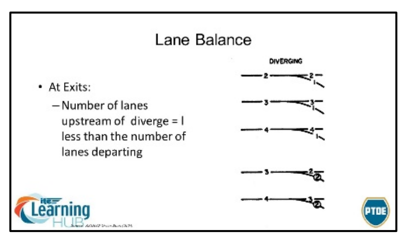
Avoiding Bottlenecks

Freeway design should follow two important principles to avoid building-in potential future bottlenecks:



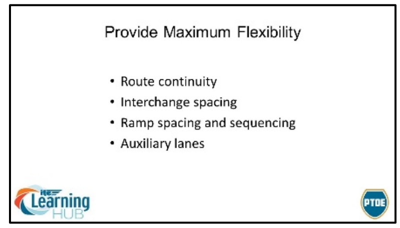
- Basic number of lanes is defined as the minimum number of lanes designated and maintained over a significant length of route, irrespective of local variations in traffic volume and auxiliary lanes required for lane balance.
- Lane balance means that the roadway capacity departing any junction should be equal to or greater than the roadway capacity approaching the junction. At entrances, the number of lanes beyond the merge should be equal to or one less than the total number of approach lanes (freeway plus ramp). At exits, the total number of approach lanes should be one less than the sum of the lanes on the two diverging roadways.





It is desirable to designate one route as the through route and treat all other routes, regardless of demand volumes or functional classification, as intersecting facilities. Drivers should not be required to change lanes or exit to remain on the major route. This is important for the unfamiliar driver since the number of lane changes required to stay on the through route will be minimized. In addition, signing is usually simplified, information search time is reduced, and the through route is more clearly delineated.

Merging, Diverging, And Weaving Areas

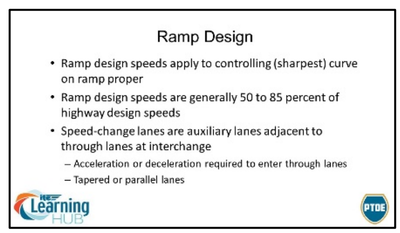


It is important that interchanges be located so as to provide the desired service and function while properly receiving and discharging traffic from connecting facilities in a safe and efficient manner. In general, interchanges usually should not be spaced closer than an average of 2 miles (3 km) within urban areas, an average of 4 miles (6 km) in suburban areas, and an average of 7.5 miles (12 km) in rural areas. In consideration of the effects of existing street and highway spacing in conjunction with natural and cultural conditions, the spacing between individual adjacent interchanges may vary considerably. The minimum distance between adjacent interchanges should not be less than 1 mile (1.5 km) in urban areas, 2 miles (3 km) in suburban areas, and 3 miles (5 km) in rural areas.

Inadequate distance between successive ramps may create weaving problems as well as a poor distribution of traffic across the lanes. In the case of an entrance followed by an exit, the appropriate length is governed by a capacity analysis.

Auxiliary lanes can be used in a variety of ways to maintain lane balance, increase capacity, and accommodate weaving movements. Operational efficiency of the freeway may be improved if a continuous auxiliary lane is provided between entrance and exit terminals where interchanges are closely spaced. Between interchanges, an auxiliary lane should be provided where the distance between the end of the entrance terminal and the beginning of the exit taper is less than 1500 feet (450 m).

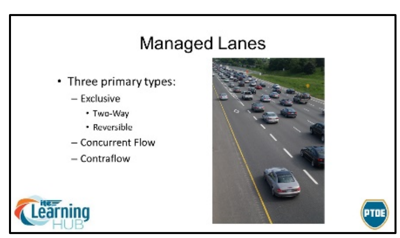
Ramps



Ramp design speeds apply to the controlling (i.e., sharpest) curve on the ramp proper. Ramps generally have a design speed that is 50 to 85 percent of the highway design speed. Right-turn movements often have a design speed that is near the upper range. Loop ramps generally have a design speed near the lower range, but for highway design speeds of more than 50 mph (80 km/h), loop ramp design speeds should not be less than 25 mph (40 km/h). Direct connections are usually in the mid- to upper-range; however, the minimum design speed for direct connections is generally 40 mph (60 km/h).

Speed-change lanes are auxiliary lanes adjacent to the through travel lanes at a highway interchange – the acceleration or deceleration required to enter or exit the through travel lanes are typically performed on speed-change lanes. Speed-change lanes may be tapered or parallel. Tapered lanes provide a direct entry or exit to the through travel lanes at a relatively flat angle. Parallel lanes are added lanes that are used for speed-changing.

Managed Lanes



Three types of managed lanes are commonly found on freeways—exclusive, concurrent flow, and contraflow lanes. In addition, two different operating strategies are used with exclusive lanes—two-way and reversible. Several elements, criteria, and controls should be considered in the design process for managed lane facilities, as they are important for the safe and efficient operation of the facility. These criteria, which are like those applied to any type of roadway, relate to the vehicle design, driver characteristics, design speed, and roadway alignment geometry.

The design of managed lane facilities on freeways is often a challenging process. In many cases, right-of-way limitations and roadway constraints may make it difficult to meet all desirable design standards. Unless a facility is being developed as part of a new project or major reconstruction of an existing facility, some compromise in design may need to be considered.

Sight Distance

Sight distance remains a key design element in the development of a freeway system. In general, speeds are higher than on conventional roadways, so sight distance requirements often require greater distances, however, the concepts are the same.

Some special considerations for freeways should be made. For example, grade separation is often established by having a crest vertical curve as the freeway crosses over an at grade roadway; at highway speeds, the length of this curve is important for ensuring a safe stopping sight distance. In addition, on horizontal curves, consideration to median barrier walls and other structures must be given, again to ensure adequate stopping sight distance.

REFERENCES

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Author(s): Transportation Research Board Inc.
Publisher: TRB, ISBN: 978-0-309-08766-7
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Title: *Manual of Transportation Engineering Studies, 2nd Edition*
Author(s): Edited by H. Douglas Robertson
Publisher: ITE, ISBN: 978-1-933452-53-1
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Author(s): ITE, Brian Wolshon and Anurag Pande
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Author(s): ITE
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Author(s): Tom Urbanik, Alison Tanaka, et al.
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USDOT, ATDM Program Brief: An Introduction to Active Transportation and Demand Management.
http://www.ops.fhwa.dot.gov/publications/fhwahop12032/fhwahop12032.pdf

In addition to these professional references, a candidate may find it advantageous to review a general traffic or transportation engineering text. Among the excellent texts currently available, the following was frequently cited in question documentation:

Title: Fundamentals of Traffic Engineering, 16th Edition (Currently not Available)
Author(s): Homburger, W., et al.
Publisher: University of California
Publication Date: 2007